An exploration of innovation in the Australian minerals industry:

an innovation systems approach

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Declaration of Original Work

The research in this thesis was conducted under the guidance of Prof M. Dodgson at the National Graduate School of Management. All the work reported is my own and has not been submitted towards a degree at this or any other university

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Abstract

Comparatively little attention has been given to the role of innovation in Australia's minerals industry. Historical accounts of Australian development acknowledge the major economic and social advances derived from exploitation of mineral resources. However, a capacity for innovation is not seen as a factor in this success. Indeed, Australia's continued exploitation of its mineral endowment is typically seen as a handicap to broader economic diversification, particularly through the creation of knowledge-based industries and Australian engagement in the knowledge economy.

This exploratory case study of innovation in Australia's minerals industry is based upon an innovation systems theoretical framework, and uses the innovation systems approach as a heuristic to guide the collection and analysis of empirical information. Its research design organises this exploration around three levels of analysis or analytical lenses, each with a distinct focus upon minerals innovation. In each level of analysis, empirically derived evidence is presented in case study subunits of minerals innovation that provide the base of evidence required for studies of innovation systems. The role of innovation in the minerals industry is explored in terms of its systemic nature, namely, a minerals innovation system (MinIS) .

The first level of analysis, an historical view of innovation in the minerals industry, maps the origins, characteristics and performance of a minerals innovation system. World-leading capabilities in radical processing innovations existed in the Australian minerals industry at the end of the nineteenth century. An early MinIS evolved during this period but lacked key public sector components characteristic of successful innovation systems. Access to international sources of knowledge and expertise, particularly in the USA, supported Australian advances in processing innovation and professionalisation of the industry. Systemic limitations in the public sector of the early MinIS restricted further growth and development of the minerals industry, and resource-led industrialisation. By the 1980s the MinIS was domestically complete, and a continuity of innovative capacity existed throughout the industry.

The second level of analysis examines more precisely how innovation takes place in the Australian minerals industry. Distinct characteristics and trends within the MinIS were identified for four of the key the minerals industry activities, including exploration, extraction, processing and environmental management. Case study subunits demonstrate that the MinIS holds considerable capacity for technological innovation, and features long-term collaboration, international technology transfer and commercialisation of radical process innovation. A general trend across minerals firms recently is to improve productivity and safety through the incorporation of critical enabling technologies. The resulting conditions of demand for high-tech services and products has created a new innovative knowledge-based industry, the Mining Technology Services Sector.

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List of Abbreviations

'D'	Development
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACMER	Australian Centre for Mining Environmental Research
ACSys	Cooperative Research Centre for Advanced Computational Systems
AGCRC	Australian Geodynamics Cooperative Research Centre
AGSO	Australian Geological Survey Organisation
AMEEF	Australian Minerals and Energy Environment Foundation
AMIRA	Australian Mineral Industries Research Association
AusIMM	Australian Institute of Mining and Metallurgy
BERD	Business Expenditure on R&D
BHEI	Broken Hill Exploration Initiative
CAD	Computer Aided Design
CAMIRO	
CIE	Centre for International Economics
CMTE	CRC for Mining Technology and Equipment
CRC	Cooperative Research Centre
CRCAMET	Cooperative Research Centre for Australian Mineral Exploration Technologies
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEST	Department of Education, Science and Training
DISR	Department of Industry Science and Resources
DITR	Department of Industry, Tourism and Resources
DIST	Department of Industry Science and Tourism
EU	European Union
FDI	Foreign Direct Investment
FG	Fractal Graphics
GDP	Gross Domestic Product
GERD	Government Expenditure on R&D
GK Williams CRC	GK Williams Cooperative Research Centre for Extractive Metallurgy
GMI	Global Mining Initiative
HBI	Hot Briquetted Iron
HI	Hamersley Iron Pty Limited
INAP	International Network for Acid mine drainage Prevention
IP	Intellectual Property
JKMRC	Julius Kruttschnitt Mineral Research Centre
LIS	Local Innovation System
MCA	Minerals Council of Australia
MIRO	Minerals Industry Research Organisation
MMAJ	Metal Mining Agency of Japan
MMSD	Mining Minerals and Sustainable Development
MNCs	Multi-National Company
MinIS	Minerals Innovation System
NGO	Non-government organisation
NIS	National Innovation System
OECD	Organisation for Economic Cooperation and Development
OH&S	Occupational Health and Safety
R&D	Research and Development
RIS	Regional Innovation System
SET	Science, engineering and technology
SIN	Systems Integration and Networks
SIS	Sectoral Innovation System
SME	Small and medium sized enterprise (employing fewer than 500)
SPRU	Science Policy Research Unit
TEP	Techno-Economic Paradigm
TR	Technological Regime
TS	Technological System
USGS	United States Geological Survey

Chapter 1:

Introduction

Australia's is a resource-based economy. Its economic development has relied heavily upon the exploitation of its natural resources, areas traditionally associated with low rates of innovation and R&D intensity. The minerals industry profoundly influenced Australia's development, beginning with the gold rush in 1851 near Bathurst in New South Wales. Wealth derived from gold and an accompanying influx of migrants saw a shift in Australia's colonial economy away from its pastoral and agricultural base. From this time forward the minerals industry has been a major contributor to Australia's economy and infrastructure; producing substantial export earnings while driving decentralisation of both industry and population as railways, ports, towns and services were established to serve regional mines and smelters.

A well-articulated problem for Australia today is that little appears to have changed. The nation has not significantly diversified from its base in natural-resources and industrial R&D performance is uninspiring due to the low-tech nature of the majority of Australian manufacturing (Marceau et al. 1997, Gregory 1993, Hill and McKern 1997, Sheehan 2000b). Economic growth and social advancement in the twenty-first century are, and will no doubt continue to be, based upon innovation and knowledge, qualities not generally associated with natural-resource industries. Successful nations are said to be those operating in the 'knowledge economy', a production paradigm driven by innovation intensity and knowledge-based competition, new organisational structures and patterns of interactivity, and emergence of knowledge-intensive, so-called 'sunrise industries'. The minerals industry, by comparison, is often referred to as a 'sunset industry', of limited value in the knowledge-based economic environment. This assumption is derived from a traditional and pervasive view of the industry, where mineral wealth and competitive advantage are said to be based upon geological 'gifts of nature' and not created from the innovative and technological capabilities of companies and countries. This thesis endorses an alternative view of innovation-driven competitive dynamics in the minerals industry (Tilton 2000) and questions the validity of traditional views on the grounds that they fail to uncover the role of innovation in the minerals industry.

It is well known that a transition to a new economic system, such as the knowledge economy, history matters (Freeman and Louca 2001). There is a great deal of contemporary debate regarding Australia's future engagement with the knowledge economy (Marceau et al. 1997, Innovation Summit Implementation Group 2000, Batterham 2000). In view of the minerals industry's historic and continuing significance in Australia, it ought to be a part of this debate. Increasing rates of globalisation in markets, capital and sources of knowledge are features of the knowledge economy, as indeed are large firms that have international knowledge-networks, globalised activities and that invest in industrial R&D. In Australia, the minerals industry is the only truly globalised industrial sector with large firms whose activities are comparable to international standards of global sales and competition (Hill and McKern 1997, Sheehan 2000a). In spite of these features of the minerals industry, its potential and current levels of engagement in the knowledge economy have been overlooked largely, it seems, because of its reputation as being 'old economy' and 'low-tech'.

The broad-based exclusion of the minerals industry from dialogues on Australia's future options for innovation and knowledge-based growth sets the scene and provides the motivation for this thesis. There is a lack of a systematic and systemic ('holistic') investigation of innovation in the Australian minerals industry. This thesis is about reassessing the minerals industry with contemporary analytical tools, particularly regarding 'innovation systems', to provide a better understanding of its innovation processes and performance. An exploratory case-study methodology is used to explore and map the historical development of innovative capacity, recent trends in innovative activities, and the structural features of a minerals system of innovation. Exploratory case studies by nature are neither able nor designed to answer specific questions, such as 'why has Australia not diversified from its resources base?' It is hoped, however, that the findings from this exploratory research will provide a base from which to make informed comment concerning pertinent issues such as, the status of innovation in the industry, the contribution the minerals industry makes to Australia's national innovation system, and the role of government in maximising the wealth from the country's mineral endowments, including the potential role the industry may hold for Australia's future integration with the knowledge economy.

The following sections are short introductions to the factors that make up the 'essence' of this thesis – they are expanded subsequently. These introduce this study's: theoretical base – *Section 1.1: The rise of innovation studies*; context – *Section 1.2: the resource-based and fragile nature of Australia's NIS;* and subject of investigation – *Section 1.3: The Australian minerals industry*. This introductory chapter closes with an outline of this thesis' structure.

1.1 The rise of innovation studies

Modern economic growth is derived from a capacity to innovate, and successful firms, industries and economies are characterised by highly integrated systems of innovation. Traditional neoclassical approaches to understanding processes of industrial and economic development are poorly suited to explaining innovation-based growth. The limitations of traditional economic methods of analysis, in combination with changes in the global competitive environment, in particular globalisation and the advent of the 'knowledge economy', precipitated interest in and development of analytical tools with which to study processes of innovation.

Innovation is a complex phenomenon of which there are different types including; technological, organisational or institutional, and different forms, such as incremental or radical. Individual innovations may be entirely novel or derived from novel combinations of new and existing elements. The processes that spawn innovations may be extremely complex and dynamic, featuring multi-layered relationships and feedback mechanisms, and involving issues of science, technology, learning, production, policy, incentive and demand (Edquist, 1997). Innovation processes are unpredictable and do not usually conform to linear paths of development, such as where basic research progresses sequentially to applied research, followed by development and then commercialisation. Hence uncertainty is an inherent characteristic of innovation. Technological innovation generally tends to involve the generation and diffusion of knowledge, and the translation of knowledge into new or improved products and processes. Technological innovation often triggers organisational innovation or vice versa.

A new style of innovation study has evolved during the past 15 years to better accommodate the complex dynamics and social embodiment of innovation and technological change in a holistic context. The so-called innovation systems (IS) approach unites families of related conceptual frameworks that all aim to better understand differences in economic performance and growth rates of nations, regions, sectors, industries or firms by examining the production, diffusion and absorption of innovations. Differential emphasis is placed upon macro-factors, such as national industrial structures, or micro-factors such as the importance of firm-level knowledge and learning-capabilities for growth. The IS approach embraces an evolutionary perspective, where historical experience, past events, and issues of path dependence underlie current innovative capacity and performance. It has proven utility as a medium for studying innovation, as a base upon which firms may construct innovation strategies and as a conceptual framework for government policy making. The suitability of either an individual or combination of these approaches is 'situation' and 'objective' dependent. Obviously in the case of national system of innovation (NIS), the national context is central. That is for any nation the makeup of its public and private organisations and institutions involved in innovation; its domestic market flexibility in the face of change; its degree of sophistication among users of new technologies; its culture and learning processes; and its public policy framework all influence a national capacity to innovate (Niosi, 2000). Chapter 3 reviews the literature on studies of innovation and the IS approach. National Innovation Systems (NIS) and Sectoral Innovation Systems (SIS) receive more attention in this work than others in the IS family of approaches.

The following section sets the scene for this study with a brief introductory review of Australia's national innovation system.

1.2 Australia's NIS is resource-based and fragile

A country's innovation system, including its investment in R&D, technological capabilities and industrial structure are the base upon which its economic prosperity depends. Nations differ considerably in their sources and amounts of financial support for R&D and innovation, as well as structural and institutional determinants and the intensity of connection between units that make-up its system of innovation. Australia's NIS is reviewed according to Niosi's seven key differences in Table 1.1. The overall industrial composition of an economy influences the purposes to which R&D is applied and the levels and change in a country's investment in industrial R&D (National Science Foundation 2002, OECD 2002, OECD 1999). Governments and public 'mission-oriented' programs of technological innovation have a critical influence upon national industrial composition in advanced countries. Nations with a strong, well-developed defence establishment, such as the United States, France, Russia and the United Kingdom, have produced a greater number of industries with military applications (aerospace, advanced materials and telecommunications) (Archibugi and Pianta 1992, Patel and Pavitt 1991a, Patel and Pavitt 1991b). Furthermore, nations with a similar sized economy can have vastly different R&D expenditure levels (and R&D/GDP ratios), in accordance with (among other factors) the reciprocal integration between public programs of research and share of export industries that are knowledge-based and devote substantial resources to R&D and innovation.

Australia's economic development has relied heavily upon the exploitation of its natural resources, areas that traditionally have a low R&D intensity. Its 'mid-way' economic structure shares characteristics of developed and developing countries: for the former, a heavy but declining reliance on commodity exports, net imports of technology and capital, and large external debt; and for the latter, high standards of living and social indicators ranking in the middle of OECD[1] nations (Hill and McKern 1997). Australia's national innovation system has tended to rely upon low value-added exploitation of its natural resource base as opposed to innovation for economic growth (Gregory 1993). A historical reliance upon foreign direct investment (FDI) contributed to this situation, as Australia was bypassed by multinational companies (MNCs) when locating their R&D activities.[2] Nearly all R&D conducted by foreign firms in Australia is financed by local affiliates of MNCs rather than the parent, and R&D activities are largely confined to adaptation of products, ie parent technology, to the Australian market (Hill and McKern 1997). The outstanding exception here is the minerals industry where production and sales are historically at world scale and minerals firms have supported local R&D facilities and capabilities (Hill and McKern 1997, Sheehan 2000a). But if this is the case, why did it happen in minerals? It is the internal contradictions here that make the minerals industry interesting. If the minerals industry operates at world scale, why are their research facilities locally based, indeed, if exploitation of mineral resources is so-called low value added, why does the minerals sector support innovative capabilities?

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[1] Current OECD members are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

[2] The location of private R&D facilities is discussed in more detail in Chapter 3.

Australia is geographically located largely at the periphery of international trends in industrial R&D. It is characterised by a low level of private investment, and a history of protection from international market forces. Many authors claim that Australia is a very 'fragile' country due to a lack of large innovative manufacturing firms, comparative inactivity in knowledge-intensive consumer and industrial goods industries, and a high degree of dependence on R&D-intensive industry by overseas firms (Marceau et al. 1997, Batterham 2000, Gregory 1993). Australia's NIS is also based on a comparatively rich public research sector, with relatively strong basic research. Australia ranks seventeenth among the 29 OECD countries in terms of gross domestic expenditure on R&D as a per cent of gross domestic product (GDP)[3] (OECD 2002). Business expenditure on R&D (BERD) is 0.64 per cent of GDP, well below the OECD average of 1.53 per cent (2.08 per cent in USA, 2.07 per cent in Japan and 1.47 per cent in Canada) (OECD 2002). In the 2002-03 financial year, total Commonwealth support for science and innovation is projected to be $5.1 billion or 0.68 per cent of GDP, similar to the previous financial year and an increase from the 2000-01 financial year at 0.658 per cent of GDP ($4.4 billion) (Commonwealth Government 2002). Australia's scientific activity produces over three per cent of the world's scientific research papers (Butler 2002).[4]

Since the 1980s, Australian Governments have successfully addressed some of the apparent shortcomings in Australia's national innovation system. The Australian economy was 'opened' during the 1980s to transform its protectionist and inward-looking stance with a set of major economic policy reforms, including the floating of the dollar in 1983 and trade-policy liberalisation (Hill and McKern 1997). Steps were taken to encourage industry sponsorship of R&D, as well as to develop stronger linkages between the public and private sectors and institutions within its national system. A proactive approach was taken to stimulating industry's investment in R&D, including the introduction of 150 per cent tax concession for R&D (reduced to 125 per cent in 1996 and coming into full effect in 1997-98), the establishment of Cooperative Research Centres (CRCs),[5] and by the implementation of external earning targets for CSIRO.

It would appear that the combination of these mechanisms was effective, with business expenditure on R&D (BERD) increasing during the 1980s at an annual rate of 13 per cent, well above the OECD average, albeit from a low starting point. Indicators revealed, however, that this performance was not enduring. BERD declined in the late 1990s, from a high of 0.86 per cent of GDP in 1995-96 to 0.72 per cent in 1997-98 and declined again to 0.64 per cent in 2001-02 (Australian Bureau of Statistics 1999, OECD 2002). Apparently, this decline was largely due to reduction in the R&D tax concession and abandonment of the R&D syndication scheme. During the same time period most OECD countries experienced an increase in BERD/GDP

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[3] These OECD figures are based upon expenditure in 1999 or closest year available.

[4] Australia's share of publications in the Science Citation Index (SCI) has increased by 25% in the past decade, however, a significant decline in citation impact is associated with this trend. Australia was placed 5th out of 11 OECD nations in 1988 and now ranks 10th (Butler 2002). Policy that distributes funding to universities on the basis of aggregate numbers of papers with no measure of quality and impact, is thought to have contributed to the decline in publication impact (*ibid*).

[5] CRCs are joint ventures between industry, higher education institutions, and Australia's major public research organization the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

ratios and many of these nations were increasing investment in mechanisms to support research and innovation (OECD 2002, Masood 1999c, Masood 1999d, Masood 1999b, Masood 1999a). Furthermore, the belief that high spending on public sector R&D (1996-97 ranking fourth in OECD) somehow compensates for low Australian BERD is questionable. Agriculture constitutes approximately three per cent of the Australian economy, and yet public sector R&D directed at this sector amounted to eighteen per cent of total public sector R&D. Removing agriculture, public R&D represents 0.64 per cent of GDP, below the OECD average of 0.66 per cent (Batterham 2000). Indeed, total public sector R&D expenditure in Australia was also in decline, falling from 0.83 per cent of GDP in 1996-97 to a low of 0.65 per cent in 2000-01.

The beginning of the new millennium saw a climax of an unabated interest in Australia's economic and innovative performance, and a reaction towards its decline with the National Innovation Summit in February 2000, convened by the Commonwealth Government and Business Council of Australia (Innovation Summit Implementation Group 2000). The Summit addressed ways of improving Australia's NIS and innovative performance. Issues examined included the national science base, improving connectivity between Australian industry and the science, engineering and technology (SET) base, commercialisation of research and the role of government in creating conditions conducive to innovation. The 'Australian Science Capability Review', a review of Australia's public and private SET base in terms of current performance, potential performance enhancement mechanisms, desirable characteristics for supporting knowledge-based industries and its contribution to long-term economic development followed (Batterham 2000). In 2001, the Commonwealth Government launched a response to reinvigorate Australia's NIS with a $2.9 billion boost to government investment in Australia's innovative capacity over 5 years (Commonwealth Government 2001). Initiatives to stimulate innovation included: additional funding for higher education research grants (via the Australian Research Council); a $583 million fund for research infrastructure funding; establishment of centres of excellence in the enabling technological fields of biotechnology and information and communications technologies (ICT); expansion of the CRC program with greater access by small and medium enterprises; and, reforming the R&D Tax Concession by introducing a premium rate of 175 per cent for additional R&D activity and a tax rebate for small companies (*ibid*). The estimated value of public sector investment for 2002-03 is, however, 0.68 per cent of GDP, still below 1996-97 levels of 0.83 per cent of GDP. It is too early to know whether these initiatives will stimulate Australian BERD, and enhance participation in the knowledge-economy. Reform of Commonwealth innovation policy is continuing and includes the establishment of national research priorities to further leverage and coordinate investment, and increase collaboration (DEST 2002). This is an appropriate response for a small economy, as efforts must be made to ensure resources are not under-utilised by spreading them too thinly. It will not, however, be a straightforward process, as implementing structural change to a NIS is a time consuming and costly process (Niosi 2002, Freeman and Soete 1997, Freeman 2002).

Table 1.1: Features of Australia's NIS according to Niosi's 7 defining characteristics

Characteristic	*Situation in Australia*
1) Countries differ in size & characteristics of their resource base	• Australia has extensive minerals, energy and agricultural resources. R&D and innovations have tended to focus in these areas. Its NIS is fragile in the sense that it has few large innovative manufacturing firms and is comparatively inactive in knowledge-intensive consumer and industrial goods industries (Marceau et al. 1997, Batterham 2000, Gregory 1993, Hill and McKern 1997).
2) Size of industrial economy matters	• Large industrial countries like the USA, Germany & the UK have more diversified innovation systems. Australia's economy and SET base are small on a world scale. Small countries tend to focus innovation activities in a few areas, eg natural resources in Australia.
3) The role of government in support for innovation – affect missions, priorities, market structures	• A high degree of government support is typical but not priority setting in the context of broad national objectives. Excellence in Australia is located in agricultural, environmental & medical sciences. Much of public sector research is aimed at specific requirements of supporting a large agricultural sector in the Australian environment. Following the National Innovation Summit (Feb 2000) initiatives are being implemented to improve distribution of resources and engagement in the knowledge economy (DEST 2002). – 18% of public sector R&D is directed toward agricultural purposes, omitting it brings GERD to 0.64% GDP below OECD average of 0.66% (2000-01) (Batterham 2000) – developing national research priorities – a new Commonwealth initiative (DEST 2002) – Commonwealth funds aimed at leveraging private sector investment is estimated to be in the order of $4.3 billion over 5 years (DEST 2002).
4) University system	• The university sector is an intrinsic component of Australia's SET base. However, it does not have a tradition of strong links with industry, philanthropic industry investment is not well developed as in countries like the USA and Germany and responsiveness to needs of industry is limited. – Australia produces nearly 3% of the world's scientific research papers – the sector accounts for 29.4% of public expenditure on R&D – is responsible for research training at the graduate, doctoral and postdoctoral levels – increases in funding for universities was part of the Government's 2001-2002 Backing Australia's Ability initiative (Commonwealth Government 2001) and the sector is involved in the priority setting initiative (DEST 2002).
5) The significance & missions of government laboratories	• Government support is delivered via research agencies, directly funded grants and support programs, non-budget support for innovation and higher education research funds (Commonwealth Government 2002). Responsibility for these mechanisms is spread across 7 Government departments, primarily departments of Education, Science and Training & Industry, Tourism & Resources. – CSIRO and DSTO are Australia's largest of 12 Commonwealth research agencies. CSIRO receives 43% ($645 million) of Government funding in this area (est$1,520 million 2002-03), primarily from the Department of Education Science and Training. – science and technology support via R&D granting programs and other support programs (est$692 million 2002-03) financed through the budget, including CRCs (est$148 million 2002-03), NH&MRC (est$339 million 2002-03) – non-budget industry innovation support measures (est$874 million 2002-03), including R&D tax concession (est$529 million 2002-03), R&D Start (est$142 million 2002-03) and rural research levies (est$190 million 2002-03) – higher education research (est$2026 million 2002-03) including ARC grants (est$356 million 2002-03.
6) National financial systems	• Since the 1980s Australia has progressively transformed and liberalised its economy. It has open capital markets and commercial banks. The links between finance and innovative industries have traditionally been weak, especially with regard to access to patient and venture capital (Hill and McKern 1997). – Australia has an 'Anglo-Saxon' financial system (as do USA, UK, Canada & New Zealand) as opposed to the 'Europe and East Asia' system where commercial banks are argued to be more supportive of industrial investment in innovation (Niosi 2001).
7) Amount of resources invested in R&D	• In 2002-03 the Commonwealth Government will provide $5.11 billion for science and innovation or 0.68% GDP. • Australian BERD is low by international standards, it: – grew rapidly in mid-1980s to mid-1990s – declined from 0.86% of GDP in 1995-96 to 0.67% GDP in 1998-99 – declined again to 0.64% of GDP in 2001-02 (OECD average 1.53%; USA 2.08%; Japan 2.07; 1.47% Canada) (OECD 2002).

Source: This table is based upon key differences NIS as defined by Niosi (Niosi 2001:11-15)

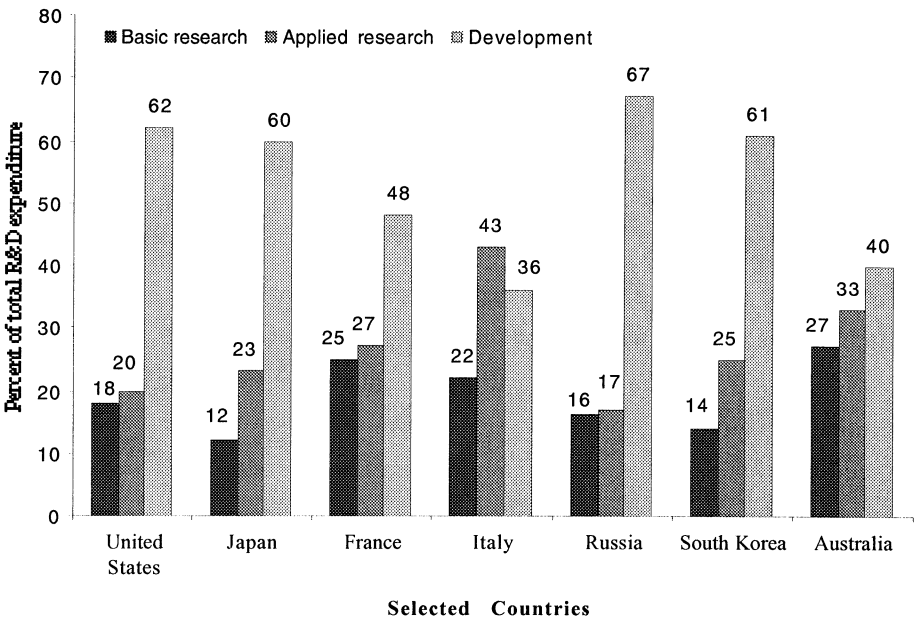
1.2.1 Increasing importance of industrial R&D

Trends in industrial R&D performance are leading indicators of current and future technological performance and competitiveness in domestic and foreign markets. The top R&D performing industries are technology-intensive manufacturing industries (computer hardware, electronics equipment and motor vehicles), although the importance of R&D in the services sector (particularly in computer services, R&D services and trade) increased significantly during the past twenty-five years in high-wage, globally competitive countries. National differences in industrial R&D performance are illustrated more clearly when R&D is disaggregated into its 'characters of work' or major activities: basic research; applied research; and experimental development (accepting that there are continuing definitional problems in allocating research activities to particular categories and that innovation is widely appreciated to be a non-linear process). A general division of labour exists among these activities, where governments usually fund basic research that is conducted in universities to generate new knowledge, as well as applied research which is primarily conducted in government research laboratories. Industry conducts the vast majority of experimental development, a much more expensive activity, and a process whereby technological innovations are converted into wealth.

In G-8 countries[6], industrial firms account for the largest share of total R&D performance, the major character of this work being experimental development (National Science Foundation 2002). Governments, on the other hand, have historically been the largest source of academic research funding in OECD countries, although over the past twenty years the government portion of university funding (both direct funding and block grants) has declined by eight percentage points or more in six of the G-7 countries. A parallel trend in these six countries is a doubling or more of the industry portion of funding for universities, a signal of increased university-firm interaction and often related to the commercialisation of university research (National Science Foundation 2002). Figure 1.1 illustrates the distribution of R&D by character of work for Australia and six OECD countries that collect R&D statistics according to character of work. For all these countries, bar Australia, experimental development is an obviously dominant character of work, with basic research coming a distinct third behind applied research and experimental development activities.

[6] The G-8 countries are a combination of G-7 countries (Canada, France, Germany, Italy, Japan, the Unites States and the United Kingdom) plus the Russian Federation.

Figure 1.1: Distribution of R&D expenditure by character of work in selected countries (1998)



Source: (National Science Foundation 2002)

Note: six per cent of Japan's R&D is undefined and unaccounted for in the figure.

In Australia, a clear division exists in source of funds for R&D and character of work. The Commonwealth funds the bulk of basic research (70 per cent), a little under half of applied research (46 per cent) and only 11 per cent of experimental development (Matthews 1998). Alternatively, business funds 15 per cent of basic research, 35 per cent of applied research and 80 per cent of experimental development (for the 1996-97 financial year) (*ibid*). Given then that business funds the majority of experimental development in Australia, Figure 1.1 further emphasises the weakness of industrial R&D performance in Australia.[7] Based on this evidence, Australia needs its industrial sector to do more experimental development to overcome the inherent fragility of its NIS. Current Australian innovation policy primarily addresses the performance of the science, engineering and technology (SET) base. This includes measures to enhance industrial R&D through both encouragement of commercialisation generally and through the formation (and promotion) of knowledge-intensive SMEs. Investment in industrial R&D by MNCs, including from parent companies based overseas, is also very important and should not be overlooked. This situation highlights the need for a study of industrial innovation by the minerals industry in Australia. If this sector has a history of experimental development and connectivity with Australia's SET base it may provide insight into strengths and weakness within the NIS and assist in the future development of innovation policy to enhance Australian industrial innovation and ultimately, engagement with the knowledge economy.

[7] The other nation weak in this regard is Italy. A discussion of Italy's performance is beyond the scope of this thesis. Italy's NIS is characterised by poor university-industry interaction and a review of high-technology Italian firms is given in (Malerba and Marengo 1995).

1.3 A brief introduction to the Australian minerals industry

The Australian minerals industry is internationally competitive, mature, and export-oriented. It is the only industry sector in Australia with large firms whose activities are 'world scale' (Sheehan 2000a). In 2000-01, the minerals industry contributed over $40 billion to Australia's total export revenues, accounting for 35 per cent of merchandise exports and 25 per cent of total exports of goods and services (AMIRA International 2002). In terms of national GDP, 8 per cent is accounted for by the minerals industry. By way of comparison, the agriculture, and food and beverage industries combined comprise 5.5 per cent of GDP. The minerals industry's performance has also been evaluated using a different measure, broadly defined as 'wealth,' the combined value of intangible and tangible assets, as opposed to direct measures of income. The World Bank's method for measuring national wealth, for example, is a sum of estimated component values of produced assets, natural capital and human resources (World Bank 1997). A study of wealth in the Australian minerals industry found:

- that '60 cents accrues as value adding for each dollar of mining production'
- the industry added $8.6 billion to Australia's wealth in 1997-98 and
- national wealth contributed by the industry has been increasing over time (Stoeckel 1999).

Additionally, an economy-wide model was used to capture the flow-on effect from minerals wealth in other sectors of the economy. The flow-on effects from a 'one-off expansion' of the industry in 2000 (equivalent to a 10 percent productivity improvement) added $37 billion (1997-98 dollars) to Australian wealth over 5 years, and $42 billion after 10 years (Stoeckel 1999). Minerals industry operations support Australia's national development. For example, since 1967 the industry has built: 25 towns; 12 ports and requisite port bulk handling infrastructure for these and other ports; 25 airfields; and over two thousand kilometres of rail line. Furthermore, the industry is a source of direct investment for the development of Australian natural resources, comprising 12 per cent of total new investment in 2001-02. Treasury estimates an increase in new investment to 33 per cent in 2002-03, and an average for the decade of the 1990s of 25 per cent (Hooke 2002).

In economic terms, Australia and its minerals industry hold a comparative advantage in terms of rich geological resources. Comparative advantage alone, however, is not sufficient to sustain competitiveness in international markets. The translation of this comparative advantage into an internationally competitive strength depends upon implementation of knowledge-based, high value-added activities that deliver cost efficiency and meet with the goals of sustainable development throughout the entire process of mineral discovery, extraction, conversion and delivery of product to customers. Underlying the Australian minerals industry's competitive advantage is its support for technological development and deep innovative capacity. Notably, this industry has remained globally competitive against a long-term trend of price decline, at a rate of two per cent per annum in real terms since the 1970s (Batterham 1999).

Over the last decade, the world minerals industry has experienced profound challenges in its competitive environment including: a period of historically low commodity prices; decreased access to sources of capital in the face of globalisation coupled with the dot-com boom and a demand for higher returns for investors; increasing regulatory and political constraints associated with sustainable development (MMSD Project 2002); and intensification of innovation associated with the emergence of enabling technologies such as biotechnology, information and communication technologies (ICT) and computational simulation and modelling. Faced with these challenges, minerals companies have changed their strategies and competencies, resulting in high rates of mergers and acquisitions (M&A), industry consolidation and globalisation of the industry. In a fiercely competitive and globalised commodities market, strategic employment of capital and attainment of competitive advantage by way of pricing power is a key issue. With the exception of some metals such as gold[8], pricing power is more related to control of supply than growth in demand for product. In other words, a deficit of supply rather than increased demand is most likely to improve commodity prices. In an increasingly globalised industry, this has translated into a rapid concentration of ownership in the industry since the mid-1990s and a general move to global supply control (see Table 1.2). For example, world production of iron ore controlled by the top five minerals companies has increased from 47 per cent in 1995 to 64 per cent in 2001 (Durie 2002). Thus it appears that globalised minerals companies believe that concentration of ownership increases competitive advantage. In the current environment, however, the role of innovation in attaining competitive advantage is often overlooked or down-played. This thesis seeks to highlight the importance of innovation for long-term competitive advantage, as well as for a sustainable and successful minerals industry (the relationship between innovation and competitive advantage is discussed further in Chapter 7).

Table 1.2: Concentration of commodity production among top 5 producers in a selection of commodity groups

Commodity group	Per cent control by top 5 producers (%)		Increase or (decrease) in concentration (%)
	1995	End 2001	
Refined aluminum	25.9	37.5	11.7
Copper in concentrate	32.7	39.2	6.5
Refined copper	22.6	27.5	4.9
Diamonds	75.0	70.0	(5)
Gold	30.5	40.9	10.5
Iron ore	46.9	64.0	17.1
Lead in concentrate	38.5	47.6	9.1
Refined lead	25.8	31.2	5.4
Nickel	61.5	60.9	(0.6)
PGMs	70.7	78.2	7.5
Refined Zinc	33.3	43.4	10.1
Zinc in concentrate	33.6	40.2	6.6

Source: reported in (Durie 2002), data from Merrill Lynch & AME

Increasing rates of globalisation have had a dramatic effect upon control of Australian resources since the merger of CRA and Rio Tinto in 1995. Once WMC finalises its de-merger, Australia will have lost its last world-scale, majority Australian-owned minerals company. Control of Australia's largest gold company, representing 60 per cent of Australian gold production, was

[8] Annual gold production equates to 4 per cent of gold held by central and private banking stores. Thus, size, even with considerable control over production will not control gold prices. It does, however, boost individual company value with big companies having greater price/earnings ratios.

transferred to US control when Newmount acquired Normandy in February, 2002. Only five years ago, resources stocks accounted for 35 per cent of the Australian Stock Exchange (ASX) and Australia had the biggest mining capitalisation in the world. Today, however, resources stocks have declined and make up only 15 per cent (including BHP-Billiton, Rio Tinto and Normandy) of the ASX, and the global centre of mining capital is London. Many analysts argue that foreign ownership is not a concern for the Australian minerals industry, since it is not as exposed to unfavourable decisions made by parent MNCs as other industries. In automotive manufacturing, for example, a parent MNC may elect to close Australian production facilities to take advantage of lower wage rates and conditions in another country. Because mineral deposits and associated production facilities are not transportable, the issue of foreign ownership of the Australian minerals industry is often .regarded as less important than for manufacturing industries. This argument, however, is superficial and undermines the reality of a deep range of benefits Australia derives from its minerals industry. Normandy, for example, invested $60 million in Australian exploration, and $35 million in Australian R&D, in 2001-02. There are no guarantees that in future Newmount will make similar decisions about investment in Australia (Normandy Mining 2002). The Australian minerals industry has supported the development of a dynamic services sector, with 60 per cent of the world's mining software being of Australian origin (Broome 1999). Following the takeover of Normandy, the small Australian software entrepreneur, for example, may now need to visit Denver, Colorado, rather than Hutt Street, Adelaide, to sell a new gold-mining idea.

The relationship between government and the minerals industry has traditionally been viewed in a simplistic fashion by both the private and public sectors. State governments are responsible for granting mining leases (usually with conditions attached), maintaining mining-law compliance, and collecting royalties. The Commonwealth Government collects taxes to which it is entitled (and is responsible for environmental management at uranium mines in Kakadu National Park). Mining activities are conducted entirely by the private sector. The self-reliant nature of the minerals industry has perpetuated this position. Indeed many in the industry see 'as little as possible' being the desirable role of government. Perhaps this aspect of the relationship between the minerals industry and government was most clearly and recently illustrated by the Government's blocking of Shell's bid for Woodside Petroleum, allegedly to maintain Australian control over a key energy export, LPG, and comparative Government silence on the sale of Normandy and the BHP-Billiton merger.

This thesis will argue that the historic development of a capacity to innovate was the key that unlocked Australia's minerals resources and that innovation has continued to support this industry sector's important contribution to the Australian economy. The innovation systems perspective taken by this study's exploration of minerals innovation will not only reveal a considerable degree of sophistication and knowledge-intensity within Australia's minerals system of innovation (MinIS), but also highlight the increasing and important role of government in supporting this innovation system. As Australian ownership declines, more responsibility may need to be transferred to government for the maintenance of the minerals industry's knowledge base and associated infrastructure, so that the MinIS' performance is sustained. In this way the MinIS will remain globally competitive in terms of investment from a globalised industry, and continue to produce knowledge-intensive new industries that are competitive in the knowledge economy.

1.4 Structure of this thesis

Chapter 2 outlines this thesis' methodology; namely an embedded, exploratory single-case study. It begins by explaining why the case-study methodology was selected for this work, before introducing this study's research questions and discussing the research design. An important feature of the research design is the use of an IS conceptual framework to develop three levels of analysis or analytical lenses – through which different aspects of innovation in the minerals industry might be brought into focus. Each level of analysis corresponds to a research question and in combination provide a rich picture of a *minerals system of innovation*. The research design also contains multiple case study subunits, examples of innovation, to be characterised for a particular level of analysis (see Table 2.1 for an outline of the research design and data collection process). The process of data collection, including selection of case study subunits and sources of information, is explained. The chapter concludes by restating the advantages and limitations of the case-study methodology.

This study uses an unusual grouping of commodities as a result of the snowball sampling technique used when selecting case study subunits for analysis. It was originally intended to exclude the energy sector (oil, gas and coal) and restrict this study to the base metals (copper, lead, zinc) industry[9] and industrial minerals in Australia. The examples of innovation found in the diamond and uranium industries (Diamond and Ranger and Jabiluka environmental management case study subunits, respectively) were so compelling that a decision was made to extend the commodities represented in this study of minerals innovation. The commodities represented in the subunits include gold (Cyanide Processing), base metals (Flotation), diamonds (Diamond Sorters), copper (Block Caving), iron ore (HIsmelt), and uranium (Ranger and Jabiluka Environmental Management).

Chapter 3 reviews the innovation literature and the IS approach. The Chapter begins by acknowledging the role of economic theory in precipitating a need for an alternative approach to understanding growth and development. The literature on innovation is presented next, taking the perspective of looking inside the innovation process 'black box'. Studies of technological development and innovation represent the theoretical origins of the IS approach. The IS approach is critically appraised in Sections 3.5 and 3.6, and this includes defining the individual approaches within the IS family, as well as a discussion of the conceptual difficulties and limitations inherent in application of the IS approach.

The competitive dynamics of the minerals industry are addressed in more detail in Chapter 4. This includes an overview of the Australian minerals industry – its scale, scope and

[9] The base metals industry is defined as a raw material-based industry – an industry closely linked to the extraction of raw materials from natural resources and related to primary manufacturing. Other global raw material-based industries are the global forest industry and the global oil industry.

characteristics. The chapter combines information sourced from the literature with information derived from this study's empirical work. It begins to introduce some basic features of innovation in the minerals industry and analyses indicators of R&D activity.

The following three chapters contain the empirical findings organised according to the level of analysis or analytical lens being employed. Chapter 5 is an historical view of innovation in the minerals industry as illustrated by three case study subunits: Cyanide Processing; Flotation and Diamond Sorters. The purpose of taking this historical perspective is not to summarise the history of mining, but intends to highlight the origins, development and features of a minerals system of innovation. The chapter also includes an example of a firm's innovation strategy and competencies in the mid-1980s, for comparison when considering current trends in minerals innovation. The advent of an environment ruled by globalisation and the knowledge economy is the context of the remaining empirical analysis.

Chapter 6 is dedicated to determining more precisely how innovation takes place in the minerals industry. The purpose of this level of analysis is to identify the characteristics, nature and trends of innovation for the following minerals-related activities: exploration; extraction; processing; and environmental management. Case study subunits are presented for each of these activities. Although the characterisation of these subunits is organised according to activity, many of the findings have implications for innovation outside of these activities and are discussed accordingly.

In Chapter 7 minerals innovation is explored with an analytical lens that focuses on identification of elements (firm and non-firm organisations) and their interaction or relationships within the MinIS. Here the purpose is to gain a better understanding of how these elements enable innovation within the MinIS, and to give some thought to the MinIS' Australian context: its location within a fragile NIS. Attention is paid to the differences between large and small minerals firms in terms of their strategies, competencies and patterns of integration within the MinIS. The latter is illustrated with two empirical case study subunits: the CRA-RTZ merger; and Croesus. Consideration is also given to the manner in which exogenous sources of change to the competitive dynamics of the industry are causing firms to change their technology strategies (knowledge base) and ultimately the dynamics/structure of the MinIS.

Chapter 8 concludes this study's exploration of minerals innovation. This Chapter reviews answers to the research questions, including an analysis of recent changes in the dynamics of minerals innovation, and the resultant challenges and opportunities facing the MinIS. Attention is then paid to how this study has contributed to the new and evolving field of innovation research, which is primarily through its use of a synthesis of existing literature as an heuristic to examine innovation in the minerals industry sector. This Section also highlights some promising directions for future research. The Chapter ends with a discussion on the policy implications for government in the MinIS. In essence, it is concluded that in the current competitive environment, there is an important role for government in creating an institutional environment and competitive conditions that enable innovation within the MinIS. The opportunity exists for Australia to become a world centre of expertise in minerals-related innovation, education and training, and production of knowledge-based products and services. Leadership on behalf of government is essential if this opportunity is to be fully exploited.

Appendices appear at the end of the thesis.

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Chapter 2:

Research Methodology

2.1 Introduction

This chapter presents the case study research methodology used to carry out this study. It states the purpose of and motivation for this study, before discussing the research design developed for this investigation: an exploratory, single-case study with multiple case study subunits and three levels of analysis. A general discussion of the case study method, including the reasons why it was selected and a review of the generic components of case study research design, follows. Finally, the protocol for conducting this case study is presented, along with its associated limitations.

This study's research design combines rich empirical material with three analytical lenses, or theoretical perspectives, derived from the innovation systems literature in order to explore some 'uncharted territory', the minerals innovation system.

2.2 The study's purpose and motivation

2.2.1 The purpose of this study

The purpose of this thesis is to explore the role of innovation in the minerals industry in Australia. At a generic level, the literature demonstrates that innovation does not take place in isolation. Instead, innovative activities involve numerous different organisations, institutions and technologies, linked together by a web of dynamic relationships and interactions; that is innovation occurs within a *system*. It is asserted here that if innovation plays an important role in the minerals industry it will necessarily be supported by a 'minerals innovation system' (MinIS). This study's picture of the MinIS is provided through three analytical lenses, each giving a view of the MinIS from a different, more precise analytical perspective developed from the innovation systems literature. A secondary, related purpose of this study is to make clear in what sense an innovation systems (IS) approach is useful.[9] This study's exploratory nature lends itself to the identification of key issues and the development of hypotheses and propositions for further inquiry.

2.2.2 Motivation for conducting this study

A primary motivation for this study was the fact that the minerals industry has been largely overlooked by both general innovation studies and analyses of Australia's innovative performance, capabilities and system of innovation. A distinct lack of attention exists within the innovation literature in relation to the minerals industry and the systematic analysis of the role of innovation. This is in contrast to other industry sectors, such as pharmaceuticals, automotive, and construction for which large bodies of empirical and theoretical knowledge have been developed from a range of innovation-based perspectives (ie role of firms, organisational structure, knowledge and learning, innovation management, technologies, and innovation systems). Pavitt's (1984) classification of industry sectors, according to the innovative characteristics of requisite business firms, identifies producers of standard materials (ie steel, other metals), consumer goods and automobiles as 'scale-intensive' innovators (Pavitt 1984).[10] However, most sectoral and industrial studies of innovation, like those presented in *The Handbook of Industrial Innovation,* overlook the minerals sector (Dodgson and Rothwell 1994). In general this oversight seems to be largely based upon the assumption that the minerals sector's low R&D intensity and lack of product innovation indicates that innovation and new technologies are not critical competitive assets for the minerals sector.

As was stated in Chapter 1, for an industrialised economy Australia has a high level of dependence on its minerals industry (MMSD Project 2002). Indeed it is the only truly globalised industrial sector in Australia, with large firms whose activities are comparable to international standards of global sales and competition (Hill and McKern 1997, Sheehan 2000). Large firms that have a capacity to innovate, maintain knowledge-based competitive assets and are engaged in international markets are key players in modern economies (Patel and Pavitt 1991, Pavitt and Patel 1995, Molero 1995, Chandler et al. 1999). Given the status of minerals firms in the Australian economy, a lack of understanding of innovation in the industry is surprising and potentially damaging in terms of future public policy development and missed opportunities for the capture and exploitation of positive spill-overs and flow-on effects from the industry and its system of innovation.

Moreover, the general perception of the minerals industry has been dominated by a prevalent and traditional view in which mineral wealth is a finite 'gift of nature' and not substantially

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[9] The notion of researchers needing to make an innovation systems approach more compelling and to clarify in what sense an innovation systems approach is useful, is described in McKelvey and Orsenigo's draft paper on the pharmaceuticals industry as a sectoral innovation system (McKelvey and Orsenigo 2001).

[10] Innovation in 'scale intensive' firms is characterised by a dominance of process innovation, a drive to reduce costs, progressive integration of technological advances and maintenance of technological leads from internal expertise (know-how), secrecy, and to a lesser extent patents (Pavitt 1984, Pavitt et al. 1989).

created from the innovative and technological capabilities held within minerals companies and countries (Tilton 2000, Tilton 2001). A lack of an holistic knowledge base and a lack of empirical studies of minerals innovation motivates this study. Additionally, it dictates this investigation's exploratory characteristic. Furthermore, a need to develop an empirical base of evidence and basic understanding of minerals innovation means there is not as much room for theoretically oriented analysis.

This study rejects the traditional view of the minerals industry and questions whether assessments of the role of innovation in the industry, based upon simple measures (BERD and R&D intensity[11]) and characteristics of minerals innovation (a lack of product innovation), are valid.

2.3 This case study's research design

This section introduces the major components of research design used in this investigation: research questions; propositions; and, organisation of data collection (multiple subunits and levels of analysis).

2.3.1 Research questions

The first stage in developing a case study research method involves determining the research question(s) to be answered by the study. The research questions must be aligned with the study's purpose. This study's questions were also shaped by a review of the innovation literature and the minerals industry-specific technological literature. In this manner, more pertinent and insightful questions were formulated. The minerals industry is diverse and this study's scope is broad. In order to tailor this exploratory study, the primary question is supported by five secondary, targeted questions, organised as follows:

Primary research question

1) *Does innovation play an important role in the minerals industry in Australia?*

As described in Section 2.2.1, innovation is assessed from an innovation systems perspective and thus the question is more sophisticated than simply, 'are there some innovative Australian minerals firms.'

Supporting research questions

There are five supporting research questions. The first three questions directly relate to the first three levels of analysis, respectively (see Table 2.1). The remaining two questions are interrelated and not explicitly emphasised in the data collection process. Rather they are addressed in an iterative fashion (ie from an accumulated understanding of minerals innovation) and deal with issues of changes in minerals innovation and future performance of the MinIS.

[11] Firm's R&D intensity represents expenditure on R&D as a per cent of sales.

i) What role did innovation play in the development of Australia's minerals industry?

The innovation literature emphasises the utility of a historical view when studying innovation systems – to understand why a system takes a particular form requires an understanding of the dynamic processes that generated and shaped it (McKelvey 1997). This question aims to more precisely determine how minerals innovation contributed to the Australian industry's historic development and highlight the origins of the minerals system of innovation. It does not cover the entire history of the industry, or measure how actors and specific relationships evolved over time. However, an emphasis is placed upon the industry's historical development in the latter half of the nineteenth century, and the conditions preceding the advent of a capacity for technological innovation. Two examples of significant process innovation (see Cyanide and Flotation case study subunits of analysis, Chapter 5) relate to the origins of the MinIS and associated industrialisation of the industry. In addition, a more contemporary example (1980s) of innovation (Diamond Sorters case study subunit, Chapter 5) is included to establish a base from which to assess current changes in innovation dynamics.

ii) What are the characteristics, nature and trends of innovation in minerals-related activities – exploration, extraction, processing and environment?

To understand the role of innovation in the minerals industry, it is necessary to know more precisely how innovation takes place. The minerals industry is comprised of distinct activities, and innovation in these activities may have equally distinct characteristics with regard to actors, relationships, technologies and dynamics. Empirical examples of innovation (selected by industry members) are analysed for each activity (see Chapter 6).

iii) How do organisations and relationships in the minerals innovation system enable innovation?

This question is really about situating the MinIS in its Australian context, that is, within a fragile NIS. A relatively basic approach is therefore taken to identify the elements (firms and non-firm organisations) within the MinIS, and the way in which they interact during technological innovation processes. The role of large versus small innovative firms in the MinIS is investigated with two empirical examples (see CRA-RTZ Merger and Croesus subunits, Chapter 7) with reference to their strategies, maintenance of internal capabilities and associated relationships within the MinIS. Consideration is also given to the way in which minerals firms are adjusting to change in the competitive dynamics of their industry, in terms of their technology management strategies.

iv) Why and how is innovation in the minerals industry currently changing?

Innovation systems evolve in response to exogenous (global) and endogenous (range of national through to firm-level) sources of change (the elements of change might be, for example technological, institutional or market-derived). This question aims to identify and gain an understanding of these dynamics in relation to the MinIS. Globalisation of the minerals industry, for example, has important implications for how innovation in the Australian MinIS is supported, by both firms and governments.

v) What challenges and opportunities are facing the minerals system of innovation?

This question concerns the policy implications, for both firms and government, raised by this study's findings. Changes in the individual actions of firms or groups of firms, as well as institutional developments and/or incentives that influence knowledge development and innovation, create opportunities and challenges for the MinIS.

2.3.2 Proposition

Once the research questions have been established, propositions may be used to guide what data need to be collected to answer them. In general terms, a proposition draws focus upon a particular area within the scope of a study. This second component of case study research design is not always necessary, particularly where the topic for investigation is exploratory (Yin 1994). However, due to the broad nature of this exploratory case study it was decided that developing some propositions would be useful.

The purpose of this case study, as noted above, is to understand the role of innovation in the Australian minerals industry. The following propositions were used to ensure that only information of relevance to the purpose of this case study was collected:

- that development of innovative capabilities drove the historical maturation and industrialisation of Australia's minerals industry
- that trends in minerals-related innovation differ according to the type of activity involved: exploration, extraction, processing and environmental management
- that the current global competitive environment is changing the Australian minerals system of innovation
- that government policy can enable or inhibit performance of a minerals system of innovation
- that the minerals industry is innovative and knowledge-based.

2.3.3 Organisation of empirical studies – multiple case study subunits and three levels of analysis

The primary unit of analysis for this single-case study is the MinIS. Each level of analysis provides a different analytical perspective of the 'whole' MinIS. When combined, the analytical lenses provide a link between theoretical perspectives contained in the literature and the rich empirical material collected in this study: 12 discrete examples of minerals innovation (case-study subunits) (see Table 2.1). The combination of subunits and levels of analysis aims to ensure that this exploration captures meaningful information as economically as possible and ultimately answers the research questions effectively. The resulting research design provides a logical framework for data collection and analysis.

Case studies with multiple case-study subunits are said to have an 'embedded' research design (See Section 2.5.2). Individual subunits highlight a feature of, or trend in, minerals technological innovation, some are new process developments and others relate to organisational change. They are not intended for direct comparison with each other, and this would not be possible as each has a slightly different data collection process. Rather, each subunit provides a detailed 'story' of innovation, told from a particular analytical perspective. They also provide a point of reference from which to expand and generalise about innovation in the industry. In spite of having an explicit link to a level of analysis, there is much overlap in the contribution these stories of innovation make across all three levels of analysis.

Table 2.1: Organisation of data collection process – 3 levels of analysis and characterisation of multiple subunits

Level of Analysis	Case study subunits being Characterised	Data Collection: Secondary sources – Qualitative	Data Collection: Secondary sources – Quantitative	Data Collection: Interviews with key individuals – Private sector managers researchers	Data Collection: Interviews with key individuals – Public sector academics researchers	Data Collection: Interviews with key individuals – Research brokers	Data Collection: Interviews with key individuals – Government managers
(research question i) ***1. Historical view of MinIS***		previous studies/ histories	indicators of innovation, numbers of schools of mines etc	subunit non-specific interviews	subunit non-specific interviews	subunit non-specific interviews	subunit non-specific interviews
	Cyanide	√	√				
	Flotation	√		√	√	√	
	Diamond sorters	√		√	√		
(research question ii) ***2. Nature of innovation in MinIS***		public domain reports, journal & news articles etc	indicators of innovation, patents publications R&D expenditure etc	subunit non-specific interviews with retired & working individuals	subunit non-specific interviews with retired & working individuals	subunit non-specific interviews with retired & working individuals	subunit non-specific interviews federal & state
	ARIES	√		√	√	√	
Exploration	**Fractal**	√		√		√	
	Block Caving	√		√			
Extraction	**Mine to Mill**	√	√	√	√	√	
Processing	**HIsmelt**	√	√	√	√		
Environment	**Ranger / Jabiluka**	√		√	√		√
(research question iii) ***3. Enabling innovation in MinIS***		public domain reports, journal & news articles, seminars etc	indicators of innovation, patents publications R&D expenditure etc	interviews with retired & working individuals	interviews with retired & working individuals	interviews with retired & working individuals	interviews federal & state
Mapping interactivity among elements (firm and non-firm organisations)		√	√	√	√	√	√
	CRA-RTZ merger	√		√	√	√	√
Private sector	**Croesus**	√		√		√	
Public sector	***BHEI**	√	√	√			√

* the BHEI case-study subunit is presented in Appendix 8.1.

Addition of multiple levels of analysis to a standard 'embedded, single-case study' research design is a significant organisational tool. It breaks this broad exploration into distinct and manageable perspectives, or as Marceau describes, 'it allows the subject to be viewed through different analytical lenses' (Marceau 1994). In the words of Edquist:

> A system of innovation should be looked upon as a 'whole' because many of its elements are – more or less closely – related to each other. Otherwise there would be no 'system'. But it is also sometimes necessary to deal with only parts of the system – one at a time or a few in relation to each other.
> Hence, it may sometimes be necessary to restrict the analysis to various sub-systems of a system of innovation. To divide the complex 'whole' into pieces…is sometimes useful – and sometimes even a necessary way of understanding and creating theories about the relations between various parts or 'elements' involved in the process of technological and organisational change. (Edquist 1997a:18)

In this study, each analytical lens provides a distinct view of the MinIS. In addition, the analytical lenses synchronise, such that each lens enhances the view of the others to create a rich picture of the MinIS and a greater understanding of the role of technological innovation for economic advance in the minerals industry.

In terms of the individual lenses:
• The first provides an 'historical view'; it looks at the origins and development of a minerals system of innovation to help determine its early structure and performance, with reference to the origins of Australia's NIS. This view also includes a more contemporary 'snap-shot' of the MinIS (late 1980s) to provide a point of comparison with its original status.
• The second provides a view of the 'nature of technological innovation' in the minerals industry, for those activities reliant upon the exploitation of technological change to improve the industry's economic performance (exploration, extraction, processing and environment). This view has the potential to deliver some detailed understanding of how innovation processes vary across the industry (in terms of trying to identify differences and changes in knowledge bases at an empirical level), and offers the possibility for identification of activity-specific 'components' within the MinIS.
• The third provides a view of the system's structure as illustrated by relationships, especially 'interactivity' among its constituent elements. It is important to find the nature of interactivity among players, in particular those involving large and small firms within the MinIS. Special consideration needs to be given to the technology strategy (which dictates the degree of interactivity within the system) of large firms (those with the facilities, capital and capabilities to support technological development in the long-term). The involvement of large firms is a vital element and driver of interactivity, and dynamics of systems generally, and this would be expected to be the case in the MinIS.

This case study's research design is stronger for its combined use of primary and supplementary research questions, case study subunits and multiple levels of analysis.

2.4 Approach – the Case Study Method

2.4.1 Reasons for using the case study method

Innovation is a dynamic, unpredictable and multifaceted process, and systems of innovation involve a variety of players and relationships. Systems of innovation can be examined at various levels such as the national, regional, sectoral or firm level (Edquist 1997b, Lundvall 1992, Nelson 1993, Niosi 2001, de la Mothe and Paquet 1996). The study of innovation requires an appropriately dynamic and flexible methodology, capable of handling a full range of evidence and multiple levels of analysis. The case study method is used widely for innovation-related research, some notable examples being at the national level with Freeman's original 1987 work on Japan's NIS, at the regional level with Malerba's work on sectoral systems of innovation, and at the firm level with Dodgson's 1991 study of the biotechnology company Celltech (Freeman 1987, Malerba and Marengo 1995, Dodgson 1991).[12]

According to Yin, 'the case study's unique strength is its ability to deal with a full variety of evidence—documents, artefacts, interviews and observations...'(Yin, 1994:8). It is precisely this strength that makes the case study methodology well-suited to studies of innovation generally and is the primary reason why it was chosen for this study.

There were additional reasons for selecting case study methodology for this study, as opposed to alternative social science research methods such as experiments, surveys and histories. Case studies are most appropriate when 'a *how* or *why* question is being asked about a contemporary set of events over which the investigator has little or no control' (Yin, 1994:9). In other words, case studies can be used in situations, such as those in this study, where multiple independent variables are involved and cannot be controlled or isolated from the context of the study. Experiments require some degree of 'control' over variables, or a situation in which an investigator can manipulate behaviour directly and divorce a phenomenon from its context. Surveys, on the other hand, can examine phenomena in context. They can only, however, handle a limited number of controllable variables and are best suited to answer research questions that have an element of frequency, such as 'how many' or 'how much'. For this study, a survey asking such questions could not capture the eclectic dynamics of innovation across the minerals industry. While surveys and experiments can produce quantitative data that are statistically significant and simple to analyse, these methods do not have the capacity to investigate innovation in its 'real-life context' and therefore are not appropriate for best answering the research questions set by this study.

While histories deal with phenomena in context, however, they focus on the 'dead' past. Historical case studies have nevertheless made a great contribution to the study of innovation; Dosi's research on 'path dependency' and the historical pretext to systems of innovation being of particular note (Dosi et al. 1988). An historical methodology alone would obviously be unsuitable for answering the principal question asked by this study, however, because an historical view has utility in uncovering many of the factors that ultimately produce an innovation system, an historical approach is utilised here as one of three levels of analysis employed (see Section 2.3.3).

Yin gives a technical definition of the case study inquiry as one that:

> • copes with the technically distinctive situation in which there will be many more variables or interest than data points, and as one result

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[12] There are many more recent examples, including *inter alia*: the technological accumulation paths of two case-study steel companies (Figueiredo 2002); and, an in-depth study of innovation dynamics in the pharmaceutical industry (Achilladelis and Antonakis 2001).

> • relies on multiple sources of evidence, with data needing to converge in a triangular fashion, and as another result
> • benefits from the prior development of theoretical propositions to guide data collection and analysis (Yin, 1994:13).

In summary, the case study as a research strategy is an all-encompassing method and can incorporate elements and techniques from other social science research methods into the research design of a particular inquiry. These and the characteristics outlined above make the case study method the most appropriate for this study of innovation in Australia's minerals industry.

2.5 Research design

The development of a research design is a key element of case study research. The research design provides the logic that links the research questions being posed to an appropriate data collection strategy and analysis. The main purpose of a research design is to avoid the situation where a study's evidence does not address its research questions.

This section introduces the generic components of case study research design, discusses the type of research design used in this investigation and presents the key components of this study's research design: the research questions; propositions; and units of analysis.

2.5.1 Key features of case study research design

The research design can be thought of as a 'blueprint' for dealing with four common research problems: 'what question to study; what data are relevant; what data to collect; and how to analyse the results' (Yin, 1994:20). These problems are addressed by a number of important components of a research study design:

- a study's questions
- its propositions (if any)
- its units of analysis, and
- criteria for interpreting the results and judging a study's success.

The importance of each component depends on the type of case study being used. However, all robust research designs need these components to ensure clear identification of what data are to be collected and what analytic generalisation may be done following data collection (Yin 1994).

A research design is not complete without the development of a conceptual framework. Theory development makes case study research distinct from ethnography and 'grounded theory'. The latter methods deliberately avoid specifying any theoretical propositions at the outset of an inquiry. The use of theory facilitates insight into a topic and greatly helps identification of meaningful areas for investigation and questioning. In addition, a conceptual framework becomes the main vehicle to guide analytic generalisation.

2.5.2 An embedded, single-case design

A number of different research designs can be utilised within the generic case study method (Yin 1994). The research design is characterised according to, whether a single or multiple-case study is required and whether or not more than one unit of analysis is involved for each case study. This study's research design is a single-case study with multiple units of analysis, namely an *embedded, single-case design.* While an embedded design is more complex, multiple units of analysis (case study subunits) can provide a structure that better guides data collection and can create more detailed points of insight from which to conduct analytic generalisation (*ibid*).

This thesis is a single-case study, the subject of which is innovation in the Australian minerals industry. It has multiple units of analysis to represent particular examples of process, product or organisational innovation (see Table 2.1).

2.5.3 Exploratory case studies

Where the existing knowledge base is poor and available literature provides no relevant hypotheses of note, an investigation assumes the characteristic of an 'exploratory' study. Exploratory case studies differ from two other types of case studies: 'descriptive' and 'explanatory'. The latter types build upon existing theoretical statements to either a) provide a description with the aim of supporting a theory, or b) make casual statements based upon existing theory to explain 'how' or 'why' particular situations or outcomes occurred. An exploratory case study is analogous to an act of 'exploration': it must have a rationale and direction. The aim is, however, to 'map uncharted territory' and thereby develop pertinent hypotheses and propositions for future lines of inquiry.

This study's exploratory nature is a result of the lack of research on innovation in the minerals industry and consequent lack of theoretical statements about innovation in this industry upon which to expand and generalise.[13] The fact that this study has a conceptual framework, derived from the vast, general innovation literature, does not change its exploratory nature. Rather, the conceptual framework is crucial, formulating insightful research questions and a robust research design from which to conduct this exploration of minerals innovation.

The case study method is well-suited to exploratory research. However, according to Yin, a well-founded exploratory case study should be preceded by statements about what is to be explored, the purpose of this exploration and the criteria by which the exploration will be judged successful. The first two points, what is being studied and for what purpose, are addressed at the start of this chapter, in Section 2.2. The obvious criteria by which this study will be judged successful is whether the research questions are effectively answered. The latter is dependent upon the findings of this exploration providing:

[13] There is little material that considers innovation dynamics and the minerals industry in a holistic manner. However, particular activities and industry sectors have received attention such as, for example, steel processing described as a capital intensive industry that favours incremental innovations (Pavitt 1984) and electrowinning (SX-EW) process for copper smelting (Tilton and Landsberg 1999).

- an understanding of the role of innovation in the minerals industry
- a description of characteristic trends in innovation for common mining activities, ie exploration, extraction, processing and environmental management
- a robust description of a minerals innovation system
- an understanding of why and how minerals innovation is changing, and
- an ability to discern the value of future investigations of various hypotheses or propositions related to innovation in the minerals industry.

2.5.4 Breadth verses Depth

An issue for exploratory social research concerns the tension inherent between the 'breadth versus depth' of a study (Foote Whyte 1988). In this case, a decision was made to maximise the breadth of the work and include a full range of core mining-related activities, as opposed to going into greater depth of description and analysis for a single activity or innovation. This decision was made in response to the lack of research, particularly of a holistic nature, on innovation in relation to the minerals industry in Australia. Furthermore, once a minerals system of innovation has been described, it may be possible to better target future research into particular phenomena or activities within the system that are under stress, or that may benefit from greater depth in description and analysis.

This study does not include all mining activities affected by innovation. A noteworthy exclusion from this study is 'mine planning', an activity that involves knowing how to manage the financing and development of an operation.

2.6 Case study protocol

This section presents the protocol for conducting this case study.

2.6.1 Pilot interviews

A series of pilot interviews with key industry individuals initiated this study's program of fieldwork. The pilot interviews were conducted in order to develop some background understanding of issues relating to innovation in the industry, and to identify potential subunits of analysis and a more extensive list of key individuals for interview.

This initial stage of fieldwork greatly benefited from the support of David Karpin (retired industry executive and Adjunct Professor at the National Graduate School of Management, ANU). Karpin identified seven industry executives, all of whom had an interest in innovation. Karpin's endorsement of this research also facilitated the necessary access to interview these individuals (see Table 2.2).

Table 2.2: Program of pilot interviews

Title*	Company / Institution
Richard Knight – Executive Director / Development	North Limited
Tony Kjar – Consultant	retired-CRA, AMIRA
Robin Batterham – Vice President Research and Technology	Rio Tinto
Dick Davies – CEO	AMIRA
Dick Carter – Consultant	retired-BHP Chairman BHP Minerals
David Karpin – Consultant	Retired-CRA
John Burgess – Vice President Safety, Environment & Technology	BHP
Rob La Nauze – Group Manager Technology	WMC

* Titles and positions held at time of interview

The pilot interviews were loosely structured and included a discussion of the following issues:

- each individual's personal experience in relation to innovation in the industry;
- what were key trends in innovation and how they were changing;
- the identification of pertinent examples of innovation across the industry's activities;
- key papers or publications; and
- other key individuals to be interviewed in the study.

The pilot interviews were assisted by the use of quantitative indicators of innovation (expenditure on R&D, publication rates and number of patents) handed to interviewees at the time of interview. All interviewees were asked to interpret these figures and, where appropriate, their company's performance when measured in this manner.

All pilot interviews were tape-recorded and notes were taken during the interview. The pilot interviews were successful in gaining a perfunctory understanding of innovation in the industry, identifying a number of potential subunits of innovation for further investigation and in extending the network of key individuals for interview.

2.6.2 Sampling process

A form of sampling known as 'snowball sampling' was used throughout this study. This type of sampling relies on those in the industry identifying key individuals and issues. This method was particularly useful given the fragmented quality and dearth of literature on the subject, and the fact that the literature is often a primary source for identifying key individuals and issues. Throughout the data collection process interviewees were asked to identify key individuals, from the private and public sectors. This also proved to be a useful method of reconfirming that the individuals and issues being pursued were indeed appropriate.

2.6.3 Interview program and method

Eighty-eight individuals from the public and private sectors were interviewed for this study (see Appendix 2). As a number of key individuals were interviewed on more than one occasion, the total number of formal interviews conducted for this study amounts to over one hundred.

The interviews were loosely structured and followed the same format as that described above in the pilot interviews.

2.6.4 Site visits

Having met with numerous key individuals from the private and public sectors in capital cities it was necessary to conduct some research on location at mine sites and operations. Gaining access to mine sites and operations proved to be considerably more difficult. A program of site visits would not have been possible without the support of Dick Davies, CEO of AMIRA, who used AMIRA's network of contacts to identify on-site personnel who might agree to a site visit. Davies also sent letters of support to these personnel, recommending participation in this study. Prior to this support from AMIRA only one mine site had responded to a request for interviews and site visit.

A major field-trip around Australia prioritised visits to company operations. Where possible, visits were also made to research providers and corporate head offices. The tables below list the operations and research institutions visited during this field trip.

Table 2.3: List of site visits during major field trip

Name of operation	Location
Ranger uranium mine	Kakadu National Park, NT
Jabiluka uranium mine	Kakadu National Park, NT
HBI processing plant	Port Headland, WA
Port Headland Port facilities	Port Headland, WA
HIsmelt processing plant	Kwinana, WA
several Croesus mine sites	Kalgoorlie, WA
public tour of 'The Superpit'	Kalgoorlie, WA

Table 2.4: List of research institutions visited during major field trip

Name of institution	Location
CSIRO Exploration & Mining – Pinjarra Hills site	Brisbane, Qld
ACMER – Pinjarra Hills	Brisbane, Qld
JKMRC, University of Queensland	Brisbane, Qld
CRC-MTE	Brisbane, Qld
Sir James Foots Institute of Mineral Resources, University of Queensland	Brisbane, Qld
ERISS – Environmental Research Institute of the Supervising Scientist, field laboratories	Kakadu National Park, NT
CSIRO – Exploration & Mining	Perth, WA
Institute for Science and Technology Policy, Murdoch University	Perth, WA
Kalgoorlie Museum of Mining	Kalgoorlie, WA

The most extensive site visit took place at ERA's uranium operations in Kakadu National Park. Over a period of ten days tours were made of the Ranger mine site, processing plant and on-site laboratory, as well as the developing underground mine site, Jabiluka. As was the case for all site visits, once on location it became possible to interview many more individuals than was originally planned. This greatly enriched the data collection process. A tour of, and interviews at, ERISS (Environmental Research Institute of the Supervising Scientist) field laboratories and environmental monitoring sites, also located in Kakadu, complemented the data collected from ERA's operations.

2.6.5 Seminars and conferences

The data collection process was augmented by attendance at relevant seminars and conferences. Apart from the proceedings at these events, they provided to opportunity to ask questions and participate in debate on issues surrounding innovation in the industry. In addition, it was often possible to interview delegates in an informal manner and generally expand the network of individuals willing to participate in this study. A list of the 30 individuals interviewed in an informal manner is given in Appendix 2. The seminars and conferences where such interviews took place are listed in Table 2.5 below.

Table 2.5: Seminars and conferences

Title	Date	Organisation
2001 Minerals Council of Australia Annual Seminar – Unearthing the Future	6/6/01	Minerals Council of Australia
2000 Minerals Council of Australia Annual Seminar	6/6/00	Minerals Council of Australia
Science and Technology in the Boardroom	2/8/00	FASTS
The Innovation Action Plan: making sure it works	9/5/01	FASTS
AMIRA Project development Committee Meeting	7/12/00	AMIRA
Milestones to the Future AMIRA's 40th Anniversary Technical Meeting	18/8/99	Australian Mineral Foundation Inc & AMIRA
Southern Africa–Australia Mineral Sector Synergies Symposium	16/3/00	AusIMM
Outlook 2000 – ABARE	29/2/00	ABARE
National Science Briefing (attended various briefings related to minerals industry) – Australian Parliament House	99-01 (several)	Department of Industry Science and Resources
Management of Technology Research Networking Seminar	6-7/7/00	ARC Management Research Networking Pilot Program
GIS for Geologists Open Day	4/5/99	AusIMM and GIS Training Centre (Perth)

2.6.6 Analysis

Data analysis was a continuing process, beginning at the time of the pilot interviews and proceeding throughout the period spent collecting data. The iterative nature of this study, where the results from a particular interview influenced which individuals and issues would be included in subsequent interviews, lead to the continuing nature of data analysis.

Data analysis was intended to follow the logical framework established by the research design's three levels of analysis. That is, historical subunits and literature would be treated first, followed by subunits in level two concerned with identifying generic types of innovation across mining activities, leaving the analysis of the minerals system of innovation until last. In reality, and due to the iterative nature of this study, the subunits and levels of analysis were treated simultaneously. As new findings were made, subunits were updated and contributed to an overall dynamic process of data analysis.

2.7 Comments on Protocol

This study's protocol, and open-ended interviews in particular, has inherent limitations and these need to be recognised and accommodated. Access to key individuals, the quality and depth of information collected at interview, and issues of confidentiality are all potential limitations. The manner in which such limitations were handled is discussed in this section.

2.7.1 Access to individuals

Access to key individuals has been touched upon in Section 2.6.2. In summary, the majority of individuals approached who were located in metropolitan centres (in company head offices or research institutions), agreed to participate in this study. The logistics of the interview process required multiple trips to Melbourne, Brisbane, Sydney and one visit to Perth (from a base in Canberra). Interviews were generally requested to run for an hour, or in the case of senior executives, half an hour. In practice, however, individuals were more generous with their time and the average length of interview was one and a half hours. It was commonly the case that interviewees were open to answering follow-up questions by e-mail or telephone if required.

As noted earlier, obtaining access to mine sites was far more difficult and required the support of AMIRA International's CEO, Dick Davies. Once access to sites was obtained, it was usual for many more individuals to be interviewed than originally anticipated. Such site visits proved to be rich sources of information.

2.7.2 Quality and depth of information

Assuring that information collected from the field was of good 'quality' and 'depth' was crucial. The fact that interviews tended not to be time-limited contributed to obtaining a wealth of information. The high number of interviews and multiple interviews of certain individuals also assured that reasonable depth of information was obtained. Information from the field was also continuously monitored for quality by crosschecking proffered ideas, opinions or statements of fact with relevant interviewees. In order to avoid aspects of 'sector bias', all sub-units included interviews with individuals from both the public and private sectors. Additionally, wherever possible the quality and depth of data collected by interview was augmented through the use of secondary sources of information.

2.7.3 Confidentiality

The issue of confidentiality did not have a big impact upon this study. Permission to use the information collected was requested and usually granted at the beginning of an interview. Often during the course of an interview comments were made 'off the record'. Such information, while obviously not included in the formal discussion of this study, greatly contributed to a general understanding of innovation in the industry. Where confidentiality was deemed to be of particular concern, information derived from notes taken at interview was sent to the relevant individual for approval prior to use. As expected, there were some topics too sensitive for open discussion. For example, BHP's HBI plant is a case where technology transfer cost a great deal more than anticipated (a widely reported budget blowout of one hundred million Australian dollars). This development was planned for inclusion in this study, however, it is not included as a subunit as its contentious nature meant it could not be candidly and openly discussed.

2.8 Summary

This thesis is an exploration of innovation in the Australian minerals industry based upon a 'systems of innovation' conceptual framework. The case study methodology was chosen for this exploratory study because it is believed to be the best method for answering the research questions. It has the flexibility to incorporate different types of information across a broad area of study, as well as a structured research design that ultimately ensures the study's data collection process addresses its research questions. An embedded, single-case study design with three levels of analysis and multiple sub-units was developed for this study. While the case study protocol with open-ended interviews has inherent limitations, these were recognised and accommodated in order to facilitate rigorous data analysis.

References Chapter 2

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Chapter 3:

Review of Literature

3.1 Introduction

The process of exploratory case study research is strikingly iterative and intimately dependent upon the literature. As described in the following quote, the process of case study research involves repetitive referral to the literature.

> While an investigator may focus on one part of the process at a time, the process itself involves constant iteration backward and forward between steps. For example, an investigator may move from cross-case comparison, back to redefinition of the research question, and out to the field to gather evidence on an additional case. Also, the process is alive with tension between divergence into new ways of understanding the data and convergence onto a single theoretical framework. For example, the process involves the use of multiple investigators and multiple data collection methods as well as a variety of cross-searching tactics. Each of these tactics involves viewing the evidence from diverse perspectives. However, the process also involves converging on construct definitions, measures, and a framework for structuring the findings. Finally, the process described here is intimately tied with empirical evidence. (Huberman and Miles 2002)

Reference to the literature serves three broad purposes in case study research. First, with regard to a case study's methodology it is used for the identification of a conceptual framework and development of an appropriate research design (namely, the three levels of analysis described in Chapter 2). Second, the literature provides information that helps to interpret and understand a case study's empirical findings. To these ends, this Chapter's review of the literature is necessarily diffuse. As was stated in Chapter 1, the literature on innovation systems is large, new and developing rapidly. Because of this, and with the attendant appearance of new approaches and refinements to methods, this literature review is more assiduous and dynamic than it might otherwise have been. In fact, the field of innovation systems has evolved considerably since the beginning of this study. Third, the literature review also serves to introduce the 'language' of innovation, necessary for the effective communication of concepts and findings relevant to this thesis.

Innovation Systems do not constitute a theoretical approach. Rather it provides an heuristic or 'conceptual framework' that has developed out of a more general ambition to better understand innovation processes, the economics of technical change and economic growth more generally. This review of the literature maps the origins and contribution of theories and concepts which precede development of the IS approach. With contributions from economists, historians, sociologists and geographers, this literature covers a broad front and has produced much understanding and knowledge of technological change and innovation.[14] Metaphorically speaking, it is about what is inside 'the black box' of innovation; understanding 'how', 'what', 'why' and 'when' innovation progresses in a certain direction, location, and at a given pace.[15] This chapter does not provide a comprehensive or detailed description of these studies. Instead, it outlines those key frameworks, basic concepts and important features of innovation, upon which the IS approach is based.

A newer, expansive literature exists on the application of the 'systemic' approach to innovation to good effect. Specifically, it has delineated factors which affect knowledge creation, learning and the links and interactions among constituents of innovation processes. Most recently the IS approach has been refined into a family of distinct innovation systems, such as, national, sectoral and technological innovation systems. There are arguments against the IS approach which are usually based upon the validity (or lack thereof) of so-called 'empirical evidence' proffered by some authors. The empirical evidence is often noted as being too general in nature to explain the actual situation of innovation processes which are, in reality, extremely complex. Such debate is to be expected in a new and developing area of research and it does not detract from the utility of the IS approach in general or for this study in particular.

3.2 A definition of technological innovation

What is innovation? In reality it depends upon the perspective of the investigator. In the broader sense, innovation is widely understood to involve social, economic as well as technological elements that interact dynamically. Thus, it can be deemed to be a socially-embedded process that involves knowledge and learning, and their application. Michael Best emphasises this broad definition of innovation when he states that innovation, 'is an ongoing social process in which problems are solved and new problems are identified,' (Best 1990:12).

This thesis is principally concerned with technological innovation. Niosi says that technological innovation,

> .... is technical novelty – new or improved products and processes – successfully taken to the market. (Niosi et al. 2000:4)

McKelvey largely concurs with Niosi; she says,

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[14] There have been several attempts to review this literature (Dosi et al. 1988, Freeman 1994a, Dodgson and Rothwell 1994).

[15] Rosenberg (1982) was among the first to use the metaphor opening 'the black box' in relation to understanding technological development. Here it is used in a broader perspective in relation to innovation.

> An invention only becomes an innovation when it is bought, sold or used to create marketable products. Innovative activities are said to have two dimensions, technical novelty and market selection and therefore are defined as 'knowledge seeking activities to develop novelty of economic value' (McKelvey 1997).

Thus, common ideas of technological innovation are ones largely measured by tangible, market-valued outcomes. This thesis takes a similar but not identical view and defines technological innovation as a new adopted technology, product, process or service occurring as a direct result of technological development and which is used successfully (eg, an innovation may increase productivity and have an indirect, positive impact in the marketplace). Here technological innovation, at least in most instances, has come about through combinations of new and existing forms of scientific and technological knowledge. From this thesis' perspective, the notions of 'successfully taking a product to market' or creating 'marketable products' are less relevant than the role played by technological innovation in continuous improvement to processes and the manner in which products are produced. This perspective is a direct reflection of the nature of the minerals industry. That is, this industry is less about 'taking new products to market' (ie product differentiation) than about improving processes to keep its products competitive in the market place (ie 'marketable products').

The processes through which technological innovation takes place, are extremely complex. Edquist (1997), makes this point well:

> ...processes through which technological innovations emerge are extremely complex; they have to do with the emergence and diffusion of knowledge elements....as well as the 'translation' of these into new products and production processes. This translation by no means follows a 'linear' path... Instead, it is characterised by complicated feed-back mechanisms and interactive relations involving science, technology, learning, production, policy and demand. (Edquist 1997:1)

As the ultimate aim of this study is to effectively explore innovation in the Australian minerals industry using an IS approach, it is necessary to have more than a passing understanding of the processes of innovation. Subsequent sections of this Chapter disclose and discuss the salient features of these processes.

3.3 Innovation and growth – the treatment of innovation by economists

> '...although economists have long appreciated that technical advance is central to the process of economic growth, a complete understanding of the key processes, investments, and actors that combine to produce it has not come easily,' (Nelson 1996)

The classical and neo classical economics approach to innovation

Understanding the economics of innovation is one of the driving forces behind innovation studies. Economic theories, concepts of home-markets and demand are all important to an understanding the economics of innovation (Malerba 2002). At a base level, economists have always grasped the central relationship between technological change and economic performance (Nelson and Winter 1982, Landau and Rosenberg 1986, Freeman 1974, Rosenberg 1982). While the renowned economic scholars Adam Smith[16], Karl Marx[17] and Alfred Marshall[18] produced vastly different economic models, they all recognised the importance of technical change and innovation for long-term growth, albeit in a simplistic and/or implicit manner. In this regard they have inspired those who study innovation systems.

Classical economic thought, post Smith and throughout the nineteenth century, focussed upon resources—capital, land and labour and centred around long-term growth.[19] This focus changed around the turn of the century with the onset of neoclassical economics, where long-term growth was largely ignored in the light of short-term business cycles and analysis centred on optimal resource allocation. In the period following the second World War, until the 1970s, economic thought was dominated by a synthesis of neoclassical beliefs in resource allocation with Keynes' views on reducing cyclical fluctuations in the economy and consequential unemployment. The ensuing economic decline in the USA, pressured a rethink amongst economists, and brought about the formation of several new schools of thought; monetarists, new classicals and supply-sides, and a rediscovery of the importance of long-term growth for economic health. Economists at this time found that the rate of technical change and investment in 'the quality of labour', were the fundamental factors for achieving this goal (Landau and Rosenberg 1986). It could be said that the gross failure of all economic theories developed over the period from Smith to the present was caused by their common treatment of technology as being an exogenous factor (an exception being Joseph Schumpeter, discussed below).

The onset of neoclassical economics, where long-term growth was largely ignored in favour of short-term business cycles has been denounced by those who study innovation. It has also, however, provided an impetus for studies of innovation. These economic models did not attempt to examine technical change and innovation in any detail, treating them instead as 'exogenous' variables outside their traditionally short-term, market-focused frameworks. From this perspective technology is generic, codified, universally available and accessed cost-free.

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16 Adam Smith's first book, *The Wealth of Nations* (1776), contains sections describing the importance of technological advance and gains derived from increased specialisation and division of labour (Landau and Rosenberg, 1986, Porter, 1990).

17 Karl Marx is one of a scant number of nineteenth century economists who understood the endogenous nature of technology and placed it in a social context: 'a critical history of technology would show how few any of the inventions of the eighteenth century are the work of a single individual'. He also described the continuity and evolutionary nature of technical change, a characteristic which has been attributed to his friendship with Charles Darwin (Rosenberg, 1982:34-51).

18 Alfred Marshall's book *Principles of Economics* (1898), is considered to be the source of neoclassical economic thought. Marshall is also recognised for stressing the importance of considering both the demand and supply sides of market analysis, as well as for introducing the now popular concept of 'externalities' (Landau and Rosenberg, 1986).

19 An exception to this trend, noted by Freeman, being German economist Friedrich List (1841) *The National Systems of Political Economy* who criticised the lack of attention given to science, technology and 'mental capital', which he believed were necessary for the sustained growth of nations (Freeman and Soete, 1997).

Traditional neoclassical assumptions also include: a constant returns-production function (the existence of competitive equilibrium); capital and labour as production factors (where only capital can be accumulated); and, under perfect market conditions, the invisible hand of market forces will lead to efficient allocation of resources. The organising principle is the rational, 'optimising' behaviour of individual economic agents. Recognition of technology as a cause of unexplained growth in resource productivity (residual of the production function) after increases in the quantity of capital and labour inputs are accounted for, can be traced to Abramovitz (1956) and Solow (1957).[20] Their discovery of a very large residual factor when measuring per capita growth in output, opened the debate on the role of technology and technological change in improved efficiency and productivity.[21] Introduction of a new technology was treated as a shift in the production function, however, technological development and innovation remained in the black box (Rosenberg 1982).

It is only in recent times (1980s) that systematic attempts have been made to model the growth process without treating technical change as an exogenous 'residual'. The so-called class of neo-classical 'new growth models' mark this change in perspective and seek to *endogenise* 'technological progress' in theoretical frameworks, as a central production factor along with capital and labour (Romer 1990, Verspagen 1992, Freeman and Soete 1997). In a sense this is new only in its belated recognition of classic ideas held by the likes of List and Schumpeter. The features of new growth theory are presented below and outlined in Table 3.1.

Table 3.1: Features of new growth theory

Technology is endogenous and a central production factor in an economic system
While technological breakthroughs appear random, altogether technology increases in proportion with dedicated resources
Unlike traditional economic theory where diminishing returns on investment is predicted, technology produces *positive* returns and sustained, robust growth
Increasing returns, 'Investment can make technology more valuable and technology can make investment more valuable' – a virtuous cycle that can stimulate and sustain economic growth
Monopoly power provides a useful incentive for technological research
The global knowledge economy is based on ideas as opposed to objects and requires novel institutions and pricing systems
Discovery and continual improvement processes provide limitless possibilities

Source: (Dodgson 2000)

New growth models represent a solid and valuable attempt to incorporate measures of externalities resulting from linked knowledge accumulation and capital, accumulation of human capital and the virtuous cycle of increasing return from technology investment. These models, however, continue in the neoclassical tradition with its assumptions regarding optimising behaviour and can only represent a schematic view of the 'real world' complexity surrounding the interaction between technology and growth (Freeman 1996, Freeman and Soete 1997).

Schumpeter – a brief look at his theories and influence

Schumpeter is widely regarded as an exception in twentieth century economic thought and his work is a galvanising point in the literature. From his early work Schumpeter made the

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[20] (Abramovitz, 1956, Solow, 1957) quoted in (Rosenberg, 1982).

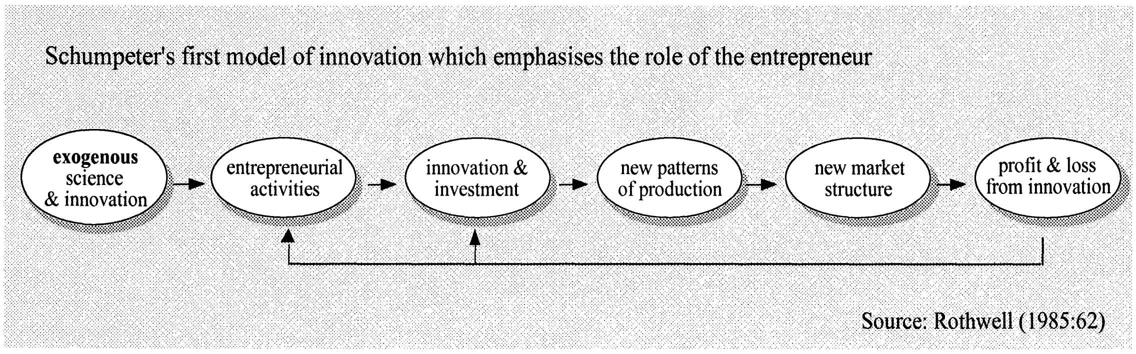
[21] For more on Solow see Freeman and Soete (1997).

conceptual distinction between innovation and invention,[22] a distinction maintained in subsequent economic theory. Schumpeter was also the first to produce theories and models of economic development that recognised the important relationship between competition stimulated by innovation and its consequent impact upon economic productivity (Freeman and Perez 1988, Nelson 1990b). Schumpeter produced three major works he produced: two models of economic growth based upon patterns of innovative activities and a theory linking radical innovations to the formation of long-waves of economic growth (*Business Cycles* (1939)). The first model (Mark I) was in *The Theory of Economic Development* (1934), and the second model (Mark II) proposed in *Capitalism, Socialism and Democracy* (1942). While some have criticised Shumpeter's limited view on the sources of invention[23] (treating them as exogenous to the economy), his works have fulfilled their intended purpose as a theoretical 'first draft' open for debate and development (Freeman and Perez 1988, Freeman 1990a, Freeman and Soete 1997). Vigorous debate and empirical testing of Schumpeter's work continues around his models of economic development and his theory of economic long-waves. There are those who have sought empirical evidence for Schumpeter's Mark I & II models of innovation. The so-called 'neo-Schumpeterian' economists have attempted to provide empirical evidence (diffusion of radical technologies) and to build upon Schumpeter's long-wave theory.

Schumpeter's Models of economic development – Mark I & II

Schumpeter Mark I emphasised that the pattern of innovative activities is characterised by '*creative destruction*' (see Figure 3.1). Here, entry of new technology into the economy is unencumbered, making the role of entrepreneurs and new firms crucial as they exploit new technology and create new markets. This generates a 'swarming effect' of imitators, snowballing into a wave of new investment. As competition increases, profit margins are gradually eroded, but before this wave equilibrates a new destabilising wave of innovation restarts the process. Schumpeter termed the destabilising effect of new radical innovation 'creative capital destruction', although it is more commonly called, 'creative destruction' (Freeman 1982, Rothwell and Zegveld 1985, Nelson and Winter 1982).

