RESOURCE DEVELOPMENT, PLANT LOCATION, AND GOVERNMENT INFLUENCE

A Spatial Analysis of the Australian Metalliferous Mineral Industries

by

R.H. Fagan

A thesis submitted for the degree of Doctor of Philosophy, Australian National University, May, 1973
For Margaret

This thesis is my own work, except where quotations and direct acknowledgments appear in the text.
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This thesis examines the development of selected metalliferous minerals in Australia and the evolution of spatial patterns of mining and processing industries. It is submitted that powers of geographical analysis are increased by considering resource development and plant location in an integrated framework, and that such a structure can be developed from classical least-cost location theory (which, in its present form, is deficient in its notions of resources). The thesis begins by considering this theory and suggests simple (informal) models to represent 'resource creation' as a spatial process.

The resource creation process begins with the collection of information (exploration) and the development of mines, and culminates in the supply of metal, in usable forms such as steel and aluminium ingot, to user-industries. The remainder of this study identifies and measures the parameters of this process and argues that the evolving spatial pattern of metal resources and attendant processing industries cannot be adequately explained without knowledge of institutional factors such as vertical-integration and, particularly, the spatial influence of government policy.

The empirical part of the thesis measures the main parameters of the processes for the five most important metalliferous minerals in Australia. Detailed analysis is made of demand parameters, regional production costs, transport costs, and the influence of isolation (reflected in levels of infrastructural investment by mineral companies). The aluminium industry is used as a case-study, but comparative data are drawn from the iron and steel, copper, lead, and zinc industries. The study is constructed in terms of the classical theory, and optimal patterns of location are generated for the aluminium industry using linear programming. Costs of resource development are specifically included in the models. The patterns are used
as 'bench-marks' against which to test the actual patterns. The importance of critical production factors in mining and processing is stressed, and much of the deviation between actual and theoretical patterns results from institutional factors, including government policies. For the other industries, least-cost location theory (as modified) appears to have reasonable explanatory power.

The study concludes with a consideration of government policies in Australia as a variable in the resource creation process, concentrating on their influence on location. Commonwealth and State governments, operating under different Constitutional constraints, have different primary goals in mineral policies, and some examples of conflict are given. Commonwealth spatial influence is restricted, and examples show that much of it is incidental or accidental. The State governments play an important role in resource creation through mining leases (in which obligations are often imposed on companies) and royalties, but exercise more spatial influence if they can manipulate the regional costs identified in the empirical part of the thesis.

Despite a wide range of government influences on resource creation, much policy has had little spatial impact on patterns of mining and processing in Australia; the most pervasive influence seems to operate not directly but through other parameters. This is the most difficult institutional influence to measure, however, and calls for an improved conceptual framework before the resource creation process can be completely understood.
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Throughout this thesis all weight measurements are expressed in pounds (lb) or long tons (2,240 lbs). Metric tons (2,204.6 lbs) and short tons (2,000 lbs) are not used, although the former appear in most mineral export contracts and some Australian companies have begun quoting production statistics in metric form. Despite the imminent change to the metric system in Australia, long tons have been retained here to achieve comparability between disparate sources of data, and consistency with published freight rates and domestic mineral agreements, both of which were expressed in long tons during the years under consideration.

Distances are in statute miles and monetary values in Australian currency unless specified otherwise.

Because of the critical importance of technical definitions and technological background information to sections of the argument of Part II, a Glossary follows Chapter 8. Terms defined in this Glossary are indicated by the use of italics at their first appearance in the chapter; for example, beneficiation is used in the first instance, and beneficiation for subsequent uses. Italiccs are also used if it is thought necessary to remind the reader of a particular definition which has been already indicated in an earlier chapter.

Since it is impossible to conceal the identity of large firms in the Australian mineral industry, especially in a study of location, companies have been identified by name; this has been made clear to firms involved. Basic information on these firms is given, in alphabetical order, in Appendix 1(b).
PART ONE

INTRODUCTION

Despite a tradition in geography for the study of natural resources and a recent acceleration in their dynamic usage, there has been few attempts to incorporate resource development processes into the existing body of geographical theory. One result of this is the difficulty of generating spatial hypotheses on which to base measurements, and of improved understanding of resource processes. Data is a prerequisite for incorporating resource into normal spatial theory. Some resources are also the subject of considerable public interest and policy, the principal aim of this study is to take a first step towards measuring the spatial influence of governments within a conceptual framework incorporating both resource development and plant location. The empirical part of the study, therefore, involves the more important metal/metallic mineral industries in Australia and identifying the factors which have shaped their development.

Governments, under all types of political and economic organization, have taken a great interest in the availability of mineral resources for their economies, since the power bases of nations (and regions) have long been dependent on industrial fuels and the relatively high-value metal industries faced with depletion or decline. Industrial countries, large North American and European countries, have taken part in development and national policies have often been in large.
CHAPTER 1: RESOURCE DEVELOPMENT, PLANT LOCATION, AND GOVERNMENT INFLUENCE: AN INTRODUCTION

The received opinions of geologists and mining engineers concerning resource endowments have been readily embraced, but the perceptive interpretation of their partial conclusions in the light of the spatial, economic, and other constraints on resource use has been conspicuously absent. These constraints must be accorded full recognition in any complete appraisal of a resource, for without them a discussion of its size and worth can lead to a gross misinterpretation of its significance (Manners, 1969, p. 153).

Despite a tradition in geography for the study of natural resources, and a recent acceptance of their dynamic nature, there have been few attempts to incorporate resource development processes into the existing body of geographic theory. One result of this is the difficulty of generating spatial hypotheses on which to base measurement, and improved understanding, of resource processes. This is a prerequisite for incorporating resources into formal spatial theory. Since resources are also the subject of considerable public interest and policy, the principal aim of this thesis is to take a first step towards measuring the spatial influence of governments within a conceptual framework incorporating both resource development and plant location. The empirical part of the study, therefore, examines the more important metalliferous mineral industries in Australia and identifies the factors which have shaped their development.

Governments, under all types of political and economic organization, have taken a great interest in the availability of mineral resources for their economies, since the power base of nations (and blocs) has long been dependent on industrial fuels and the maturity of basic metal industries. Faced with depletion of their initial sources, large North American and European corporations have taken part in developing new mineral deposits, many of them in less-developed countries. Hence, as well as being of strategic
importance, resource development has become a vital issue in national and regional economic growth, and plant locations are of political importance. Public debate over future resource adequacy, pollution, and environmental issues has increased sharply in the last decade. Notwithstanding the type of government influence in the economy as a whole, it would be expected that mineral resource developments and the basic metallurgical industries would be strongly conditioned by mineral policy. Incorporation of the role of governments thus seems essential if resource development is to be considered as a spatial process beginning with the investigation and evaluation of the environment, and culminating in the supply of basic inputs to other sectors of the economy.

The integration of resource development and plant location is logical and essential for two main reasons. First, classical location theory emphasises the locational attraction of resources. In the scheme proposed by Alfred Weber (Friedrich, 1929), even market-oriented locational optima were produced because of particular relationships between raw materials and final products. The pattern of mineral processing industries, whatever their orientation, is influenced by the spatial distribution of resources; yet the geography of resources is also partly determined by the location of the processing plants and the users of their products. Second, most of the companies undertaking mineral processing in Australia are integrated 'backward' into mining and even into exploration. Many foreign companies whose principal business is the export of ores also become involved in various types of local processing. Hence there are good empirical reasons for studying the location of mining and processing together; individual firms make decisions at both levels.

In the first part of this thesis, the process of 'resource creation' is examined in