Figure 3.1: Schumpeter's first model (Mark I – *widening*)



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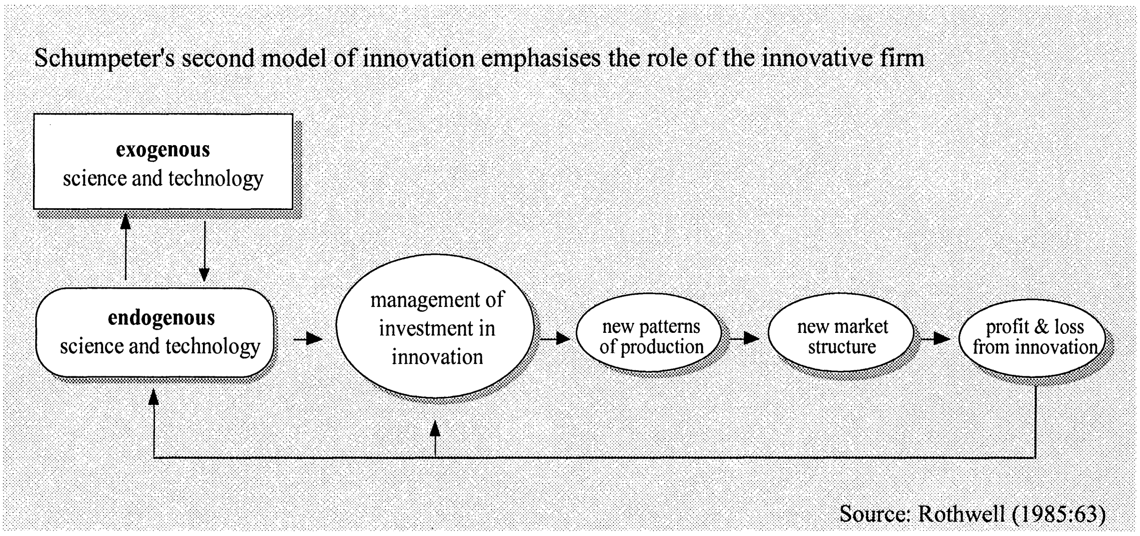
[22] An invention is a new product or device or a new method for a new or improved product, process, device or system. Invention is often considered the first step in the innovation process. Inventions may be patented, but usually do not lead to technical innovation and further development.

[23] For example, Nelson chastises Schumpeter for ignoring networks of pubic and private institutions (Nelson, 1990b) and Freeman for neglect of the role of international trade or international diffusion of technology and historical context (Freeman and Lundvall, 1988).

The period of time between the two World Wars saw rapid growth of industrial R&D, mostly in large corporate laboratories. In reflection of these changes, Schumpeter's later theory (Mark II) proposed in *Capitalism, Socialism and Democracy* (1942), shifts away from single entrepreneurs and onto large firms as the focus of innovative activity and competition (see Figure 3.2). The pattern of innovative activities is characterised by '*creative accumulation*' with large established firms dominating innovation, developing monopoly regimes (where innovation produces a monopoly in a particular product(s)) and the presence of barriers to entry of new innovators (Nelson and Winter 1982, Freeman 1990b).

Figure 3.2: Schumpeter's second model (Mark II – *deepening*)



Schumpeter's characterisation of innovative activities triggered many different attempts to empirically verify the two patterns. One perspective sought empirical evidence for Schumpeter Mark I & II models of innovation according to how innovative activities proceed in stages in industry life-cycles and across technologies (Malerba and Orsenigo 1995, Malerba and Orsenigo 1996, Breschi et al. 2000). In the early history of an industry, uncertainty is high, technology changes rapidly, barriers to entry are low and new firms are major innovators. In a mature industry, in contrast, technology tends to follow trajectories and a few large firms accumulate technological and innovative capabilities over time that are important to the competitive process, while barriers to entry and financial resources are established (Malerba and Orsenigo 1996). The innovative activities in Mark I & II have also been called *widening* and *deepening* in relation to an innovative base: widening due to entry of new innovators (erosion of competitive technological advantage in established firms), or deepening due to an accumulation over time of an innovative base in a few dominant firms (Malerba and Orsenigo 1995, Malerba and Orsenigo 1996, Breschi et al. 2000) (see Table 3.2). Empirical evidence suggests that innovative activities differ across technology classes in a manner that resembles Schumpeter Mark I & II models, and that these patterns continue for technology classes located in different countries (Cefis and Orsenigo 2001).

Table 3.2: Schumpeter Mark I & II

	Schumpeter Mark I *widening*	Schumpeter Mark II *deepening*
Organisation of innovative activities	• concentration of innovative activities low • innovators are of small economic size • stability in ranking of innovators is low and turbulence high	• concentration of innovative activities is higher • innovators are of larger economic size • stability in ranking of innovators higher and turbulence lower
Industrial sectors	• mechanical technologies • traditional sectors	• chemicals • electronics
International technological specialisation	• relatively higher degrees of asymmetries among innovators and innovative turbulence	• linked to the existence of a stable but competitive core of persistent innovators
Persistence of innovative activities	• absence of persistence	• significant degrees of persistence contributes to 'creative accumulation'
Sectoral patterns of innovative activities and nature of underlying technological regime	• low degrees of cumulativeness and appropriability • high importance of applied sciences and increasing importance of external sources of knowledge	• high importance of basic science • relatively low importance of applied science as source of innovation

Source: (Malerba and Orsenigo 1996, Cefis and Orsenigo 2001)

Schumpeter's Long-waves of economic development

Schumpeter also emphasised the central role of technical progress for understanding instability in capitalist economies and the inherently discontinuous nature of technical progress by building upon the work of Russian economist, N.D. Kondratiev. In the 1920s, Kondratiev popularised a theory of half-century 'long cycles' or 'long waves' in economic development[24]—being regular, cyclical patterns of economic structural crisis.[25] He identified three major long-term cycles beginning with the *industrial revolution* (1780s-1840s), *steam power* and *railways* (1840s-1890s), and lastly, *electricity and steel* (1890s-1940s), based upon a systematic analysis of price and production time series data for the United States, France, Germany and England (Freeman and Soete 1997).[26] The influence of technology upon long-waves was considered by Kondratiev to be a minimal one. On the other hand, in *Business Cycles* (1939), Schumpeter argues that radical technological innovations were the driving force behind the formation of economic long-waves of structural crisis, where each wave was unique because of coexistent exogenous events, such as gold rushes and wars (Rothwell and Zegveld 1985, Rosenberg 1982, Freeman 1983, Freeman and Soete 1997, Dosi et al. 1992a). The neo-Schumpeterian economists employ a Schumpeterian long-waves theoretical framework to analyse the emergence and diffusion of new technologies and complexity of technological change and economic growth (discussed below).

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[24] The Dutch Marxist, J. van Gelderen was the inventor of long cycle theory, in 1913.

[25] A critique of cycles in economic activity is given in *Technological Innovation and Long Waves* (Rosenberg and Frischtack 1983), and in another paper by Tinbergen, called 'Kondratiev cycles and so-called long waves. The early research.' (Freeman, 1983).

[26] Schumpeter only analysed the first three waves. More recently, a number of economists have suggested that the world economy has experienced a fourth (1940s-1990s) (Fordist 'mass production,' and fifth 'information and communications technologies) wave of structural change. See (Fagerberg 1995, Freeman 1981, Freeman 1982, Freeman 1983, Freeman 1990a, van Duijn 1983) and for a critique (Rosenberg and Frischtack 1983).

3.4 Understanding technological innovation – key theories and concepts

3.4.1 The roles of science and technology

Science and technology are different activities and both, to varying degrees, are relevant to technological innovation. While in the past the boundaries between these activities were easily identifiable, this is not the case today. It is often exceedingly difficult to untangle the web of interaction between science and technology. Rosenberg exemplifies this point and says that a historical view is helpful:

> The first thing that needs to be said about relationships between science and technology in the twentieth century is that sweeping generalisations of any kind are almost certainly going to be wrong. In fact the first thing that is necessary is to change the singular forms to plural: to think in terms of 'sciences' and 'technologies'. It is precisely the diversity in the nature of these relationships that makes a historical approach so essential. One cannot treat the relationships between the scientific and technological realms adequately unless one descends from the abstract to the particular, and looks at these relationships in the historical contexts of specific industries, firms and scientific disciplines. (Rosenberg 1992)

In the early 1800s science and technology were largely independent of one another, and actors in each of these fields pursued unrelated goals.[27] In other words, individuals engaged in these activities had different motivations, with clear divisions of labour. They were housed in separate organisations (that is, firms versus non-firm organisations such as universities), frequently with no direct interactions or other relationships with one another. A traditional, Anglo-Saxon view of technological innovation tended to emphasise the significance of pure scientific research and scientifically-derived knowledge as opposed to technologically-derived knowledge (Walker 1993, Freeman 1992). Table 3.3 gives some examples of both science-and technology-led innovation.

A tendency to treat technology as 'the mere application' of scientific knowledge is traditional and dated. Rosenberg says:

> 'One of the more misleading consequences of thinking about technology as the mere application of prior scientific knowledge is that this perspective obscures a very elemental point: *Technology is itself a body of knowledge about certain classes of events and activities. It is not merely the application of knowledge brought from another sphere.* It is a knowledge of techniques, methods, and designs that work, and that work in certain ways and with certain consequences, even when one cannot explain exactly why. It is therefore, if one prefers to put it that way, not a fundamental kind of knowledge, but rather a form of knowledge that has generated a certain rate of economic progress for thousands of years. Indeed, if the human race had been confined to technologies that were understood in a scientific sense, it would have passed from the scene long ago,' (Rosenberg 1982:143, emphasis added).

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[27] Scientists, by and large, generate and disseminate new knowledge and gain kudos from publication in the scientific literature. 'Technologists' or engineers, appropriate new knowledge and pursue invention, artifacts and commercial success for recognition.

Table 3.3: Empirical examples of various interactions between sciences and technologies

	Science	Technology	Refs
19th century **electronics industry driven by basic research**	Faraday – discovered electromagnetic induction 1831, first step towards development of electric power	Science based technical development of products, telephone, gramophone & incandescent light	(Cohen 1948, Dunsheath 1962, Nelson and Rosenberg 1993)
	Hertz – discovery of radio waves 1887 when seeking empirical evidence for their predicted existence	Basic science stimulated applied development and arrival of radio and television	(*ibid*)
20th century **aviation industry evolved from technical advance**	Aerodynamics – scientific discipline developed in response to technical advance	Construction of original Wright brothers flying machine 1903 relied on experience of bicycle manufacturing not understanding flight	(Nelson and Rosenberg 1993)
	Thermodynamics – scientific discipline developed in response to needs of technical advance	50 years after invention of the condensing steam engine, Sidi Carnot's (1796-1832) attempt to understand constraints upon the engine's efficiency, pioneered the development thermodynamics	(Cardwell 1971, Nelson and Rosenberg 1993)
	Radioastronomy – the discovery of 'star noise' marked the birth of this scientific discipline	At Bell Laboratories, Karl Jansky (1905-50), worked on problem of radio static plaguing the international radiotelephone service and discovered 'star noise', a source of radio waves from outside the solar system.	(Rosenberg 1982)

Source: compiled from listed references

Regardless of their individual roles, the fundamental relationship of science and technology to technological innovation, in essence, is to provide the necessary knowledge (both scientific and technology-based) to facilitate the process.

The interplay between science and technology is increasing, and the boundaries between them are blurring to the point that in many areas the relationship can be described as symbiotic. In terms of technological innovation in the new industries of the twenty-first century, empirical research has shown the emergence of an increasing number of firms that are producing science-based technologies (Achilladelis and Antonakis 2001, Ramani 2002, Orsenigo et al. 2001, Lal 1999). According to Nelson and Rosenberg (1993) the role of university 'pure science' and basic research may be expected to increase when a nascent technology is coming into being. Consider, for example, biotechnology in the 1980s (Nelson and Rosenberg 1993). Empirical studies of the biotechnology *industry* have confirmed this point (Rothwell 1992, Dodgson 1991, Dodgson 2000), as have empirical studies of the science and technology interface and of drug and medical technologies, electronics, optics and nuclear technology (Jaffe 1989).[28]

In essence, the interplay or interface between pure science and technology is particularly important for innovation. Montobbio says 'an essential bridging role between pure sciences and technical change is played by *transfer sciences*' (Montobbio 2001:17). Transfer sciences are developed mainly in university-based laboratories or by university trained staff in industrial-based laboratories (*ibid*). The OECD refers to transfer sciences in the following way:

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[28] Jaffe (1989) found a positive correlation between corporate patents and university research for these industries.

> ...their activity is driven principally by the urge to solve problems arising from social and economic activities; their research centres are located in technical universities, engineering schools, sectoral government establishments, and industry; a large part of their funding comes from industry, their graduates are normally employed in the industry. They tackle subjects broadly relating to artificially made objects and phenomena, and the communities of scientists active in research in these areas are very close to professions most concerned with application of their results. (OECD 1992:37 quoted in Montobbio 2001)

Models of the technological innovation process described in the 'technology management' literature also illustrate the progression of the reciprocal and intertwined interface between science and technology (see Section 3.4.2 below). An examination of the history of innovation is useful in providing insight into the relationship between science and technology, and the industrialisation of R&D and innovation today.

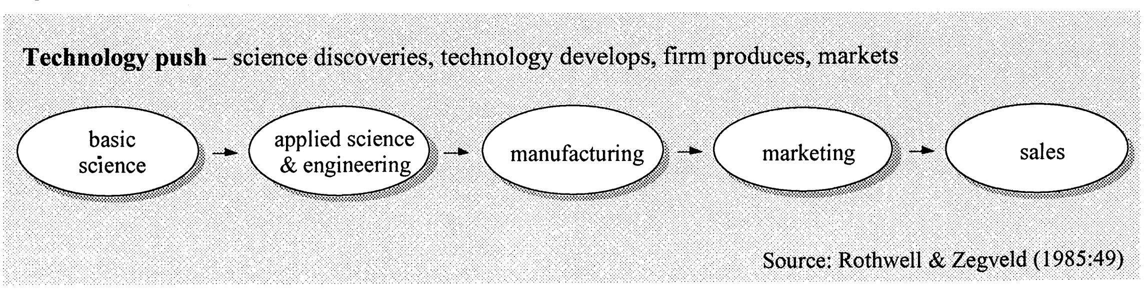
3.4.2 Models of technological innovation in the technology management literature – 5 generations

With the potential rewards from successful innovation being so rich, public policy makers and private-sector managers have sought models of the innovation process to allow the design of effective innovation policies. The increasing sophistication of research on innovation is clearly illustrated when the various models of the innovation process are seen in chronological order. Rothwell categorises each major development in modelling the innovation process into a 'generation', and describes five generations of the innovation process from the 1950s to the present (Rothwell 1994a).

First generation – technology push

Early models of innovation are typified by their simple *linear* representation of the interaction between science and technology and the market place. The first generation 'technology-push' model was developed in the early 1950s, endorsed by Vannevar Bush in 'Science, the Endless Frontier' (NSF, 1945) and remained dominant until the late 1960s (see Figure 3.3). According to this model, advances in basic science initiate a stepwise progression through applied research and technological development, firm-based production, to new products in the marketplace. The marketplace is seen to be a veritable 'sink' for the consumption of these new commodities. The role for policy makers was comparatively simple, since it was believed that funding basic research was all that was necessary to ultimately stimulate economic growth (Rothwell and Zegveld 1985, Rothwell 1994a).

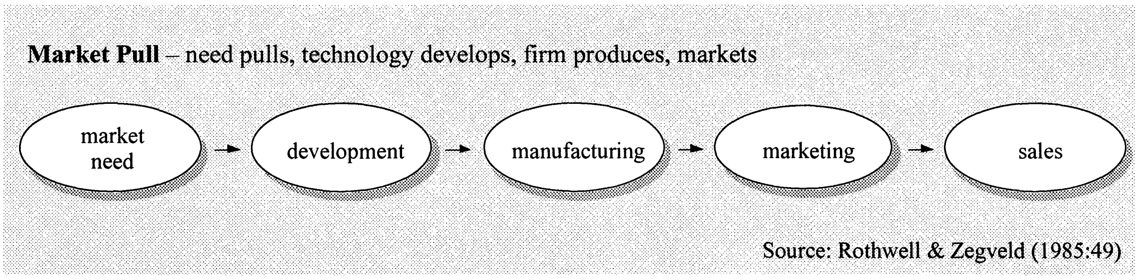
Figure 3.3: 'Technology Push' model of innovation



Second generation – need or market pull

Competition in the market place increased in the late 1960s and is reflected in empirical research findings conducted at that time. These tended to emphasise the role of the marketplace in driving the need for innovation. The R&D department no longer drove innovation. Instead, it reacted to the articulated or perceived needs and ideas of customers and the marketplace. The updated second generation linear model of innovation developed by Smockler (1966) emphasises 'need-pull' or 'market pull' directing innovative activity (see Figure 3.4) (Rothwell and Zegveld 1985, Rothwell 1994a).

Figure 3.4: 'Market Pull' model of innovation



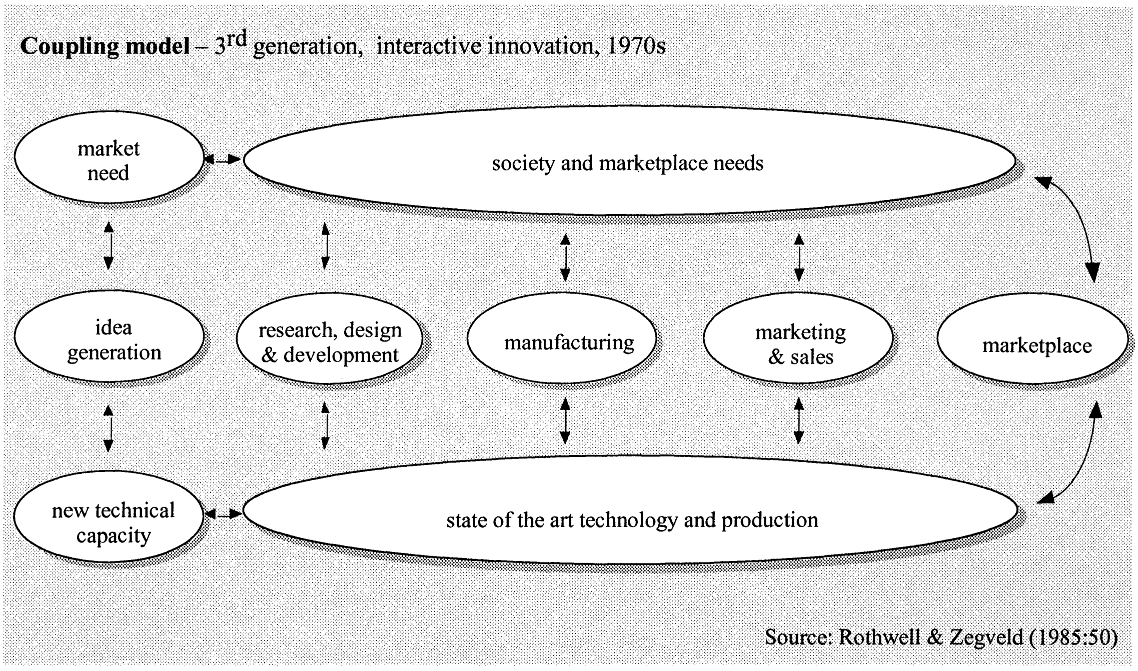
Third generation – coupling model

The third generation, in the 1970s, saw a rejection of the two linear models as little evidence supported the notion that more R&D necessarily meant more innovation (Rothwell and Zegveld 1985), and fears that overemphasis of marketplace needs may dampen radical innovation (Hayes and Abernathy 1980). In addition, Rothwell and Zegveld suggest that the impact of either the technology-push or need-pull models might vary in accordance with different phases of the innovation process (Rothwell and Zegveld 1985: 50).[29] Accordingly, the simple yet more representative 'coupling' model was proposed, as Rothwell and Zegveld describe (see Figure 3.5):

> According to this model innovation is regarded as a logically sequential, though not necessarily continuous process, that can be subdivided into a series of functionally separate but interacting and interdependent stages. The overall pattern of the innovation process can be thought of as a complex net of communication paths, both intra-organisational and extra-organisational, linking together the various inhouse functions and linking the firm to the broader scientific and technological community and to the market place. In other words the process of innovation represents the confluence of technical capabilities and market needs within the framework of the innovating firm. (Rothwell and Zegveld 1985: 50)

[29] The evidence favoring the view that both linear models of innovation are oversimplified, extreme and atypical is summarised in a paper by Mowery and Rosenberg (Mowery and Rosenberg 1978).

Figure 3.5: 'Coupling' model of innovation



Fourth generation – integrated (parallel) model

Although the coupling model is far more interactive than any of its predecessors, its usefulness is reduced by the fact that innovation is presented as an essentially sequential process. Empirical research examining innovation practices in Japanese automobile and electronic sectors found that innovative activities occur concurrently or in parallel, and that throughout the innovation process there is a high degree of functional integration among these activities (Graves 1987, Clark and Fujimoto 1989, Rothwell 1994a).[30] Also called the 'rugby team' approach (Imai et al. 1985), it delivered considerable speed and cost advantages to Japanese firms over their Western competitors (see Figure 3.6). The manner in which suppliers become involved in innovation is an important feature of this model, as a result innovation here is no longer seen as the activity of a single firm.

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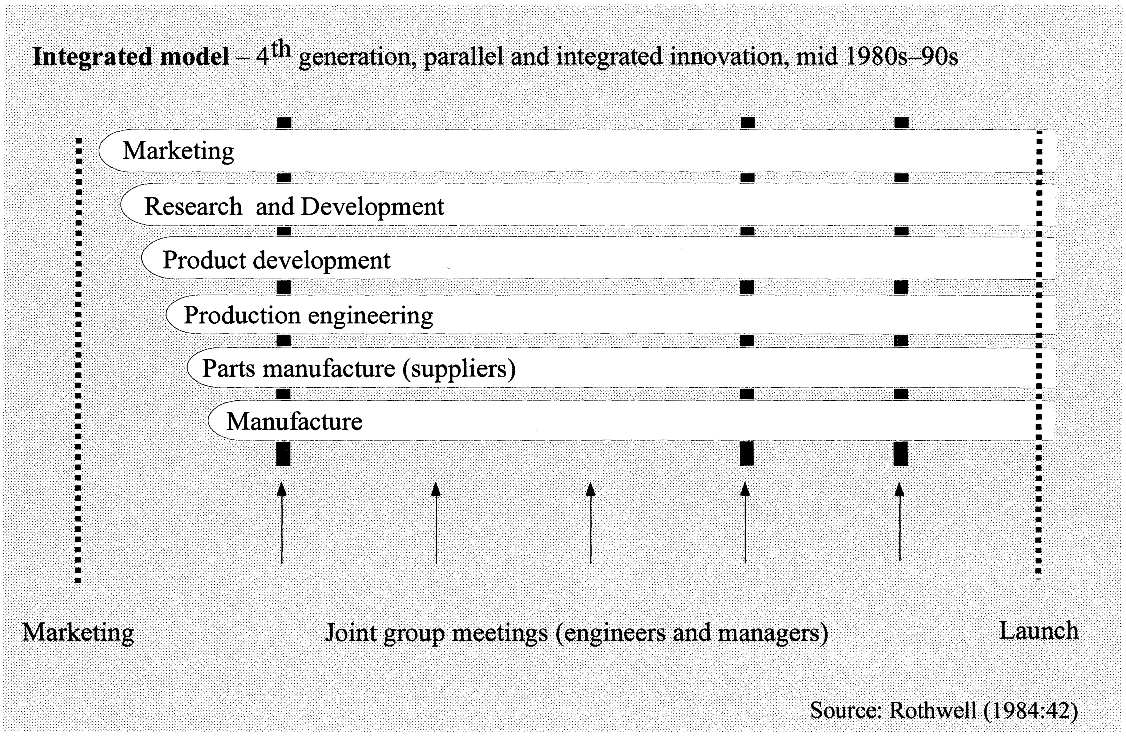
[30] A voluminous literature exists concerning innovation in Japanese firms and presenting it is beyond the scope of this thesis. Rothwell's chapter in *The Handbook of Industrial Innovation* gives a brief introduction to this field (Rothwell 1994b).

Figure 3.6: Integrated model of innovation



Note: this figure displays internal firm processes (parallel & integrated). A similar web of external interactions also exists, ie similar to 3rd generation model.

Fifth generation – Systems Integration and Networking (SIN)

The fifth generation process is one of systems integration and networking. It emphasises the increasing strategic and technological integration of innovative activities, inside and outside the firm (Rothwell 1994a, Dodgson 2000). Firms operating under these principles have increased speed, ease and efficiency of product development across all innovative activities. Strategic integration is increasingly global and is present in technological, market and financial areas. Technological integration involves various combinations or fusions of technologies, as in glass, cable and electronic device technology in opto-electronics. This generation is also characterised by a dramatic increase in networking in a multitude of forms, including strategic alliances, R&D collaborations, and closer relations with suppliers.[31] Another distinguishing feature is the employment of an 'electronic toolkit' comprised of digital communication technology, CAD systems and computational simulation and modelling programs. Table 3.4 lists some of the major managerial, organisational and technological factors which contribute to the fifth generation innovation process.

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[31] The point made in the previous footnote applies here in relation to the vast literature available on networking processes and again this is beyond the scope of this thesis. For an introduction to the topic refer to Rothwell (*ibid*) or (Dodgson 1993) 'Technological Collaboration in Industry'.

Table 3.4: The 5th generation innovation process: Systems Integration & Networking (SIN)

Underlying strategy elements

- Time-based (fast, efficient product development)
- Development focus on quality and other non-price factors
- Emphasis on corporate flexibility and responsiveness
- Customer focus at forefront of strategy
- Horizontal technological collaboration strategies
- Electronic data processing strategies
- Policy for total quality control

Primary enabling features

- Greater overall organisational and systems integration:
  - parallel, integrated development process
  - early supplier involvement in product development
  - involvement of leading-edge users in product development
  - establishing horizontal technological collaboration where appropriate

- Flatter and flexible organisational structures for rapid and effective decision making:
  - greater empowerment of managers at lower levels
  - empowerment of product champions/product leaders

- Fully developed internal databases:
  - effective data sharing systems
  - product development metrics, computer based heuristic, expert systems
  - electronically assisted product development (eg 3D-CAD)
  - linked CAD/CAE systems

- Effective external data links:
  - co-development with suppliers using CAD
  - use of CAD at the customer interface
  - data links with R&D collaborators

Source: as stated in (Rothwell 1994a:49)

Rothwell emphasises that while attaining fifth generation and 'lean' innovation is neither costless nor frictionless, the benefits are considerable.

> Entry costs include not only equipment and training, but more importantly learning costs across the complete system of innovation. Whatever the entry costs, however, it seems likely that it is those companies that succeed in mastering the essential features of 5G today will be the leading-edge innovators of tomorrow. (Rothwell 1994a:50)

Taken together, these models of innovation provide a clear illustration of the maturation in understanding of innovation, from science-driven and linear to integrated, dynamic and complex.

3.4.3 Radical innovation and long-term patterns of economic growth

Schumpeter's long-wave theory noted that technological innovations appear in periodic clusters and are not evenly distributed over time or across industries. An initial problem with Schumpeter's long-wave theory of economic development was an apparent lack of macro-economic evidence of productivity gains resulting from application of new technologies. One group, the so-called neoSchumpeterian economists, focused on gathering empirical evidence to support Schumpeter's theory. Their approach is characterised by a descriptive, more qualitative, case-study based method that combined economic histories with related theoretical concepts such as 'technological paradigms' (Dosi 1982) and 'technology trajectories' (Nelson and Winter 1977), as well as 'technological revolutions' (Freeman and Perez 1988), to analyse the relationship between historic clusters of intense technological change and historic long-waves of economic growth (characterised by the concomitant success or failure of economies and/or industrial sectors). In essence, the neoSchumpeterian approach converges upon the complex processes of *diffusion* that accompany periods of intense technological change (technological revolutions). Clusters of mutually supporting technological innovations may occur at any time in economic cycles (Freeman et al. 1982). The accompanying social innovations (which may be radical and/or incremental innovations) in areas from the organisation and management of work through to changes in legal institutions (for example, employment and tax law), that can lead to dramatic upswings of investment characteristic of long-wave booms (Freeman 1994b). These technological revolutions that cause giant discontinuities with the past have been described as changes in the '*techno-economic paradigm*'[32] (TEP) by Perez[33] (Perez 1983, Perez 1985) and Freeman (Freeman and Perez 1986). A change in the techno-economic paradigm, accompanied by social and institutional change, is thus the basis for an upswing in economic long waves.

Neo-classical economists failed to find any measurable productivity gains from so-called 'generic technologies' (the productivity paradox described by Solow in 1957) because they did not understand the process of diffusion. Attaining potential productivity gains requires far more than changes of production. Fundamental changes in societal attitudes, institutions and organisation are also required. The learning processes that embody such dramatic change mean that economic and social potential from such technologies will be realised over the long term (Freeman and Louca 2001). Thus, the interaction between new radical technologies and institutional structures, a continuing tension while institutional set-ups adapt and regenerate to match new technologies, may occur for several decades prior to the onset of a new upswing (ie, the Kondratiev long wave) (Freeman and Perez 1986, Freeman 1994b).

The theory of changing techno-economic paradigms emphasises long time frames in the development and diffusion of technological innovations, as well as the social and economic returns. It shows how a pervasive constellation of economically related innovations (technological, organisational and managerial) can be profoundly disruptive, uncertain and genuinely 'revolutionary'. That is, it can influence an entire period of economic growth, creating new and rejuvenating old industries (Freeman and Perez 1986, Freeman and Perez 1988, Perez 1985). Freeman and Perez refine the influence of innovation into four categories:

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[32] Perez's 'techno-economic paradigms' speak of the economy as a whole and as such are sometimes described as a 'meta-paradigm' or a 'pervasive technology' theory (Freeman 1994b).

[33] Perez detailed the inhibition of technological diffusion due to institutional frameworks supporting mature and near obsolete technologies.

- incremental innovation
- radical innovation
- changes in the technological system (when incremental and radical innovations combine with organisational and managerial innovation), and
- changes in the techno-economic paradigm (when all sectors of the economy are effected leading to new product and industry development, for example, computerisation). (Freeman and Perez 1986)

From this context, a major policy concern is how well countries adapt to such intense waves of change (Freeman 2002, Freeman and Soete 1997, Freeman 1996, Freeman 1995). The theory of changing techno-economic paradigms (TEPs) has been used to explain why countries have different patterns of economic development, why some grow faster, some catch-up and others fall behind (Freeman 1994b, Freeman 1996). Countries that are most adept at inducing institutional innovations that match the emerging new TEP are predicted to be the most successful at capturing economic returns. On the other hand, those countries that experience institutional 'drag', or a prolonged mismatch between organisational and institutional set-ups and the innovative requirements of the new TEP, may fail to fully capture the growth potential of new technologies (Freeman 1994b, Freeman 1996, Freeman and Louca 2001).

The types of social innovations and economic transformations that accompany each new TEP, as described in Table 3.5 below.

Table 3.5: A list of social and economic transformations that accompany new techno-economic paradigms

• new skill profile in the workforce, affecting both the quality and quantity of labour and corresponding patterns of income distribution and industrial relations
• new 'best-practice' form of organisation within firms and their operations
• new trends in technological, organisational and institutional innovation (incremental and radical) induced by the diffusion and substitution of new for old technologies
• new patterns in the location of investment both nationally and internationally as new factors change relative comparative advantages
• new patterns of institutional regulation at national and international levels
• new waves of infrastructure investment to enable the diffusion of new technologies
• new waves of entrepreneurship with small, start-up firms using new technologies and becoming part of new industries
• tendency for large firms to develop capabilities and concentrate in the new TEP (by means of growth or diversification)
• new technologies representing a growing proportion of gross national product
• new patterns of consumption of goods and services and new types of distribution and consumer behaviour

Source: adapted from (Freeman and Perez 1988, Soete 1991, Dodgson 2000)

3.4.4 History matters when understanding innovation processes

Freeman suggests that:

> Perhaps the main conclusion which emerges from the work of neo-Schumpeterian economists...is that *history matters*. Both the internal accumulation of knowledge within the firm and the external networks are strongly affected by the national environment and national policies, as well as by worldwide developments in science and technology and international flows of capital, trade and migration. (Freeman 1982:85, emphasis added)

In studies of innovation, scholars are wary of separating the technical artefact from the social context. That is, the choices made by actors that are in turn historically embedded in social, economic and technological contexts. History matters in developing innovation processes since the course of history shapes a present-day context, including the accumulation of learning processes, routines and other technological, organisational and institutional capabilities that determine a capacity to engage and exploit innovation processes. The combination analysis of innovation processes within an historical context allows for the inclusion of a much broader set of variables surrounding the emergence of technologies (and rate thereof), how they develop, their diffusion and impact upon productivity growth.

The idea that over time, firms accumulate particular 'competences', skills and knowledge can be traced to Edith Penrose (1959) and her 'resource-based' theory of the firm (Freeman and Soete 1997). Research has also demonstrated that successful innovative traditions can become embedded in firms. 'Corporate technology traditions', for example, are said to exist when success in innovation is linked to previous experience, and a firm may dominate a particular area (ie introduce a disproportionate number of innovations in a field) over a period of some thirty or forty years (Achilladelis et al. 1987, Achilladelis et al. 1990).

In summary, an historical view sheds light on long-term trends in technological innovation and economic development, as Rosenberg points out:

> The particular path of innovation followed in each country or region has historical origins. (Rosenberg 1982)

The reinstatement of 'history' in economic theory (and studies of innovation) is often accompanied by the notion of *path-dependence*, where path-dependent processes are, 'those phenomena whose outcome can only be understood as part of a historical process' (Rosenberg 1994:205).

> Path dependence means that history matters. We cannot understand today's choices (and define them in the modeling of economic performance) without tracing the incremental evolution of institutions. But we are only just beginning the serious task of exploring the implications of path dependence. (North 1990:100)

Path-dependency can explain the survival over time of inefficient institutions, societies, economies and innovations. It is not an uncommon phenomenon and it directly contradicts implications of evolutionary theory (that over time inefficient institutions are weeded out) (Araujo and Harrison 2002). Persistence of the 'QWERTY' configuration of keyboard letters, for example, shows how incremental changes in technology along a particular path may lead to a technological solution that is less efficient than abandoned alternatives (David 1985). It is said that the basis of many present inefficiencies can be traced to past decisions; path-dependent results of technological and organisational trajectories derived from localised learning and initial conditions (Foray 1997, Niosi 2002). The central explanations of path-dependence are given in Tables 3.6 and 3.7: first in terms of self-enforcing sequences that favour less efficient choices and reactive sequences that trigger choices that transform processes and create new paths; and second, in terms of the explanations pertaining to the generation of systemic inefficiencies.

The dynamics of path-dependent inefficiencies are complex, being generated by overlapping and reinforcing effects (Foray 1997, Edquist 1997, Niosi 2002, Araujo and Harrison 2002). There are instances where path-dependent inefficiencies may be remediable or where their effects may be innocuous. Path-dependency, however, is not a story of inevitability (North 1990) as the maximising behaviour (search for increasing returns) of agents may break a path-dependent process (Williamson (1988) in Niosi 2002).

Table 3.6: Path-dependence – self-enforcing and reactive event sequences

Event sequence	Description	Consequence
Self-enforcing	• *large setup or fixed costs* – deliver advantage of declining unit costs as output increases	• *multiple equilibria* – numerous solutions possible and outcome is indeterminate
	• *learning effects* – improve production or lower their costs as prevalence increases	• *possible inefficiencies* – a 'better' technology loses out
	• *coordination effects* – confer advantages to cooperation with other economic agents taking similar action	• *lock-in* – once reached, a solution is difficult to exit from
	• *adaptive expectations* – increased prevalence on the market reinforces beliefs of further prevalence	• *path dependence* – consequence of small events & chance circumstance can determine solutions that lead to a particular path
Reactive	• initial events initiate a sequence of tightly linked reactions • each event in sequence regarded as a reaction to temporally antecedent events	• initial disturbances do not generate positive feedback and instead initiate powerful responses that shift a path into a novel direction (not necessarily reinforcing first move)

Source: constructed from writings on (Arthur 1988, Arthur 1994) found in (North 1990, Araujo and Harrison 2002)

Table 3.7: Niosi's explanations of path-dependence

Explanation	Description
Increasing returns to scale	• for industries with increasing returns, first entrants can impose their technology and dominate the market • new entrants begin with lower production scales, less experience and higher costs
Network externalities	• early entrants may diffuse their standards, regardless of the quality of their technological solution and exclude future competitors
Sunk costs	• existing firms may lock-in to their technology due to past investments in machinery and equipment
Contracts	• institutions reduce uncertainty and contracts make explicit expectations and performance requirement – the downside being the tendency for contract to 'freeze' organisations, particularly as costs of radically changing contracts may be particularly high
Human learning	• sunk costs of an intangible type—investment in codes of communication, human capabilities etc, are unrecoverable, making change to a new technological/organisational trajectory costly
Multiple equilibria	• economic systems may have multiple organisational equilibria – sets of organisations may function well in different economic environments but all may not be equally efficient. Organisations may be locked-in to specific characteristics efficient for a selection environment at time t_1, but these characteristics may be inefficient/ineffective in time t_2 with a different selection environment

Source: (Niosi 2002)

When analysing historical path-dependence it is important to understand that ultimately this process concerns decision making in organisations, and not primarily by competition among technological trajectories:

> In fact (although I am not aware that Arthur makes this distinction), the competition is only indirectly between technologies. Directly it is between organisations embodying the competing technologies. The distinction is important because the outcome may reflect differing organisational abilities (tacit knowledge of the entrepreneurs) as much as specific aspects of the competing technologies. (North 1990:94)

This discussion has implications for the analysis of IS. In the case of NIS, for example, countries are comprised of dissimilar institutions generated under unique historical circumstances. Path-depended inefficiencies cause institutional evolution to lag in time, be frozen by contracts and/or past investments, and remain poorly adapted to modern performance requirements (Niosi 2002:294). Decision makers may not have adequate information about world best or other practices and therefore support inefficient institutions (bounded rationality). Other organisations (universities, policy-making agencies) may exist outside of market forces and be isolated from maximising inducements that break path-dependent processes (ibid:295).

3.4.5 Evolutionary theories of technological change

Another theoretical framework developed in response to the 'bare-boned' neoclassical treatment of technological innovation is evolutionary theory (also referred to as evolutionary economics). Evolutionary theory treats innovation as an open-ended, path-dependent process of variation and selection that never equilibrates. Technological innovation is endogenous. In particular, evolutionary economists reject the neo-classical conception of innovation in the abstract 'representative' firm, in terms of cost-benefit calculations (simple comparison of expected pay-offs with the estimated costs) (Nelson and Winter 1977).

Nelson and Winter initiated the evolutionary theory based upon their studies of innovative firms (Nelson and Winter 1977). From this point evolutionary theory has been developed and applied to all agents involved in innovation, including firm and non-firm organisations (Malerba 2002, McKelvey 1997, Metcalfe 1995b, Dosi 1997). For the sake of simplicity this discussion of evolutionary theory refers to the original, firm-focused view of Nelson and Winter (Nelson and Winter 1977, Nelson and Winter 1982, Nelson 1987) with more recent comments from Malerba (Malerba 2002).

Firms are confronted with uncertainty, and evolutionary economists believe that uncertainty is a more important influence upon decisions to innovate than the incentive to maximise profits. Firms cannot predict which technologies will be successful and certainly do not have the resources to overcome this limitation by investigating all technological alternatives. Learning and knowledge are key elements in the evolutionary economic models of technological change, and 'bounded rationality' (Simon 1965)[34] a key concept. 'Boundedly rational' agents, such as firms, have unique knowledge, experience, skills and resources. When facing uncertainty, they will make different choices about when and whether to conduct R&D or other innovative activities (Nelson and Winter 1977, Nelson 1987). According to Malerba:

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[34] 'Boundedly rational' agents act, learn and search in uncertain and changing environments (Malerba 2002).

> Thus, learning, knowldege and behaviour entails agents' heterogeneity in experience, competencies, and organisation and their persistent differential perfomance. (Malerba 2002:249)

When dealing with uncertainty, firms are inclined to innovate along known and familiar paths (ie in a path-dependent manner). Nelson and Winter describe this behaviour in terms of heuristic search routines (Nelson and Winter 1982). Such routines reinforce technological trajectories, generate path-dependent variation and link technological development to a *cognitive* frame of reference. In addition, specific industry sectors and groups of firms share a frame of reference, their technological regime (Nelson and Winter 1977) or technological paradigm (Dosi 1982), and a dominant technological paradigm tends to exclude alternative developments (Dosi 1982). As summed up by Malerba:

> ...evolutionary theory places emphasis on cognitive dimensions such as beliefs, objectives and expectations in turn affected by previous learning and experience and by the environment in which the agents act. (Malerba 2002)

A central and defining feature of the evolutionary approach is its description of processes driving innovation and economic change. In essence, biological-type evolutionary principles of change have been reproduced in the context of the general economy (Nelson and Winter 1982, Nelson 1987). Within a given environment (selection environment) there are three processes driving economic change: *processes that create variety* or generate novelty (in technology, products, firms and organisations); *processes of selection* that reduce variety; and, *processes of replication* (the retention and transmission of information) (Nelson 1995, Metcalfe 1995b).

Thus, routines found in firm and non-firm organisations equate to 'genes' that can be passed on to future generations. Firms, for example, generate novelty (new variations), under the influence of search routines (*cumulative* processes of active learning) and the dominant technological paradigm. As in biological systems, random mutations, events and recombinations also introduce novelties into an environment in the form of innovations. The success of new variations depends upon how well they compete in a 'selection environment', where selection mechanisms operate in a similar fashion to the biological process of 'natural selection'.[35] Selection forces are described in terms of 'opportunity' and 'appropriability' conditions, while the technological environment effects innovation intensity, industry intensity and industry entry rates (Nelson and Winter 1982, Nelson 1987).

For evolutionary theory, the environment and conditions in which agents operate may drastically differ. Particular attention is given to opportunity conditions related to science and technology, the knowledge base underpinning innovative activities, and the institutional context (Malerba 2002). When situating evolutionary theory in the context of a capitalist economy, Nelson highlights the non-equilibrating dynamic and degree of diversity generated by technical change. Ultimately, this makes technological change an extremely wasteful process, riddled with technological dead-ends and duplication of effort (Nelson 1988, Nelson 1990c). Nelson notes that this waste is unavoidable, as by definition, a planned system would fail as it is

[35] McKelvey further adapts these principles to the particularities of socio-economic processes and differences between biological evolution and socio-economic evolution (McKelvey 1997).

impossible to know where to allocate resources, a dilemma exacerbated by the rapid pace of technological change. Based upon evolutionary theory, Nelson describes an ideal capitalist economy as one that provides:

> ...access to basic general knowledge necessary for successful innovation; multiple sources of innovation; competition between innovative firms; and effective incentives to observe market signals. (Nelson 1988:314)

3.4.6 Knowledge and learning processes

Knowledge and learning are fundamental to, and at the heart of, all types innovation (technological, organisational, institutional, radical and incremental). Learning processes and knowledge are the key elements of innovation and an understanding of how they work to facilitate innovation helps in understanding the link between innovation and economic growth. Analytical frameworks that have been established for doing this are largely derived from the quest to better understand how innovation stimulates economic growth.

The literature on knowledge and learning is somewhat complicated due to its diverse origins, and a lack of clarity in what is meant by 'knowledge', 'learning' and related dynamics of change. In addition there is a tendency to treat knowledge and learning discretely rather than as different but interdependent factors that affect the outcomes of innovative processes. Studies in this area have been further complicated by the (now familiar) problem of gathering empirical evidence to account for the heterogeneous realities of knowledge and learning processes. The following quote from Rosenberg illustrates this point:

> The assertion that economic activity involves a significant [knoweldge and] learning dimension would probably command universal agreement. Indeed, at the level of bald and unqualified assertion, there is very little to disagree with. The more interesting questions arise when we attempt to give the assertion some empirical or analytical content. (Rosenberg 1982:120)

New notions, such as 'the knowledge economy' (where technologically advanced economies are knowledge-based and characterised by an increasing intensity of technological innovation (OECD 1998)), have fuelled interest in knowledge and leaning and have added momentum to the production of a very large literature. In a review of the literature on learning, Dodgson (1991) notes its widespread origins in writings on: firm theory (Cyert and March 1963); analysis of organisational forms and learning (Burns and Stalker 1962; Argyris and Shon 1978); strategic management (Ansoff 1982); product development (Maidique and Zirger 1985); and labour costs per unit of production (learning by doing) (Arrow 1962).[36] More recently, literature on learning considers learning by using (Rosenberg 1982), experience-based learning or interactive learning (through users and producers) (Lundvall 1988, Lundvall 1992a), and dynamic organisational capabilities that facilitate learning (Teece 1988, Teece and Pisano 1998). The knowledge literature is similarly diverse. It includes studies that seek to analyse specific scientific and technological fields of knowledge (Dosi 1982, Dosi et al. 1988, Nelson and Rosenberg 1993, Nelson and Romer 1996), and studies that seek to develop measurements

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[36] These examples from literature were given in (Dodgson 1991).

of knowledge (OECD 1999, Narin and Olivastro 1992, Patel and Pavitt 1988) through to theories on the 'new production' of knowledge (Gibbons et al. 1994).

Knowledge is commonly regarded as a *resource* with unique characteristics: its value can increase with use, and it is a renewable resource (and not particularly scarce). *Codified* knowledge is more easily transferable than *tacit* (or experience-based) knowledge which is embodied in individuals, firms or industries. There are other traits of knowledge. Property rights to knowledge, such as intellectual property, are not simply defined. It is not easy to use knowledge in market transactions or to easily appropriate it privately. Considerable market failure occurs in relation to knowledge (see Table 3.8) (Polanyi 1967, Lundvall 1988, Lundvall 1992a). Tacit knowledge is not easily expressible in words and numbers and thus is characterised by being highly personal and difficult to communicate or distribute. It can be divided into two forms: skills relating to 'know-how' which have a *technical* dimension; and a *cognitive* dimension or individual image of reality and vision for the future, such as beliefs and perceptions that are 'boundedly rational' (Nonaka and Takeuchi 1999).

Table 3.8: Two types of knowledge

Tacit knowledge	Explicit knowledge
• knowledge of experience – body	• knowledge of rationality – mind
• simultaneous knowledge – here and now	• sequential knowledge – there and then
• analog knowledge – practice	• digital knowledge – theory

Source: (Nonaka and Takeuchi 1999)

Learning is a heterogeneous process: it may be active or passive, strategic or tactical, and involve patterns of search and review ('unlearning' and learning from mistakes). Rosenberg illustrates this point in describing learning as a single function, namely R&D as 'a learning process in the generation of new technologies':

> At the basic end of the spectrum, the learning process involves the acquisition of knowledge concerning the laws of nature. Some of this knowledge turns out to have useful applications to productive activity. At the development end of R&D is a learning process that consists of searching out and discovering the optimal design characteristics of a product. At this stage, the learning is oriented toward the commercial dimensions of the innovation process: discovering the nature and combination of product characteristics desired in the market (and in relevant submarkets), and incorporating all of these in a final product in ways that take into account scientific and engineering knowledge. (Rosenberg 1982:121)

Many typologies of learning categories have since been developed, for example, Rothwell has categorised learning processes found in industrial innovation (see Table 3.9), whereas Malecki prioritises 'explicit' (stated intent with investment) learning processes according to degrees of strategic intent and required capabilities (see Table 3.10). Learning involves organisational capabilities (or so-called dynamic capabilities) as well as individual skills, common 'codes' of communication and coordinated search methods (Teece and Pisano 1998). Teece defines learning in firms as:

> ...a process by which repetition and experimentation enable tasks to be performed better and more quickly and new production opportunities to be identified. (Teece and Pisano 1998:200)

Table 3.9: Rothwell's Categories of learning in industrial innovation

Internal learning	External or Joint Internal/External Learning	
• Research, Design & Development – learning by developing	• learning from/with suppliers	• learning through reverse engineering
• learning by testing	• learning from/with lead users	• learning from acquisitions or new personnel
• learning by making – production learning	• learning through horizontal partnerships	• learning through customer-based prototype trials
• learning by using in vertically integrated companies	• learning from/with the S&T infrastructure	• learning through servicing/fault finding
• learning by failing	• learning from the literature	• learning from competitors' actions
• cross-project learning		

Source: (Rothwell 1994b)

Table 3.10: Malecki's Categories of 'explicit' learning

Learning category	Characteristics
1) Learning by operating	• most elementary form of learning • variant of learning by doing • resulting improvement to operating capacities small
2) Learning by changing	• improving upon equipment and techniques as a consequence of use • technical changes can be major – following investment in successive projects and mastery of technology is gained
3) System performance feedback	• learning from performance monitoring of technology • requires allocation of resources to generate flow of data • gain understanding of why things work
4) Learning through training	• high level of technological learning needed to move beyond the *how* of technology to learning *why* of technologies – so as to move beyond basic operation and make significant improvements in products or processes • maintains explicit reliance on external sources of technology
5) Learning by hiring	• create technological capacity – not simply accumulation • may be as important as intra-firm accumulation of experience
6) Learning by searching	• organisation has capacity to investigate sources of knowledge, absorb various 'disembodied' knowledge and select what is most suitable • requires explicit allocation of resources for non-productive tasks, usually R&D

Source: (Malecki 1991)

The utility of approaches to the study of knowledge and learning is increased, both empirically and analytically, when combined with other theories relating to technological innovation. The central role of knowledge and learning in innovation is strongly emphasised in the evolutionary literature (Nelson 1995, Dosi et al. 1995, Dosi 1997, Metcalfe 1995a):

> ...there might be an intimate relation between learning theories and ecolutionary theories in the sense that learning is one mechanism through which diversity is created. Learning might even be an element in processes of selection. (Edquist 1997a)

Evolutionary theory also:

> ...places emphasis on cognitive dimensions such as beliefs, objectives and expectations, in turn affected by previous learning and experience and by the environment in which agents act. (Malerba 2002:249)

The central role of knowledge and learning is also noted in the literature on knowledge-based economies (Lundvall and Johnson 1994, Cohen and Levinthal 1990):

> Technological innovation is a matter of producing new knowledge or combining existing knowledge in new ways – and of transforming this into economically significant products and processes. (Edquist 1997a:16)

Furthermore, due to the social embeddedness of knowledge and learning, the ability to acquire and appropriate knowledge cannot be properly understood without considering history, as with the 'historical establishment and development' of institutional and social context (Freeman and Perez 1986, Freeman and Louca 2001, Lundvall 1988, Lundvall 1992a).

What has been learned previously strongly influences and may even prevent what is selected to be learned subsequently, meaning that learning processes are *cumulative*. Solving complex problems involves dynamic capabilities, combinations of new (and existing) forms and types of knowledge and new patterns of learning. It is not simply emulation or imitation (Lundvall 1988, Lundvall 1992b, Teece 1999, Dosi et al. 1995). Firms, for example, build upon past learning experiences and their existing knowledge base when searching for new opportunities (Teece 1988, Dosi 1988, Dosi et al. 1988). Access to new technological opportunities is often influenced by conditions in the external environment and the institutional framework (for example, the degree of access to such things as new sources of knowledge, human capital) (Malerba 2002, Orsenigo et al. 2001). A firm's ability to exploit technological opportunities is influenced by its organisational knowledge and learning processes that deliver advanced integration capabilities and absorptive capacities (Cohen and Levinthal 1990, Teece 1988, Teece and Pisano 1998). In general, cognitive and path-dependent aspects of knowledge and learning processes tend to reinforce industry sector-specific technological trajectories (Dosi 1988, Malerba and Orsenigo 1996, Malerba et al. 1997). That is, of course, unless a paradigm shift occurs (Perez 1983).

Most recently, the literature has reported upon insights gained into the dynamics of change in knowledge bases and learning processes in innovation systems,[37] based upon empirical studies.[38] Malerba uses evolutionary theory and empirical evidence to identify the complexities of how knowledge and learning processes affect change over time in the performance of industry sectors (Malerba 2002). Empirical studies in the evolutionary literature have shown that industry sectors and technologies differ markedly in terms of the *knowledge base* and *learning processes* related to innovation (Malerba 2002).[39]

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[37] A description of these dynamics and its empirical and theoretical antecedents is given by Malerba (Malerba 2002).

[38] Analyses of Schumpeterian Models of technological innovation in industry sectors (Malerba and Orsenigo 1996, Breschi et al. 2000) and empirical studies conducted as part of the European Sectoral Systems of Innovation (ESSY) Project (McKelvey and Orsenigo 2001), have demonstrated that knowledge bases are specific to industry sectors and technology regimes, and that the response to changes in the knowledge base of a sector (learning processes) is affected by the opportunity conditions in a localised selection environment.

[39] Section 3.4.1 – The roles of science and technology, made the point that respective science and technology 'knowledge bases' share an increasingly dynamic interface, particularly in the 'transfer sciences'.

> ...learning, knowledge and behaviour entail agents' heterogeneity in experience, competencies, and organisation, and their persistent differential performance. In addition, evolutionary theory places emphasis on cognitive dimensions such as beliefs, objectives and expectations is affected by previous learning and experience and by the environment in which agents act. (Malerba 2002:249)

Successful technological innovation can now begin to be explained by how well knowledge bases are *exploited* through learning processes. The differing emphasis upon the exploitation of technological opportunities is of particular relevance to this study, as it helps to demystify concepts of 'high-tech' and 'low-tech' as they are traditionally applied to the technologically innovative performance of industry sectors, in this case, the minerals industry.

3.4.7 Institutions in innovation processes

It is necessary to know what is meant by 'institutions' to understand their role in technological innovation. A simple sporting analogy put forth by Douglass North (1990) is an elegant way to begin. In a game of innovation, institutions are the rules outlining how the game is played (North 1990). Institutions are not only *formal* rules, but also *informal* codes of behaviour understood by players (or actors) in the game. In a broad socio-economic context, institutions are fundamental building blocks in all societies (Johnson 1992) as they reduce uncertainty and thus the amount of information necessary for individual and collective action. Their interaction and influence upon economic systems is multi-levelled and complex, as the following quote demonstrates:

> Technological change and institutional change are the basic keys to societal and economic evolution and both exhibit the characteristics of path dependence. ... The perceptions of the actors play a more central role in institutional than in technological change because ideological beliefs influence the subjective construction of the models that determine choices. Choices are more multifaceted in an institutional context because of the complex interrelationships among formal and informal constraints. In consequence, both lock-in and path dependence appear to be much more complicated in the case of institutions than in the case of technology (North 1990:103-204)

Returning to institutions and technological innovation, the literature surrounding technological innovation recognised the importance of institutions and institutional change. However, explicit treatments of institutions in innovation processes and systems has appeared only recently.[40] Johnson (1992) employs a wide definition when considering institutions and is dismissive of the view that institutions simply cause 'institutional drag' which inhibits the innovation process. In his view, institutions have a critical role in innovation processes by virtue of the fact that learning is an interactive process, and open to influence by the institutional set-up of a nation and its economy.

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[40]For an integrated view on the 'structuralist perspective to economic growth and development,' as opposed to the neoclassical view, see (Justman and Teubal 1991). A paper by (Zysman 1996) examines how the 'historical roots' of a nation's institutions help explain their economic and technological growth.

> Institutions are sets of habits, routines, rules, norms and laws, which regulate the relations between people and shape human interaction. (Johnson 1992:25)

A detailed review by Edquist and Johnson (1997) produced a taxonomy of insitutions as a base for understanding how the makeup of formal and informan instutions influences innovation (Edquist and Johnson 1997). Here a dynamic tension exists between the rigidities often inherent in institutions and the contrasting need for institutional flexibility in the face of continuous change. They also found that 'institutionalists' use many varieties of the concept but tend to favour use of the term for 'important and general economic phenomena' such as basic behavioural patterns and ground rules. Table 3.11 gives an overview of the taxonomy of institutuions.

Table 3.11: A taxonomy of institutions

Types of institutions	
Formal	**Informal**
laws – patent laws, regulations & instructions, formal instructions	Common law, customs, norms, conventions, practices
Basic	**Supporting**
constitutional rules or ground rules, eg conflict resolution and cooperation rules in firm	rules that define and specify certain aspects of basic rules eg industry specific rules
Hard	**Soft**
binding and in some way policed	Rules of thumb and suggestions that need not be obeyed

Source: Produced from Edquist and Johnson's descriptions (Edquist and Johnson 1997)

The interaction between innovation and institutions is multileveled, occurring within firms, at the market level (eg among firms or firms and consumers), and between public regulators and firms. Edquist and Johnson provide four types of instituions in terms of their relevance to innovation:

- institutions that reduce uncertainty by providing information;
- institutions that manage conflicts and cooperation;
- institutions that provide incentives; and
- institutions that channel resources into innovative activities. (Edquist and Johnson 1997:51)

The way in which these types of institutions function is not well defined and they tend to overlap. In addition, their relevance and impact varies considerably in accordance with the level at which innovation is being addressed (industry sector, technology, nation and so forth). Legal institutions in relation to intellectual property rights, for example, may reduce uncertainty in some industries and provide an incentive to innovate (such as in the pharmaceutical industry) (McKelvey 1996, Achilladelis and Antonakis 2001, Orsenigo et al. 2001, McKelvey and Orsenigo 2001). By comparison, the legal patenting regime is unimportant in the software industry (Malerba et al. 2001b, Malerba et al. 2001a).

For the purpose of this study it is important to understand that institutions can act to *enhance* or *impede* innovation processes (and systems). They can do this, for example by ensuring that more than marginal resources are directed towards innovative activities or, by failing to deliver institutional changes necessary to exploit technologcal opportunities (*ibid*). The institutional set-up in a modern economy is highly complex. While normally institutional change occurs in an incremental manner, flexibility and responsiveness to change are seen as sources of competitiveness (Coriat and Weinstein 2002, Nelson 1988, Zysman 1996, Best 1990).[41] The concept of 'techno-economic paradigms' illustrates the dynamic tensions between radical technical change and institutional change, by highlighing the period of economic stagnation before institutional restructuring can facilitate a new match among institutions and technologies, and support renewed growth (Freeman and Perez 1988). In regard to the latter, successful systems of innovation are those which embrace 'institutional learning', and in so doing overcome the tension between reducing uncertainty and maintaining flexibility within their institutional framework (Best 1990, Grick 1998, Hage and Hollingsworth 2000, Nelson and Nelson 2002, Zysman 1996, Malerba 2002).

In this light there appears to be support for Nelson's contention that the most important task for any capitalist system is to design and continually evolve a rich institutional environment to reap the most reward from the beneficial interplay between innovation in the public and private sectors.

> One can see the task of institutional design as somehow to get the best of both worlds. Establish and preserve property rights, at least to some degree, where profit incentives are effective in stimulating action, and where the costs of keeping knowledge private are not too high. Share knowledge where it is of high cost not to do so, and the cost in terms of diminished incentives is small. Do the work cooperatively, or fund it publicly, and make public those aspects of technology where the advantages of open access are greatest, or where proprietary claims are most difficult to police (Nelson 1988:315).

3.4.8 Role of firms in innovation

Firms are key actors in processes of innovation, since they are involved in 'the innovation, production and sale of sectoral products, and in the generation, adoption and use of new technologies' (Malerba 2002). Firms are characterised by specific beliefs, expectations, competencies and organisation, and are engaged in processes of learning and knowledge accumulation (Nelson and Winter 1982, Dosi et al 1988, Malerba 1992, Teece and Pisano 1994, Metcalfe 1998, Malerba 2002). The heterogeneous reality of types, level and forms of innovations means that firms can simultaneously be important *users* and *suppliers* of new technological innovations (Lundvall 1999, Lundvall et al. 2002, von Hippel 1988). Thus, firms are users and suppliers with different relationships among many other innovating, producing or selling firms (Malerba 2002). Empirical studies show that firms innovating at the technological frontier have increased levels of interactivity and programs of collaborative R&D (Meyer-Krahmer and Reger 1999, Andersen 1999, Bayona et al. 2001, Georghiou 2001, Rappert et al. 1999).

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[41] Some scholars believe that the analysis of social systems of innovation which focuses on the institutional dimension is crucial to account for the coexistence of different types of modern developed economies, (that is, those characterised by substantially different institutional structures) (Amable 2000).

> ...interfirm relationships are important in structuring the system of innovation. In standard economics these relationships are assumed to be characterised by competition and by pure markets. Focusing upon innovation makes it clear that *cooperation between {and among} firms* is a necessary supplement to competition,' (Lundvall 1992:14)

This brief review of innovation and firms does not address 'theories of the firm' but is restricted to those features relevant to this study, and found in the vast literature on innovation in firms. As firms are ultimately the vehicles by which technological innovations enter a market place and gain an economic return, they are of obvious significance in studies of innovation. However, when it comes to determining what are the most important elements that enable innovation by firms there is a multitude of different views and approaches. These include: dynamic capabilities-based (organisational approach) views coupled with evolutionary theory; organisational learning; patterns of learning and user-producer relationships; management literature concerning technological innovation and R&D strategy; importance of rivalry, competition and market-place; and product-cycle and location of R&D activities by MNCs (some of this literature is presented in Appendix 3.1). A guide to the issues here is presented in Dodgson and Rothwell's *The Handbook of Industrial Innovation*, (Dodgson and Rothwell 1994) in which some key points about innovation processes and firms of relevance to this study are made.

Research has demonstrated that the size of a company usually dictates whether its technology strategy adopts a broad front or niche (Pavitt et al. 1989, Patel and Pavitt 1991b, Pavitt and Patel 1995, Patel and Pavitt 1999). The following quote illustrates this point:

> Large firms (10,000 employees) are almost always 'broad front': in other words, active in a range of technologies and product markets. They are also organised into product and functional divisions, with specialised and professionalised technological activities performed not only in R&D laboratores, but in production engineering departments, design offices, and sorftware and systems groups. Small firms (<1000 employees), on the other hand, are typically less diversified in both their technological activities and their product range, with a high proportion of innovative activities performed outside formally established R&D departments. (Pavitt and Patel 1995:327)

The pattern of innovation-derived growth in firms can be described as one of continuous learning (Lundvall 1992b). As illustrated in Table 3.12, firms have many internal and external sources of knowledge. Success with innovation depends on a great deal more than R&D alone, including external networks and relationships, the integration of internal activities, training, quality of management and the selection environment. While the pattern of learning networks, external and internal, varies across industries and size of firm, all firms utilise external sources of knowledge (Foray 1991, Foray and Freeman 1993, Freeman 1994b). R&D intensity fluctuates greatly between industries and empirical studies show a positive relationship between very high R&D intensity and rapid growth. At the opposite extreme, low R&D intensity is often associated with stagnation and decline of firms (Freeman 1994b, Wakelin 2001). The association between R&D intensity and growth does not hold, however, for firms operating between the extremes. This is not necessarily surprising due to the huge diversity of circumstance, modes of learning, cultures, management ability, on top of inherent technological uncertainties (Freeman 1994b). In terms of R&D intensity and *the long-term growth rates of industries* the association is more durable, since the advancement of science and technology, and competitive processes generally precipitate predictably rapid growth in the same industries in developed countries. The success or failure of individual firms within those industries, however, is not predictable (Freeman 1982, Freeman 1994b).

Table 3.12: Factors for successful innovation in firms

Innovation in firms – determinants for success		**Key References**
Features of firm innovation	• Fastest growing firms have capacity for flow of incremental and (less commonly) success with radical innovation • *Cumulative* aspects of technology, generates path dependency • Multiple inputs to innovation from diversity of internal & external sources • Diffusion of innovations & changes to technology introduced by numerous adopters • Original entrepreneur not as important as diffusion for economic growth	(Dosi 1988, Freeman 1994b, Freeman and Soete 1997, Malerba et al. 1997, Malerba and Orsenigo 1999)
Firm-specific knowledge accumulation and learning	• Internal sources of learning – experience of design, development, production and marketing	(Achilladelis and Antonakis 2001, Dosi 1988, Eliasson 1990, Pavitt 1984, Teece 1988)
	• Exogenous scientific advances – importance of contacts in world science • External sources of learning – customers, suppliers, contracts, organisations such as universities, gov labs & agencies, consultants, licensors, licensees etc	(Carter and Williams 1959, Cantwell 1994, Cantwell 1999a, Nelson 1992, Dosi et al. 1992a, Pavitt 1992, Oerlemans et al. 2001, Zander 1999, Foray 1991, Foray and Freeman 1993)
	• Increasing interdependence of science and technology	(Nelson 1962, Freeman 1974, Price 1965) (Kaufmann and Todtling 2001)
Networking relationships	• Importance of corporate strategy and government policy in developing *networking* relationships	(Orsenigo et al. 2001, Huggins 2001, Nooteboom 1999, Hage and Hollingsworth 2000) (Dodgson 1993, Carlsson and Jacobsson 1994, Tebal et al. 1991)
	• ICT and biotechnology two new generic technologies where science-technology interface has intensified along with external knowledge networks	Biotechnology - (Orsenigo et al. 2001, Dodgson 1991, Dodgson 1993) ICT - (Freeman 1991)
	• Scientometric literature analyses patents and citations to demonstrate the intensification of interaction between science and technology	(Narin and Noma 1885, Narin and Olivastro 1992, Narin et al. 1997, Van Vianen et al. 1990, Hicks et al. 2001)
Interactivity	• Interaction with contemporary and future users of an innovation	(Lundvall 1988, Lundvall 1992b)
	• Users may take the lead in stimulating and organising innovation	(von Hippel 1988)
	• Internal integration among R&D, design, production and marketing – delivers shorter lead times and simultaneous product and process improvement	(Freeman 1994b, Dodgson 2000)

Source: this table was constructed along the arguments presented in (Freeman 1994b:80-84)

The competence theory of the firm begins with an assumption that resources are heterogeneously distributed and are imperfectly mobile (Chandler 1992, Teece 1988, Teece et al. 1994, Teece and Pisano 1998). Firms differ with regard to their endowment of resources, along with the routines developed to exploit resources and maintain a sustainable competitive advantage in the longer term (Niosi and Bas 2001, Niosi 2001). As a consequence, firms exhibit long-term differences in their rates of return. A great deal of research has been directed at understanding the competencies firms must maintain if they are to be innovative over long periods. The latter includes the abilities to:

Carry out a routinised search for new knowledge
Change the search routines when necessary
Utilise the search results
Absorb new knowledge created elsewhere (in other firms etc)
Stimulate the emergence of 'unexpected' new knowledge
Utilise unexpected new knowledge. (Edquist and Johnson 1997:58)

The majority of industrial R&D is aimed at new or improved products and services. 'R&D carried out by business firms, in rivalry with other firms in the same industry and looking to innovation to get ahead or stay up, is the heart of the modern capitalist engine,' (Nelson 1988:316). Nelson has maintained an interest in the ways in which firms appropriate the returns from their investment in R&D. Of course, it is vital for firms investing in the ever escalating costs of R&D to know that their competitors will not be able to, 'reap on the cheap what they did not sow,' (*ibid*). While private firms initially benefit from proprietary knowledge, this knowledge does not remain in the private sector and eventually leaches into the public domain. This is a beneficial phenomenon, since it stimulates the economy's use of new technology by way of production and through the enhancement of further R&D. A problem may arise, however, if firms relinquish their investment in innovation because they see that significant benefits from their investment are being appropriated by consumers and their competitors (*ibid*:318). Nelson has also emphasised the importance of maintaining a healthy balance between property rights and the degree to which scientific knowledge remains a public good, in order to maximise competition investment in innovation among firms (Nelson and Romer 1996).

Contemporary understanding of the product cycle model[42] notes that technology leaders in foreign markets may be challenged by protectionist barriers and the incremental catch-up of local competitors in foreign markets (Cantwell and Andersen 1996, Cantwell 1999a, Oerlemans et al. 2001). For this among other reasons, technologically competent companies are increasingly strategic in the location of foreign technological activity, primarily in leading centres of technological excellence to exploit external sources of expertise and enhance core technological competencies through internal learning processes (Meyer-Krahmer and Reger 1999, Meyer-Krahmer 1998, Meyer-Krahmer 1999, Cantwell and Andersen 1996, Cantwell 1999a, Oerlemans et al. 2001, Carrincazeaux et al. 2001). External sources of new technology may be utilised throughout all operations of a MNC, making innovation in such companies genuinely globalised (Cantwell and Janne 1999, Cantwell 1999a, Meyer-Krahmer 1999).

A debate about MNCs and the internationalisation of their R&D activities is ongoing. Some argue that such programs aimed at generating new technologies are strategically important and are therefore, located primarily in the firms' country of origin (Patel and Pavitt 1991b, Patel and Vega 1999, Pavitt and Patel 1999, Archibugi and Michie 1995). Others reason that the R&D activities of MNEs are increasingly globalised and driven by factors such as governments' encouragement of overseas R&D investment. Sirgurdson suggests that a new way of analysing this issue is to look at the technological links between NIS and 'corporate' IS, and how they have evolved (Sigurdson and Cheng 2001).

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[42] See Appendix 3.1 for an early understanding of this model.

3.4.9 A note on Globalisation and innovation

Globalisation is a descriptive concept for the processes by which firms and financial markets operate internationally, largely as a result of deregulation and improved communication (OECD 1992, OECD 1996, OECD 1999). It is often applied in the context of 'mapping' the impact of global factors upon economic and social developments, or placed in a policy context where it is frequently given an equivalent meaning to 'liberalisation'.

Dodgson (2000) lists six general drivers of globalisation, while noting that 'the *creation*, *use* and *sale* of technology' is causing firms to be increasingly globalised. These drivers of globalisation include:

- Greater participation in, and integration of, world trade
- Liberal government policies
- Changing corporate strategies
- Creation of global capital markets
- Capacities of information and communication technologies
- Increasing market homogeneity. (Dodgson 2000:49-50)

A complex and self-perpetuating interplay exists between technological innovation and globalisation. This is seen, for example, when new ICTs facilitate globalisation which in turn encourages diffusion and more innovation. There is plenty of evidence of the internationalisation of R&D. For example, independent studies found that 15 per cent of US industrial R&D was undertaken by foreign firms (Florida 1997, Florida 1999), and that 45 per cent of United Kingdom R&D was conducted overseas (Martin and Slater 1996).

It is now widely believed that globalisation and national specialisation are complementary factors in economic growth (Archibugi and Michie 1997). The relevant question is how innovation systems are shaped by global and location specific (regional, national, sectoral) factors. Archibugi describes four criteria that characterise the interplay between innovation systems and globalisation (Archibugi et al. 1999). First, globalisation encourages the transmission of 'best-practice' techniques across nations. Nevertheless, this does not indicate an immediate acquisition of knowledge because the nature of learning is neither immediate nor automatic.[43] Second, the transmission of goods and services is also facilitated by globalisation. Thus, national and firm-based competitiveness requires access, as well as the capacity to use international sources of knowledge to generate new or improved processes and products. Third, location-specific advantages are increasingly important and are reinforced by foreign direct investment from MNCs in select centres of excellence or best-practice conditions in specific locations. In other words, nation-specific advantages are becoming more important for MNCs (Meyer-Krahmer 1999, Meyer-Krahmer 1998, Meyer-Krahmer and Reger 1999).[44] Fourth, evidence suggests that the distribution of production and technological capabilities is

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[43] For more on learning in the global economy see (Lundvall 1999).

[44] Cantwell's chapter in Archibugi *et al.* discusses the importance of national policies to encourage local institution building and other enhancement mechanisms of technological development, in order to create and environment that appeals to MNCs when they consider where to extend their capacity (Cantwell 1999b).

increasingly sectorally differentiated, indicating that nations are concentrating their efforts in selected industries and capabilities, and rely on trade for other needs (Archibugi and Michie 1997, Archibugi et al. 1999).[45]

There are implications here for policy-making since globalisation and location-specific factors influence the effectiveness and impact of certain policy instruments. While some traditional macroeconomic policy instruments may have become less effective, it is argued that others, such as policies supporting competence in areas of eduction, training and technological change, are the only way to maintain and enhance national competitiveness in a globalised environment (Archibugi and Michie 1995, Archibugi et al. 1999).[46]

In summary, the literature seems to suggest that the globalisation of technological innovation, including the MNC's integrated but geographically dispersed and local specialised innovative activities, has the effect of *reinforcing* and not dismantling national, regional and sectoral innovation systems. When companies decide to augment their innovative activities abroad, they are most likely to select centres of excellence and exploit a nation-specific capability. More often, however, they conduct core R&D in their home countries. In either case, national innovation systems are relevant.

> Even very large corporations in most cases perform most of their R&D at home. As a consequence, companies' innovative activities are significantly influenced by their home country's national system of innovation: the quality of basic research, workforce skills, systems of corporate governance, the degree of competitive rivalry, and local inducement mechanisms, such as abundant raw materials, the price of labour and energy, and persistent patterns of private investment or public procurement. (Pavitt and Patel 1999:94)

3.5 Innovation systems

In broad terms, the need for a 'systemic' analysis of innovation arose in a pragmatic fashion as a response to developments in the study of innovation. These developments can be grouped into three areas. First, there was the wide recognition of innovation as a dynamic, unpredictable, socially embedded process; the result of choices made by actors rather than a force within itself. Second, the advancement of innovation theory (developed in the 1970s and 1980s, see Section 3.4) provided real alternatives to the poor treatment of innovation by neo-classical economic approaches and simplistic linear models of innovation processes. Third, findings based upon empirical evidence generated from a variety of studies of technological innovation required an explanation. With regard to this last point, empirical evidence showed that: innovative performance (measured at firm level) is persistently uneven between regions and countries

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[45] Guerrieri (1999) has more on patterns of national specialisation and the linkage with globalisation, from an investigation of the dynamics of world trade and trade specialisation of major economics (Guerrieri 1999).

[46] See chapters by Lundvall, Pavitt and Patel, and Archibugi and Iammarino in *Innovation Policy in a Global Economy*, for discussions of the roles of policies directed at increasing technological competence and national competitiveness (Archibugi et al. 1999).

(Patel and Pavitt 1994b, Archibugi and Pianta 1992, Malerba et al. 1997, Patel and Pavitt 1991a, Patel and Pavitt 1988, Nelson 1990a); that there is a link between technological innovations and competitive advantage at the national level (Fagerberg 1988, Dosi et al. 1990, Freeman 1994a, de la Mothe and Paquet 1996); and that persistence and variation in firm and country performance tends to be sector specific (this empirical evidence has developed more recently) (Pavitt 1984, Dosi et al. 1990, McKelvey 1996, Breschi and Malerba 1997, Malerba et al. 1997, Cefis and Orsenigo 2001).

Box 3.1: The family of innovation systems

Geographic

- *National Innovation System (NIS)*
  — national borders delineate boundaries of the system
- *Regional Innovation System (RIS)*
  — spatial context of innovation, or regional innovation networks within or beyond national borders delineate(s) boundaries of the system
- *Local Innovation System (LIS)*
  — similar to regional systems only more focused - borders delineate boundaries of the system
- *Pan-national (continental and international) systems*
  — geographically dispersed

Technological

- *Technological Systems (TS)*
  — Particular technology fields or technology-specific industries delineate boundaries of system

Firms in a technological regime

- *Sectoral Innovation System (SIS)*
  — Industry sectors (specific industries or clusters of industries) in the same technological regime delineate boundaries, making boundaries endogenous and not delineated in a geographic or technological sense

In a sense, these developments pointed to new research questions, such as, to what degree is the uneven distribution in innovative and economic performance due to national and regional factors? To understand innovative performance and growth thus requires a conceptual framework that links the performance of innovation to the technological and social contexts: that is, the factors that affect knowledge creation and learning. The resulting IS approach emphasises the links and interactions among actors (firms and non-firms). In addition, the influence of institutions and infrastructures is not exogenous with respect to the innovative activities of individual or groups. Long-term historical views and knowledge of the evolutionary development of organisations, institutions and behaviours are important when studying innovation systems. The systemic approach tries to capture and explain the heterogeneous realities and multi-dimensional sources of influence that are important in processes of innovation. No single framework is yet to capture all of the factors shaping and influencing innovations, nor is this likely to happen given the complexities involved. This is reflected by the emergence of a family of IS approaches, each distinguished by its level of aggregation (see Box 3.1) (Edquist 1997a).

The IS approach is often criticised for an apparent lack of formal theoretical rigour and structure. In part such criticism is self-inflicted, a result of undisciplined application of the term 'theory' when discussing systems of innovation. In another sense this criticism is superficial. It is unlikely that those who espoused innovation systems theory ever meant 'theory' in the 'formal' or 'appreciative' sense, given the fact that innovation systems are conceptually diffuse and still developing (Edquist 1997a, McKelvey 1997, Edquist and Hommen 1999, Archibugi et al. 1999, Gambardella 2001, Montobbio 2001).[47] Edquist does not consider the IS approach as a formal theory since it 'does not provide convincing propositions as regards established and stable relations between variables' (Edquist 1997a:28).[48]

When innovation systems are not treated as theories, it is possible to appreciate their role as empirical tools; as a conceptual *pooling device*, that brings together contributions from the different fields of study of technological innovation, 'providing common language and creating bridges for different case studies and empirical analyses,' (Montobbio 2001:3). In this regard the IS approach has potential to *support* theoretical development. For example, Niosi points towards an important future role for the NIS perspective in the development of a 'competence theory of nations' (Niosi et al. 2000:24). This new theory draws upon a convergence among the NIS perspective, recent theories of the firm, the concept of the knowledge economy, and evolutionary economics (*ibid*). The competence theory of the firm begins with an assumption that resources are heterogeneously distributed and are imperfectly mobile. Firms then differ with regard to their endowment of resources, and with the routines they have developed to exploit resources and maintain a sustainable competitive advantage in the long term. As a consequence, firms exhibit long-term differences in their rates of return. Addition of the NIS perspective to competence theory of the firm generates an hypothesis that national economies are characterised by the idiosyncratic endowment of assets and resources (including human resources), and the institutionally based routines and incentives nations have developed to exploit and their particular resources. The competitive advantage of nations is thus deeply embedded and difficult to imitate (*ibid*).

3.5.1 The IS family approaches

Defining systems of innovation is not a categorical or straightforward process. As has been demonstrated, the IS approach has evolved from a very broad literature which overlaps and contains may points of view and theories. Diffuse terminology, where authors write about the same phenomenon but with different meaning, along with the inherent vagueness of some of the concepts upon which IS approaches are based, has created a high degree of ambiguity. For example, definitions of innovation systems range widely (see Table 3.13).

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[47] There has been much debate (past and present) in the literature on this point. Some examples include (McKelvey 1991, Dosi et al. 1992b, Niosi et al. 1993).

[48] Edquist discusses Nelson and Winter's (1982) distinction between *appreciative* and *formal* theorising. Given that little is known about causal relationships between variables within innovation systems, or

Table 3.13: Definitions of 'innovation systems' for different IS approaches

Author	IS	Definition	Refs
Freeman	NIS	'...the *network of institutions* in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies.'	(Freeman 1987)
Lundvall	NIS	...the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge...' and '...all parts and aspects of the *economic structure* and *institutional set-up* affecting *learning* as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place.'	(Lundvall 1992b)
Nelson and Rosenberg	NIS	'...a set of institutions whose interactions determine the innovative performance ... of national firms.'	(Nelson 1993)
Metcalfe	NIS	'... set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process.'	(Metcalfe 1995a)
Patel and **Pavitt**	NIS	'...the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country.'	(Patel and Pavitt 1994a)
Niosi	NIS	'A national system of innovation (or national R&D system) is a system of interacting private and public firms, universities and government laboratories, aiming at the production and use of science and technology within national borders.'	(Niosi et al. 2000)
Carlsson and **Stankiewicz**	TS	'...a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion and utilisation of technology.'	(Carlsson and Stankiewicz 1995) and also quoted in (Carlsson and Jacobsson 1997)
Malerba	SIS	'...that system (group) of firms active in developing and making a sector's products and in generating and utilising a sector's technologies; ...related in two ways: through processes of interaction and cooperation in artifact-technology development and through processes of competition and selection in innovative and market activities.' 'A sectoral system of innovation and production is a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products.'	(Breschi and Malerba 1997) (Malerba 2002)

Furthermore, within a particular IS approach, additional variety exists in terms of: the degree of focus given to constituent elements; what aspects of their roles are highlighted; and the application of theory(ies) (historical, evolutionary, knowledge etc). The practical utility of different IS approaches is also influenced by the quantity and quality of existing empirical evidence. The book, *Systems of Innovation: Technologies, Institutions and Organisations*, (edited by Edquist 1997)[49] is a useful source on information on IS as it contains some much needed stocktaking on the IS approach.

whether relevant hypotheses are true or false, the innovation approach is not considered to be an example of appreciative or formal theorising.

[49] Edquist formed the 'Systems of Innovation Research Network' in 1994 to build 'a more solid and sophisticated conceptual and theoretical foundation for the continued study of innovations in a systemic context' (Edquist 1997:preface). The results of the Network's work comprise the 1997 book, *Systems of Innovation: Technologies, Institutions and Organisation* (Edquist, 1997b).

3.5.2 National Innovation Systems

The national perspective on innovation systems was the first to develop. Upheavals in national economies and related technological achievements, such as the spectacular rise of Asian economies, particularly that of Japan, and poor innovative performance of some European countries, triggered interest in the national perspective. Many institutions and organisations involved in technological innovation possess a national character or 'culture'.[50] Technology policies, education, and public funds for innovation tend to be implemented within national borders. In addition, firms in the same country share a common historical background and tend to have evolved sets of informal networks more conducive to flows of tacit knowledge and technological 'know-how'.

Related studies also pointed to a need to understand NIS in terms of knowledge-networks and learning. Fagerberg (1995), for example, employed econometric methods to confirm that the nature of the home market and user-producer relations were critical for growth (Fagerberg 1995). Using Porter's (1990) studies in conjunction with his own findings, Fagerberg argues that a nation's long-term comparative advantage lies where its *rates of learning* are superior and where the *demands of its domestic users* are greater or more sophisticated than those of its competitor nations (see Appendix 3.2 for summary of Porter's (1990) 'factor conditions' for national competitive advantage).

Since the 1990s, soon after its genesis) the NIS approach was quickly picked up by governments and international organisations, such as the OECD and EU, for use in policy development. In particular, the approach was useful for an understanding the performance of different economies, and for identifying appropriate support mechanisms for innovation (OECD 1997, OECD 1996, OECD 1994, OECD 1992).

Founders of NIS emphasise different elements, characteristics and dynamics. Freeman, for example, is interested in history, macro-economic phenomena and the importance of social innovations that accompany changes in techno-economic paradigms. Lundvall is interested in interactive learning and the networks among firms that support shared learning following technological change. Nelson's early contribution favoured descriptive empirical studies that mapped the co-evolution of institutions that support the innovative performance of firms.

Freeman – historical

The roots of Freeman's approach to NIS lie in his collaboration with Carlota Perez, which expanded upon Schumpeter's 'long wave' economic theory and introduced the concept of 'techno-economic paradigms' (Freeman and Perez 1986, Freeman and Perez 1988, Perez 1985). Thus, the analytical starting point in Freeman's approach is radical technological change (changes in the techno-economic paradigm) as the driving force for change within a nation. It is not surprising that Freeman chose to study innovation in Japan, a nation proven to be particularly adaptable in the face of the fifth techno-economic paradigm, the ICT revolution

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[50] Montobbio (2001) provides some new insights into the role of culture in innovation systems (Montobbio 2001).

(Freeman 1987). His analysis of Japan focused upon four elements in the NIS that enabled institutional changes and 'catch-up' including:

- the role of the Ministry of International Trade and Industry (MITI);
- the role of company research and development strategy in relation to imported technology and 'reverse engineering';
- the role of education and training and related social innovations; and
- the conglomerate structure of industry. (Freeman 1987:4)

Lundvall – interactivity for knowledge and learning
Lundvall and the Aalborg Groups'[51] book, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (1992), is a theoretical analysis that focuses upon what type of interactive relations are most supportive of learning. They stress the dimension of *knowledge* in NIS, those learning processes and interactions that take place between users and producers of new technologies. NIS are essentially *socially embedded* and *dynamic* in nature.

Lundvall considers the creation of new 'factor conditions'[52], as well as demand conditions and sources of supply in the home-market, are vital stimulants of innovation and learning. Although national borders are inherent in Lundvall's definition of an innovation system, they can not be located precisely. Lundvall does not believe this to be necessary in a definition of a NIS, as flexibility and openness are of greater importance.

Nelson – descriptive studies and characteristics of NIS
Despite being a committed evolutionist, Nelson does not refer to this theory in his book on NIS (Nelson and Rosenberg 1993). This does not indicate a rejection of evolutionary theory; rather it represents the need at the time to identify the characteristics of institutions in existing NIS. The book, *National Systems of Innovation: A Comparative Study* (Nelson 1993), relies upon empirical evidence and is comprised of thirteen country case studies, with most authors being residents of those countries. The case studies utilised existing knowledge of the relationship between technical change and economic growth in an attempt to 'map' the similarities and differences among national systems. Despite criticism that this study is undermined by each of the 13 authors having their own vision and interpretation of what is important in a NIS approach, the study established three general rules for successful national innovation systems.

- The first, is that government cannot be a substitute for the technological efforts of firms, particularly in regard to manufacturing.
- The second, is the vital importance of an effective national education and training system, with strong links to the demands and needs of national industry.
- The third general rule emphasised a critical role for government to ensure that its fiscal, monetary and trade policies coerce and support national firms to compete on world markets (Nelson 1993).

An issue not clarified by this study is:

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[51] Most of the contributions to the book come from academics at the IKE Research Group at Aalborg University in Denmark, and Denmark is the country used for the majority of empirical examples given.
[52] Here Lundvall draws upon Porter's framework, a 'diamond' of four sets of factors that create competitive advantage (Porter 1990); as well as Fagerberg's econometric studies (Fagerberg 1988, Fagerberg 1995).

> ...the extent to which the particular features of a nation's technical innovation system matter centrally in affecting a nation's overall economic performance in such dimensions as productivity and income and their growth, export, and import performance. (Nelson and Rosenberg 1993:20).

Other contributors to NIS

Patel and Pavitt present a definition of a NIS that bridges the 'institutional' approach of Nelson and the 'relational' approach of Lundvall. They highlight the role of incentives, such as temporary monopoly profits, to encourage basic research as well as the strategic capabilities of firms (Patel and Pavitt 1994a). Their definition of a NIS is further developed according to a nation's financial, management and education set-up, to distinguish between 'dynamic' and 'myopic' systems. They have also researched the manner in which the strategies of large corporations are influenced their respective NIS (Pavitt and Patel 1995). Their findings support the notion that NIS become increasingly important as MNCs globalise their innovative activities.

Niosi stresses the importance and continued relevance of NIS in his book on Canada's NIS, (Niosi et al. 2000). In his work four major systemic aspects of NIS are described.

- Markets are essential and are usually domestic.
- Innovations mostly occur in the research departments of *established* corporations and to a lesser extent, in public research institutions (government labs and universities) and entrepreneurial firms.
- Governments play a key role by provision of: some financial support for innovating companies facing high risk levels and the market reaction to novelty; high quality workers; and, a regulatory framework that supports innovation and stimulates positive externalities such as networks among players in the NIS.
- Innovation rarely occurs in isolation and usually occurs in clusters where flows of knowledge among innovative organisations flourish (*ibid*).

Innovation is thus a geographically located phenomenon at both the local and national levels (Niosi and Bas 2001). Only about twenty industrialised countries have the markets, supporting technological infrastructure, financial institutions and qualified workforce required to generate *systemic* innovation. Within such nations exist a limited number of highly innovative regions, such as Silicon Valley in the USA. Furthermore, nations with an innovative capacity differ in the ways they conduct innovation in reflection of their institutions, role of government, openness to new ideas, linkages among innovative regions and in the 'relative weight' of universities, government laboratories and private corporations (Niosi 2001, Niosi 2002, Niosi 1999).

3.5.3 Sub- and pan- national systems

Sub-national (regional and local) systems and pan-national (continental and international) systems recognise that innovation is not distributed in a homogenous manner within and beyond national borders. Alfred Marshall's analysis of 'industrial districts' in the late nineteenth and early twentieth centuries was perhaps the first to show that local or 'regional agglomerations' were hot spots for innovative activity (Marshall 1948). Examples of regional agglomerations include Silicon Valley in California and Route 128 in Greater Boston studied by Saxenian (1994), and of particular interest to Cooke and Morgan (1994), Baden-Württemberg in South

Germany, and Emilia-Rimagna in Northern Italy. Research directed at understanding the importance of the 'spatial context of industrial innovation' led to the development of theories including 'the creative milieu', 'industrial districts', 'territorial production systems' and 'regional innovation networks,' (Saxenian 1994, Cooke and Morgan 1994, Camagni 1991, Scott 1988, Pyke et al. 1990).

A useful discussion of the innovation systems in terms of the 'view from above' (globalising innovation systems) and 'view from below' (micro-level innovation systems such as small firms and industry clusters) can be found in, *Evolutionary Economics and the New International Political Economy* (de la Mothe and Paquet 1996).

3.5.4 Technological systems

The more recently developed 'technological systems' (TS) approach features systems of innovation specific to particular technology fields and, in some instances, technology-specific industries.[53] The TS approach highlights 'dynamic knowledge flows' and 'competence networks' among agents (Carlsson and Stankiewicz 1991, Carlsson and Jacobsson 1997:268).[54]

The TS approach places a greater emphasis on the utilisation and diffusion of technology, or microeconomic aspects of these factors, as opposed to the creation of new technology. In this way TS helped to design policy instruments that create systemic conditions and processes that breed winning firms as opposed to 'picking winners' (Carlsson and Jacobsson 1997).

> The creation of a new technology pushes out the production possibility frontier or opportunity set. But it cannot be simply assumed that just because a technology exists, it is also known and used effectively. Unless the expanded opportunity set is converted into economic activity, ie unless it results in entrepreneurial activity, it has no economic impact. (Carlsson 1994)

This approach also highlights economic knowledge in innovation systems. A factor called 'economic or business competence' is said to be present when a technology system has, 'the ability to identify, expand and exploit business opportunities,' where those business opportunities arise from the effective use of new technology (Carlsson and Stankiewicz 1991, Carlsson 1994). Furthermore, Carlsson says that:

> 'economic competence must be present in sufficient quantity and quality on the part of all relevant economic agents, users as well as suppliers, government agents, etc. in order for the technological system to function well.' (Carlsson 1994:15)

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[53] It developed from a five year Swedish 'Technological Systems and Future Development Potential' research program, led by Bo Carlsson (Carlsson and Stankiewicz 1995, Carlsson and Jacobsson 1997). The program aimed to develop a theoretical framework based upon empirical studies of four technology systems: factory automation, electronics and computers, pharmaceuticals (particularly biotechnology) and powder technology.

[54] For more on the role of interactivity from the TS perspective see Appendix 3.3.

3.5.5 Sectoral systems

As the scope of the SIS approach is vast, a discussion of the scope and shortcomings of this approach is beyond the realms of this thesis. The comments made here serve only to point out some features of this approach.

Sectoral innovation systems (SIS) first appeared in the mid-1990s, including the work of Malerba in collaboration with Orsenigo and Breschi (Breschi and Malerba 1997). According to Malerba's perspective of SIS, the approach 'relates to relevant intellectual and theoretical traditions' (Malerba 2002:249). Evolutionary theory of technological change (Nelson and Winter 1982), for example, is used in the SIS approach to not only link change in 'knowledge and learning processes' with agents' heterogeneity in experience, competencies and organisations, but also to explain the evolution of cognitive dimensions of knowledge and learning processes, including beliefs and expectations. SIS also relates to three other theoretical 'traditions': existence of technological regimes[55] (Dosi 1982, Dosi et al. 1992b); Schumpeterian (Mark I & II) patterns of change among innovators; and industry life cycle theories ('development blocks')[56] that relate to SIS boundaries, links and interrelations with other sectors.

Malerba (2002) broadly defines his approach to SIS in the following way:

> A sectoral system of innovation and production is a set of new and established products for specific uses and the set of agents carrying out *market* and *non-market* interactions for the creation, production and sale of those products. Sectoral systems have a *knowledge base*, *technologies*, *inputs* and *demand*. The agents are *individuals and organisations* at various levels of aggregation, with specific learning processes, competencies, organisational structure, beliefs, objectives and behaviours. They interact through processes of communication, exchange, cooperation, competition and command, and their interactions are shaped by *institutions*. A sectoral system undergoes processes of change and transformation through the co-evolution of its various elements. (Malerba 2002:248).

The analytical focus of Malerba's approach to SIS covers five broad 'dimensions':

- knowledge base and learning processes;
- actors and market/non-market interactions;
- capital/financial structure and demand;
- institutions; and
- evolutionary processes of variety generation and selection environment (Malerba 2002).

Application of the SIS approach depends on an understanding of the impact of technological change in particular industry sectors based upon detailed empirical evidence. A vast number of heterogeneous case studies of sectors exist. These usually focus upon a single dimension of technological innovation (such as technological strategy in pharmaceutical start-up companies),

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[55] Technological Regime (TR) refers to technology specific factors that influence the nature and intensity of competition, technology selection processes, the structure of innovative activities and dynamics in the population of innovators (Breschi and Malerba 1997).

[56] For examples of studies in this area see (Malerba and Orsenigo 1995, Malerba and Orsenigo 1996, Breschi et al. 2000, Cefis and Orsenigo 2001, McKelvey and Orsenigo 2001).

and answer different research questions. However, for some industry sectors, such as pharmaceuticals, such studies have accumulated a sector-specific, general body of understanding. More detailed studies of specific sectors has shown that their technological regimes (technology entry and innovative turbulence) are mostly invariant across countries, but that national-specific institutions affect the performance of specific industry sectors (that is, when the same industry sector with the same technological regime is present in different countries) (McKelvey and Orsenigo 2001, Breschi and Malerba 1997, Malerba 2002).

Recent writings on SIS note that currently ill-researched issues are the *emergence* of sectoral institutions, as well as the *relationship* between *national* and *sectoral systems*.

3.6 The IS approach – its application

The way in which the IS conceptual framework might be used in studies of innovation is directly related to a research program's objectives as well as its subject for investigation. The IS appraoch can act as both an important pooling device and as an heuristic in studies of technological innovation. In this manner the IS approach guides the collection of emprical evidence and 'teaches' about how a particular example of technological innovation might be best understood as an innovation system. This approach also provides a 'bridging mechanism' uniting multiple sources of relevant evidence from different fields of study (including from other IS approaches) and the broad pool of 'theoretical and intellectual traditions' of technological innovation to allow more effective study and understanding of one or more aspects of the heterogeneous facets of technological innovation.

IS approaches can not be 'applied' to make ex-ante predictions[57] about the elements contained in a system of innovation. In other words, it is not possible to select a specific IS approach (based upon selected principles and evidence of persistent invarience in technological innovation performance) and automatically have a testable 'system archetype' which identifies the elements to include in a system (Montobbio 2001).

For a particular study of innovation, the degree of choice available among individual IS approaches is constrained by the degree of previous understanding and existing emprirical evidence. Use of a SIS (and TS), for example, requires substantial detailed data for its (their) implementation. Logically, it would not be possible to study the Australian minerals industry from a TS or SIS perspective alone, when the fundamentals concerning the role of innovation in this industry have not been determined (that is, what is the role of technological innovation in terms of the minerals industry's competitive dynamics?). Nor would it make sense to use a single IS approach in terms of this study's objectives. Thus, this is not a study of minerals innovation as a SIS, rather there is an intersection between the national and sectoral IS

[57] Archibugi et. al, note the lack of predictive power of innovation systems and suggest an alternative 'bottom-up' perspective (of how national/sectoral systems of innovation may condition and influence the innovation decision making and behaviour of firms) as a better way to determine what elements are of importance in an IS (Archibugi et al 1999:8).

approaches. Unlike purely sectoral studies, this study seeks to situate minerals innovation within a national context. Emphasis is placed upon gaining an understanding of how the MinIS might be influenced by the 'fragile' nature of Australia's NIS.

3.6.1 Using an IS approach to analyse an Australian minerals innovation system

In a broad and simplified sense, innovation systems are comprised of individuals and organisations (firm and non-firm), various sources of knowledge and knowledge bases, and the institutions (formal and informal) that influence interaction and relationships. In this study, the boundaries of the innovation system under investigation are outlined by its national standpoint and choice of industry. Deciding more precisely how to conduct an analysis of an Australian minerals innovation system has been guided by the literature: a sound understanding of innovation; a need to balance the conservative perspective of past studies (such as Gregory's (1993) review of Australia's NIS) with more broad views on innovation (such as, for example, those of Best (1990) and Lundvall (1992) who emphasise the social embeddedness of innovation); and contemporary understanding of innovation systems and the IS approach (for example, Montobbio (2001), Malerba (2002), Freeman (2002), McKelvey and Orsenigo (2001)).

This literature review has highlighted some of the salient features necessary for the identification of innovation systems. While many of the individual elements and factors necessary for successful IS superficially seem 'obvious,' the fact is that their *systemic* relationships and interactions, (that is, the dynamics of how they operate as a system), are complex and often not readily apparent. Common elements to be considered in this analysis of a minerals IS include, for example: firms (engaged in processes of technological innovation), universities, government research laboratories, other government agencies that support technological innovations, knowledge bases and technologies, systems of finance and law, a 'culture', and formal and informal institutions. This study of innovation becomes much more taxing when trying to understand systemic dynamics: how various types and combinations of elements/systems interact (market and non-market forms which take place both internally and externally) during processes of technological innovation, as well as how interactions might be enabled or inhibited due to the characteristics of the institutions, infrastructure, capabilities and past experience within the system. This is why an IS framework with three levels of analysis has been developed to analyse the MinIS, as illustrated in Table 3.14.

Table 3.14: The IS framework developed to analyse a MinIS

Lens	Analysis of MinIS
Historical	Use of long-term view to help explain present day realities
Nature	Use of trends & characteristics view of innovation to identify sector specific features
Systemic relationships & interactions	Use of systemic relationships view to unravel dynamics and structure

The framework (detailed in Chapter 2) reflects the literature in the following manner. Little is known about the role of a MinIS during the course of the minerals industry's history in Australia and to what degree the long-term duration of this industry is related to successful technological innovation. A long-term view may reveal social/cognitive and historical/path-dependent factors that influence innovative performance and economic advancement (see Section 3.4.4 in particular). For the second level of analysis the IS approach is used as an heuristic to guide the collection of basic empirical data on the nature of innovation in the minerals industry. This is because studies of IS require a general body of understanding of the impact of technological change and role of innovation in industry sectors (that is, baked by detailed empirical evidence). In the final level of analysis, attention is placed upon how a MinIS 'works' and the extent to which interactivity and institutions enable or disable innovation. Firms do not innovate in isolation, and those that are dependent upon technological innovation for their competitiveness are distinguished by their knowledge-based relationships. A theme throughout this review of the literature has highlighted the importance of interactivity, at all levels and among all actors. Furthermore, interfirm relationships delineate the 'structure' of an innovation system, within which a resulting pattern of innovation-derived growth is described as one of continuous learning, accumulation of capabilities, and change to knowledge bases.

3.6.2 Actors to be included in analysis of an Australian minerals innovation system

As previously stated, identifying key actors within an innovation system is relatively straightforward. Constituents have roles that differ in importance depending upon the particulars of an IS (national/regional, industry/sectoral, or technology/related-technologies) and the level at which elements in an IS are aggregated. Patel and Pavitt (1994), for example, describe four sets of actors that are characteristic, central features of all national systems of innovation:

> 1) *business* firms, especially those investing in change-generating activities;
> 2) *universities* and similar organisations, providing basic research and related training;
> 3) a mixture of *public* and *private organisations*, providing general education and vocational training;
> 4) *governments*, financing and performing a variety of activities that both promote and regulate technical change (Patel and Pavitt 1994a).[58]

Table 3.15 presents the actors to be included in this analysis of a MinIS. Much has already been discussed in regard to their role (division of labour[59]) in innovative activities. What follows is a short summary of features and general assumptions of such central actors in innovation systems.

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[58] In this quote the term 'institution' has been replaced with 'organisation' in keeping with this thesis' interpretation of these terms (see Section 3.4.7).

[59] Most fundamental R&D, for example, is carried out by public organisations including universities and research institutes. The diffusion of product and process innovations primarily occurs through firms.

Firms and other private sector organisations

The most important point to make in relation to the role of firms in national innovation systems is that 'strong firms' are essential for effective innovative performance. It is not possible for government-sponsored R&D to be a substitute for R&D conducted in the private sector (Nelson and Rosenberg 1993) (for more on innovation and firms see Section 3.4.8).

Other organisations in the private sector that are important in innovation systems, particularly for supporting levels of connectivity, include, research brokers/managers, industry associations and professional and scientific societies. The technological innovation literature clearly shows that cooperation and interaction among firms (as well as among firms and non-firm organisations) is a *necessary supplement* to competition. The process of technological development and successful innovation, by definition, takes place among firms acting as users and suppliers of technological innovations.

When addressing what is required for successful and prolonged economic growth in innovation systems, Carlsson (1994) notes that only one or a few competent actors (firms and non-firms) cannot sustain a system. Rather, *diversity* is required, with a variety of actors, each with their own unique or specific competence (Carlsson and Jacobsson 1994, Carlsson 1994). Furthermore, an innovation system with a diversity of actors will not function to its full capacity unless the actors interact and *collaborate* by fashioning clusters or networks.

The financial system

The system that finances innovation is critical for the long-term stability of an innovation system.[60] Financial systems are, in general, divided into two broad categories: *bank based* (with high degree of government investment) like those of Germany, Italy, France and Japan; and *market oriented systems* of the Anglo-Saxon countries, the US and UK, that have a financial system based on stock exchanges (Montobbio 2001). Each of these systems has advantages and disadvantages in relation to innovation. In simple and brief terms, the role of shareholders in Anglo-Saxon financial systems tends to form short-termism in investment but a greater variety of venture capital for high-risk, new developments (*ibid*). Thus, in Anglo-Saxon countries such as Australia, UK, US, Canada and NZ, venture capital firms support innovative activities (Niosi 2000).

However, where new knowledge bases are being exploited (ie in the transfer sciences), there tends to be very close interaction between public and private sector organisations (as discussed in Section 3.4.1).

[60] The vast literature on economic systems is outside the scope of this literature review. The economic aspects of technological innovation and innovation systems has tended not to be addressed in an explicit manner (Malerba 2002).

Table 3.15: A simplified overview of the activities of actors in innovation systems

Actors	Technological innovation activities (what they do)	Outputs (results)	Measurements (of success)	Source of funding
Firms with research capabilities	• New technology: – development – utilisation & – diffusion • Training • Entrepreneurship • Build links to knowledge base(s): – many forms of collaboration • Build dynamic absorptive capacity	• New (or improved) products, processes & services: – intermediary products eg pilot plants, prototypes, blueprints • Capacity to innovate • Improved competitiveness: – intermediary products eg operating manuals – managers with innovation experience – skilled manpower	• Profits, shareholder value, market share • R&D expenditure, Patents, JVs, license agreements • Indicators of networks and interactivity (not well developed and difficult to measure)	• Retained earnings • Shareholders • Government grants • Venture capital • Loans • Institutional investment
Private research brokers	• Identify and manage collaborative research projects (no internal research facilities)	• Results of those projects • New (or extended) research projects • Networks	• Dollars & in kind investment • Projects, firms involved •IP	• Firms (principally)
Universities	• Basic research • Applied research • Training • Consulting • Collaborative research	• New knowledge, knowledge bases & ideas • Educated workforce • Skilled personnel • Transfer sciences	• Publications, patents • Spin-off companies • Private investment • Graduates	• Government funds & competitive grants • Philanthropy • Firms • Internals revenue raising • IP
Government laboratories	• Mission oriented or national objective-based R&D eg environmental, health and defense • Applied R&D	• Improved processes, products & services: – Intermediary products eg prototypes, pilot plants, algorithms – Incremental & radical development	• Patents, publications, • Collaborative agreements, JV, contract research • Spin-off companies	• Government (principally) • Firms • Exploitation of IP
Gov tech development agencies	• Facilitate public-private collaboration • Network generation & support	• Organised market system • Improved knowledge flows	• Collaborative agreements	• Government
Government regulatory agencies	• IP laws • Standards • Procurement	• Organised market system	• Level of interactivity in system	• Government
Government technology policy	• New policy initiatives • Managing existing policies	• Stimulate private R&D • Increase diversity of industry base • Promote diffusion • Early entry emerging technologies • Strategic trade in new technology	• BERD, GERD & other input measures • National levels patents, publications • Growth new knowledge-based industry • Networks • Economic performance	• Government

N.B. Table 3.14 is adapted from Niosi's introduction in (Niosi 2001)

Government

Governments are important elements in IS, whether at a local, state or national level. They provide funding for R&D[61], are responsible for the training of scientific and technical personnel in particular and the broader population in general, establish formal and informal institutions (that is, the 'rules of the game' such as those relating to IP, standards, antitrust laws and so-forth), and articulate goals (Niosi and Bellon 1996). They also create national 'research agendas' by funding mission-directed research that is linked to national priorities in areas such as defence, health and the environment. Government agencies have differing degrees of participation in IS, although generally those most commonly involved are departments of education, science, industry, defence and communications (Niosi and Bellon 1996). Nations possess marked differences in the makeup and role of government agencies in IS, particularly in relation to the degree of interaction with the private sector. Some often quoted examples include Japan's Ministry of International Trade and Industry (MITI), which has played an active role in the transfer of foreign technologies, and the US Department of Defence's role as an 'engine' in public sector innovation in the United States. A discussion of Australia's NIS, and the role of government was given in Chapter 1, (Section 1.2).

In addition, Lundvall highlights the role of government as a *user* of technological innovations,

> ...it is involved in direct support of science and development, its regulations and standards influence rate and direction of innovation and is the single most important *user* of innovations developed in the private sector. (Lundvall 1992:14).

Governments and their policy instruments hold great influcence over *linkage formation* within an innovation system (Niosi 2000, Freemand & Soete 1997, Malerba 2002). First, the rules and regulations create the environment in which organisations operate (Lazonick 1991). Thus, government programs can foster cooperation in technological development, such as the EU's ESPRIT and EUREKA programs (whereas anti-trust laws, such as those in the US, can deter cooperation among firms). Second, according to Niosi (2001), the role of government in the form of markets is particularly pronounced when it comes to technological fields. This is due to governments funding around 40 to 50 per cent of each industrialised country's total R&D and the influence this has on institutional routines and missions. Private firms may, for example, change their internal routines to meet requirements attached to government-funded programs of research (Noisi 2000). Finally, governments have a critical role to play in the creation of new technological systems through the provision of funds, and coordination of an institutional framework (Niosi 2000, Carlsson and Jacobsson 1997, Malerba 2002).

The many public organisations with a role in innovation include: regulatory and standards agencies; research, education and training organisations (universities); research organisations (government laboratories); technology support agencies (extension and training or industry specific agencies); patent offices; and departments that formulate and implement policy. These organisations can be categorised according innovation-oriented activity: new knowledge production (universities); knowledge diffusion (science or technology parks); and knowledge regulation (patent offices and standard setting organisations, which contribute to the institutional environment for private organisations).

Education system and science-based laboratories
The education system and universities are very important elements in innovation systems because it is in their laboratories that research on 'pure' or 'basic' science is conducted, and it is here that production of skilled graduates (practitioners and engineers) takes place. Section 3.4.1, *The roles of science and technology*, highlighted the rise of science-based technologies and growing importance of R&D as one of the main vehicles driving present-day technological advance (Nelson 1988, Nelson and Rosenberg 1993, OECD 1992), as well as the related increasing importance of human resources. Thus there is an increasingly important role for education, training and research organisations in innovation systems (OECD 1996, OECD 1997, Freeman 1992, Nelson and Romer 1996).[62] There is much literature comparing different national education and training systems, engineering capabilities, and success of the innovative performance of firms and national economies.[63] According to Montobbio (2001), the role of universities in innovation processes is threefold:

1) they provide *general training* to influence skills and attitudes toward complexity and novelty;
2) they provide *engineers and scientists* with basic competencies and specialised training;
3) they conduct *basic and applied research* which is performed inside university laboratories (Montobbio 2001).

A national network of public and private sector education and training systems, national standards institutions, and national research institutes, as well as integrated scientific and technical societies, is now necessary to produce the pool of technically skilled and well qualified people required by industry (Freeman 1992).

3.7 Summary

This literature review has covered a broad terrain, from early theories of innovation and economic growth, models of innovation, central theories and intellectual traditions, to the complexities of innovation systems and application of the IS approach. It provides a foundation upon which this study's analytical framework is based, and guides the interpretation of research findings in the rest of this thesis. This chapter has sought to define a language of innovation, one which avoids confusion over terminology and concepts. Ultimately, the literature review helps to avoid becoming overwhelmed by the heterogeneous nature of this topic (that is, the dynamic, multi-dimensional realities of innovation systems), while concurrently maintaining a

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[61] The debate on public investment in R&D and problems when measuring such returns is given in Appendix 3.4.
[62] For a review of Australia's capabilities in this area see (Batterham 2000).
[63] From examples of engineering capabilities and national economies see: British (Walker 1993, Freeman and Soete 1997); the US, (Nelson 1990a) Germany (Beise and Stahl 1999, Meyer-Krahmer 1998, Weigand 1999)& Japan (Freeman 1988, Sato 1993, Branscomb et al. 1999).

focus on the key facets relevant to the existence and performance of an MinIS within its Australian context.

In case study research, reference to the literature proceeds in a continuing and iterative fashion. Recent developments to the IS approach augment the need for this process as new and existing ways of understanding innovation systems evolve and improve. Indeed, this investigation of a MinIS is a novel approach since it is primarily an exploration of the role of innovation in an industry sector (that is, a study of a sectoral innovation system). It is strongly influenced by a national standpoint and research on national systems of innovation.

The literature review is vital for the successful identification and analysis of a MinIS conducted in the remainder of this thesis because it informs what information needs to be collected and guides its subsequent analysis. The next four chapters are linked to this bank of literature through their analytical themes. Chapter 4 leads from the definition of innovation (in Section 3.2) which notes that innovation involves tangible, market-valued outcomes. It is necessary, therefore, to know of the competitive dynamics of the minerals industry (particularly as this industry does not compete upon product innovation) in order to assess whether innovation has contributed to the industry's success. Chapters 5, 6 and 7 relate to the literature through their respective analytical perspectives on innovation: the long-term view; the nature of innovation in the industry; and systemic interactivity and relationships among components. Finally, this investment in an extensive literature review comes to fruition as these analytical themes converge and conclusions are made in Chapter 8.

References Chapter 3

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Chapter 4:

The Australian minerals industry – competitive dynamics

4.1 Introduction

Recent studies have begun to reassess the minerals industry from a perspective that this industry is not one facing imminent decline due to exhaustion of raw materials, decrease in demand or substitution with synthetic materials (Simpson 1999b, Tilton and Landsberg 1999, Tilton 2001, Peterson et al. 2001, David and Wright 1997). The price increases for metals, that were once heralded as the inevitable consequence of depletion, have been offset by successful innovation: the implementation of advances in technology to all aspects of the industry's activities (Simpson 1999b, Batterham 1999, Tilton 2001). Innovation has been behind dramatic productivity improvements in workers and equipment. For example, minerals industry labour productivity (output per employee) in the US has almost tripled since World War II (Parry 1999). A new perspective, therefore, sees falling prices as the result of improvement through successful innovation (Section 4.4). In other words, to some extent the minerals industry has become a victim of its own innovation-based success.

Australia, along with other developed economies such as those of Norway and Canada, are dependent upon export revenues created from their mineral resources (Ala-Härkönen 1997). An overtly negative connotation is associated with minerals and economic development, with some having views that a rich minerals endowment is a 'resource curse' as nations lacking such endowments, and of similar size and economic development, were found to perform better in terms of per capita economic growth (World Bank 1994, Davis 1995). While many of these arguments are unfounded,[64] most analyses of the minerals industry and economic growth are conducted using traditional neoclassical or mineral-economy case study frameworks which do not consider benefits derived from minerals innovation.[65] The use of the IS approach by this study is an alternative to the extensive economic literature on Australia's minerals industry (Industry Commission 1991, Barnett 1988, McKern 1988, McColl 1984, Prime Ministers Science Council 1991, Ranford et al. 1998, Reid 1991, United Nations 1994).

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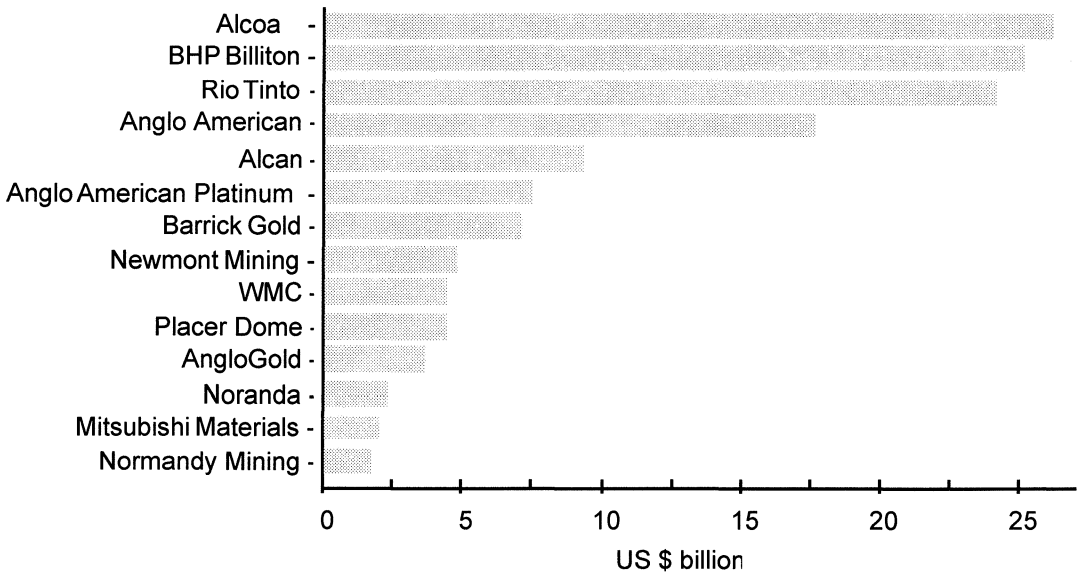
[64] The considerable literature on minerals economics is beyond the scope of this thesis. For a critical rebuttal of 'the resource curse thesis' refer to (Davis 1995).
[65] See Chapter 3 for limitations of neo-classical economics when studying innovation.

This Chapter begins with an introduction to some general features of the global minerals industry, including current changes in its competitive environment driven by the combined pressures of low commodity prices, increasing rates of globalisation, and the knowledge economy. Characteristics of the Australian minerals industry are then addressed. The findings from these introductory sections highlight the complexity of the industry in both the international and Australian contexts. Having outlined the complex nature of the industry and its mode of competition, the Chapter then focuses on an issue central to this study, specifically, the degree to which innovation is a source of competitiveness in the minerals industry. The remainder of the Chapter reviews some general features of minerals innovation and highlights the limitations and failings associated with traditional linear measures of innovation and narrow definitions of the minerals industry. Data on the scale and direction of innovative effort in the minerals industry is also presented.

4.2 World trends in competitive dynamics

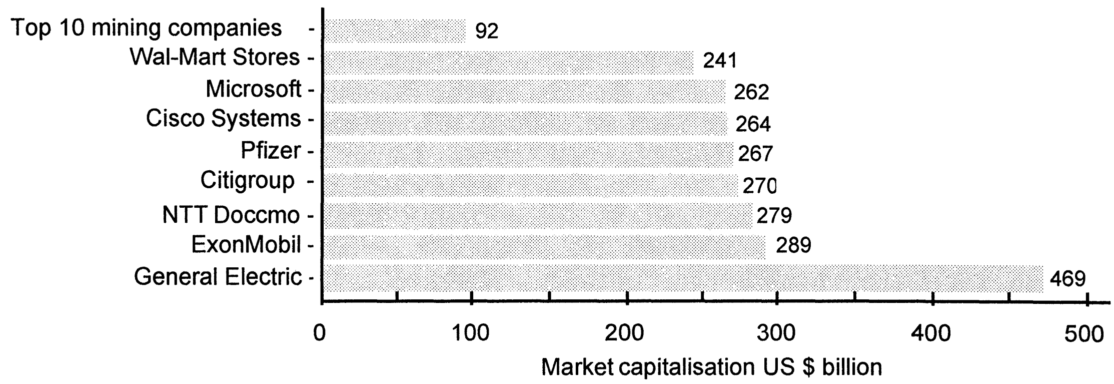
Although the larger minerals companies operate on a massive scale, on a market capitalisation basis they considerably smaller than the giants. Alcoa, for example, even though it has the highest market capitalisation in the industry, has only one-tenth the market capitalisation of Wal-Mart Stores. Figures 4.1 and 4.2 put this into perspective. The ten top minerals companies combined have a market capitalisation that is less than half that of Wal-Mart.

Figure 4.1. Market capitalisation in the mining sector, September 2001.



Source: (MMSD Project 2002)

Figure 4.2 Minerals industry capitalisation versus other sectors.



Source: World Bank, July 2000 figures (sourced from (MMSD Project 2002))

4.2.1 Industry structure – activities and investment

The processes collectively known as mining can be separated into three major activities that relate to the physical handling of ore: *exploration* – locating an ore-body; *extraction* – removing it from the ground; and *processing* – isolating and producing the metal. An over-riding knowledge-based activity, *mine planning* (which includes financial assessment and review of new developments, together with environmental assessment), is another important component of mining, but is not covered in this study's exploration of minerals innovation. Some of the large mining companies, such as Rio Tinto, have developed a strategic competitive advantage based upon their finance-based acquisition and planning capabilities, as opposed to the more traditional strategic emphasis upon internal growth through constant capacity expansion and productivity improvement. In the current industry environment, more companies are adopting the strategies and core skills typical of *minerals finance houses*, as opposed to minerals production-based firms (Ala-Härkönen 1997). The effect of this shift in technological innovation strategy is discussed in Chapter 7.

> RTZ is an extremely experienced mining finance house equipped with thorough understanding of worldwide mineral markets. We carry excellent technical capabilities in the fields of mine development, project mangement and oversight, and also from the funding of world-class mining operations in different parts of the world.[66] (Ala-Härkönen 1997:98)

The nature of ore bodies dictate methods of exploration, mining, processing, refinement and end usage. Different types of mining include underground methods (lead, zinc, coal, copper, nickel), superficial open-cut methods (iron ore, bauxite, coal, copper, nickel), alluvial mining (tin), sinking wells (petroleum) and surface evaporation (salt) (McKern 1988:2). The degree and complexity of processing also varies according to the type of mineral and the nature of its deposition. While some, such as coal, phosphate and rich grades of iron ore need little treatment, most requiring several processing stages. Other obligatory steps for the production

[66] Comments made by Phillip Crowson, then Head of RTZ's Economics Department, when evaluating RTZ's core competence in November, 1992 and prior to its merger with its Australian subsidiary CRA Ltd in 1995.

of a concentrated final product include concentration (lead, zinc, tin, copper, nickel), refining (bauxite, nickel), and smelting (aluminium, lead, zinc, copper, nickel and tin) (*ibid*).

As are all natural resource industries, the minerals industry is capital intensive. According to Crowson, 'A mine is an assemblage of dedicated capital, equipment and labour to exploit a specific ore deposit,' (Crowson 2001). Prior to the decision to invest in a particular deposit, substantial initial capital costs are incurred, including exploration or acquisition, as well as costs involved with accessing the ore and preparation for production. Substantial capital investments then follow in the mine and associated processing facilities (concentrators, smelters, refineries), as well as transportation infrastructure from the often distant mine location to markets. Other infrastructure investments include access to water supply, power, communications, and accommodation. A more recent and growing area of expenditure is environmental management and meeting regulatory commitments and industry codes of practice (Hooke 2002, Peterson et al. 2001). These days it may take a decade to develop a large deposit, and a company will usually remain committed to its original processes and techniques until the initial investment has been written off and this often takes some twenty years (an exception being small-scale and fast payback operations most common in the gold industry) (Crowson 2001).

The primary source of investment funds for the minerals industry is the privately raised capital of minerals companies. Access to capital is increasingly difficult for the global minerals industry, particularly during economic downturns. During the mid 1980s, conditions were so depressed for the US copper industry that *Business Week* ran a cover story declaring the death of mining in the US, whereas some 15 years earlier the US was the world's largest producer of copper (Tilton and Landsberg 1999). Most recently, the minerals industry's access to capital was squeezed during the high-technology dot.com boom. Planned projects were stalled and many Australian gold exploration firms switched industries and became dot.coms themselves.

The organisational structure of minerals operations is extremely complex since many activities other than those related to core competencies are employed. In his book, *Intelligent Enterprise*, James Brian Quinn uses the Australian mining industry as an example of:

> enterprises which outsource—or partner—many important elements of their value chains with others who can find, assay, drill or cut, transport, process, or distribute in specific regions more effectively than they can (Quinn 1992:40).

Whilst this pattern still holds for the majority of companies, others, like Normandy and Hamersley Iron, are re-integrating some previously out-sourced mining activities in circumstances where long-life ore bodies make a capital investment in mining equipment economically viable.

4.2.2 Factors influencing competition in the minerals industry

During their long lifetime, mine developments exist in a dynamic, competitive environment. A developed mine with its associated processing facilities has a competitive advantage based primarily upon the richness of the deposit, as well as other factors, including potential for production of by-products, labour costs, energy costs and so forth. The potential economic returns, however, may be eroded by the discovery and development of richer pay-loads which may lower prices unless demand is great enough to meet increased supply. Innovations in processing can have the same effect. For example, the development of high-pressure leaching of lateritic orebodies has the potential to revive the Australian nickel industry by opening up previously uneconomic nickel deposits. Additionally, new mine developments may have the advantage of implementing improved processes and equipment that embody technological advancements (see the Block Caving subunit in Chapter 7) and/or advantages from an increase in the scale of operations from start-up. Thus, mine developments must continuously improve their performance to avoid progressing up the cost curve to a position of marginal or un-viability.

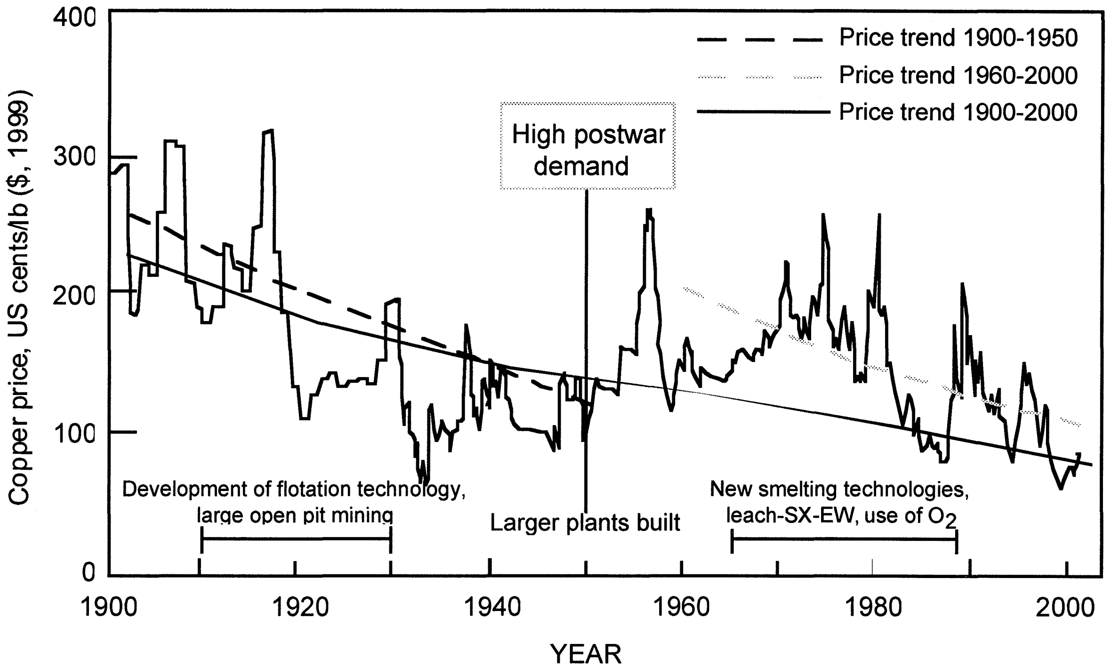
The cyclical nature of the minerals industry must also be accounted for during the life of an operation. Against a backdrop of price decline, major price peaks occurred for base metals in 1966, 1969, 1974, 1979 and 1989 (Ala-Härkönen 1997). Most deposits have more than one 'payable element', which allows for some manoeuvrability as the ratios between the values of a mine's constituents fluctuate. Financial tools, such as hedging, may also be used to deal with cyclical prices. However, as demonstrated by the recent collapse of Pasminco brought about through hedging, such strategies can be high risk.

Issues of supply and demand

> The physical quantites of natural resources produced and sold are enormous.
> (Simpson 1999b:1)

All natural resource industries are essential. The global minerals industry extracts some 25 billion tonnes of raw materials and contributes over 5 per cent to global GDP each year (Journal 1999). Products provided by the minerals industry are used for the simplest building materials through to the most sophisticated technological devices, as well as in a plethora of other manufactured goods. In spite of the their ubiquity of use, the prices of mineral resources remain modest. From the first decade of the twentieth century until the second World War, commodity prices displayed a downward trend (Freebairn 1987). Most mineral prices did not fluctuate significantly in the immediate post-war period, and apart from increases in the mid 1970s and late 1980s, prices have continued to decline (Freebairn 1987, Industry Commission 1991). In fact, real prices continue to decline at a rate of 2 per cent per annum, even as the most easily accessible and treatable ore deposits have (over time) been depleted. Figure 4.3 demonstrates the downward trend in copper prices and highlights the significant price drops that accompany introduction of radical innovations in copper processing. The combined impact of such factors has led to an inevitable focus on economies of scale, productivity and *ipso facto*, to bigger more efficient equipment and higher levels of automation. In the 1960s, for example, the average size of an open pit haul truck was 50 tonnes: it is now 170 tonnes, and 240 tonnes is not extraordinary.

Figure 4.3: Downward trend for copper price over 100 years (in constant US$).



Data supplied by P. MacKey (Noranda Inc)

Certainly, prices have not been inflated due to exhaustion of the world's resources as was predicted in popular texts, including *The Limits to Growth*[67], and by the Club of Rome reports during the 1970s. In fact, a lack of pricing power is driving a rapid pace of consolidation of ownership and globalisation of operations across the industry. Table 1.2 illustrates the concentration of production since 1995 among the world's largest minerals companies as they globalise their operations. A clear strategy during this time has been to prioritise growth from financial management capabilities, primarily through mergers and acquisitions, and associated access to new sources of capital, such as from fund managers that work from a minimum investment scale of $50 million (for future development) (Durie 2002).

Another external economic factor placing pressure on the industry is a low inflation environment. When inflation is high, price increases tend to compensate for unprofitable decisions. In a low inflation environment it becomes very difficult, if not impossible, for managers to keep within expenditure margins, resulting in a greater insistence upon cost control and reduction in expenditure. While the industry does have the capacity to think in the long-term, as demonstrated by the fact that it my take 15-20 years to develop a mine, the pressure of low inflation tends to foster decision making and investment for the short term (Kjar 1997). In particular, the industry's attitude to investment in R&D and exploration is adversely effected by this situation, as projects which do not have immediate returns tend to be aborted (*ibid*).

More recent changes to the global political environment have opened up new prospective regions of the world, such as in the ex-Soviet Union and various countries in South America, Africa and Asia. Such regions are often eager to encourage development and offer generous tax, royalty and infrastructure development incentives. In 1999-2000, Australian companies were expending 36 per cent of their exploration funding overseas. In previous years this figure averaged 44 per cent (Minerals Council of Australia 2000) (the increase in exploration expenditure overseas by Australian companies is noted below).

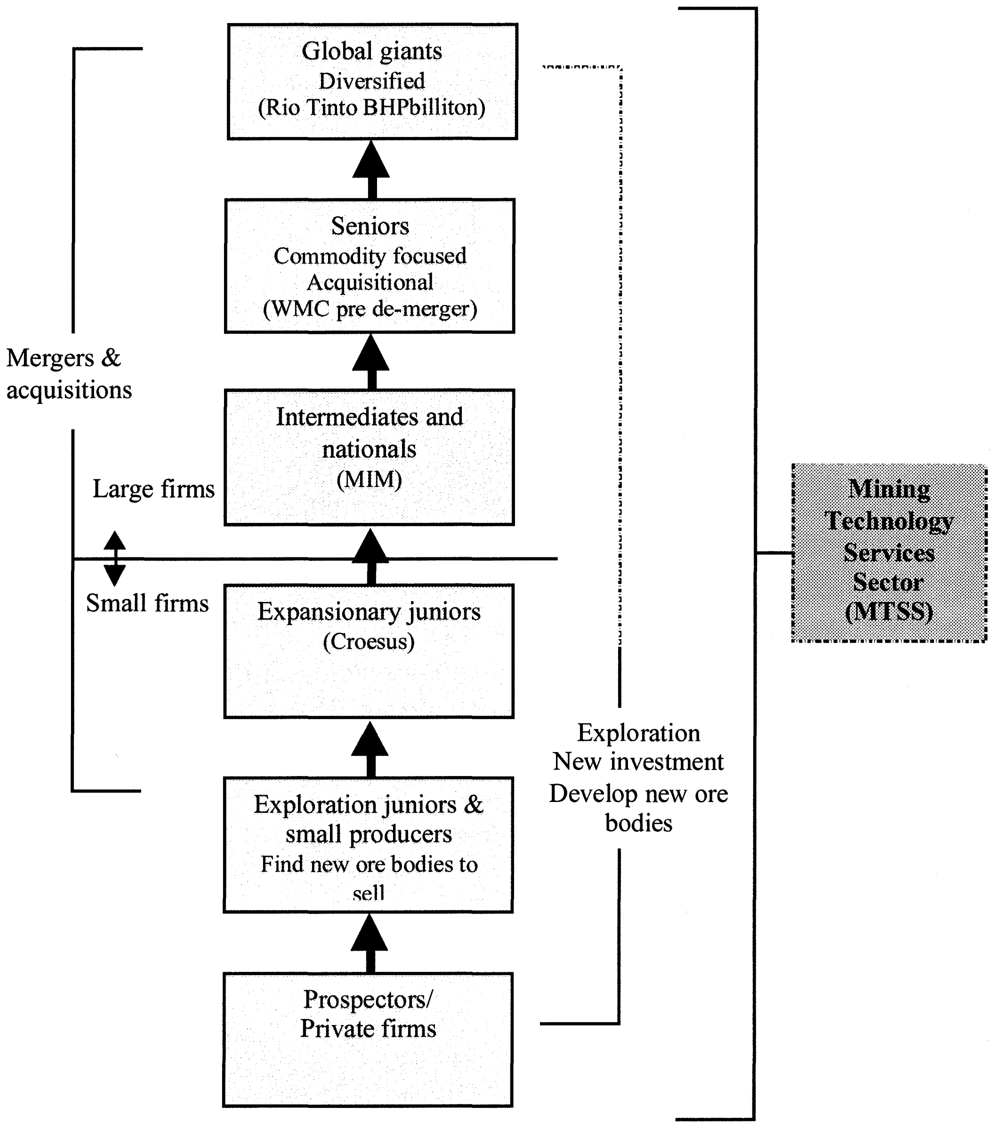
4.3 Details on Australia's minerals industry

As noted in Chapter 1, the Australian minerals industry is increasingly globally integrated, forcing it to be internationally competitive and export-oriented. It is a mature and diversified industry with large firms whose activities are 'world scale' (Sheehan 2000). Figure 4.4 is a representation of the current situation in the Australian minerals industry in terms of types of activities and relationships between players in the industry.

The Australian minerals industry has not been isolated from the competitive pressures of globalisation and the knowledge economy. It has always possessed a global perspective due to its historical reliance upon international sales of its products. Over the past five years, however, global competitive pressures have clearly translated into the Australian context. Since this study began there have been many mergers and acquisitions within the Australian minerals industry. For example, North Ltd was acquired by Rio Tinto (ERA, which holds the Jabiluka and Ranger uranium mines, is now part of Rio Tinto), Normandy Gold was acquired by US company Newmont, and BHP merged with Billiton. Even Croesus Gold, included in this study as an example of a small gold miner, acquired WMC's holdings in Central Norseman Gold Corporation and, following the departure of Normandy, is now the third biggest Australian gold mining company. WMC is currently in the process of a demerger, separating its 40 per cent holding in Alcoa Australia into Alumina Limited, and the remaining copper-uranium, nickel, fertilisers and development projects into WMC Resources Ltd.

[67] A comprehensive critique of *The Limits to Growth* (Meadows et al. 1972) may be found in (Cole et al. 1973).

Figure 4.4: Schematic representation of types of minerals firms in Australia.



4.3.1 The Resource Base

Australia is one of the world's leading mineral resources nations and the world's largest producer of bauxite and alumina (37.8 per cent estimated world production), diamonds (37.1 per cent), lead (18.3 per cent), tantalum (73.4 per cent), and mineral sands – ilmenite (34 per cent), rutile (45.9 per cent) and zircon (55.4 per cent) (Australian Bureau of Statistics 1999). The world's largest lead-zinc-silver deposit, estimated to be worth $75 billion, is located west of Broken Hill, while the Mount Isa/Cloncurry Belt is one of the world's richest base metals provinces with reserves worth an estimated $194 billion. Australia also boasts the world's largest economically demonstrated resources (EDR)[68] of lead, mineral sands, silver, tantalum, uranium and zinc (AGSO 2000). In 1999, Australia's EDR of bauxite, diamonds, gold, iron ore, manganese ore, magnesite, mineral sands (ilmenite, rutile and zircon), nickel, phosphate rock and tantalum rose, while its EDR for copper, lead, lithium, silver, uranium and zinc decreased. The latter reductions were primarily due to high levels of production, with low commodity prices being a subsidiary factor (*ibid*).

4.3.2 Contributions to the economy

Around 90 per cent of Australian mineral production is exported directly or indirectly, with exports are projected to rise to as high as $45 billion in 2001-2002 (AMIRA International 2002). The minerals industry contributes directly to government revenue through mineral royalties, rail and port charges, and various forms of taxation. In 1999-2000 total government revenue from the minerals industry (including taxes levied on lenders and shareholders) totalled $4.8 billion (Minerals Council of Australia 2000). Export earnings derived from mineral resources rose by 13 per cent (from the previous year) in 1997-98 to $41.2 billion, and fell to $39.2 billion in 1998-99 (ABARE 1999). Mineral and energy exports in 1997-98 represented 46 per cent of Australia's merchandise exports and 36 per cent of Australia's total exports and contributed $24 billion (4.3 per cent) to Australia's GDP (AMEC 1999).

Traditional measures of the minerals industry's contribution to Australian wealth rely on a narrow definition of the industry and its related activities (see Figure 4.5 and note). With a broader definition that includes directly related activities such as smelting, the wealth of the sector (as defined in Section 1.3) is estimated to be $654 billion, or 19 per cent of Australia's total non-financial assets (Stoeckel 1999). A similar trend of under estimation occurs when examining employment by the minerals industry. While this industry employs some 60,000 Australians directly, such direct employment figures fail to account for flow-on employment effects. These flow-on effects are very important. Direct employment in the industry is comparatively low, at 1 per cent of Australian employment (Australian Bureau of Statistics 1999). However, it is estimated that each direct employee generates another 3.5 jobs elsewhere in the Australian economy (AMEC 1999). Another estimate suggests that there may be 6 times the number of direct employees working on mining operations, and as many as 10 times more employed in the area of auxiliary services to mining-related industries (Broome 1999). Debates on direct employment also overlook the increase in labour productivity that accompanies the trend in declining employment (see Table 4.1).

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[68] An EDR classification indicates minerals resources for which profitable extraction or production is possible. An EDR has a high degree of certainty with regard to its size and quality. Importantly, the EDR of a country or company may change if new technology and innovation allow previously uneconomic or unworkable deposits to be treated. The term is mostly used for international comparisons of economic resources with other countries and replaces the term 'reserves'.

Figure 4.5: Australian and New Zealand Standard Industrial Classification – separation of minerals industry activities.

MINERAL RESOURCES INDUSTRY
ANZSIC divisions

MINING

Subdivisions
- Mining
- Oil and gas extraction
- Metal ore mining
- Construction material mining
- Services to mining

MANUFACTURING

Classes
- Petroleum refining
- Basic iron & steel manufacturing
- Alumina production
- Aluminium smelting
- Copper, silver, lead, zinc smelting & refining
- Basic non-ferrous metal manufacturing not elsewhere classified

A note on limitations of ANZIC codes

The ANZIC industry codes are favoured for use by Government departments (such as the ABS) that report on the Australian industry and economic performance. These codes are troublesome for this study as they incorporate energy resource with minerals resources and do not account for activities conducted post-extraction. They also do not capture the spill-overs into the Australian economy from the industry's outsourced activities or the positive effects such conditions of demand have for the provision of services. Demand conditions for knowledge-based goods, services and skills are a vital component of IS and successful technological innovation (see Chapter 3). Thus the ANZIC code under represents the minerals industry on a number of levels. Thus, at a fundamental level the data on the Australian industry is not truly representative.

Table 4.2 illustrates the far greater average size of Australian mining firms in comparison with other Australian industry (Sheehan 2000). The average firm sales for all industries was $1.5 million in 1992-93, rising to $1.8 million in 1994-95. These figures overstate the contribution of the Australian minerals industry as ABS includes coal and energy (oil & gas) in its 'mining sector'. Even so, the scale of difference between the mining sector, including minerals companies, and the rest of Australian industry is vast. The minerals industry makes a special contribution to the Australian economy because it contains firms whose sales activities are relatively large-scale (*ibid*).

Table 4.1: Trends in labour productivity 1993-94 to 99-2000 by average annual growth rate (ANZIC)

Industry	percent
Agriculture, forestry and fishing	2.7
Mining	7.3
Manufacturing	2.8
Electricity, gas and water supply	6.7
Construction	1.0
Wholesale trade	6.0
Retail trade	1.9
Accommodation, cafes and restaurants	1.2
Transport and storage	2.4
Communication services	6.0
Finance and insurance	3.9
Health and community services	1.2
Cultural and recreational services	-0.5
All market sector industries	**3.0**

a Gross product per hour worked. (source: Australian System of National Accounts 2000-01).

Table 4.2: Average size of firm sales by Australian industry sectors (1992-93 to 1994-95)

Industry	1992-93 ($ million)	1993-94 ($ million)	1994-95 ($ million)
Mining	29.7 (67%)	23.2 (61%)	21.7 (55%)
Manufacturing	3.6	4.1	4.5
Construction	0.8	0.8	0.8
Wholesale trade	4.3	4.7	5.8
Retail trade	1.1	1.3	1.3
Transport & storage	1.4	1.3	1.3
Finance & insurance	1.1	1.2	1.1
Property & business services	0.6	0.5	0.5
Cultural & recreational services	0.8	1.0	1.3
Personal & other services	0.2	0.3	0.2
Accommodation, cafes & restaurants	0.6	0.6	1.0
Average for all industries	1.5	1.6	1.8

Source: (Sheehan 2000:2)
Note: Data from ABS 1995 Business Longitudinal Survey, Industry Commission (1997). Data includes all firms with exception of government sector, non-employing business and businesses in agriculture, communications, health, education and some other small service industries. Data represent a little more than half the economy in terms of GDP or the private non-agricultural sector.

Investment activity in the minerals industry tends to follow the cyclical nature of the industry. Since 1992-93 investment has been strong, but is expected to fall in coming years (Minerals Council of Australia 2000). In 1997-98 new capital expenditure in the industry rose to a record level (in real terms) of $11 billion, due in part to a number of major new processing and mining developments. These include BHP's $2.4 billion hot briquetted iron plant (HBI), Anaconda's $1 billion Murrin Murrin lateritic nickel project, Pasminco's $840 million Century zinc mine and Rio Tinto's $270 million Yandicoogina iron ore development (ABARE 1999). However, capital expenditure fell by 21 per cent to $8.7 billion in 1998-99, the first fall in six years (ABARE 1999, ABARE 2000). The Minerals Council of Australia warned in 2001 that many large projects are now complete and a lack of such projects on the horizon may cause a reduction in net capital expenditure in coming years (Minerals Council of Australia 2001).[69] Growth in fixed assets in mining has increased by 40 per cent since 1990, outperforming the 16 per cent increase in the manufacturing industry (Stoeckel 1999). Net expenditure on fixed and deferred assets fell by 27 per cent in 1999/2000, by 16 per cent in the mining sector and by around 50 per cent in the smelting and refining sector (Minerals Council of Australia 2000).

Expenditure on exploration

Exploration expenditure is commonly used as a measure of the industry's contribution to the economy. During the past decade, however, larger minerals firms have been reducing their exploration budgets and much exploration, including the development of new exploration technologies, is being conducted by small firms defined as 'Dedicated Exploration Companies' by this study (see Chapter 6). It is important that Australia's mineral investment climate remains competitive, as new prospective regions of the world provide an alternative location for exploration (See Table 4.3).

The Minerals Council of Australia's figures show that following rises every year since 1990/91, a decrease in the share of total Australian exploration expenditure directed towards overseas activities occurred in 1999-00, with large firms reporting a 50 per cent drop in funding for overseas exploration (Minerals Council of Australia 1999, Minerals Council of Australia 2000). Expenditure on exploration in Australia declined throughout the 1990s (apart from 1995-1997), and from 1998-99 expenditure has been below the ten year industry average, dropping by 21 per cent in 1998-99 and a further 26 per cent in 1999-00 (*ibid*). The Minerals Council found larger Australian minerals companies were spending 36 per cent of their exploration budgets overseas in 1999-00, a drop from the previous five year average of 44 per cent (Minerals Council of Australia 2000). Total exploration expenditure by all companies surveyed was $832 million and $534 million for the constant group[70] of respondents, in 1999-00. The Minerals Survey also quotes 'official data' which have a much broader coverage of the industry, that show that exploration expenditure by the industry falling by 21 per cent between 1997-98 and 1998-99.

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[69] Most recently, however, Rio Tinto announced it had financial backing to build a $400 million HIsmelt plant at Kwinana in Western Australia (Marsh 2002).

[70] Due to the variation in respondents each year the Minerals Council uses a smaller group of 'constant' companies (those who have consistently responded to the survey), in order to deliver more precise comparisons.

Table 4.3: Minerals Council of Australia's survey of exploration expenditure over six years – constant group

	1994-95	1995-96	1996-97	1997-98	1998-99	1999-2000	10 year average
				($ million)			
Australia	460.8	468.7	506.2	468.5	396.7	344	403
Overseas	285.8	319.1	381.5	384.1	333.1	190	252
Total Exploration	746.6	787.8	887.7	852.6	729.8	534	655
Overseas Percentage	38.28%	40.51%	42.98%	45.05%	45.64%	35.58%	38.47%
Net profit return (%) on average assets employed	3.0	5.4	1.7	1.0	1.9	2.0	3.6
Net profit return (%) on average shareholders' funds	5.3	9.2	2.9	1.8	3.7	4.0	6.7

Source: (Minerals Council of Australia 2000)

4.3.3 Service providers – the advent of an emerging high-tech & knowledge-based Australian industry

Rapid growth in the number of minerals-related service providers in Australia in the past decade has culminated in the identification of an emerging, high-technology and knowledge-based industry, the Mining Technology Services (MTS) sector. This sector encompasses capabilities and products relating to mining software and equipment, exploration assessment technology, scientific analysis, mineral processing technology, environmental services, and occupational health and safety (OHS) services. MTS are particularly involved in developing products and services for the following minerals-related activities: information and communication technologies (ICTs) for process optimisation; remote control and automation; operations and maintenance; and unit-operations capabilities (Peterson et al. 2001). Australian MTS companies are world leaders and have internationally competitive, innovative capabilities. Sixty per cent of the world's mining software, for example, originates from Australia.

The expertise of MTS companies is supported and marketed internationally by Austmine – 'Australia's Mining Marketing Team', which is the minerals industry's international business and development organisation. Austmine's activities are supported through its partnership with Austrade, the Australian Trade Commission, and Austrade's network of 98 offices in 67 countries. Austmine has over 135 members and successfully marketed over $1 billion of exports in 1998, with annual export earnings exceeding $1.5 billion in 2001 (Broome 1999, Broome 2001). Current estimates are that exports from Austmine members alone will reach $3 billion in 2005, and this will double by 2010 (DITR 2001).

A new Federal Government initiative is the Mining Technology Services Action Agenda, launched in June 2001, which aims to manage a wide-reaching consultation process and assist in the development of strategies for long-term development and growth in the MTS industry. Particular areas of concern include: response to the globalisation challenge; technology and R&D coordination; education and training; and promotion and marketing (DITR 2001). The Action Agenda also involves delineation of the MTS sector and its industrial structure and knowledge networks, since this new sector is yet to be identified by the government agencies, including the Australian Bureau of Statistics, and available data sets on the MTS tend to be generic or incomplete.

4.3.4 Traditional role of government

Given that the mineral industry's only rival for the position of Australia's biggest export earner is the agricultural industry, it may be expected that governments would dedicate a similar level of support to the two industries. The agricultural industry is distinguished by its political force in the guise of its own representative political party. The Country Party, as it was originally known, now called the National Party, currently holds power federally in coalition with the Liberal Party. It is argued that as a direct result of this political clout, federal agencies market and sell Australian wheat and wool, represent agricultural interests by instigating international trade delegations, and mete out favourable tax treatment to the agricultural industry (Barnett 1988). Surprisingly, and in stark contrast to this position, the mining industry has received minimal assistance from successive governments (see Appendix 2 for more detail).

The federal government's jurisdiction over foreign trade and commerce, as well as taxation, gives it considerable power and influence over the industry. Exportation of certain minerals, for example, must have approval from the appropriate Minister or equivalent federal authority (Barnett 1988:132). The Commonwealth extracts rent from the industry through three main policy vehicles: company income tax, an excise on mineral products and export duties. For some time it has also had an indirect influence on State-directed infrastructure development through its sponsorship of the Loans Council (Lloyd 1984:6). An important consideration for this thesis is what influence the Commonwealth may have upon innovation. While its funding of minerals industry research may be only minimal at best, its support for research institutions such as CSIRO and for the education and training of industry graduates is a vital and often overlooked contribution.

Ownership of minerals is the State Governments' most influential power over the industry. Thus, they control the procurement of onshore exploration and mining leases (the Commonwealth has similar powers in offshore areas as well as over uranium and other agents stipulated by the *Atomic Energy Act*) (Lloyd 1984). The States have used this leasing power to influence the establishment of processing plants. For example, Western Australia and South Australia employed such a strategy to develop their iron and steel industry (Barnett[71], 1979, quoted in Barnett, 1988, p 132). Revenue collection by the States occurs mainly as royalties on mineral production, with royalties varying for each mineral and between States (Galligan et al. 1988:133). Royalties increased significantly in the late 1970s following the federal government's constraint on State borrowing (Galligan et al. 1988:134). The States also differ in their provision of infrastructure (Galligan et al. 1988). A unifying trend that has been developing since the 1960s, is that companies are becoming increasingly responsible for the costs of social and transport infrastructure related to their operations (Lloyd 1984).

From industry's perspective, government legislation and its inefficient bureaucracies present a major impediment to the development of mining activity in Australia (Kjar 1997, Champion de Crespigny 1994, Richards 1994). The frustration felt by industry is expressed by the following quote from Western Mining Corporation:

> Overall there is an absence of policy focus and consistency. Conflicts between policies exist and often there is a wide disparity between the objectives of a government policy, the means by which it is implemented, and the outcome which it achieves. Consequently, a specific policy may encourage exploration but another may discourage or delay development of any mine. Still other policies may influence the extent to which the mine product is processed or the marketing mechanism adopted. (quoted in (Industry Commission 1991))

In the current global environment, a lack of support for the industry in the form of inconsistent and ineffective policies, poses a serious risk to the derivation of wealth from Australia's minerals resources. Australian companies may choose to invest in competitor nations where support is deemed to be more favourable. While recent initiatives like the MTS Action Agenda are a welcome start, considerable scope remains for improvement, as is discussed in Chapters 7 and 8.

4.3.5 Sustainable development – Environmental, Land Rights and OH&S issues

Three other characteristics raise the mineral industry's profile. First, is its exploitation of non-renewable resources. Its continued operation is dependent upon a 'social license to operate' in order to gain access to new resources (Algie 1997). Second, land access and the issue of 'Native Title' cause immense social discontent and an uncertain business environment, particularly with regard to exploration. Third, it is a dangerous industry for its workers with a long and tragic history of injury and death amongst its workforce. An ABS survey of innovation in the industry found that the most important objectives for 75 per cent of minerals businesses undertaking technological innovation during the past three years were 'reducing environmental impact', increasing 'safety of staff' and achieving an 'increase of production output' (Australian Bureau of Statistics 1998). The concern for safety in part explains the industry's heavy emphasis on training. In 1996, the minerals industry offered 17.1 hours of training per employee, compared with an industry-wide average of 4.9 hours (Australian Bureau of Statistics 1998).

The pressure from social and environmental issues has recently united most international minerals companies in an endeavour to embrace the mantra of 'sustainable development', along with 'triple bottom line' accounting (encompassing environmental, social and business performance measures). Sustainable development and incumbent issues of climate change, human rights, biodiversity, and health and safety are regarded as key issues integral to the industry's future success. Sustainable development is equally widely regarded as a mechanism to attract the best employees, to sustain access to resources and markets, and to reinforce the reputation of individual firms as suppliers and/or partners of choice. The Global Mining

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[71] Barnett, D.W. (1979) Minerals and Energy in Australia, Sydney, Cassell.

Initiative (GMI) is a consortium of international mining companies aiming to achieve sustainable development, to raise the profile of the industry and to ensure 'stewardship of the highest order'. Another international consortium aimed at addressing a particular environmental problem is the International Network for Acid Prevention (INAP). INAP was created as a consortium of 15 of the world's leading mining companies to develop high levels of understanding and industry practice in the amelioration and management of acid rock drainage. INAP currently has eight research projects under way, a large and active website and an enthusiastic and growing industry membership.

In 1996 the Australian industry developed the *Australian Minerals Industry Code for Environmental Management*, to which 37 companies were signatories by November 2000. The Code provides a framework for continual improvement in environmental management across all phases of mineral development (exploration to mine closure and site rehabilitation), as well as communication of environmental performance to industry stakeholders and the community in the form of annual environmental reports (Minerals Council of Australia 2000). Furthermore, signatories to the Code are expected to apply its standards both domestically and internationally. Expenditure on rehabilitation reported to the Minerals Council was $242 million in 2000 (*ibid*).

Many of the minerals industry's production processes are inherently energy-intensive and contribute to Australian greenhouse gas emissions. The Minerals Council conducted its own survey into the implications of greenhouse gas reduction policies upon regional Australia, and found that compliance with the protocol would reduce Australia's GDP by 1.9 per cent per annum and severely disadvantage industries such as those in aluminium and alumina (Minerals Council of Australia 2000). On the other hand, the MCA's survey would not have factored in potential long-term opportunities for growth as a result of investment in and development of new environmental technologies and capabilities. Despite misgivings toward implementation of greenhouse gas emission targets in Australia, many minerals companies participate in the Australian Greenhouse Challenge, enter into voluntary reduction commitment programs and support R&D related to the issue of greenhouse gases.

The Commonwealth *Native Title Act 1993*, requires minerals companies to be respondents to claims for native title on land where they have interests in minerals exploration and development. Legislative and common law developments arising from native title are increasing the external costs of mine development in Australia, as well as causing significant delays in gaining access to land for exploration. In 1999-00 the Minerals Council reported that industry expenditure on native title and aboriginal development expenditure (compensation payments to titleholders) was $48 million, excluding any costs arising from delays in gaining access to land for exploration (Minerals Council of Australia 2000). It is suggested that the issue of native title is one of the drivers behind a reduction of Australian greenfields[72] exploration compared to either brownfields exploration or prospects offshore.

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[72] The term 'greenfields' refers to exploration conducted on previously unexplored leases, whereas 'brownfields' exploration refers to exploration adjacent to operating mine sites.

4.4 The role of innovation in the minerals industry – changing dynamics of competition

Having addressed key characteristics of the global and Australian minerals industries in Sections 4.2 and 4.3, this Section begins to consider the role of innovation in the minerals industry and whether there is any support for the position advocated by this study: that the minerals industry is innovative and knowledge-based. If the minerals industry is to be likened to a high-technology, knowledge-based industry, competitive advantage must be primarily derived from technological and innovative capabilities (Archibugi and Michie 1997, Chandler et al. 1999, Dosi et al. 1998, Teece and Pisano 1998). The following subsection considers the traditional view of the minerals industry (low-tech and stagnant) and the attainment of competitive advantage. If technology and innovation are the basis by which minerals companies compete, then wealth derived from minerals resources is not simply a 'gift of nature' but instead is substantially *created* from the technological capabilities held within minerals-based countries and companies.

4.4.1 Rethinking the drivers of competitiveness in the minerals industry

Emergence of an alternative view on the role of innovation and competitiveness in the minerals industry can be found in the literature. The key feature of this alternative view is that wealth from minerals is created and not simply derived from the quantity or quality of the natural endowment.

The traditional and prevailing view of the basis of competition in the minerals industry is that the quality and quantity of resource endowment is fundamental and overriding. Tilton, one of the proponents of the alternative view, notes the following about the traditional view of competitiveness in the minerals industry:

1) All other determinants of competitiveness, including the generation and diffusion of new technologies, are of second order importance.
2) Comparative advantage is a gift of nature and transitory. Countries with the best ore deposits will be the most globally competitive, but only until these endowments are exhausted or new discoveries shift competitive dynamics.
3) Little can be done by corporate managers to improve the competitiveness of any particular mine. Therefore, companies must maintain competitiveness by the discovery or acquisition of new high quality deposits.
4) The role of governments in mineral economies is limited. Governments can support exploration and incentives for national resource development (land use policies and taxation) and improve the capture of rents from domestic reserves and improve national welfare. Governments cannot prevent the ultimate exhaustion of reserves, the associated loss of comparative advantage and movement of firms offshore in search of new reserves (Tilton 2000).

In thinking about the importance of resource endowment and competition in the minerals industry, it is necessary to understand *what makes resource endowments change over time.* First, depletion of the most productive mineral deposits may cause prices to rise, allowing second order deposits to become economically viable. Second, exploration leads to increases in reserves through discovery of previously unknown deposits. Third, innovation and technological change may bring previously uneconomic or untreatable deposits online, or facilitate the reworking of old deposits or waste dumps to amplify known reserves (Tilton 2001).

In terms of understanding competitiveness, the traditional view emphasises the first two options for change to resource endowments and pays scant attention to the third innovation-based option of change. The current environment, however, questions the validity of the traditional view of minerals competition since real prices have continued to decline. Exploration is certainly important, although large companies have divested themselves of their exploration assets in recent years, as they have failed to generate a reasonable rate of return (Batterham 1999) (see Chapter 6).

An alternative view endorses the third option as the most important basis for competition in the minerals industry: *competitive advantage is derived from technological capabilities.* Tilton describes a country or company's minerals endowment as 'the metal contained in those deposits that are both known (discovered) and profitable to exploit with current technology and prices' (Tilton 2001:71). In light of the latter it can be said that mineral wealth is not a fluke of nature. Rather it is *created* by innovations that lower the costs of existing operations, develop profitable treatments for previously uneconomic deposits, and of secondary importance, the discovery new deposits.

Many managers and associates in the minerals industry have long recognised the importance of innovation (Innes 1991, Innes 1993, Manners 1995, Algie 1999, Batterham and Shaw 1998, Batterham 1999, Hood 1998, Hood 1997). This view was often expressed by interviewees during this study. Since the commencement of this study, a *limited* number of investigations have been published that address the issue of competitive advantage and innovation in the minerals industry (Ala-Härkönen 1997, Tilton and Landsberg 1999, Simpson 1999a, Figueiredo 2002). None of these studies has an IS theoretical framework. They have instead approached the subject from a number of different standpoints, largely using traditional economic performance measures of such things as productivity and prices. Ala-Härkönen (1997) employs a 'diversification paths' framework to understand performance in the global base metals industry (Ala-Härkönen 1997). Tilton (1999) uses an assessment of productivity performance and the role of innovation in controlling costs in the US copper industry (Tilton and Landsberg 1999). Simpson (1999)[73] in a comparison of productivity in different resource-based sectors, considers the dynamics of innovation, particularly in relation to resource depletion, increasing competition, and other features of innovation typical of the natural resources sector (Simpson 1999a). Most recently, Figueiredo (2002) compares the performance of two Brazilian steel manufacturers based upon their learning paths and 'technological capability-accumulation' over time (Figueiredo 2002). In spite of their different conceptual frameworks, all of these studies concur with the alternative emerging view of the minerals industry as a technologically-intensive industry, in which competitive advantage is derived from innovative and technological capabilities.

Despite these recent studies, the dominant view of the minerals industry held by industry, analysts and policy makers remains traditional and conforms with the implications outlined above. There is a belief that this industry is stagnant and based on mature technology.

4.4.2 Factors that influence technological progress in the minerals industry

Three factors influence innovative performance in the minerals industry (Simpson 1999a). The first is summed up by the adage, 'necessity is the mother of invention'. As no two mineral deposits are the same, all operations require some technological adaptations just to ensure that an operation's suite of selected (and proven) extraction, processing, and rehabilitation methods work effectively. In addition, the most easily discovered, accessed and treatable deposits have been depleted, necessitating the development of new enabling and cost-reducing technologies to sustain the economical discovery and treatment of more refractory orebodies.

While the competitive environment may necessitate innovation, a second factor influencing innovative performance is the general state of available technologies. Minerals firms are more likely to solve technological problems by the recombination and gradual adaptation of existing technologies than new technological development. The minerals industry is an avid user of proven new technologies and will readily incorporate new technologies developed by industry sectors far removed from their own in order to meet a specific need. Thus, the manner in which a technological need is serviced tends to be defined by the general state of existing technologies at a particular point in time. The history of the minerals industry is littered with exceptions in the form of radical new process innovations. Examples include directly reduced iron ore by the HIsmelt process, carbon-in-pulp extraction for gold, and solvent extraction-electrowinning (SX-EW) processing for the extraction of copper from waste dumps. Such radical innovations seldom transform the minerals industry overnight and implementation tends to be gradual due to the capital intensive nature of the industry. Thus, continuous technological change, through the combination and recombination of new and existing technologies, is a dominant feature of minerals innovation.

An integral third factor affecting technological progress is the continuing ability to be innovative. The Australian minerals industry and composite firms have maintained international competitiveness in spite of its history of depletion (consequent difficult geology)

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[73] Simpson writes the introductory chapter to a study of productivity in natural resource industries and the role of innovation (Simpson 1999b). Tilton's case study on the US copper industry is included in the latter study as the example of productivity and innovation in the minerals industry.

and competition from more prospective developing regions of the world (where minerals resources are less depleted and of higher grade). This study ascribes the international competitiveness of the Australian minerals industry to a capacity to innovate more readily than international competitors and produce exports at costs that keep them competitive in global markets. Of great interest to this study is the how the dynamic, innovative capabilities of the Australian minerals industry are supported by an Australian minerals innovation system (MinIS) (see Chapter 3 and (Niosi 2002, Nelson and Nelson 2002, Freeman 2002, Freeman and Soete 1997b)).

4.4.3 Drivers of innovation in the minerals industry

A unanimous view held among participants in this study was that the primary driver of innovation in the minerals industry has always been, and continues to be, performance enhancement, with the objective of increased competitiveness. This overriding objective can be divided into several components which will continue to drive minerals innovation, namely, increasing the productivity of workers and equipment, reducing production costs, and opening up new minerals reserves and extending the life of existing operations (Peterson et al. 2001). In more recent times an additional driver of innovation, often referred to as 'sustainable development', has taken form. This is the need to meet regulatory and stakeholder requirements in areas of occupational health and safety (OH&S), environmental impact, site-rehabilitation and land use.

The following Chapter provides evidence of a history of innovation in the Australian minerals industry, characterised by a culture that embraces innovation as a source of future competitiveness and growth. This tradition of innovation is being challenged by current trends in the global minerals industry. Historically low commodities prices, globalisation, industry consolidation, and sustainable development are having an impact upon innovation in the minerals industry. Current trends have induced many companies to significantly cut their expenditure on R&D activities and only support those projects that deliver 'sustainable competitive advantage' in the short-term (see Section 4.6 for examples of shifting R&D expenditure). Private sector cuts have tended to coincide with similar cuts to innovation expenditure by the public sectors.

The changes that drive minerals innovation, and their impact upon the Australian MinIS, are discussed in Chapters 7 and 8. While the current environment is extremely challenging for the future performance of Australia's minerals industry and the MinIS, new opportunities are also being generated, particularly in relation to social and environmental concerns and a new demand for high-technology services, as minerals companies move away from internal technology development.

4.5 Types of minerals innovation

This section examines types of innovation and R&D, and the way they are influenced by industrial sector and commodity group within the minerals industry. It further explores the general types and characteristics of minerals innovation. This section is based upon findings in the literature, pre-dating current understanding of knowledge-based innovation as outlined in Chapter 3. This material is not meant to be solely assessed from a IS perspective.

4.5.1 Characteristics of innovation according to industry sector and commodity group

The nature of innovation in the minerals industry varies according to the minerals activity it is associated with (exploration, extraction, processing, OH&S and environment), as well as commodity type, requirements for further processing and an operation's stage of life (Algie 1999, Batterham and Algie 1995, May 1992).

Innovation associated with *exploration*, for example, has traditionally been seen as the industry's equivalent of cutting-edge, high risk research and often involves a large proportion of basic research (the exception being the Australian Mineral Industries Research Association, (AMIRA)-type collaborative research). Developments in *extraction* innovation have been animated by the pressure to improve safety and productivity (Hood 1998, Peterson et al. 2001). The drive to increase productivity has inevitably focused attention on innovation in bigger, more efficient and automated equipment. The minerals industry buys most of its earthmoving and other mining equipment 'off the shelf'. The large-scale and complexity of such equipment and need to coordinate mine development plans with technology acquisition, means the acquisition of new technologies embedded in equipment entails massive amounts of capital (Peterson et al. 2001). As a result the industry purchases relatively few pieces of equipment. As mentioned earlier (Section 4.2.1), the highly competitive nature of the minerals industry (thin profit margins, see Table 4.3 MCA survey of exploration) means more time is required to recover the cost of new technology investments in mining equipment than for other industries (Crowson 2001, Hooke 2002). Equipment manufacturers have high R&D, demonstration and development costs when related to the number of equipment units sold (see Block-caving subunit Chapter 6). The scale and ruggedness of mining equipment tends to limit the potential for application in other sectors. As equipment increases in size, power, versatility, durability and sophistication of on-board ICT technologies, minerals companies are purchasing fewer units. This increases pressure on equipment manufacturers in terms of their development-cost recovery cycle.

Once a process plant is functioning, the research emphasis in *processing* is towards incremental improvements and to ensuring maximum performance of process methodologies and equipment. Fundamental change at this stage involves enormous injections of capital and associated risk, which is why dramatic technological shifts in process technology are rare.

Social values and expectations have forced profound changes in the ways industry deals with *environmental* and *safety* issues. This situation has driven innovation across the entire industry, from automation to mine planning, with a view towards site rehabilitation. Much of this work has been collaborative since environmental and safety issues are increasingly international and seen as an 'industry' problem beyond the scope of a single company. The formation of global consortia that address particular environmental concerns, for example INAP and the GMI, supports this trend. There are, however, many instances in which individual companies must deal with sites in which the natural environment is localised and requires specific projects. An example of the latter is the development of bio-indicators for the Ranger and Jabiluka mines (see Chapter 6, Ranger & Jabiluka subunit).

The degree of processing required influences the characteristics of innovation. Algie (1997) separates 'tailored' from 'commodity' products. *Tailored* products undergo some form of downstream processing and are usually sold through long-term contracts (Algie 1997). *Commodity* products are generally sold freely (on spot markets) as stock, or forward sold as futures, and undergo minimal processing. Both types of sales may exist for a single ore. The need for processing tailored products raises the importance of processing technology and innovation. In the case of commodity products, such as minerals that require a minimum of processing, technology may assume greater importance in the areas of exploration and mining. It is common for a well-developed service industry to exist and assist commodity product producers across the areas of exploration, mine planning, mining and sales (Algie 1997). Some characteristics of tailored and commodity products are given in the table below.

Table 4.4: A comparison of tailored and commodity products

Characteristics	**Tailored products** *Iron ore, Alumina*	**Commodity products** *Gold, Base metals, Nickel, Scrap steel*
Sales	Contract	Spot market
Entry	Difficult	Easier
Business focus	Marketing	Securing resources
Operational focus	Efficiency	Opportunism
Major value from technology	Meeting contract grades & production	Exploration and evaluation
Spread of technology	Proprietary	Rapid diffusion
Suppliers	Fewer support services available	Wide range of support services available
Industry characteristics	Fewer players	More players
Prices	More stable	More volatile
Capital cost	Higher	Lower

Source: (Algie 1997:19)

Another factor that influences the nature of innovation in the industry is the *life cycle* of a mine. There are a number of definable phases: exploration, planning, operation and decommissioning/site rehabilitation. Any long-term operation will necessarily be comprised of many projects at these stages of development and successful mining companies have effective strategies for managing all three phases. The latter does not mean that a successful company needs to house each phase internally; companies are looking more closely at out-sourcing an ever-increasing number of their activities. As stated previously, more emphasis is being placed upon 'financial planning and management' as a core competence, where a competitive advantage may be efficiently and economically gained.

4.5.2 Product versus process innovation

The amount of product innovation being conducted by the minerals industry is limited. There is important research in the CSIRO in new high-strength alloys using magnesium and aluminium. Generally, minerals companies have not been working on new uses for metals to expand their market and generate demand. This is in contrast to other primary industries, such as the wool industry, which has a comparatively strong commitment to developing new uses and combinations of its product. With the exception of the aluminium and steel (tailored product) industries, the minerals industry funds this area in a fairly minimal way.

4.5.3 Evolutionary verses revolutionary innovation

Technological progress in the industry is typically evolutionary, as opposed to revolutionary (Groeneveld 1998, Peterson et al. 2001). This is similar to the manufacturing industry as a whole (Freeman and Soete 1997a). Despite the extensive technological innovation that has been incorporated into the minerals industry since its inception, the fundamental mining process has essentially remained unchanged. This indicates that the industry, in common with most of manufacturing industry, has gained more from incremental technological development and its efficient transfer than from radical technological breakthroughs (*ibid*). Revolutionary new technologies do, however, emerge.

When radical process innovation occurs, as in the carbon-in-pulp technology used in gold production and solvent extraction-electrowinning (SX-EW) processing used in copper production, there can be substantial reductions in production costs and consequent increases in mineral reserves. The history of the minerals industry is littered with examples of radical process innovations. It is hoped that the high-pressure, acid-leach technology being used in some nickel mines in Australia will have a similar effect (Treadgold 1999).

The highly capital-intensive nature of the minerals industry means that it is very unusual for the industry to adopt novel revolutionary processes on a 'wholesale' basis (Batterham 1999, Groeneveld 1998). As capital investment is the primary vehicle for the transfer of technological advances, a time delay generally occurs between the advent of new technologies and their effect on production (*ibid*). This has meant that technology 'adaptation' to particular geological conditions is often a more common form of technological transfer than 'adoption'. To refer again to HIsmelt, it would appear that the long time horizon for commercialising this technology is, in part, a reflection upon industry reticence when it comes to revolutionary technologies. HIsmelt has only recently won commercial backing by steelmakers from the US, Japan and China, and $400 million to build a plant at Kwinana in Western Australia to compete the first stage of a projected $1.2 billion commercialisation process (Marsh 2002).

4.5.4 Technology Transfer verses new technology development

According to numerous respondents in this study the minerals industry readily embraces commercially proven new technology. A preference exists to buy technology embodied in equipment. Such technology advances are, of course, available in the marketplace, which means that competitors may also access the full range of new developments. Ultimately, the important issue for companies operating in this manner is how to develop the competencies and skills required to successfully transfer and apply technologies (see Chapter 3). Companies that are technologically more adept will be able to squeeze enhanced performance out of their equipment (Dodgson 2000).

4.5.5 Types of R&D: in-house and collaborative

The following has not incorporated some of the more recent mergers and acquisitions. Thus, some of the comments relating to particular companies may no longer hold.

Research in the minerals industry can be classified according to whether it is undertaken in-house, or collaboratively. In-house R&D is usually typified in large firms by long-term projects of a substantial scale, supported by strongly-committed top management. Large companies, such as BHP and Rio Tinto dominate this type of research as they have their own internal research units as well as the ability to deal with the associated financial risk (see Diamonds sorters subunit Chapter 5). Companies such as QMC and MIM, with smaller resources and a committed research strategy, may also perform this type of research. However, small- to medium-sized firms often are unable to sustain this type of research, particularly when there is a need for short-term savings. As shown later, however, there are some highly research-intensive small firms.

Collaborative research can be undertaken between firms, or between the private and public sectors. Collaborative research within the private sector is unusual in the Australian research environment generally, but common in the minerals sector. This type of research is cooperative in nature, often pre-competitive (it does not have immediate market use), and is a totally industry-backed venture conducted by groups of companies that pool their resources to share the costs, risks and results of the research. Industry groups, such as AMIRA International, have evolved specifically to manage this type of minerals research. It has proven to be a successful method of conducting R&D, and has been critically important to the industry's success in many areas. Projects tend to be generic, and companies need to develop their own spin-offs from the outcomes of such research in order to gain competitive advantage. Expenditure on this type of research in the exploration sector amounted to $4 million, or approximately 0.5 per cent of total expenditure on exploration, in 1996-97 (Cucuzza and Goode 1998:52).

The third type of research is cooperative research with participants from the public and private sector. Here, sponsorship by industry of research conducted in public institutions has developed centres of excellence across a variety of mineral research fields within the university system. Examples include the Julius Kruttschnitt Mineral Research Centre (JKMRC), the Queensland Centre for Advanced Technologies, and the Kalgoorlie School of Mines (funded by Western Mining). There are also several mineral-related CRCs. Many companies prefer to conduct their collaborative research projects through a CRC due to the increased leverage they receive on their research dollar from the Government's contribution to funding these centres.

These types of R&D are not mutually exclusive. Large R&D projects may well involve substantial in-house R&D complemented and supplemented by partnerships with other companies and research institutes.

4.5.6 Section Summary

The characteristics of minerals innovation are influenced by the type of commodity and minerals activity concerned. Within this framework, broad generalisations can be made about minerals innovation. Process innovation is more important than product innovation. Technological progress tends to be of an incremental and cumulative nature as opposed to revolutionary. A preference exists within minerals companies for technology transfer, particularly with regard to mining equipment, as opposed to internal technological development. Proven technologies are readily embraced even if the origins of such technologies are far removed from the minerals industry. Minerals companies tend to support a range of research programs, including in-house strategic, applied and basic cooperative research. An issue of relevance for this study is the move away from support for internal research facilities by large minerals companies and the impact this will have on the Australian minerals research base.

4.6 Scale and direction of innovative effort in the minerals industry

Chapter 3 and Appendix 3.4 address the difficulties associated with measuring innovation processes and the limitations of associated 'innovation indicators' generally, including input/output measures such as R&D expenditure, R&D intensity, patents, publications, and innovation surveys. Measuring the scale of innovation in the Australian minerals industry is not immune from such difficulties, and may be more problematic than for those industries that depend upon product innovation as a primary source of competitiveness (see Figure 4.5).

Minerals companies vary greatly in their interpretation of what activities actually represent R&D. For example, when does business process re-engineering (BPR), used in developments such as the NorthParkes block cave, become R&D? From an aggregate industry perspective, commitments to a major project, such as HIsmelt, may substantially inflate R&D expenditure figures for the entire industry. The organisations that collect such data employ different industry and research classifications (the ABS's definition of the 'mining' sector includes coal, oil & gas), and many attempts to collect such data seem to collapse altogether (for example, the ABS' report on Minerals Innovation (1998)). Attempts to measure innovation by R&D scoreboards are limited due to the lack of long-term data and lack of consistency in reporting. Furthermore, indicators of 'innovation', such as R&D intensity (based upon R&D as a per cent of sales and/or patent applications), are unsuitable for the minerals industry. A comprehensive review of these measures is outside the range of this thesis, although some points raised might be useful for future debate. The following section reviews a selection of quantitative measures of innovative effort in the minerals industry.

4.6.1 Data on business R&D Expenditure (BERD) in the Australian minerals industry

Table 4.5 below presents the ABS figures for industrial R&D for a 'broadly' defined minerals industry. While the minerals industry's level of BERD remains under-estimated, the total for broad minerals-BERD ($882m) is considerably larger than the standard (narrowly defined) 'Mining (including services to mining)' definition ($456m).

Table 4.5: Australian BERD with 'broad' minerals industry definition

Industry Expenditure on R&D	1998-99 A$m	1999-00 A$m	2000-01 A$m
Broadly defined mining sector			
Mining (including services to mining) (narrow)	485	291	456
Non-metallic mineral product	324	377	385
Metal product	53	47	41
Subtotal	862	715	882
Manufacturing			
Food, beverages and tobacco	209	184	205
Textiles, clothing, footwear and leather	21	18	27
Wood and paper products	84	102	100
Printing, publishing and recorded media	20	15	13
Petroleum, coal, chemical and assoc'd product	324	377	385
Motor vehicle & part & other transport equipment	379	410	473
Photographic and scientific equipment	107	128	180
Electronic and electrical equipment and appliance	399	342	385
Industrial machinery and equipment	116	131	140
Other manufacturing	19	20	23
Subtotal	1678	1727	1931
Other industries			
Wholesale and retail trade	365	387	388
Finance and insurance	83	138	264
Property and business services	620	744	831
Scientific research	162	211	218
Other not elsewhere classified	348	312	498
Total other industries	1578	1792	2199
Total all industries	***4118***	***4234***	***5012***

Source: (Australian Bureau of Statistics 2002)

Table 4.6 presents 2000-01 R&D expenditure by the alternative Australian Standard Research Classification (ASRC) data set, where R&D expenditure is collected and classified by socio-economic objective (SEO) and for source of funds. The ASRC classification is more representative of the minerals industry's activities than ANZIC. Table 4.6 illustrates the point of the minerals industry's comparatively low use of direct public support mechanisms for R&D. There is a distinct division of sources of funds for activities, with Commonwealth Government expenditure on exploration being much higher than for business. Expenditure on R&D by industry is focused on extraction and processing. The industry funds environmentally-related research on a greater scale than does the public sector.

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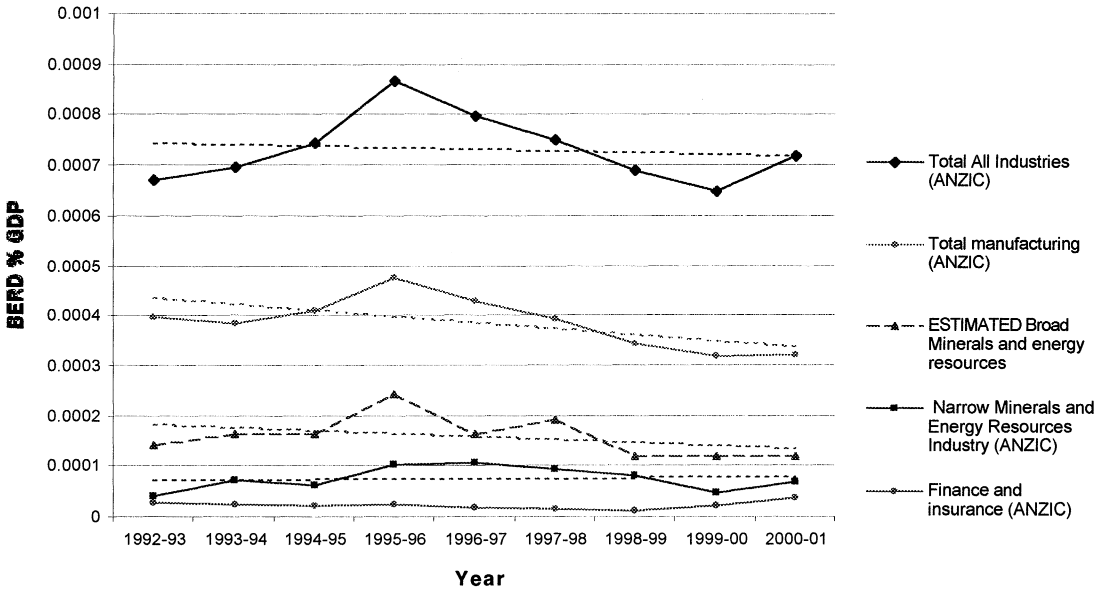
Table 4.6: The minerals and energy resources and energy supply sectors' expenditure on R&D by Socio-Economic Objectives, and source of funds (ASRC) 2000-01

ASRC classification number	*Name of ASRC Group (Research area)*	*Source of funds ($m)* Business	Government	Higher education
Subdivision 640000 Mineral Resources (excluding energy)				
640100	exploration	31,011	40,730	8,964
640200	primary mining and extraction processes	125,253	7,764	4,654
640300	first stage treatment of ores and minerals	155,104	22,122	16,914
640400	prevention and treatment of pollution	5,849	1,039	2,238
	Subdivision 650000 Energy Resources			
650100	exploration	4,367	32,921	7,672
650200	mining and extraction	68,515	19,872	8,516
650300	preparation and supply of energy source minerals	25,774	1,007	1,630
650400	prevention and treatment of pollution		5,116	696
659900	other		2,548	5,366
	Subdivision 660000 Energy Supply			
660100	energy transformation	48,365	5,679	1,826
660200	renewable energy	28,149	2,567	10,630
660300	energy storage and distribution	18,177	5,438	3,252
660400	conservation and efficiency	17,039	3,910	7,607
660500	prevention and treatment of pollution	1,644	8,087	2,950
669900	other	8,438	77	108
	Totals	**537,685**	**158,876**	**83,022**

Source: Data per favour Department of Industry (July 2002)
Note: ASRC are not collected on an annual basis. The last ASRC dataset 1998-99 has a different classification and thus these figures were not used.

Bureaucrats argue about yearly shifts in industry BERD (calculated as per cent total BERD). Such annual changes are not meaningful, particularly for the minerals industry where 'one off' projects (such as a single pilot plant) or the development of new operations can cause great increases in the BERD figures for a given year. It is more useful to refer to long-term trends. It is even more useful for comparisons of BERD between industry sectors to be based on the GDP and not as a per cent of total BERD. Figure 4.6 shows trends in BERD as a percent of GDP for nine years (ABS data with ANZIC codes). An overall downward trend in expenditure exists for total industries BERD. In spite of the recent increase in BERD by the 'narrow' minerals and energy resources sector, the long-term trend remains unchanged. Specifically, the concern is the downward trend for BERD in the 'broadly' defined minerals and energy resources sector specifically, and in total manufacturing BERD generally. Accurate reporting of these trends would require a great deal more work than is currently expended.

Figure 4.6: Trend in BERD for wide and narrow defined Australian minerals industry (1992-93 to 2000-01)



Note to figure: The ANZIC data for this table was provided by Department of Industry. *It has not been revised by the ABS and therefore is not reliable.* In addition the 'Broad' Minerals and energy resources industry *is not a tested grouping*, rather it is a very rough first cut at what such a 'real' representation of the industry might be. It is only provided in an attempt to have a slightly more representative and realistic interpretation of the trend in BERD for minerals industry. Of course this thesis does not support the use of single, quantitative measure of expenditure on R&D as a measure of technological innovation.

In 1998 the ABS (using ANZIC industry codes) conducted a survey of minerals businesses to measure the extent to which they had undertaken 'technological innovation' during the three year period from July 1994 to June 1997 (Australian Bureau of Statistics 1998). This first survey of its kind involved 1,650 minerals businesses. It found that 42 per cent of the minerals businesses had undertaken 'technological innovation.'

The ABS also reported in some detail on the expenditure on technological innovation and found that out of a total investment by industry of $8.5 billion in 1996–97, 'metal ore mining' spent the most, $3.8 billion, double the amount spent by any other industry group (see Table 4.7 below). This may have something to do with the NorthParkes mine being developed at the time (the latter development was based around incorporation of ICTs, see Chapter 6). According to the ABS, the 'metal ore mining' businesses spent the most on 'new technology and capital replacement.'

Table 4.7: Expenditure on technological innovation by industry

Type of innovation activity	Coal mining	Oil & gas extraction	Metal ore mining	Other mining	Services to mining	Total
			($ million)			
Exploration	24.4	581.3	748.5	21.1*	439.8	1,815
Feasibility studies	37.0	37.0	150.6	1.5	40.4**	266.6
Research and development	71.5	34.6	305.8*	20.0*	27.2	459.3
Mine development and construction costs	534.7	740.5	1,060	59.4**	686.2	3,081
New technology and capital replacement	629.6	207.6	1,384.3	111.1*	72.3	2,405
Environmental assessment, management and rehabilitation	70.4	24.9	113.8	6.5	31.0	246.7
Marketing	52.6	19.2	72.6	19.7	6.4	170.4
Training and further education	29.4	6.7	44.5	3.3	12.0	95.9
Total	1,450	1,652	3,880	243	1,315	8,539
Average expenditure per business	25.1	67.2	23.8	1.5	5.7	13.4

*Estimate has a relative standard error greater than 25% ** Estimate has a relative standard error greater than 50%
Source: (Australian Bureau of Statistics 1998)

A 2000 review of Commonwealth support for R&D (direct and indirect) found that the 'narrow' minerals industry is by far the largest industry sector utilising the R&D tax concession, at over a billion dollars a year (Matthews and Howard, 2000).[74] If the broad definition of the minerals industry (including machinery and equipment manufacturing, metal product manufacturing etc) is used, then the minerals industry's use of the R&D tax concession may well be far greater (see Figure 4.7 below). The minerals industry's dominance in terms of use of Commonwealth Government R&D Tax Concession (1995-96 to 1997-98) is perhaps not surprising since it is a very large industry with large firms (Sheehan, 2000) that conduct industrial R&D. In other words, as Australia's only world-scale, firms-based industry, one might anticipate this finding. Thus, minerals firms by the very nature of the types of R&D they do (such as build pilot plants) and conduct R&D on a continuous basis (process improvements etc), would be expected to utilise a large share of this type of Commonwealth R&D support.

More interesting information on the direction of the minerals industry's innovative effort is revealed when expenditure through the R&D Tax Concession is analysed by field of research (FOR) (see Figure 4.8). This analysis suggests that the minerals industry is principally active in 'general engineering', 'applied sciences and technologies', and 'ICT'. These are fields associated with the engineering sciences or science-based technologies (see Chapter 3), where a high degree of new technological and applied scientific knowledge is based. There is much less industry effort in the pure science areas of 'earth sciences' and chemical sciences'. This gives a strong indication that the innovative effort of minerals firms, claimed under the R&D tax concession, relies upon knowledge bases in applied or engineering sciences and technologies, in addition to knowledge bases related to the enabling technology field of ICT.

[74] This is in contrast with Australia's other major resource based industry, agriculture, which is not included in ABS reports on BERD, as agricultural R&D is funded from levies on production which support R&D corporations with 'matching' Commonwealth funds.

Figure 4.7: R&D claimed under the Australian R&D tax concession by industry sector (ANZIC)

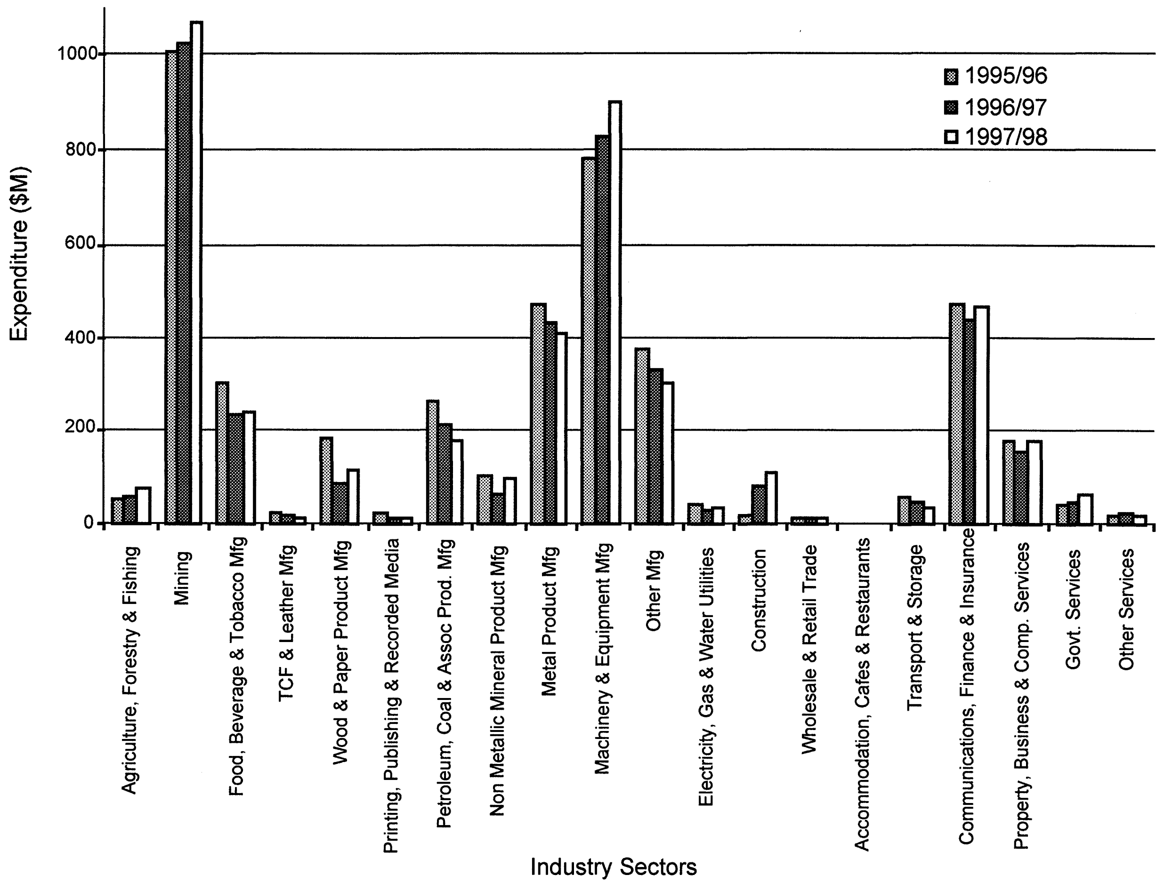
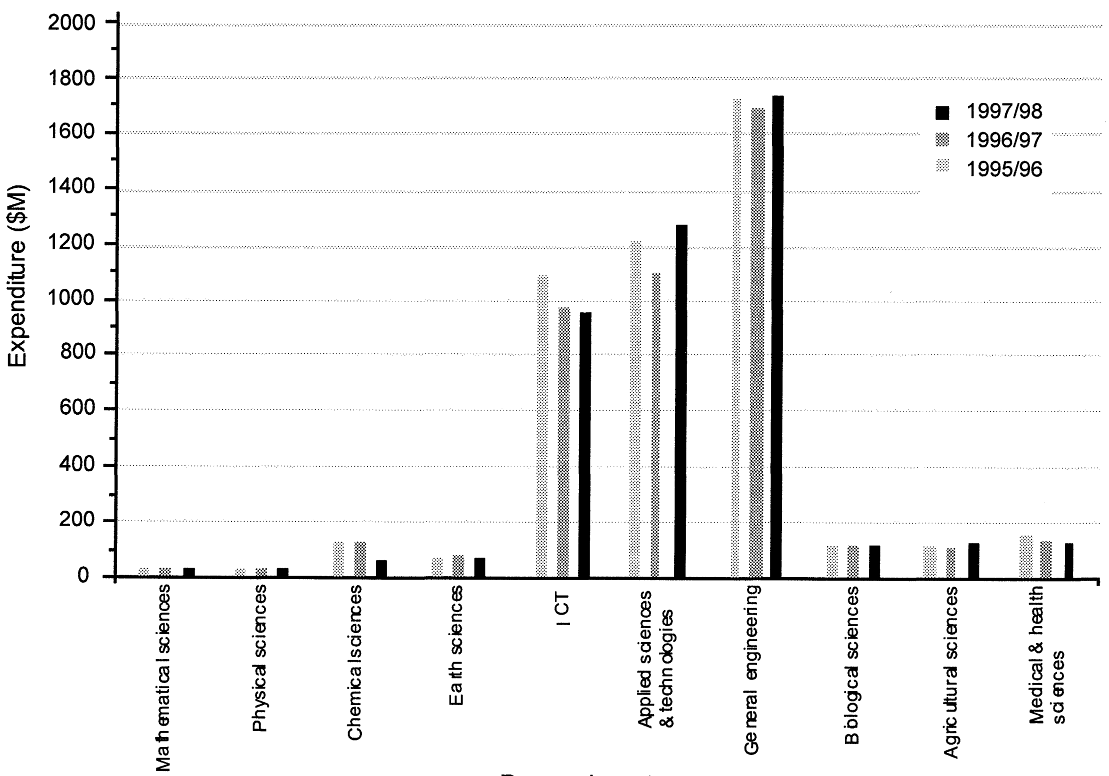


Figure 4.8: R&D claimed under the Australian R&D tax concession by field of research (FOR)



Source for Figures 4.7 and 4.8: (Matthews and Howard 2000)

4.6.2 Department of Industry Science and Resources 'R&D Scoreboard'

The *R&D Scoreboard*, a report on R&D expenditure by Australian industries, is produced annually by the IR&D Board and the Department of Industry Science and Resources. In this survey, the term 'mining industry' is assumed to mean minerals industry. Following the National Innovation Summit, the scope of the Scoreboard included 'benchmarking innovation' in Australian firms with new indicators: an innovation index[75]; R&D intensity; and patent, trademark, and design applications (Melbourne Institute of Applied Economics & Social Research 2000). As participation in all versions of the Scoreboard is voluntary, the information is not comprehensive. In interpreting the Scoreboard the following limitations must be considered:

- companies may differ in their accounting and reporting of R&D activities;
- they may have varying degrees of offshore investments in research activities which may or may not be included in calculations of local investment in R&D;
- some subsidiaries of larger companies have participated in the Scoreboard and their activities may have been accounted for twice; and
- the agency undertaking the survey has changed several times, adversely affecting the cumulative development of the data set.

The following Tables present R&D Scoreboard data on Australian industry's BERD for 1995-96, 1996-97, 1997-98 and 1998-99 (the last two years are in one table as they were compiled in the 2000 Scoreboard). An indication of the minerals industry's support for research is demonstrated by the presence of BHP and Rio Tinto among the top ten Australian industry investors in industrial R&D for all years, and WMC, in 1996-97 (see Tables 4.8, 4.9 and 4.10).

Table 4.8: Top ten investors in industrial R&D, 1995–96

	Company	Industry Sector	R&D
1	Telstra	Telecommunications	$239m
2	Broken Hill Proprietary Company	Mining	$200m
3	General Motors Holden	Motor vehicle & parts manufacturing	$139m
4	CSR Limited	Construction & construction services	$113m
5	Ericsson Australia Pty Ltd	Telecommunications	$110m
6	Ford Motor Company of Australia	Motor vehicle & parts manufacturing	$106m
7	Rio Tinto	Mining	$95m
8	Alcatel Australia Limited	Telecommunications	$62m
9	Optus Communications	Telecommunications	$51m
10	ICI Australia Limited	Chemicals & Associated Products	$39m
		Total	**$1,153m**

Source: (Industry Research & Development Board 1997)

[75] The innovation index incorporates a firm's R&D expenditure, patents, trade marks and designs applications into a single figure. The index controls for firm size by dividing each of the latter indicators by the value of a firm's assets and weights their intensity according to a statistical analysis of the market value of innovative activities (Melbourne Institute of Applied Economics & Social Research 2000). This index is not particularly useful for the minerals industry, due to its capital intensive nature and reduced significance of activities such as patenting, trademarks and designs.

Table 4.9: Top twenty investors in industrial R&D, 1996–97

	Company	Industry sector	R&D
1	Broken Hill Proprietary Group	Mining	$310m
2	Telstra Corporation Limited	Telecommunications	$225m
3	Rio Tinto	Mining	$106m
4	Ericsson Australia	Telecommunications	$90m
5	Alcatel Australia Limited	Telecommunications	$86m
6	Amcor Limited	Wood and Paper Product Manufacturing	$65m
7	WMC Limited	Mining	$55m
8	CSR Limited Group	Construction and Construction Trade Services	$42m
9	Orica Australia Pty Limited	Petroleum, Coal, Chemical and Assoc Products	$40m
10	ERG Limited	Telecommunications	$36
11	FH Faulding and Co Limited	Pharmaceuticals	$34
12	CSL Limited	Pharmaceuticals	$34
13	BTR Nylex Limited	Petroleum, Coal, Chemical and Assoc Products	$32m
14	NEC Australia Pty Ltd	Telecommunications	$31m
15	Goodman Fielder Limited	Food, Beverages and Tobacco Manufacturing	$27m
16	Qantas Airways Limited	Transport and Related Services	$25m
17	Fujitsu Australia Limited	Computer Software and Services	$25m
18	Hewlett-Packard Australia Limited	Computer Software and Services	$23m
19	Normandy Mining	Mining	$23m
20	Pasminco Limited Group	Mining	$22m
		Total	**$1,332m**

Source: (Industry Research & Development Board 1998)

Table 4.10: Top ten investors in industrial R&D, 1997-98 and 1998-99

	Company	Industry Sector	R&D 1997-98	R&D 1998-99
1	Broken Hill Proprietary Company	Mining	$180m	$221m
2	Alcatel Australia Limited	Telecommunications	$88m	$95m
3	Rio Tinto	Mining	$105m	$84m
4	Ford Motor Company of Australia	Motor vehicle & parts manufacturing	$83m	$73m
5	Ericsson Australia Pty Ltd	Telecommunications	$90m	$65m
6	FH Faulding & Co Limited		$48m	$57m
7	Orica Limited		$38m	$44m
8	CSL Limited		$39m	$40m
9	Pacific Dunlop		$32m	$37m
10	Telstra	Telecommunications	$43m	$34m

Source: (Melbourne Institute of Applied Economics & Social Research 2000)

There have been criticisms of the scoreboard statistics from industry representatives, mostly relating to the limitations of Scoreboard data described above. In reference to the top 20 mining companies' research expenditure for 1996-97, concern was expressed from a number of minerals industry sources about the absence of companies such as MIM and WMC, as in those years both companies claim that their expenditure was around $40-50 million per annum, and placed considerable emphasis upon their R&D strategy. A reason for the presence of a number of coal companies on the 1996-97 list is perhaps a reflection of the coal levy, which was being collected during those years and was voluntary. At five cents a tonne it raised about $9-10 million for research per annum. This levy was included as part of R&D expenditure by BHP, QCT, Centennial Coal and Novacoal (a subsidiary of Rio Tinto). What is clearly illustrated by the list of company expenditure on research is the magnitude of the difference between the major companies (BHP and Rio Tinto), middle order companies (such as Newcrest and Normandy, and should also include MIM and WMC), and companies with relatively little investment in R&D. The reported $310 million expenditure by BHP in 1996-97 (see Table 4.11) is dubious as company reports do not concur, stating that R&D expenditure was $190 million and $195 million in 1996 and 1997 respectively.

By 1998-99, BHP and Rio Tinto were among only three minerals companies in the top twenty firms investing in R&D, the third being a high-tech minerals services company, Mincom Limited, ranked sixteenth at $22 million (up from just $2 million the previous year) (Industry Research & Development Board 1997). Again these figures demonstrate the considerable gap between the firms at the top of the list, and middle order companies. MIM ($3.4 million) and WMC ($4.9 million) were not among the top fifty firms for R&D expenditure in 1998-99, although the list does include Comalco (twenty-first, $17 million), Alcoa of Australia (thirty-first, $12 million) and Pasminco (forty-fourth, $7 million) (Industry Research & Development Board 1997).

Table 4.11: Top twenty minerals companies' expenditure on R&D in 1996-97

Rank and Company		R&D ($m)	Turnover ($)	Employees	Per cent R&D to turnover	R&D per employee ($)
1	Broken Hill Propriety Gp	310	14 billion	40,000	2.21%	7,750
3	Rio Tinto	106	9 billion	31,876	1.17%	3,336
7	WMC Limited	55	2 billion	3,860	2.52%	14,210
19	Normandy Group	23	1.3 billion	3,000	1.74%	7,751
20	Pasminco Limited Group	22	1 billion	3,222	2.14%	6,954
28	North Limited	18	946 million	3,300	1.9%	5,443
68	Aberfoyle Resources Ltd	5	158 million	349	3.15%	14,327
95	World Geosciences Corp Ltd	2.8	21 million	175	12.92%	15,949
107	Queensland Alumina Ltd	2.2	474 million	1,056	0.47%	2,106
108	Ticor Limited	2.2	238 million	598	0.93%	3,696
112	Energy Resources Australia	2	241 million	246	0.84%	8,293
133	SDS Corporation Ltd	1.5	48 million	160	3.07%	9,350
134	QCT Resources Ltd	1.5	792 million	540	0.19%	2,728
139	Brandrill Ltd	1.3	76 million	329	1.69%	3,957
140	Kalgoorlie Lake View	1.3	196 million	228	0.66%	5,649
153	Macmahon	0.9	411 million	1,631	0.24%	598
162	Mitsui Iron Ore Dev	0.8	69 million	2	1.81%	412,500
175	QMC Ltd	0.7	43 million	183	1.64%	3,896
178	DHT Technologies Ltd	0.7	217 thousand	6	312.5%	113,333

Source: IR&D Board (1998), R&D Scoreboard 98 Business Expenditure on Research and Development.

The findings in Table 4.11 are revealing when considered in light of the overall circumstances of the Australian minerals industry in 2002. Of the first five companies on the list, Rio Tinto is the only company still extant, arguably because it was already the product of a mega-merger

(CRA-RTZ in 1995) and was big enough to acquire North Ltd in 1999. The others have merged (BHPbilliton), been acquired (North by Rio Tinto, Normandy by Newmount), demerged (WMC) or have failed due to poor business decisions (Pasminco). During this period of intense merger and acquisition activity, R&D expenditure and R&D intensity have dropped, with R&D intensity in major companies like BHP and WMC as low as 0.1 per cent and for Rio Tinto 0.4 per cent.

In summary, the R&D Scoreboards report a great degree of fluctuation in R&D expenditure by minerals companies, with considerable differences between those companies that made up the top twenty from 1995-96 to 1998-99. According to the Scoreboard, BHP's R&D expenditure fluctuated by one-third ($100 million), Pasminco's doubled, and QCT's expenditure decreased to around one-fifth. It is not possible to give a precise reason for such fluctuations, although a contributing factor may be the capital intensive nature of commissioning new plants and equipment, and the degree to which such activities involve additional R&D expenditure. Alternatively, these differences might be explained by different approaches taken in the three surveys, as well as the representation of different groups of companies. The absence of a cumulative time series of data, with a constant group of reporting companies in this area, is extremely unhelpful.

4.6.3 Patenting by the minerals industry

The minerals industry differs from others, such as the pharmaceutical industry, in that patenting and intellectual property have not been as important for creating competitive advantage. Firms patent only when it makes strategic sense to do so. According to senior management in BHP, for example, when the company wished to make known internationally its world-class reputation in the manufacture of steel and coated metal products, it vigorously defends its patent position in these technologies. Furthermore, 'knowledge' is an increasingly important component of competitiveness for the minerals industry and patents are an indicator of ownership of knowledge. Table 4.12 presents the patenting activity of a number of Australian institutions.

Table 4.12: The top ten Australian patenting institutions

Name of Institution	Number of Patents 1981-92
CSIRO	130
ICI	128
Broken Hill	117
Australian Government	113
Unisearch	63
Telectronics PTY. Ltd	59
University of Melbourne	31
National Consolidation Ltd	25
CRA Limited (now Rio Tinto)	24
Memtec Limited	23

Source: (Patel and Pavitt 1995)

Insight into patent activities by Australian companies and institutions may also be gained by examining their patenting activity in the United States. Table 4.13 presents the number of patents approved (in the United States) for a selection of Australian minerals companies, the CSIRO and some Australian Universities. As stated above, minerals companies do not embrace patenting as a strategy for gaining competitiveness as readily as firms in other industry sectors. Most minerals-related patenting relates to downstream processing developments. CSIRO is clearly the most active patenting institution, well ahead of the minerals companies and universities.

Table 4.13: US Patents acquired by a selection of minerals companies & research organisations between 1976-99

Company	Number of patents 1976-99	Research organisation	Number of patents 1976-99
Alcoa	66	CSIRO	247
BHP	144	Australian National University	50
CRA (up to 1995)	36	Griffith University	4
Great Central Mines	1	Monash University	29
MIM Holdings	23	University of Adelaide	6
Placer Dome	1	University of Queensland	38
Rio Tinto/RTZ	9	University Melbourne	98
Hamersley (subsidiary of Rio Tinto)	1	University of Sydney	60
WMC Resources Ltd	1	University of Western Australia	16

Source: US Patent Office website http://patents.uspto.gov/, 17 November 1999

Table 4.14: R&D intensity in top 10 global industries and minerals

Industry	R&D Intensity: global firms 1977 (%)	R&D intensity: global firms 1998 (%)	Total number of patents for industry 1998	Total number of patents for industry 1999
Biotechnology	–	46.51	793	920
Pharmaceuticals	4.70	12.64	2,342	2,519
Software	–	12.08	770	828
Scientific, photo & control equipment	5.60	7.59	–	–
Electronics	4.30	6.46	22,941	25,016
Computer	5.50	5.80	9,682	9,635
Chemicals	3.33	4.66	4,898	4,879
Automobiles	2.80	4.22	3,458	4,071
Telecommunications	–	4.12	738	942
Rubber & Plastic Products	–	3.99	–	–
Minerals	0.9	1.09	422	397

Source: (Bowonder et al. 2000)

Table 4.14 compares the global minerals industry's performance with the top ten global industries in terms of R&D intensity and number of patents. The analysis was based on figures from the world's top 500 global firms, selected on the basis of sales turnover and R&D spending (eliminating firms that spent less than US$6 million on R&D per annum) (Bowonder et al. 2000). Overall the study found that the biotechnology, software and pharmaceutical industries had the highest R&D intensity and that many industry sectors had experienced a surge in patenting activities. Regarding the minerals industry, note that the majority of minerals firms included in this study were American and Japanese, downstream-integrated, light metal (aluminium) or steel manufacturers. BHP was the only Australian firm among the 15 minerals companies included in the study. This study highlights the low R&D intensity and low level of patenting activity in the minerals industry. It is worth pointing out, however, that minerals firms are sophisticated users of biotechnology and software, two of the most high-growth, and innovation-intensive fields. Indeed, some minerals companies have developed strategic competitive advantages based upon their technological capabilities in these industries. Billiton (now BHPbilliton) developed, patented and commercialised the BIONIC™ and BIOCOP™ bacterial leaching processes. Billiton's internal innovative capacity in this field provided the leverage necessary for the company's selection as a 50/50 joint venture partner by Codelco to gain access to copper deposits in Chile.

4.6.4 Rates of academic publication

Rates of academic publication in the minerals industry may reveal some information about trends in industry innovation, as well as of an individual company's approach to research (see Table 4.15). The data in the tables below represents material published in the ISI scientific publications database (prepared by Ms Linda Butler, RSSS, ANU) and does not include conference proceedings and annual reports.[76]

The most striking result is the performance of BHP, whose rate of publication has been akin to that of a division of CSIRO. John Toomey (personal communication), retired BHP senior executive, explained that this phenomenon reflected the historically strong commitment of the company to research. Furthermore, he likened the research culture to that of a university where performance is judged by the number of refereed scientific papers produced. This culture may be related to the fact that past directors of BHP's research centres were university professors and that support for this activity came from Board level.

BHP's (BHPbilliton) publication rate is expected to decline due to rationalisation of corporate laboratories and a move away from corporate funding toward business unit sponsorship of research. The latter change, to a focus on the interests of business units (time, cost, returns and confidentiality), is expected to introduce a cultural shift away from support for the publication of learned papers.

BHP (BHPbilliton), Rio Tinto, WMC and MIM have maintained an average annual publication rate of more than ten papers for the past two decades. This is an indication of their solid contribution to the knowledge base of the Australian MinIS. These companies conduct a large proportion of their research in collaborative arrangements. In 1995, MIM was the biggest sponsor of new projects in AMIRA (although not the largest contributor in dollar terms). Paul Keran from MIM said, "MIM wants to let the world know of their attitude to research and of

[76] A counteracting factor which may be affecting publication rates is an increased desire for publications to be in ISI listed publications, and thereby gain international recognition for the individuals and associations involved (Butler 2002). Thus, an overall decline in publication rate may be somewhat obscured by an increase in the number of publications going into ISI listed publications.

their level of competence in areas of expertise. Publications also promote the cross-fertilisation of ideas, visits from outsiders and the overall exchange of information."

CSIRO's contribution to research is clearly shown by its continued high rates of publication. There is a trend toward increasing publication rates for CRCs over the given time periods as the oldest centres only came into existence in 1991 and it takes time for publication rates to develop. Some of these CRCs have now expired or been refunded (see Chapter 7 for details).

Table 4.15: Rates of publication during three time periods

Company or Institution	Number of publications			Average Number of Publications per annum		
	1981-98	1994-98	1999-00	1981-98 (18 years)	1994-98 (5 years)	1999-00 (2 years)
Aberfoyle Ltd.	14	3	2	0.78	0.60	1.00
Acacia Resources Ltd.	2	2		0.11	0.40	0.00
Alcoa International Holdings Company	76	37	9	4.22	7.40	4.50
AMDEL Ltd.	45	3	2	2.50	0.60	1.00
Anaconda Australia Inc	4	2	3	0.22	0.40	1.50
Broken Hill Proprietary Group	758	275	60	42.11	55.00	30.00
Capricorn Diamond Ltd.	2	2		0.11	0.40	0.00
CRA Ltd. (now Rio Tinto)	209	83	34	11.61	16.60	17.00
Croesus Mining NL	2	2	1	0.11	0.40	0.50
CSR Ltd.	67	16	5	3.72	3.20	2.50
Delta Gold NL	3	2	2	0.17	0.40	1.00
Great Cent Mines NL	9	9	9	0.50	1.80	4.50
Hamersley Holdings Ltd.	11	9	2	0.61	1.80	1.00
HIsmelt Corp	2	2		0.11	0.40	0.00
MIM Holdings Ltd.	136	66	21	7.56	13.20	10.50
Normandy Poseidon Ltd.	5	5	2	0.28	1.00	1.00
North Ltd.	50	26	11	2.78	5.20	5.50
NorthParkes Mines	6	6	1	0.33	1.20	0.50
Pasminco Ltd.	110	60	13	6.11	12.00	6.50
Placer Dome Inc	11	6	2	0.61	1.20	1.00
Queensland Alumina Ltd.	10	6	2	0.56	1.20	1.00
Western Mining Corp Ltd.	160	73	31	8.89	14.60	15.50
CRC Mining Technology and Equipment	25	25	7	1.39	5.00	3.50
GK William CRC for Extractive Metallurgy	68	52	17	3.78	10.40	8.50
Australian Petroleum CRC	59	58	27	3.28	11.60	13.50
AJ Parker CRC for Hydrometallurgy	74	72	48	4.11	14.40	24.00
CRC for Australian Mineral Exploration Technologies	49	49	8	2.72	9.80	4.00
Australian Geodynamics CRC	25	25	26	1.39	5.00	13.00
CRC for Landscape Evolution & Mineral Exploration	28	28	21	1.56	5.60	10.50
CRC for Advanced Computational Systems	5	5	12	0.28	1.00	6.00
CSIRO Division Building Construction & Engineering	482	165	45	26.78	33.00	22.50
CSIRO Division of Exploration and Minerals	936	289	114	52.00	57.80	57.00
CSIRO Division of Minerals	872	238	75	48.44	47.60	37.50
Julius Kruttschnitt Mineral Research Center	105	65	30	5.83	13.00	15.00

NB The CRC publication data may be slightly exaggerated. Source: Ms Linda Butler, Australian National University September 1999.

4.6.5 *A brief desk-top review of minerals companies reported innovative activities*

An attempt was made to examine the innovative activities of minerals companies by conducting a 'desk-top' review of three Australian minerals companies, MIM, WMC, BHP (as noted BHP has since merged with Billiton) and the globalised Rio Tinto (formed from the 'CRA-RTZ merger' subunit Chapter 6). Figures were collected for a six-year period in order to elucidate trends. Company Annual Reports were the primary source of data but were augmented with statistics from patent databases and other sources. Again, it must be noted that this data can only be used as a guide to general trends and comparisons since companies vary in their definitions and reporting of sales, exploration and R&D. In addition, as companies often do not comment on their patent portfolios, two sources for this data were used: patents granted under the company's name (not subsidiary companies or internal technology groups) on US patent databases; and patent applications lodged in Australia as reported by the *R&D and Intellectual Property Scoreboard, 2000* (3 years data only) (Melbourne Institute of Applied Economics & Social Research 2000).

MIM Holdings Limited

Indicators of innovative activities	1995 (Aus$m)	1996 (Aus$m)	1997 (Aus$m)	1998 (Aus$m)	1999 (Aus$m)	2000 (Aus$m)	2001 (Aus$m)
Research & Development	9.8	1.1	–	6.3	3.4	2.0	2.1
Exploration						29.3	33.5
Patents granted in USA	4	4	1	0	0	0	0
Patent applications in Australia*	na	2	5	4	na	na	na
Sales revenue	2,528	2,583	2,150	2,664	2,854	2,973	3,376
R&D % sales & operating revenues	0.39%	0.04%	–	0.24%	0.12%	0.07%	0.06%

Source: Figures sourced from MIM's 2000, 1999, 1996 Annual Reports. *Australian patent applications R&D and Intellectual Property Scoreboard 2000 (Melbourne Institute of Applied Economics & Social Research 2000). Patent data obtained from the Derwent World Patents Index. Note: Patent data is expected to be under-representative as the search did not include an abbreviated company title as assignee.

MIM's expenditure on R&D and R&D intensity fluctuated dramatically, hitting significant lows in 1996 and 2000. The limited data on granted patents in the US and applications in Australia suggests that this activity is not important for MIM.

WMC Limited

Indicators of innovative activity	1995 FY (Aus$m)	1996 FY (Aus$m)	1997 (Dec 31) (Aus$m)	1998 (Dec 31) (Aus$m)	1999 (Dec 31) (Aus$m)	2000 (Dec 31) (Aus$m)	2001 (Dec 31) (Aus$m)
Research and Development (net book value)	10.3	6.1	10.1	8.4	4.9	9.8	7.4
Exploration Expenditure (net book value)	na	na	4.0	11.5	27.0	72.2 (total)	77.6 (total)
Patents granted in USA	–	–	–	1	–	–	–
Patent applications in Australia	na	2	5	4	na	na	na
Sales revenue	2,052.8	2,349.6	2,130.2	1,721.4	2,094.8	3,092.0	2,796.9
R&D % sales	0.50%	0.26%	0.47%	0.49%	0.23%	0.32%	0.26%

Source: Figures from 99,98& 96 WMC Limited Annual Report–Financial Statements. Patent data obtained from the Derwent World Patent Index. Australian patent applications R&D and Intellectual Property Scoreboard 2000 (Melbourne Institute of Applied Economics & Social Research 2000).

WMC's R&D intensity ranges between one-half and one-quarter of a per cent, and expenditure on R&D dropped to a five-year low in 1999. Unusually for the industry as a whole, expenditure on exploration increased dramatically over the three years to 1999. Like MIM, the data on patents suggests that this is not an activity of importance for WMC. WMC refers to its 'tradition of technical excellence and innovation' in its 2001 Annual Report and further makes a qualified claim of a potential $1.2 billion return to the company if its portfolio of research projects is implemented (the qualification being a 22 per cent likelihood of this portfolio being successful) (WMC 2001).

Broken Hill Proprietary Company Limited

Indicators of innovative activity	1996 (May 31) (A$m)	1997 (May 31 (A$m)	1998 (May 31) (A$m)	1999 (May 31) (A$m)	2000 (June 30) (A$m)	2001 (June 30) (A$m)
Exploration	576	689	712	454	293	394
R&D	190	195	174	221	94	35
Patents granted in USA	160	180	166	182	105	na
Patent applications in Australia	35	30	10	na	na	na
Sales revenue	19,800	22,300	24,600	19,229	21,506	20.698
Exploration % sales	2.9%	3.0%	2.8%	2.36%	1.36%	1.90%
R&D % of sales	1.0%	0.9%	0.7%	1.15%	0.44%	0.17%

Sources: BHP Annual Reports, 1998-2000, BHP Description of Business and Financial Statements, 1996 & 1999. US Patents data obtained from http://www.delphion.com/ Australian patent applications R&D and Intellectual Property Scoreboard 2000 (Melbourne Institute of Applied Economics & Social Research 2000).

BHP is an interesting case since its R&D expenditure and intensity were strong by industry standards from 1996-1999. A massive drop in R&D expenditure and a halving of exploration expenditure occurred in 2000, a year when BHP's priority was restructuring the company in preparation for is merger with Billiton (approved by shareholders in May 2001). While BHP has traditionally been a top performer in terms of industrial R&D in Australia, its reported R&D expenditure in 2001 is a mere $35 million, approximately one-fifth of the amount invested in R&D in the mid 1990s. This change is addressed in more detail in Chapter 6. The large number of patents held by BHP is a reflection of its capabilities in downstream steel casting and coatings technology.

Rio Tinto

Indicators of innovative activity	1996 (Aus$m)	1997 (Aus$m)	1998 (Aus$m)	1999 (Dec 31) (Aus$m)	2000 (Dec 31) (Aus$m)	2001 (Dec 31) (Aus$m)
Research and Development	106 (96-97)*	105 (97/98)*	84 (98/99)*	68	67	75
Exploration Expenditure	322	321		211	234	251
Patent applications in Australia	2	5	4	na	na	na
Gross turnover	10,797	12,427		14,421	17,212	20,187
R&D % gross turnover				0.47%	0.39%	0.37/%

Source: Figures from 01, 99 & 97 Rio Tinto Annual Report–Financial Statements. Australian patent applications and * R&D expenditure from 'R&D and Intellectual Property Scoreboard 2000' (Melbourne Institute of Applied Economics & Social Research 2000).

Rio Tinto is the result of the first mega-merger in the Australian minerals industry, between London-based RTZ and CRA, its Australian subsidiary, in 1995 (see CRA-RTZ merger subunit, Chapter 7). The figures in the table above are for the merged entity Rio Tinto. Little data on patenting was found. As is discussed in Chapter 6, RTZ's predominant 'mining finance-house' culture translated into a low R&D intensity in the new entity, Rio Tinto.

4.7 Chapter summary

The global minerals industry's current competitive dynamics are largely being driven by three factors: globalisation and the knowledge economy; historically low commodity prices; and the need to meet new costs imposed by legislative and regulatory constraints relating to sustainable development. The Australian minerals industry is not isolated from these dynamics, as suggested by recent rates of consolidation, amalgamation and changes to strategy.

The Australian minerals industry has been misrepresented in terms of its economic and innovation-based contributions to Australia. This is due to a 'narrow' definition of the industry and a lack of understanding of how the industry competes. The lack of understanding of its competitive dynamics is compounded by linear views of innovation and the use of simple quantitative measures of innovative effort. There is an emerging understanding of how all this should be viewed. Knowledge-based continuous improvements (incremental innovation) are key factors in increasing competitiveness through increases in productivity. The industry's features of capital-intensity, mass-production, and poor scope for new product differentiation, emphasise the potential benefits from incremental innovations. These incremental innovations are sometimes very valuable since even small changes in productivity can be comparatively cheap to introduce and can easily translate into substantial economic returns due to the sheer scale on which commodities are produced.

In Australia there is a despairing lack of continuity in the collection and reporting of indicators of innovative effort, making it very difficult to assemble reliable data beyond the standard (linear view) report from the ABS. Furthermore, reporting 'innovation intensity' for an amalgamated group of industries is unhelpful since it takes a 'one size fits all' approach to industries' technology and innovation strategies, and wrongly assumes, for example, that patenting is equally important for all industries (Bowonder et al. 2000, Hicks et al. 2001). The IS approach specifically warns against simplistic and short-term approaches to the measurement of innovation-based economic growth. It is well known, for example, that growth in R&D investment (by firms or government) cannot be used to explain the innovative and internationally competitive performance of industries or national economies.

Malerba sums up the issue succinctly when he says:

> The basic point to be made here is that simple observations and analyses based on quatitative data on R&D expenditures, even if highly disaggregated by secotor or source of funds, are not able to explain fully and satisfactorily a country's innovative and competitive performance. R&D is a very articulated process, with several dimensions and numerous casual mechanisms. To understand this process it is necessary to couple quantitative and qualitative analyses and to include in such analyses both institutional and historical variables. (Malerba 1992:315)

The IS approach used in Chapters 6 and 7 develops a much more revealing picture of the scale and direction of innovative effort in minerals firms, and the degree of interaction between public-sector knowledge bases and firms' innovative activities that takes place within the MinIS.

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Chapter 5:

Using an 'historical lens' to explore innovation in the minerals industry

5.1 Introduction

This Chapter presents an historical level of analysis which aims to determine more precisely how innovation contributed to the Australian minerals industry's development and performance. The value of an historical view is well established in the technological innovation literature and is an important tool when using the IS approach (see Chapter 3). This level of analysis is not a recounting of Australian minerals history.

Given that the Australian minerals industry has not been examined with an innovation systems approach, the aspirations for this level of analysis are quite specific. The IS approach says that studying the origins of systems of innovation is informative and useful when trying to understand (and identify) a system in contemporary terms (Edquist 1997, Freeman and Soete 1997, Freeman 2002, McKelvey 1997, Malerba 2002). The literature further emphasises that capacities for technological innovation develop over time. Thus, the basic logic behind this historical lens was to map the origins and development of the mining industry and look for evidence (key elements) of the origins of an Australian MinIS.

In the first instance, it was hoped to identify a MinIS early in the industry's history, perhaps at its origins, and thereby gain insight into the characteristics that ultimately shaped the overall system's structure and performance. If evidence for a MinIS could be found, then it could be revisited to see whether much had changed. Thus, this study took these notions into account and examined the history of the Australian minerals industry in the following manner.

- First, the origins of the industry were examined, starting with the gold rush days of the 1850s. After this colourful but technically unsophisticated start, the Australian industry went through a remarkable period of growth based largely on the back of two notable examples of process innovation. These were Cyanide Processing and Flotation. These innovations are the subject of two case study subunits of analysis. These innovations contributed to a great boom in the minerals industry that started in the late 1880s and lasted until post-WWI. They marked a great leap forward in the innovative capability of the Australian industry.

- Second, the Australian industry was revisited in the mid-1980s, a time when the industry's performance was again strong. The success of a new (to Australia) diamond mine was dependent upon the development of a 'diamond sorting' machine. The latter example of innovation is the subject of this Chapter's third case study subunit, Diamond Sorters.

The Chapter's discussion analyses this historical view of the Australian minerals industry from an IS viewpoint. This will provide insight into how components of a MinIS influenced development, growth and transformation in the industry.

5.2: Colonial Australia's regional development – built on sales of gold and silver

5.2.1 Australia's early transformation brought about by the 1851 gold-rush

English law inhibits early exploitation of minerals

Prior to the gold rushes of the 1850s, Australia's penal colony mentality endured. The British Crown governed the then independent colonies of New South Wales, South Australia, Western Australia and Tasmania (Van Diemen's Land).[77] The colonies each had a local administrator or governor (appointed by the Crown) and a Legislative Council. The governor held the right of veto over any bills initiated by the Legislative Council and, most importantly, controlled any revenue derived from the colony, particularly from land sales and leases (Maddock and McLean 1984). Under this form of governance, Australia inherited the English law which stipulated that gold and silver were 'royal mines' and all such deposits belonged to the Crown (Blainey 1994). This archaic English law perhaps marks the start of what has been a history of ill-conceived policy with regard to creating wealth from Australia's resource endowment. Despite numerous findings of gold and geological reviews recommending panning for gold in the rivers, the first two generations in Australia's penal colonies did not take to gold mining, and the first mines established in 1884 were 'non-royal' copper mines in South Australia.

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[77] The colony was comprised of four independent settlements with Victoria split from New South Wales in 1851 and Queensland in 1859. Bicameral parliaments had been established by 1856 in New South Wales, Victoria, South Australia and Tasmania. To a large extent these parliaments were modeled on the Westminster system with the notable exception that all authority was derived from a written constitution. Federation in Australia occurred in 1901.

Early attempts to prevent and control an Australian gold rush

The Australian gold rush began in New South Wales in April 1851 (three years following the Californian rush), despite the fact that gold mining was actively discouraged by Crown administrators in all Australian colonies. Governor La Trobe of Victoria believed that a gold rush was undesirable for a young colony and had succeeded in preventing an Australian rush two years earlier by arresting some 40 prospectors for trespass (Blainey 1994, La Croix 1992). The gold rush started in New South Wales, despite Crown ownership of gold (and a disbelief in the possible existence of payable gold fields[78]). This rush was due largely to the individual efforts of Edward Hammond Hargraves. Upon returning from the California gold rush, Hargraves armed with his new-found knowledge of gold mining, proffered the notion that gold was not being mined in Australia because 'few who sought it knew where to search or how to search' (Blainey 1994:15). Hargraves, aware of previous finds in the Bathurst region, inflamed the story locally to encourage others to search for gold. By the time the Governor of New South Wales came to believe the unbelievable and ordered the Inspector of Police to halt the digging of Crown land, there were approximately five hundred 'diggers' working furiously at Ophir. The government faced a crisis. It was too late to ban digging for gold and the rush quickly followed in Victoria.

Australian officials anticipated that a gold rush would have a negative impact upon the fragile Victorian colony, disrupting primary industry, urban services and society generally (Blainey 1962, Blainey 1994). Such fears saw enactment of the Crown's prior claim to all gold and silver through the introduction of a licensing system. All diggers required a licence before they could dig on Crown land. Between the discovery of gold and enforcement of the licensing system, however, the miners of Ballarat established their own regulatory system, as opposed to collapsing into anarchy. On September 8 the Melbourne *Argus* reported that:

> Six-and-twenty tents stretch along the hills commanding the creek; upwards of a hundred diggers are already spread along its margin, which is divided in proportion to the numbers composing each party, by mutual consent. The greatest unanimity prevails, and all are resolved to preserve themselves in their present integrity... (Crowley 1980:205).

The licensing system was based upon 'claim size', which was limited to eight square feet per individual.[79] While this system initially quelled a rush-induced crisis, the inherent unjust nature of a tax upon an individual's labour, as opposed the finding of gold, eventually triggered Australia's only armed uprising at the Eureka Stockade on December 3, 1854.

From this infamous moment in Australian history, the events of Eureka provoked an evolution in Australian minerals law to a point where it '...was recognised at the turn of the century to be very detailed and superior to mining law in other countries' (La Croix 1992:225). In Victoria, revenue from the licence tax was replaced by an export duty equivalent to 3% of the gold price (2s.6d per ounce). A new egalitarian legal system included: suffrage legislation for adult males

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[78] Advice from the American Consul supported skepticism by saying that Australian mountains were not high enough to yield gold (Blainey 1994).

[79] This was increased to a claim size of twelve square feet in 1853. By contrast Californian claims were approximately 100 square feet or 156 times larger (La Croix, 1992).

in 1857 (Victoria); local courts[80] to serve major mining districts; addition of eight representatives from new mining electorates to the Legislative Council; and establishment of a 'miner's rite' at a cost of £1 per annum, which authorised digging for gold and the right to stand for and elect members to the local courts and Legislative Council.

Mineral development was *enabled* by the institutional change to a more flexible legal system that could meet the needs of mining techniques used in a particular region (La Croix 1992:215). As such it was recognised as one of the most advanced in the world (David and Wright 1997). As alluvial gold deposits were depleted in Ballarat and Bendigo and workings shifted underground, the local mining courts relaxed legislation controlling claim size to ensure that deep mining was economically viable. According to Freeman (2002), 'complementarity' between legal systems and industry (as well as other social sub-systems) is a critical element for the long-term attainment of, and maintenance of, healthy innovation systems (Freeman 2002). It seems that 'complementarity' between the gold industry and minerals law was achieved in Australia at this time.

5.2.2 Colonial development – impact of gold rush

While social and industrial dislocation followed the rapid growth produced by the gold rush, it is clear that the gold rush also induced immense positive changes in Australian colonial society, politics and economies. Thus, in essence, the gold rush was the event that transformed what was a penal colony into a fledgling nation. In the decade 1850 to 1860, the population of Australia nearly trebled. It reached 1.1 million and between 1850-53 and the value of exports underwent a ten-fold increase and remained high for the remainder of the decade (see Table 5.1). Moreover, Australia benefited from the fact that most migrants settled and reinvested their labour, savings and skills in their new home. Many academics endorse the view that Australia was transformed by gold. For instance:

> No subsequent decade in Australian history has witnessed comparable upheavals. (Maddock and McLean 1984:1064)

and

> Possibly no other country in the world had been so quickly transformed by metals. The normal growth and achievement of several decades were crammed into one. Australia ceased to be a land of exile in British eyes and became a respectable field of migration and investment. (Blainey 1994:1959)

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[80]The Gold Fields Act ushered great changes to the management of the gold fields, for details of the legislation see Act 18 Victoria, No. 37, 12 June 1855, (La Croix 1992).

Table 5.1: Australian population and trade growth during 1850-1860

	1850	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860
						POPULATION (thousands)					
Population											
Victoria	76	97	168	222	284	347	390	457	496	521	538
Australia	405	438	514	601	695	793	877	970	1,051	1,097	1,146
% Change in Australia	8.6	8.0	17.4	17.0	15.6	14.2	10.5	10.7	8.3	4.4	4.4
Migration											
Net Migration	23	22	65	74	78	80	63	71	56	21	21
Assisted	9	8	26	31	37	41	17	31	17	11	7
Assisted Males	4	4	13	12	15	18	8	15	8	4	3
						EXTERNAL TRADE (millions of pounds, nominal)					
New South Wales											
Exports	1.4	1.8	4.6	4.5	4.1	2.9	3.4	4.0	4.2	4.8	5.1
Imports	1.3	1.6	1.9	6.3	6.0	4.7	5.5	6.7	6.1	6.6	7.5
Victoria											
Exports	1.0	1.4	7.5	11.1	11.8	13.5	15.5	15.1	14.0	13.9	13.0
Imports	0.7	1.1	4.1	15.8	17.7	12.0	15.0	17.3	15.1	15.6	15.1

Sources: (Maddock and McLean 1984:1048).

5.2.3 Changing cultures in early minerals industry

Scholars emphasise the importance of 'a culture of innovation' among key determinants in a system of innovation (see Chapter 3) (Lundvall 1992, Nelson 1993, Edquist 1997). This essential ingredient was certainly missing during the gold rush, where the 'digger' was dominant. A bare minimum of available new technologies, such as the steam-powered engine, was transferred to the Australian goldfields in the 1850s. Even at difficult fields, such as the deep sinkings at Ballarat, groups of 'diggers' chased gold leads with shafts up to 160 feet deep, removing earth and water with a windlass turned by two or three men.[81] The introduction of machinery and new technology was minimal because a digger, by nature, preferred to struggle on independently with low-tech, unevolving methods and tools:

> Up to the middle of 1853 the digger had proved to be a man of resource, an improviser, but not an inventor. As a writer in the *Empire* put it in August 1853,

[81] Eminent Australian historian, Manning Clark, credits the lack of innovation and machinery at Ballarat as one of the factors which contributed to unrest at Eureka (Cathcart 1993). Although intensive labour at Ballarat offered no guarantee of payment, the idea of working for a company which utilised new technology such as steam-engines, was as abhorrent as the 'bloody licence tax' (Cathcart 1993). In contrast, much machinery was introduced at Bendigo's goldfields, along with quartz-crushing techniques. Bendigo offered a future working for wages, whereas Ballarat, without new mining machinery and methods, offered no such security (*ibid*).

> the diggers had only dug holes. They remained after two years what they had been at the beginning, 'shifting, irresolute and ignorant diggers.' Colonial peoples not only did not make their own history: their very status, their dependence on Mr Mother Country, drained away their creative energies. By the end of 1853 every party was still digging its own hole without any reference to the doings of others. The pick and shovel and cradle still constituted the principal machinery of Australian goldmining. Their proudest boast that they were British, that they had inherited the British constitution and the birthrights of Englishmen condemned them to dependence, to that state of pupillage and infancy out of which neither prophets nor inventors could grow. They had borrowed all the steps forward—the railway, the steamship, the electric telegraph, political institutions and law from Britain, and the road coach from America. (Cathcart 1993:248-49)

Culture of Cornish miners and the 'selective method of mining'

As mine workings moved deeper, a gradual shift in culture, organisation and method of mining emerged. An environment with an increasing requirement for capital (to construct underground operations) saw companies begin to take the place of informal business arrangements. Concurrently, organised teams of labourers under the management of skilled miners began to replace the individual diggers. The managers were mostly Cornish skilled miners, and their culture and method of mining dominated the Australian gold fields. The Cornish miners were well known for their practical ingenuity and ability to organise their labour. However, the Cornish 'selective method of mining' was traditional and unscientific. Success of this method centred upon the skilled miner predicting and following rich seams of ore as they descended underground, while concurrently managing the activity of unskilled teams of labourers. These miners were artisans, whose skills were founded upon apprenticeship and long practice. This method worked well where it was established, in Cornwall, with its availability of cheap, unskilled labour (women and children). Little thought was given to pre-planning or subsequent handling and treatment of ore (transportation, sorting, milling and processing). In essence, selective mining was a *low-volume, high-value* technique that prioritised the quality of the ore extracted (Hovis and Mouat 1996).

The Cornish miner and mining tradition dominated the early Australian mining industry between 1860 and the 1880s. This was a period of expansion into metals other than gold (such as tin, copper, lead and silver) and mechanisation of Australian mining. This was not a period of innovativeness in Australian minerals, although some, such as Burt (2000), have mistakenly believed that mechanisation under the Cornish system is an example of innovation (Burt 2000). The low-volume, high-value tradition remained unchanged by the introduction of mechanical drilling and blasting equipment that enabled excavation of greater amounts of ore. Skilled miners continued to conduct traditional tasks with new machinery. Without innovation accompanying mechanisation, returns from selective gold mining were diminishing in Australia throughout the 1880s. Victoria's 614,838 ounces mined in 1889, for example, was a far cry from the three million ounces of gold mined in 1856 (Todd 1995:112). The Cornish miners were, in effect, artisans who never realised the need for metallurgical or engineering skill, and their dominance has rightly been cited as a reason for an early lack of innovativeness in Australian minerals (Todd 1995, Cathcart 1993, David and Wright 1997, Blainey 1994).

5.2.4 Development of minerals education and training infractructure – role of Schools of Mines

The existence of a 'knowledge' gap between Australia and minerals districts in Europe, Africa and America, at the time of the gold rush is well-documented (Blainey 1994, Haas 1990, Todd 1995, David and Wright 1997). At this time Australia was lacking the most fundamental determinants driving the first and second techno-economic paradigms (public research infrastructure, education and training facilities, professional engineers, institutes of technology, knowledge flows etc), and even though the technology was externally available (particularly from the UK), cultural, political and financial trends inhibited technological change and development.

Attempts to establish minerals education began early in the industry's history[82] (1860s) at both grass-roots and government levels (Haas 1990). These admirable attempts to provide tertiary 'professional' minerals education and training, however, could not be sustained since the new Australian colonies lacked the basic foundations for a tertiary education and research system. The Universities of Melbourne and Sydney were founded in the 1850s, but they essentially remained as teaching facilities until the turn of the century (Inkster and Todd 1988). The University of Melbourne, for example, established a 'Certificate of Engineer' course in 1861, only to see its demise due to a lack of industry acceptance and able students. A phenomenal boom in Australian Schools of Mines followed, with a school opening in virtually every Victorian[83] mining town during the late 1880s, with a similar trend following in other States[84] (see Table 5.2). This is interesting because, rather than providing specialised educational services for the minerals industry, Schools of Mines seem to have temporarily filled the considerable gap in Australia's education system to provide more general educational services and were often the only mechanism by which regional populations could improve their education. Actual 'miners' attending these schools represented a minority of students. The Ballarat School of Mines, for example, opened in October 1868 with a curriculum developed in consultation with the London Royal School of Mines (Haas 1990). Any lofty ideals centred around advanced learning soon disappeared, however, in favour of Certificate courses which began in 1871. These Schools had to evolve to meet the realities of educational needs at that time in Australia.

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[82] Initiatives were present at government and local levels: the Victorian government implemented Select Committees and Mining Commissions to appraise mining education; and local mining communities organised their own Institutes and Associations in order to, for example, 'establish a mining museum and facilitate the presentation of papers on mining topics,' (Haas 1990:279).

[83] The Victorian expansion correlated with a buoyant State economy and Victorian government spending on science and technology education increased from £10,500 in 1887 to £38,308 in 1890 (Haas 1990:282).

[84] New South Wales (NSW) differed to the other states as its Department of Public Instruction administered mining courses and hence, diluted localised attempts to establish Schools of Mining (Haas 1990). In 1893 a NSW mining school was established within the University of Sydney by incorporating it into the engineering faculty. The latter step centralised professional mining education, and based it upon a solid academic foundation. Moreover, the 1890s were a rather depressed period for the mining sector and yet mining engineering education was the strongest new field of engineering education (Edelstein 1988).

The lack of a state run secondary education system meant that many classes were not directly concerned with mining education *per se* but with continuing education; and students were often ill prepared for study and did not finish courses; and, while miners and managers were catered for, advanced training for engineers and metallugists was lacking (Haas 1990:281).

Table 5.2: The evolution of education and training facilities for the minerals industry

State & town	Year	Educational organisations, associations etc
Victoria	1852	• Alfred Selwyn (British) appointed Mineral Surveyor for Victoria, assistants from Royal School of Mines (UK)
	1863	• Chemical and metallurgical lab to assist survey, established at the University of Melbourne
Bendigo,	1855	• Australian Miners' Scientific Association
	1857	• Became the Mining Institute of Victoria
	1859	• The Bendigo Miners' Association
Ballarat,	1860	• Mining Institute of Ballarat
	1868	• Ballarat Mining Board decide to establish Ballarat School of Mines
	1871	• Classes began
	1887	• Affiliation with University of Melbourne which lasted until 1894
	1873	• Sandhurst (later Bendigo) School of Mines
	1874	• University of Melbourne appointed part-time lecturer in mining
	1882	• Upgraded to 4 year Bachelor of Civil Engineering
Geelong,	1887	• Melbourne Working Men's College • Gordon Technical College • Castlemaine School of Mines
	1888	• Maryborough and Kyneton School of Mines
	1889	• Bairnsdale, Creswick and Sale School of Mines
	1890	• Ararat, Clunes, Daylesford, Harrietville and Stawell School of Mines
	1891	• St Arnaud School of Mines
South Australia	1888	• Board of Inquiry formed to examine need for technical education in South Australia
	1889	• South Australian School of Mines and Industries
	1891	• Schools of Mines established at Gowler, Moonta, Kapunda, and later Peterborough and Port Pirie
Tasmania	1883	• Tasmanian Royal commission on Public Education heard of need for a school of mines
	1884	• Zeehan School of Mines and Metallurgy
	1902	• Affiliated with the University of Tasmania
	1901	• Beaconsfield School of Mines
	1913	• Queenstown School of Mines
Queensland	1897	• Charters Towers Mining Institute
	1900	• Became the Charters Towers School of Mines, operated under Queensland Department of Mines
Western Australia	1902	• Coolgardie Institute moved to Kalgoorlie in 1904
	1904	• Western Australian School of Mines (in Kalgoorlie)
New South Wales	1883	• Board of Technical Education
	1884	• Certificate of Industrial Expert of Sydney Technical College
	1891	• Diploma courses available at Broken Hill, Newcastle, West Mainland and Wollongong
	1893	• Mining school at University of Sydney, extension of engineering faculty, caused centralisation of mining education

Source: (Haas 1990)

At the time of Federation, formally organised public systems of education had begun to catch up with societal and industry needs (Inkster and Todd 1988). Most Schools of Mines were incorporated into state technological education programs, and universities came to be recognised as the culminant institutions for higher education in mining (Haas 1990, Todd 1995, Blainey 1994). Haas defends the role of early Australian Schools of Mines against doubt cast upon their success in the literature (Haas 1990:290). From an evolutionary innovation systems perspective, however, such doubts reveal a lack of consideration of the Australian 'selection environment' or broader social context at that time. Clearly, as conditions did not exist for absorption of 'traditional' Schools of Mines, these Schools responded rapidly and successfully to suit the prevailing conditions, namely the lack of an education system. The fact that early Schools of Mines serviced the educational needs of the wider community, as opposed to catering to evolving minerals industry needs, should be interpreted as a significant benefit for Australia's evolving education system and not a failing. In addition, those schools situated in remote minerals regions, such as Kalgoorlie, Zeehan and Charters Towers, did develop expertise in minerals education and training (Haas 1990, Todd 1995). The only reputable school of mines that still exists is the Western Australian School of Mines at Kalgoorlie which is associated with Curtin University.

5.2.5 A note on sources of capital and regional development in the early Australian gold industry

Up until the 1880s, Australians owned almost all of the mines in the country (Blainey 1994). The UK, the wealthiest nation in the world, financed Australian public works but tended not to invest directly in Australian mines. Stocks in American railways or mines in North America, Spain, Sweden or Cornwall were favoured by British investors. Thus, the capital for Australia's early mining operations was sourced nationally, primarily through a dispersed financial system of regional stock exchanges. Bendigo and Ballarat stock exchanges were busier than Melbourne's until the 1890s. A permanent exchange in Sydney came in 1872 after a local gold rush (Hill End) (Blainey 1994). This early investment structure was advantageous as it enforced positive cycles of regional reinvestment, as opposed to profits being siphoned to other regions or nations (Walker 2001).

Speculation in gold shares was perhaps more frenzied than the modern 'dot.com' stock-market boom, and shared its characteristics of poorly informed investors, gullible targets for risky projects, and corrupt operators. Buoyant expectations also encouraged investment for associated developments by bankers, import merchants, commercial builders and the public purse (by spending on State infrastructure). According to Blainey (1994) the primitive state of company law made mining shares more risky than physical mine development and kept high net-worth investors away from minerals, as well as the banks that were exposed to the risk associated with the development of many mines (that is, those that financed speculation) (Blainey 1994:96). In response, in 1871 the Victorian State Legislative Council passed a *No Liability Act* for minerals companies (the principle of which was adopted by other States), which meant investors could only lose the amount of their direct investment and not be liable to greater losses incurred when a project failed. The Act may have overcome an initial shortfall in capital investment, however, it also contributed ultimately to a dearth of capital as it encouraged companies to initiate new projects with insufficient funds, which increased the overall risk of failure (Blainey 1994).

The potential for British capital investment in Australian minerals companies changed with the telegraphic communication link between the two countries (Blainey 1994). As the gold price was fixed, speculators required timely news on gold discovery and production to incite share-price fluctuations. The Queensland town of Charters Towers was the first to exploit British capital, due in no small part to effective promotion by the Queensland government. In 1886, it staged an attention-grabbing exhibit at the Colonial and Indian Exhibition in London, transporting over one hundred tonnes of gold-bearing rock to be crushed 'on-show' by a stamp mill. Before the boom ended a year later, twenty-seven Queensland mines were floated in London (Blainey 1994). London replaced Melbourne as the primary source of capital for Australian mineral developments. In a virtuous cycle of development, Charters Towers reinvested its new source of capital and became the second largest town in Queensland. The Cassel Gold Extracting Company, developer and patent holder for the cyanide process, chose Charters Towers as the base for its Australian processing plant and plans for technology transfer. Charters Towers was the most productive Australian goldfield between 1891 and 1896 (Blainey 1994, Todd 1995).

5.2.6 A note on continued regional development

Industrial expansion in Europe sustained a global minerals boom which began with the Californian gold rushes in the late 1840s and lasted until the early 1890s (Blainey 1994, Mouat 1996). Silver, copper, lead and other minerals were shipped from developing regions including southern Africa, western North America, as well as Australia.

The minerals industry continued to support Australia's economic development. The interest in minerals prospecting, aroused by gold, flowed onto prospecting for other metals, and many base metal deposits were discovered and mining initiated during the late 1880s. Australia became a major producer of the world's tin in the 1870s to early 1880s and also produced copper, silver, and lead. As confidence in quality and long-life of new mines grew, so too did investment in regional townships and supporting infrastructure, services and related industries. In monetary terms, more gold was exported than wool in the 1850s and 1860s, breaking an economic dependence upon wool exports (Inkster and Todd 1988). The dynamics of the gold industry drove decentralisation of the population (total population trebled in the first twelve years after the discovery of gold), changed the perception of Australia among potential immigrants to that of a 'respectable' destination (as opposed a land of exile), and opened the society's structure of opportunity away from one that favoured the elite 'landed gentry' (Blainey 1994). The new minerals-based economy demanded investment in commercial and public infrastructure, boosted domestic markets for foodstuffs and manufactured goods (mines in particular created markets for tools, timber, candles, pumps, engines and other equipment), and created an atmosphere of optimism and self-belief in a new nation.

Discovery and minerals-boom at Broken Hill

The fabulously rich and immense silver-lead-zinc Broken Hill load was 'discovered' in 1883 and continues to be widely regarded as one of the world's greatest (Mouat 1996). According to Blainey (1994), the long low 'Broken Hill' was a distinctive landmark in the flat and barren landscape of Western NSW. An outcropping iron cap stretched for 1.2 kilometres along the rise and slopes were covered with boulders of manganese and iron oxides. Twenty years of settlement preceded recognition of the Hill's potential (Blainey 1994)

The Broken Hill Proprietary (BHP) company was among the first to begin operations in 1885. Two years later, the fledgling company transported 48 tonnes of ore (by bullock cart) to the Intercolonial Smelting and Refining Company in Melbourne, and returned 35,600 ounces of silver (Blainey 1994). The silver, placed on display at the City of Melbourne bank, began the great Australian boom in silver shares (during its peak, eighteen new silver companies advertised their prospectuses in as many days). This provided the capital to fund mining operations, smelters, and more tests of deposits at Broken Hill. It was Australia's first inter-colony boom, with substantial investment coming from other colonies.

Development of Broken Hill marks a significant turning point in the industry's culture, dominated previously by the Cornish. This shift is illustrated by BHP's 1886 decision to source knowledge and experience in mine engineering and metallurgy, necessary for development of the challenging Broken Hill deposit, from the Rocky Mountain states of America:

> The directors sat around a dark table in a small room in Collins Street, Melbourne, in July 1886 and made perhaps the most momentous decision in Australia's industrial history. They decided to send Wilson abroad to sign the best man money could sign. And they sent him not to Cornwall, which had long been the crumbling home of Australia's mining skills, but to the United States, which was probably the most advanced mining country in the world. (Blainey 1994:150)

Introduction of mining at Broken Hill had an enormous impact on the local area. A rail link was opened in 1888 and in the space of just three years the settlement at Broken Hill had expanded to the largest in the State of New South Wales. An 1891 census estimated that 20,000 people inhabited the town and earnings from mining operations were greater than all of Victoria's gold operations (*ibid*). The economic impact of the field was also far-reaching and large. Supplies were sourced from South Australia which revived that State's flagging development, creating employment in silver smelters, wharves and railways, as well as stimulating demand for agricultural produce and other services. Machinery and equipment were sourced from Europe and America. In one instance, Oregon (Douglas fir) logs were shipped from California for use in construction of vast underground workings (Walker 2001). The great silver boom ended abruptly in 1892 in a rapid spiral of decline. Falling silver and lead prices, devaluation of the field as shareholders abandoned inflated stocks in local companies and exhaustion of easily treatable ores ended the opportunity for quick returns. This did not, however, signal the demise of the field. As outlined below, Broken Hill had developed into a highly competitive district with many large companies. This, plus the richness of the ore, sustained the industry.

The radical process innovation, which released a far greater proportion of minerals wealth at Broken Hill, is addressed in the Flotation subunit below (Section 5.3.2).

5.3 Advent of significant capabilities for innovation – processing innovation

5.3.1 Successful transfer of new processing technology, cyanide processing

The invention of cyanide processing for the recovery of gold from its ores was filed for patent protection by the Scottish company, Cassel Gold Extracting Company, in October 1887 (Lougheed 1989). The cyanide process held the potential to solve a crisis threatening the world's gold industry in the 1880s. As alluvial gold deposits were exhausted, extraction methods of the day were failing in the treatment of low-grade, unoxidised (refractory), gold-bearing ores, due to failure of metallurgical (mercury-gold amalgamation) or commercial (chlorine treatment) reasons. Following a year of experimental development by the Cassel Company, which included field-trials at a small processing plant at Ravenswood in Queensland, the Cassel Board agreed on a strategy for the international diffusion and practical implementation of the cyanide process. The company's 'best', who embodied significant technical knowledge and skill, would travel to the world's established centres of gold mining (initially Australia, New Zealand and South Africa) to facilitate the transfer of cyanide process technology. Concurrently, the home-based Cassel company would support technology transfer through continuous improvement (experimental development) and perfection of the process' working details (Lougheed 1989).

Barriers to the use of the cyanide process were experienced in every major gold-mining nation into which it was introduced, resulting in significant national time-lags in uptake and diffusion of cyanide processing (Lougheed 1989, Jack 1984, Todd 1995, Burt 2000). In the Transvaal the rate of diffusion of cyanide processing was most rapid, being adopted during 1888-91, followed by New Zealand in 1893-94. It was less rapid in Australia, where introduction occurred early in 1888, but the process was not widely embraced by companies until 1897. Adaptation was slowest in the United States where, despite successful demonstration of cyanidation in 1891, there were only 40 cyanide works in the country by 1897 (Lougheed 1989, Jack 1984, David and Wright 1996).

The fact that Australian production of gold by cyanide extraction rose from zero to 683,900 ounces at the turn of the century, compared with the US at 497,280 ounces and New Zealand at 452,524 ounces (Todd 1995), shows that the transfer of cyanide processing to Australia was a success. A critical ingredient of this success was the creation of the skills, knowledge and infrastructure that supported radical technological innovation.

The Cyanide processing case study subunit

A description of the cyanide process

In essence, the cyanide method of gold processing involved two major steps. The first step exploits a physical property of gold; namely that gold dissolves in the presence of alkaline cyanides. The second step, a precipitation, then isolates gold from the alkaline solution. In practice the method involved mechanically agitating crushed ore in a 0.5 per cent potassium cyanide solution, followed by draining off the solution and running it through a mass of zinc threads. The powdery gold precipitate was thus isolated onto the zinc.

Cyanide extraction had several advantages, despite its toxic nature. The process removed the need for smelting and roasting with their attendant requirements for fuels and fluxes. Furthermore, the chemicals could treat multiple quantities of ore, unlike chemicals used in chlorination extraction where the reaction chemicals were exhausted after treatment of relatively small amounts of ore. These features made the process ideal for use in remote locations such as those in Australia. In association with the British Cassel Gold Extracting Company, commonly called the Cassel Company, Macarthur's syndicate gained patent protection for both steps of the process, and by July 1888 the Cassel Company was ready to introduce their cyanide extraction process to the world (Todd 1995:117).

The 1885 *Report of Cassel Directors* outlines a policy for transferring their methodology to Australian and other gold mining centres. Public demonstrations were thought to be the most effective way of illustrating the benefits of cyanide extraction and of encouraging its adoption (*Report of Cassel Directors*, 1885, p4-5, in Todd 1995, p119-120). To this end, the directors undertook to ship their most proficient staff overseas to establish and conduct cyanide demonstrations (*ibid*).

Introduction of cyanide processing to Australia

In 1888, Cassel Company employees Peter and Duncan McIntyre, arrived in Ravenswood, Queensland (approximately 100 kilometres east of Charters Towers) to establish a base for demonstrating cyanide processing. Little did they know that Australia was not in a position to diffuse best-practice technology, and implementation of the process by companies was meagre until 1897 (Todd 1995). Some of the barriers to rapid uptake of cyaniding were to do with the vastness Australia, disparate geochemical characteristics of its ore deposits, as well as its inhospitable terrain. While the McIntyre brothers might have appreciated Australia's isolation from the rest of the world, they were not prepared for the internal geographical isolation of Australian gold mining operations. It could take months to travel between Australian gold mines, whereas by comparison, in the South African Transvaal, all mines were within a day's travel (Todd 1995). Australian gold deposits also tended to be highly geologically differentiated, which precluded a single recipe for cyanide extraction that could be simply transferred between deposits (Todd 1995, Lougheed 1989). More potent barriers to cyanide implementation related to a lack of a system of innovation to enable successful technology transfer. For example, the dominant culture among mine managers was prejudiced against new methods, the underlying source of this reticence being a lack of scientific understanding and experience. Mine owners were wary of having to pay more for employees with qualifications, preferring the traditional ethos of 'experience' as opposed to scientific experimentation (Haas 1990).

Ultimately, the clear correlation between directed scientific endeavour and increased profit margins eliminated the introspective and individualistic culture that had previously dominated the industry and replaced it with a ‘culture of innovation’. Considerable experimentation and continuous incremental innovation was a necessary factor for the successful diffusion of cyanide processing. In general, regional variation in the degree of success and experimentation among the goldfields saw distinct waves in uptake of cyanide technology.

Although the structure of mining operations at Charters Towers assisted the uptake of cyanide in the first instance, it inhibited further experimentation. Dominant single miners and small syndicates used central crushing mills, followed by crude cyanide treatments. The richness of the ore meant that there was no immediate need to enhance yields derived from this rudimentary system, nor was there the knowledge or financial latitude to challenge the technique. Consequently, cyanide extraction was adapted to practices and pre-treatments developed twenty years earlier, and its use declined with the reduction of tailing heaps (Todd 1995:169).

Nowhere held the 'imperative to innovate' more fiercely than at the 'golden mile' in Kalgoorlie in Western Australia, nor were conditions as adverse. Isolation meant inflated freight, living and import costs, limited supplies of fresh water, limited fuel, and high wages (Todd 1995, Blainey 1994). Collaboration between companies was undermined by the sheer variability among ore deposits. It became common for mines to sponsor on-site, private laboratories and the region became a hot house for testing new metallurgical ideas. According to Blainey, 'Kalgoorlie's success in mastering rebellious ores made it probably the world's leading goldfield in metallurgy. Its young managers and ideas were exported to fields in every continent' (Blainey 1994:196). Incremental innovation and experience gained from 'learning by doing' resulted in most plants developing customised versions of cyanide extraction. In this manner, an important cluster of innovations occurred between 1897 and 1902 (Lougheed 1989). This also correlated to a 40 per cent reduction in costs for many companies between 1901 and 1904 (Todd 1995:182). The continuous and disciplined nature of experimentation in the region required significant injections of capital, the majority of which came from the London stock market (Blainey 1994). By the end of 1898, the combined capital of Kalgoorlie gold operations was 30 million pounds (Todd 1995:167).

State governments, motivated by employment and production potential, assisted dissemination through a variety of incentives, the most widely recognised being advocacy in the cyanide processing patent disputes for securing rights that favoured Australian users (Inkster and Todd 1988). The variety of State government approaches are detailed by Todd (1995). Two examples follow:

- In South Australia, government contributed to private initiative in a supportive and complementary manner, opening a number of public cyanide treatment plants. South Australia and other states also benefited from its Government Analyst, whose ground breaking basic research facilitated the adaptation of cyanide to Australia's copper-bearing ores, and subsequently hastened the diffusion of an improved process.

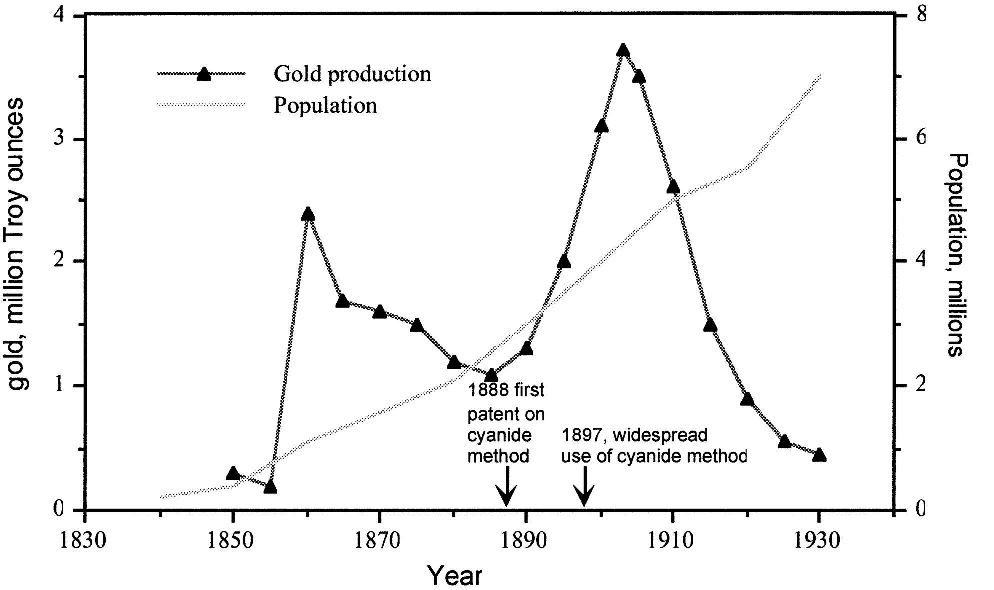
- Victoria experienced three distinct bursts in the use of cyanide, all corresponding to government initiatives. In 1896-97 government loans for 'pioneer mining' and metallurgical testing, and a government sponsored lecture tour which espoused the benefits of cyanide extraction. In 1900-01, the government purchased the patent rights to the technology and reduced royalty payments. And, an extension of the latter policy in 1905 saw the removal of all royalty payments and a subsequent increase in cyanide utilisation in 1906-07.

Contribution of cyanide processing to a minerals innovation system

Cyanide processing introduced 'scientific' mining to the Australian gold industry. This first industrial application of science to mining dramatically changed the culture and capabilities of the minerals industry, and marks the beginning of the MinIS. Contributory factors and flow-on effects included, for example, a demand for qualified metallurgists and other scientifically trained technicians that spearheaded the professionalisation of the Australian industry. Companies, in turn, were prepared to pay higher salaries for qualified professionals. Nationally, infrastructure for the training of suitably qualified technical experts to service industry needs did not exist (Inkster and Todd 1988). An influx of metallurgists and mining engineers from overseas was necessary to further develop capabilities within the MinIS. Schools of Mines, while failing in their intended role of technically specialised training, played an important role in introducing the new era of scientific understanding to local mining communities (Inkster and Todd 1988). Private and public experimental infrastructure, such as on-site laboratories in Kalgoorlie and the South Australian testing and research laboratories, began to develop. Public departments, professional societies and associations administered a variety of knowledge networks that supported the flow of information within the MinIS. Expansion of Australian gold reserves created by successful transfer of cyanide processing created a new potential for sources of profits for investors and attracted overseas injections of capital, particularly from Britain. New sources of capital were in turn reinvested into the development of the fledgling MinIS, including much experimental infrastructure. This innovation had clear positive effects upon minerals wealth (see Figure 5.1).

Cyanide extraction was successfully adapted to the idiosyncratic nature of different ore bodies, in geographically dispersed locations. According to Rosenberg, the ability to digest new technology through such measures as experimentation and incremental innovation (to access a technology's full potential), is as important as 'inventiveness' itself (Rosenberg 1982). There were strong regional differences in the patterns of organisational and institutional innovations that facilitated the uptake of cyanide processing. The ultimately ubiquitous transition from 'simple importer' to 'absorber' of new technology across the Australian minerals industry, lends weight to this study's conceptualisation of a minerals innovation system that is 'national' in structure, but with regionally distinct characteristics they are the result of the 'local' selection environment.[85]

Figure 5.1: The production of gold in Australia versus population growth 1850-1930



Source: values for gold production and population supplied by Phillip MacKey of Noranda Inc.

5.3.2 Industrialisation of research and discovery of flotation

Another crisis was looming for the global minerals industry in the 1890s, as newly found high-grade ores were exhausted and more complex refractory ores were encountered as workings moved deeper. As was the case in the gold industry, traditional processing techniques for industrial minerals were failing upon complex, refractory ores. A metallurgical process breakthrough was required to ensure that low-grade, complex ores could be treated efficiently and economically.

Conditions within the Australian minerals industry had changed by the turn of the century. Through uptake of cyanide processing, the minerals industry as a whole had its first experience of investment in experimental capabilities leading to increased production and profit. The resulting growth also brought an understanding of the types of investments required to produce high returns based on the strategy of applying scientific knowledge on an industrial scale. This first foray into knowledge-based (scientific) approaches saw an additional change, the building of well-equipped industrial laboratories. This new body of experience provided a foundation from which to meet the new technological challenge of processing the complex ores at Broken Hill.

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[85]See Chapter 3 and (McKelvey, 1997) for more on evolution of IS and selection environments.

The Flotation case study subunit

> It is not overstating the case to claim that flotation's development was of central importance to the smooth functioning of the global economy, for without it metals such as copper, lead, and zinc would have become increasingly difficult to produce and their price would have risen as a consequence. (Mouat 1996:4)

Introduction

Flotation is one of the three outstanding advances in metallurgy, the other two being cyanide processing and the Bessemer process[86] (Blainey 1994). Flotation revolutionised lead and zinc mining, vastly increased the world's mineable copper reserves (which in turn depressed its price), and its application to a variety of other minerals made it a dominant method of mineral extraction (Bangerter 1998). All of the applications for flotation are ultimately derived from a decade of innovation and development at Broken Hill.

The process of flotation involves mixing finely crushed ore with an oily, mildly acidic solution, and agitating the slurry to generate bubbles. The principles involved in flotation are extremely complex, and are related to the differential attachment of minerals to rising bubbles. Mineral particles literally float to the surface while waste rock sinks. Pioneering work in Australia and Britain[87] contributed to the initial flotation plants at Broken Hill.

Early development created a favourable environment at Broken Hill for the discovery and development of flotation at the turn of the century. Principal among these was the sheer richness of the orebody, which attracted and supported many large mining operations (whose claims could finance experimental development), and engendered a highly competitive local environment. Most of these mines were prepared to invest in research and had a culture that believed in the worthiness of scientific endeavour. This trust in the experimental method ultimately paid off. As mine shafts reached deeper sulphide zones, metallurgists were having difficulty extracting the mineral content of their loads and it was only the richness of Broken Hill deposits that made mining profitable. The richness of these deposits and rather poor recovery rate are typified by the Block 10 mine, which in 1903 recovered £90,000 worth of metals from ore containing potential mineral wealth of £380,000 (Blainey 1994:49). As a result of these factors, vast dumps of zinc tailings accumulated and were cheap to purchase for those

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[86] The Bessemer process, discovered by British engineer Sir Henry Bessemer, is a radical innovation for producing steel by blowing air through molten pig iron. A cheap process for the production of steel is a 'key factor' in the third techno-economic paradigm. Steel production contributed to a wave of innovation from the 1850s affecting every branch of industry and services, as well as the American spurt of growth from 1880-1913. (Freeman and Soete 1997).

[87] Frank and Stanley Elmore were the first in Britain to experiment and patent a flotation process. Their patent was granted in 1898. Further development of the process in Britain is obscured by an extraordinary degree of patent litigation, while concurrent developments in Broken Hill had more immediate effects (Mouat 1996, Burt 2000).

interested in experimentation. It was also fortuitous that routine extraction required the ore to be finely crushed, as flotation can only liberate minerals that are in this state.

New process development

Although not the first to notice the phenomenon of bubbles attracting minerals and lifting them to the surface, Charles Vincent Potter, a Melbourne-based brewer and chemist, applied for patent protection for his flotation process on 5 January 1901 (Blainey 1994, Mouat 1996). A Broken Hill company, Block 14, was experiencing treatment difficulties and built an experimental flotation plant based upon Potter's process. They were successful and between 1903 and 1905 overcame translation and scale-up difficulties to recover 60 per cent of the zinc, as well as lead and silver, from their tailings (Mouat 1996).

In another Broken Hill laboratory, some hundreds of metres away from Block 14, flotation was discovered in an independent set of experiments. Guillaume Delprat, the sixth general manager of Broken Hill Proprietary Company, was also interested in discovering a method for extracting the wealth of minerals contained in their tailing dumps. By 1904, BHP erected a rival flotation plant and was successfully producing zinc concentrate. BHP was also taken to court by Potter for patent infringement and following several years of legal wrangling Potter lost his case, but the process became known as the Potter-Delprat method.

This was not an all-conquering beginning for flotation and a great deal more development was required to make the process economical and reliable. The early process was expensive and even Block 14 returned to its formerly used magnetic treatment process. Companies, however, continued their programs of development in a highly competitive and strictly secretive environment. The strict adherence to secrecy no doubt inflated the costs associated with advancing the flotation process, as rival laboratories and experimental mills repeated each other's mistakes and duplicated each other's efforts. Patent protection was unreliable since the process was novel and scientific understanding could not explain how or why it worked overall, let alone explain apparently idiosyncratic improvements (Mouat 1996). Thus, companies did not disclose their findings for fear of being sued for infringing someone else's patent or losing a competitive advantage. During 1902 to 1915 it is estimated that forty individuals made significant metallurgical improvements to the flotation process in eleven companies based in Broken Hill and Melbourne (Blainey 1994:258). Such breakthroughs were not confined to the large mining houses. For example, the small Junction North mine made a remarkable contribution with six of its staff members making important advances to the flotation process (Mouat 1996, Blainey 1994).

Australian inventiveness is illustrated by a readiness to patent at a much higher rate than that of other nations, including Britain, the USA and Germany (Inkster and Todd 1988). A total of 13,600 patent applications were lodged in Australia during 1900-1905. Over 50 per cent of these applications were in the fields of manufacturing and minerals processing, with NSW the dominant region of inventiveness (*ibid*:119).

The majority of improvements to flotation originated at Broken Hill, in spite of the fact that the process was relevant across the industry, and therefore incentive existed for other countries to innovate. It is also interesting to note that the flotation process came out of Australia and not, for example, the United States which mined more lead and zinc than Australia. The minerals industry in America played no significant part in the development of flotation (Hovis and Mouat 1996, Burt 2000). Indeed, the US was slow to take up the new flotation process (David and Wright 1997, Mouat 1996), its first successful plant coming online in 1911 in Butte, Montana, by which time 8 million tonnes of ore had already be 'floated' and a fifth of the world's zinc concentrate was being produced at Broken Hill (Blainey 1994).

A note on Australia's continued excellence in flotation process innovation

Australia continues to be a world leader in flotation technology, as seen in a recent approach, the Jameson Cell. In 1985, Professor Graeme Jameson of the University of Newcastle was commissioned by MIM Process Technologies to improve upon their conventional flotation columns that required regular and labour-intensive servicing. He succeeded and the first commercial Jameson Cell was available in 1989. Currently around 200 Jameson Cells have been installed globally (Bangerter 1998).[88]

Collaborative research on flotation continues and most recently AMIRA announced a research project to develop a flotation simulator at the Julius Kruttschnitt Mineral Research Centre (JKMRC). Sponsorship came from the Queensland Government's Department of State Development ($157,000) and nine industry sponsors including Anglo Platinum, Impala Platinum, KCGM, Lonmin Platinum, Normandy Golden Grove, Pasminco Century, Phelps Dodge, Rio Tinto/IOC and WMC Resources. The new software package 'JKSimFloat' will replace generic calculation spreadsheets that take six to twelve months to develop and are usually only understood by the individual developer. JKSimFloat will model specific flotation circuit problems in less time and in a more logical, user-friendly way. The first phase of JKSimFloat is due for release at the end of 2002.

Summary of impacts from flotation

The discovery and commercial application of flotation at Broken Hill is an innovation of great significance to the Australian (and global) minerals industry. It demonstrates significant technological capability in process innovation and marks the entry of the mining industry into an era of industrialised R&D (a feature of the third techno-economic paradigm, 1890s-1940s) (see Table 5.3). This significant change occurred in both large and small firms and included the development of 'professionally' organised R&D programs, housed in well-equipped corporate research laboratories.

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[88] A review of recent advances and improvements to the Jameson Cell may be found in *The AusIMM Bulletin*, No 8 December 1998 p32-36.

Table 5.3: Long waves of economic change (Kondratieff waves)

Long waves or techno-economic paradigms			*Key features of dominant infrastructure*		
Approx timing	*Kondratieff waves*	*Science technology education & training*	*Transport & communication*	*Energy systems*	*Key factor industries & goods*
First 1780s-1840s	Industrial revolution: factory production textiles	Apprenticeship, learning by doing, science societies	Canals, carriage roads	Waterpower	Cotton, pig iron
Second 1840s-1890s	Steam power & railways	Professional mechanical & civil engineers, institutes of technology, mass primary education	Railways (iron), telegraph	Steam power	Coal, transport
Third 1890s-1940s	Electricity & steel	Industrial R&D labs, chemicals & electrical goods, national laboratories, Standards laboratories	Railways (steel), telephone	Electricity	Steel, synthetic dyestuffs, heavy engineering
Forth 1940s-1990s	Mass production (Fordism) of cars & synthetic materials	Large-scale industrial & government R&D, mass higher education	Highways, airlines, radio & TV	Oil	Energy (especially oil), plastics
Fifth 1990s-	Microelectronics & computers	Data networks, R&D global networks (3rdG), lifetime education & training	Information highways, digital networks	Oil/gas	'Chips' Miroelectronics
Sixth ? 2000-	Information & communication technologies	Specialised, global centres of excellence, new enabling technologies biotechnology, remote sensing, real-time data processing, increasing intensity of R&D (5th G)	ISDN, satellite communication systems	'Clean' power photovolatics, hydrogen?	Computers & telecommunication

Source: modelled on Freeman and Soete (1997:19&66).

Although initial development of mining at Broken Hill was based upon a rich and easily treatable geological endowment, an ability to capture the vast potential wealth present in this *natural* endowment had to be *created.* Innovative capacity at Broken Hill was linked to agglomeration in the regional economy of an intensively competitive environment, where capital investment flowed freely. It was not, however, established upon cooperation and shared knowledge. Unlike Foray's description of localised innovative districts where 'the secrets of industry are in the air' (Foray 1991), any secrets regarding flotation were carefully guarded or protected by patents. The majority of this capacity was housed in the 'professionally' organised R&D departments of individual large and small firms that conducted large amounts of experimental development in well-equipped corporate research laboratories. Technological development progressed well ahead of scientific understanding of the principles by which flotation actually works. Indeed, the use of industrial research laboratories by the minerals industry signals that it was operating in the third techno-economic paradigm (1890-1940), and endorses the argument that the Australian minerals industry was indeed innovative (Freeman and Soete 1997). Furthermore, Australian companies operating at Broken Hill seem to have been imbued with an innovative culture that sustained their future growth and competitiveness.

5.4 Minerals industry innovation in the 1980s

A global collapse of metal prices following the First World War saw the closure of many mines and the value of mineral exports decline from $15.3 million in 1919-20 to $7.6 million in 1921-22 (Australian Bureau of Statistics 2000). Following the flood of prospecting and discovery in the previous century, the need for new ore reserves was a major concern for the industry in the 1930s and early 1940s. During this period Australia lost its positive atmosphere expectation about the discovery of new major deposits. This pessimism was clearly reflected in deeply misguided government policies of the day.

Changes eventually took place in government policy and world demand (outlined below) that saw a recovery in the industry and a renewed enthusiasm for investment. This resulted in a boom period that lasted from the mid 1960s until the late 1970s. This boom ended after a fifteen year period of growth due to factors upon which the Australian industry was dependent, including world decline in demand for minerals, and competition from an increasing number of mines in new prospective regions of the world (Australian Bureau of Statistics 2000, Blainey 1994).

Leading up to the 1980s, large Australian minerals firms such as MIM, WMC, CRA and BHP typically supported extensive and centralised corporate research laboratories and a culture among industry leaders that supported innovation (Australian Bureau of Statistics 2000, Blainey 1994, Griffiths 1998).[89] At this time these were strongly 'Australian' companies within a strong national identity (corporate leaders shared long personal-histories within the minerals industry and detailed knowledge and understanding of its short-term and long-term competitive dynamics). Collaborative research was also widely supported, particularly through the industry's privately funded research management organisation, AMIRA established in 1959. The minerals industry also sponsored the development of university research centres (such as the JKMRC), and established strong networks and linkages with other public research organisations (see Chapter 7). This is the environment in which the diamond sorters development took place.

<u>The diamond sorters case study subunit</u>

Introduction

The Argyle diamond sorter is a classic example of innovation in the minerals industry being conducted out of necessity and delivering a strategic competitive advantage. What is most unusual about this story of innovation is the bold incorporation of a high degree of technological risk contained in CRA's commitment to develop the Argyle diamond mine.

[89] Company specific management styles and corporate cultures have been identified among these companies (Griffiths 1998).

In the 1970s, Argyle Diamonds (a CRA subsidiary) found a promising major new diamond deposit. CRA had no previous experience in diamond mining and the commercial viability of the Argyle deposit was dependent upon successful process innovation, a method for isolating diamonds that was specifically suited to the particular characteristics and nature of deposition of Argyle diamonds. Ultimately, the new diamond sorter could not be called radically innovative. Rather it was an engineered, incremental improvement upon a technology which had already been extensively and successfully used in South Africa. Nonetheless, the financial commitment, mine planning and construction of the 'fly-in, fly-out' operation all proceeded while the extraction method remained a 'black box' in the overall plan for diamond production at Argyle.

Of primary interest here is how the parent company, CRA, managed this technological risk and ensured that proven and reliable diamond sorters were delivered to Argyle in time to meet the date for commencement of production and on budget.

Conditions for process innovation – the Argyle deposit and available technologies

The Argyle deposit had many unique properties. Some estimates suggest that it was one hundred times more concentrated than other diamond deposits and although it was 'rich' the stones were of a much smaller size range and poorer quality than other world class deposits. Only 5 per cent of diamonds, for example, were of gem quality and 50 per cent were industrial quality.

Methods for diamond extraction were originally developed in Africa, where deposits were of a higher grade than at Argyle. The combination of the Argyle diamonds' characteristics rendered existing diamond sorting machines ineffective. In fact, an African machine was tested at the Argyle site and it was estimated that up to 60 such machines, three times the number of sorters eventually deployed, would be required. Even then around 30 per cent of the diamonds would not be recovered. Argyle Diamond Mines had an obvious need for a new line of diamond sorters capable of handling a high throughput of concentrated, low quality, small diamonds.

The African sorting machines rely upon a physical property of diamonds: they fluoresce upon X-irradiation. As diamond-containing material passes through an X-ray sorter, fluorescence activates a targeting device which focuses compressed air jets that send a blast of air to knock the diamond-containing material from the ore stream. Gravel associated with the diamond containing material does not fluoresce, and is channelled away. As Argyle diamonds are small, their response under X-irradiation is different to the generally larger South African diamonds. It was soon discovered that the South African sorters were not sensitive enough to detect the smaller Argyle diamonds. A further problem for Argyle was that alternative diamond sorting methods posed substantial environmental problems. The company was also operating under tight time constraints.

Management of the innovation process

Electronic sorting machines were introduced to Australia in the 1960s by a small mining group called Mary Kathleen Uranium (MKU). This was only the second instance of automated sorting in the world and the machines were successful enough to attract the attention of RTZ, who purchased the operation. A new technology group, RTZ Ore Sorters, was created by the takeover. Mark Schapper became the Technical Director of the Ore Sorters' team, which included Peter Hawkins and others who had been involved with the initial design and development of the MKU sorting machines.

During the mid to late 1970s, RTZ Ore Sorters developed novel mineral sorting machines for RTZ and other minerals companies. Although government rhetoric of the day referred to a '$28 billion mining boom,' sales were particularly poor in Australia and in 1981 RTZ closed the group.

The RTZ Ore Sorters team scattered, but the skills and experience they gained in designing X-ray detection systems later proved to be of considerable value when some of them worked on the Argyle project.

Schapper, subsequently headhunted by CRA, developed an interest in the problem of separating Argyle diamonds from their ore. A strong group already on-site at Argyle had ideas for improving the X-ray sorters. However, it was up to Schapper to pull together a technical team to determine whether the X-ray sorters could be engineered to suit the Argyle deposit.

Mark Schapper, acting on behalf of Argyle Diamonds, contracted Minscan (which had been formed by Peter Hawkins) in 1981 to conduct preliminary investigations into the X-ray fluorescent properties of Argyle diamonds. Initial evaluation of the diamonds, conducted at the Royal Melbourne Institute of Technology (RMIT), established that they exhibited a wide range of responses to X-ray exposure. The next step was to brainstorm how these physical parameters of the diamonds could be handled in the context of the Argyle deposit. Their solution utilised the same principles as the African sorters, but there was a crucial difference. The machine had a concentric design, with X-ray beams covering 360°. Furthermore, it contained five air jets also arranged concentrically and driven by a computer. These modifications were projected to drastically reduce the response time and therefore increase the throughput capacity of the machine. This radial sorter was sensitive enough to detect the Argyle diamonds as well as remove them at a much greater rate, about 170 shots per second at a pass rate of fifty thousand stones a second.

The radial sorter concept excited the Argyle technical staff, and CRA provided establishment funding for the development of two prototypes. A small factory in Dandinong, Victoria, housed the design and development phase of the radial sorter. The first small prototype machine was tested at the Argyle site before Christmas 1983, and the larger prototype arrived early in the new year. Following successful demonstration of the pilot machines, Argyle provided funding to establish a manufacturing facility in Preston, Victoria. CRA established a new unit called Group Special Equipment (GSE) to focus on highly technologically advanced equipment for the minerals industry, and in particular to manufacture an additional 19 radial sorters by December

1985. At its peak the Preston factory employed 35 technical and trade personnel. The machines were running and performing well on time, and the project was on budget at approximately \$4.5 million. According to Hawkins 'they probably got what would have been valued in the open market at \$20 million.'

The Argyle diamond mine came on full production in November 1985 and every diamond produced since that time has been recovered by the radial diamond sorters. The project was therefore highly successful. In a CRA publication describing the effectiveness of GSE, Mark Schapper describes the diamond sorter project as 'a model of what can be achieved between an operating business unit and a specialist unit helping to service it'. The CSIRO also recognised the outstanding contribution the project had made to Argyle and awarded the Directors of GSE the 1986 CSIRO Medal for Research Achievement. It was the first time the award was allocated outside the CSIRO.

Summary
This case study subunit illustrates a number of characteristics of minerals innovation in the late 1980s. The expertise and knowledge in sorting technology required for this innovation was found in Australia. This was the case for those individuals who joined GSE, as well as for those with specialist scientific expertise on X-ray fluorescence (RMIT). Personal networks and industry-science interaction were significant enablers of this process of innovation, particularly as CRA was an inexperienced diamond-miner and built the requisite learning processes and capabilities for technological innovation in this area in a short time. The separation of the GSE unit, who were given independence (unbridled by bureaucratic and financial distractions) and allowed to simply get on with the task, also helped to met the 1985 deadline. The decision to develop the sorting machines in-house was typical of many firms' technology strategies of the day. These supported a high degree of technological autonomy and embraced innovation as a source of strategic competitive advantage. While outsourcing may be a preferred method of technology development today, in this case, Schapper' view was that he could not have guaranteed Argyle Diamond Mine that their machines would be delivered on time and on budget, unless he had full control of the project.

The high degree of technological risk (along with the success of the Argyle operation) accompanying this innovation was also offset by the leadership qualities and management capabilities within CRA. Viability of the Argyle mine was dependent upon an ability to integrate technological innovation with the overall project development and business processes within the firm.

5.5 Discussion – using an IS approach to analyse an historical view of minerals innovation

The following discussion brings together the empirical data (presented in Sections 5.2, 5.3 and 5.4) and analyses it from an IS perspective. The history of the Australian minerals industry is well researched by branches of the academic literature. For example, 'economic histories' highlight the role of the minerals industry in supporting regional development (Australia's five largest regional towns Bendigo, Ballarat, Charters Towers, Broken Hill and Kalgoorlie were built and paid for by gold or silver). 'Industry histories,' on the other hand, emphasise the industry's pioneering spirit and achievements. These historical accounts have shown that events, such as the Gold Rush and the Eureka Stockade,[90] deeply affected national perspectives the national psyche (Blainey 1962, Blainey 1994, Crowley 1980, Clark 1981, Wilkinson 1996). In terms of 'technology histories,' there are many accounts of individual technologies (a notable example being Todd (1995)),[91] but few works take a holistic approach and a minerals industry perspective.

Outside of the Australian focus, economic histories of political economies emphasise the role of mineral resources in new nations as they play 'catch-up' to the rest of the world in terms of growth and development. Minerals industry histories, on the other hand, highlight important technological or mechanical 'breakthroughs', the origins of such innovative feats, and subsequent global patterns of dissemination and uptake (particularly regarding 'new' and 'old' mining nations, the UK and Europe versus the USA and Australia).

The literature on technological innovation and innovation systems seems to take innovation in the minerals industry into account only as a 'factor' and not a primary subject of investigation. Thus, this literature does not cover industry's innovations systematically but does, for example, pay tribute to major technological breakthroughs in process technology in terms of their influence upon different techno-economic paradigms (Rosenberg 1982, Freeman 1983, Freeman and Soete 1997).

This analysis has used the IS approach as a pooling device,[92] to combine evidence provided in this Chapter with new material from the aforementioned literature. The IS approach provides an heuristic for the identification a minerals innovation system, as well as for the conceptualisation of 'performance' within a system and an industry's (or nation's) growth, development and transformation. In this way, the minerals industry is reviewed with reference to knowledge bases and learning processes, technologies and competitiveness, interaction among firms and other organisations, and evolution of institutions (particularly public policy). Issues of complementarity between the minerals industry and other social systems (financial, legal, educational and cultural),[93] as well as the dominance of British culture are also of importance when considering development of the Australian MinIS. An iterative process of analysis

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[90] A detailed description of the Eureka stockade is given in *Manning Clark's History of Australia*, Book Four: The Earth Abideth For Ever, 1851-1888, chapter four: That Bloody License Tax, or in *A New History of Australia*, Chapter X: Australian Gold. Blainey provides insight into conditions at the Ballarat field in *The Rush That Never Ended*, chapter four: Ballarat's Ditch of Perdition.

[91] A notable contribution is Jan Todd's *Colonial Technology* which profiles the transfer of two technologies to Australia (anthrax vaccination and cyanide processing) and their influence upon Australia's developing technological sovereignty (Todd 1995).

[92] See Chapter 3 for more on IS approach, and Malerba (2002) and Montobbio (2001).

[93] Freeman (2002) describes the importance of *complementarity* among 'social' sub-systems (financial, legal, educational and cultural) for successful performance of NIS (Freeman 2002).

follows, which involves building a case from the overarching trends and events that were of direct relevance to the formation and performance of the Australian MinIS.

5.5.1 Early shaping events

Historical accounts that focus directly upon the cyanide and flotation innovations and consequent industrialisation in the Australian minerals industry, give the impression that this was a miraculous or Rostovian great leap forward. However, as was discussed in Section 5.2, a transformation took place between the days of the digger of the 1850s and the organised industrialised scientific-mining era 50 years on. Complementarity among societal factors (such as the legal framework, financial system, government facilitation of industry-led development, and a culture of buoyant outlook) has been found to have a positive influence upon innovation systems (Freeman, 2002). This transformation involved dynamic processes of social and economic advancement across Australia's fledgling colonies. Regional gold and silver bonanzas fuelled capital accumulation, reinvestment and industrialisation of mining districts. 'Resources industrialisation' is a term used to describe the pattern of positive cycles of wealth accumulation and development following from an initial minerals rush:

> Resource plunder and small property have been repeatedly eclipsed by the force they help set loose: capital accumulation on a majestic scale. Yet nonetheless, there was a recurrent dialectic of prospecting/development, speculative claims/long-term investment, and rent/profit played out with every new resource bonanza. (Walker 2001:181).

Importantly, there is also evidence of an accompanying, gradual accumulation of knowledge, learning processes and experience within the nascent industry. Many of those associated with mining tended to travel great distances to participate in a new gold rush (Blainey 1994). This facilitated the spread of first-hand experience, knowledge and skills, which was particularly valuable for a country of under-developed communication and transportation infrastructure. Schools of Mines also played an important enabling role in dissemination of knowledge and provision of a generalist education. The first two decades of the minerals industry were a resourceful and inventive period. The Cornish approach to mining and the selective mining method, however, were unchallenged. The latter engendered a culture of 'experience', apprenticeship and skill of an artisan as opposed to scientific understanding and experimentation. Mechanisation of this mining method did not increase gold production (Todd 1995) or labour productivity (Hovis and Mouat 1996). However, structural changes in the industry, growth in number and size of firms, development of management skills and understanding of long-term investment were all occurring and were important for subsequent industry development. This type of basic organisational and management learning in the Australian industry tends to be overlooked.

5.5.2 Advent of capacity for technological innovation

The cyanide and flotation processing innovations were radical in terms of both the technological breakthroughs they represent and the impact they had upon the minerals industry.[94] They were also accompanied by significant institutional and organisational innovation, on behalf of firms and state governments.

The Cyanide and Flotation case-study subunits provide irrefutable evidence of significant capabilities and capacities for technological innovation within the Australian minerals industry. As described in Section 5.3, implementation of these two radical process innovations (transfer and diffusion of cyanide treatment of gold, and the discovery and commercial-scale application of flotation at Broken Hill) was neither smooth, linear inevitable nor immediate.[95] Patterns of diffusion and uptake display commodity- and regionally-specific differences, due to the characteristics of ore bodies and local conditions within 'selection environments.' For example, important institutional changes implemented by state governments (such as mechanisms to avoid the royalty payments for cyanide processing, encouragement of foreign investment, and state testing laboratories) enabled the uptake of cyanide processing. Differences aside, the Australian industry's technological capabilities evolved from those of a simple importer, to those of a lead-user and innovator, and eventually to those of an exporter of knowledge-based services. In the first decade of the twentieth century, the Australian minerals industry was leading the world in its capacity for technological innovation in minerals processing (Lougheed 1989, Mouat 1996, Burt 2000). This is amply demonstrated by a further breakthrough discovery of 'selective flotation' in 1911 at Broken Hill that ultimately allowed recovery rates in excess of 95 per cent from complex ores (Mouat 1996, Blainey 1994).

The cyanide and flotation innovations together induced fundamental change in the nature of mining. Productive capabilities and minerals reserves dramatically increased. The nature and organisation of mine work, as well as the critical skills and knowledge base, changed (Mouat 1996, Hovis and Mouat 1996, Lougheed 1989, Jack 1984). The technical training of professional mining and metallurgical engineers became essential factors in the success of a mine, as opposed to accumulated skill of underground (Cornish) miners. These process innovations expedited a transition in the minerals industry from selective to non-selective mining methods because it was now possible to treat large volumes of low-grade, complex ores. In a major shift, the mining method changed from one of targeting the quality of ore brought to the surface, to the extraction of a high quantity of low grade, complex ore. The industry's pattern of unplanned plunder and volatility now progressed towards scientific mining and a rational form of big business.[96] Over time, these radical changes in processing methods allowed

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[94] The impact of cyanide processing is reflected in a significant increase in the gold yield and augmentation of Australia's treatable gold reserves (see Figure 5.1).

[95] Studies of the long-term patterns of implementation of radical technological innovations are given in Chapter 3. For the basic characteristics of radical technological innovations see (Rosenberg 1982, Rosenberg and Frischtack 1983, Freeman and Soete 1997).

[96] Studies have demonstrated that Australia's minerals industry restructured along the lines of mass production (the fourth techno-economic paradigm 1940s-1990s), including implementation of mass

the industry to be innovative in its organisational approach and gradually adopt practices of mass production and the 'systems of mines' methods (Hovis and Mouat 1996). Taken together, these radical innovations demonstrate the strength of technological capability in process innovation, a considerable capacity for learning in Australian minerals firms, and marked the entry of the Australian mining industry into an era of industrialised R&D and professionalisation (a feature of the third techno-economic paradigm, see Table 5.3 above).

5.5.3 *The early MinIS*

Periods of rapid technological catch-up among new and developing nations are well documented in the innovation literature (Freeman 1996). Sustained performance, however, is dependent upon systemic complementarity within innovation systems and related social systems (Freeman 2002). In the second half of the eighteenth century, Australia and its minerals industry needed to catch up with the technological advancements made during the first and second techno-economic paradigms (the industrial revolution and steam power / railways) (see Table 5.3). The Australian SET base was in its infancy and fragmented among the colonies. Growing government bureaucracies increasingly relied upon qualified scientists and engineers to attend to the provision of basic needs of society: public services and infrastructure, food and water supplies, transport and public health. The emergent culture of science, appearing from the 1860s, replicated the British system with British-style scientific 'societies' and professional 'institutes' (largely funded by state governments). By following British science, however, Australia also inherited British attitudes to engineering, described as:

> the tendency not merely to neglect engineering but to look down on industry as in some way socially inferior compared with the professions or the way of life of the aristocracy. (Walker, 1993:179).

It is well documented that Britain's loss of technological leadership in the 1880s and 1890s was not due to a lack of scientific innovation but rather because Britain did not capture the institutional and organisational innovations to support the diffusion and application of these discoveries into new industries, in the manner that was so successful in Germany and the USA (Walker 1993, Freeman 1992, Montobbio 2001). Accompanying and supporting the 'industrial R&D laboratory' innovation in the latter countries was an equally significant organisational innovation, namely the 'Technische Hochschule,' or 'Institute of Technology.' These organisations had a focus upon the practical application of science and technology and formal training of engineers (Freeman 1992).[97] Importantly, they enabled close industry-science relationships and provided knowledge bases in the engineering sciences (Nelson 1988, Nelson 1990).

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mining and milling techniques, as well as application of engineering principles to the organisation of labour by the 1930s (Hovis and Mouat 1996).

[97] By 1913, it is estimated that Germany was producing 3000 professional engineering graduates per annum, who were employed by the new chemical and electrical industrial R&D laboratories (Freeman

The early MinIS is domestically incomplete
It is possible to describe a system of innovation supporting the innovative capacity in the early minerals industry. While replete with considerable capability, the early MinIS system has some unusual characteristics.

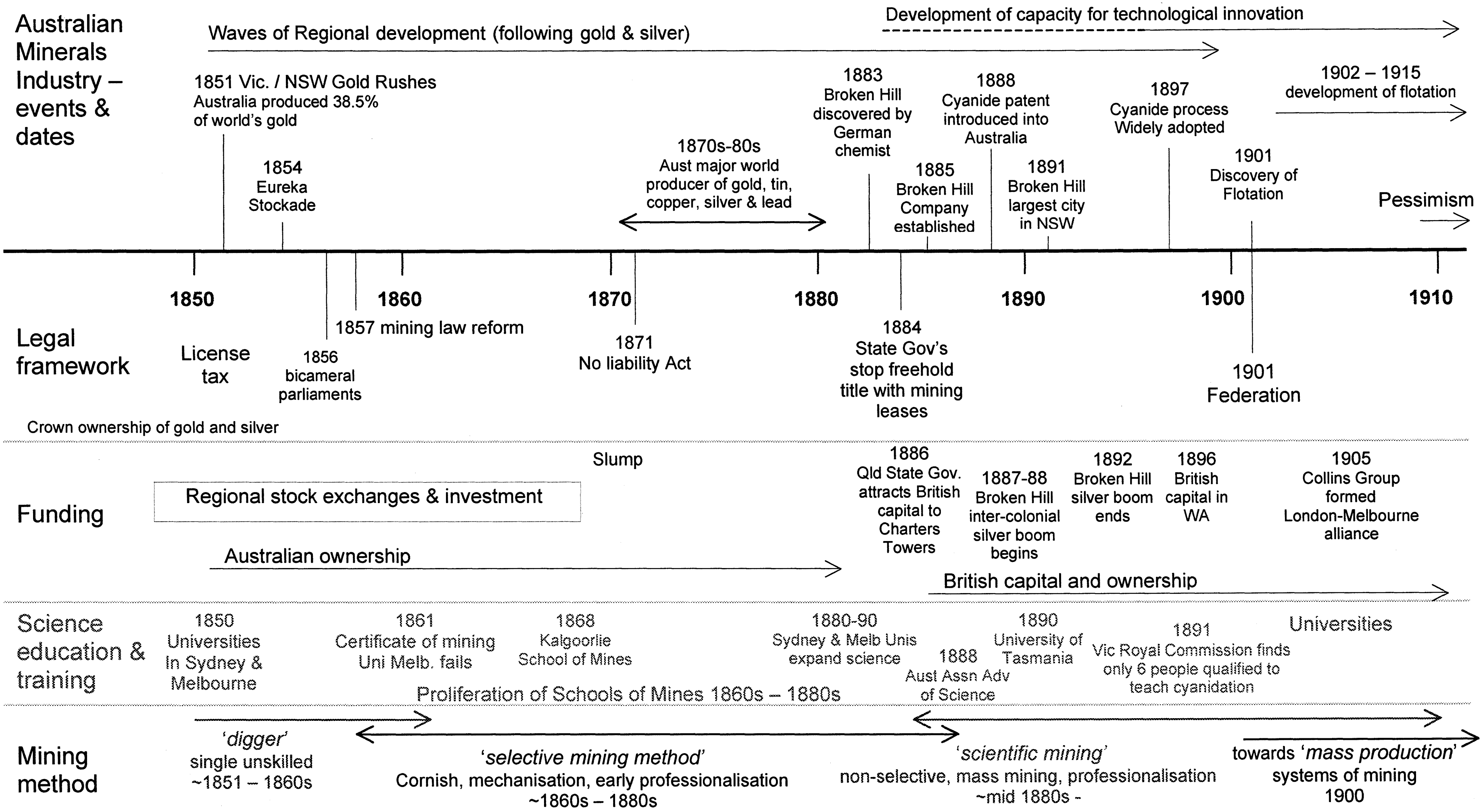
Figure 5.2: *Development of Australia's minerals industry*, highlights the development, on a time-line, of a selection of components relevant to the early MinIS. Its origins correlate with the advent of 'scientific mining' and the minerals industry's need for industrial application of science and technology. It was supported by a financial system with international sources of capital, and colonial governments that developed policy mechanisms to encourage the application of new technologies and subsequent industrial development (to capture sources of income and employment). The process of professionalisation of industrial R&D displayed by Australian minerals companies was in keeping with international trends (Freeman and Soete 1997).[98] However, the knowledge-based assets and technological capabilities that existed at the origins of the MinIS show a distinct bias. The early MinIS contained only rudiments of a key component of innovation systems, the tertiary sector. Thus, the accumulation of skills, knowledge (much protected intellectual property), shared experience and an overall capacity to fund, organise, and commercialise innovations (an important competitive-asset for the MinIS), was primarily located in the private sector. This consequently made the division of labour[99] in the system biased towards the applied end of the spectrum. Australian colonial governments played an enabling role during the application of cyanide processing (for example, from state cyanide treatment plants to mechanisms for avoidance of royalty payments to the cyanide patent holders), but were slow to invest in tertiary infrastructure (universities, for the creation of new knowledge in the scientific fields of metallurgy and geology, and the production of suitably skilled, scientifically trained graduates) (Inkster and Todd 1988, Griffiths 1998). Government scientific research agendas had a practical emphasis upon the 'acclimatisation' of European plants and animals to the Australian environment (Inkster and Todd 1988). Australia's first Universities of Melbourne and Sydney were founded in the mid-nineteenth century. However, they were teaching institutions with little in the way of advanced training and research, or in engineering sciences (Boardman 2001). A 50 year lag ensued before determined efforts were made to professionalise these organisations with appointments of professors of geology, chemistry, physics and biology in Melbourne, and geology, chemistry, mineralogy, and physics in Sydney (*ibid*).

1992). In contrast, science, technology and mathematics graduates only amounted to a total of 350 graduates in Britain (*ibid*).

[98] The literature on the history of industrial innovation shows that specialised R&D laboratories in industry first appeared in the 1870s, although in developed nations government and university laboratories existed earlier (Freeman and Soete 1997). Furthermore 'the professionalisation of R&D', the transfer of a greater proportion of R&D into the private sector, is characterised by 'its scale, scientific content and the extent of professional specialisation' (*ibid*, 9).

[99] That is, the distribution of basic and applied research, and experimental development among universities, government laboratories and firms (for more detail see Chapter 3).

Figure 5.2: Development of Australia's minerals industry



Access to tacit knowledge and knowledge bases
The commercial application of flotation and the dissemination of cyanide processing relied on the influx of metallurgists and minerals-related scientific and technically trained experts from other countries, particularly the USA (David and Wright 1996, David and Wright 1997, Blainey 1994). The decision by BHP directors in 1886 to recruit 'the best' professional mining engineers and metallurgists from the USA signifies an incisive shift in attitude away from the Cornish unscientific method of mining, in favour of scientific mining and consideration for long-term development. Historical accounts indicate an active flow of internationally trained experts into Australia (Blainey 1994, Griffiths 1998, Todd 1995).[100] In this way, the early MinIS accessed knowledge bases and sources of new knowledge in emerging transfer sciences of metallurgy and mine engineering.[101] In essence, the early MinIS can described as 'domestically incomplete' since its requirements for the products of a tertiary sector were sourced internationally. In addition it can be classified as an 'applied' system in light of a lack of government-funded basic research agendas aimed at exploitation of Australia's mineral resources. In spite of these characteristics, the early MinIS functioned well in terms of supporting the industry's technological innovations.

5.5.4 A comparison of American and Australian early minerals industies

The IS approach embraces history because events shaping the development of innovation systems can help to explain a system's subsequent dynamics and performance (McKelvey and Texier 2000, McKelvey and Orsenigo 2001, Malerba 2002). An obvious question for this analysis concerns how the structure of the early Australian MinIS influenced future performance of the industry in Australia. A comparative analysis of the Australian situation with that in the western states of the USA helps to clarify this issue.

The minerals industry in the western states of the USA shares some developmental similarities with Australia. Both began with initial gold rushes (the California gold rush beginning in 1848), and shared features like the tyranny of distance (to European markets), forbidding landscapes, and lack of infrastructure (David and Wright 1997). In 1850, San Francisco had a population of 450, yet by 1880 it was the world's largest mining and manufacturing industrial complex (David and Wright 1996). Over the period 1880-1920, the USA attained world

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[100] For example, Herbert G Hoover, an expert in geology and metallurgy (attended Stanford University and the Rocky Mountains School of Mines), was employed by the London consulting firm 'Bewick Moreing and Company' to introduce American mining practices to a portfolio of cyanide operations in Kalgoorlie in 1897. Over seven months he toured the districts, introducing specialists to manage discrete stages of operations and improving overall costs of production. Hoover also visited Victorian gold fields before travelling to Broken Hill to work of the flotation process in 1905 (Blainey 1994). A collection of his lectures on the scientific mining method were published in *Principles of Mining* (New York 1909). This publication was a forerunning text for the industry, especially as such detailed technical knowledge became more valuable and privileged (Hovis and Mouat 1996).

[101] Chapter 3, Section 3.4.1, gives a definition of transfer sciences as those that an important bridging role between purse science and technical change (Montobbio 2001). It could be argued that metallurgy and mine engineering are early examples of 'transfer sciences' as they were developed by university-trained professionals working on the commercial application of the science of geology.

leadership in production of a majority of industrial minerals.[102] This is despite the fact that Australia was ahead in the application of new processing technologies: American gold miners were comparatively slow in uptake of cyanide processing (Lougheed 1989), and the USA played no role in the discovery and development of flotation (Mouat 1996). Much of the historical (Burt 2000) and economic (Parker 1972) literature simply states that America's leadership was a foregone conclusion due to the nature of America's geological endowment. However, new research challenges this assumption, based upon the fact that until the 1950s the USA exploited its geological resource potential[103] well ahead of other nations (David and Wright 1996). Walker takes a 'Marxist political economy' approach to argue that in the case of California's road to riches, resource endowment played a secondary role to positive cycles of resource-led industrialisation on a massive scale (Walker 2001). Comparison of the Australian and American experience from an IS viewpoint provides some interesting new perspectives upon this debate.

Previous accounts of the Australian minerals industry have amply documented and lauded Australia's technological leadership in minerals processing. None of these studies have, from an Australian perspective, considered why this position of leadership with its attendant wealth creation did not engender further positive cycles of resource-led industrialisation on the scale experienced in America. Following the halcyon days of remarkable innovative advances, Australia seemed to lose enthusiasm for the minerals industry after World War One and began what might be described as a negative spiral of development constraint. Over the first 60 years of the twentieth century, Australia failed to create an environment that encouraged continued exploitation of its mineral resources (Griffiths 1998). David and Wright (1997) argue that this period of decline and lack of government support for the minerals industry in Australia explains the creation of a national technology gap between Australia and the US, which exists today (David and Wright 1997:240).

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[102] The USA was the largest producer of coal, iron ore, copper, lead, zinc, silver, tungsten, molybdenum, petroleum, arsenic, phosphate, antimony, magnesite, mercury and salt, and the second largest producer of gold and bauxite (David and Wright 1997).

[103] American minerals production between 1870-1950 far exceeded its geological endowed share. For example, in 1910 a report on Iron Ore Resources of the World reported that the USA was the most richly endowed with 'actual' reserves of 22.6 per cent and had the greatest opportunity for future growth as 'potential' reserves were 70 per cent of the world's total. By 1955 the USA's actual reserves had dropped by 8.1 per cent as new reserves were found in Asia, Australia, Africa, South America and the Soviet Union (David and Wright 1997).

Evolution of enabling institutions in the USA

An illustration of early development in the American and Australian minerals industries (1850-1910) is provided in Figure 5.3. It highlights developments which contributed to the advent of scientific mining, technological innovation and industry development in the two countries. Close interaction between university science, engineering and science-based industry led to the development of an education system in America that was conducive to the success of its minerals industry.[104] As previously stated, however, the early Australian MinIS imported many of these benefits (knowledge, skilled scientists and engineers). In their explanation of endogenous, socially created resource abundance in America, David and Wright (1996 & 1997)[105] identify three key forces driving positive feedback and mineral-intensive development: 'development of an infrastructure of public scientific knowledge; investment in mining education; and the 'ethos of exploration' (David and Wright 1996, David and Wright 1997). From the perspective of this study, David and Wright's 'ethos of exploration' introduces a compelling, new component driving minerals development. The latter term encompasses:

> ...the broad cultural complex that lay behind the belief in the desirability and feasibility of continuing mineral discoveries, and accommodating legal and political environments supporting these developments. (David and Wright 1997:26)

The USA was the first nation to produce geological maps for the explicit purpose of increasing exploration by the private sector (David and Wright 1997). American universities were well advanced in the practical application of the new science of geology. In addition, from the 1830s to 1880s a strong tradition of well-resourced state geological surveys existed in the western states of America, with funding for field work and publication of findings. The US Geological Survey was established in 1879 to provide government science that combined 'economic geology' and technology (David and Wright 1997). Credited with the development of the American petroleum industry, the USGS was the most productive government research agency in the nineteenth century and reputedly influenced the widespread appreciation of scientific research and 'intelligent searching' for success in the minerals industry (*ibid*). Ultimately, the USA early-on recognised an important 'positive feedback' whereby intelligent searching and exploitation of known mineral reserves increases actual and predicted mineral reserves in 'ever-increasing rates of discovery and production'(*ibid*). Thus, the USGS institutionalised modern approaches to exploration.[106] This innovation was critical for the growth of the American minerals industry.

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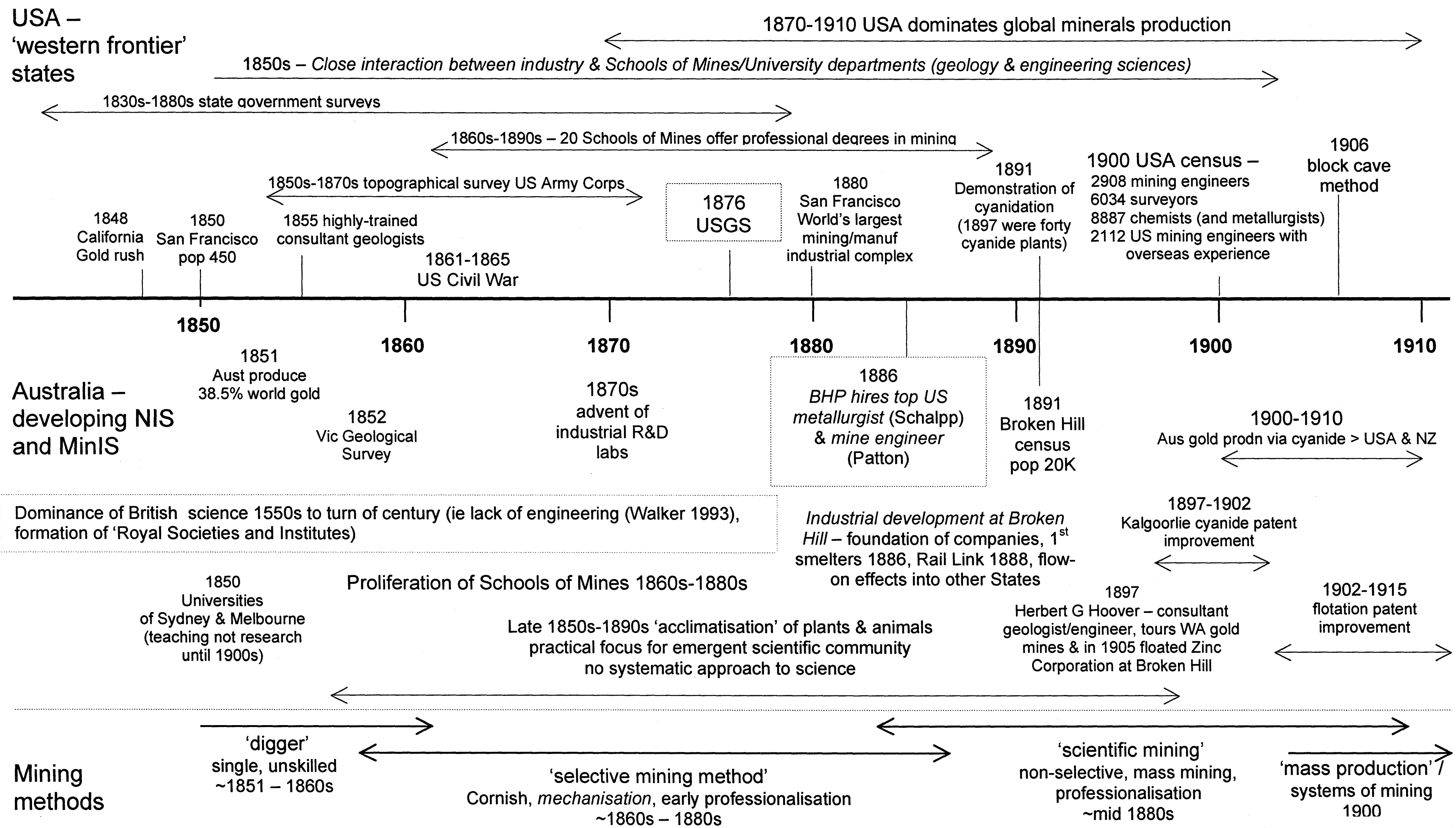
[104]The education systems of the USA, Germany and Japan were more conducive to the success of innovative performance of national firms as they provided what industry needed – new knowledge and knowledge bases, as well as skilled scientists and engineers (Nelson 1988, Nelson 1993, Freeman 1988).

[105] David and Wright argue that American mineral resource abundance was an endogenous, socially constructed state and not geologically pre-determined. Mineral wealth was derived from 'complex legal, technological, institutional and organisational adaptations that shaped the US supply-responses to the expanding domestic and international industrial demands for minerals and mineral-products.' (David and Wright 1996)

[106] This is the dissemination of government science and technologies to increase prospectivity, mineral resource endowment and industry growth. See the Broken Hill Exploration Initiative case study subunit for a modern example of this in Appendix 8.

Figure 5.3: Differences in development between US and Australian minerals industries



Institutional developments in Australia

By comparison, early Australian geological surveys were under-resourced with the type of knowledge and expertise necessary to deal with Australian geology (Table 5.4 lists the formation of state geological surveys). A clear example of this relates to the NSW Government's geologist who, on a tour of the State's silver mines in 1884, allocated half an hour of his time at the newly discovered, enormous Broken Hill deposit, and could not understand the geology of the ore or conclude whether the deposit was silver/lead or gold (Blainey 1994). State geological survey efforts of NSW employed only six geologists in 1878 to sample and record the growing number of state mining fields. Reports of these 'surveys' began to be published in the *Records of the Geological Survey of New South Wales* in 1889 (Inkster and Todd 1988). Victoria's geological survey employed 16 professional staff in 1900 (*ibid*). While the USGS began work on a geological map of the country from 1879, Australia lacked a nationwide geological map in 1953 (Griffiths 1998).

Table 5.4: Formation of state geological survey organisations

Date	State
1852	Geological Survey of Victoria
1875	Geological Survey of New South Wales
1878	Geological Survey of Queensland
1882	Geological Survey of South Australia
1896	Geological Survey of Western Australia
1899	Geological Survey of Tasmania

Source: (Wilkinson 1996:386)

Instead of developing an 'ethos of exploration,' Australia lost its enthusiasm for discovery of new major deposits. Negative expectations, though utterly unfounded, contributed to a reduction in government geological surveying and impeded exploitation of Australia's mineral potential.

> Prior to the 1960s, Australians had indeed accepted any number of unscientific rationalisations for the absence of important minerals such as petroleum: oil could not be found south of the equator; Australia's rocks were too old to contain oil; the country had been so thoroughly scoured by prospectors that surely nothing valuable could remain to be found. But this very attitude could lead to lethargic and therefore self-confirming search behaviours. (David and Wright 1997:336)

Blainey's account (1994) of the history of Australian mining supports this pessimism with a quote from a company geologist (Conzinc Rio Tinto Australia (CRA)), searching for oil deposits near the Weipa mission in Cape York Peninsula in 1955:

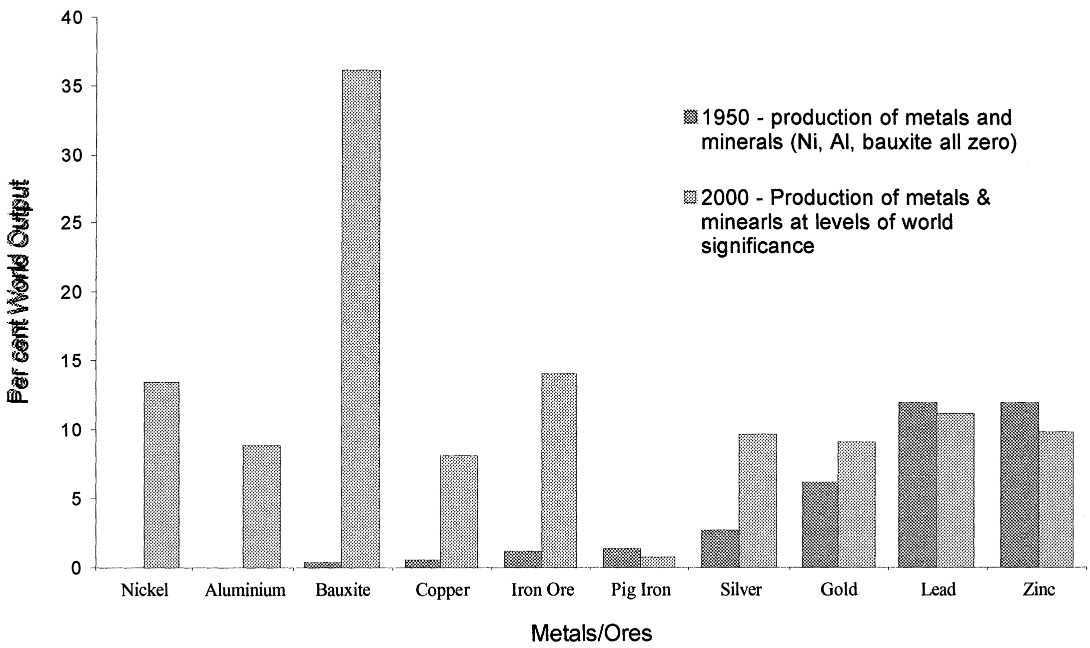
> As the journey down the coast revealed miles of bauxite cliffs Evans confessed, 'I kept thinking that if all this is bauxite, then there must be something the matter with it; otherwise it would have been discovered and appreciated long ago.' (Blainey 1994:332)

Nonetheless, the bauxite at Weipa proved to be the largest payable deposit ever discovered in Australia, and early drilling in 1964 suggested that it held one-quarter of the 'known potential resources of bauxite in the world' (Blainey 1994).

Negative sentiment and a general lack of understanding of the minerals industry on behalf of the new Commonwealth Government is also reflected in poor policy decisions (Blainey 1994, Inkster and Todd 1988). In 1938, for example, a Commonwealth embargo was placed on the export of iron ore to preserve reserves (at that time believed to be 260 million tonnes). This effectively stifled all prospective minerals exploration for the following 25 years (Australian Bureau of Statistics 2000, Blainey 1994).

When policy changes took place in the 1960s and state assistance was implemented (directed at encouragement of exploration and construction of infrastructure), new discoveries were made for iron, as well as copper, nickel, bauxite, uranium, phosphate rock and petroleum (see also Figure 5.4) (David and Wright 1997). By 1967, demonstrated reserves of iron ore (of over 50 per cent metal content) were 40 times greater than 10 years previously (*ibid*).

Figure 5.4: Expansion of Australian metal and minerals production 1950-2000



Source: values supplied by Phillip MacKey of Noranda Inc.

In sum, comparing the American and Australian minerals industries from a systems perspective has been useful. It provides new insight into the reasons why Australia did not exploit its mineral resources in the same way as America. It appears that the underdeveloped tertiary sector and public policy components identified in the early Australian MinIS represent a mismatch or blockage within the system. These components induced a vicious cycle that blocked the rest of the system's potential for growth, development and transformation. Australia's failure to capitalise upon its early development of a professionalised minerals industry is by no means a reflection upon its natural resource endowment or (more importantly) the innovativeness of the industry. As David and Wright note, 'realisation of the country's [America's] mineral potential came only after large-scale mobilisation of human resources and applications of new technologies' (David and Wright 1997:4). Additionally, America's minerals industry benefited not only from the well-documented innovations occurring within its tertiary sector (Nelson, 1988),[107] but also from the advent of the ethos of exploration and the USGS. America's resource-led industrialisation (Walker 2001) occurred at a time when these commodities were in global demand, and sustained America's ascension to world leader in manufacturing during 1880-1920 (Walker 2001, David and Wright 1997).

This analysis also says something about knowledge: sources of knowledge, access to knowledge and the importance of local knowledge bases. It appears that the MinIS worked well in terms of accessing internationally-located sources of new knowledge and practices in metallurgy and mine engineering. To a large extent such knowledge was embodied in professionally trained engineers employed by Australian minerals firms. It was not possible, however, to 'import' a knowledge base on Australian geology. Australia lacked basic geological knowledge bases and furthermore, lacked the organisations and institutions necessary to develop and promote geological knowledge and technologies in Australia. Without such knowledge, at a time when discovery was important for industry growth, exploration in Australia was conducted on an ad hoc basis (Blainey 1994, Griffiths 1998).

This analysis highlights the role of government in supporting the growth and development of knowledge- and science-based industries, such as the minerals industry.

5.5.5 The MinIS in the 1980s

From the mid-twentieth century many of the deficiencies found in the early MinIS were diminishing. As alluded to in the previous section and by Figure 5.4, changes in public policy were a significant factor in a renewed exploitation of minerals resources. Australia's national geological survey organisation, the Bureau of Mineral Resources (now Australian Geosciences), was founded in 1946. It is credited with the discoveries of bauxite at Gove, manganese at Groote Eylandt, uranium at Coronation Hill and iron at Mt Bundey and Francis Creek, as well as for contributing to many more discoveries by the private sector. Australian-based public-sector research in the geological and related sciences was being conducted at Universities and the CSIRO.[108] The tertiary sector's ability to meet the needs of the minerals industry were also improving, in part due to the establishment of specialised centres of excellence for minerals research and education, such as the JKMRC (established in 1970).

The next mineral boom in Australia was preceded by the introduction and application of a new, radical process innovation for the treatment of gold which initiated the 1980s gold rush (see Figure 5.5). By the time a CRA geologist discovered diamonds in the Kimberley (1978), the Australian minerals industry was supported by a robust MinIS.[109] It was this MinIS that

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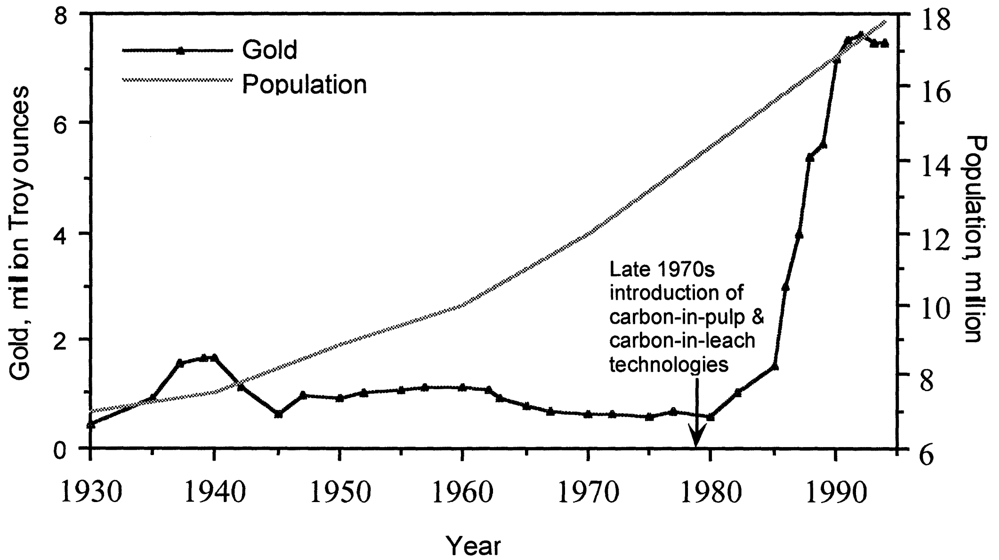
[107] Authors agree that the loss of technological leadership of Britain at the turn of the twentieth century was a lack of responsiveness of the educational system (Freeman, 1992 p171; Nelson 1993 p321; Walker 1993 p 178-180 all in Montobbio 2001).

[108] The history of public sector research in Australia is beyond the scope of this thesis. However, *Australian Science in the Making* (1988) provides a reasonable report on this topic (Home 1988).

[109] It is interesting to note that the first recorded find of seventy alluvial diamonds from the far north-west of WA occurred in 1895 (Blainey 1994).

allowed CRA to quickly access well-entrenched knowledge bases and specialised sources of expertise located in both the private and public sectors to facilitate the process of incremental innovation that resulted in the Argyle diamond sorter. This example of technological innovation also demonstrates a high degree of innovative capacity within corporate technology groups, as well as an intrinsic recognition within minerals firms of the value of innovation as a source of competitive advantage.

Figure 5.5: The production of gold in Australia and population growth 1930 -2000



Source: values for gold production and population supplied by Phillip MacKey of Noranda Inc.

5.6 Chapter summary

This Chapter's historical view has shown that technological innovation played a critical role in the development, growth and transformation of Australia's minerals industry. The Chapter began by examining the origins of Australia's minerals industry to identify factors that influenced the advent of technological innovation and shaped the industry's performance. These included the gold and silver booms of the 1850s-1860s and late 1880 that funded regional development and resource-led industrialisation. This was a resourceful period of social and economic advance, during which industry-led demands drove significant improvements in legal, educational and financial systems. During this early period, methods of mining were dominated by the Cornish unscientific approach, and development of Australia's scientific infrastructure was dominated by British influence and a characteristic lack of engineering sciences and associated infrastructure (professional institutes of technology). The advent of the capacity for technological innovation in the minerals industry was documented next in two case study subunits, Cyanide Processing and Flotation. These are examples of radical process innovations which introduced corporate research laboratories and industrial R&D to the industry. They also dramatically increased mineral endowment and productive capabilities. In addition, these process innovations exerted fundamental change in the nature of mining to scientific, non-selective mass mining methods. Successful mines increasingly relied upon the technological training of professional engineers and their ability to plan the extraction and processing operations on the basis of a deposit's geology. This Chapter's third case study subunit (set in the 1980s) profiles an Australian firm's successful management of an incremental process innovation, the Argyle diamond sorter. In this case, innovation contributed to the creation of an Australian diamond industry.

This history of technological innovation in the Australian minerals industry has not previously been analysed in a holistic manner using the IS approach. The early MinIS was found to be replete with a capacity for technological process innovation. However, it was also domestically incomplete, dominated by a British culture of science and lacking an Australian tertiary sector to meet industry needs. Scientific mining required professionally educated and trained mining and metallurgical engineers. The Australian minerals industry overcame domestic limitations by accessing international sources of knowledge and expertise, and in the process became a world leader in technological process innovation. It could therefore be argued that an Australian tertiary sector was unimportant for a minerals system of innovation. A comparison with the development of a minerals industry in America's western states demonstrates that this is not the case. Without a tertiary sector, the Australian MinIS lacked local geological knowledge bases and application of new geological technologies in the Australian context. In addition, Australia's early MinIS failed to capture the organisational and institutional innovations developed in the USA to support intelligent searching and an ethos of exploration. Public policies effectively impeded development within the MinIS and the industry's growth and development. It was for these reasons that Australia's technological lead in processing innovation did not translate into positive-reinforcement and rapid exploitation of its mineral potential. Indeed, it was not until limitations within public sector components of the MinIS were redressed that conditions favoured exploitation of Australia's mineral resources.

An understanding of a MinIS was helpful in identifying those components that enabled or impeded the development and transformation of the early Australian minerals industry. Previous studies of Australia's minerals industry and technology have not revealed the mismatch in capabilities between the public and private sectors, or how this affected innovation-based growth and development. Industry and technology histories tend to praise the technological accomplishments of the industry without recognising that private sector capabilities alone were insufficient for maximum exploitation of Australia's mineral resources. More traditional economic studies simply presume that mineral resource production is pre-ordained by geological endowment.

Much of the IS literature is devoted to attributing the economic history of nations and regions (in particular variations in growth rates over time) to the anatomy and performance of requisite innovation systems (Lundvall 1992, Nelson 1993, Freeman 1994, Archibugi and Michie 1997, Freeman 2002). This Chapter's historical review does not find support for the traditional view (Gregory 1993) that Australia's minerals resources somehow compromised the nation's innovative capacity and economic growth. Instead, the anatomy and performance of the early MinIS, in combination with many other factors, contributed to Australia's inability to maximise potential returns from its mineral reserves. These factors included the timing of a world decline for mineral exports; a lack of buoyant expectations and belief in Australia's actual minerals endowment and a knowledge-based minerals industry; prioritisation of agricultural research and acclimatisation during the early decades of the Commonwealth Government's research organisation, CSIRO; and, the Commonwealth embargo on iron ore exports and consequent stifling of minerals industry growth until the 1960s.

Finally, this Chapter highlights the importance of the role of government in innovation systems, especially in developing research agendas that provide public-sector knowledge bases that cannot otherwise be sourced to meet the needs of knowledge-based industries.

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Chapter 6:

The nature of technological innovation in the minerals innovation system

6.1 Introduction

In this Chapter the nature of innovation in the minerals industry is explored. It is necessary to know more precisely how innovation takes place (for example, with regard to actors, technologies, interactions and dynamics) to understand the role of innovation in the industry (Malerba 2002, McKelvey and Orsenigo 2001, Achilladelis et al. 1990). This level of analysis also provides some insight into the breadth and depth of innovative capacity within the MinIS, as well as the extent to which the characteristics and dynamics of minerals innovation vary according to the minerals activity involved. The distinct activities of exploration, extraction, processing and environmental management have different innovative characteristics (some trends were outlined in Chapter 4). For the purposes of this Chapter, the innovative activities relating to exploration, extraction, processing and environmental management are treated as components acting within the MinIS.

The case study subunits in this Chapter are organised in the following manner:

- Exploration – the ARIES case study subunit examines the progressive commercialisation of remote sensing technologies, while the Fractal Graphics case study subunit looks at high-tech and innovative 'Dedicated Exploration Companies' (DECs).
- Extraction – while the gross procedure for the extraction of mineral ore has changed little over the industry's history, the Block Caving case study subunit shows how incorporation of new technologies into mine planning can lead to successful re-engineering of the extraction process and dramatically improve productivity. The 'Mine to Mill' case study subunit continues the theme of improved productivity from new technology, with an example of image processing technology improving coordination between 'extraction' and 'processing' activities.
- Processing – the HIsmelt case study subunit profiles the long term development and early commercialisation of a new processing method (the direct reduction of iron).
- Environmental management – the location of the Jabiluka and Ranger Uranium mines in a World Heritage listed National Park makes the program of environmental management one of the world's most scrutinised. This program of environmental management is profiled in the Ranger and Jabiluka case study subunit.

Taken collectively, these case study subunits contribute to the accumulation of detailed empirical evidence on technological change and innovation in the minerals industry.[110] Each case study subunit 'tells a story' of a significant technological innovation.[111] As is common in case study research, these stories are rich in colour and detail, and reveal more about minerals innovation than might be anticipated. They are designed to create a general understanding of the MinIS. This analysis provides further evidence of the importance of innovation for competitiveness in the minerals industry, and highlights the existence and contribution of knowledge-intensive new technology sectors. Where it is relevant, the role of government is mentioned, although as pointed out by Montobbio, capturing the role of firms in innovation systems is most important:

> Ultimately I think that the relevant point is the innovative performance of firms and, in turn, their ability to learn, to create new knowledge and to exploit it. (Montobbio, 2001:p4).

6.2 Innovation and exploration

The nature of exploration innovation and rates of industry expenditure on exploration were described in Chapter 4. This section describes how trends in exploration innovation are changing in response to the current competitive environment for the minerals industry.

6.2.1 Introduction to recent trends in Australian exploration

Increased knowledge of Australia's prospective geology from systematic geological and geophysical survey coincides with the opening of the national Bureau of Mineral Resources in 1946 (Wilkinson 1996). This knowledge encouraged an influx of overseas investment in Australian exploration, accompanied by new ideas and expertise. A new era of exploration commenced, based upon new developments in geophysical and geochemical exploration technologies suited to Australian conditions (Griffiths 1998, Hobbs et al. 1993). A series of discoveries dating from the late 1940s repositioned Australia as a major global exporter of newly discovered minerals including manganese, mineral sands, nickel, titanium and uranium. The minerals industry spent $22 million on exploration in 1965 and this increased to $576 million in 1980-81 (Australian Bureau of Statistics 2000).

Expenditure on exploration tends to fluctuate according to global waves of demand for minerals and minerals prices. Exploration in the gold industry is much more vulnerable to short term investment cycles and access to capital than other mineral sectors. Global waves of minerals investment also influence both private and public sector investment in and support for the advancement of exploration-related technologies and knowledge. As minerals companies

[110] Studies of sectoral innovation systems state that it is important to accumulate sector-specific, detailed empirical evidence on the impact of technological change and innovation from a variety of different dimensions (McKelvey and Orsenigo 2001, Malerba 2002).

[111] Selection involved 'snowball sampling' and allowed industry members to identify significant examples of minerals innovation (see Chapter 2 for more detail).

become more loosely affiliated with their 'home' countries and internationalise their exploration activities, the role of government becomes increasingly important in creating conditions and incentives that encourage exploration and associated innovative activities in developing exploration technologies.

Australian minerals companies have had to rely upon the development of innovative exploration technologies to overcome a maturation of prospectivity and the nature of Australian geology (much of the country is covered by 'regolith', a layer of rock impervious to traditional exploration technologies), as stated by mining magnate Sir Russell Madigan in 1986:

> Nearly all the ore bodies mined today were found by tramping through the spinifex, indeed, mostly by prospectors rather than by geo-scientists, but we are nearing the end of the outcrop or other surface indication of the good things below. A new era of scientific exploration has begun, and its success will depend more on the mind of man than his feet. (Madigan, quoted in Griffiths 1988:172)

Large Australian minerals companies responded to the scientific era of exploration with substantial financial investment in extensive internal exploration capabilities. Western Mining Corporation's (WMC) discovery of Olympic Dam in 1975 was the first giant deposit whose discovery was directly linked to this exploration strategy (it incorporated skilled geologists, sophisticated corporate laboratories and expensive drilling rigs) (Blainey 1994, Griffiths 1998). The surface geology provided scant evidence of the deposit that was around 350 metres below. The knowledge and critical thinking of WMC geologists, developed from their in-house program of theoretical research and modelling into the formation of sediment-hosted copper deposits, was applied to magnetic and gravity geological survey data (provided by the Western Australian Bureau of Mineral Resources). Based upon the predictions from this model, WMC's Board agreed to what was initially a highly speculative program of drilling. Vindication of the four year extensive drilling program came with the identification of the 570 million tonne Olympic Dam ore body (Blainey 1994), currently valued at $3,614 million dollars (Chenoweth 2001).

The problem for Australia's minerals industry is that despite many discoveries in recent years (see Table 6.1), Olympic Dam is the only giant discovery to have resulted from extensive corporate programs of exploration. As a consequence, large minerals companies are currently responding to a lack of return on investment in exploration and associated technologies and knowledge. Furthermore, innovation in exploration has intensified due to the sophisticated, high-tech nature of critical exploration technologies (remote sensing, complex data modelling and gravity gradiometry). This has increased the expense and risk associated with the development of exploration technologies. These changes are driving a transition of exploration-related innovative capabilities out of large minerals companies and into small exploration companies, so-called Dedicated Exploration Companies (DECs). These factors are causing a break from tradition where the discovery of previously unknown deposits was a primary source of growth (Tilton 2001). Large minerals companies now seek to obtain strategic competitive advantage through innovations that augment known mineral reserves. Changing dynamics in exploration innovation also have implications for the role of government.

Table 6.1: Australian minerals discoveries 1989-1999

Discoveries in Australia 1989-1999	Reserves (Mmt)	Copper (%)	Gold (g/mt)	Silver (g/mt)	Zinc (%)	Lead (%)	Nickel (%)	Cobalt (%)	Value Total Reserves (US$ b)
Bronzewing	23.8		4.08						0.98
Cadia East	125	0.48	0.42						1.76
Cadia Hill	295	0.16	0.75						3.07
Cannington	10.6			477	5.67	11.6			2.14
Cawse	30.3						1	0.06	2.26
Century	99			42.86	11.6	1.7			13.76
Ernest Henry	130	1.14	0.55						4.13
Jundee	24.7		4.8						1.2
Kanowna Belle	18		4.67						0.85
Maggie Hays	15						1.45	0.05	1.72
Ridgeway	39	0.85	2.9						1.72
Sunrise dam	23		3.69						0.86
	833.4								34.45

Source: (Metals Economics Group 2000)

Competition for investment in exploration is being felt on a global scale. It is being driven by factors including the depressed economic climate in minerals; changing minerals-related policy; political reform, particularly in South America, which has reduced the risk associated with exploration in those countries; and the establishment of publicly sponsored, pre-competitive exploration programs on a large scale in prospective regions of the world (Waring 1999). These factors have induced an increase of exploration in comparatively under-explored regions in South America and Africa.

6.2.1 Australian geography and exploration innovation

The Australian continent is dominated by an unhomogeneous, variably thick, regolith terrain. Discovery of ore bodies has become progressively more difficult, requiring increasingly sophisticated exploration technologies, and strategies to enable the discovery of 'blind' ore bodies. Expenditure on exploration R&D increased between the early 1980s to mid 1990s, driven in part by the need to develop such Australian exploration tools and a mining boom (Cucuzza and Goode 1998).

Most major Australian discoveries are still being made in well-known mineral provinces, which in some cases have borne 100 years of exploration and mining. However, new discoveries under areas of relatively thin regolith are also occurring due to advances in modern exploration techniques. In the past decade, for example, CSIRO's research has directly contributed to the discovery of $6 billion of nickel deposits and $5 billion in gold reserves (CSIRO 1998a). As exploration in Australia has become increasingly complex, there has been a move towards a multi-disciplinary approach combining 'modern geological concepts with advanced geophysical and geochemical exploration methods and state-of-the-art data processing, visualisation and modelling backed by comprehensive drilling programs' (Jaques and Ewers 1998).[112] This approach is exemplified by CSIRO's Division of Exploration and Minerals' 'Glass Earth' multidisciplinary research project which aims to discover the next generation of Australian deposits by making the upper first kilometre of the Australian continent 'transparent'.

Australia has subsequently become a world leader in certain fields of exploration technology and exports such expertise internationally. R&D expenditure in particular industry sectors is in decline as a result of successful research and innovation. For example, CSIRO and the CRC for Landscape Evolution and Mineral Exploration are receiving less funding for research on Archaean gold exploration in Western Australia as a direct result of their past success (Cucuzza and Goode 1998).

6.2.2 Australian minerals companies and exploration innovation

It has been said that 'The main assets of a mining company are its ore bodies; the second are the people who find them' (Hobbs et al. 1993). As mentioned above, however, major minerals companies are changing the way they value and view their internal exploration groups and associated capabilities. Major Australian companies, such as BHP and Rio Tinto, have drastically cut their internal exploration research and project development groups (see Table 6.2). BHP announced its intention to reduce exploration expenditure by 25 per cent in 1998-99 to $164 million. Australia's biggest gold miner, Normandy, cut its exploration budget by 22 per cent (Bloomberg 1999).

The move to cut internal exploration groups is due in part to companies auditing their exploration performance and identifying traditional or 'greenfields' exploration as the least cost effective means of acquiring new deposits. Exploration conducted at a mine site and surrounding area is called 'brownfields' and is believed by some companies to be the most cost effective form of exploration. When the Granny Smith gold mine was discovered, for example, it was identified as a 1 million ounce deposit. Brownfields exploration has revealed a further 3 million ounces associated with the Granny Smith deposit. Mid-Stage Project exploration (MSP), which involves acquiring and exploring projects developed by DECs, was found to be the second most cost effective form of exploration. MSP exploration boomed during 1988-1993 (Hall 1999).

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[112] The close interaction between pure university science and application of technologies for exploration resembles other industries of the twenty-first century that produce science-based technologies (Orsenigo et al. 2001, Montobbio 2001) and display characteristics of 5th generation R&D (Rothwell 1994).

Table 6.2: Estimated cuts to corporate exploration expenditure & research groups in 1997-99

Company	Estimates of exploration cuts
BHP	40%, included closure of offices and staff cuts; May 1999 another 60% budget cut with a 75% staff cut (750 to 170)
Rio Tinto	Initial cuts of approximately 50% of budget; world support services group disbanded; another 15% cut in August 1999 and let go Chief Geophysicist
MIM	50% cut including office closures in Perth and Asia and staff cuts of 50-60 people
Placer Dome	40% cut to budget, staff cut from 270 to 70 internationally with 5 staff remaining in Australia
WMC	Two rounds of 20-25% budget cuts, 50-60 staff lost in 1997 and another 79 the following year
North Limited	20% cut in March 1999 and a second round of the same amount to follow
Normandy	16% cut including 15 staff (4 geologists) and office closures in Kalgoorlie, Darwin and Charters Towers
Aberfoyle	35% cut and then company taken over by Western Metals and lost most of staff.
Anglo American	60% global cuts in late 1999 – 5 of 12 African countries to be 'closed'. Fiji, PNG, Indonesia and Singapore hard cut

Source: Estimates provided by AMIRA

Exploration innovation seems to be developing an organisational structure more akin to that of biotechnical pharmaceuticals, where major pharmaceutical companies focus upon drug manufacturing and marketing and small specialist companies carry out the high risk, initial stages of finding and testing a potential drug candidate (Ramani 2002, Achilladelis and Antonakis 2001, Orsenigo et al. 2001). In the minerals industry, DECs are becoming increasingly important in early-stage, high-risk mineral exploration and the major companies are taking on the role of developers of the DEC's promising discoveries. It is not surprising then that 62 per cent of 'metal ore mining' businesses (defined as management units) use advanced exploration technologies (Australian Bureau of Statistics 1998).

There is a lack of accurate statistical data when it comes to determining what percentage of total exploration budgets is spent on research, and how companies partition their exploration research effort between internal (in-house) and external collaborative research, let alone in how these categories of research may have fluctuated over time. In a 1992 paper, Mackenzie and May suggested that collaborative research in exploration ranged between 4 and 10 per cent of total exploration expenditure (Mackenzie and May 1992). Estimates of approximately 1 per cent have also been suggested as the proportion of total exploration expenditure spent on pre-competitive collaborative R&D (Cucuzza and Goode 1998). If these estimates for competitive and pre-competitive R&D are applied to the 1997-98 total exploration budget for Australian minerals companies, then somewhere in the order of $43-107 million was allocated to competitive exploration research, and $11 million to pre-competitive R&D.

It would appear that Australia's exploration technologies have paid off in terms of the value of mineral discoveries during the decade of 1989-99 (see Table 6.3). The ratios in Table 6.3 provide a rough estimate of regional efficiency in exploration and suggest that Australia has delivered a better return than other developed and more prospective regions (Latin America and the Pacific Southeast/Asia). According to the Metals Economic Group, Australia is the top ranking country in global exploration spending in 1999 and 2000 (Latin America was the top ranking region). Australia, however, also experienced the largest decline in global allocation of exploration expenditure (18 per cent) for any country or region (8.8 global average decrease) in 2000 (Metals Economics Group 2002).

Table 6.3: Value of minerals discoveries 1989-99 verses exploration expenditure by region

Region	No. of discoveries (1989-99)	Value found reserves (US$b)	Exploration expenditure (US$b)	Ratio value/ expenditure
Latin America	19	129.39	7.47	17.32:1
Pacific/Southeast Asia	5	46.72	2.54	18.40:1
Canada	9	42.4	4.78	8.87:1
Australia	12	34.45	6.57	5.24:1
United States	7	23	4.18	5.50:1
Africa	6	14.65	2.69	5.45:1
Europe	3	7.93	na	na

Source: (Metals Economics Group 2000)

The Australian minerals industry holds some influence over the exploration research agendas, as demonstrated by the networks and relationships it holds with research providers (see case study subunits). The majority of industry 'pre-competitive' R&D is handled by AMIRA, while the CSIRO's division of Mineral Exploration and Mining received $15.4 million, or 48 per cent, of its funding from industry (Cucuzza and Goode 1998, CSIRO 1998b). Cooperative Research Centres (CRCs) also provide considerable expertise and benefit for Australian exploration innovation. In July 2001, the CRC for Predictive Mineral Discovery and CRC for Landscape Environments and Minerals Exploration (a continuation of the CRC for Australian Mineral Exploration Technologies established in 1992) were established. Other CRCs that supported minerals innovation in the 1990s have since ceased operation including the Australian Geodynamics CRC that was established in 1993, the CRC for Australian Mineral Exploration Technologies that was established in 1992, and the CRC for Advanced Computational Systems that was established in 1993.

In spite of the strong relationships between the minerals industry and research providers, many industry representatives expressed frustration (to this study) with the exploration research agenda within external research institutions, suggesting that it was being set by researchers and not by explorers, resulting in many cases of solutions being found for problems of limited relevance.

The ARIES – Australian Resource Information and Environment Satellite
Case Study Subunit

Introduction to the ARIES project

A 22 year research collaboration in geological remote sensing, between CSIRO and the minerals industry, brokered by AMIRA, underlies the Australian Resource Information and Environment Satellite (ARIES) concept. During the collaboration both infield and airborne geological remote sensing instruments were developed and commercialised. CSIRO's remote sensing group had always wanted to take mineralogical sensing into the international market place, and knew that a remote sensing satellite was the next step in the application of their previously proven technology. ARIES was another delivery mechanism with the advantages of constant global surveillance and relatively modest cost of information following an initial high capital outlay.

ARIES is planned to be launched late in 2003 to provide geological and biophysical information on the earth's surface on a commercial basis and to an international remote sensing market. The satellite carries a hyperspectral sensor and collects images at a much higher sensitivity than other satellites. Apart from building the remote sensing equipment and satellite, the ARIES-1 project aims to develop value-added products and information systems to deliver into its market. The minerals industry is considered to be a major ARIES customer.

Drivers of the ARIES concept

A number of serendipitous opportunities were important for the development of the ARIES project. The then Minister for Science, Chris Schott had an interest in remote sensing and dedicated the 1995 Australia Prize, an international award, to the field. Drs Ken McCracken, Andrew Green and Jon Huntington of CSIRO won the award for their research and its application to mineral exploration. This meant that in 1995 remote sensing received some very good press. At the same time the Australian Space Office, also Minister Schott's responsibility, announced its intention to develop an Integrated National Space Program. It would underwrite a project to the value of $10 million and bids were called for ideas for a space initiative. The government funding was intended to be seed money with industry supporting the chosen initiative.

Armed with good publicity from the Australia Prize, the expertise and history of their research group and a $10 million incentive, McCracken *et al* put a proposal to a number of potential collaborators to join their bid for the space project. Several agencies including Auspace in Canberra, ACRES (Australian Centre for Remote Sensing in Canberra), three small firms from Western Australia, Queensland and New South Wales together with CSIRO submitted a proposal called AMSAT to government. During the evaluation process it became known that the government was reviewing the Space Program and that in all likelihood it would be closed down. Although AMSAT won the bid the incentive Space Program initiative was abandoned.

The proposal process engendered a level of excitement around the idea and a ground-swell of support and interest from the minerals industry and AMIRA. The AMSAT project continued to evolve and became the much larger ARIES project.

The minerals industry and ARIES

At this time it became apparent that the ARIES project required more funding, estimated to be $15 million plus the cost of the launch. Given the Australian minerals industry's history of development in remote sensing technology, CSIRO promoters had the idea that ARIES too could be developed by the minerals industry. An ARIES development proposal seeking $10-20 million of funding, gaining in return the ownership and control of the satellite, was put to the Managing Directors and Chairmen of several companies. Serious contemplation of the proposal on behalf of the industry generated a common response – it was an interesting idea but they were minerals companies, they knew nothing about satellites and had no interest in the space business. However, if the satellite were up and running they would purchase the data. This was an important and tangible result as it gave confidence that a market existed for the technology. The statement of industry's support was in turn taken to the government to show that resource companies liked the idea but were not going to pay for it. The ARIES proposal received a $300,000 grant from government for a feasibility study. It was unlikely that the government would give $300,000 without industry's support and interest. The Macquarie Bank became financial advisers for the ARIES project because of the stated industry support for the project and undertook the task of raising $15 million for the project.

ARIES feasibility study

Eleven international companies and agencies sponsored the initial feasibility study and paid $75,000 dollars each. As a one year's subscription to a project it was the largest that AMIRA has ever managed. This support represents a long-term vision. In return for their support these companies received the knowledge that ARIES was feasible, and they learned something about the science and its utilisation through a series of workshops. This is very different to an AMIRA project where the short term deliverable is tangible. The project also captured the imagination of enough members who believed in the broader industry benefits. There is also a tangible benefit from sponsoring ARIES, namely $75,000 worth of ARIES information and services once it is operating. Members are given priority in ordering services for an extra fee.

AMIRA managed the feasibility study, undertaken between September 1996 to April 1997. Funding was provided by the major consortium partners CSIRO, Auspace Pty Ltd and ACRES as well as:

- Space Policy Unit (Australian Government)
- Australian Geological Survey Consortium
- Canada Centre for Remote Sensing
- European Geological Survey Consortium
- The Natural Environment Research Council (UK)
- Anglo American Corporation of South Africa Ltd
- Outokumpu Metals and Resources Oy
- Phelps Dodge
- Placer Pacific Ltd

- Rio Tinto Ltd
- Sumitomo Metal Mining Oceania Pty Ltd
- WMC Resources Ltd

The two major objectives during the feasibility study were development of a business plan and an overall model for investment during the development of the project, and to define user needs and systems to meet such requirements.

Future of ARIES

Commercialisation of the ARIES satellite is continuing. If it is successful, it will deliver a number of benefits for Australia's innovative capacity, such as, new intellectual capacity in complex systems management, knowledge and expertise accompanying space systems manufacturing, international recognition for the successful hosting of such a complex innovation, and creation of a tax paying, high tech Australian company.

Historically, the field of remote sensing from space has been associated with the US, Europe, Russia, Japan and India. The highest resolution data which currently serves the market comes from India and is not of the same quality as that planned for ARIES. Australia will enter the field in an unusual manner, having a product designed to suit industry needs and sponsored on that basis. Space programs in the Northern hemisphere tend to place technology first and consider the application later. ARIES is totally the other way round as is evidenced by the fact that users paid for the feasibility study.

The three original partners involved in the development of ARIES continue to have quite distinct functions: Auspace is in charge of the space operations – satellite, instrument and launch; ACARES the global ground operations; and CSIRO the basic science, experimental development, early stage marketing and generation of products.

It is expected that minerals companies, as well as state and federal governments, will be among ARIES' global customer base. In terms of exploration, ARIES will have great potential outside Australia, especially in newly developing countries where the exploration knowledge base is less well developed.

6.2.3 Dedicated Exploration Companies (DECs)

As described above, minerals companies are dealing with cuts to their own corporate laboratories and the related issues associated with managing exploration research. Many of those interviewed said that designing an internal corporate exploration group was the most vexing challenge they faced. Due to the nature of exploration, described by one senior geologist as 'seeing what others see and thinking what others haven't thought,' talented individuals carry a heightened degree of influence, even to the point where they determine the success of a company's research program (as demonstrated by the WMC's discovery of Olympic Dam). Many major companies feel that highly innovative individuals are stifled by the corporate system, causing 'the smart ones' to move into smaller and more innovative Dedicated Exploration Companies (DECs) or to start their own companies.

Recent cuts to corporate exploration groups have created a rich and growing pool of exploration expertise and knowledge outside of major companies. Geological consulting companies, such as SRK Australasia, have the capacity to manage the complexities of geological exploration and have appeal since they house a broad range of skills and can provide a 'one-stop-shop' that other consultancies cannot provide except through alliances. Geological consultancies may draw together exploration teams to suit a particular exploration problem. In turn, consultancies benefit from the multiplier learning effect gained from exposure to a large number of mine sites.

Over the past few years, major companies have been changing their attitude towards alliances with DECs and geological consulting companies and see such alliances as a cost-effective alternative to corporate-based research (Davis 1998). The explorer, PlatSearch, houses specialist expertise in geophysical exploration of Proterozoic rocks, as found in Mount Isa–Concurry region of Queensland, and has joint ventures with BHP, WMC, Plutonic/Homestake Mining and Delta Gold, in the broad area of regional, generative or grass roots exploration, and use the latest geoscientific techniques (*ibid.*).

It is difficult to quantify the extent to which DECs contribute to new developments and investment in R&D. Clearly, the trend in utilising DECs can only succeed in the long term if the generative research base continues to be supported and DECs are well linked into this base. Some highly innovative DECs invest heavily in innovation. Fractal Graphics, for example, invests 'all of its profit' back into R&D activities and has strong links into the research base (see Fractal Graphics subunit below).

A problematic implication also arises for DECs from cuts to exploration, as DECs are usually founded by executives from the major minerals companies. The fact that the relevant level of exploration management has been lost from major minerals companies potentially undermines the source of future DEC managers. The US-based international company, Placer Dome, for example, has cut its exploration group from around 720 staff to 70. The overwhelming majority of Placer exploration staff are based in the company's home country, the USA. In the year 2000 only five staff members remained in the Australian-based Asia Pacific exploration group, down from 50-60 people five years earlier (see Table 6.2).

DECs and access to exploration capital – risk capital

DECs require access to risk capital to conduct early-stage, greenfields, high-risk exploration. According to industry analysts, the global exploration expenditure is nearing the bottom of a cycle (Metals Economics Group 2002). Global exploration spending exhibited an upward trend from 1993-1997, which dramatically reversed in 1998 when exploration allocations worldwide dropped by 29 per cent, and again by 24 per cent in 1999. The global trend in decline was slower in 2000 at 7 per cent. The ramifications of these declines and effects are being felt by the Australian DECs which are experiencing greater difficulty gaining access to equity capital. During the 'dot.com' stockmarket boom many DECs turned to investments in areas like the Internet to attract capital. Recent improvement in the gold price has created some buoyancy with regard to Australian exploration but is yet to translate into the creation of new exploration companies (Manners 2002). Recovery of liquidity in the equity markets for DECs is expected to take some time (Metals Economics Group 2002).

The importance of access to exploration capital for DECs is illustrated in Table 6.4 below, which shows how the proportion of company finance spent on exploration is dependent upon the size of these finances. It appears that the more capital a company raises, the more is retained for future use. DECs fall into the smallest class of finance and actually spend more than they raise on exploration. Thus, given the reliance upon these companies for greenfields exploration and project development to sustain the health of exploration more broadly, access to capital is vital. Additionally, access to capital allows DECs to reinvest in their technological capabilities and sustain the development of new exploration technologies. According to some industry analysts interviewed for this thesis, a lack of risk capital is the single greatest obstacle confronting Australian exploration.

Table 6.4: Finance raised spent on exploration for 3 classes of company finance

Level of finance	Total amount of finance raised ($m)	Exploration expenditure ($m)	Percent of total finance spent on exploration
$1–2 million	57.7	66.0	114%
$2-5 million	117.5	90.9	77.3%
> $5 million	628.4	196.0	31.2%

Source: adapted from (Harper 1999,p33)

The Fractal Graphics Case Study Subunit

A brief history of Fractal Graphics

Fractal Graphics (FG) is a highly innovative, high tech, geological company established by Dr Nick Archibald in 1991. It may be characterised as a Dedicated Exploration Company (DEC), although some of its products are applicable to mining and mine planning, not to mention their potential for use in other industries. FG aims to exploit the potential of 3-D computer visualisation to redress a gap in exploration technology. While digitalisation increased the amount of geological data stored in databases, such growth tended to carry a negative correlation with the discovery or prediction of new ore bodies.

A collaboration between Dr Archibald's consulting company, Port Management Services Pty Ltd, and CSIRO Division of Geomechanics (now incorporated into the Division of Exploration and Mining) founded FG. Financial support, obtained in the form of a Government Industry R&D (GIRD) grant in metallurgical and information sciences, facilitated Fractal Graphics' participation in past CRCs (the Geodynamics CRC (AGCRC), the Advanced Computational Systems CRC (ACSysCRC)) and present CRCs (CRC for Predictive Mineral Discovery).

With a group of three, work began at Fractal Graphics (FG). However it soon became apparent that conventional, commercially available computer software could not deliver the system FG wished to develop: an integrated visualisation environment with a minimalist interface and maximum efficiency. The FG system that was sought would allow users to interact intuitively to analyse data. The deficiencies in commercially available software led FG to take a sideways step into designing its own program for software development in 1992, and a scientific collaboration was initiated to look at data modelling and the representation of geoscientific information.

According to Dr Archibald, by the end of 1994 CSIRO was uncomfortable with the fit of Fractal Graphics within the organisation and the direction in which it was heading. Negotiations resolved for Fractal to buy CSIRO out of the collaboration, and by mid-1995 the company had become a fully commercialised, privately listed proprietary company. As part of the continuing agreement FG must provide $150,000 per annum to support research in CSIRO in return for royalty rights from commercialisation of the CSIRO intellectual property. CSIRO maintained all rights to the original IP.

During the next three years FG grew its staff to 19. Its business of supplying state-of-the-art computer modelling capabilities to the minerals industry generated an annual turnover of $3m. In addition, in February 1998, FG was awarded a $0.98m Start Grant.

Research and business strategy at Fractal Graphics

Research and development is central to FG's business strategy, and all profits are returned to its research program. FG understands that an active research program is critical to sustain and enhance its products and services. Its internal R&D department supports both the commercial and collaborative sides of the company. For the former, the R&D department is responsible for the development of software in line with commercial needs. In the latter case it involves commercialising new technologies generated within the research institutes with which Fractal collaborates. The commercialisation of new technologies feeds back into Fractal's commercial business as novel tools are proven and taken up by the minerals industry.

Fractal's major research project is FracSis, a 3-D spatial information system in which data from different sources may be handled, integrated, queried and visualised in 3D environments. This research and development project is supported by the $0.98m Start Grant mentioned above. The major research projects at Fractal are listed in the table below.

Table 6.5: Current research projects at Fractal

Project name	Description
FracViwer	A powerful 3-D geological visualisation application, version 1.8 commercially available with version 2.0 being developed
FracWormer	A tool that extracts geometrical information from potential field data sets and displays it in an intuitive, understandable manner
FracSIS	A fully integrated 3D spatial information system which may be used as a 'back-end' to existing visualisation and modelling applications

Fractal Graphics' collaborative research program

Fractal supports a rich network of linkages into the wider minerals industry research base in Australia through its collaborative research projects. Its portfolio of collaborative research involves a complete spectrum of Australian research organisations within the MinIS: CSIRO's Division of Exploration and Mining; past and present CRCs; University research centres; and AMIRA-brokered research projects. A great deal of this research involves high performance computing, modelling and the application of 3-D, interactive, virtual environments to the minerals industry. It carries potential for application in other industries.

The Menzies-Norseman Project (formerly part of the AGCRC) aims to build terrain scale models of 350km x 150km x 10km into the earth's crust. Part of this research program also involves collaboration with the Australian Crustal Research Centre in Monash University. In a strict sense, the Australian Crustal Research Centre is one of FG's competitors, and one of a number of groups building 3D digital models. It made strategic sense, however, for FG to tie up their competitor in a collaborative project and move them out of the competing commercial realm. From FG's point of view, 'parsimonious operators' who are looking to tie up the area or to buy up academics on the cheap are a real threat to their own viability.

This research project has also been the basis of an application for a government SPIRT grant.

FG was very disappointed with a decision to discontinue funding for the ACSys CRC in December 2000, in spite of the CRC secretariat's recommendation for continued funding. It was suggested that a factor which may have acted against the AGCRC receiving another round of funding was the manner in which support from industry is obtained. Mainstream industry support was at arms' length, with direct collaboration based on small service-providing companies. Whatever the case, FG believes that the government's decision to discontinue support came at a time when it should instead be building up R&D capabilities in the fields concerned and, furthermore, that the decision represents a lack of insight on behalf of government into the potential of high tech developments in the minerals industry. In July 2001, the development of the Action Agenda for Minerals Technology Services Sector suggests that the government is moving, albeit belatedly, to support this important, high-tech sector. In addition, the Government's 'Backing Australia's Ability' policy statement in 2001 announced measures to increase the inclusion of SMEs into the CRC program.

Managing the application of technologies via strategic relationships with clients

FG understands that as a geological consulting company its core business focus is 'turn-key' consulting that provides immediate solutions to particular problems. To this end one-on-one small collaborations are conducted with members of the minerals industry, and contracts are usually of the order of $30-40,000. In future, however, FG aims to expand its consulting relationship with major clients into longer term strategic collaborations. This was the case with WMC Resources, who licensed the FracViewer technology and engaged in a collaborative venture on ore targeting and the use of 3D GIS imaging techniques. The value of this collaboration was reported in WMC's 1997 Annual Report which stated:

> Collaborative research with Fractal Graphics in Perth has produced fully interactive three dimensional images of underground geology in the Kambalda area. This state-of-the-art imaging technology markedly increases understanding of the ore bodies that are presently being mined. Its greatest benefit is in improving the probability of finding new ore bodies. Detailed analysis of the images guides exploration to possible high-quality ore bodies, reducing discovery costs by up to 50 per cent. (WMC 1998)

Returns from application of Fractal Graphics technologies

Until recently, few mining managers understood computing technology and viewed it as a cost rather than an investment. Application of FG technology products can provide many examples where the use of appropriate software can have an enormous impact upon a minerals companies' ability to exploit their ore bodies, both in terms of exploration and extraction. In one case, FG was contracted by a minerals company to redesign a database from a particular mine. The original coding system contained 59,000 unique rock codes, when at most only 40 rock types exist. An unduly complicated coding system made the database unworkable; FG software solved this problem. It can recast jaded mine sites and identify exploration targets, as another company found when it relogged 160 kilometres of diamond and air drill holes and with an improved exploration program and went on to increase its share price from 20 to 80 cents.

Large pits can no longer afford to support teams of geologists on the ground to map the position of the mine at the mine face (on a continuous basis), not to mention that these days such a position would not be upheld on safety grounds. It is possible, however, to obtain and annotate such data remotely. This is not only safer but also is an extremely powerful method of analysis. Fractal Graphics sees its role as providing the software system whereby 3D visual and tactile queues assist the analysis of such remotely obtained data to improve mine design.

Fractal Graphic's future

Despite its successes, FG's viability is on a hand-to-mouth basis. Forward planning relies upon the company landing substantial private contracts and integrating its commercial work with its collaborative research program. Given the current state of the minerals industry and some 'poor Government decisions in relation to public sector support,' Dr Archibald questions whether the minerals services sector, and DECs in particular, will have the stamina to sustain future growth. According to Dr Archibald, new high-tech exports can only develop in a fertile back yard, and this requires a cultural change in Australia and an awareness among governments of how Australian minerals companies sustain competitive advantage (that is, through innovation) in the global marketplace.

6.2.4 Section summary

From the mid-twentieth century the MinIS has produced exploration technologies suited to Australian conditions. Exploration innovation is being threatened by a number of interrelated factors: a global decline in exploration expenditure; reassessment by major minerals companies of their corporate exploration programs leading to significant cuts in expenditure and to exploration groups (personnel, internal research programs and associated capabilities); a transition of exploration innovation capabilities out of large minerals companies and into smaller DECs; and a lack of access for DECs to venture capital.

The structural organisation of an exploration component of innovation is moving to a state more like that of the pharmaceutical industry, and DECs are becoming increasingly important in early-stage, high-risk mineral exploration. Anecdotal evidence suggests an increasing number and variety of strategic alliances are developing between DECs and major minerals companies. DECs are involved in a diverse array of strategic knowledge networks, particularly in collaborative research programs among public sector research organisations, and alliances with the private sector during commercialisation of promising new technologies.

If the incentive for companies to support exploration research is undermined then a considerable risk is posed to Australia's position as a world leader in exploration research and as a participant in the fast-growing Minerals Technology Services Sector (MTSS). The latter holds important implications for the role of governments in this area. Policies need to ensure a number of factors: continued government surveying and production of detailed knowledge of the geological prospectivity of Australia (globalisation and opening up of new prospective territories has increased competition for exploration activities); continued development of Australia-specific exploration technologies; maintenance of Australia's knowledge base in exploration in the long term as it shifts into DECs; and creation of conditions that support the newly created high-tech minerals exploration services industry.

6.3 Innovation in extraction

This section reviews the nature of extraction innovation in the Australian minerals industry.

6.3.1 Introduction to trends in extraction innovation

Improvements in production rates and safety have been the primary drivers of innovation in extraction (or 'mining') (Simpson 1999, Peterson et al. 2001). To this end, the mechanisation of mining processes was embraced with vigour from the early days of the industrial revolution (Hovis and Mouat 1996) through into the twentieth century and machines now operate virtually all stages of the mining production line. Mechanisation has significantly reduced the unit cost of mineral production.

Innovation in extraction is unlikely to change existing mining processes and equipment due to the amount of capital invested in these operations. Typically, innovation is an incremental process with a focus on: performance of mining equipment; remote control and automation; and monitoring, maintenance and control systems. The R&D agenda in extraction increasingly centres on the application of new critical technologies to mineral operations. Such technologies include information and communication technologies, remote sensing, on-board sensors, Global Positioning System (GPS), and 3-D visualisation technologies. The trends in innovation in these areas differ according to a mine's location (underground or on the surface). A trend towards increased size and power has dominated equipment innovation for surface mining (although this trend in now reaching its limits), whereas underground mining leads the way in automation (see Block Caving case study subunit). Innovation in mining equipment is mainly conducted by international equipment manufacturers with comparatively little in the way of equipment manufacture present in Australia. Cutting Edge Technologies, a small spin-off company from CSIRO in Queensland, is an exception.

The pace of innovation in extraction is being constrained by the current competitive environment in the global minerals industry and the fact that equipment manufacturers and companies are currently doing little in the way of long-term research (Peterson et al. 2001). This situation places increasing importance upon the role of research providers, like the CRC for Mining Technology and Equipment (CMTE) and the JKMRC, and in particular, their pre-competitive and more basic research programs. It will also be important for such organisations to maintain their linkages with operating mine sites to better understand industry requirements for mining technology. It is ironic that at a time when companies are reducing their internal technological capacity, a competitive advantage in excavation is increasingly linked to how well new technologies are identified, understood and adapted to suit individual mines, as Dr Robin Batterham says:

> … the competitive advantage in mine mechanisation will not necessarily lie in the technology and equipment, that will be on sale for everyone, it will be in the understanding of the process and best implementation of the innovations within the mines that we manage. (Batterham et al. 1997,p10)

6.3.2 Automation of mining operations

Despite the increasing levels of automation in mining operations, its uptake has been slower than in other industries. According to Batterham, this is because:

> The application of automation in mining is much more complex due to the uncontrolled domains in which mining machinery are required to operate. A highly variable domain dictates that the information required to define the environment in which an autonomous system functions has to be that much more detailed. Hence, while the mining industry can utilise much of the technology developed for automation of other industries it will have to undertake significant amounts of research and development of its own to overcome the idiosyncrasies of mining. (Batterham et al. 1997:1)

Automation has focused upon applications for standard processes as opposed to designing a new and entirely novel, fully automated extraction process. The block cave mine at NorthParkes is the best example in Australia, if not the world, of a company re-engineering an entire mining system to extract the full potential of automation (see Block Caving case study subunit). Other types of mines are not as amenable to automation, and the high costs and risks associated with radical change prevent most minerals companies from being active in the area.

The transfer and adaptation of enabling technologies from other industries, such as GPS and image analysis (see Mine to Mill case below), has been a preferred strategy. Thus, most mines operate in the same manner as 50 years ago but with 'islands of automation' at particular points of the production line (Batterham et al. 1997).

This is not to belittle the gains achieved from an incremental approach to automation. For example, in a joint venture with AMDEL and at a cost of $6 million, ERA developed a radioactivity discriminator – a camera that can measure within 0.02 per cent accuracy the gamma radiation coming off a loaded haul truck and gather other information over 104 different variables. This information is sent by radio modem to a central computer which calculates the load grade and then directs the truck to the appropriate stockpile. These cameras, installed at Ranger uranium mine, also help with water management practices that require monitoring the position of all ore. Previously, the calculation of load grade involved individuals climbing into the back of loaded trucks with a Geiger counter and physically measuring gamma radiation levels. The new automated system has improved productivity and safety (see Mine to Mill case study subunit).

6.3.3 Innovation in new extraction systems – precompetitive colloboration

Innovation in new systems of extraction is focused upon improved methods of rock excavation that can remove miners from the rock face, along with the ubiquitous drill-and-blast method. This area of innovation primarily involves pre-competitive research and tends to be housed in universities and CRCs, with support from industry. The CRC for Mining Technology and Equipment (CMTE) has several projects in the field, including the oscillating disc cutter (ODC) which is a radical system for the rapid excavation of hard rock (Hood 1997, pers com September 1998). The system has potential for both underground and surface mining. It can excavate with precision and being a lightweight machine it has flexibility to quickly change direction or easily be moved to a different location in a mine. There is the hope in the industry that commercialisation of the ODC will take place with an Australian equipment manufacturer.

The Block Caving Case Study Subunit

The Northparkes copper mine

Northparkes Mine was developed in a joint venture between North Limited (80%) and the Japanese Sumitomo group of companies (20%). This joint venture was established to exploit the greenfields copper province known as the Goonumbla area at a minesite about 30km north of Parkes in central NSW. The unique geological properties of the Endeavour (E) 26 deposit at Northparkes made block caving an appropriate method of extraction. The partners had no previous experience of block caving and the method had never previously been used in Australia. In a massive and complex development beginning in November 1993 with the conceptual 're-engineering' of the block caving method, the greenfields site was transformed to a fully commissioned mine by December 1997 (Vink 1998). The operation is now owned and managed by Rio Tinto, following its acquisition of North Ltd in 1999.

Description of the block caving method

Block caving is the most cost effective underground method of mining with costs averaging one-third less than those of conventional drill and blast underground mining alternatives (Broomhead and Bodkin 1998). The drawback of block caving is that it may only apply to 5 per cent of the world's ore bodies, as they must have suitable geometrical (a vertical pipe) and geotechnical characteristics for the technique to work. A basic analogy for block caving is taking a sliced loaf of bread, turning it vertically and removing the bottom slice from the packet. As each slice is removed the remaining slices progress down the packet. Thus block caving involves an initial development phase during which the orebody is undercut, and the broken rock removed creating a void into which the orebody 'caves' under its own weight and no further conventional drill-and-blast mining is required. The broken ore is extracted from the cave via 'cones' and draw points and the cave progresses vertically to the surface creating a 'glory hole'. The critical phase of block caving at Northparkes is the removal of ore through 148 draw points, which in turn controls the stress distribution of the ore body and maintains a controlled and regular caving process.

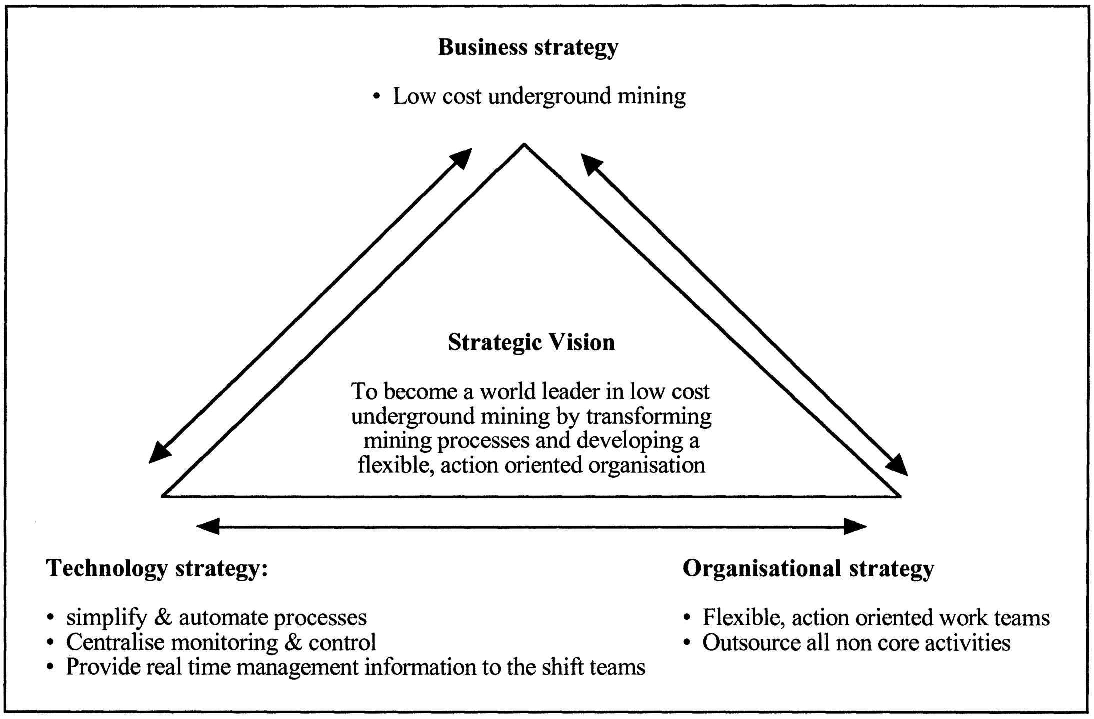
The block caving technique is not new to the minerals industry. The 1941 edition of the *Mining Engineers Handbook*, notes that at that time the technique was 100 years old and was originally devised for mining iron ore deposits in Michigan, when even in those times declining prices were placing producers under tough economic pressure to increase productivity and reduce costs. As block caving is labour intensive the method continued to be used in countries with an abundant supply of relatively cheap labour. To make block caving economically viable in Australia, labour numbers had to be reduced by a factor of 20 in comparison with levels for similar mines in developing countries (Hamilton 1998).

North's decision to use block caving at Northparkes – creating competitive advantage

North was interested in building its copper business and in developing world class expertise in block caving. This was seen as an opportunity for creating a competitive advantage. Nevertheless, the decision to commit to this large, low grade, base metal development, and a method of mining predominantly used in developing countries, was not taken lightly. More than 15 years and a slump in copper prices passed between the initial discovery of the resource in 1976 and the eventual commitment to the project in 1992. Feasibility studies on ways to mine at Northparkes began in 1984. A 1986 proposal to employ opencut extraction methods would have left a large proportion of ore *in situ*. The total underground option was examined in 1990-1992.

The 1992 decision in favour of block caving was accompanied by the realisation that simple application of this method at Northparkes was not sufficient in itself to lift the economics of the deposit from its marginal base to viable levels. The challenge was to re-engineer the traditional block cave method for use in an industrialised, high labour cost country, to allow the product to compete effectively in a global copper marketplace characterised by increasing productivity and competition, and falling prices. This was achieved through alignment of business, organisation and technology strategies under the strategic vision 'to become a world leader in low cost underground mining by transforming mining processes and developing a flexible, action oriented organisation.' (see Figure 6.1 below) (Vink 1998, Hamilton 1998, Tota and Aslaksen 1996).

Figure 6.1: Northparkes block caving strategic vision – integrating business, organisational and technology strategies.



Source: (Tota 1997)

Implementation of strategic vision

With no operational mine in place at Northparkes (with attendant inefficient processes to re-engineer) and no history of block cave mining in Australia, the Northparkes operation presented a 'blank canvas'. North understood that automation and information technology in themselves do not produce dramatic performance improvements (Tota and Aslaksen 1995). With the implementation of block caving it was necessary to 're-engineer' the entire mining process to determine which activities or steps added the greatest value. North simultaneously searched globally for new ways of conducting those steps. In other words, new technologies were not used to simply automate existing processes. Rather, they enabled new processes to be developed (Dudley 1997, Vink 1998, Vink 1995, Hamilton 1998).

A three day 'system re-engineering' workshop was organised by North. Participants included strategic thinkers from six top Australian minerals consulting firms and Northparkes staff. The purpose of the workshop was to consider current technological opportunities and organisational capabilities available to the minerals industry, to identify points in the block cave method where processes could be reorganised in order to achieve improvements in performance, and to encourage discontinuous thinking and brainstorming to 'decide how advanced technology could be implemented to transform and improve upon traditional methods and management control systems' (Tota 1997, Tota and Aslaksen 1996, Vink 1998, Hamilton 1998, Roberts 1996).

The workshop ultimately proposed several major changes to traditional block caving concepts:

- Eliminate the haulage level
- Crush large rocks at the earliest point
- Match the crusher size to the largest rock size
- Centralise the control of the underground ore handling system
- Continual load haul dump (LHD) operations, and
- Centralise and automate LHD operations (Tota 1997).

The mine was designed to operate as a continuous, underground, mass-production line, that North described as an underground 'rock-factory'. A Supervisory Control and Data Acquisition (SCADA) system is essential to the mine's functioning, centralising the operation, and monitoring and controlling of all the mine's processes and functions from a remote position. It supplies information in real time to small, multi-skilled teams who operate the mine. This re-engineering affected all forms and organisation of work in the mine as opposed to those found in a traditional block cave mine. A horizontal management structure among teams, managers and technicians is used, and all employees have full access to the information required to run the mine efficiently.

A complex R&D and experimental development program supported the transfer of globally-sourced, new and improved technologies at Northparkes. It was conducted during an intense 4 year period of mine construction and implementation of the re-engineered block cave design. This program was primarily organised around 6 core research programs related to critical processes in the mine's operation. It involved activities such as international search (literature and mine site visits), identification, adaptation and integration of advanced technologies. It also involved intense exploration and 3-D mapping of the orebody (using state-of-the-art technologies) to determine precise geological structure, and thereby predict the orebody's behaviour during blasting and caving. The research programs involved different types of strategic alliances with equipment suppliers (Brandrill for blasting technology), public research organisations (JKMRC) and international consultants. Briefly the 6 projects included:

- *Advanced Blasting Technology* – to establish a drill and blast design for the block cave's undercut and construction of drawpoints. The design had to cause minimal damage to the extraction level infrastructure and ensure subsequent rock fragmentation allowed ore to pass through drawpoints without need for secondary blasting. The blasting methods required had never been used in Australia. Joint venture partners Brandrill Ltd (drill and blasting) and ICI (charges) also had no previous experience with block caving (Vink 1998). Conceptual studies began in 1994, drilling in December 1995 and first blasting January 1996. The research program included a collaboration with the JKMRC and use of their WIN predictive software program that links rock mass character with fragmentation behaviour.
- *Groundwater Research for Mine Dewatering* – to design, develop and implement a practical dewatering system for block caving. Investigation of the design options was based upon analytical modelling of groundwater (knowledge of aquifer area) and integration of pumping for the dewatering system with the facility's centralised monitoring of mine's services, the SCADA system.

- *Development of Undercut Mining Technology* – primarily involved the development of a novel 'double undercut' method to construct the mine's extraction level. The research program included international intelligence gathering, site visits at El Teniente's Isla mine and an iterative development process.
- *Block Caving Development* – integration of data on the geological structure of ore body with planned *in situ* layout of the block cave, level of undercut, placement of drawpoints, placement of the ore handling system (position of crusher chambers), *et cetera*. North's small cross-functional Mine Design Team managed overall integration of this complex development. It was led by the Manager of Mining and comprised of: North's Planning Manager responsible for drill and blast design ; North's Senior Geologist (who had two geologists working to complete mapping modelling of the orebody and a Geotechnical Engineer to conduct rock mass analysis); a Principal Block Caving Consultant; and, four technicians to support the team with drafting and geology services (Vink 1998:151). North's Planning Manager was supported by the Principal Drill and Blast Consultant (from Brandrill) and North's Engineer for Drill and Blast Design, the Principal Ground Support Consultant, and a Mining Surveyor experienced in mine design and drafting of construction drawings
- *Totally Integrated Ore Handling* – preliminary design assessment of the ore handling system (OHS) focused upon the use of fully automated 'load haul dump' (LHD)' trucks, principles of just-in-time LHD operation made possible though ICTs, and integration of drawpoint ore production (size of ore fragments) and crusher operation (suitable for fragmented ore). Centralised monitoring and control of the OHS was included in the SCADA system. 'The OHS and infrastructure supporting it have been designed using a top-down systems engineering methodology, starting with the mine's innovative operating and maintenance philosophy, and progressing through to a phased process of definition, analysis, design, implementation and verification' (Tota and Aslaksen 1996).
- *Secondary Rock Breaking Technology* – when large boulders are blasted with explosives, toxic fumes are emitted and the area must be evacuated. This causes intermittent stoppages of LHD movements. To overcome such a problem at Northparkes, this research program developed non-explosive secondary rock breaking technology from a worldwide search, benchmarking and testing procedure (Hamilton 1998, Dudley 1997, Tota 1997).

Most of the re-engineered processes are currently in place at Northparkes and many are part of a continuous improvement program (Tota 1997, Hamilton 1998, Vink 1995, Dudley 1997). Table 6.6 provides a list of examples of advanced technologies being used at Northparkes.

A description of the Northparkes mine

A 'decline' from the surface of the mine provides drive-in access for personnel and equipment. Mining will occur in two stages or lifts, with the first and second lifts located 520 metres and 850 metres below the surface respectively. All ore is hoisted to the surface through a 5.3 metre diameter shaft located 800 metres away from the ore body and outside the zone of movement created by the 'caving' process. The caved ore handling system involves electric LHD units that collect caved ore from one of the 148 draw points on the extraction level and deliver it to one of two underground crushers. The crushers are in turn connected to the hoisting shaft by conveyor belts. This ore handling system avoids the use of intermediate truck or rail haulage systems.

Table 6.6: Application of advanced technology at Northparkes

Location	Technology involved
Cave management – draw control system, ore flow monitoring and geotechnical monitoring	Automatic bucket weighing, position identification (tag readers), communications infrastructure, scheduling software, rock stress monitoring and seismic monitoring
LHD extraction – Dust suppression, draw point loading & hauling and area isolation	Position monitoring, tele remote control loading and automatic guidance & dumping
Secondary breaking – secondary drilling and area isolation	Tele remote control drilling, automated isolation of tunnels and personnel access control
Ore handling – crushing and conveying and shaft management	Video monitoring, automated operation and condition monitoring
Communications – voice and data	Mine wide mobile radio, mine wide local area network and underground / surface tele-conferencing
Production management – management information and maintenance system	Fully integrated SCADA system, condition monitoring, integrated maintenance and planning software
Services management – ventilation, electric power and pumping & drainage	Automated ventilation controls, power monitoring & measurement and automated pumping
Logistics management – personnel security, traffic control and warehouse management	Personnel tag readers, automatic gates & lights and integrated stores management

Source: adapted from (Tota and Aslaksen 1995)

A special feature of the extraction level of the mine is that it is free of personnel. The electric LHDs use automatic guidance systems between the draw points and crushers. The only time human intervention is required is when a LHD is loading or discharging. These steps are controlled remotely by human operators equipped with a TV screen and joystick, located in a control room distant from the extraction level.

Interaction with external research providers

North rarely develops its own technology. However, site-directed, small-scale research is conducted to maximise plant and equipment performance. In re-engineering the block cave method, North assembled technological developments from around the world, and in doing so became manager of a complex system of development from a position of total inexperience with the block cave method. Given this limited experience, consultants were employed in every core area of mine design and development, while international experts in the Mine Design team created an 'experience base' to assess and manage the complex development.

The international block cave extraction consultant, Dr Laubscher, had previous experience with block caves elsewhere in the world and was a key source of knowledge when selecting a mine concept appropriate to conditions at Northparkes (David and Wright 1996). Other specialists supplied detailed design advice. For example, Guilfoyle and Associates were employed to advise on upper and lower undercut designs because of their past drill and blast design experience. In light of the Julius Kruttschnitt Minerals Research Centre's (JKMRC) links with

Chilean El Teniente and Andina block cave mines, the Centre was involved in many of the core research programs. Use was also made of the JKMRC's predictive WIN software minimise structural damage during blasting.

Over 40 major contractors were used in the Northparkes development, and services ranged from straightforward supply (the Australian mineral services company MinCom's supply and installation of decline mobile communication systems), to strategic alliances involving incremental innovation processes. Brandrill's successful tender for the drill and blast contract, for example, was based on a commitment to innovative problem solving and participation (including provision of funds) in core research programs. Contracts with key equipment suppliers were conditional upon incorporation of advanced technologies. Tamrock of Finland supplied the LHDs featuring advanced tele-remote control hardware from Canadian manufacturer Nautilus (Roberts 1996).

In November 1997, Northparkes joined forces with four other major mining companies (Rio Tinto, Freeport Indonesia, Minocro (De Beers) and Noranda) on a three-year international caving study with the aim of improving methods for block, panel and induced caving. The project is a joint venture between the JKMRC Mining Group and the US international geomechanics group, Itasca. The industry members contributed funding of $1.72m, paid in annual $100,000 instalments. This amount was increased with a $330,000 Australian Research Council (ARC) grant for supporting PhD students working on the project at the JKMRC. The planned outcome from this project is a handbook of caving methods and a 'CaveBase' database of state-of-the-art caving methods.

Northparkes, along with Mount Isa Mines, led Australia in driverless underground haulage systems. While the operation of LHDs by tele-operation has been successful at Northparkes, the broader mining community accepts that this is a stopgap measure since full automation is the ultimate goal (Hood 1998). The CRC for Mining Technology and Equipment (CMTE) is currently running a project to develop a prototype system for a fully automated underground vehicle. The CMTE concept differs from other work as it does not rely on the installation of enabling infrastructure such as guiding rails, cabling, strips of lights or other types of markers. Rather, CMTE is developing a range of sensors; 'gyros, laser rangefinders, inertial navigation, ultrasonic and machine vision,' that recognise the natural surrounding to establish vehicle location.

Outcome of re-engineering the block cave process at Northparkes

The transformation of the greenfield Northparkes deposit to a fully commissioned 'rock factory' block cave mine, demonstrates North's considerable capability in complex systems management. Northparkes has set a new world benchmark for low cost underground mining because of its implementation of leading edge technologies throughout the entire operation (Hamilton 1998). The outcome of North's strategic implementation of advanced technology has made a traditionally labour intensive method competitive in the international marketplace. It has also had a radical impact on the organisation of management for the operation, as automation and the SCADA system eliminate the need for people to be placed throughout the mine. Centralisation of 'whole of mine' control allows underground teams to respond in real time to any event in the mine (Tota and Aslaksen 1995).

The re-engineered block cave method also provides evidence of minerals-derived wealth being created from innovative capabilities and use of state-of-the-art technologies. The fact that Rio Tino has not divested itself of this operation is an additional endorsement of the success and competitiveness of the Northparkes mine.

The Mine to Mill Case Study Subunit

Introduction to the Mine to Mill innovation

Implementation of the 'Mine to Mill' innovation does not require large technological advances or outlays of capital, although Australian Institute of Mining and Metallurgy (AusIMM) president, Dick Carter, speculated at the first Mine to Mill conference that it may deliver a step change in operations performance (Goeldner 1998). Mine to mill is a philosophical change enabled by a new technologically-based operating technique. It advocates an integrated approach to mining and milling so that they are treated as a continuous operation rather than as independent business units. The mantra of Mine to Mill states that blasting and excavation practices have a direct impact upon the quality of material delivered to a preparation plant, which in turn has an impact upon yields and recovery rates during processing. Traditionally, miners and metallurgists operate in separate mining and processing units and are costed separately, the rationale being that a reduction in their individual component costs will lead to a reduction of costs overall. Research on the Mine to Mill project has now proven that this common assumption is not always valid. In fact, increasing costs at one end of an operation may improve overall performance and economic returns.

To illustrate this point with an example from industry, the JKMRC was invited onto an open cut coal operation by its processors who were at a loss to explain poor yields and recoveries from their plant. The associated mining unit had recently cut its costs through an investment in larger mining equipment and changed blasting practices. The increase in production rates at the mine was not being translated into the forecast gains at the mill. Analysis of the inputs to the mill by JKMRC researchers showed that the incoming ore had decreased in quality. There was no problem with processing. Rather, the new mining regime resulted in contamination with dilute ore. This was resolved by the mining unit reverting to their old mining practices, and while their overheads increased the overall performance and net revenue from the entire operation was restored.

Development of the Mine to Mill innovation

The concept of Mine to Mill was developed by the JKMRC which is one of the only major research institutions working in both fields of comminution (breaking / crushing of ore) and blasting. Research in the area began in 1996 with an AMIRA-managed project to develop a new method for optimising fragmentation holistically across the mining and processing systems (sponsors of the AMIRA project are given in Table 6.7 below). Data was collected on the distribution and fragmentation size and on production rates at the site's comminution circuit for each blast. This data was used to create a model encompassing each step in the mine-mill process and demonstrated that potential existed for increased productivity by simply modifying the blasting design which would improve the lump yield and efficiency of the processing mill (JKMRC 1997).

Table 6.7: Sponsors of AMIRA project P483: Optimisation of mine fragmentation for downstream processing

Sponsors
Acacia Resources Limited
BHP Iron Ore
BHP Manganese
Hamersley Iron Pty Limited
Iscor Mining (South African)
Kalgoorlie Consolidated Gold Mines Pty Ltd
MIM Holdings Limited
Newcrest Mining Limited

Andrew Scott, Manager of Mining at JKMRC, explained that it had long been known that the lack of communication between mining and processing business units generated significant inefficiencies. The difference now is that this 'feeling' can be measured and the mine to mill theory proved, due to advances in computer processing and imaging fragmentation. 'SPLIT' image analysis software developed by the University of Arizona, with enhancements developed at the JKMRC, is the primary analytical tool for measuring and monitoring the size distribution of fragments. The AMIRA project aims to develop a 'robust predictive mine-mill system that, from an assessment of factors such as geological ore type and variation within a deposit, can make reliable predictions with regard to the final product outcomes' (AMIRA International 2002a).

Mine productivity improvements of 15 per cent have resulted from implementation of the Mine to Mill operating technique (AMIRA International 2002a). Furthermore, the optimisation of rock fragmentation, with the requirements of processing equipment achieved by the technique involves little, if any, cost increases or capital expenditure (*ibid*). Industry implementation is continuing and being managed through an extension of the original AMIRA collaboration.

Future of Mine to Mill

The Mine to Mill innovation has a number of notable characteristics.

- The idea and its development were initiated by research providers at the JKMRC.
- Early research was based on 'belief' in the theory, and now this 'belief' can be measured and the theory proven due to advances in enabling technologies such as simulation modelling and imaging fragmentation technology.

- Seemingly obvious factors are central to the innovation. For example, improved lines of communication between miners and metallurgists and attitudinal change to view them as dependent components of the same production chain.

The first Mine to Mill conference held in November 1998 brought the two cultures, miners and mineral processors, together at an international forum to begin improving the interface between the two and extend application of Mine to Mill to encompass all components of an operation through to the final customer (Goeldner 1998). Industry implementation of the operating technique is continuing.

The JKMRC has proved itself as a leader in development, technological excellence and innovation on the Mine to Mill technique. In 2001 the Australian Institute of Mining and Metallurgy (AusIMM) recognised this excellence with the prestigious 'Minerals Industry Operating Technique' award.

6.3.4 Section summary

Australian extraction innovation displays characteristics typical of industry-wide trends, namely innovations that improve the productivity of existing operations are readily embraced. A high degree of industry involvement in the implementation of the Mine to Mill operating technique, for example, reflects the potential for this innovation to deliver significant productivity improvements without cost increases and with minimal capital expenditure.

The use of high-tech enabling technologies, such as predictive modelling, computational monitoring systems, remote sensing and ICTs, is a feature of extraction innovation. Its associated innovative capabilities are typical of those identified in fifth generation R&D (Systems Integration and Networking) (Rothwell 1994, Dodgson 2000). The Northparkes development, in particular, highlights a significant capacity for complex systems management and a depth of innovative capability. While the block cave method is not novel, the re-engineered Northparkes operation takes the method to a new level of productivity and performance. It also demonstrates that innovation and technological change ensure that exploitation of Australian mineral endowment remains globally competitive.

There is evidence that the extraction component of the MinIS has regional centres of excellence, such as Queensland University's JKMRC and CMTE in Brisbane. Importantly, it also appears to support good international knowledge networks and links to international sources of expertise, knowledge and technologies. Internationalised knowledge networks and collaborations are important factors for the knowledge economy.

While this summary is a positive endorsement of extraction innovation in Australia, recent trends in the minerals industry pose a threat to this component of the MinIS. North, clearly an innovative company, has since been acquired by Rio Tinto, with uncertain implications for its continued innovativeness. A small country like Australia can ill afford the loss of innovative companies, particularly those like North, that are capable of engagement with global technological developments, successful international technology transfer and complex systems management. Rio Tinto's strategy with regard to North will have implications for Australia's innovative capacity in this sector of the industry.

6.4 Innovation and processing

This section examines process innovation in the Australian minerals industry.

6.4.1 Introduction to processing innovation – high risk versus high returns

General trends in processes innovation are similar to those in extraction innovation. Incremental improvement of existing processes is the prevailing form of innovation in this area of the minerals industry, as opposed to the development of entirely novel processing methods. This is due to the capital-intensive nature of process plants and, because large volumes of materials are processed in these plants, small improvements to production can quickly translate into large returns.

Throughout the history of the minerals industry, process innovation has been a 'high risk' 'high returns' strategy. As the Cyanide and Flotation case study subunits in Chapter 5 illustrate, new major process innovations create giant discontinuities in the 'techno-economic paradigm' of the minerals industry (Freeman and Perez 1986). Mineral reserves can be dramatically enhanced, organisational restructuring of firms induced and entire industries revived or created. This was the case when the US copper industry used solvent extraction-electrowinning (SX-EW) process technology to enable recovery of commercial quantities of metal from waste dumps (created from less-efficient processing methods) (Tilton and Landsberg 1999). New processes are usually the result of substantial investment in time and money, and a wave of interrelated innovations at the frontiers of scientific understanding and technological opportunity. The stakes are high, even for the transfer of proven new processes. Like any innovation, process innovation is unpredictable and offers no guarantees of a return on investment, even if successful.

Recent Australian experiences in process innovation have not always been successful. This was made obvious by BHP's billion dollar budget blow-out when constructing its Hot Briquetted Iron (HBI) plant. Anaconda nickel is also experiencing difficulties implementing a process called pressure-acid-leach at its Murrin Murrin plant, despite a $2 billion public and private investment in the implementation of this novel process to Australian laterite nickel deposits (Treadgold 1999).

Lederman, in 1993, suggested that to a measurable extent, base metal processes had remained as they were in the 1960s (Lederman 1993). In light of some spectacular cost blow-outs it is understandable that inertia exists when it comes to the uptake of radical new ideas in processing innovation. This is true even when they have been proven elsewhere (Lederman 1993, Mozley 1993). In his analysis of the use of new processing technology, Lederman stated that:

> The reluctance of minerals companies to place priority in our area is not because we lack new ideas: our senior management has not been convinced, based on our

> previous results, that such investments will pay off as well as other investment opportunities competing for the same resources. (Lederman 1993,p7).

Nevertheless, successful process innovation can produce substantial returns and successful companies are good at process innovation (Batterham and Algie 1995). The basis for capturing such returns is 'the proper establishment of technology strategy and more effective transfer of technology' (Lederman 1993:7).

6.4.2 Intensification of processing innovation

The advent of the powerful enabling technologies, such as biotechnology, information technology and advances in computer-generated simulation and modelling is generating new options for process innovation, and forcing a fundamental shift in the way in which new process technologies create a competitive advantage in minerals processing.[113] These dynamics are driving an intensification of innovation in processing.

In keeping with current trends in knowledge intensive industries, ideas and enabling technologies are being sought from fields not traditionally related to minerals processing. Biotechnology, for example, has created a range of new processes and strategic competitive advantages for firms like Billiton, which has successfully commercialised and patented BioNIC and BioCOP bacterial leaching process methodologies (Groeneveld 1998). Australian company, Titan Resources, announced a breakthrough (February 2002) in development of its BioHEAP bacterial leaching process, following a three year experimental development program and $13 million of public ($2 million research grant) and private investment (private-equity: Credit Suisse First Boston acquired 20 per cent holding in Titian) (Treadgold 2002a).

These fundamental shifts influence the ways in which leading firms are improving their experimental development processes. Experimental development[114] in minerals processing is costly as it involves extensive rounds of testing, in some cases involving construction of pilot plants and a large investment of time (see Chapter 3). Companies which can conduct their experimental development more cheaply and faster are likely to establish an early competitive advantage. Innovation in minerals processes relies upon experimental development activities to effectively transfer proven new technologies into processing methodologies and plants. Traditional experimental development methodologies are being replaced by theoretical modelling and simulations that reduce the requirement to physically test whether something works. In other words, 'theory' is being substituted for 'practice' in experimental development, and firms are applying their research capabilities to quantify, measure and model the process of experimental development itself (Matthews and Howard 2000).

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[113] In a report commissioned by DETYA for the National Innovation Summit, Matthews and Johnston describe the division of labour among national innovation system components and changes in company strategy aimed at reducing the cost of experimental development (Matthews and Johnston 1999). This report provided the basis for the following analysis of experimental development in mineral processing.
[114] Note: While research generates new knowledge and an understanding of how this knowledge can be transformed into an option for future exploitation, experimental development is the transformation of a well-defined option into a tangible product or service.

This shift in experimental development is international and permeates all industry sectors, although it has not been articulated in the literature nor identified in relation to the minerals industry (Matthews and Howard 2000). The ultimate aim of this shift in strategy is to significantly reduce costs and risks involved in experimental development to deliver new products and processes more cheaply and more quickly. As the bulk of industry R&D expenditure is captured by experimental development, the potential for cost cutting is significant. Minerals processing also stands to gain substantial returns from the substitution of theory for practice. This strategy is already at play in processing as a direct result of the important development of mathematical models of computational fluid dynamics (CFD) for multi-phase fluid processing systems (see HIsmelt case study subunit) (CSIRO 1998a).

Multi-phase fluid systems are fundamental to most mineral processing operations, making CFD modelling applicable to a wide range of processing systems. These include generic systems (fluid beds, cyclones and thickeners), and commodity-specific processes such as bath smelting for ferrous and base metals, flotation cells for base metals, hydrocyclones for iron ore and diamonds, stirred tank reactors for titanium and precipitators for alumina (CSIRO 1998a). Thus, CFD may become the most important technological breakthrough for minerals processing in the past decade.

The HIsmelt Case Study Subunit

Introduction to the HIsmelt innovation

CRA's 1981 commitment to a direct reduced iron (DRI) process innovation was made out of necessity. However the necessity for a *radical* process innovation was created by a number of factors. The Western Australian State Government granted a mining lease for Pilbara iron ore deposits on condition that ironmaking facilities (downstream processing facilities) were built in the region (Algie 1997). Thus the government created the incentive to innovate, while the geological nature of Pilbara ores, and high natural gas prices, influenced selection of the type of process technology.

Pilbara iron ores are low-grade with a fine consistency and high level of phosphorus and other contaminants. Without the removal of phosphorus, a contaminant which is unacceptable for steel-making (blast oxygen furnaces, electric-arc furnaces and open-hearth furnaces), Pilbara ores are unsaleable (Sproull 1997, Treadgold 2002b). High natural gas prices in the 1970-80s influenced the selection of a coal-powered direct smelting technology, called HIsmelt.

CRA's HIsmelt project came to Rio Tinto through the RTZ-CRA merger in 1995. Rio Tinto continued to endorse a strategic vision to become a world leader in iron smelting. Commercialisation of HIsmelt is continuing, and was recently reinvigorated by $400 million of commercial backing from the steelmakers in the US (Nucor), Japan (Mitsubishi) and China (Shougang Corporation), and the Australian government ($125 million) (Marsh 2002). Rio

Tinto has a 60 per cent holding in this commercial venture, which involves construction of a HIsmelt plant at Kwinana, Perth, with annual production capacity of 800,000 tonnes.

Ultimately, if full commercialisation of HIsmelt is a success, Rio Tinto will be well placed for a major role in the modernisation and invigoration of the global steel industry. It will have a process technology to sell, as well as the key to unlocking the wealth in the vast Pilbara mineral reserves.

The HIsmelt Process

HIsmelt can make use of the majority of Pilbara ores, it reduces greenhouse gas emissions from traditional iron and steelmaking by up to 50 percent, it is energy efficient, and makes a product of superior quality to alternative techniques. It also indirectly reduces steelmaking capital costs by removing the need for coking ovens, sinter plans or blast furnaces, and makes smaller electric-arc furnace steelmaking plants commercially viable.

The HIsmelt process revolves around two processing techniques, injection metallurgy and the use of a molten iron bath for smelting, which in combination dramatically increase reaction rates and enhance the economics of the process (Innes 1996). HIsmelt's primary step consists of injecting iron ore and coal with a flux, into a bath of molten iron at around 1400-1500°C. Under these conditions the ore is rapidly reduced to form molten iron. Unlike traditional methods, iron fines can be injected directly into a HIsmelt reaction vessel. Furthermore, fines are advantageous as their tendency to disintegrate hastens the rate at which they dissolve into the iron bath. The contaminants are also dissolved, but are tapped out of the reaction in a molten state as slag. Iron ore and coal used in the process can be of a quality inferior to that required for conventional ironmaking.

While the HIsmelt process sounds simple in metallurgical terms, the mechanics for transfer of energy in the process are complex and at the leading edge of scientific and technological developments.

Invention and experimental development of direct reduced iron technology

The 1960s and 70s were typified by rapid developments in ironmaking. Research into direct smelting or bath smelting in Australia began in the 1960s and was pioneered by Professor Howard Worner. This research was a forerunner to process developments such as SIROSMELT, ISASMELT, AUSMELT and others (Innes 1996). At the time minerals companies maintained large internal research groups and their employment of career academics was common. Worner was Chair of Metallurgy at the University of Melbourne (1946) before becoming Director of Research at BHP (in 1955), and subsequently joined CRA as the Director of New Process Development (in 1965). On a trip to North America and Europe for BHP, Worner examined the latest developments in ironmaking and recommended the introduction of oxygen ironmaking vessels as opposed to open-hearth furnaces to Australia. It was at this time that he also realised the potential of continuous processing, particularly as it applied to steelmaking (Innes 1996).

The scientist and engineer, John Innes, joined CRA in 1963 having also been earlier employed by BHP and being influenced by Worner's interest in iron- and steelmaking technologies. Innes worked on steelmaking systems for 16 years prior to conceiving the HIsmelt process in 1981. Early research carried out in conjunction with several overseas companies (Stelco, Republic Steel and Daido Steel), helped lay the foundations for today's DRI / electric arc furnace (EAF) steelmaking system.

In 1981, Innes, with encouragement from successive CEOs, Sir Roderick Carnegie and Sir Russel Madigan, initiated a joint venture with the major West German steelmaker Klockner Werke. During a trip to Germany that year Innes:

> ... conceived that if it was possible to inject coal into a bath of liquid metal, simultaneously add iron ore and transfer energy from the offgas back to the molten bath, then there were all the elements of a new ironmaking process. (Innes: interview, 1999).

Whilst this direct smelting concept was, in part, reminiscent of Worner's oxygen continuous steelmaking techniques, significant differences existed in the technical details (Innes 1993, Innes 1995).

Klockner Werke were the first partners to be involved in developing HIsmelt. International experts helped to develop models of what was occurring inside a HIsmelt reactor to understand the parameters of this novel ironmaking process, such as post-combustion effects and heat transfer efficiency. Developments from this collaboration led to a small scale test plant being built in 1984 at the Maxhutte steelworks in Germany.

Klockner disengaged with HIsmelt in 1987, and Midrex Corporation (USA), world leaders in direct reduction technology and a subsidiary of Kobe Steel in Japan, joined the project in 1989. Work on the project continued and the new consortium committed to construct a US$105 million, 100,000 tonne per annum Pilbara ore pilot plant at Kwinana, WA, which was completed in 1991. The Midrex collaboration lasted until 1995 when the potential for conflict of interest with other projects with which the Japanese parent was involved, and other issues, led to their withdrawal (Sproull 1998a, Treadgold 1998, Sproull 1998c, Sproull 1998b).

It was clear, even before Midrex' departure, that HIsmelt was facing some apparently intractable technological problems. Furthermore, the WA government had deregulated the State's gas industry in the early 1990s, triggering a $4 billion rush of competing direct reduction developments in the Pilbara (Bulletin 1998, Sproull 1998a, Sproull 1998b). BHP's HBI project was the most ambitious and expensive new development and its presence increased the pressure on CRA to either take up the option of developing its own HBI project or continue with HIsmelt.

A new Chief Executive, Leon Davis, supported the continuation of HIsmelt. At this stage the most pressing problems were the limited life of refractory bricks inside the HIsmelt reactor and the engineering complexities associated with a horizontal, rotating reaction vessel. Uncertainty surrounding HIsmelt's future intensified when CRA merged with RTZ. Early in 1996, however, the London based Directors of Rio Tinto flew to inspect the Kwinana plant and the project's continuation was broadly endorsed (Sproull 1998a, Sproull 1998b).

Due to continued problems with the horizontal reaction vessel, plans were made to change the shape of the reactor and the manner of coal injection. Preliminary engineering work for a new vertical vessel was underway. The HIsmelt project team and their engineering partner, Kvaerner, constructed and installed the new vertical HIsmelt vessel. Trials of this new reactor were given a deadline for completion of December 30, 1997. However, the pressure on the HIsmelt team abated somewhat in August when BHP announced their HBI-related cost blow-out due to technical, industrial and onsite management difficulties (Sproull 1998a, Sproull 1998b). The removal of imminent local competition, and some of the immediate pressure from the WA government, came at a critical time for HIsmelt's development.

In January 1998, Rio Tinto announced that the vertical reactor had successfully completed 12 and 38 day trials, producing 7,850 tonnes of quality pig-iron (Treadgold 1998, Bulletin 1998, Sproull 1998a, Sproull 1998c). The plant had used a variety of ores and made a product of exceptional grade: 96% iron and 4% carbon. This success at Kwinana meant that HIsmelt had successfully progressed from being Australia's largest research and development project, consuming $300 million of research funding, to being ready for trial commercialisation.

Key decisions and drivers behind successful process development

Continued support for the project – The survival of a project of this scale through periods of extreme technological difficulty and slow progress, would not have been possible without continued support from successive CEOs and Innes, the project champion.

Competition from other DRI projects – Rio Tinto maintained an active research program in competing DRI technologies in parallel with HIsmelt. It even had the option of developing its own HBI plant using technology it had acquired under a license agreement. This strategy of active involvement across the field of DRI kept Rio Tinto up to date with, and knowledgeable about, other ironmaking developments. Such knowledge was vital when making comparisons between HIsmelt and other processes and when deciding whether or not to continue its support for HIsmelt.

As already suggested, BHP's problems at its Port Headland HBI plant were an unexpected bonus for Rio Tinto as it removed some external pressure and concerns Rio Tinto may have had about developing its own HBI plant. HIsmelt had other advantages over its national and international competitors. DRI products in a briquetted form, while usually derived from higher quality ores, still contain impurities such as silica and alumina. Steel makers must purify briquetted iron at their own expense. HIsmelt removes all impurities to produce a superior quality of iron, which can then either be used as a replacement for traditional cold iron feedstock or be fed directly as liquid iron into an EAF (Sproull 1998b, Sproull 1998c).

Collaboration – CRA and Rio Tinto used a variety of private and public external research providers to complement their internal research efforts with HIsmelt. At no time, however, were HIsmelt collaborations conducted outside of a one-to-one or joint venture agreement.

Tests at Kwinana, for example, with the Kvaerner engineering partner were conducted under the utmost secrecy (Sproull 1998c). According to Innes, CRA chose to collaborate with the German company Klockner Werke in 1981 as they were world leaders in the application of coal and oxygen injection techniques (interview, Innes, 1999). The same rationale underpinned the collaboration with Midrex, who were direct reduction specialists. CSIRO's Division of Mineral Resources was invited to become involved in developing particular areas of the HIsmelt project as early as 1982 (*ibid*).

One of the most important collaborations with CSIRO occurred in 1995 at a time when the HIsmelt research team needed to successfully demonstrate the practicality of a vertical HIsmelt reactor. CSIRO expertise in CFD was employed to demonstrate that it was possible to inject non-coking coal from above a molten iron bath, as opposed to its previous position below the bath. This successful demonstration contributed to the Board's decision to continue supporting HIsmelt's development during the move to a water-cooled vessel.

Surviving in Rio Tinto – The CRA-RTZ merger coincided with HIsmelt's seemingly intractable technological problems at a time when other DRI methods were looking positive. A number of factors contributed to the continued endorsement of the HIsmelt project by the dual listed company. Leon Davis, the first CEO of Rio Tinto, continued to provide top level support for the project, as John Ralph (CEO of CRA who departed from CRA in 1995) had done. It was no accident that following the first annual meeting of the company, held in Australia in May 1996, a delegation of London-based RTZ directors was flown to Perth to inspect the Kwinana pilot plant.

The fact that Rio Tinto regards iron ore mining as of great importance strategically, worked in HIsmelt's favour. Another successful CRA research project developed processing methods for the Century Zinc deposit, although the resource was sold to Pasminco in 1997. The primary reason given for the sale was that 'zinc mining was no longer compatible with Rio Tinto core competence' (interview Rio Tinto executive).

Finally, HIsmelt was a mature research project and the past commitment of funding made it easier to commit to more funding in future. In other words, if HIsmelt were presented to the Board as a research project with a potential cost of $300-600 million today, it would not be funded.

Outcomes from the HIsmelt process innovation

Rio Tinto may become a major force in global iron and steel production based on the potential of HIsmelt (Sproull 1998b, Sproull 1998c, Treadgold 2002b). Despite this, a high degree of risk is associated with the full commercialisation of HIsmelt, and the project is yet to deliver any returns. It took Rio Tinto two years to attract commercial backing for latest phase of commercialisation at Kwinana (Treadgold 2002b, Marsh 2002)

6.4.3 *Process innovation in the longer term*

> Development of new processes is most likely to only come from an identifiable need within a company for a specific opportunity. This is usually going to be associated with a specific ore body which will have to be attractive enough to warrant the time and money risks associated with such a new development. (Batterham and Shaw 1998:4)

New process technologies like HIsmelt are extremely rare. As pointed out by one industry analyst, large steelmakers are not beating a path to Rio Tinto's door to purchase the HIsmelt technology, even though it has been proven in a pilot plant and promises to revolutionise the industry (Treadgold 2002b). The latter may say more about the depressed and conservative state of the global steelmaking industry, than the success HIsmelt represents in itself.

The processing component of innovation of the MinIS was found to be incorporating new, critical, enabling technologies, like biotechnology, to create new processing methods. Such process innovations seem more able to attract venture finance and commercialise at a comparatively rapid pace (Broome 2001, Treadgold 2002, AMIRA International 2002b, AMIRA International 2002a, National Research Council 2002). In essence, such developments are examples of sophisticated technology transfer and 5th generation R&D, as opposed to entirely novel and previously unconceived process methodologies like HIsmelt. These dynamics also reflect the global performance of individual commodity groups. The steel industry, for example, is currently in deep depression. Twenty-seven steelmakers in the US have closed in the past 4 years, and Australian steelmakers are having difficulty attracting investor confidence in new projects (Treadgold 2002b).

Minerals companies involved in 'technology transfer' process innovation appear to be aligning their related experimental development strategies in line with intentional trends to reduce expenditure in this area through improved simulation and modelling capabilities (Matthews and Howard 2000). The current shift in experimental developments strategy has created a demand for technology service providers with a capacity for simulation and modelling.

CSIRO houses a core capability in CFD. This was the first Australian research group to be established in this field in the mid 1980s. The minerals industry's uptake of this new technology has been rapid, and was facilitated through a number of AMIRA projects, one-to-one research projects on the development of new processes like HIsmelt and ISAsmelt (sponsored by MIM), and participation in three CRCs (GK Williams CRC for Extractive Metallurgy; CRC for New Technologies for Power Generation from Low-ranked Coals; and the AJ Parker Centre for Hydrometallurgy). The 1990s saw Rio Tinto and BHP establish their own CFD groups and Alcoa appoint a CFD expert to provide an informed interface with CSIRO's CFD group (CSIRO 1998a).

6.5 Innovation in environmental management

This section addresses environmental management innovation in the Australian minerals industry.

6.5.1 The dynamics of environmental innovation

The global minerals industry has clearly come to understand that there are real, not just perceived, benefits from being 'green', 'safe' (OH&S) and socially responsible. In the present day the industry has to deal with concerns of not just government regulators but also with local communities, NGOs, and individual consumers' concerns about environmental and sustainability issues. In addition, inappropriate environmental 'behaviour' by the industry can have an adverse impact upon its investors, insurers and lenders. Ten of the world's largest minerals companies, which recognised that past practices were responsible for environmental degradation, and gave the industry as a whole a sullied reputation, set up an initiative, the Global Mining Initiative (GMI) in 1999 to examine these issues. It is also noteworthy that (in recent times) the industry has become aware of the social implications of its activities. The (GMI), established in preparation for the World Summit on Sustainable Development, Rio+10, in August 2002, was set up to give the industry a strategic focus on how to deal with the pressing environmental, social and sustainable development issues it is facing (MMSD Project 2002). Some key elements of the GMI include: a commitment to internal company reform; a review of international minerals sector associations; a major independent study of the sustainable development challenges confronting the industry (particularly those related to the needs of the wider community); and the best responses to those challenges. The independent study is referred to as the Mining Minerals and Sustainable Development (MMSD) initiative. Its findings were prepared at arm's length from the industry under the auspices of the World Business Council on Sustainable Development, and presented at the Global Mining Initiative Conference in Toronto on May 12-15, 2002 (AMEEF 2002).

Innovation in environmental management differs from innovation in other sectors of the minerals industry, as it is a growth area that attracts a comparatively high proportion of industry-sponsored basic research. Several drivers are behind this trend, one being the realisation on behalf of the minerals industry that investment in environmental R&D will help the *quality* of company profits (that is, they will be seen as derived in a clean, green and sustainable fashion), and thereby increase shareholder value. Public perception of the minerals industry and the fact that the public tends to hold the entire minerals industry responsible when an environmental 'event' occurs and not the individual companies concerned, has been another potent driver of change in environmental practices. The industry has also learned lessons from past disasters, such as the release of cyanide into a tailings dam at Northparkes gold mine and the correspondingly negative press and public relations that ensued for the industry as a whole. Thus, a new sentiment exists within the industry, namely that the worst environmental performers cannot be allowed to drag the industry down. At the August 1999 AMIRA 'Milestones to the future' forum, the Managing Director of North Limited, Malcolm Broomhead, stated that community and environmental expectations held by the general public were of greater importance than technical and financial bottom lines, and that 'it is now the rule of the triple bottom line'.[115] A precedent has also been set in the United States where companies have been denied access to new resources due to poor environmental management practices.

Australian minerals companies and the Minerals Council of Australia have been heavily involved in the Global Mining Initiative (GMI), which aims to support the minerals industry in a transition to sustainable patterns of economic development.

Whilst there is increased investment in environmental management, and companies now are aware of the benefits of sound environmental management, ecologically sustainable development can be expensive. A major proportion of the cost of mining, for example, is tied to moving rocks. In the past, small gold mining companies have not filled their deep voids (mine shafts). The costs involved in refilling voids, which encompasses double handling large volumes of rock, would make many small gold mines uneconomic. According to industry members, downsizing across the industry generally has reduced the number of environmental officers. The latter is particularly true for small minerals companies, who have difficulty incorporating the relevant environmental technology into their operations (MMSD Project 2002). The industry-backed Australian Centre for Mining and Environmental Research (ACMER) is just one organization working to demonstrate the cost savings incurred when site rehabilitation is conducted progressively with mine development and to assist small miners with their technology transfer. Where it is not economic for small companies to rehabilitate a site it is ultimately up to government to decide whether it will tolerate the damage to the environment or provide some kind of assistance for rehabilitation. Whatever the case, an abandoned site must always be made safe.

6.5.2 Collaboration in environmental management

Some environmental issues are shared across large sections of the minerals industry, making them potential areas for collaboration. One such issue is the problem of 'acid drainage' from tailing dumps. Naturally occurring metal sulphides[116] in tailing dumps, when exposed to oxygen and water, produce sulphuric acid. The acid can dissolve metals (for example heavy metals) and transport them into surface and groundwater. The cost of remediating acid drainage in Australia is estimated at $900 million and between US$2-3 billion in North America (Australian Journal of Mining 1998). An international, industry-driven, collaborative initiative that addresses acid drainage is the International Network for Acid Prevention (INAP). This initiative encompasses 17 international companies which jointly represent around 40 per cent of global mining activity. According to Dr Batterham, 'INAP will allow timely and cost effective access to best practices in acid drainage management and be a focus for collaboration for longer-term environmental research' (Australian Journal of Mining 1998). Joint research

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[115] Perhaps this is not a surprising position to be held by North given the company's experience in relation to the Jabiluka and Ranger uranium mines. However, there is substance behind the rhetoric coming from North as demonstrated by their transparent environmental reporting system, which includes the use of independent auditors and serious attempts to align local community expectations with commercial objectives and sophisticated environmental management programs at the controversial sites (see Ranger and Jabiluka case study subunit).

projects may be out-sourced to research providers with relevant excellence and the transfer of results is assisted by the INAP internet site which also has a database of relevant professionals, case studies on implementation of technologies at different sites, virtual workshops, chat rooms, and a database of research proposals being undertaken by all or some INAP members (Australian Journal of Mining 1998).

Further evidence of the minerals industry's commitment to environmental management is present in the ABS's report on the Australian mining industry, which examined expenditure on environmental protection (Australian Bureau of Statistics 1999a). It was found that the 'metal ore mining' subdivision spent $7.9 million on environmental R&D and $103.9 million on 'other current expenditure,' which includes the cost of mine site rehabilitation, environmental impact statements and environmental audits. In 1998-99 the 'metal ore mining' subdivision spent significantly more (56 per cent) on 'other current expenditure' than the other industry subdivisions: 'coal mining' $58.5 million (31 per cent) and 'oil and gas extraction' $ 21.9 million (13 per cent). Current expenditure on environmental matters by the 'metal ore and mining' subdivision was 1.2 per cent, or $103.9 million of its total current expenditure. Capital expenditure on the environment, which includes 'changes in production processes' and 'end-of-line techniques' (remedial treatment of environmental degradation), amounted to 2.3 per cent or $69.2 million of its total capital expenditure (Australian Bureau of Statistics 1999b, Australian Bureau of Statistics 1999a).

6.5.3 The role of government legislation in environmental innovation

Government has also had an important role to play in environmental management through the creation of relevant legislation. In broad terms there are three post-mining guidelines to which all minerals operations must conform:

- rehabilitation must ensure future alternative land use,
- there must not be any offsite pollution of waterways, and
- erosion must be eliminated.

These guidelines are not prescriptive, allowing companies to fulfil them in a manner suitable to the situation. There is also the threat of prosecution with liability charges ranging in the tens of millions of dollars.

The Ranger and Jabiluka Case Study Subunit

The Ranger uranium mine

The Ranger uranium deposit was discovered in 1969, and a proposal to mine at two locations, the Ranger 1 and Ranger 3 orebodies, was developed jointly by a fully owned ERA subsidiary

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[116] Metal sulphides are naturally present in rock, however, such rock is usually underground, and therefore not exposed to conditions which cause acid drainage.

Ranger Uranium Mines Pty Ltd and the Australian Atomic Energy Commission. The Ranger Uranium Environmental Inquiry (RUEI) followed and in 1977 delivered its recommendation that mining in the region could occur without unacceptable damage to the environment. The inquiry also recommended the establishment of Kakadu National Park, as well appointment of a Supervising Scientist. Construction of the Ranger facilities began in 1979, with open pit mining commencing in May 1980.

Of the entire environmental protection scheme at Ranger the water management system is the most critical. Its location in the tropics, with seasonal monsoonal rainfall, means that large volumes of water need to be managed and releases safely into the environment. Water collected on site is classified into three groups according to its quality (see Table below).

Table 6.8: Water treatment program at Ranger mine site

Classification	Source	Treatment
Non-Restricted Release Zone	Water run-off from ground undisturbed by mining activities, ie without stockpiles or processing equipment.	Water not contaminated – meets drinking water standards and is released into the surrounding waterways during the wet season.
Restricted Release Zone	Rainfall run-off from stockpiles and the process plant.	Contains very low concentrations of uranium. Disposal methods include: evaporation, watering of lawns and wetland filtration.
Never Released	Water involved in the 'process circuit' comprised of tailings dam, process plant and run-off from sulphur stockpiles, mine workshops and vehicle wash-down areas.	Water is recycled through the process plant and lost via evaporation from the tailings dam in the dry season. It is never released.

Ranger's water management differs from that of Jabiluka, which has a total containment policy. This is due in part to the outcropping of the Ranger deposit where erosion naturally leads to background levels of uranium in surrounding waterways. While restricted release waters are permitted by law, this option has not been used due to the concern of people living downstream. Concerns have also been voiced in relation to disposing of restricted release water by irrigation of adjoining land. Scientists have determined that 15 years of permanent habitation on this irrigated land could lead to an unacceptable dose of gamma irradiation. Research into an improved method for treating restricted release water expects that wetland filtration will reduce contaminants and facilitate disposal of treated water without a significant environmental impact.

The mechanisms behind wetland filtration are not well understood. However, as water flows through a system of artificial wetlands which are well vegetated, up to 98% of uranium and magnesium sulphate are removed. There is no uranium taken up by the aquatic vegetation and it appears that the contaminants bind to the walls of ponds or to particulate matter, and drop out of solution. Researchers at the Environmental Research Institute of the Supervising Scientist (ERISS) are examining the thermodynamics of uranium in the wetlands system to find out if it is possible for the uranium to be freed. Further research is also required into the usefulness of wetland filtration as a post-rehabilitation scheme. The build up of hot-spots at overflow sites between ponds in the system suggest that this wetland filtration may be of limited use in the long term.

The Jabiluka uranium mine

The Jabiluka ore body was discovered by Pancontinental Mining Ltd in 1971. However, Pancontinental's efforts to exploit the deposit failed due to the 1983 federal election leading to the withdrawal of approval to mine. ERA purchased the Jabiluka lease in 1991 and began a feasibility study into the best method of mining and completed an Environmental Impact Study (EIS) in October 1996. The EIS focused on ERA's preferred option for mining at Jabiluka which is comprised of an underground mine to remove the ore with processing and the treatment of the majority of tailings conducted at the existing Ranger facilities. The proposed haul road linking the two mine sites would remain inside the Ranger and Jabiluka mining leases.

Approval for the EIS, accompanied by 75 environmental recommendations, was granted by the federal Minister for the Environment in August 1997. The Supervising Scientists Group is responsible for monitoring ERA's compliance with these recommendations, which are designed to ensure that the mine does not have a detrimental impact on the surrounding national park. In other words, Jabiluka shares similar issues to Ranger in relation to environmental management. However, new controls at the Jabiluka mine are more stringent than at Ranger, with a large proportion of the mine site being a 'Total Containment Zone' with a 'zero-release' program for water management (ERA 1998).

Planning for the treatment of the Jabiluka mine tailings at Jabiluka will be more of a problem than at Ranger. The tailings cannot simply be returned underground as they will exist in greater volume than prior to being mined. A method of tailings treatment called 'paste fill' has been proposed for Jabiluka, a technique developed in Canadian underground operations. It is a straightforward technique employed to stabilise underground mining by filling stopes (underground excavations created when mining) with cemented tailings to allow mining to continue nearby. Studies on adapting this technique to the Jabiluka situation have involved research, with input from French researchers, into the behaviour of tailings when stabilised with cement and how such tailings behave underground. The principal limitation of this technique is the sheer volume of tailings to be treated and the expense incurred when excavating stopes specifically for housing tailings underground.

An alternative to paste filling was also reviewed, namely storing tailings in underground pits, surrounded by a geological membrane and covered with sand. CSIRO's Mine Site Rehabilitation Program was contracted to test a geological membrane. However, while the membrane was found to be feasible, its cost, of $80 million on top of the cost of the covering sand (that would have to be brought in to Jabiluka), was deemed to be too high. Currently the preferred and more economically viable method of tailings treatment is paste filling, although an alternative option to use new technologies, if and when they are developed, always exists.

Construction of the Jabiluka mine ceased indefinitely upon Rio Tinto acquisition of both uranium mines from North in 1999.

6.5.4 Future trends in environmental innovation

The environmental component of the MinIS has quite a different dynamic to those of others identified previously in this Chapter. The difficulty of obtaining a strategic competitive advantage from what is often site-specific and basic research, along with the existence of some serious and shared industry-wide environmental issues, makes collaborative and long-term research programs a characteristic of environmental innovation. Some companies such as ERA[117], however, are having success in obtaining a return on their environmental expertise by transferring internal environment research groups into subsidiary, commercial companies, and marketing their environmental services to the world.

The environmental component of the MinIS receives significant government support in terms of funding and incentives through legislative requirements for site rehabilitation. In some instances, however, such as the Australian Government's response to the Kyoto Protocol and the issue of greenhouse gas emissions, governments are out of step with the industry's mood to improve its environmental performance. Thus, the Commonwealth Government may be squandering the opportunity for Australia in the development of environmentally sustainable minerals innovations. Minerals companies, such as Rio Tinto, are keen to do their part in dealing with the greenhouse gas environmental issue. Their efforts are largely made on a voluntary basis and many such companies are members of the voluntary Greenhouse Challenge in Australia. Their efforts in dealing with greenhouse gases through innovations such as inert anode/wetted cathode process technology for aluminium, and HIsmelt, are expected to dramatically reduce greenhouse gas emissions. Many of the most dynamic companies in the Minerals Technology Services Sector (MTTS) are in the area of environmental services. Global opportunities for these companies are predicted to grow, particularly as other minerals companies tighten their environmental and occupational, health and safety standards. New mine safety legislation introduced in the USA in July 2002, provided the opportunity for Australian MTTS company, MicroFreshFilters, to supply exhaust filters to the USA in conjunction with the 3M company (Kirby 2002).

6.6 Chapter Summary

This Chapter's exploration of minerals innovation identified distinct components that display heterogeneous trends and characteristics among the activities of exploration, extraction, processing and environmental management. In exploration innovation, there is a clear role for government to support the development of new exploratory tools and methods that will underpin Australia's prospectivity. Experimental development and commercialisation of exploration technology tends to take place in dedicated exploration firms, often in alliance with large minerals firms. Innovation in extraction and processing is commonly incremental, driven by the short-term necessity of continuous improvement of existing operations. Innovation in processing is increasingly regarded as a competitive way to augment known mineral reserves. The short-term focus that characterises much extraction and processing innovation is raising concerns in regard to the maintenance of long-term knowledge bases and capacity for innovation in these areas. Innovation in environment tends to be motivated by long-term necessity. Industry consortia have been established to manage collaborative research programs when environmental problems are shared, while a high degree of basic, site-specific research is also characteristic of this innovation component.

The MinIS supports a capability for accessing and incorporating critical enabling technologies developed by other industries. These technologies include biotechnology, information and communication technologies, 3-D simulation and modelling software, image processing, and computational fluid dynamics. However, these technologies are not equally important across the MinIS. For example, biotechnology and computational fluid dynamics are most relevant to process innovation, whereas GPS and 3-D simulation and modelling are important for exploration. Minerals firms also display advanced strategies in the application of simulation and modelling technologies to reduce the cost of experimental development. This strategy, when taken into consideration with other innovative capabilities (international technology transfer, incorporation of enabling technologies), suggests that minerals firms are engaged with current developments in innovation in the knowledge-economy.

The MinIS contains regionalised centres of excellence in public sector research, education and training organisations, such as the JKMRC and various CRCs. Most importantly, the MinIS contains large innovative firms capable of complex systems management, international technology transfer and commercialisation of radical innovations. A new type of innovative small firm (the Mining Technology Service provider) has recently emerged as a dynamic element within the MinIS. Companies such as Fractal Graphics exemplify the important role played by the Australian minerals industry in creating conditions of demand for new high-tech service providers.[118]

It appears that the MinIS as a whole has played a vital role in the support of a deep and sophisticated innovative capacity in the Australian minerals industry. The relationships and interactions which sustain innovation in the MinIS are investigated further in Chapter 7.

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[117] ERA was originally owned by North, and is now owned by Rio Tinto.

[118] The innovation systems literature emphasises the importance of demand conditions, for example see (Edquist and Hommen 1999, Malerba 2002, Mowery and Rosenberg 1978, Achilladelis and Antonakis 2001).

References Chapter 6

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Chapter 7:

Structure of the MinIS – organisations and relationships

7.1 Introduction

This Chapter presents the third level of analysis which examines how organisations and relationships in the MinIS enable innovation. The innovation systems literature states that the types and level of relationships define the structure and functional dynamics of a particular system (see Chapter 3). In regard to sectoral innovation systems Malerba says:

> The key role played by networks in a sectoral system leads to a meaning of the term 'sectoral structure' different from the one used in industrial economics. In industrial economics, structure is related mainly to the concept of market structure and of vertical integration and diversification. In a sectoral system perspective, on the contrary, structure refers to links among artefacts and to relationships among agents: it is, therefore, far broader that the one based on exchange-competition-command. Thus, we can say that a sectoral system is composed by webs of relationships among heterogeneous agents with different beliefs, competencies and behaviour, and that these relationships affect agents' actions. They are rather stable over time. (Malerba 2002:256)

Edquist (1997) notes that the interdependent and non-linear nature of relationships in innovation systems (which are in turn influenced by institutions) makes them very complex and difficult to analyse (Edquist 1997). A relatively basic approach, in the form of a mapping exercise, is therefore taken in this analysis. The contribution of key research providers (that is, universities and government laboratories), as well as that of other organisations with an explicit role in enabling connectivity in the 'R&D system' (Niosi 2001), is identified. Attention is then given to the role of large versus small minerals firms in the MinIS. According to Lundvall:

> The internal organisation of private firms is one important aspect of the system of innovation. Most innovations are developed by firms, and many innovation studies have demonstrated that the organisation of the flow of information and of the learning processes are important and affect the innovative capability of the firm. The interaction between different departments engaged in respectively sales, production and R&D is one important aspect of the organisation which is attracting a growing interest in comparative innovation studies. (Lundvall 1992:14)

Two case study subunits examine the technology and innovation strategies in a large and a small minerals firm respectively:

- CRA-RTZ merger – maps changes in technology strategy and corporate research programs which took place after the Australian minerals company CRA merged with its British counterpart RTZ, resulting in the creation of the globalised minerals company Rio Tinto Ltd.
- Croesus – analyses technology strategy and the innovative activities in a small, highly innovative Australian gold mining company.

Interaction and degree of connectivity are long-term driving forces and sources of competitiveness in any innovation system. The issue of connectivity within the MinIS is particularly pertinent for this study and its Australian context. Chapter 1 highlighted the fragile nature of Australia's NIS, in particular the poor degree of connectivity between the public and private sectors. Findings from this study indicate that the minerals industry does not share this characteristic. However, this level of analysis also identifies a fundamental shift in innovation strategy among minerals firms that is being driven by the current global competitive environment, but which holds serious implications for continued coherence within the MinIS.

7.2 The minerals R&D system – firms, universities and government laboratories

> ...the Australian mining industry is regarded worldwide as being technology leaders... a significant reason for that has been a tradition in the tertiary institutions and in CSIRO, going way back, of working very closely with industry... (Industry Commission 1995:224)

In this and the following Section, the MinIS is interpreted according to Niosi's narrow[119] definition, namely the R&D system (Niosi et al. 2000). Niosi identifies three sectors within a nation's 'R&D system' according to their outputs: *industrial firms* with R&D capabilities ultimately producing improved products and processes, as well as intermediary products (research reports, pilot plants, etc); *government laboratories* mainly conducting applied research and producing publications, intellectual property, prototypes etc; and *universities* with programs of education and training, and basic research producing new knowledge, skilled graduates, and future research options among other outputs (Niosi et al. 2000).

7.2.1 Minerals firms

This study has already presented evidence of the contribution minerals firms make to Australia's R&D system in Chapters 4, 5 and 6. In brief, some salient features include: a history of large firms supporting corporate laboratories, knowledge across a wide range of disciplines, and significant innovative capabilities; internal programs of experimental development and continuous productivity improvement from innovation; independence and

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[119] In Niosi's view, a NIS has two broad elements: the R&D system and the supporting system for financing innovation. A narrowly defined NIS, the 'R&D system', is comprised of three sectors: 'private and public corporations with innovative capabilities (usually with R&D centres or laboratories), research universities, and government laboratories.' (Niosi et al. 2000:9)

leadership in the formation of strong industry-science bridging mechanisms with research providers, and consequent transfer and application of new knowledge and technologies into the private sector; low R&D intensity (however, the industry makes a significant contribution to Australian BERD); and, the important role played in creating domestic demand for, and being sophisticated users of, new technologies.[120]

The minerals industry also has a strong tradition of collaborative research between firms and research providers, perhaps best illustrated by the foundation of AMIRA in 1959 (Section 7.3.1 discusses AMIRA). The motivation for collaborative research tends to be the uncertain and costly nature of innovation as well as the complexity of technology (Bayona et al. 2001). Collaborative research can reduce exposure to risk, generate a high degree of leverage on investment and allow participation in a wider scope of projects than might otherwise be the case. It has also been found that firms must have certain internal capacities, or absorptive capacity, to learn from and implement knowledge and technologies generated in collaborative research (Bayona et al. 2001, Cohen and Levinthal 1990, Dodgson 1993). According to some participants in this study, most minerals-related collaboration is aimed at filling out the knowledge base and not concerned with the real cost drivers and quantum leaps for the industry. The spread of collaborative projects managed by AMIRA confirm this trend, as most are incremental in nature (Cucuzza and Goode 1998). Minerals firms also interact with the R&D system through one-to-one research projects such as consultancies, and the training and movement of graduate students. These mechanisms of interaction can act as a potent source of innovation and change in both individual firms and across the industry.

Previous chapters have also made reference to the move by large minerals firms to downsize their internal corporate research facilities, particularly in exploration. This trend is illustrated in Figure 7.1, which shows human resources devoted to R&D in large firms has halved during the past decade. The corresponding rise in human resources devoted to R&D in small firms, suggests that a transition of knowledge workers out of large and into small firms (some of which are technology service providers) has taken place. While a decline in total human resources has occurred, these figures give some support to anecdotal evidence of knowledge assets being redistributed as opposed to lost from the MinIS, at least in the short-term. This change in the structure of the MinIS is examined in more detail in Section 7.4 and the two case study subunits.

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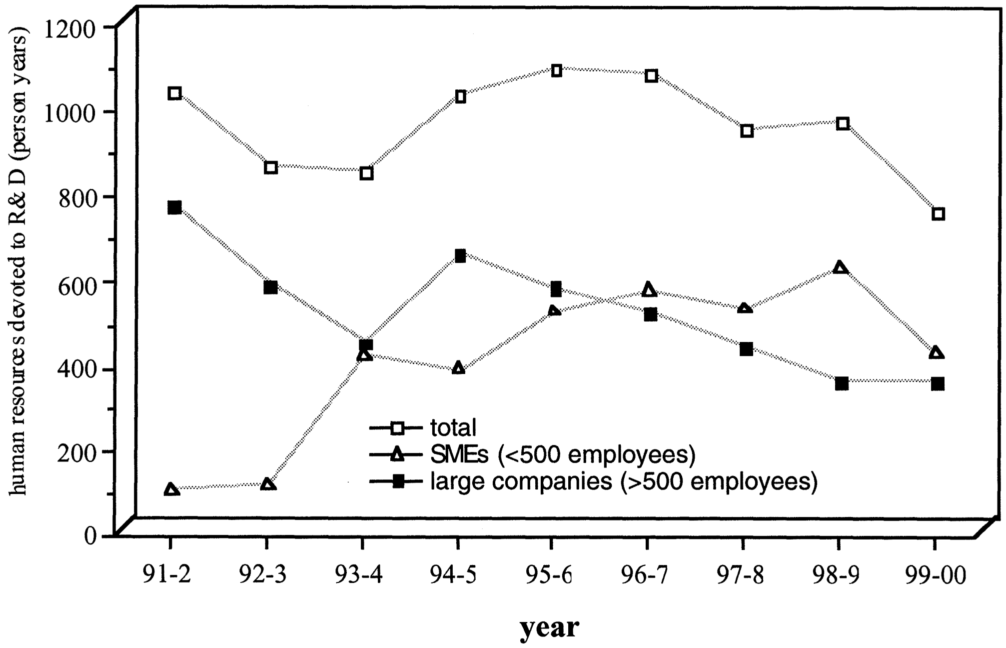
[120] Porter identified 'demand conditions' as one of four factors needed for an industry to attain competitive advantage. In addition the quality of demand was said to be more important than the size of demand (Porter 1990). Edquist notes that 'lead users' described in technology systems correspond to Porter's emphasis upon demand conditions (Edquist 1997).

Figure 7.1: Trends in human resources devoted to R&D in the Australian Mining (including services to mining) sector for SMEs and Large firms



Source: (Australian Bureau of Statistics 1992-2000) and Dr Allan Jones (DEST)
NB: these figures are based on the ANZIC narrow definition of the minerals industry

7.2.2 Tertiary education sector

The role of the tertiary education sector in the MinIS as a source of basic research and new knowledge, as well as provider of suitably qualified and technically literate graduates, is in keeping with the characteristics of innovation systems (see Chapter 3). Indeed, Chapter 5 demonstrated the critical role played by this element of the MinIS in the early development and professionalisation of the industry. Many accounts in the literature have also found that close relations between universities and minerals firms have served the industry well (Industry Commission 1995, May 1992, Napier-Munn 1996, Cook and Porter 1984, Prescott 1993, Minerals Council of Australia and National Tertiary Education Taskforce 1998). The minerals-related tertiary sector is characterised by diversity in terms of the size and scope (range of disciplines) of individual departments and research institutes, geographical spread, the balance between research versus education and training, and the type and structure of linkages within and between institutes, as well as with other elements in the R&D system.

Tertiary education in the minerals industry is organised around three disciplines: mining engineering; metallurgical engineering; and geology. Large departments at the University of Queensland, the University of New South Wales and Curtin University (WA) are active in all minerals disciplines and dominate tertiary minerals education in Australia. Nonetheless, every capital city (excluding Darwin) has a presence in at least one discipline, and usually has many smaller providers of minerals education, as do regional centres like Kalgoorlie and Townsville. In 1998 there was a particularly high proportion of universities (26 out of 37) offering degrees in geology, nine universities provided degrees in metallurgy or materials and six universities provided mining engineering degrees (not including civil engineering courses with 'mining majors') (Minerals Council of Australia and National Tertiary Education Taskforce 1998).

Tertiary research capabilities are similarly diverse in terms of size and scope of capabilities, and to some extent this diversity is driven by geographical location and proximity to activities in the minerals industry. In general terms (although, there are many exceptions), WA and Qld have significant capabilities in exploration and extraction, whereas Victoria tends to have more capabilities in processing. Diversity among tertiary research organisations is also influenced by the nature of informal and formal relationships between universities and the minerals industry. A close association between the University of Queensland and MIM, for example, led to the establishment of the Julius Kruttschnitt Minerals Research Centre (JKMRC) in 1970.[121] In a review of university research for the minerals industry, the JKMRC is described as an 'entrepreneurial research unit' and characterised by a dominance of contract funding and expertise in networking effectively with industry (including internationally) to deliver commercially viable research results (Napier-Munn 1996). Development of such an entrepreneurial tertiary institute in the minerals R&D system suggests a level of maturity in industry-tertiary relations that is uncommon across the Australian R&D system and Australia's private sector in general. The JKMRC is also following the industry's trend towards more global operations. In 1996, 20 per cent of the JKMRC's revenue was sourced from international projects, and this market grew by a third in 1998 to over 30 per cent of an expanded revenue base (JKMRC 1999, JKMRC 1996).

Federal Government initiatives also influence the tertiary sector's organisational structure. For example, the Australian Research Council's Key Centre research initiative created the Key Centre for Ore Deposit Studies (CODES) at the University of Tasmania (now a Special Research Centre), the Key Centre in Strategic Mineral Deposit Research at the University of Western Australia (now lapsed), the Key Centre in Economic Geology at James Cook University (now lapsed), and the Key Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC) at Macquarie University. The participation of tertiary education institutes in minerals CRCs is discussed below.

The tertiary education sector has not been immune to the cyclical business dynamics inherent in the minerals industry and consequent fluctuation in demand for graduates and expenditure on R&D. The 1990s, however, have seen the tertiary education sector come under fiscal pressure from a combination of changing terms and conditions of support from government, as well as fundamental changes in the industry's treatment of innovation. Concern within the minerals sector over the direction of education policy (under the Dawkins reforms), and in particular the manner in which quantity of tertiary places was given greater priority than the quality of graduates, triggered an active debate:

> A small population like Australia's can only raise its living standards if it can mobilise the intellectual capacities of all its people, not just a minority. Let there be no misunderstanding. This is the absolute antithesis of the 'levellers' approach. We must not hold back the best and strive to achieve mediocrity for all. On the contrary, we must 'level-up' our school students, our university students and our workforce. (Prescott 1993:6).

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[121] See Appendix 7.1 for more on the JKMRC

Frustration was also articulated at a lack of government understanding regarding the industry's 'right' to a pool of well-educated graduates:

> Unfortunately, neither the university system nor the Department of Employment, Education and Training match educational priorities with the nation's export business, or with various industries' roles in the economy. (Richards 1994).

Industry concern for the tertiary sector's welfare was matched with practical initiatives. The National Industry Education Forum (NIEF), was founded in 1991 to '...coordinate business and industry activities in education and to strengthen their contribution to policy and direction in education' (McIntosh 1994). Another significant initiative was a detailed, industry-sponsored review of Australian minerals tertiary education. The Minerals Council of Australia (MCA) established a National Tertiary Education Task Force to report on opportunities and limitations for minerals education in Australia. Recommendations released in *Back from the Brink: Reshaping Minerals Tertiary Education* (February, 1998) were not unanimously endorsed by the tertiary sector. However, the initiative highlighted an opportunity for Australia to become a world leader in minerals education, and in a sense usurp the role played previously by international schools of mines. The decline in minerals education in Europe and the United States has been widely reported (Hall 1999, National Research Council 2002). There also is a belief that centres of minerals education were migrating from Europe and the US to technically developed and developing minerals nations such as Australia, Canada, South Africa, Brazil, Chile, Peru and central Africa (Brady 1998). *Back from the Brink* also described the state of tertiary education as 'fragile' and limited by:

- a shortage of academic staff (partially due to poor remuneration in comparison with industry);
- the student population is small but expensive, thus making departments prone to closure, especially during cyclical downturns;
- while excellence exists in many areas there are too many small schools which do not have an adequate critical mass in order to deliver excellence in teaching;
- graduates are not fully equipped to meet the demands of a minerals career, especially in terms of how to effectively transform theory into practice;
- industry's historical interaction with tertiary education providers has been inconsistent and *ad hoc*; and,
- the industry has not been active in appointing new graduates (only 16 per cent of responding companies to the WA Task force survey intended to employ new graduates), a situation exacerbated by cyclical downturns in the industry.

In response to these findings the Minerals Tertiary Education Council (MTEC) was established to oversee the development of a new education program to which industry is expected to contribute $15 million and non-industry sources a further $10 million. This program ultimately aims to deliver excellence in Australian minerals tertiary sector over a five-year period (Minerals Council 1999).

Numerous respondents in this study expressed their concern in regard to the pressure being placed upon the tertiary sector. The financial squeeze in recent years, and greater loads on academic and research staff, are eroding capabilities. An associated trend is for tertiary research institutes to perform more short-term 'strategic' projects suited to the industry's immediate needs. In addition, respondents believe the minerals R&D system is being overlooked in the current national research priorities initiative. This raises the question of whether basic research and regeneration of Australia's minerals knowledge base is being sustained.

7.2.2 Government laboratories – CSIRO

The CSIRO is a key component of the MinIS, representing 'critical mass' in terms of expertise and knowledge across a wide range of scientific disciplines, research infrastructure, and capacity for applied research. It has several modes of interaction which enhance connectivity with minerals firms, including joint ventures, firm-specific one-to-one contracts, collaborative research projects, its roles in the CRC Program, and the movement of personnel from CSIRO into new or existing firms. In this manner it supports the innovative efforts and learning processes of firms and the productivity and competitiveness of the industry. Additionally, CSIRO has an important role to play in the applied development and diffusion of new knowledge and technologies, as well as research agendas (such as the Glass Earth initiative) that will sustain the industry's future competitiveness. The minerals industry has a solid relationship with CSIRO, as indicated by the fact that external funding from the minerals industry is well above the 30 per cent target (see Table 7.1).

CSIRO Divisions of Exploration and Mining, and Minerals are the two most relevant to the minerals industry. CSIRO divides its minerals research activities into 'Mineral exploration and mining' and 'Mineral processing and metal production.' The breakdown of funding sources for these two groups is given in Table 7.1. Other Divisions of CSIRO that house expertise of relevance to the two minerals related sectors include the CSIRO Office of Space Science and Applications, Land and Water, Wildlife and Ecology, Manufacturing Science and Technology, Mathematical and Information Sciences, Telecommunications and Industrial Physics, Building Construction and Engineering, and Petroleum Resources. These, however, contribute relatively insignificant amounts to the CSIRO's total minerals budget.

Table 7.1 : Source of funds for CSIRO's minerals related sectors

Source of funds	**Mineral Exploration & Mining** ($ million)			**Mineral Processing & Metal Production** ($ million)		
	97-98	**98-99**	**99-00**	**97-98**	**98-99**	**99-00**
Appropriation funds	16.6	17.1	16.9	23.1	25.6	25.6
External funding	15.4	15.8	16.0	15.6	18.6	20.8
Total funding	32.0	32.9	32.9	38.7	44.2	46.4
External/total ratio	48%	48%	49%	40%	43%	45%

Source: (CSIRO 1998b)

The benefits arising from CSIRO's research are substantial. Advances in laterite geochemistry, for example, have demonstrated how traces of minerals migrate from ore bodies buried under regolith and create a 'halo'. Analysis of this phenomenon has assisted exploration techniques and directly contributed to the discovery of the Plutonic and Bronzewing gold deposits in Western Australia. These two deposits have an estimated value of $4.5 billion. Models developed to assist nickel exploration, based on an understanding of how volcanic activity affects deposit formation, have been adopted with great success by exploration companies. Australia's share of the world nickel market is consequently expected to increase from 8 per cent to over 24 per cent as $6 billion worth of nickel deposits have been discovered over the past decade (CSIRO 1998a). Research expertise in computational fluid dynamics (CFD) has been applied to understanding multi-phase fluid systems in mineral processing systems. Such expertise was particularly important during the optimisation of Rio Tinto's HIsmelt reactor (see HIsmelt case study subunit).

One-to-one industry sponsorship of CSIRO research can also give smaller minerals research companies a strategic advantage. For example, the Queensland Metals Corporation (QMC) and CSIRO jointly developed the Australian Magnesium Process, which now aims to deliver a world-class magnesium industry to Australia. Construction of a $750 million processing plant began in 1999 in Gladstone, Queensland. Furthermore, the Ford Motor Company is committed to purchasing 45,000 tonnes of product annually, and to the construction of a local pilot plant for the manufacture of car doors (Riemens 1996). Research at CSIRO is also being undertaken in new high-strength alloys using magnesium and aluminium. .

Industry members have expressed support for the recent changes to CSIRO to meet external earnings targets and develop a more commercial culture (see Appendix 7.2). However, some concerns were raised by respondents to this study about potentially detrimental effects these changes may have upon CSIRO's knowledge base in the long term. In addition, an emphasis upon capturing returns from CSIRO's research through commercialisation was cited as a problem where commercialisation processes involved collaborative research projects. Disputes over intellectual property have caused breakdowns in past industry-CSIRO collaborative projects.

7.3 Public and private sector organisations that enable connectivity and relatedness in minerals R&D system

Industry-science bridging mechanism are important enablers of interactivity in innovation systems (Dosi et al. 1995, Edquist and Hommen 1999, Kaufmann and Todtling 2001, Sigurdson and Cheng 2001). This section profiles private and public organisations that have explicit commitments to enabling interaction and connectivity within the minerals R&D system.

7.3.1 Private sector enabler of connectivity – AMIRA International

From an IS perspective, AMIRA International is a very important organisation. AMIRA represents more than 80 minerals companies (an increasing proportion of which are based outside Australia), and 19 mostly Australian research providers (which when desegregated includes some 45 research groups) (AMIRA International 2001). Its role of managing collaborative research projects for members of the minerals industry enables connectivity and coordination between industry needs and public-sector science, technology and knowledge. The networks and relationships created by AMIRA's operations are rich due to the number and location of minerals companies and research providers involved, and the diversity of scientific and technological fields incorporated within AMIRA's portfolio of research projects. AMIRA also creates alliances among research providers through the formation of multi-disciplinary research teams for particular projects, and these relationships may encourage Australian research providers to participate in international research consortia. The networks supported by AMIRA are becoming increasingly global and have the potential to engender long-term research collaborations. The P9 Minerals Processing project, for example, which began in 1970 (as part of the JKMRC's original research program), is continuing, and recently held its first sponsors' group meeting in Montreal (AMIRA International 2002b). Estimates suggest that AMIRA's pre-competitive collaborative R&D is 0.5 per cent of the global minerals industry's R&D expenditure[122] (Andersen Consulting 2002).

Originally set up as a vehicle for the industry's involvement in a joint venture with government to form the Australian Mineral Development Laboratories (AMDEL), AMIRA soon established its primary role as 'research broker' for pre-competitive, collaborative research projects on behalf of members. This included companies across the entire spectrum of minerals related activities. As AMIRA does not have its own research facilities, it operates by developing and managing jointly funded research projects on a fee-for-service basis. Members of AMIRA provide funding for the association in the form of an annual subscription and a 'management charge' on each project.[123] In the past 40 years it has managed 550 projects, worth over a quarter of a billion dollars (in year 2000 dollar terms) (AMIRA International 2002a). AMIRA's inception was highly progressive, occurring long before governments were interested in supporting closer networks and collaboration between industry and research providers. Throughout its existence AMIRA has maintained its private sector status, without seeking government support. AMIRA membership and representation on its 15-member Council and Project Development Committee (PDC) has remained exclusive to the private sector. Representation on AMIRA's Council and PDC has always been of high standing, attracting senior industry leaders and managers in private sector research departments/operations. Their role in AMIRA is to guide the overall direction and the prioritisation of research projects, and thereby bolster AMIRA's capacity to meet the industry's changing needs.

Apart from the direct benefits derived from the results of projects (such as new tools and methods to improve competitive performance at operations), individual members gain considerable financial leverage when sponsoring AMIRA projects, as well as; access to a diverse range of research expertise, a forum in which to network, shared ideas and solutions to common problems, and access to trained graduates and post-doctoral researchers for recruitment. Project sponsors have the option of keeping research findings confidential. A feature of the AMIRA model of research are the projects' tightly timed reviews, conducted every six months, combined with the option to extend projects beyond their planned termination date. This model develops long-term research collaborations based on focused, short-term

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[122] This study does not believe this to be a reliable figure.

[123] Membership fees contribute to the costs of maintaining the association's corporate structure and operations. Individual projects have their own funding arrangements and the viability of each project depends upon whether or not sufficient interest, in the form of funding, can be raised.

justifications. The outstanding example of long-term research is the industry-famous AMIRA/JKMRC collaboration on the 'P9 Mineral Processing' project, which is currently in its thirteenth extension. Mineral processing simulation capabilities developed through this collaboration are now routinely used in the industry. The project was awarded the Business and Higher Education Round Table Award for 'Outstanding Achievement in International Collaborative R&D' in 2001. Management of this project has not been straightforward. For example, over half the 'sponsorship base' altered during the period from 1986 to1995, when three project reviews were conducted. This involved 35 companies, seven of which went out of business and 13 of which significantly altered their ownership or structure (Napier-Munn 1996). Currently, the project covers a broad range of interests (represented by four project modules), and is supported by 38 companies. It also includes the University of Cape Town in South Africa and McGill University in Canada as principal research providers.

As shown in Table 7.2, AMIRA's research effort concentrates on mineral processing and exploration. The decline in funds for exploration correlates with changes in the industry's activity in the area (see Chapter 6), and with the closure of the CRC for Australian Mineral Exploration Technologies in 2000. AMIRA has not had much success in attracting sponsorship for projects in environmental management and sustainable development. This may be due to competition from new research providers (see ACMER below) and industry consortia (such as INAP). AMIRA is leading the so-called 'Project Phoenix', a proposal to establish a CRC for Sustainable Minerals and Metals Processing whose success would redress AMIRA's performance in this field.

Table 7.2: Breakdown of AMIRA's research funding by research project, combined value of all projects under management

Research projects under management	1997 ($'000)	1998 ($'000)	1999 ($'000)	2000 ($'000)	2001 ($'000)
Petroleum	194	0	0	0	0
Mineral Exploration	12,610	9,680	10,243	9.263	10,528
Mining	2,767	3,221	4,679	4,631	6,843
Mineral Processing	15,032	18,8334	19,082	22.368	22,257
Engineering	1,537	621	694	940	1,150
Environmental	1,213	2,339	2,853	2,543	2,423
Others	332	332	0	0	597
Total	**33,684**	**35,026**	**37,551**	**39,747**	**43,780**

Source: AMIRA Annual Reports (AMIRA 1998, AMIRA 1999, AMIRA International 2001)

NB: AMIRA experienced difficulty in project establishment in 1998 and 1999, however, the decline in funding was not as severe as anticipated due in part to funding from established research projects. The drop in funding on an annual basis in 2001 is the result of a higher than average number of projects being completed in the previous year (AMIRA International 2001).

Table 7.3 provides a breakdown of AMRIA funds by research provider. Universities receive the majority of AMIRA's research funds, with the largest proportion of funds directed to the JKMRC (with research funds for minerals processing and extraction). Other universities that receive a significant proportion of AMIRA funding include the University of South Australia (funds primarily for processing, and a small amount for environmental research), the University of Cape Town (processing), the University of Western Australia (primarily exploration, lesser amounts for mining and environment), and the University of Tasmania (exploration). The CSIRO Division of Exploration and Mining (funds primarily for exploration and a small amount mining) receives more funding from AMIRA than the Division of Minerals (funds primarily for processing and less for metallurgy). AMIRA is a core partner in the AJ Parker CRC for Hydrometallurgy and the CRC for Predictive Mineral Discovery (established July 2001).

Table 7.3: Breakdown of AMIRA's research funding by research provider, per annum

Type of contractor	1999		2000		2001	
	Total ($ '000)	Percent (%)	Total ($ '000)	Percent (%)	Total ($ '000)	Percent (%)
University	4,334	48	4,562	49	5,080	59
CSIRO	740	8	294	3	1,594	18
CRCs	3,376	37	3,591	38	1,187	14
Other	635	7	952	10	799	9
Total	9,085		9,399		8,660	

Source: AMIRA Annual Reports (AMIRA 1998, AMIRA 1999, AMIRA International 2001)

The distribution of AMIRA funding by project field and key research providers (from 1999-2000), is as follows:

- *Exploration* – CRC for Australian Mineral Exploration Technologies, CSIRO Division of Exploration and Mining, the University of Tasmania, and the University of Western Australia.
- *Mining* – JKMRC and CRC for Mining Technology and Equipment
- *Processing* – JKMRC, the AJ Parker CRC for Hydrometallurgy, the University of South Australia, the University of Cape Town and CSIRO Division of Minerals.
- Environment – the University of South Australia and the Australian Centre for Mining Environmental Research.

Adapting to changes in the minerals industry

With considerable advantages to be gained from conducting research through AMIRA, comments made in the 1995-96 Chairman's Report to Members remain pertinent. Chairman Anthony Kjar identified the comparatively low proportion of members' funds being directed towards collaborative research, with the exception of the alumina industry:

> However, it was of concern to note the relatively low proportion of funding currently directed to collaborative research by members, despite the demonstrable value of technical advances arising from fundamental and applied research of this type since AMIRA's foundation.
> Just as important is the need for the industry to nurture and sustain its research and development infrastructure, the researchers and resources for the betterment of the Australian industry at large. (AMIRA 1996:4)

The changes to innovation in the minerals industry have placed considerable pressure upon AMIRA and its model of collaborative research. In response to changes in its operating environment, AMIRA began a strategic planning process in 1995-96 (which included AMIRA's first independent survey of its customers) and identified four major changes including:

- A 'shift to competitive advantage and shareholder value in mining research which has become particularly apparent in the last five years';
- Increased globalisation of the mining industry, which has increased its tempo and is reflected in the rising number of off-shore activities, particularly in developing countries eager to enhance their economic growth;
- Recent changes in government policy including CSIRO's 30 per cent external earnings target and restraints on university funding, which have enhanced the public sector's responsiveness to industry needs; and
- The increasing rate of technological development and change, which is particularly evident in the area of 'infotronics.' (AMIRA 1996:6)

AMIRA's operating environment is far more competitive due to the shift in Australian innovation policy in the 1990s and related initiatives (CRC programs, external earnings for CSIRO, Key Centres) aimed at improving relations between research providers and industry in the NIS. From AMIRA's perspective, achieving an increase in the number of research providers actively supporting collaborative research was challenging, and new competitors were seen as having an unfair advantage in the form of matching government funding for industry sponsorship (industry found additional leverage for their research expenditure very attractive). This competition placed increased pressure on what were always limited funds for collaborative research. This raises questions about how research associations such as AMIRA can be sustained in the future, and the possible need to implement a process of rationalisation. Another disconcerting accompaniment to current trends, noted in the Chairman's 1996 Report, is the tendency for member companies, uncomfortable with the pace of change, to move towards short-term projects with foreseeable short-term gains, as opposed to higher risk and more substantive long-term projects which may 'change the nature of the industry' (*ibid*).

Management of individual projects is also becoming more onerous, expensive and time consuming due to structural changes in industry's management of innovation. Industry restructuring and general devolution of responsibility for research from head office to company business units, means that where AMIRA used to work through ten or twenty head offices, they now need to visit a higher number of mine sites located all over the country (and increasingly the world), and whose owners' commitment to R&D is inherently unstable. Industry changes have also led to a high degree of mobility of technical staff with whom AMIRA deals, and in some cases, an overall decline in on-site expertise. This situation can impede the successful championing and exploitation of research. In the last five years AMIRA has had to deal with a more basic problem of generating the quantum of support necessary for projects and project generation. The industry's rapid pace of mergers and acquisitions has seen the number of sponsors for AMIRA projects halve.

Reaction to globalisation

In light of the changes to its collaborative research environment, AMIRA developed and implemented a 1996-2000 Strategic Plan, the most important priority of which was to develop the scope of its markets (AMIRA 1997a). In keeping with industry trends, AMIRA made a commitment to globalising its operations. In 1998 membership of AMIRA was opened to companies without a subsidiary in Australia (AMIRA 1998). Branches of AMIRA have been opened in Perth, Cape Town and Johannesburg. Following a strategic review of global opportunities for AMIRA in 2000, the 'Global Technology Initiative', AMIRA changed its name to AMIRA International Limited, restructured its business units, provided web-based access to projects, and established affiliations with similar organisations to AMIRA in Canada (the Canadian Mining Industry Research Organisation CAMIRO) and Europe (the UK-based Mineral Industry Research Organisation MIRO). Representation in South America is being sought through Austrade. Representation on the Council now includes members from southern Africa and new members include companies from South Africa, France and Norway. Opportunities for collaborative research are currently being sought in North and South America and Asia. An average of 40 per cent of AMIRA's funding is now derived from countries other than Australia. AMIRA is also expanding its services and leadership, an example being the initiation and convening of the 'Alumina Technology Roadmap Workshop' for 40 senior managers from 9 countries involved in alumina production.

Another evolving role performed by AMIRA concerns its activities as an advocate for the industry, particularly in relation to innovation policy. According to industry participants in this study, until the 1990s and appointment of Dick Davies as CEO, AMIRA's culture was one of fierce independence and interaction with government was not actively pursued. AMIRA now lobbies Government Ministers, makes submissions to relevant government reviews (such as the Mortimer Review of Business Programs, and most recently the review of Australian Research Priorities), and represents the minerals industry at government forums. In this manner, for example, the government has been advised that 'Australian-based companies which are operating globally may not retain their local research and development base unless there are compelling reasons of competitive advantage' (AMIRA 1997b:3).

Summary

AMIRA is a vehicle for the rapid application and transfer of new ideas, technologies and other breakthroughs for the minerals industry, making it a key constituent of the MinIS. The AMIRA model of privately managed and sponsored collaborative research has supported a culture of innovation, and has been of enormous benefit to the industry by uniting industry needs with the minerals research base. The organisation has been proactive and effective in its response to changes in the industry, and continues to function in an increasingly complex and competitive environment. Furthermore, new opportunities, such as developing globalised operations, have been embraced. AMIRA research projects offer an avenue for the transfer of Australian university innovations to a global market.

In Australia's NIS, AMIRA is unique as a privately funded coordinator and enabler of collaborative research and associated relationships.

7.3.2 Public sector enablers of connectivity – Cooperative Research Centres

The Cooperative Research Centres (CRC) program was established in 1990 to provide an institutional framework for encouraging collaborative research between researchers in the public sector and 'users' of research in both the public and private sectors (see Appendix 7.3 for more detail).

The CRC concept has gained broad support from the minerals industry (see Table 7.4). The relatively high number of minerals CRCs established early in the program's history underlines the strength of interactivity in MinIS prior to the Program's inception. There is evidence also that CRCs have, on occasion, stimulated beneficial interaction when it might not have occurred otherwise. For example, the automation of drag lines for coal mines:

> ...was considered impossible 3-4 years ago, but was facilitated through the Centre for Mining Technology and Equipment CRC which was able to access visual-sensing software from the CSIRO Division of Manufacturing for application in the mining industry. ... These developments would not have happened if the CRC had not brought together the right mix of researchers, skills and technologies. (BHP Coal Pty Ltd in: (AMIRA 1997b))

Table 7.4: Minerals-related CRCs

Name	**Date** established to current end	**Full-time research staff** (per 7 years)	**Post-graduate students** (per 7 years)	**Average annual funding for CRC** ($million) CRC program	Total resources	**Total funding over life of CRC** ($ million) CRC program	Total resources
CRC for Mining Technology and Equipment (CMTE)	July 1991 – July 2004	36	31	1.4	5.8	11.0	45.5
GK Williams CRC for Extractive Metallurgy	July 1991 – July 2004	29	21	1.5	9.2	10.1	64.4
AJ Parker CRC for Hydrometallurgy	July 1992 – July 2006	75	46	2.6	15.6	18.5	109.0
CRC for Australian Mineral Exploration Technologies	July 1992 – July 2000	19	11	1.4	5.8	11.0	45.5
CRC for Welded Structures	July 1992 – July 2005	68	72	2.2	10.8	11.5	75.5
Australian Geodynamics CRC	July 1993 – July 2000	37	24	2.5	10.0	17.4	63.9
CRC for Advanced Computational Systems	October 1993	25	18				
CRC for Landscape Evolution and Mineral Exploration	July 1995 (renewed)	28	16				
CRC for CAST Metals Manufacturing	July 1999 – July 2005	65	25	3.0	15.4	21.0	107.6
CRC for Predictive Mineral Discovery	July 2001 – July 2008	55	36	2.6	13.6	18.0	95.1
CRC for Landscape Environments and Mineral Exploration	July 2001 – July 2008	72	19	2.9	16.0	20.2	118.0

Source: (DEST 2002)

NB. There are four other 'mining' CRCs in the coal, petroleum and renewable energy sectors. The CRC for Advanced Computational Systems in the 'Information and Communication Technology' sector had strong links with minerals exploration (see Fractal Graphics case), while the 'Manufacturing Technology' sector contains two CRCs which receive minerals firms support, the CRC for Welded Structures and the CRC for CAST Metals Manufacturing.

From the point of view of the JKMRC (see below) there are numerous benefits in being associated with CRCs.

> ...the CRC mechanism does present a unique opportunity to develop new and powerful multi-disciplinary research networks, and to access genuinely new funding which is one step removed from traditional short-term industrial funding,

> and which allows work of a more strategic and fundamental kind to be undertaken. (Napier-Munn 1996, p49)

Given the current cuts to industry's expenditure on exploration R&D generally, it is a concern that three of the four exploration related CRCs did not receive a second round of funding. This is despite the CRC Secretariat's recommendation for a further round of funding for the CRC for Australian Mineral Exploration Technologies and the Australian Geodynamics CRC. Exploration expenditure and changing industry needs will be met by the new CRC for Predictive Mineral Discovery. The Secretariat also recommended continued funding for the CRC for Advanced Computational Systems. Many participants in this study believe closure of this program was more a result of unfortunate timing, as it had a high participation rate among SMEs and certainly met current priorities for development of 'high-tech' Australian industries. Recent moves to open up the CRC program to smaller companies (see Appendix 7.3) is a positive step, particularly for minerals technology service providers.

There is some question as to whether CRCs have increased funding or simply reallocated funds for minerals research. When examining the role of CRCs in Western Australia, Dr Steven Algie notes that it is not clear whether or not the CRC program has increased the minerals industry's total funding for research. He also notes that 'Some companies appear to have redistributed their external funding to direct a greater proportion to CRCs, without increasing the total' (Algie 1997:52). What is not in dispute is the role of CRCs in expanding the education of graduates and in enabling the transfer and diffusion of new technologies and knowledge into minerals firms. On this point, Kjar emphasises the enhancement of technology transfer into minerals firms through the movement of postgraduate students (Kjar 1997, AMIRA 1997b).

7.3.3 Enabler of environmental R&D – ACMER

The Australian Centre for Mining and Environmental Research, ACMER, is an incorporated tax-exempt research organisation comprised of five research providers in the environmental research area and five of Australia's major mining companies (see Table 7.5 below). In some respects ACMER is similar to AMIRA, but acts as an environmental research broker. It differs significantly, however, in that research providers are members of ACMER, and it does not operate on the same scale as AMIRA. The Centre was formed from the restructure of the Australian Centre for Minesite Rehabilitation Research (ACMRR) in July 1998, which in turn had been established as an industry initiative in July 1993.

Table 7.5: ACMER's industry sponsors and internal research providers

Contributing sponsors	Sponsors lost since 1998	Environmental research providers
Anglo Coal Australia	RGC Limited	ANSTO – Environmental Science Division
BHPbilliton	Shell Coal Pty Ltd	CSIRO – Environmental Projects Office
Placer Dome Asia Pacific Limited	Normandy Mining Ltd	Curtin University of Technology – Mulga Research Centre & Mine Rehabilitation Group
Rio Tinto	North Limited	The University of Queensland – Centre for Mine Land Rehabilitation
WMC Resources Ltd		The University of Western Australia – Centre for Land Rehabilitation

Source: (ACMER 2002)

The need for a centre of environmental expertise was first recognised in the 1980s. However, the idea proved to be ahead of its time, and little support came from industry. The same concept was then launched as a CRC bid, but this strategy also failed. By the early 1990s a number of industry champions embraced the concept and worked with CSIRO to establish ACMRR, which also included AMIRA as a joint venture partner. The Centre began by teaching courses on mining and the environment at the University of Queensland to a mix of engineering, scientific and agricultural science students. The Centre evolved into ACMER to expand its research and scientific scope beyond rehabilitation, or 'weeds and seeds' research. The restructure aimed to facilitate more direct input from industry in policy formation and direction to ensure that their research and training requirements in strategic environmental issues were being met. AMIRA's formal relationships with ACMER ended once individual companies became ACMER members. The Centre also assists government with a scientific base to define standards for environmental management in the minerals industry (ACMER 1998).

ACMER has a Board comprised of representatives from the joint venture partners, academics, company general managers of environmental management, State government representatives and the Office of the Supervising Scientist. The technical advisory committee identifies areas and issues for projects, while the Research Coordination Committee is responsible for a more detailed level of planning and monitoring projects. The aim is to attract funds from industry for joint venture research proposals and facilitate transfer of results, with the research being conducted by the member research providers. Strategic areas of research include acid mine drainage, waste rock dump and final void stability, tailings disposal and remediation, and ecosystem reconstruction processes and strategies. There are also strategic areas in environmental management within the research projects, such as site rehabilitation, which have a 50 per cent funding subsidy from the federal government.

According to the Director of ACMER, Clive Bell, acquiring sufficient funding for the new Centre is a constant battle. Payments from industry are proportional to firm size and what they stand to gain from the research project. Industry would like the Centre to become self-funding, although the Director currently doubts that this will occur easily.

Clive Bell suggests that as ACMER is unique in Australia there is a chance for it to become the nation's leading facility for environmental research delivery, as well as an international player. There are many environmental consulting firms that conduct a little research and often such companies have outstanding and talented staff. Bell further notes that ACMER has an added advantage over these smaller players in its ability to resource research teams with an international reach.

7.3.4 Section summary

Sections 7.2 and 7.3 have described a well-developed minerals R&D system. The system is characterised by diversity in the types and levels of relationships between minerals firms and research providers, as well as in the institutions and organisations that enable interactivity. The minerals industry has displayed initiative and leadership in developing and maintaining good interaction with its public knowledge base. For example the industry initiated, and is responding to, a review of the tertiary education sector. It provides a high percentage of funding to CSIRO's minerals related divisions and strong engagement exists with the CRC program. The industry is also recognised for the establishment of AMIRA International, whose unique role in managing collaborative research has established strong and often long-term relationships, and enhanced connectivity in the MinIS. The high degree of connectivity among organisations in the MinIS suggests that it does not share Australia's characteristic weakness in this area.

The minerals R&D system is coming under pressure from a contraction in its source of funds. Additionally, the research being conducted by virtually all players is moving towards the applied end of the R&D spectrum at the expense of longer-term, basic research.

7.4 Firms and the MinIS – a broad view of current dynamics in the MinIS

The minerals industry in Australia is heterogeneous. Firms differ in size, integration across commodity groups and minerals activities, degrees of downstream processing, and history. Until the last decade, however, the industry was united by an overriding Australian identity and culture. While operations within companies may have internationalised along with technology alliances, corporate headquarters and research laboratories were located in Australia and a firm's innovation strategy was primarily influenced by its history of experience in the Australian minerals innovation system. Rapid globalisation and increased competition in the face of falling commodity prices (discussed in Chapter 4) are changing corporate strategy and driving a wave of global consolidation. Australian ownership of large minerals companies has dropped dramatically in recent years. The Australian MinIS is no longer guaranteed support from large minerals companies with a strong national identity. The acquisition of middle ranking and small firms (particularly in the gold sector) has significantly reduced the number of firms within the MinIS (Treadgold 2002, AMEEF 2002, Durie 2002, Manners 2002). The effect of such changes upon the technology strategies and innovative capabilities in minerals firms is investigated in this section. Changes in corporate strategies are of interest as they integrate innovative activities with the business processes within firms, and establish a firm's level and type of engagement with the MinIS. When the corporate strategies of large companies change, they represent significant shifts in the institutional environment within the MinIS.[124]

7.4.1 A comparison of innovation strategy and capabilities in a large and a small minerals firm

The following two case study subunits of analysis, when considered together, provide a better understanding of, and insight into, the capabilities of large and small innovative minerals companies and their relations with the Australian MinIS.

The CRA-RTZ merger case study subunit

Introduction

This case study subunit examines the changes in organisation and technological strategy which followed the CRA-RTZ merger and the implications this has for the Australian MinIS. The 1995 merger of CRA with RTZ to become Rio Tinto was at the time the biggest in the minerals industry and initiated what is now a standard response to the pressure of globalisation: growth through mergers and acquisition. While it may have made sound business sense, it has created some long-term concerns about both the innovative capacity of the company and its impact on the minerals innovation system in Australia.

The CRA-RTZ merger

The $27 billion merger between CRA Ltd in Australia and RTZ Corporation Plc in the UK was announced in October 1995. RTZ, with interests in gold and copper, already owned 49 per cent of CRA – a leading producer of coal, iron ore and aluminium. Since the 1950s, RTZ Corporation's dominant corporate strategy was that of a 'mining finance house', where the parent company grew and diversified by acquiring and developing the world's most profitable mines (Ala-Härkönen 1997). Corporate head office housed core skills in market and economics intelligence, as well as mine project evaluation, project financing and project management. The professional qualifications of CEOs and Presidents were typically from law, business, finance and general management (Ala-Härkönen 1997). Skills and capabilities in minerals activities were decentralised into operations and subsidiaries, usually managed by mining and metallurgical engineers (*ibid*). CRA, by contrast, was a 'production-based' minerals firm with a highly developed internal capacity for technology development and application. As has been demonstrated in the Argyle Diamond and HIsmelt case study subunits, the company supported significant and core capabilities in technological innovation and management. The Board and senior executives were committed to innovation as a means of sustaining competitive advantage. Its CEOs and Chairmen were great leaders of the minerals profession. In the past,

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[124] See Chapter.3 for the role of institutions in innovation systems.

CRA's technology strategy centred on self-sufficiency. It possessed corporate laboratories in Perth and Melbourne as well as the Advanced Technical Development Group. This organisational structure necessarily involved developing strong linkages between CRA's corporate research laboratories and its business units. In 1994, CRA was one of the five largest minerals companies in the world and a highly innovative, major player in the Australian MinIS. The merger brought together these two very different cultures.

An RTZ statement highlights four factors which compelled the companies to merge:

- the convergent strategies of the two companies;
- the opening up of opportunities in the changing geopolitical environment;
- the ability to get the best out of the two companies' management skills and expertise;
- the complementary nature of the two portfolios in terms of size, geography and product. (RTZ Corporation 1995)

In essence, the merger involved combining the operations of the two companies under a dual-listing, while their identities and listing on the stock exchange remained separate. The Australian government placed conditions on the merger that it considered necessary to protect Australia's national interest, including an undertaking on behalf of RTZ to reduce their interest in CRA. Other conditions were designed to preserve Australian management of particular operations (Reuters News Service 1995, RTZ Corporation 1995, LaRue 1996). The dual-listed company, CRA-RTZ, renamed its two entities 'Rio Tinto Ltd' (Australian arm) and 'Rio Tinto Plc' (British arm) in 1997 (Reuters New Service 1997).

Since the merger, innovation has become more tightly focused, with a strategic shift away from an internal capacity for technological independence towards reliance upon sourcing new technology externally and successful international technology transfer. The current approach to technology strategy comes from the company's focus on creating shareholder value and maintaining competitive advantage. Prior to the merger, CRA's expenditure on R&D was around 1 per cent of sales, whereas RTZ's was less than 0.5 per cent. Over the past three years, Rio Tinto's expenditure on R&D has averaged approximately 0.4 per cent of sales, with R&D expenditure reported at A$67 million in 2000 and A$75 million in 2001 (Rio Tinto 2002).

Global restructure of operations

The announcement of a major management reshuffle in March 1997 heralded a new era for Rio Tinto and, according to some analysts, effectively signalled the end of CRA (Bendeich 1997, Fitzgerald 1997, Stevens 1997). Rio Tinto decided to replace its geographic management structure with one based on commodities. Six new commodity groups, with the leadership of three to be based in London and the other three in Australia, would operate as independent businesses and be supported by international Technology and Exploration Groups (RTZ Corporation PLC-CRA Limited 1997). The restructuring announcement was delivered by Rio Tinto's Chief Executive Leon Davis, who explained:

> Following the merger of RTZ and CRA, our organisation was mainly on a geographical basis. Whilst retaining our devolved management philosophy, the new product-based organisation not only brings a keener focus on customers and opportunities, but simplifies relationships, better concentrates our technological expertise and streamlines decision making. It sharpens our business and makes

> us more competitive by achieving efficiency gains and cost savings. (RTZ Corporation PLC-CRA Limited 1997)

The six new groups are: *Aluminium* (Comalco), Brisbane; *Copper*, London; *Energy*, Melbourne; *Gold and Other Minerals*, London; *Industrial Minerals,* London; *Iron Ore*, Perth. The strategy was designed to allow Rio Tinto's business units to act globally in their decisions about capital investments and management.

With Rio Tinto's headquarters to remain in London, the brunt of the changes would be felt at what were originally CRA's Headquarters in Melbourne. Essentially Melbourne was to become a services centre, with its responsibilities devolved, sections moved to new bases either in Australia or the UK and staffing levels halved (RTZ Corporation PLC-CRA Limited 1997, RTZ Corporation PLC–CRA Limited 1997).

> Put at its most blunt, 55 Collins Street has been gutted. It will continue to provide support services like accounting, legal and technical advice and media and external relations to other Australian-based divisions, but with vastly reined numbers. (Stevens 1997)

Despite the forecast benefits from the organisational realignment, the changes proved contentious. The issues relating to Australia's national interest raised when the dual-listed company was originally proposed were raised again. Some analysts regard the shifting of management and control of Australian assets to London as a cheap buy-out of CRA (Bendeich, 1997; Fitzgerald, 1997).

Rio Tinto's innovation strategy – merging of different cultures of innovation

Since the merger, corporate and innovation strategies at Rio Tinto have been dominated by an RTZ approach. Innovation strategy is directly related to the company's focus on creating shareholder value and maintaining long-term competitive advantage. Innovation and R&D have become more tightly focused with a strategic shift away from an internal capacity for technological independence (CRA's approach) towards reliance on sourcing new technology externally and the successful transfer of that technology into operations. However, the corporate base for technological innovation is based in Australia and retains a strong CRA influence. Thus, the innovation strategy for the merged entity did not amount to complete domination by an RTZ approach. It appears that consideration was given to each company's history of innovation and strengths of the system of innovation in which they were historically based.

In July 1996, the company announced its first major structural changes since the merger, following a review of expenditure on exploration. The review recommended a 'refocussing' of expenditure on Australian exploration programs. One hundred Australian jobs in exploration were to be cut, leaving approximately five hundred staff and contract employees in the area. Internationally, three hundred and thirty jobs were to be cut from exploration (Reuters News Service 1996). Many other minerals companies have since followed Rio Tinto's lead and divested themselves of internal R&D programs in exploration.

Four months after the restructuring, an internal review endorsed the notion that best practice in corporate research was an asset that should be maintained, and a decision was made to base Rio

Tinto's corporate research and technology development operations in Melbourne (Reuters News Service 1997). The decision to locate the so-called Technology Group in Melbourne was a strong endorsement of CRA's leadership in minerals research and recognition of its history in the Australian MinIS. The Technology Group is responsible for Rio Tinto's corporate collaborative research program, much of which is conducted through AMIRA, providing an additional reason for the Australian location.

The decentralised organisation and independence of each Product Group's research facilities resembles RTZ's style of management. Each commodity group has its own on-site research team responsible for technical support for operations and commodity-specific product extraction and processing R&D. These operating companies do not conduct their own exploration, and early evaluation and development of research projects is handled in London. There is no obligation for the commodity groups to use the services of the corporate Technology Group to meet their innovation needs. Commodity groups' research focus tends to be short-term, particularly since they are under pressure to make quick positive returns from investments in R&D. A noteworthy exception is Comalco, which maintains a significant research laboratory and infrastructure and undertakes work on new process development. Comalco's smelting technology development has been running for many years and has cost $100 million, but has the potential to greatly reduce industry cost. This work has involved the development of metal coatings for the cathode of aluminium reduction cells, and the possibility of developing radically new cost-effective cells, called drained coated cells.

The majority of Rio Tinto's R&D is conducted at each Product Group's own research laboratories or by external research providers.

The organisational structure and role of the Technology Group

Dr Robin Batterham, Chief Technologist at Rio Tinto, describes the Technology Group as the 'glue' which holds Rio Tinto together and says that, 'the glue makes the value of the group higher than if it were broken up into six companies'. The company's corporate Technology Group provides additional technical support to Product Groups, supports corporate policy development in areas such as health, safety and environment, and advises management and the executive. It also manages a corporate program of external research (both short- and long-term), as well as developmental research projects. It employs 300 staff with corporate research laboratories at Bundoora, Melbourne, with a smaller group at Bristol, UK. The merger saw considerable downsizing of corporate research programs, such as closure of CRA's corporate research facilities in Perth with a staff of 70 to 80. Comalco's research staff were cut from 250 to 100 employees, and while a number of staff were relocated into technical support positions for the individual operations, there were a significant number of retrenchments. According to Dr Batterham, however, cutbacks to Comalco were a product of research success and reflected completion of some major developments at Comalco.

The Technology Group is organised into three areas: Technical Services and Office of Chief Technologist; Technical Evaluation and Project Management; and Health, Safety and Environment (see Table 7.6 below). It is noteworthy that in spite of the majority of the Technology Group being based in Australia, the head of the Technology Group, John O'Reilly, is based in London. Almost half of its work focuses on Product Group improvement, followed by approximately equal amounts of work on Group-wide support and major initiatives to meet defined technological needs. Other areas of activity include major pilot plant work, and contracted-out or collaboratively-leveraged research. The principal focus is very much on improvement of processing.

In a globalised company like Rio Tinto, the dissemination of knowledge and best practice procedures for new technology developments within the company is critical for its long-term performance. This is particularly true for ideas and developments generated by a Product Group, as there is no incentive for the Product Groups to fund dissemination of information outside their own operations. Technology Services are responsible for developing and instilling knowledge-based systems throughout Rio Tinto. As there is a great deal of information and knowledge within the company, this is far from a straight-forward problem. It involves intelligence gathering, networking and knowing what is happening elsewhere, including the activities of other companies. This is facilitated by: the movement of staff, together with their tacit knowledge, between companies; by staff attendance at international meetings and conferences; by regular reviews of new patents; and from general industry intelligence. Technology Services also develop Rio Tinto's 'Operations Manual', and are responsible for encapsulating knowledge into software programs for training, safety and employment. Importantly, they are also responsible for ensuring that best practice procedures in scheduling and mine planning are carried out. Best practice procedures here have enormous financial implications. The Technology Group as a whole is responsible for all new developments and also has outright responsibility to vet and approve the technical soundness of major capital proposals or acquisitions coming from the operations. There are almost as many people in the Group evaluating proposals and acquisitions as there are conducting R&D.

Table 7.6: Organisation of Rio Tinto's Technology Group

Group	Activity
Technical Services and Office of Chief Technologist	
	Technical Services – • supports key areas of mine planning, mineral & metallurgical processing and environmental sciences • disseminates best practices across company • provides support for acquisitions. **Office of Chief Technologist –** • development work on operational issues • in-house research program • external research program • provides broad technology advice to Executive and Board • intellectual property and legal services.
Technical Evaluation and Project Management	
	• supports major project teams for projects in execution and at feasibility stage • independent review of all major investments.
Health, Safety and Environment	
	• provides corporate policy guidance and support for improvement of standards and performance.

External and collaborative research

Rio Tinto's external research program is managed by the Office of Chief Technologist. R&D activities in this area can be broadly defined into two approaches:

- *external pre-competitive – collaborative* research with other minerals companies and managed by research brokers such as AMIRA International or the UK-based MIRO and industry groupings, such as the International Network for Acid Prevention (INAP). All participants in these projects share in the benefits of the research.
- *external competitive* – individual research programs undertaken with organisations in the tertiary education sector, government laboratories and industrial partners (eg Caterpillar, Komatsu) which are usually confidential and where Rio Tinto retains the rights to use the resultant technology.

Rio Tinto is currently involved in more than 60 pre-competitive and competitive external research projects. Company executives suggest that this represent 15 to 30 per cent of the company's total R&D budget. Managers in Rio Tinto believe that the Company gains considerable advantage from participating in collaborative research. This includes the leverage acquired per research dollar, reduced exposure to risk, and participation in a wider range of projects than might otherwise be possible. A portfolio of well-managed collaboration also allows Rio Tinto to maintain global networks among public and private centres of excellence in minerals research. Dr Batterham suggests that external collaborative research is on the increase, including new strategic forms of competitive collaboration. This form of collaboration involves companies combining their proprietary technologies to generate performance output that is often synergistic rather than additive.

A large proportion of Rio Tinto's pre-competitive collaborative research is managed by AMIRA. The AMIRA website in July 2000 showed Rio Tinto, or an affiliate, to be involved in 13 of 28 exploration projects, 2 of 9 mining projects, and 26 of 35 processing projects. The balance of AMIRA projects across minerals activities clearly reflects Rio Tinto's strategic preference for production innovation as the most effective way of obtaining a competitive advantage. The company does not believe that an investment in generic extraction technologies can deliver a strategic advantage, and therefore prefers to collaborate with the manufacturers of mining equipment to develop such new technology. Other areas in extraction, cutting and blasting have been outsourced to the CRC for Mining Technology and Equipment, in Queensland with CSIRO, JKMRC and Queensland University. Dr Batterham argues the need for mining development within the groups is minimal, and suggests that it makes more strategic sense to invest about $500,000 per year for 'way out things' such as new cutting techniques rather than to develop in-house expertise in this area. An exception is Rio Tinto's acquisition of North Ltd and inheritance of a strategic capability in block caving.

The environment is an area where the amount of technological collaboration is expected to rise, which makes strategic sense as the environmental area is broadly perceived to be an industry-wide problem and Rio Tinto would not expect to gain a competitive advantage by locking up new environmental technology. The Office of Chief Technologist headed the creation of the International Network for Acid Prevention (INAP), a consortium of 15 of the world's leading mining companies, to develop high levels of understanding and industry practice in the amelioration and management of acid rock drainage. INAP currently has eight research projects under way and is managed by Rio Tinto Technology Group. Similarly, Rio Tinto was a founding member of the Global Mining Initiative (GMI).

Post-merger, Rio Tinto continues to exploit the centres of excellence among Australia's minerals research providers and believes that this research infrastructure, associated knowledge base and depth of talent among personnel is of world standing. Apart from CSIRO, the external research program primarily utilises the following research providers:

- Julius Kruttschnitt Mineral Research Centre, University of Queensland
- AJ Parker CRC for Hydrometallurgy
- Ian Wark Research Institute, University of South Australia
- GK Williams CRC for Extractive Metallurgy
- CRC for Black Coal Utilisation
- CRC for Australian Mineral Exploration Technologies (Centre concluded 2001).

Summary – implications for Rio Tinto and the Australian MinIS

Rio Tinto's current approach to innovation is directly related to the company's focus on creating shareholder value and maintaining long-term competitive advantage. It appears that, since the merger, innovation strategy at Rio Tinto has been dominated by an RTZ approach, but incorporates elements of CRA's approach and history of innovation in the Australian MinIS. Innovation strategy has become more tightly focused with a fundamental strategic shift away from an internal capacity for technological independence towards reliance upon sourcing new technology externally and the successful transfer of that technology into operations (often described as 'fast-follower' in the use of commercially proven new technology). Such technology advances are available in the marketplace and to competitors. Ultimately, when operating in this manner, Rio Tinto must develop the skills and competencies required to not only successfully transfer and apply technologies, but also to do so in a manner that outperforms their competitors.

Rio Tinto has developed some organisational capabilities to meet the requirements of being a 'fast-follower', primarily in the corporate Technology Group with its role of developing knowledge-systems, intelligence gathering and dissemination of best practice in planning and development to product groups. In addition, the Technology Group's external research program provides exposure to a wide range of developments, and options for future competitive advantage. The weak link in this strategy, however, seems to be with the long-term innovative capability, in particular the absorptive capacity of individual operations. The short-term focus of operations research programs and lack of funds and personnel for less applied research is said to be undermining their capacity for innovation (a view shared among many interviewees). Furthermore, according to participants in this study, many operations only have a handful of individuals who 'champion' research programs and their departure can leave such programs vulnerable, as seen, for example, in the departure of Malcolm Richmond from Hamersley Iron in 2001. Such limitations raise serious doubts about the long-term sustainablility of this strategy.

From a MinIS perspective, the Rio Tinto merger offers challenges and opportunities. The reduction in expenditure on R&D as a per cent of sales places pressure on the Australian MinIS, as does a lack of long-term commitments and regenerative research programs. There also appear to be fewer avenues for the training of future technological experts who have with first hand experience of successful innovation. The Australian MinIS will benefit from Rio Tinto's Australian-based research facilities: the corporate Technology Group (although the Head and primary control of the group is based in London), and the comparatively large research facilities associated with the aluminium (Comalco) and iron ore (HIsmelt) product groups.

The Croesus case study subunit

Introduction to the small gold mining company Croesus

Croesus is a small, fully integrated gold mining company that listed on the Australian Stock Exchange in 1986. Croesus is based in Kalgoorlie and was started by Ron Manners, who was the company's Executive Chairman until he became Non-Executive Chairman in 1998. In 2000, the company employed 35 staff directly, and derives additional support from around 150 specialised contractors and small technology based service providers. While the company maintains its own exploration, mining and processing activities, it describes its business as 'turning ideas into gold bars, profitably.'

During its short lifetime, Croesus has operated from 10 open pit mines and one underground mine. The company relies upon its exploration program for future growth which makes it particularly sensitive to Native Title claims on its exploration leases. Issues surrounding Native Title are cited by the company as severely retarding its growth between 1996 and 1998 (Manners 1998). Small gold miners also have increased exposure to changes in the global minerals environment and fluctuations in the global price of gold. These dynamics are reflected in rates of Croesus' production which peaked in 1996 at 38,817 ounces; fell for the following two years due to high costs and diminished production to 31,415 ounces in 1997 and 26,616 ounces in 1998; and, reached a new record high of 73,089 ounces in 1999, boosting cash reserves to $22.4 million from a low of $5 million in the previous year (Croesus Mining NL 1998, Croesus Mining NL 1999). Recent acquisition of Central Norseman is anticipated to increase annual production output to 300,000 ounces per annum (Treadgold 2002).

A brief history of Croesus' operations

Nine months after its 1986 listing, with exploration activities showing no sign of generating an immediate cash-flow, Croesus bought CRA's subsidiary, Forrest Gold Pty Ltd, for $20.3 million. The acquisition included a Carbon-In-Pulp (CIP) plant and a short-life mine at Hannan South, as well as CRA staff, some of whom remained with Croesus. During its first 9 years, Croesus did not find a significant ore body. The Hannan South deposit was exhausted at the end of 1988 and with its mill operating under capacity, low grade dumps, old tailings and small pits which were uneconomic for larger companies were mined. When the gold price slumped in 1991-92 Croesus reacted to conserve cash and while exploration continued, many exploration projects were leveraged through joint venture arrangements.

Croesus' breakthrough occurred in 1993 following its acquisition of Binduli tenements from Defiance Mining for $405,000, a purchased designed to meet a short-term shortage of ore. Although original projections of returns from Binduli amounted to $600,000, Croesus earned about of $30 million from the site. Other companies had explored the area with drilling at a depth of 40 metres, but did not discover the underlying mineral wealth. Croesus had the advantage of owning the site outright and according to Managing Director, Mike Ivey, 'had a smaller opinion of themselves,' and were not confined to meeting grade thresholds usually set when operations are linked to larger companies. The first two deposits at Binduli were discovered following a $5,000 investment in deeper drilling. During the next 6 years, seventeen deposits were discovered and mined.

In September 1995, Croesus' first high grade deposit was discovered beneath its Centurion pit at Binduli. This discovery provided the impetus to build an onsite treatment plant, since ore was being trucked 19 kilometres to the Hannan South mill for treatment. These plans were postponed indefinitely in April 1997 due to problems associated with reaching an agreement with native title claimants (see Native Title below). As a compromise, the Hannan South plant was upgraded in 1998 with the addition of a second ball mill and gravity circuit. Additional crushing equipment was installed at Binduli.

The Binduli pit performed exceptionally well, with a 50 per cent improvement on original head-grade estimates. The development of the Centurion deep pit in 1998-99 contributed to the record results in gold production, projection costs and profit. These developments left Croesus debt-free and in a prime position to fund exploration and acquisition programs.

An innovative culture and sharing ideas

The Normandy Group listed at a similar time to Croesus and grew into Australia's largest gold producer prior to its recent acquisition by Newmont Mining, while Croesus remained one of the smallest. This is not to imply that Croesus was unsuccessful. In 1998, Ron Manners was invited to the Normandy Group Mining Conference to speak on 'Why do smaller companies do it better?.' According to Manners, Croesus' success derived from its innovative culture, embracing innovation as a method of improvement across all of its activities.

In his role as Chairman, Manners claims always to have encouraged the uptake of new ideas, believing that 'improvisation and innovation are the foremost keys to successful small companies' (Manners 1998:3). In addition, he stated that it is more difficult for bigger companies to introduce new ideas, particularly as employees in such companies are not encouraged and empowered to use their initiative. On the other hand, it was Croesus' unspoken policy to always be open to giving a new idea a go. In one case, for example, a student metallurgist examined every aspect of the Hannan South treatment operations, and following some fine tuning, improved recovery rates from 91 to 94 per cent. Each year a consultant metallurgist reviews the plant. On another occasion, Newcrest Mining expressed an interest in hiring the Hannan South mill for a year. Newcrest declined the use of the mill after they completed a detailed study of the plant which included a suite of options for change with varying predicted effects upon production. In reviewing this valuable input, Manners requested that all of the suggested changes be implemented, which resulted in a 15 per cent increase in throughput.

Croesus, being a small company, has no internal separation of exploration, mining, metallurgy and production, or administration, allowing ideas to flow readily around the company. An important time for sharing information among company employees is at Friday night drinks, which are held at the back of the Kalgoorlie-based head office. The Managing Director and the Chairman attend these informal get-togethers to be brought up to date with problems and achievements. The weekly 'Scoreboard' is another tool to ensure that all Croesus staff keep abreast of critical issues and company performance. The idea was adapted from The West Australian Newspaper's printing plant where a daily scoreboard is prominently displayed to keep production staff up to date with various critical parameters (see Figure 7.2). Croesus' weekly Scoreboard is sent out to each operation and to the Head Office.

Figure 7.2: The West Australian and Croesus Scoreboards

The West Australia	
Country (finish time)	**Waste** (% for night)
Metro (finish time)	**Agents** (% delivered on time)
Copies – 1 am (no. produced)	
Running Message	**Share Price** (today's)

Croesus Weekly 'Scoreboard'	
Exploration	(location & method)
Mining	(actual & budget)
Processing	(actual & budget)
Admin	(special items)
A$ Gold price:	
Share price:	

Flexibility and innovativeness in Croesus

The company's flat structure facilitates quick decision making and timely response to changes in the competitive environment. When the company was low on ore in 1993, for example, the exploration team identified a promising small ore body. The Managing Director and a colleague spent an hour working up a brief feasibility study and calculated that a 100 per cent return on investment could be attained. This study was faxed to board members at approximately mid-day and by the afternoon the project had been approved.

Croesus continued to remain profitable during times of considerable adversity. In 1988, for example, the introduction of Carbon-In-Pulp (CIP) plants induced a world shortage in cyanide supplies and the price of cyanide quadrupled. This was due in part to the two major global cyanide suppliers placing restrictions on their supply. Larger companies were protected by long-term cyanide purchasing contracts and gold forward sales contracts (Manners 1995). Croesus' response to this situation was to down-play their own mining activities and instead conduct toll mining, where other companies paid for use of the Hannan South mill. The cost of cyanide meant that most small companies could not afford a mill of their own. Concurrently, Croesus saw this time as an opportunity to concentrate on their exploration activities. This downturn continued for a period of four years, during which time all workers voluntarily accepted a three-year freeze on their salaries. Croesus prefers a reduction in salaries to losing workers. Ron Manners explained that 'when the company is small it can adopt more easily to circumstance.'

An expectation in Croesus is that since a consultant visits every mill in the district, they have more skill for the job. Being a small company, Croesus is 'never too proud to accept good advice' (Manners 1995). Furthermore, since the company is small, ideas are rapidly incorporated into its system, often to be up and running on the same day (*ibid*). The company also manages exposure to global downturns in the gold price by hedging and forward selling, a common practice among gold producers. The gold price hit a 19-year low during 1998 and the average price Croesus obtained for its sales was $587 per ounce, well above the record low market price (Croesus Mining NL 1999).

Employment

Within Croesus it is believed that 'quality people' are the key to its flexibility and adaptability. The average age of Croesus employees is 25 years and Croesus policy demands that all employees are involved in further technical training (Manners 1995). Manners stated that his preferred employment policy was not to employ anybody who knew less than he did. It is believed that not employing the best people and supporting their development would be to the detriment of the entire company.

Managing Director, Michael Ivey, expresses the opinion that smaller minerals companies are better able than large companies to maximise the proportion of 'top notch' staff, so that they make up 50-70 per cent of the company. In comparison, larger companies may only have 25 per cent of their staff as 'top', with 50 per cent being 'good' and 25 per cent 'lousy'. To encourage good staff to remain with Croesus, new staff are given an option on 50,000 shares at 15 cents with a two-year period before this option may be exercised.

The company also benefits from the fact that four of its seven executive staff members have an average of 10 years service with Croesus. During his eleven years with Croesus, Michael Ivey moved from Senior Geologist, to Exploration Manager, to General Manager, to become Managing Director and CEO in 1998. The upward growth and development of staff is pursued to extend the overall capacity and skills base of the company.

As mentioned above, employees are expected to actively further their technical training and keep their career path heading upwards. Training may take a variety of forms, from short seminars, one-day courses, week-long in-house seminars and longer specialist training courses.

These various types of training are undertaken at a range of organisations, including AusIMM, the geological society, AMEC, the tertiary education sector and mining 'expos'. Croesus noted that it is often the only small company participating in such projects (Manners 1995).

Access to external developments and sources of new knowledge

Croesus maintains no corporate research laboratories and is reliant on relations with external research providers, consultants and minerals technology service providers to access new ideas and technology developments. A variety of methods are employed to improve the company's external intelligence gathering and keep abreast of innovative developments in the industry, including: sponsorship of AMIRA projects; engagement with post-graduate research programs, to allow CSIRO PhD students to conduct their research at Croesus operations; and maintenance of close links with the local Kalgoorlie School of Mines. Croesus allows final year engineering students from the Kalgoorlie School of Mines to conduct research projects at a Croesus pit.

Certain capabilities in the area of mine planning and scheduling, such as calculating the economics of a pit and the actual pit design, are considered to be areas of core competence and are kept inhouse. Additional expertise may be required during the planning of a project, as when geotechnical consultants were employed to determine the angle of the pit walls, but once a project is worked up it is put out to tender to a range of external service providers.

According to industry representatives, Kalgoorlie leads the world in minerals contracting and is world-renowned in areas such as exploratory drilling. The advantage of using consultants for a small company like Croesus, is access to their expertise and tacit knowledge generated from experience at a range of companies and locations. Croesus is also of the opinion that service providers are becoming increasingly innovative in their own right. Furthermore, there is now less of an 'us and them' attitude between external service providers and company staff and more of a focus on working together on a shared challenge (Manners 1998).

A spectrum of service providers are employed by Croesus, from those who specialise in earth moving, such as Roche Brothers, and suppliers of heavy mining equipment through to high-technology drilling and modelling companies, such as Fractal Graphics, as well as individual specialists in areas like metallurgy, exploration and engineering. Every two years the high-tech company, Fractal Graphics, is employed to conduct 3D modelling of high-grade regions of Croesus ore bodies.

Native title

As with most minerals companies, staff in Croesus claim not to have a problem with the principle of Native Title. They are concerned, however, that in its current form the legislation is unworkable and benefits only lawyers. Native Title has had a negative impact upon Croesus' exploration and development plans. Croesus experienced protracted (3-year) Native Title negotiations with multiple claimants over State-issued Mining Titles, during which time the company was unable to access its most prospective deposits. For the company to remain viable mining was conducted at less favourable sites and low grade stockpiles were treated. This strategy, while keeping the company running, pushed production costs up considerably. Prior to the Native Title claims on some of its mining leases, Croesus had invested $2.5m in research and design for a planned $23m integrated milling facility. The costs were incurred during negotiations. Eventually, following settlement of the Native Title claim out of court, the integrated milling facility project was deferred indefinitely. Instead, primary and secondary crushing mills were installed at the Binduli mine site, from where the crushed ore is transported 19km to the processing plant at Hannan South.

Croesus remains committed to the Kalgoorlie region and is not actively spending on exploration overseas, however, the company says that unless the Native Title issue is resolved, their exploration dollars will be allocated elsewhere. It is the opinion of Croesus that what is required in relation to the Native Title legislation is a logical, transparent, fair and non-political system which benefits the interests of industry and Native Title holders.

Summary

An innovative approach to the management of all its activities gives Croesus a sustainable competitive advantage. The company exploited the advantages of its small size to be flexible in the face of change, and overcame inherent limitations through exploitation of external sources of knowledge and experience.

Croesus did not have the internal capabilities to develop new minerals technologies. However, such small companies play an important role within the MinIS by: creating a demand for, and being sophisticated users of, new minerals technologies; utilisation of external contractors and service providers; support for continuous education and training among its employees; and relations with research providers.

Ron Manners recently warned that although the recent rise in the gold price had revived the Australian gold sector, this activity was yet to translate into the formation of new companies, necessary for the industry's long-term growth (Manners 2002). Australian gold production continues to fall when the Australian dollar price of gold is at a 15-year high. The latter is the direct result of lower exploration expenditure during the past 4 years and a situation where new discoveries and developments are not keeping pace with exhaustion of old operations (Australian Journal of Mining 2002).

Supplementary note on Croesus

Croesus Mining was considered to be a small gold mining company and was widely recognised in the Australian minerals industry for its innovative culture at the time this study was conducted (1999-2000). While the company's innovative capacity remains unchallenged, as does the company's motto of 'growth through persistence', its ranking among Australian gold producers currently stands as fourth-largest (Treadgold 2002). This is primarily due to mergers in the gold sector. Should AurionGold[125] be acquired by Canada's Placer dome, Croesus will mover into third rank in Australia, behind Newcrest Mining and Sons of Gwalia (Australian Journal of Mining 2002, Treadgold 2002). Croesus' gold production has also received a boost

[125] AurionGold is the product of a merger between Australian gold miners Delta Gold and Goldfields, and is currently the largest Australian based producer (200,000 ounces a quarter). Takeovers in the Australian gold industry during the past 12 months have dramatically changed ownership; some 60 per cent of production in Australia is controlled from overseas (Australian Journal of Mining 2002).

from its acquisition of WMC's holdings in Central Norseman on January 18, 2002. Croesus is the only remaining listed minerals company with a head office in Kalgoorlie.

7.4.2 A brief note on BHP's change in technology and innovation strategy

Broken Hill Proprietary Company Limited (BHP) was incorporated in 1885, based upon the richness of the Broken Hill orebody and successful process innovation with flotation. It rose to become a major international resources company, with three principal areas of operation:

- Minerals – mineral exploration, production and processing (principally coal, copper and iron ore)
- Fuel – hydrocarbon exploration and production, and
- Steel – steel production and fabrication.

In May 2001, shareholders agreed to the merger of BHP with South African minerals giant Billiton. The merger has contributed to a large shift in BHP's (now BHPbilliton) technology and innovation strategy.

Since 1999, under the direction of Paul Anderson, BHP has undergone a period of dramatic change and restructuring involving closure of operations once considered core activities such as, the Newcastle steel plant, a platinum mine in Zimbabwe, copper mines, and the Nevada smelter in the USA. This period will not be discussed in detail here, however, changes in the company's technology strategy parallel broader corporate change.

Technology and Innovation Strategy

BHP's huge economies of scale, across a number of areas of the minerals industry, meant that until quite recently the company could innovate both broadly and deeply, in a manner unknown to most other mining corporations. The company's sheer size facilitated the establishment and maintenance of very large corporate research facilities and capabilities. As mentioned, in Section *4.3.6 Rates of academic publication*, in the 1980s and early 1990s, BHP's publication rate was similar to that of a small Division of CSIRO. Corporate laboratories were often directed by university professors and supported an academic culture, as did the Board. In these times, the portfolio of corporate research projects included projects peripheral to BHP's core competences, and the direct requirements of individual operations. The BHP Institute of Railway Technology, BHP Information Technology, BHP Capital Advisers and the BHP Methanol Research Plant are some examples of BHP's internal research institutes.

The end of the 1990s began a dramatic redirection of company policy and attitude toward innovation and technology strategy. The appointment of senior personnel such as Paul Anderson, Don Argus and David Jenkins coincided with a shake-up of BHP's management philosophy. It appears that BHP endorsed a 'Minerals Finance-House' corporate strategy (see Table 7.7), which downgraded innovation as a primary source of growth. The difficult external environment and preparation for merger with Billiton contributed to a need for change. However, BHP had also sustained some spectacular technological and business failings. For example, closure of a mineral sands development at Beenup, failure of the Ok Tedi tailing dam, a $100 million cost blow-out with the HBI development, and unwise investment in the US Magma copper mine.

Plunging expenditure on R&D over the three years to June 2001 (from $221 million to $94 million and $35 million respectively) is indicative of the sheer scale of shift away from investment in innovative activities by BHP, as it merged with Billiton (BHPbilliton 2001, BHP 1999). The rationalisation of BHP's research operations reduced the number of employees in research from 500 to around 160. It also involved closure of its Melbourne Research Laboratories during the 1999-00 financial year, following 30 years of operation. BHP Information Technology and the Methanol Research Plant were sold in mid 2000 (BHP 2000). Other research projects were placed in universities under short term contracts, such as the Institute of Railway Technology and Maintenance Research Institute which now exists as a joint venture with Monash University; Materials and Modelling is at RMIT; Fire and Risk Engineering is at the Victorian University of Technology; Composites Construction is at the University of Western Sydney; and the Laboratory for Environmental Chemistry is at the University of Melbourne. US corporate research facilities in Reno, Nevada, were also closed. Small subsidiary entities have been developed for the commercialisation of the gravity gradiometer development, 'Falcon,' as well as for the aluminium/zinc alloy coating technology for steel (a wholly owned subsidiary, BIEC International Inc). Two corporate laboratories remain in BHPbillton. The Newcastle Laboratories (previously BHP Minerals Technology Laboratory) has capabilities in ferrous minerals and coal, processing and product performance, and non-ferrous minerals processing. The Port Kembla Steel Laboratory has capabilities in ironmaking, steelmaking, steel processing and products.

According to BHPbilliton, this organisational restructure better aligns research activities with business requirements and the needs of business units. Corporate laboratories support areas of competitive advantage, such as continued development of patented, solid paint technology and other coated products for steel, and the reduction of coke plant emissions. BHPbilliton claims that its new technology strategy has maintained a deep innovative capacity, while curtailing the 'breadth' of its innovative effort. The Technology Council manages the company's research program. The Council is comprised of two senior members from each of three business groups, the Chief Intellectual Property Adviser, and a representative from Corporate Services. The Council's responsibilities include risk assessment for any research proposal valued over $50 million, and ensuring that funds for research comply with business strategy.

An important consideration from this study's perspective is what the demise of BHP's R&D intensity and commitment to research capacity mean for Australia's MinIS? BHPbilliton contend that their support for the Australian minerals research base may increase, since more of its research needs are being externally sourced. It is difficult, however, to believe this contention given the company's annual R&D expenditure of just $35 million (to June 2001) and R&D intensity of 0.44 per cent (June 2000) and 0.17 per cent (June 2001) which are low even by minerals industry standards (BHPbilliton 2001, BHP 1999). In some respects, BHP's change of innovation strategy represents a windfall for those universities that have gained infrastructure, research contracts and human resources. However, it is not clear how these changes will affect the MinIS in the long-term. Furthermore, each of the premerged entities' technology strategy was influenced by their respective home country's NIS. It remains to be seen whether the historical ties between Billiton and South African minerals research, or BHP's history with Australia's NIS, will eventually dominate BHPbillitons's innovation strategy. In particular, it remains to be seen where the company will place the majority of its corporate research facilities.

7.4.3 Changing Corporate Strategies in minerals firms driving changes in innovation and technology strategies

This is a time of rapid change in the minerals industry (Chapter 4). Rio Tinto led the way in what has now been a decade of widespread re-examination of performance and shift in firm' business strategies. Most firms and the industry in general found that they were not creating the kind of returns shareholders were demanding (Frith 1998). Traditional measures of a firm's performance such as, 'output tonnage, integrated product portfolio or range of metals covered,' were now overlooked in favour of improved shareholder value (Batterham and Shaw 1998). A trend in corporate strategies sought growth from cost cutting and acquisitions, in order to obtain a critical mass required to attract the attention of investors and funds. Globally, annual spending on mergers and acquisitions by the 'metals mining and refining' industry jumped from US$12 billion in 1996, to US$19 billion in 1997, to US$25 billion in 1998 (Ericsson 1999). This trend appears more dramatic when compared with parallel drops in global exploration investment of US$4-5 billion or a drop of 30 to 40 per cent by 1998 (Ericsson 1999).

These changes in corporate strategy are accompanied by a dramatic shift in the treatment of innovation and technology strategy in the minerals industry, and hold important implications for the Australian MinIS. While changes in minerals innovation and technology strategy manifest themselves in a variety of ways, a dominant feature is the short-term focus on innovation. Table 7.7 provides a generic summary of the shift in corporate strategy from 'Production-based' to 'Minerals-finance house,' and how these changes affect technology and innovation strategy. More detail on distinct changes in technology strategy: (such as technology leader to follower, technology outsourcing, incrementalism, and technology transfer) and internal organisational changes of R&D activities (such as budget cuts and decentralisation) are provided in Appendix 7.4. These changes have been well articulated in the Rio Tinto case study subunit.

A desk-top review (that is, data sourced from publicly available reports) of technology strategy among a selection of large globalised minerals firms is presented in Table 7.8. Companies were selected according to their size in the global minerals industry in mid-2001, however, smaller Australian companies MIM, and WMC were also included. Where possible, data was gathered over 5 years, from 1996-2001, in order to identify trends and overcome the inherent limitations of this type of analysis. It is clear that the aluminium companies Alcan and ALCOA spend more on innovation, in line with their downstream processing capabilities. Some companies have targeted specific capabilities in enabling technologies, like Billiton's targeting of biotechnology. The dominant trend, however, is decreased expenditure on R&D (per cent of sales) and more short-term treatment of innovation.

Table 7.7: A comparison between production-based and minerals-finance house corporate and innovation strategies

Production-based	Minerals-finance house
Strategy for growth	
• Production based	• Finance based
– Capacity expansion from successful exploration & continuous productivity improvement at existing operations	– Acquisitions and mergers to bring the most valuable ore bodies into firm's portfolio of assets
Priority areas for attainment of competitive advantage	
• General capabilities, experience and knowledge in extraction and processing (mining and metallurgy)	• Capabilities in new project development, planning and scheduling
Organisational structure	
• Strong national identity	• Integration of globalised operations
– head office in city proximal to leading operations	– head office in global capital of mining finance, ie London
– corporate research laboratories usually in same city as head office	– downsized corporate research facilities, decentralisation of corporate research into business units
Innovation and technology strategy	
• Underpins strategy for growth	• Supports operations and for industrial minerals, provides technical support for customers
– internal capability in new technology development and leadership	– preference for 'fast following' and uptake of commercially proven new technologies
– large, technologically independent corporate research facilities	– downsized corporate research facilities, decentralised facilities among business units
– capabilities augmented through pre-competitive collaboration	– increased use of strategic alliances, joint ventures, contract research and new forms of collaboration
– strong links with national innovation system	– increasingly globalised knowledge networks, source global centres of technology competence in minerals innovation
– technology strategy addresses short and long-term goals including in some cases, new process & technology development	– technology strategy primarily addresses short-term goals and incremental gains
– wide knowledge base across all minerals activities, support and capacity for technology development	– knowledge base preserved in areas of strategic competitive advantage, reliance on external technology development and international technology transfer of enabling technologies
Minerals activities and trends in innovation	
• Exploration	• Exploration
– internal capabilities in exploration important and complement strategy for growth	– transference of capabilities in exploration into DECs
• Extraction	• Extraction
– extraction improvement from increases in size of equipment and automation	– new 'system of extraction' approach, centralised & real-time monitoring, transformation of work. 'Mine to Mill' offers better coordination with processing
• Processing	• Processing
– new process development in corporate research program and continuous improvement at operations	– strategic emphasis to increase existing minerals reserves by improving processing, high use of enabling technologies (simulation & modelling, biotechnology
• Environment	• Environment
– site specific environmental programs of research, performance linked to local legislative regime	– initiative among global corporate leaders to embrace sustainable development, use of strategic corporate alliances to solve shared environmental problems

Table 7.8: A comparison of innovation strategy among globalised minerals firms

Firm	Average R&D % sales (last 5 years)	Trend R&D % sales (last 5 years)	Patents Number (last 5 years)	Features of Technology Strategy
Alcan	0.93%	↔	142	• tech strategy tied to business strategy and increased customer-orientation • core tech capabilities housed in 3 research laboratories that conduct long-term R&D and support technical centres • engineering and technical centres house customer focused expertise and product development support
ALCOA	1.01%	↓	280	• tech strategy aligned with product/market priorities • significant corporate R&D • long-term target development in-house
Anglo American	0.45% (last 2 years)	↓	10	• history of self-sufficiency in new tech development • corporate research lab now a commercial entity but also supported by subsidiaries • sheer size allows it to finance more risky/long-term R&D programs and maintain considerable breadth/depth of innovative capacity
Anglo Platinum	0.58% (last 3 years)	↑	0	• tech strategy tied to long-term drive to promote demand for platinum • corporate research centre of significant breadth/depth • organisational knowledge/skills enhancement initiative • engages in strategic outsourcing with suppliers to enhance external tech transfer
Asarco	1.22% (research & exploration)	↓	9	• financial commitment to research and exploration dropped since 1996 in proportion with company-wide financial hardship • corporate research centre houses broad expertise with considerable depth in niche areas that has produced proprietary technologies • developed environmental research capabilities in 1990s in reaction to new retrospective US environmental regulations
Barrick	7.78% (exploration & development)	↓	6	• tech strategy appears to be one of fast follower • user of new technologies and demonstrated record of successful technology transfer • the youth of most operations assists the use of improved established technologies to increase efficiency
BHP	0.9% (4 years 1999-1996)	↓	793	• by the late 1990s an emergent strategy was to retain an in-depth capacity to innovate while curtailing breadth • corporate research groups downsized with many groups privatised or merged with external interests • in spite of downsizing, reported R&D expenditure increased from 1998 (A$174m) to 1999 (A$221m) while concurrently revenue from sales decreased from 1998 (A$24.6b) to 1999 (A$21.9b)
Billiton	1.34% (new business & technology)	↓	34	• tech strategy complements an overall growth through acquisition business strategy • supports internal capacity for process-technology development and commercialisation in niche areas, like bioleaching and plasma smelting • tech capacity's utilised to promote company's attractiveness as a JV partner for new deposit development
De Beers	3% (prospecting & research)	↓	94	• self-reliance dominates its tech strategy and involves breath of capability and the capacity to commercialise in-house technologies • supports internal basic research on an industry-needs basis • includes support for value-added services that allow the company to increase the price of diamonds, such as, inscribing polished diamonds
Freeport McMoRan	na	↓	2	• tech strategy seems to be conservative with little public domain information available • recent support for environmental and anthropological research programs, in response to difficulties at operations in Indonesia
Inco	0.98%	↔	70	• regards a 'technological edge' as a major competitive advantage • internal innovative capacity maintained with expertise in target areas (includes process and new product development), support for long-term research and collaborative research projects • committed to investigating any external technology with the

				potential to deliver a competitive advantage
MIM	0.22%	↓	9	• history of significant innovative prowess and commercialisation of strategic technologies • recent dramatic cuts to R&D expenditure • continues to conduct a significant amount of collaborative research
Newmont	5.84% (exploration & research)	↓	5	• maintaining innovative capacity is regarded as a balance for the company's high political risk operations and increasingly difficult mature operations • innovative in all phases from discovery to processing but not in new product development
Noranda	0.7% (2 years 1999-1998)	↓	48	• a deep commitment to innovation held with tech strategy seen as primary vehicle by which to obtain long-term, sustainable competitive advantage • also supports growth in its customer base via provision of quality products and services and maintenance of supplier relationships • internal innovative capacity includes strategic new process development, targeted product-related research and is enhanced via selective collaborative partnerships
Phelps Dodge	2.1% (exploration & R&D 4 years 1996-1999)	↓		• the downstream manufacturing arm of the company is more innovative • Phelps Dodge mining has a conservative tech strategy that supports incremental changes to reduce costs and improve production
Placer Dome	0.87% (1 year)		7	• a fast follower tech strategy is employed with the strategic application of new and existing technologies, primarily sourced externally • emphasis is placed upon leveraging R&D investment and 90% of R&D is outsourced via joint ventures and collaborative research • the in-house research group is set operations-related performance targets
Rio Tinto	0.4% (last 3 years)	↓	34	• recent cuts to research budgets are reported to have maintained innovative capacity in core areas • internal research must create value and is focused on a 'core technology effort' • internal research group must compete for funds from business units • external research program does not compete for funding and manages long-term collaborative research on behalf of operations
WMC	0.39%	↓	1	• tech strategy said to be one of a technology 'enabler' (fast follower) as opposed to the development of new technology • supports a rich program of collaborative research • history of technological leadership including in exploration and the discovery of Olympic Dam

Source: All data in this table was collated from company Annual Reports

7.4.4 Summary

The case study subunits demonstrate the difference in innovative capabilities and the role played by large and small firms within the MinIS. Both types of firms rely on the MinIS as a source of new knowledge, skills and expertise and utilise a variety of methods for accessing the external resources (collaborative research, strategic alliances, industry consortia, use of service providers, employment of graduates, attendance at forums, among others). The juxtaposition of these extremes of firm size and innovative capabilities demonstrates that no single innovation strategy is applicable across this heterogenous industry. Small firms like Croesus have horizontal management structures that facilitate shared learning processes, and create advantages in terms of flexibility and short response-times when reacting to sources of change, including incremental technological change. However, the innovative capabilities of large minerals firms, like Rio Tinto and BHPbilliton, have far greater parameters of scale and scope, making them key players in the MinIS. The current change in corporate strategy (from a 'Production-based' to a 'Minerals-finance house' approach) and resulting changes in technology strategy and innovative effort in large firms, are therefore key concerns. While these changes hold implications for the long-term learning processes and accumulation of technologies within minerals firms, they also raise serious questions in regard to the future coherence, connectivity, innovative capability and competitive rivalry within the MinIS.

7.5 Chapter Summary

This Chapter mapped organisations and their interactivity in order to better define the MinIS' structure and coherence. Organisations, institutions and relationships that enable connectivity within the MinIS were highlighted. The minerals industry has been proactive in establishing and maintaining a high degree of interaction and strong connectivity between public and private sector organisations involved in minerals innovation. A long-held propensity for industry-led programs of collaborative research, as exemplified by AMIRA, has promoted the formation of knowledge-based networks, a shared sense of 'industry', and efficient use of the knowledge and technology-based resources in the MinIS. A cohesive web of interaction underpins minerals innovation, and these interactions provide significant benefits to the minerals industry and add to its international competitive advantage. In addition, industry trends of globalisation offer an opportunity for Australian innovations to be transferred to the global market place. Furthermore, the scale and scope of interactivity within the MinIS is a characteristic generally lacking within Australia's NIS. This makes the MinIS an important component of the NIS, particularly in terms of the potential to engender new knowledge-based services and exports.

Yet the minerals R&D system is under pressure and may be in danger of fragmenting, with adverse consequences not only for its capacity to undertake research but also for the all-important networking and interaction that facilitates innovation. Research providers are facing funding difficulties and a lack of support for long-term, regenerative basic research may undermine innovative capacity for the future. This is of particular concern in relation to inter-disciplinary research, where the combination, or fusion, of different knowledge bases and technologies creates new (or minerals-related applications for) enabling technologies

As they currently do, globalised minerals firms will need to constantly be searching for and applying new technologies and innovations that reduce costs and increase productivity, their future competitiveness depends on it. The forces shaping competitive advantage in the industry are similar to those of industries (and countries) that produce and export knowledge-based goods and services. However, recent changes in firms' strategy raise questions with regard to whether firms can sustain an internal absorptive capacity for the selection (possibly from organisations with which there is no tradition of doing business) and combination of different knowledge bases and technologies. The latter is of importance for collaborative programs of innovation. It is also unclear whether the culture of innovation previously embodied by firms, and related support for knowledge-networks and interactivity with research providers, will be sustained.

In summary, the findings in this Chapter suggest that the cohesiveness of the MinIS is currently being challenged by exogenous and endogenous sources of change. The industry's competitive dynamics are driving trends of industry consolidation and globalisation. In response, minerals firms are redesigning their technology and innovation strategies and reducing their internal capabilities for technological innovation. It appears that the MinIS is experiencing a contraction as well as a shift in capabilities, out of large firms and into small firms and the public sector. These changes present challenges which, along with commensurate opportunities for the MinIS, are discussed in Chapter 8.

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Chapter 8:

Conclusions and reflections

8.1 Introduction

This study aimed to identify and characterise an Australian minerals system of innovation and better understand the role of innovation therein. A primary motivation for this study was the fact that the minerals industry has been largely overlooked by both general innovation studies and, in particular, analyses of Australia's innovative performance. In light of the historic importance of the minerals industry in the Australian economy, the oversight is somewhat surprising and may also be damaging given the likelihood of missed opportunities for the capture and exploitation of positive innovation spill-overs from the industry.

This conclusion begins with a review of answers to research questions. This includes a discussion on how innovation in the industry is changing, and the challenges and opportunities facing the MinIS. The following section reflects upon the theoretical traditions and empirical method used in this thesis, in particular, application of the IS approach. The chapter ends with the implications this study has for the role of government in the MinIS.

8.2 A review of findings – the role of innovation in the minerals industry

8.2.1 Answers to the research questions

The purpose of this thesis was to explore the role of innovation in the minerals industry in Australia. The exploration was guided by a primary question and five supporting questions which are addressed below.

1) Does innovation play an important role in the minerals industry in Australia?

The simple answer to this primary research question is 'yes' – innovation does play an important role in the minerals industry in Australia. This study has shown that technological innovation is a long-term driver of increased productivity and competitiveness for minerals firms. At a fundamental level, competitive advantage and wealth production in the minerals industry are created through the cumulative development of knowledge and skills, and are not derived from simple geological endowment. The importance of innovation is best demonstrated by this study's main finding, that there is systemic minerals innovation in Australia. This minerals innovation system (MinIS) contains basic elements of innovation systems:[126]

- firm and non-firm organisations (such as universities, government research laboratories, financial institutions, central government, local authorities and non-government organisations) with different competencies, organisational structure, objectives, behaviours and roles;
- modes of interaction (both within and among organisations) such as collaborative research feature strongly in the MinIS;
- numerous knowledge bases and learning processes (depending upon the innovative or production activities involved);
- basic technologies, inputs and demand conditions;
- institutions (such as regulations, codes of behaviour, and standards) which shape interactions; and
- processes of change, selection, competition and transformation over time.

The Australian minerals industry has a history of significant innovative achievement that underpins the industry's success. Chapter 5 noted the advent of a capacity for technological innovation which dramatically augmented Australia's mineral reserves, and coincided with a transition toward professionalisation, industrialisation, and mining becoming a long-term, rational business. Until organisational and institutional innovation occurred to support Australian geological knowledge bases and an ethos of exploration, the industry's growth and development was stifled. The case study subunits in Chapter 6 profiled recent innovations occurring across the industry's activities. Well-developed relationships and interactions support access of agents within the MinIS to new technologies, sources of knowledge and support learning processes, as shown in Chapter 7. Chapters 6 and 7 reveal innovation in the minerals industry to be 'systematic' (discussed further below).

The findings of this study challenge commonly held views on the industry, particularly that it is neither innovative nor a participant in the knowledge economy. Other recent studies of the minerals industry (that use different theoretical and empirical approaches), have recorded similar conclusions regarding the role played by innovation in wealth creation from mineral resources (Tilton 2000, Tilton 2001, David and Wright 1996, David and Wright 1997). They also find that the role of innovation in the minerals industry has been poorly understood.

Continuity of the Australian minerals industry's innovativeness is by no means certain. Throughout its history the MinIS has received strong support from the private sector, a feature that makes the MinIS unusual in Australia. Recent private sector sources of change including

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[126] The elements highlighted here are based upon Malerba's definition of a sectoral system of innovation and production (Malerba 2002).

shifts in firm strategy, a reduction in the number of large Australian minerals firms, and the global competitive environment are a concern for the MinIS's future performance.

i) What role did innovation play in the development of Australia's minerals industry?

The historical level of analysis, contained in Chapter 5, demonstrated that innovation played a pivotal role in the development and transformation of Australia's minerals industry (see Table 8.1 for a summary of the key findings).

Table 8.1: Summary of findings from the first level of analysis

First level of Analysis	Subunits being Characterised	Main findings about the MinIS
1. Historical view of MinIS (1850s-1880s)	**shaping events**	**Domestically incomplete MinIS –** The reasons why the early MinIS was domestically incomplete can be linked to early shaping events. The developing NIS was influenced by a British culture of science and of mining which did not embrace developments in engineering sciences, including organisational innovations (technical schools & institutes) that supported closer interaction between industry and academia.
1880s-1910s	**Cyanide** **Flotation**	The early MinIS housed significant capabilities characteristic of the third TEP: industrialisation of R&D, science-based mining, professionally trained personnel (science of geology, transfer sciences mine and metallurgical engineering), and ultimately, capabilities for adaptation and diffusion of radical processing innovations (including state government incentives). These capabilities were primarily confined to the minerals industry and not distributed more broadly into the Australian NIS. The early MinIS was domestically incomplete, lacking the following: 1) universities to conduct research, education and training, and to provide Australian knowledge bases in geology and applied transfer sciences, 2) a nationally-driven agenda to develop tools for intelligent search and to coordinate knowledge-based exploitation of Australia's actual minerals endowment, 3) a buoyant set of expectations and belief in Australia's actual minerals endowment and a long-term Australian minerals industry.
1980s-1990s	**Diamond Sorters**	**Domestically complete MinIS –** Evidence was found to support the notion of a domestically complete MinIS by the mid-late 1980s. The MinIS housed capabilities for innovation among private and public sector constituents. Government laboratories and the tertiary sector were now active in minerals research, education and training. Close relations between these sectors was fostered by collaborative research (AMIRA formed in 1959) and industry-sponsored university research and training centers (JKMRC formed in 1970). These levels of interactivity seem to have created a 'balance' between the supply and demand dynamics for new technologies and knowledge between firms and non-firm research providers. The diamond sorters case study subunit showed that corporate strategy supported the internal development of new technologies with well-funded research programs and laboratories. A key enabling factor for this successful innovation was connectivity within the MinIS (the formal & informal knowledge networks among sources of expertise).

The early MinIS was shaped by Australia's status as an outpost of British 'culture' (with its attendant approaches to science and technology) and successive gold and silver booms that stimulated regional development. This was an inventive period when many basic elements of the MinIS developed, including minerals firms, systems of finance, law and basic education, as well as a body of experience in mining that was dominated by the so-called selective or Cornish method. A capacity for technological innovation and the non-selective or scientific method of mining developed from the late 1880s (as evidenced by the two examples of radical process innovation, cyanide and flotation) while the industry transformed, matured and began displaying characteristics of the third techno-economic paradigm (an era of industrialised R&D, scientific mining and professionalisation). This transition saw the introduction of new competencies particularly in firms, different organisational forms (such as, industrial research laboratories and government testing laboratories), new networks and new strategies for long-term planning and science-based mining. These indicate that innovation played a pivotal role in the development of the Australian minerals industry.

Other studies (such as (Burt 2000), although not specifically stating so, imply that innovation is not important in the minerals industry as early technological leadership did not translate into further growth, diversification and resource-led industrialisation. Indeed, following the first World War the industry lost a positive expectation of discovery and long-term growth, reinforced by a path-dependent cycle of negative reinforcement (poor policy, poor assessment of Australia's actual minerals endowment, industry stagnation and contraction). A comparative analysis with the western states of America[127] draws different conclusions about the reasons for Australia's failure to capitalise on its technological lead (and the role of innovation in the industry). Australia's early success with technological innovation was upheld by the international transfer of skilled professionals, and sources of knowledge developed in universities and schools of mines in the USA. Australia's early MinIS was domestically incomplete, lacking the organisational infrastructure associated with a tertiary sector and, more importantly, the fundamental learning processes and interactions between academia and industry that had evolved in America (Nelson 1988, Nelson 1990, Nelson 1993, Freeman and Soete 1997, David and Wright 1997, Todd 1995). A knowledge base incorporating an understanding of Australia's geological endowment could not simply be 'imported' into the MinIS. It had to be created from an Australian-directed basic research effort in geology, and related development of 'engineering' knowledge bases and exploratory technologies to reveal Australia's 'actual' as opposed to 'predicted' mineral endowment. Additionally, while state governments played an enabling role in the application of processing technology, there was no tradition of interaction between government science and industry for intelligent searching (like that in the USA), and an 'ethos of exploration' failed to develop in Australia. The MinIS locked into inferior learning processes and public policy with regard to geological surveying, at a time when the minerals industry's growth strategy was 'discovery-based.' Thus, Australia failed to move into a period of 'resource industrialisation,'[128] due substantially to path-dependent, systemic limitations within the MinIS.

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[127] This comparison relies upon David and Wright's ground-breaking analysis of 'America's resource abundance' (David and Wright 1996, David and Wright 1997).

[128] A process of economic industrialisation, diversification and growth derived from the full exploitation of minerals resources, found in the USA (Walker 2001).

Government attitude towards the minerals industry and its institutional framework changed decisively in the 1960s (for example, the iron ore embargo was lifted, and incentives to encourage exploration and mining infrastructure were introduced). Australia then experienced a 15-year minerals boom in which production increased, new companies were founded and expansion into new commodities took place. The MinIS had become more integrated and cohesive, particularly with regard to interactivity between government, the minerals R&D system and industry. By the 1980s, the MinIS had a public sector with a capacity to meet industry demands for knowledge and technologies, as well as skilled graduates. The coherence of the MinIS was enforced by firms with strong corporate knowledge bases, disembodied knowledge-networks (linking public and private knowledge bases) and strategies consistent with innovation-based growth (as illustrated in the Diamond Sorters case study subunit).

This analysis shows that a domestically and systematically complete MinIS was necessary to facilitate the exploitation of Australia's mineral resources. Growth and development of a minerals industry required access to enabling sources of knowledge and technology, demonstrating that this is a knowledge-based industry.

ii) What are the characteristics, nature and trends of innovation in minerals-related activities – exploration, extraction, processing and environment?

In Chapter 6 the role of innovation was explored by looking more closely at how it takes place in minerals-related activities. The findings from this second level of analysis are summarised in Table 8.2.

A recent trend in minerals innovation is the integration of previously separated knowledge and technologies, or so-called enabling technologies (mostly developed in other industries). Use of enabling technologies has contributed to a change in the dynamics of minerals innovation in a number of ways. Their use provides an effective strategy for increasing the competitiveness of existing minerals operations and activities without the need for radical change to methods and equipment. Conditions of demand for knowledge-based services and products has produced firms with new competencies and areas of specialisation in the technology services sector. Enabling technologies have induced intensification in innovation (described as 5th generation: systems integration and networking (SIN) (Rothwell 1994)), as minerals firms meet their requirements for new technologies through external strategic alliances, as opposed to centralised programs of technological development. Although currently poorly-defined, the Minerals Technology Services Sector is playing an increasing role in the supply of knowledge-based services to the industry.

Table 8.2: Summary of findings from the second level of analysis

Level of Analysis	Subunits being Characterised	Main findings about the MinIS
2. Nature of innovation for minerals activities		**MinIS with activity-based components –** Activity-based components within the MinIS have the following trends and characteristics:
Exploration	**ARIES** **Fractal**	*Exploration* – trend of transference of knowledge bases and knowledge workers from large into small companies (downsizing of large firm corporate exploration R&D); increasing importance of small DECs; lack of venture capital; incorporation of new enabling technologies; knowledge-intensive, high-risk and difficult; and the unchanged role of public research programs for the generation of new sources and combinations of knowledge.
Extraction	**Block Caving** **Mine to Mill**	*Extraction* – incremental nature of innovation driven by demand for improved productivity and safety; sophisticated use of enabling technologies (eg to integrate a 'whole of mine' approach); general responsiveness to industry demands; regional centres of excellence in education research and training, and increasingly international knowledge networks.
Processing	**HIsmelt**	*Processing* – the nature of processing innovation driven by incremental advances and continuous improvements to productivity and safety at existing operations; industry support for long-term collaborative research programs, and potential for new forms of competitive-collaboration; infrastructure includes regional centres of excellence in processing education, research and training; majority of large firms do not develop new radical processing technologies; enabling technologies (such as biotechnology) have revived interest in new processing methods and increased capabilities in simulation and modelling has been used to reduce the costs of experimental development.
Environment	**Ranger / Jabiluka**	*Environment* – driven by regulatory constraints, social demands, and long-term competitive advantage; tendency for a high degree of site-specific basic research; new forms of inter-firm consortia where environmental problems are shared; development of new centres for environmental research, education and training; and, a rise in knowledge-based environmental service providers, some of which have been spun-out from large firms.

iii) How do organisations and relationships in the minerals innovation system enable innovation?

The third level of analysis explores the connectivity that underpins innovation in the MinIS. A summary of key findings from this level of analysis is presented in Table 8.3.

A well-integrated, dynamic web of alliances among private research providers, universities, CSIRO, CRCs, DECs, high-tech service providers, equipment suppliers and contractors, government bureaus and agencies, as well as other minerals companies, underpins minerals innovation. Indeed, these cohesive networks and the high degree of connectivity among actors that support innovation in the MinIS, are seen as a source of competitive advantage and strength for the industry. This type of knowledge-based network is also of high value to the Australian NIS, particularly as minerals knowledge networks are becoming increasingly international. This is demonstrated by AMIRA's pursuit of global leadership in the management of pre-competitive collaborative research, and by internationalisation of research and education programs at the JKMRC.

Table 8.3: Summary of findings from the third level of analysis

Third level of Analysis	**Subunits being Characterised**	**Main findings about the MinIS**
3. Actors and their interactivity in the MinIS Mapping the structure		**MinIS –** The MinIS is well supported by firm and non-firm organisations that perform research, education and training. Connectivity among agents in the MinIS is supported by organisations that encourage collaboration and networking, such as AMIRA and CRCs. Many networks are internationalising, particularly through AMIRA.
Private sector	**Croesus**	*Minerals firms* – large and small firms are active in the MinIS. Small firms do not have internal corporate research programs but make wide use of external consultants and do some collaborative research. Large firms are externalising development of new technologies & innovation and are increasing their use of strategic alliances and collaborative research for capturing innovative needs. Firms are globalising and growing through mergers and acquisitions. This has reduced the number of large majority Australian owned firms in the MinIS.
	CRA-RTZ merger	
Public Sector*	**BHEI**	*Commonwealth government* – while some initiatives support the MinIS (such as the Broken Hill Exploration Initiative (BHEI)), the Government lacks a high-level, coordinated approach to supporting innovation in the industry. A traditional view of the industry has contributed to poor understanding and a lack of reference to minerals industry when articulating national goals.

* Details of Public sector and BHEI contained in Appendix 8.1

In Chapter 7, the role of firms in the MinIS was investigated with examples of innovation in a large and a small firm. Their strategies, maintenance of internal capabilities and associated relationships within the MinIS were examined (see CRA-RTZ Merger and Croesus case study subunits). Both types of firms source new knowledge, technologies, skills and expertise from the MinIS through a variety of mechanisms. They also create conditions of demand within the MinIS and assist the training of graduates and managers. While small innovative minerals firms are an important part of the mix of players in the MinIS, large firms have provided a critical role in supporting more extensive, diverse and longer-term programs of research within the MinIS. It is possible to identify 'corporate technology traditions' (Achilladelis et al. 1987, Achilladelis and Antonakis 2001) in firms such as CRA (direct reduction of iron), MIM (flotation cells), and BHP (steel coatings), where in-house expertise and past experience contribute to a high incidence of innovative success in a particular field. However, recent changes in corporate strategy, from 'production-based' to 'minerals-finance house,' along with rapid consolidation in the industry, suggests that the traditional role of large firms in sustaining the MinIS has diminished. Of particular concern are the massive cuts to expenditure on innovative activities. Some companies contend that the Australian research base will benefit from their new approach, as more of their innovative requirements are externally met. In light of the overall reduction of funds available for both internal and external research, it is hard to imagine that this will be the case.

iv) Why and how is innovation in the minerals industry currently changing?

Innovation systems, including the MinIS, exist in dynamic selection environments and evolve over time in response to exogenous and endogenous sources of change (McKelvey 1997, McKelvey and Orsenigo 2001, Malerba 2002). The way in which innovation takes place in the minerals industry has changed markedly since the late 1980s when firms performed a significant amount of in-house research, experimental development and new technology development in well equipped corporate research laboratories (see Chapter 5). Recent conditions in the global competitive environment for minerals (outlined in Chapter 4) are driving changes to the dynamics and patterns of innovation in the MinIS. These exogenous sources of change include the advent of the globalised knowledge economy, historically low commodity prices, a greatly reduced access to new sources of capital, and the need to meet new costs imposed by legislative and regulatory requirements relating to sustainable development. Australian minerals firms have not been isolated from these dynamics (Peterson et al. 2001), as recent rates of consolidation and amalgamation, changes in corporate strategy and associated cuts to research programs demonstrate.

In this competitive environment, the primary focus of corporate research is upon short-term, incremental improvements and extension of the life of existing operations and ore bodies. Leadership in creation and development of new knowledge and technologies for the long-term is of lesser importance. Technology strategies now favour notions of being a 'fast second' or 'fast follower' of new technology developments. However, minerals technology strategy needs to distinguish (and accommodate) those innovative activities in fields with strongly cumulative, firm-specific learning processes where it is advantageous to be a leader, from other innovative activities in fields without strong property rights, with fast, non-firm-specific learning where followers benefit by learning from the mistakes of leaders (Teece 1986). In other words, it may not be effective to be a follower in some fields of innovation. Accumulated competencies and firm-specific learning processes that are costly to develop (and difficult to transfer) are easily forfeited when firms downsize corporate laboratories and in-house innovative activities (Pavitt and Patel 1995, Teece and Pisano 1998). It is also wrong to assume that, when engaging with a technological frontier, the investment required to be a 'fast second' is vastly different from being 'first' (Levin et al. 1984, Levin et al. 1987). The effectiveness of the 'minerals-finance house' corporate strategy and accompanying change in technology strategy requires monitoring because their long-term viability is uncertain.

There appears to be a change in the role of technology-based service providers in the MinIS. The presence of service-providing firms is not new to the industry. It has been common for minerals firms to outsource activities that are not in an area of core competence (Quinn 1992). Today, however, these firms seem to have a bigger role in the development of new knowledge and technologies. Malerba says that:

> During the evolution of sectoral systems, change may occur in the technological and learning regimes and in the patterns of innovation. …a change in regimes may transform a Schumpeter Mark I pattern of innovative activities to Schumpeter Mark II. Or, in the presence of major knowledge, technological or market discontinuities, a Schumpeter Mark II pattern of innovative activities may be replaced by a Schumpeter Mark I. (Malerba 2002:258).

It may be that new types of competencies necessary for innovation in ICT-related and other enabling minerals technologies (along with opportunity conditions for these technologies), allowed entry of new knowledge-based firms into the minerals industry. The knowledge base of innovative activities in this field (and attendant capabilities and learning processes) seems to be located in specialised service provider firms and public research providers. The organisation of innovative activities in the technology services sector appears to be similar to Schumpeter Mark I models where entrepreneurs and new firms play a major role in innovative activities (Breschi and Malerba 1997, Breschi et al. 2000). However, a thorough investigation of the technology services sector is required to understand the dynamics of innovation in this component of the MinIS. Some key questions include: how do new firms come into being (are they emerging from minerals firms, research providers or unrelated industry sectors), do their organisational forms, strategies and competencies represent a drastic change in the MinIS, and how have relationships and networks integrated these new firms into the MinIS? A related question concerns the totality of capabilities in the MinIS and whether current changes are directing a contraction in the MinIS. For example, is the disappearance (through mergers and acquisitions) of many senior Australian minerals companies, which were active participants in the MinIS, in any way compensated by the emergence of new firms in the technology services sector and their role in the MinIS?

Globalisation of the mineral industry has important implications for the Australian MinIS. As Australian firms globalise, there is the potential for corporate research programs to be located elsewhere in the world. A national identity among diversified giants is increasingly difficult to identify. This holds ramifications for the location of corporate laboratories in newly merged multinational entities (this is usually in the so-called home country (Patel and Vega 1999, Cantwell and Janne 1999, Bas and Sierra 2002)). BHPbilliton is a case in point. Unlike the merged entity Rio Tinto (CRA-RTZ), it is unclear where BHPbilliton will locate its corporate research facilities and the majority of its innovative effort. It has been stated that national (and regional) innovation systems affect an ability to 'generate and exploit opportunity conditions' (Nelson 1993, Niosi et al. 2000, Lundvall 1992, Lundvall et al. 2002), and that globalisation makes national innovation systems more important (Archibugi and Michie 1997, Archibugi et al. 1999, de la Mothe and Paquet 1996). Less is known about the globalisation of industry sectors and its effect upon nationally-located sectoral innovation systems (Malerba 2002, Malerba and Orsenigo 1996, McKelvey and Orsenigo 2001). Given the historical underpinning of strong support from minerals firms, it can be said that a departure from their traditional types and levels of innovative effort will cause changes to the patterns and dynamics of innovation in the MinIS.

The reduction in the number of large innovative minerals firms may reduce the amount of available funding (and partners for collaborative research projects) for all types of innovation within the MinIS. However, this reduction also has the potential to adversely change conditions of demand (for new technologies) and competitive rivalry within the MinIS. Literature on national sources of competitiveness and innovation stress the importance of strong competition policy that favours technological progressiveness in large companies and discourages mega-merges (Pavitt and Patel 1995, Porter 1990, Sharp and Pavitt 1993). Pavitt and Patel (1995) found that the degree of competitive rivalry within a sector is more important for technological progressiveness and international competitiveness than firm size.

> …analysis of US patenting across 16 sectors by large companies based in Japan, the USA and Western Europe shows that sectoral technological advantage is significantly and positively associated with the number of large firms in all three regions, but with size only in Western Europe. (Pavitt and Patel 1995:325)

More empirical research is required on the dynamics of competitive rivalry and innovation in the minerals industry, particularly on how such dynamics are changing and whether public policy initiatives might encourage technological progressiveness in minerals firms.

v) What challenges and opportunities are facing the minerals system of innovation?

This study has found that the MinIS is experiencing a period of transition. As outlined in the previous question, minerals innovation is changing in a multi-dimensional manner. There have been significant changes to the traditional role of firms and level of innovative effort, demand conditions, geographical boundaries, competencies, types of knowledge and enabling technologies used to improve productivity and competitiveness, organisational structure, modes of interaction, and institutions (established practices, routines, laws). The pace of change in minerals innovation has intensified in recent years, after most of the field work for this study had been completed. With little evidence in the innovation systems literature of how these changes might affect innovation in the natural-resource based sectors, the following discussion contains a degree of speculation about the types of challenges and opportunities believed to be facing the MinIS.

Challenges facing the MinIS

In the current competitive environment, maintaining a well-functioning MinIS is a fundamental challenge. The minerals industry is knowledge-based. The MinIS has demonstrated instances of flexibility in accessing knowledge from outside of the country, and from industry sectors not traditionally associated with mining. The minerals industry is currently benefiting from knowledge largely generated in the now greatly downsized corporate R&D laboratories. As one minerals industry representative described:

> The effects of these cuts are not expected to show until the long term. Currently there is still a body of people around who have been through the system and while that body of knowledge remains, the company will float. But as people move on, if the knowledge base that was previously being developed through the big projects is no longer there, real negatives will come through. (Keran 1997 personal communication)

Many highly skilled and experienced research and exploration staff who have lost their positions in large firms are being re-employed as consultants or in small technology firms. It is worth noting that if these knowledge workers, and the small firms that employ them, do not maintain contact with a research environment in the MinIS, their skills base and competencies will ultimately become outdated and lost to the minerals industry. Times of economic downturn are often more acute for small innovators since they tend to have limited cash reserves and their technology development programs are often dependent upon support from large minerals firms. Thus a challenge for the MinIS is to create conditions that support a degree of continuity among innovative small firms, and stability of knowledge bases, during the down times.

It is ironic that as industry needs for increasingly sophisticated new technology become more important to productivity and competitive advantage, minerals firms are reducing their innovative effort and internal capacity for innovation. As stated previously, changes in technology strategy raise concerns regarding firms' internal learning processes and their ability to generate options and exploit opportunity conditions in the long-term. Many of those interviewed expressed concern that, in their efforts to gain short-term competitive advantage, support for the fundamental research base is being ignored, potentially damaging future research. Changes in corporate strategy also have an impact upon formal and informal institutions that enable industry-science bridging mechanisms and encourage interactivity among agents. A recent study of operational performance and the innovative effort in two Brazilian steel companies, USIMINAS and CSN in a late-industrialising context, highlights the inadequacy of short-term approaches to in-house learning processes and research. Findings suggest that the potential of increasing the market value of assets by US$630 million was lost to CSN due to an ineffective technological capability and knowledge accumulation path (Figueiredo 2002).

On a different note, it is not clear how changes in the MinIS might present challenges to Australia's NIS. It may be that as minerals firms globalise, aspects of the NIS become more critical for the MinIS. Some of these include the quality and range of public-sector research, support for mechanisms that encourage exploration and prospectivity, and public policy that encourages investment in innovative activities, competitive rivalry and technology progression.

Opportunities facing the MinIS

Australia and the MinIS, has the opportunity of becoming a global centre of technology competence (Meyer-Krahmer and Reger 1999) and expertise in minerals-related innovation, research, education and training. There has been a worldwide contraction in the area of mining research and education, making Australia a bastion of effective research in the minerals industry (Napier-Munn 1996, AMIRA 1997, Peterson et al. 2001, National Research Council 2002). Australian centres of excellence, such as the Julius Kruttschnitt Minerals Research Centre and the Ian Wark Research Institute, are already servicing global demands. Conversely, Australia's research base could suffer the same fate as that of minerals research and development elsewhere in the western world.

Globalisation also brings the opportunity of attracting investment in innovative activities by non-Australian minerals firms. There is great opportunity to be gained from extending effective and cohesive global networks. AMIRA has had increasing difficulty maintaining sponsorship of research projects with Australian companies. To meet this shortfall it has 'internationalised'. Forty-seven per cent of AMIRA's funding now comes from countries outside of Australia. The Australian MinIS benefits from this since 95 per cent of AMIRA's research projects are conducted in Australian research organisations.

Opportunities also exist from the development of new applications for enabling technologies. The incorporation of ICTs, in many forms, in the complex operation of the North Parkes block cave mine (see Chapter 6) is an example of the industry's willingness to seek out and apply enabling technologies. It also demonstrates the potential of these technologies in facilitating organisational innovation and transformation of work, seen in the integration of labour and machinery and the formation of specialist teams of skilled workers (remote-control operators) at North Parkes. The minerals industry's demand for specialist applications of enabling technology across all of its activities (exploration, extraction, processing and environment) has created a great deal of diversity in expertise, knowledge and technologies within the mining technology services sector (see Appendix 8). This diversity increases the potential for positive spill-overs, such as expansion of user-producer interaction and development of technology services for other industry sectors.

At a more fundamental level, new scientific discoveries and new fusions of scientific and technological knowledge (such as the ease with which genes and micro-organisms can now be manipulated), have already begun to offer significant possibilities for new waves of innovation in the minerals industry (bio-leaching and environmental restoration). It may be that greater opportunity for radical innovation, and changes to mining methods, lie with more prospective commodities such as mineral sands and magnesium.

The types of opportunities outlined here relate to an ability to generate and exploit opportunity conditions. This ability is dependent upon sustained performance of the MinIS.

8.3 Policy implications – the role of government

The importance of innovation in the Australian minerals industry has been poorly understood and perhaps for this reason, its potential role in Australia's future has been undervalued. This study has found a MinIS of inherent value to the industry and to Australian wealth creation. As a mature innovation system, the MinIS incorporates a heterogeneous mix of firms, a capable public research sector, a diverse array of knowledge bases, stable industry-science relationships, a culture with experience of the value of innovation, and organisations 'skilled in the art' of innovation. The intangible framework of formal and informal institutions within the MinIS is of high value, difficult to replicate and easily lost.

Perhaps the most significant implication from this study's findings is the need to think differently about this industry. This is a professional, knowledge-based industry with requirements for tertiary trained personnel, research and technology infrastructure, new scientific and technological knowledge bases, and technology-based services. Potentially the innovative elements and capabilities within the MinIS could launch Australia into high-growth, service sectors in areas such as environmental management, remote sensing, and development of software (for example, 3-D interactive interfacing, data mining and image processing). Mention has also been made of developing new innovative institutions in the area of *competitive* collaborative research. It is not possible to predict how support for the MinIS may lead to future positive spill-overs, such as new combinations of radical innovations, new knowledge networks, and new knowledge-based exports, only that a lack of support will hamper or even terminate the generation of knowledge-based options for future growth.

The IS perspective provides some guidance on the role of government in national innovation systems. Governments can create institutional conditions (rules of the game) and a competitive climate to enable innovation and improve the competitiveness of firms and countries (Freeman and Lundvall 1988, Freeman 1995, Freeman 2002, Lundvall 1992, Nelson 1993, Pavitt and Patel 1995, Niosi et al. 2000, Valery 1999) (see Chapters 1 and 3). Comparisons of sectoral patterns of innovation in different countries point to a role for government in supporting national innovation systems. It has been found that while a given industry sector has predominantly similar patterns of innovation that are somewhat invariant across countries (due to technology regimes, knowledge base, and learning processes), the ability to generate and exploit opportunity conditions varies considerably (Malerba and Orsenigo 1996, McKelvey and Orsenigo 2001). This is directly related to the presence and effectiveness of national innovation systems.

From this study's perspective, government has an important enabling role to play in the MinIS. The historical view of minerals innovation in Australia (see Chapter 5) clearly illustrates that industry proactivity and technological capability alone are insufficient for the transformation, development and growth of the industry. It also outlined how poorly-thought-out public policy can create vicious cycles that block innovation systems.

For government to play an effective role in the Australian MinIS, it must first expand and refine its understanding of the industry, and recognise the important role of innovation. The traditional view of the minerals industry, which is held by the current government, is neo-classical in its approach to the role of innovation. This view is that mineral resources only produce one-off windfall gains and mineral wealth is in no way created or augmented by innovation. Economic analysis has produced much to support this notion by focusing upon short-term, unpredictable boom and bust cycles in the development of mineral resources, rather than their cumulative impact over the longer term (Davis 1995). Definitions of high-tech and low-tech industries, (as used by the OECD, and based on levels of R&D expenditure as a percentage of sales), have also down-played the role of innovation in the minerals industry. As demonstrated by this study, an understanding of knowledge bases is critical to developing more sophisticated measures of innovation than the simple concepts of 'high' and 'low-tech.' Reference to the minerals industry as low-tech and low-innovation are dated and inappropriate; the industry is engaged with technologies of the fifth techno-economic paradigm (ICT, remote sensing, biotechnology). The effectiveness of government support is also constrained by its failure to regard the industry in its entirety (that is, official statistics segregate minerals activities into 'mining' and 'manufacturing' sectors, and omit the technology services sector). Clearly there is much more work to be done on the evaluation of this industry.

The government particularly needs to fully appreciate the role of the minerals industry in creating demand conditions for new knowledge and technologies. The minerals industry is not only reliant upon, but also an important *source* of innovation and a *user* of new technologies.

Fagerberg argues that a nation's long-term comparative advantage lies where its *rates of learning* are superior and where the *demands of its domestic users* are greater or more sophisticated than those of its competitor nations (Fagerberg 1995).[129] From this viewpoint, the minerals industry represents significant potential in contributing to Australian comparative advantage. It is unrealistic to expect that the Australian minerals industry would produce equivalent rates of diversification and growth as seen in those nations which supported this industry during the industrial revolution (David and Wright 1997, Walker 2001). However, it equally would be wrong to think that new types of spill-overs, diversification into new knowledge-based industries, and an Australian form of resource-industrialisation are not possible.

The global minerals industry is cycling through a very difficult period of intense competition. The Australian minerals industry, far from being isolated from such trends, has already lost ownership of its largest minerals firms and has effectively reduced the degree of competitive rivalry in the MinIS through mergers and acquisitions.[130] It should not be believed, however, that this marks the demise of the Australian MinIS. From a purely national perspective, for example, it may be possible to encourage the next generation of minerals firms, in new commodity groups and niche miners, to regain competitive rivalry and technological progression of the minerals sector in Australia. Furthermore, as demonstrated by the near collapse of the American copper industry in the 1980s (and its revival precipitated by radical process innovation), this industry is extremely resilient (Tilton and Landsberg 1999). However, in the current conditions there is a greater need for leadership by government in its enabling role within the MinIS. This will require a commitment by policy makers to support the MinIS in a strategic and systematic manner.

The Government's role in the MinIS, according to a 'narrow' definition of an innovation system (that is, those organisations and institutions that are directly involved in knowledge accumulation and dissemination, and are sources of innovation), was discussed in Chapter 7. Government bureaucracies also have a role in the 'broadly' defined innovation system:

> ...a much wider socio-economic system in which political and cultural influences as well as economic policies help to determine the scale, direction and relative success of all innovative activities. (Freeman 2002:194)

At a macro-level, institutional frameworks (taxation, environmental standards, land access and so forth) and complementarity among socio-economic components (finance, legal, educational, cultural) are important for minerals innovation. At the micro or sectoral level, government bureaus that do not have large internal laboratories still support the MinIS through the development of sector-specific institutions, assessment of industry performance, and development of policy (see Appendix 8). There is a need for advanced and long-term thinking by policy makers when developing policy instruments. The Commonwealth Government's position with regard to ratifying the Kyoto Protocol raises serious concerns in regard to stifling

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[129] Fagerberg employed econometric methods to confirm that the nature of the home market and user-producer relations were critical for growth (Fagerberg 1995).

[130] Pavitt and Patel found that the degree of competitive rivalry within a NIS is more important for technological progressiveness and international competitiveness than firm size (Pavitt and Patel 1995).

future growth of sustainable production of minerals (see Chapter 6 Section 6.5.4). Technological developments that reduce production of greenhouse gases, such as inert anode/wetted cathode processing for aluminium smelting and HIsmelt, are positive developments in this regard.[131] However, plenty of evidence warns of the consequences of protectionist policies in the knowledge economy:

> The persistent shortening of the product, innovation and technology life-cycles forecasts an intensification of competition between the leading world centres, and an increase in the speed at which the possible rise and fall of a centre may occur. If this is disregarded, industrial or regional centres of competence could become centres of core rigidities. This happened, for instance, under different premises in the past in the old steel and coal regions. (European Commission 1998:xvi)

That said, there are examples where Government's role in supporting and enabling the MinIS has been exemplary, as seen in the Broken Hill Exploration Initiative (BHEI) case study subunit in Appendix 8.1. It is well understood that bridging mechanisms that increase connectivity and shared learning process in any innovation system are key sources of competitiveness, particularly in this fifth wave of technological development (Lundvall 1992, Lundvall 1999, Fagerberg 1995, Niosi 2002, Figueiredo 2002, Malerba 2002). The BHEI provides a parochial example of an 'ethos of exploration' in the Australian MinIS, and the effectiveness of support for knowledge creation and dissemination through network promotion and facilitation of learning. Put simply, the initiative coordinated the formation of multi-disciplinary research teams to develop new geological technologies to survey the Broken Hill region. Following this the process of disseminating the resulting geological maps and data into the private sector was actively facilitated. Ultimately, the initiative succeeded in meeting its objective of increasing regional investment by boosting the prospectivity of this famous minerals district. Such initiatives in support of connectivity and learning processes need to be conducted on a much larger scale and across all of the industry's activities. The latter is particularly important in relation to maintaining user-producer relationships and access to scientific knowledge bases for the technology services sector. To some extent this is already occurring through Austmine and the Mining Technology Services Sector Action Agenda (see Appendix 8.1). This is exactly the type of intensely innovative and knowledge-based activity Australia needs to integrate with the knowledge economy. The Government's initiative here is welcome, although, as stated earlier, its efforts also need to be directed to gaining additional insight into the plight of the minerals industry in its current competitive environment and ultimately, to establishing a thorough understanding of the MinIS, with all its nuances, in Australia.

Other countries are reviewing the role of their minerals industries. Following a period of dramatic decline in the US Government's support for minerals-related R&D, including the demise of the US Bureau of Mines in 1996, efforts are now being made to revitalise Government support in the area. A recent report by the American National Academy of

[131] Geological sequestration of CO_2 is not included in this list as it does not reduce the production of greenhouse gas emissions. If successful, this technology will perpetuate production methods with high emissions of greenhouse gasses. A full discussion on this technology is beyond the scope of this thesis, and debate regarding its use is continuing. From the IS perspective of this thesis, the prioritisation of this

Sciences strongly recommends Government support for minerals R&D (The National Academy of Sciences 2002). The report justified Government investment in minerals R&D in pure economic terms. The Canadian Government has articulated a commitment to innovation in its minerals industry 'to remain the world's smartest resources developer, user and exporter' (Jaques 1999). This commitment includes initiatives such as raising community awareness of the industry and its importance under the 'Mining Matters' program, sending delegations of Canadian mining companies to Latin America and Japan, and committing C$60 million over five years to the 'GeoConnections' project to place Canada's geospatial data on the internet.

It would be an unfortunate repeat of history if the Australian Government did not take advantage of the opportunities before it. With changes in corporate strategies and government policies, Australia has the opportunity of becoming a global centre of expertise in minerals-related innovation, education and training. If leadership is not shown by government, and effective innovation strategies and policies are not developed, in this era of globalisation the opportunities will be taken up elsewhere.

8.4 Reflections upon the empirical approach

This was an exploratory case study, based upon an innovation systems theoretical framework, and application of an IS approach. As such, this study's contribution was weighted towards gathering an empirical body of knowledge on innovation in the Australian minerals industry. Some comments on the use of the IS approach and this study's method are given below. This thesis concludes with some thoughts on an agenda for future research.

8.4.1 Contribution to innovation research – use of the IS approach

The IS family of approaches, a new and developing area of research, is largely incomplete (Edquist 1997b, Montobbio 2001, Malerba 2002). The IS approach works well as an heuristic; uniting different theoretical traditions and concepts with a common language, and providing a conduit for different empirical analyses and case studies (Montobbio 2001). It provides broad guidelines for selecting the types of agents that comprise a system, including:

> ...all important economic, social, political, organisational, institutional and other factors that influence the development, diffusion and use of innovations (Edquist 1997a:14).

However, as Montobbio points out:

> ...what is interesting is not the 'system of innovation' in itself but rather the processes, links and interactions that it tries to label. (Montobbio 2001:3)

In other words, while the IS approach gives guidelines to what elements are in a system, it provides limited information about how that system actually works. The IS framework does not

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technology by government ahead of sustainable production and alternative energy is misguided and damaging.

provide testable archetypes of 'sets of links, relationships and interactions' that can be used to explain the differences in performance of sectors and nations. According to Malerba:

> While relevant progress has been done in identifying sectoral differences in the types of innovation and procduction, the kinds of agents, the sources of knowledge, the key dimensions of demand, the geographical boundaries and the presence of non-firm organisations, less advancement has concerned the extent and features of within-sector firms heterogeneity and the structure and change in the relationships among agents. (Malerba 2002:262)

The exploratory nature of this study meant that it was utilitarian in practice and not directed at making theoretical or conceptual advances to the IS approach. This study's contribution to this field was to identify how innovation takes place in the Australian minerals industry. A further contribution was in identifying a MinIS that proved to be innovative on a level far greater than was anticipated at the inception of this study.

This study's research design, where a synthesis of innovation theories and intellectual traditions were incorporated into distinct levels of analysis, may also be of use in future studies of innovation. The development of this research design aided the exploration of minerals innovation in a number of ways. First, as the IS approach draws upon a very diverse literature, the use of analytical lenses located each view of innovation to particular sets of theoretical traditions and concepts. Subsequently, benefit was derived from a final amalgamated view of an innovation system that is broad but focused. Second, as innovation in the minerals industry is under-researched, multiple analytical lenses provided a way of covering a number of alternative views in an efficient manner. Third, the design helped to capture an understanding of innovation from a group of individuals representing a broad spectrum of expertise within the MinIS. This type of qualitative measurement of innovative effort is particularly important in industries where process innovation, as opposed to product innovation, drives competitive advantage. The idea of combining a number of 'analytical lenses' in studies of innovation is not new (Marceau 1994, Edquist 1997a). This study, however, has extended and formalised this method. If further developed, this research design may offer a means of improving the empirical application of the IS approach.

There are a couple of comments to make regarding this study's findings, and relationships to national and sectoral innovation systems. As outlined in Chapter 1, the scene for this exploration of innovation was set by Australia's fragile NIS and the fact that minerals innovation has been overlooked. The MinIS seems to be a sectoral innovation system, with minerals firms that have innovative activities embedded at the national level, that is, firms' innovative efforts are affected by conditions in the NIS (such as, changes in government support for public research facilities, incentive mechanisms, or to other social systems). There is also some evidence to suggest that the bridging mechanisms and connectivity within the MinIS were created by industry-led demands, as opposed to conditions in the NIS favouring development of this type of interactivity. This study suggests that an understanding of the interaction and influences between the NIS, the MinIS and Australian growth and development is limited. Indeed, commonly held notions of how the minerals industry acts to undermine Australia's competitiveness seem naive.

8.4.2 Reflections on the method

Einstein once noted that 'everything should be made as simple as possible, but not simpler.' Achieving such a balance in this study of minerals innovation was difficult. At one extreme the IS approach requires detailed empirical data, but the reality, found at the other extreme, was an under-researched industry sector that is both vast and highly heterogeneous. Furthermore, the IS approach is not very helpful when determining what to exclude when examining an innovation system. There were also difficulties in matching this study's research method with a particular approach within the IS family.[132] As there was little previous research on minerals innovation in the IS literature, guidance was limited. The resulting approach incorporated elements of a national approach (where characteristic limitations of Australia's NIS served as a base for comparison with the MinIS) and a sectoral approach (where the primary focus was placed upon minerals firms and their innovative efforts).

The research design had to take these factors into account. The case study subunits captured gross, macro-level events and components of minerals innovation to amass a wealth of information on minerals innovation. However, this method did not work as well in detecting emerging developments, such as how enabling technologies and new sources of technology (developed outside the minerals industry) were being incorporated into the MinIS, and how they were changing the dynamics of minerals innovation. The research design did provide, however, a clear organisational framework for integration of the empirically derived information (that is, case study subunits) with respective levels of analysis. That said, there was a tendency for case study subunits to 'spill-over,' outside of their respective level of analysis. For example, the Block Caving subunit contained a lot of information on the implementation of externally sourced enabling technologies and the types of skills and management expertise required for this type of integrated technological innovation. The Mine to Mill subunit gave insight into the role of research providers as sources of innovation, while most of the case study subunits in the second level of analysis touched-on enabling technologies in the MinIS. This overlap is, to a degree, inherent to this type of qualitative research. However, it also raises the question of whether the research design may have been improved. It may have been better to have had more levels of analysis, for example, with a specific focus upon the 'building blocks' of innovation system (agents, knowledge bases and learning processes, technologies and demand conditions, mechanisms of interaction, institutions, evolution of processes of selection and competition) (Malerba 2002).

Perhaps these limitations in the research design are not surprising given the exploratory character of the study. It is not immediately clear what might have been done differently to improve this method, particularly given the iterative nature of this type of research. Fewer case study subunits, or a reduction in the breath of this study (confining it to a particular commodity group or to a few select companies) would have curtailed the ability to define an innovation system accurately. 'Meaningful' quantitative measures for assessing minerals innovation would

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132 The sectoral IS approach is the most underdeveloped in the IS family. However, a sectoral approach requires multi-dimensioned and detailed empirical evidence (multiple innovation case studies) (Malerba 2002, McKelvey and Orsenigo 2001) (see Chapter 3).

have made this study easier, and would assist future studies of industries that are process-based. Ultimately, this type of research is laborious and offers no guarantee of an outcome of consequence. In this case, however, the study design has worked well.

8.4.3 Future research agenda

A good start to developing an understanding of the minerals system of innovation has been accomplished, however there is a great deal more to be achieved. Indeed, more questions seem to be raised by this study than answered, particularly in terms of the long-term viability of the MinIS. A broad structure of the MinIS, for example, has been outlined but it is lacking detail on its workings and dynamics, particularly with regard to the extent and features of specific learning paths, absorptive capacities and innovativeness in minerals firms. Recent research centred on the balance between innovative and routine forms of learning, and the technology-accumulation paths of steelmaking firms (Figueiredo 2002). It would be worthwhile to study such aspects of learning in Australian minerals firms, particularly where firm-specific programs of technological development have failed. It would also be useful to develop international comparisons of 'corporate technology traditions' and determine whether an 'Australian style' of minerals innovation is supported in the MinIS. A comparison between the minerals innovation systems of other minerals nations, such as the USA, Chile, Norway, and South Africa and the competitiveness of minerals firms in these countries could prove valuable. This type of investigation would help to find out whether certain areas of Australian expertise or knowledge are in demand within the global minerals industry and could be promoted as centres of technology competence in minerals innovation.

A continuation of this study's effort to understand the minerals industry's contribution to competitiveness and knowledge-based growth in Australia, might include a closer look at the capacity for complex-project integration in the industry. In many respects, mining is a project-based enterprise in which minerals firms act as 'system integrators,' combining knowledge bases, technologies and technical expertise from other organisations during the development of new operations. Success involves considerable firm-specific capabilities in project management, the implementation of organisational and institutional change, as well as financial management. The NorthParkes' block caving mine is a good example of this type of enterprise. According to Gann, who has examined 'project-based service-enhanced' firms in the engineering and construction industry,

> ...these firms are only able to effectively harness and reproduce their technological capabilities by integrating project and business processes within the firm. (Gann and Salter 2000:955)

Research on the role of service providers and systems integrators in innovation systems may be a promising way to further develop this study's findings.

The innovation literature contains a great deal of information on the impact of globalisation on regional and national innovation systems (Archibugi and Michie 1997, Archibugi et al. 1999). However, research on the impact of globalisation of industry sectors is preliminary, with initial investigations finding that innovation systems are closely related to the ability of firms and sectors to exploit technological opportunities (Malerba and Orsenigo 1996, Breschi and Malerba 1997, Breschi et al. 2000, McKelvey and Orsenigo 2001). An interesting and critical issue in minerals innovation concerns the impact of globalisation and industry consolidation upon Australia's MinIS. For example, how does globalisation affect nationally-embedded sectoral systems, like the MinIS, particularly when large firms themselves are losing their national identity and reducing their innovative capabilities? More research needs to be done on how globalisation, with its attendant increase in innovation intensity, is affecting firm heterogeneity, and the structure and types of relationships within the MinIS.

It may also be worthwhile to revisit the role of successful exploitation of mineral endowment in shaping national economies. Despite the esoteric nature of this line of research, it could change the current view of a natural resource base as something from which to be 'liberated' (Edquist and Lundvall 1993, Niosi et al. 2000). Some new studies outside the innovation systems literature reveal that exploitation of a minerals resource is, contrary to the prevailing view in the IS literature, based upon innovation and knowledge-based capabilities (David and Wright 1996, David and Wright 1997, Tilton and Landsberg 1999). New research here should include the role of public policy.

Finally, as an impetus for future research, communicating these findings to a wider audience, including members of the minerals industry and government policy makers, might be useful.

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Appendix 2

List of those interviewed on a formal basis

Organisation	Name & Title at time of interview
Pasminco Limited	Tom Eadie – Executive GM Exploration & Technology
AMIRA	Joe Cucuzza – Team Leader Exploration, Minerals & Hydrocarbons
AMIRA	Allan Goode – Research Coordinator Exploration
AMIRA	Dick Davies – CEO
AMIRA	Jim May – retired Chairman
ACMER	Dr Clive Bell – Director
AGSO	Neil Williams – Executive Directory
AGSO	Dr Lynton Jaques –Chief Research Development Division
SRK Consulting	Dr Lynn Pryer - Consultant Geologist / Business Manager ACT
ALCOA Australia	Ivan Anich – Technical Manager WA Operations
SH Algie & Associates Pty Ltd	Dr Stephen Algie – Director
National Graduate School of Management (ANU)	David Karpin – Adjunct Professor
BHP	Cory Williams – Group Manager Strategic Planning
BHP	Garnett Hollier – Manager Technology Development
BHP	Murray Eagle – BHP Iron Ore
BHP	Allon Brent – Manager Strategic Technology
BHP	Dick Carter – former Executive General Manager & CEO BHP Minerals
BHP	John Burgess – Vice President Safety, Environment & Technology
BHP Iron Ore	Alan Bewsher –
BHP Iron Ore	Doug Bissell –
BHP Coal	John Toomey – retired GM BHP Coal
Gibson Crest Pty Ltd	Tony Kjar – Managing Director
North Limited	Richard Knight – Executive Director Development
INPUTS Pty Ltd	John Innes – Director
Croesus Mining N.L.	Ron Manners – Chairman
Croesus Mining N.L.	Michael Ivey – Managing Directory & CEO
Croesus Mining N.L.	Martin – Exploration Geologist
GK Williams CRC	David Narin – Director
CRC Mining Technology & Equipment	Prof Michael Hood – Director
Advanced Computational Systems CRC	Prof Darrell Williamson – CEO
CRC for Australian Mineral Exploration Technologies	Dr Brian Spies – Director
Hamersley Iron Pty Ltd	Noel Poetschka – Principal Metallurgist Resource Development
Hamersley Iron Pty Ltd	Terry Box – General Manager Resource Development
Hamersley Iron Pty Ltd	Malcolm Richmond – Managing Director Development (now retired)
JKMRC	Prof Tim Napier-Munn – Director
JKMRC	Andrew Scott – Manager Mining Research
JKMRC	Ron Morrison – Director JKTech
Sir James Foots Institute of Mineral Resources University of Queensland	Prof Don McKee – Director
Normandy Mining Limited	Ian Gould – Group Managing Director
Rio Tinto	Bruce Kelly – General Manager Technology Group
Rio Tinto	Ray Shaw – General Manager
Rio Tinto	Barry Cusack – Managing Director Rio Tinto Australia
Rio Tinto	Dr Robin Batterham –Vice President Research & Technology

Rio Tinto	Peter Hill – Advanced Technical Development Group
MIM	Peter Munro – Principal Engineer Metallurgy
MIM	Nick Stump – Managing Director
MIM Process Technologies	Grant Casley – General Manager MIM Process Technology
MIM	Paul Keran – Group Engineer Metallurgy
WMC	Rob La Nauze – Manager Technology Development
Noranda Ltd	Phillip Mackey _ Principal Scientist
HIsmelt Corporation Pty Ltd	Michael Buckley – Senior Process Engineer
HIsmelt Corporation Pty Ltd	Carolyn McCarthy – Principal Consultant Metallurgy
HIsmelt Corporation Pty Ltd	Peter Bates – General Manager Development
Victorian Chamber of Mines	Chris Fraser – Executive Director
The Chamber of Minerals and Energy of WA Inc	Ian Satchwell – CEO
Andersen Consulting	Dr Dan Evans – Associate Partner
Centre for International Economics	Dr Andrew Stoeckel – Executive Director
Dept Industry Science & Tourism	Peter Ferber – Assistant Director Minerals Section
Dept Industry Science & Tourism	Keith Crocker – Assistant Secretary Resource Processing Branch
Dept Industry Science & Tourism	Kevin Bryant –Director, Science and Technology Analysis
CSIRO Exploration & Mining	Dr John Huntington – Chief Research Scientist Group Leader Mineral Mapping Technologies
CSIRO Exploration & Mining	Dr Graham Carr – Research Group Leader Ore Deposit Processes Group
CSIRO Exploration & Mining / AGCRC	Dr Sie – Project Leader AUSTRALIS (Heavy Ion Analytical Facility)
CSIRO Exploration & Mining	Dr David Dekker – Mining Science Manager, Group Leader Automation
CSIRO Exploration & Mining	Dr Bruce Hobbs – Chief of Division
CSIRO Exploration & Mining	Dr Michael Gladwin – Research Group Manager Minescale Geophysics
CSIRO Mathematical & Information Sciences	Kevin Smith – Senior Principal Research Scientist, Interactive Modelling & Visualisation Systems
CSIRO Mathematical & Information Sciences	Duncan Stevenson – Interactive Modelling & Visualisation Systems
CSIRO Corporate Affairs	Garrett Upstill – Principal Adviser Planning
Applied Sorting Technologies Pty Ltd	Peter Hawkins – Director Technology
Applied Sorting Technologies Pty Ltd	Rodney Tamblyn – Directory Customer Service
Cutting Edge Technologies	Paul Maconochie –Senior Engineer
Cutting Edge Technologies	Ian Follington – Technical Director Geotechnical Design
Fractal Graphics Pty Ltd	Dr Nick Archibald – Director
ERA Ranger & Jabiluka	Greg Hill – General Manager Ranger
ERA Ranger & Jabiluka	Andrew Jackson - Manager Site Rehabilitation
ERA Ranger & Jabiluka	Renee Doyle – Environmental Officer Jabiluka
ERA Ranger & Jabiluka	Peter Lloyd – Project Manager Jabiluka
ERA Ranger & Jabiluka	Marty Knauth – Mine Engineer Ranger
ERISS – Environmental Research Institute of the Supervising Scientist	Paul Martin - Senior Professional Officer Environmental Radioactivity
ERISS – Environmental Research Institute of the Supervising Scientist	Chris Legras – Senior Professional Officer Environmental Chemistry
ERISS – Environmental Research Institute of the Supervising Scientist	Chris Humphry – Senior Research Scientist Biological Monitoring
ERISS – Environmental Research Institute of the Supervising Scientist	Rick Van Dan – Research Officer Risk Assessment and Restoration
Dept of Environment	Stuart Needham – Supervising Scientists for Alligator River Region
Placer Dome	Greg Hall – General Manager Exploration
Private Consultant	Mark Schapper – Retired CRA
Australian Petroleum CRC	Peter Cook - Director

Science Policy Research Unit	Dr Diana Hicks
Murdoch University	Dr John Phillimore Lecturer Institute for Science & Technology Policy
Australian Bureau of Statistics	John Ovington Assistant Director Innovation Statistics
Australian National University, Research School of Social Sciences	Linda Butler Research Evaluation & Policy Project

List of those 'interviewed' informally

Name	Associated organisation at time of meeting
Dr Graham Price	Australian Geodynamics CRC – Director
Dr Gill Bourke	Raw Materials Group – Mineral Economist
Terry Burgess	Delta Gold – Managing Director & CEO
Dr Ravi Anand	CRC Landscape Evolution & Mineral Exploration – Senior Principal Research Scientist
Nick Daws	World Geoscience Corporation Pty Ltd – Corporate Marketing Manager
Joseph Gutnick	Great Central Mines – Managing Director
Max Richards	Aberfoyel Resources – Director
Campbell Anderson	North Limited – Managing Director
Malcolm Broomhead	North Limited – Managing Director & CEO
Dr Greg Smith	The IP Factory – Director
Dr David Denham	Geoscience – Consultant
Robert Watts	BHP – Chief Scientist
Prof Michael Barber	University of Western Australia – Pro Vice-Chancellor (research & Innovation)
Sandy Lambert	Anglo Platinum – Manager Minerals Technology
Ian Scott	WMC – Manager Orebody Imaging
Lesley Crombie	WMC – Manager Information Services
Ian Lawrence	Strategic Technology Evaluation & Management – Managing Director
Bob Gunthorpe	Normandy Mining Limited – Group Chief Geologist
Mark Van Leuven	Normandy Mining Limited – Group Mining Engineer Technical
Roye Rutland	Australian Geodynamics CRC – Visiting Fellow
Prof Paul Robertson	University of Wollongong – Department of Management
Dr Manuel	CSIRO Thermal & Fluids Engineering – Business Development Manager
Yuji Tokumasu	Metal Mining Agency of Japan – Chief Representative Australia
Janet Elliott	Rio Tinto – Commercial Manager Office of Chief Technologist
Paul Roberts	Pasminco Group Geologist – Exploration
Rod Hill	CSIRO Minerals – Chief of Division
Malcolm Macpherson	Iluka Resources Limited – Managing Director
Julian Malnic	Nautilus Minerals Corporation – Chief Executive
Alan Broome	AUSTMINE - Chairman

Appendix 3.1:
More on Firms and innovations

Schumpterian models of economic growth are unconcerned with the origins or management of innovations at the micro- or firm-level (Freeman, 1994b, Freeman, 1990). Any deficiencies in this regard have certainly been compensated for subsequently and it is not possible to say that innovation in firms is a neglected area of research. Of course, theoretical and analytical advances in understanding of innovation in firms has co-evolved with similar developments in the previously mentioned fields of study, to a point where firms are the critical element in national and sectoral innovation systems.

Product-cycle

Original justifications for the product cycle model (Vernon, 1966) were developed at a time when innovation was viewed as a demand-led process (Schmookler, 1966). It was consequently hypothesised that MNC located their R&D activities in a single centre close to company headquarters where there were economies of scale, and close interaction between research, production facilities and demanding users. The 1970s grew a new literature[1] on the internationalisation of industrial R&D. During this decade innovations in MNCs became geographically dispersed, primarily as a consequence of the exploitation of domestic strengths abroad and associated novel demand conditions. Debate initially centred upon whether this was indeed a new trend (Mansfield et al., 1979) or not (Patel and Pavitt, 1991b). Other theories of technological competence in companies, combined with the cumulative, path-dependent and firm-specific characteristics of technological change, further stimulated this debate (Cantwell, 1994, Nelson, 1992, Dosi et al., 1992, Pavitt, 1992, Teece, 1988). Firms that were technological leaders would be most able to expand their technological activities internationally, to gain access, and adapt, to new markets (Cantwell and Andersen, 1996, Cantwell, 1999, Oerlemans et al., 2001).

Economic competence

A related factor called 'economic or business competence' is associated with technological systems and is said to be present when a technology system has 'the ability to identify, expand and exploit business opportunities' where those business opportunities arise from the effective use of new technology (Carlsson and Stankiewicz, 1991, Carlsson and Jacobsson, 1994). Furthermore, Carlsson says that, 'economic competence must be present in sufficient quantity and quality on the part of all relevant economic agents, users as well as suppliers, government agents, etc. in order for the technological system to function well,' (Carlsson, 1994:15).

Thus, Carlsson finds that firms can increase their potential for success from innovation, while concomitantly strengthening the technological system of which they are a part, by enhancing economic competence, as well as by increasing their R&D efforts, maintaining and extending networks or bridging institutions (see below), the timely articulation of requirements with the public sector to ensure a quick repose when needed and by widening their technology base (Carlsson, 1994:20). In regard to the latter criteria of an increasing technology base, research has shown that major corporations in the United States, Japan and Sweden do this, particularly by employing engineers with expertise outside their traditional technology base (Granstrand et

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[1] For a list of literature on 'new' internationalisation of industrial R&D see (Cantwell, 1999).

al., 1990). There are two major advantages gained from this strategy. The first is a greater preparedness and ability to cope with shifts in technology and new developments. The second is the more serendipitous advantage of being better equipped to take advantage of their own unanticipated research findings (Carlsson and Jacobsson, 1994).

Internationalisation of R&D

Much of the empirical analysis in this area converges on multinational enterprises (MNE) and their R&D programs as a means to indicate the impact of globalisation on technological innovation. Early research on diffusion found that technology tended to be developed at home and exported in products. This led to the implementation of international research programs to ensure products met local requirements. Later it was recognised that some industry sectors conducted R&D in multiple markets, particularly high-technology sectors (Vernon, 1966 & 1979; quoted in Dodgson, 2000:50).

Appendix 3.2:
A note on Michael Porter

Michael Porter – national competitive advantage

Porter (1990) accentuates the dynamic nature of competition, where clusters of firms play an active role in shaping their competitive environments. In a move away from Ricardo's notion of comparative advantage, Porter, while not abandoning the market, outlines conditions in which the forces of innovation and competition are stronger stimulants of competitive advantage and therefore, increased productivity and economic growth. In his book, *The Competitive Advantage of Nations*, Porter describes four major conditions, designed as an interactive 'diamond', which are the foundations of a nation's competitive advantage (Porter, 1990). These are:

factor conditions—a nation's existing endowment of resources and factors of production such as skilled labour, knowledge resources and infrastructure;

demand conditions—the home market's demand for the industry's product or service and the presence of demanding users;

related and supporting industries—presence of internationally competitive supplier and related industries; and

firm strategy, structure and rivalry—national conditions that influence how companies are created, organised and managed, as well as, the intensity of domestic rivalry.

The fitness of each factor in the diamond is dependent upon the state of the others, in a mutually-reinforcing fashion. Despite criticism of Porter, including his lack of distinction between firm's national and international interactions, his work remains highly influential (McKelvey, 1991).

Appendix 3.3:
Interactivity in Technological IS

When addressing the characteristics of technological systems, Carlsson (1994) points to several important factors which are required for successful and prolonged economic growth (Carlsson, 1994). The first is that only one actor, or a few competent actors, will not sustain a technological system. Rather, diversity is required with a variety of actors, each with their unique or specific competence. A technological system with a diversity of actors will not function to its full capacity unless the actors collaborate by fashioning *clusters* or *networks*. These communication links give the participants an advantage of carrying a reduced amount of risk with the onset of a new venture. Timely access to information and quick feedback mechanisms facilitate expeditious responses to problems and allow corrective action to be implemented as soon as it is required. The second characteristic which Carlsson notes is the role of *competent buyers,* where a buyer might represent industry or government. Further to this point he notes that long-term, close collaboration between buyers and suppliers is essential. The third characteristic is the continuing importance of competent local or domestic technological systems, even in the face of increased internationalisation, and despite the fact that links to technological systems in other countries, via for example, multinational companies may be considerable (*ibid*).

Research by Carlsson found *bridging institutions* were an important component of any technological system as they established relationships between otherwise disconnected actors, in particular between basic or academic research sourced locally or internationally and the users and suppliers in a system. In relation to this finding he says, 'While such institutions do not necessarily have to conduct original research themselves, they can help in early identification of new technologies, increasing awareness, providing testing facilities and training programs, thereby significantly speeding up the diffusion process (Carlsson, 1994:20).

Appendix 3.4:
Measuring the returns on investment in technological innovation – some approaches and their limitations

The social climate post World War Two, with transparent evidence that expenditure on R&D conferred military dominance, is perhaps another element which ensconced the technology push model. Freeman observes that at the time, 'Ideas, which before the War had seemed Utopian and visionary, now became acceptable,' (Freeman, 1992:175). During the thirty years following WWII a tenfold increase in expenditure on R&D occurred in most industrialised countries, from 0.1–0.3% to approximately 1–3% of GNP. Unlike the present day environment, it was legitimate for governments to play an extensive role in the support for R&D (*ibid*). Reports such as *Science the Endless Frontier*, by Vannevar Bush (1946), expounded upon the limitless supply of wealth to be derived from R&D and influenced the US government's decision to establish the National Science Foundation (NSF), as well as its support for university research (Freeman, 1992:175).

Measuring the economic returns from technological innovation

While there is no doubt that innovation is essential to the growth of industries and economies, measuring the contribution of technological innovation is not a simple matter (Freeman, 1994a). Technological innovation is not a discrete activity; it involves numerous dynamic interactions over lengthy periods of time. Therefore, measuring the relationship between economic growth and technological innovation with any degree of precision is fraught with methodological difficulties and data shortcomings. In spite of difficulties and limitations, many studies employing a variety of methodologies are directed at the relationship between technical innovation and economic performance (Martin and Slater, 1996). Governments and firms are driving this research as they no longer have 'faith' in the returns from basic research, and instead expect clear evidence of the economic and social benefit derived from investment in research. An important and comprehensive review of this literature was commissioned by the British Treasury (1996) and conducted by the Science Policy Research Unit (SPRU), at the University of Sussex. According to the SPRU review, *The Relationship Between Publicly Funded Basic Research and Economic Performance*, there are two main reasons for government support of research conducted in the public sector:

> According to the 'public good' argument, basic research yields economically useful information that can be used by firms to develop new products and processes. However, because of the inability of firms to capture all the benefits from basic research, firms tend to under-invest in basic research. To compensate for this, governments need to fund basic research. In a second view, scientific knowledge is seen as embedded in individuals and organisations, and the main benefits flow through training and networks. Public funding is needed to provide training and to maintain the nation's access to international networks, (Martin and Slater, 1996):vii.

Proxy indicators of innovation – R&D expenditure and number of patents

Rather than measuring innovation *per se*, proxy input and output measures of innovation, such as R&D expenditure, numbers of patents and publications, are commonly used (Rothwell and Zegveld, 1985, Freeman, 1995). While superficially these indicators may appear to be straightforward and reliable, there are problems with all of them. It is usual, for example, for R&D expenditure to be treated as a discrete unit of analysis, where in fact R&D encompasses basic research, applied research and experimental development activities. This treatment of R&D also neglects the division of labour and structural interdependencies that exists among organisations (universities, government research organisations and firms) in the emphasis placed upon R&D activities (Matthews, 1998). In the private sector, confusion exists over inclusion of activities such as design activities, software development and reverse engineering in R&D expenditure (Rothwell, 1994, Freeman, 1992). Although patents are an output measure of innovation, they are not used across all industries and nations have different IP legislation. Nonetheless, a combination of R&D expenditure and US patenting data is said to produce a plausible indicator of leading edge technological activities (Patel and Pavitt, 1991a). National R&D statistics were also embraced by organisations such as the OECD to make regular international comparisons of innovation, in particular leading to the development of the *Frascati Manual* (1963) and later an internationally comparative innovation survey, the *Oslo Manual* (Freeman, 1992). Nonetheless, national expenditure on R&D, usually expressed as a proportion of GDP, remains the most widely utilised indicator of innovation which in turn reinforces a simplistic interpretation of the innovation process, ie, that of technology push.

Econometrics

In an extensive review of econometric methods it was found that virtually all econometric studies measuring the degree to which basic research impacts upon productivity in general, detect a comparatively high rate of return (Martin and Slater, 1996). They are, however, generally plagued with 'measurement' and 'conceptual' problems. Nonetheless, a general consensus is that investments in R&D produce advantageous rates of return (as high as 100 to 120 per cent (Coe and Helpman, 1993)), with benefits more than compensating for costs. Benefits from innovation, however, do not usually accrue to the firm or organisation that undertakes the initial research. The effect of 'spillovers' means many econometric studies favour measurement of 'social' rather than 'private' rates of return. However, these studies note that capturing spillovers requires internal strength in basic research, as opposed to relying upon the importation of externally-generated information. From a national perspective, integrating basic research with postgraduate training was found to be an effective way of accruing benefits from spillovers, as this integration was deemed to enhance the linkage between technological development and basic research.

Surveys and case studies

Case study and survey methodologies define six main areas of economic gain from basic research (see Table A3.1). While the generation of 'new useful information' is the most often cited gain, only a comparatively small proportion is directly translated into new products and processes. The relative significance of the six forms of economic benefit varies across different fields of science, technology and industry. This means that it is impossible to trace the nature of economic benefits from basic research with one simple and all-inclusive model. Consequently, deriving an optimum structure for government support of basic research is extremely difficult (Martin and Slater, 1996).

Table A3.1: Economic benefits from basic research (in surveys and case studies)

1) new useful information
2) the creation of new instrumentation and methodologies
3) skills developed in the process of conducting basic research, especially in relation to graduate students who tend to mobilise codified and tacit knowledge
4) participation in basic research providing an 'entry ticket' into networks of experts and information
5) the fact that those trained in basic research are generally expert at solving complex technological problems, an ability especially beneficial for industry
6) the creation of 'spin-off' companies

Source: (Martin and Slater, 1996:viii)

A comprehensive study of American industrial R&D managers in seven manufacturing industries found the importance of recent basic research varied across sectors, with pharmaceuticals rating highest and oil refining lowest (Mansfield, 1991). Furthermore, eleven per cent of new products and nine per cent of new processes would have been retarded without input from academic research institutions. Placing any emphasis upon exact figures, such as the twenty-eight per cent rate of return determined by Mansfield, is unhelpful due to a reliance upon 'heroic' assumptions (Martin and Slater, 1996).

In sum, analysis of the economic benefits of innovative activities demonstrates that R&D expenditure and patenting are positively associated with increasing productivity and export growth. Indeed, with the advent of the 'knowledge economy', R&D-intensive products and knowledge-intensive services account for an increasing proportion of world trade. It may be that 'faith' in the benefits of investment in innovation will be restored as more economies expand their level of knowledge-based economic activity.

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Appendix 4.1:
Overview of government policy for minerals industry

Federal Policy

Prior to the 1960s, the minerals industry experienced a 'virtual policy vacuum', a position which favoured the development of an export industry but among other failings did not encourage domestic processing and value adding (Barnett 1988:131). New interest in the minerals sector developed from the 1970s, the broad trends of which are described below:

> Government policy towards the mining industry has undergone some evolution during the last two decades. In the Australian case, the comparatively laissez-faire policy of the 1960s (with specific fiscal incentives) gave way to a chauvinistic and distribution-oriented policy in the 1970s, to be followed more recently by a more rationally based, yet interventionist approach. (McKern 1988:10)

It is interesting to note that mineral resources are not specifically mentioned in the Australian Constitution. Barnett suggests that the founding fathers, with their desire to minimise Federal intervention, encouraged the Federal government to, 'pay less attention to the minerals industry than perhaps it should have done,' (Barnett 1988:131). Whatever the intention, the Constitution divides responsibility for the industry between Federal and State governments and both have sought to exercise control over the industry and have experienced periods of conflict (Lloyd 1984:6). It has also been suggested by Lloyd that the fundamental combination of public ownership of resources and infrastructure, with private ownership of mining companies exploiting those resources, is inherently prone to friction (*ibid*).

Apart from income taxation incentives introduced by the Chifley government in 1946, intervention at the Federal level began in earnest during the 1970s, a period when public awareness concerning issues such as foreign ownership and the economic and political role of multinational corporations was heightened (Bambrick 1979:21). The Liberal-Country Party coalition, which had held office since 1949, lost power in 1972 to the Whitlam-led Labour Party. The new government created the Minerals and Energy Portfolio, replacing the National Development Portfolio and appointed Rex Connor[1] as Minister. Over the following three years, the Whitlam government attempted to introduce, 'a program for rational development in the best interests of Australians,' (Whitlam 1985:262).

One of the important concerns for the government was described by Whitlam:

> ... the adequacy of the export prices was seriously affected by, first, combinations of overseas buyers presenting a united front to competing Australian suppliers, as happened with sales of iron ore and coal, and secondly, exports by foreign-owned companies on the basis of cost of production or some similar non-commercial basis. Such foreign groups had little concern in developing the processing of minerals in Australia. (Whitlam 1985:240)

In an attempt to ensure fair pricing for Australian minerals, export controls were introduced by amending the *Customs (Prohibited Exports) Regulation,* providing government with power to intervene in negotiations between Australian exporters and overseas purchasers. The government also took issue with the related issue of foreign ownership, which had become a political issue, with uranium mines requiring 100 per cent and all other minerals 50 per cent Australian ownership.

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[1] Descriptions of Rex Connor's ministry, its style, achievements and pitfalls are given in (Bambrick 1979:21-24) and in (Whitlam 1985:238-372). A combination of the two sources gives a balanced portrayal of events.

Connor commissioned T.M. Fitzgerald to prepare a report on *The Contribution of the Mineral Industry to Australian Welfare*[2]. The report's finding led to the abolition of taxation concessions (available under certain parts of the *Income Tax Assessment Act)*, which were being abused. The petroleum search subsidy was also revoked as it was believed to be an inefficient use of capital, with little reward for tax payers (Bambrick 1979). Connor supported government intervention in the exploration and development of Australian mineral resources and to this end attempted to establish the Petroleum and Minerals Authority (subsequently the *Petroleum and Minerals Authority Bill* was declared invalid by the High Court due to a technicality related to its passage through Parliament). Other initiatives which were not supported by Parliament, were the *Seas and Submerged Lands Act* which was designed to give the Federal government sovereignty over Australia's offshore regions, a program of loans to increase Australian ownership of resource development, and a plan to construct a transcontinental natural gas pipeline.

By 1974, Connor's dominance of the portfolio had diminished to some degree as exemplified by: the agreement between the government and the Japanese owned company Peko-E.Z. to jointly develop the Ranger uranium deposit; softening of the previously firm stance on foreign ownership, particularly in relation to exploration; and, a recognition that the new tax policies may have been too severe for a depressed industry, the matter of industry taxation being examined by the Industries Assistance Commission (Bambrick 1979).

According to Barnett, federal policy initiatives in the 1970s with the most pronounced effect were those in the area of price and market regulation and not those in the area of taxation, foreign ownership and investment. From this observation he concludes that, '...mineral companies, provided that they are permitted to earn profits that are internationally competitive, may not be as sensitive to socialist or nationalistic governments as is often believed,' (Barnett 1988:143).

The Fraser Liberal-National government removed export controls upon entering office in 1976. Two years later the deputy Prime Minister and Minister for Trade Resources, Doug Anthony, attempted to reinstate export controls on coal, iron ore, aluminium and bauxite. While he had the support of the NSW coal producers, other states such as Queensland and Western Australia were strongly opposed, and ultimately iron ore was exempt from export control pricing (Barnett 1988). Foreign ownership laws were relaxed. Uranium mines required only 75 per cent Australian ownership and foreign-owned companies with intentions of becoming 51 per cent Australian-owned, so called 'naturalising companies[3]', were allowed to invest in new projects (Barnett 1988, Lloyd 1984). The government did not overturn Labor Party legislation in relation to Aboriginal Land Rights or to environmental protection. In summary, the Liberal–National government policies saw a return to a more free-market ideology, although some of the more nationalistic policies remained.

Industry policy underwent a major shift away from an internal to a more outward-looking focus under the Hawke-Keating Labor government. A period of deregulation policies initiated this shift, with the floating of the Australian dollar in 1983, removal of foreign exchange controls and a phasing out of tariff protection[4] (Hart and Richardson 1993). The move towards a more competitive and international

[2] Australian Government Publishing Service, Canberra, may 1974, the report came to be known as the *Fitzgerald Report*.

[3] A company that had a minimum of 25 per cent Australian ownership, a majority of Australians on its board and with intentions to become at least 51 per cent Australian owned, was termed a naturalising company.

[4] This period of change is documented thoroughly in Kelly (1992), *The end of certainty* and in Kenwood (1995) *Australian Economic Institutions since Federation.*

Australian industry was supported by tripartite consultative mechanisms that delivered Ministerial advice and facilitated direct policy development in support of certain industry sectors. One initiative which emerged was the steel plan, the first of the so-called 'Button Plans[5], which tackled the threat by BHP to cease steel production in Australia. The plan encompassed a series of commitments from the major players; industry, the unions and the government. At its conclusion in 1988 the steel plan had delivered a doubling of productivity per employee and facilitated steel exports (DIST[6], 1990). Complementary to its position on deregulation, the Labor government loosened export controls and opened access for foreign investment in exploration (Kenwood 1995). While measures to encourage innovation were welcomed by the industry, uncertainty surrounding land access became the '...single biggest issue threatening the Australian mining industry,' (Champion de Crespigny 1994:13). The introduction of the Commonwealth's *Native Title Act* in 1993[7] exacerbated this situation as it was believed that land claims would further stifle exploration and investment in Australia (*ibid*).

The current Liberal-National coalition government came to power in 1996 with a commitment to increase the competitiveness of the Australian economy through macro and micro economic reform and smaller government. The minerals industry may have benefited from moves such as deregulation, the reform of industrial relations and moves away from support for minority groups such as the green movement, but it lost support with its funding cuts to higher education and training and the downgrading of support for innovation. Direct resource development initiatives under the Howard government have included the establishment of the Regional Minerals Program and a Project Facilitation Division within the Department of Primary Industries and Energy, both aimed at coordinating and streamlining bureaucratic procedures (Commonwealth Government 1997). More importantly, the Government has received support from the industry for the introduction of the *Native Title Amendment Bill 1997*. This legislation, commonly called the 'Ten Point Plan', aims to, '...achieve a workable framework for native title which respects the legitimate interests of indigenous people, restores certainty to land administration and facilitates the future development of the pastoral, mining and petroleum interests,' (*ibid*, p39). It is too soon to determine the impact of this amendment but the investment activity of Australian companies, particularly in the critical area of exploration, is low and an increased degree of certainty with regard to land access is necessary. A decrease in the funds made available for exploration in Australian companies has been combined with a trend to place such investments offshore (Richards 1994, Champion de Crespigny 1994). It is alarming to note that in 1995-96, 41 per cent of total investment in exploration by Australian companies was offshore, up from 38 per cent in 1994-95 and 27 per cent in 1991-92 (AMIRA 1997:18).

State policy

The states echoed the federal government, with their lack of interest in policy development for the mining industry during the 1960s and early 1970s. With the arrival of the resources boom in the 1970s and 1980s

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[5] John Button was the Minister for Industry, Technology and Commerce.

[6] As referenced in (Kenwood 1995:108).

[7] The intense debate concerning the introduction and subsequent ramifications of native title legislation for the mining industry is beyond the scope of this thesis. The mining industry concerns are presented in three papers in *The Mining Review*, 1993, Vol 17, no 2, pp10-20. These papers are titled, 'The Mabo judgement—the way ahead' by Laughlan McIntosh, 'The Mabo case: identifying legal and political implications' by Colin Howard, and 'Aboriginal land rights, sacred sites and resource development' by Warren Atkinson.

their position became more proactive. While not becoming directly involved in the marketing or planned development of minerals, the states were pro-development and in favour of private ownership[8].

As mentioned above, the states increased the amount of rent from royalties[9] levied at the industry following the Federal government's constraint on their borrowings in the late 1970s (see Table A2). During the seventies, net taxes and royalties paid by the industry increased by 340 per cent, a trend not shared by Australian industry as a whole (Barnett 1988:143). The states differ in their ability to maximise rent from royalties per unit of production, however, there has been a general trend towards increasingly sophisticated policy instruments in this area (Galligan et al. 1988). States may also trade-off rent in order to attract development, however, mines are fundamentally tied to a deposit and thus the notion that horizontal competition between states decreases returns to the public from mining is more relevant to the 'footloose' smelting and refining or manufacturing industries (*ibid*, p226).

Table A4.1: Royalties collected by states, territory and the Commonwealth 1978-79 to 1983-4 ($m)

Government	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84
NSW	35.9	86.9	116.7	88.2	105.4	110.1
Vic	60.1	90.6	118.6	108.8	124.9	180.6
Qld	53.6	73.5	73.3	81.4	89.7	107.6
SA	4.5	5.9	7.3	8.8	9.3	14.2
WA	57.8	66.7	78.3	81.3	102.5	179.4
Tas	2.2	5.3	3.6	2.2	2.1	2.2
NT	1.3	2.6	5.7	3.0	2.9	4.0
Total[1] States & Territory	**215.4**	**331.4**	**403.4**	**373.7**	**436.8**	**598.9**
Commonwealth[2]	28.0	43.3	57.3	56.6	73.3	89.9
Total[1] Australia	**243.5**	**374.7**	**460.8**	**430.3**	**510.1**	**688.7**
Commonwealth share (per cent)	11.5	11.6	12.4	13.1	14.4	13.1

[1] Totals do not add up due to rounding. [2] Does not include Bass Strait and petroleum levy.
Source: Galligan et al, (1988) in *Comparative State Policies*, p220.

Infrastructure policies have been extremely important for states wishing to encourage growth in mining activity, and thereby contribute to regional economic growth. An examination of policy development in the area reveals a complex relationship between state governments and resource companies, which can not easily be explained[10]. States with similar ore deposits, such as coal deposits in Queensland and NSW, have adopted different approaches to the implementation of policy. Policy development does not conform to party lines. Infrastructure policy development in 'conservative' Queensland, for example, has been 'toughest' involving the highest degree of government intervention in planning and control, with industry bearing most of the cost of development. Such an approach is more typical of Labor and rather than conservative governments (Galligan et al. 1988). According to Galligan, it is not even necessarily true that states whose economy is most dependent upon mining apply the most favourable policies for resource companies. For example, states which have not been active in recent resource development, such as Tasmania and South Australia, may be prepared to woo industry development with the use of public

[8] With the exception of the electricity sector where the States have taken a direct active interest.
[9] There are three distinct types of royalties employed by the States: unit, *ad valorem* and profit-based royalties. Unit royalties apply to a 'volume of production basis', ie, cents per tonne of ore produced. *Ad valorem* royalties refer to 'ex-mine' or free-on-board (fob) revenue. Profit-based royalties can be scaled to collect proportions of the pre-tax profits of the company operating a mine. These royalties may be instituted in different combinations in order to maximise returns to the States. See Galligan *et al* (1988) p219-226 for a detailed account of the differing usage of royalties by the States.
[10] Refer to Galligan *et al* for annotation on individual state infrastructure policy.

funds, in order to benefit from future resource booms. If the resources sector does make a visible contribution to a state economy, more pressure to 'drive a hard bargain' may apply. Furthermore, states well endowed with resources may not have comparable financial resources to subsidise their exploitation, as is the case in the Northern Territory (*ibid*).

In Barnett's opinion, state governments have been more dedicated to the further processing of minerals than the Federal government (Barnett 1988). While this may be thought of as beneficial to the mining industry, state governments are prone to decision making which does not consider long-term economic and market factors (Industry Commission 1991, Lloyd 1984, Champion de Crespigny 1994). BHP developed a blast furnace in Western Australia and steel mill in South Australia when threatened with losing lease extensions in these states. These developments went against the global trend of large, concentrated processing plants and caused loss in BHP international competitiveness (IAC[11], 1979). The Industry Commission's report, *Mining and Minerals Processing in Australia*, reports that regulations imposed by state governments, 'represent a major impediment to the efficient development of mining and minerals processing activities in Australia,' (Industry Commission 1991:pxxxiv). In particular, the report highlights a lack of coordinated and consistent policy within a state and between different jurisdictions. Outmoded regulations were also said to impinge upon the ability of companies to adapt to changing conditions and provoke inefficiencies in the industry. While it was noted that some states had addressed such problems, it stressed that there was a broad scope and urgent need for advancement. In particular the Commission recommended that:

> ... State/Territory governments review their Mining Acts to take account of advances in technology, to limit the scope for discretion, and to modify those provisions which currently induce inefficiency (eg expenditure conditions). Consideration should also be given to some form of co-ordinated review of Mining Acts to promote consistency between States/Territories where this would be in the interests of the nation as a whole. (Industry Commission 1991:pxxxv)

In summary, industry sentiment regarding support from government continues to be negative (personal observation). It is widely felt that governments do not appreciate the complexities involved in managing mine developments or the contribution the industry makes to Australia and that, in spite of recommendations generated from numerous inquiries, little headway has been made in the development of policy (Kjar 1997). Additionally, moves towards increasing globalisation are expected to erode the authority governments currently believe they hold over the industry.

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Appendix 7

Appendix 7.1: Julius Kruttschnitt Mineral Research Centre

Mount Isa Mines led the way in industry support for education when it provided a foundation grant to the University of Queensland for the establishment of the Julius Kruttschnitt Minerals Research Centre (JKMRC) in 1970. JKMRC was created to undertake:

- industry funded, collaborative projects
- projects with direct application to improving operations
- experimental research to be conducted in the field upon operating mines
- research into and development of computer modelling and simulation
- training of postgraduate students (Batterham 2000:18, Commonwealth Government 2001)

This approach was established by the AMIRA P9 Mineral Processing project. P9 provided the foundation upon which the JKMRC's technical focus in modelling and simulation of comminution, and its relationship with AMIRA and industry were based. Three significant expansions of the Centre that grew from P9 included: coal preparation research in 1974; blasting research in 1977 which has continued to evolve into a new portfolio of mining research topics; and, JKTech in 1986 which houses the Centre's consulting and commercial software development activities (*ibid.*).

Research conducted at the JK Centre broadly covers the following topics: mining research; mine to mill research; mineral processing research; titanium minerals research; image analysis for mineral processing; and coal preparation research. Outstanding outcomes from the JK Centre's research program include advances in flotation technology and the 'mine to mill' concept (see relevant case studies).

The Centre's director, Professor Tim Napier-Munn, once described the JKMRC as, 'a contract research and consulting outfit that happens to use post-graduate students as part of the workforce,' (personal communication 1997). The Centre has a twofold mission:

- Postgraduate training for the minerals industry; and,
- Production of useful and effective R&D for the minerals industry (Napier-Munn 1989).

Postgraduates conduct a significant proportion of their research at mines and processing plants belonging to companies sponsoring their research. Thus, students become 'industry literate' due to their exposure to industry and gain practical experience in technology transfer. Centre staff are employed on short-term contracts without the security of tenure. They undertake regular University staff duties as well as an extensive component of industry liaison activities required to locate industry support and to deliver research outcomes.

The Centre is largely self funding with university recurrent funding amounting to less than 5 per cent of the Centre's total budget. Competitive funding makes up the majority of the Centre's funding and is sourced primarily from industry, JKTech and government agencies. Ten years ago, 75 per cent of the Centre's industry funding was managed through AMIRA. This proportion, however, has declined to around 30 per cent.

Following the industry trend towards more global operations, the JKMRC recently experienced a dramatic increase in the volume of activities sourced from outside Australia. In 1996, 20 per cent of the JKMRC's revenue was sourced from international projects and this market grew by one-third in 1998 to over 30 per cent of an expanded revenue base (JKMRC 1999, JKMRC 1996).

The Centre also responded to changes in its operating environment by implementing a strategic plan which had been conducted in 1997. Changes include restructuring the Centre into five operating programs. This involved the establishment of a new commercial program, JKProducts, and the formalisation of the Centre's education programs through the Sir James Foots Institute located on the University campus. Another development was the creation of a JKMRC Board to replace the Policy Committee which had fulfilled an advisory role since the Centre's establishment.

In a review of university research for the minerals industry, the JKMRC is described as an entrepreneurial research unit (Napier-Munn 1996). Such university-based units are characterised by a dominance of contract funding and their expertise in networking effectively with industry to deliver commercially viable research results. The early development of such an entrepreneurial research unit in the minerals industry indicates a level of maturity in the relationship between the minerals industry and the private sector that is uncommon across the Australian private sector in general.

Appendix 7.2: Strategic planning at CSIRO

Government laboratories – CSIRO

CSIRO (Commonwealth Scientific and Industrial Research Organisation) was established in 1926, primarily to support the agricultural industry. Currently it is one of Asia-Pacific's largest public sector research organisations and has expertise in 22 market sectors.

Commonwealth support for CSIRO in accrual terms is forecast to be $604 million, or 15 per cent of the Commonwealth's support for science and innovation, in 1999-2000 (Commonwealth Government 1999). A further $267 million is expected to be earned from external sources. External earnings targets of 30 per cent were set for CSIRO in August 1998, to facilitate a more commercial approach, closer interaction with industry and reduced government spending.

Government demands, coupled with those of industry and community, in combination with external economic change and globalisation, have created a new agenda for CSIRO. Excellence in research must now be complemented by a closer alignment of, and linkages between, CSIRO's strategic research portfolio and the market at large, as well as excellence in technology transfer and exploitation of results. To meet these expectations CSIRO needs to change its established culture and the way it interacts with its external environment (Upstill 1998).

In an effort to align industry needs with research priorities, CSIRO has adopted a sector-based planning process. The use of a matrix devised from 23 discipline-based divisions of CSIRO and the 22 market sectors that CSIRO serves, clearly mapped the intersection of scientific expertise and markets. In some cases scientific expertise in different divisions was relevant to a single market, which meant that cross-divisional, multi-disciplinary research teams were appropriate. Each sector is also represented by an external advisory committee comprised of members from companies, State and Commonwealth government and industry organisations. The committees allow industry and stakeholder input into the broad direction of CSIRO's research.

CSIRO has also implemented a sector-based process for the allocation of corporate resources. Individual sectors, the CSIRO executive and relevant Divisions partake in an iterative, triennial review of funding alternatives in order to obtain the best possible funding regime (CSIRO Australia 1997).

Appendix 7.3: Additional details regarding the CRC Program

CRC Program

Core participants in a CRC enter a seven-year collaborative research contract and represent either the 'research provider' or 'research user'. Research providers in a CRC must include: one or more universities; and any combination of Commonwealth research organisations such as CSIRO and AGSO; State organisations; and private sector research organisations. Research 'users' may include: government departments; utilities; Government Business Enterprises (GBEs); industry associations, such as AMIRA: and private companies. All participants in a CRC provide cash or in-kind contributions. The average breakdown of resources is: universities 23 per cent; industry 17 per cent; CSIRO 14 per cent; other Commonwealth organisations 5 per cent; and, State government organisations 9 per cent. The CRC program provides less than 30 per cent of the total funding/resources for all of the CRCs and varies from providing 16-49 per cent of an individual CRC's resources (Mercer and Stocker 1998). Industry support for CRCs has increased from 12 per cent for the first round CRCs, established in 1991, to 25 per cent for fifth round CRCs, established in 1998. Each CRC has a Director, a governing Board and independent chair. The CRC Secretariat monitors the progress of CRCs through reviews conducted every third and fifth year. A CRC may apply for a second round of funding but must compete with new applicants.

There is no doubt that CRCs address a weakness in Australia's innovation system, namely, the lack industry's support for innovation *per se* and lack of a platform upon which to grow such support. Among other benefits, CRCs provide education and training for researchers and establish a critical mass of expertise around each Centre. Some controversy exists, however, with regard to the overall success of the program, particularly as CRCs were originally intended to become self-funding and the vast majority of Centres remain unincorporated.

Controversy surrounded the Program in the mid-to-late 1990s regarding its overall success. This was because the CRCs were originally intended to become self-funding and at this point the vast majority of Centres remained unincorporated. The program was first reviewed in 1995 by a committee led by Sir Rupert Myers. The Committee's report, *Changing the Research Culture*, supported the continuation of the program and noted that the major impacts of the program would not be evident for some years. The 1997 'Mortimer Review' was far more critical of the Program, recommending that Commonwealth funding be reduced from $140 million per annum to $20 million per annum. This report took the rather limited view that CRCs were a business incentive program where public funds inappropriately supported private companies. This review's conclusions must now be seen as premature if the Program were going to achieve the ultimate goal of 'changing cultures of both industry and research sectors to embrace collaboration'. By comparison, a recent analysis of the Commonwealth's funding commitment to the CRC program found that 86 per cent of Commonwealth funding was allocated to 'government services', that is university departments and State and Commonwealth organisations (Matthews and Howard 2000). Nevertheless, the Mortimer Review triggered strong dissent and ultimately culminated in 'the Stocker Review', entitled *Review of greater commercialisation and self funding in the Cooperative Research Centres Program.* The latter review strongly advocates support of the program, particularly at a time when advanced economies are looking to develop such bridging mechanisms and when, 'There is no evidence that other international approaches are likely to be more effective in Australia than is the CRC Program,' (Mercer and Stocker 1998,p iii).

In contrast, the recommendation by the Chief Scientist's review of Australia's Science Engineering and Technology (SET) base to 'expand the CRC program to encourage greater SME access and to facilitate stronger networks between the SET base and industry, nationally and internationally', was endorsed with an 80 per cent boost in funding for the program over five years at a cost of $227 million (Batterham 2000:18, Commonwealth Government 2001). In future, larger CRCs are to be established with greater flexibility for access by SMEs.

Appendix 7.4: Changes in corporate technology strategy and organisation of R&D.

Key changes in technology strategy

Technology leader to follower

Globalisation has dramatically increased the global flow of information, and superior technology is no longer a monopoly of a few nations, let alone individual companies. In the current environment companies are recognising that a competitive advantage can be gained, not only from the ownership of technology *per se*, but also from how well a company develops and manages its technology portfolio. Research-based improvements are being scrutinised against their cost of development and in many areas companies are adopting a 'fast follower' mentality and culture as opposed to the tradition of 'technology development'. As we have seen, exploration is an area where many of the large minerals houses believe investments have not delivered a suitable return and that smaller, niche market exploration companies are better placed to develop new exploration technologies.

Technology outsourcing

A move away from in-house technological competencies imposes considerable challenges and risks for companies. The success of such an outsourcing strategy demands a company knowledge base in order to scan the global scope of technical developments, select the most appropriate technology and successfully incorporate it into the company's operations. According to one senior manager, once companies scale down their internal technology development there is a tendency to lose the people with the skills to select, apply and adapt the best technology for various situations. Consequently the databank of technology intelligence or technological capacity within a company is undermined.

Incrementalism

In conjunction with the identification of particular areas in which to be a 'follower', companies are looking to gain the maximum degree of leverage from an investment in technology. As we have seen, revolutionary or major step changes are extremely costly and difficult. Many companies now believe that greater productivity can be gained from incremental improvements to processes or from paying more attention to the 'mine to mill' concept (see case study). Incremental improvements are also more easily united with the shorter-term focus on returns (Kjar 1997).

Technology transfer

A final issue, fundamental to innovation, is the success of technology transfer. Researchers in both the public and private arena interviewed for this study shared a concern about this issue. When a company's technology strategy relies on outsourcing, its ability to effectively transfer new technologies or innovations is of paramount importance and requires internal expertise which in many cases has been lost. Research providers complain that companies are looking to increase their outsourcing without understanding the costs of doing so and that many managers do not understand technology and are undermining its application within the industry. Equally, many companies recognise their slow pace and limited ability when it comes to effective technology transfer throughout their operations. It was often stated that they simply were not 'ready' for the changes to their operating habits and for the introduction of new methodologies and technologies.

These features of changing technology strategy are part of the general shift, described earlier, of the industry moving from the era of R&D-integrated minerals companies to the dynamic minerals innovation complex. Such changes are not peculiar to the minerals industry, and are characteristic of a diverse range of industries and technologies such as electronics and new materials. Such industries are also confronting the challenge the minerals industry is facing in the organisation of R&D.

Changing R&D organisation

R&D activities in the minerals industry are being affected by the pressures of budget cuts, short-termism and decentralisation.

Budget Cuts

In difficult economic times expenditure on R&D is often viewed upon as a cost which must be reduced. In keeping with the tighter margins in which companies are currently working, both corporate and on-site internal research units have been subjected to cut-backs.

MIM used to spend in the order of $10 million per annum on R&D through its central research group, and through this expenditure successfully developed Isasmelt technology. However, support for research had halved by 1998. The effect of such cuts is profound:

> The effect of these cuts is not expected to show until the long term. Currently there is still a body of people around who have been through the system and while that body of knowledge remains, the company will float. But as people move on, if the knowledge base that was previously being developed through the big projects is no longer there, real negatives will come through. (Keran interview, 8.12.97)

According to Jim May (CEO of AMIRA 1968-94), one of the concerns associated with downsizing internal research capabilities is the loss of corporate technical knowledge and innovative culture, 'it takes decades to build that culture up and it can be destroyed overnight.'

Decentralisation

In-house or corporate research units that conduct competitive R&D are an important institution for minerals research, although they have undergone significant change in the past five years. Major companies have, in the past, committed vast resources to developing and maintaining core technology competencies as well as to developing new technology (see Argyle case study). A healthy corporate research unit was a key element in a company's research strategy because it was believed to produce competitive advantages. Corporate research units were championed by senior management, and protected from having to compete for funding.

Corporate research laboratories were dramatically downsized in the mid to late 1990s, and often responsibility for R&D matters was devolved to mine sites or business units. While the units may still receive a proportion of support from centralised sources, a proportion of their funding may also have to be obtained from business units. The match between research groups and business unit culture, however, is not comfortable. It has been suggested that a research culture is not present in business units, as, according to one observer, 'There only has to be a problem with the price of commodities and pressure comes straight to the mine manager from head office to meet the budget. Generally the first thing to be cut is R&D, followed by the biscuits'. Business units and operations are currently focused upon increasing productivity, reducing costs, industrial relations and other short-term, profitability related issues. Research providers and brokers are concerned that the increased influence of business units is causing companies to move away from research that is scientific and not related to their core business, encouraging short-term, low-risk research.

The possible implications of these changes are described by Kjar:

> With the current improvement emphasis based on cost reduction the amount of discretionary spending on improvements available to front line managers has declined dramatically. This is slowing down the company led improvement cycle and making it more difficult for these managers to sponsor projects that could make a large step improvement in their operations. ... Under these circumstances it should not be surprising that the good intentions and concerns of more CEOs on achieving world class performance in safety, environment and technical innovation is not being reflected in proactive actions by subordinates two or three stratum below. (Kjar 1997, p5).

Short-termism

The combined result from factors such as globalisation and increased pressures on costs (which focus on shareholder value and the devolution of responsibility for R&D-related decision making to business units) has resulted in minerals-sponsored research programs moving towards a shorter-term nature. This is a global trend (Batterham and Shaw 1998).

Another external economic factor placing pressure on the industry has been the advent of a low inflation environment. When inflation is high, price increases can compensate for unprofitable decisions. While the industry does have the capacity to think in the long term, as demonstrated by the fact that it may take 15-20 years to develop a mine, the pressure of low inflation tends to foster decision making and investment for the short term. In particular, the industry's attitude to investment in R&D and exploration is adversely affected by this situation, as projects which do not have immediate returns tend to be aborted (Kjar 1997). There is a danger for the industry, according to some of its members, to slip further into short-termism, adversely effecting its longer-term health.

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Appendix 8.1: Additional detail on the Commonwealth Government's activities in the MinIS

This Appendix is a brief review of the role of the Commonwealth Government in the Australian MinIS, beginning with a reference to government bureaus that do not have large internal laboratories but still have a role in the provision of information and assessment of the minerals industry. The final subunit of analysis characterises a government initiative which boosted exploration activity at Broken Hill. The role of Austmine in support of the Minerals Technology Services Sector is also presented.

A8.1 Government bureaus specialising in provision of minerals information and analysis

Three independent research bureaus located within Federal Government administrative departments provide scientific and economic analysis to assist policy development and support industry interests (Commonwealth Government, 1997). These are Geoscience Australia, The Bureau of Resource Sciences and The Australian Bureau of Agricultural and Resource Economics.

Geoscience Australia, previously the Australian Geological Survey Organisation (AGSO), provides independent geoscientific information to government, industry and the community. Geoscience Australia plays an important role in support of minerals exploration, participating in related CRCs and fulfilling the critical requirement of basic information gathering and dissemination through the National Geoscience Mapping Accord. Geoscience Australia has a key role in promoting the Australian minerals industry internationally at forums like the Prospectors and Developer Association of Canada's (PDAC) Annual Convention. Attendance at such forums raises the Australian mineral industry's international profile, facilitates the promotion of Australian expertise and provides an important opportunity to gain feedback on areas of interest to potential investors. Geoscience Australia's contribution to exploration research, which has in the past involved a significant proportion of collaborative work, particularly through CRCs, has come under increasing pressure as a result of government funding cuts.

The Bureau of Resource Sciences (BRS) provides scientific and technical analysis on the prospectivity of mineral deposits. The Australian Bureau of Agricultural and Resource Economics (ABARE) manages and reports upon a comprehensive collection of physical, financial and socio-economic data. ABARE is devoted to applied economic research for Australia's rural and resource industries. ABARE's research focuses on the identification of domestic and international trends in economic performance and cost-benefit analysis of alternative public policy options. On a fee-for-service basis, ABARE provides commodity forecasts and public policy analysis to government and other stakeholders. It hosts the annual

'Outlook' conference for assessment of the outlook for commodity prices and industry performance, a forum that attracts international attention.

The Australian Bureau of Statistics (ABS) also conducts periodic reviews of the industry's performance.

The BHEI – Broken Hill Exploration Initiative Case Study Subunit

Background to the initiative

The Broken Hill silver-lead-zinc deposit is one of the most substantial in the world, producing since its discovery in 1883, $70 billion of metal in today's terms (NSW Mining and Exploration Quarterly, 1999). Its scale is mirrored by the number of now international minerals companies and technological innovations spawned by the deposit and its contribution to national wealth. In particular, the Broken Hill deposit supports the townships of Broken Hill, New South Wales, and Port Pirie, South Australia, where lead concentrates are smelted.

In the late 1980s Broken Hill, Port Pirie and all those dependent upon wealth from the Broken Hill deposit, faced the problem of an estimated 10 year life span of reserves. Effects were being felt in Broken Hill where the population in the city was at its lowest this century (20,963 in 1996) (NSW Mining and Exploration Quarterly, 1999). In the early 1990s companies were pulling out of the district and exploration rates were in decline. If the long term future of the region were to be sustained new deposits needed to be found.

Prior to the BHEI an overall lack of communication and coordination existed between stakeholders in the Broken Hill region and geological maps of the region were of poor quality and did not delineate areas of potential mineral wealth.

The Broken Hill Exploration Initiative

BHEI is an attempt to redress the decline of the minerals industry associated with Broken Hill by stimulating exploration. The initiative originated with the National Geoscience Mapping Accord, a Commonwealth–State/Territory initiative with the aim of using modern technology to generate geoscience maps, databases and related information of prospective and strategically important areas of Australia, and disseminate this information into the exploration sector. In this manner, the Accord would encourage and support exploration and ultimately, regional development. Members of the Accord involved in the BHEI included AGSO, the Department of Primary Industries and Resources South Australia (PIRSA) and the New South Wales Department of Mineral Resources (DMR). The region under geological review crossed state borders and covered the Broken Hill and Olary regions, the Koonenberry belt, and the Mount Painter and Mount Babbage inliers. These regions hold rock sequences similar to those of Broken Hill, suggesting potential for silver, lead and zinc deposits, as well as for gold, copper and uranium mineralisation.

In 1994, the BHEI began with the objective of providing, '...through a multi-disciplinary approach, a new generation of geoscientific information for the Broken Hill region in New South Wales and South Australia as a basis for more effective and efficient exploration by the mineral industry,' (generic brochure). A program for development was organised in two stages: 1) Identification and application of advanced methodologies to generate detailed geological information and construction of geological maps; and 2) Dissemination of this information into the exploration industry.

The BHEI's first phase was supported by the creation of multi-disciplinary teams of public sector research organisations which were in turn developing advanced geological research tools and methods (see table 7 .7 below). During a four year period, a variety of research methods were used to gather information to support the production of regional geological maps. Gathering geophysical data, for example, involved a total of 475 thousand line kilometres of airborne magnetic and radiometric data, and helped to interpret the geology of the region. The Australian Geodynamics CRC was active in generating deep seismic reflection surveys which produced some of the most informative data gathered by BHEI.

Table A8.1: Research organisation involved with the BHEI

Universities	Melbourne, New England, Monash
CRCs	Australian Geodynamics CRC
	Australian Mineral Exploration Technologies CRC
	CRC for Landscape Evolution and Mineral Exploration

The transfer of this data into the exploration industry was the critical step for this initiative. The preferred vehicles for this were a conference series, field trips and technical presentations. The conference setting provided a forum for BHIE partners and associated collaborators to present new geological information sets. Exploration companies also presented outlines of their activities. The environment fostered informal networking among delegates who represented exploration companies, government geoscientists, CRCs, university researchers, consultants and service providers.

A return on investment in the BHEI

To date the Commonwealth and two State governments have contributed \$13 million to the project. Early measures of the impact of this investment show exploration expenditure has increased significantly with a ten-fold increase in the total area under exploration licence (see Table 7.8). There have also been some encouraging preliminary exploration results. Pasminco, in joint venture with Werrie Gold Ltd, produced positive drilling results for copper, gold and other base metals in the Benagerie Ridge at Portia, South Australia. It is hoped that the increase in exploration activity will eventually lead to the development of major new mines, and ultimately, to the preservation of the regional centres Broken Hill and Port Pirie.

Table A8.2: Growth in private exploration expenditure in the BHEI region

South Australia		New South Wales	
1992	$2.70m		
1993	$2.64m		
1994	$2.76m	1994/95	$7.29m
1995	$5.19m	1995/95	$7.20m
1996	$4.98m	1996/97	$8.19m
1997	$10.70m	1997/98	$9.00m

Source:(NSW Mining and Exploration Quarterly, 1999)

Summary

The BHEI exemplifies the effectiveness of strategic public policy for the minerals industry, that is, how a coordinated and proactive government initiative can reinvigorate exploration activity. It also demonstrates the importance of a well functioning MinIS in ensuring the success of initiatives that involve the generation of new information by the public sector and dissemination/application into the private sector.

A8.2 Austmine and support for the Mining Technology Services Sector

Formal identification of the Australian Mining Technology Services (MTS) Sector occurred in June 2001, after the empirical component of this study was complete (DITR, 2001). That is not to say that MTS-type firms were overlooked, Fractal Graphics, is an example of such a firm. Rather, the momentum of interest surrounding this sector has increased dramatically. The MTS sector is of interest to this study because it is exactly the type of intensely innovative and high technology industry sector Australia needs to grow in order to integrate with the knowledge economy. Furthermore, the domestic minerals industry was a catalyst for the development of internationally competitive MTS companies.

As mentioned in Chapter 4, Austmine was established to support and market minerals services companies, however, it has recently come to emphasise the technological nature of this industry sector and exports from Austmine-member companies exceeded $1.5 billion in 2001. Apart from software, MTS were also active in exports of training, undergound mining systems and contract mining in Argentina, Bolivia, China, Peru, Poland, South Africa and Vietnam (Broome, 2001). While the demand for MTS goods and services is global, considerable competition exists among thousands of suppliers located around the world.

Firms in the MTS sector range from very small, independent operators to the very largest minerals companies which develop significant MTS capabilities internally or within subsidiary companies, for example, ERA's Environmental Services and BHP Billiton's Falcon (gravity gradiometer). A 1999-00 Austmine members survey found 48 per cent employed less than 50 people, 38 per cent employed more than 100 people and the remainder were mid-sized operators (Broome, 2001).

One of Austmine's strengths is its ability to provide consortia of member companies for individual projects when a particular combination of specialised equipment, technologies or services is required. Furthermore, there are strong links between Austmine and the research base with research projects being conducted through AMIRA and other public and private research providers. This support for innovation has led to the successful development of some of the most technologically advanced mining and processing equipment including an All Terrain Underground Transporter and a Roadway Development Machine. Other specialised areas include: dragline efficiency, the treatment of tailings, materials handling and wear-resistant materials technology (Austmine, 2000).

The success of Austmine and its marketing of Australian-grown, knowledge-based exports is based upon the minerals industry being active users of new technology.

A8.3 Government support for innovation

There are also many government programs, at federal and state levels, which aim to encourage and support industry R&D, innovation, value-adding, commercialisation and related activities. A number of programs provide indirect support for the minerals industry as they apply to small, high-technology service companies. Through these programs, government has played a crucial role in supporting major Australian innovations in minerals, such as Isasmelt. According to MIM:

> MIM Isasmelt development, an innovative cost-saving process for smelting copper, began with a pilot plant in 1975; yet a full-scale production plant only came on line in 1990. This project would have died if not for government grants in the late '70s and early '80s at a critical stage in its development. ... Now regarded as state-of-the-art, it belies the long development time frame which preceded it. (MIM Holdings Limited in (AMIRA, 1997:11)).

Government support for business programs to encourage investment in innovation is a pressing issue for the minerals industry. The industry usually regards government intervention with suspicion and yet in this case its programs have been enthusiastically embraced (see Chapter 4 for details). From the minerals industry's present perspective, the most significant government support schemes are the tax concession for R&D, the CRC program and the Australian Research Council's (ARC) Collaborative Grants Scheme (AMIRA, 1997).

It is not surprising then that in its submission to the Mortimer Inquiry, AMIRA's primary recommendation was to reinstate the Tax Concession for R&D at 150 per cent, excluding syndication, and the disbanding of the R&D START program[1] (*ibid*). Industry testimonial contained in the submission also illustrates the success of the tax concession incentive. In the broad sense it reduced risk associated with the development of prototypes and research facilities and enhanced the profile of R&D culture among the financial sector. It also encouraged small minerals companies to conduct research, fostered high risk projects and retained project development in Australia. In AMIRA's submission to the Mortimer Report, it suggested a guiding principle for government business programs: 'Industry Leads; Government Follows' (AMIRA, 1997). It also recommended that the government make use of AMIRA to

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[1] AMIRA's opposition to this program is based upon its bureaucratic nature and the difficulties involved in picking winners, not the fact that it has assisted some minerals service companies.

deliver some of its programs and to encourage industry participation in collaborative research grants (*ibid*).

A8.3 Summary

The IS approach has utility when trying to understand the role of government in the MinIS. This review has shown that there are many Federal departments and programs that support the MinIS, such as, through the provision of administrative and analytical services. It also found that public sector initiatives, such as the BHEI, are an effective means of supporting the MinIS. However, due to the a lack of government understanding of the nature of minerals innovation and the inherent value of the MinIS, the supporting role of government is poorly coordinated and lacking a uniting strategic vision. There is a great need for governments to respond to challenges facing the MinIS and create conditions that enable innovation.

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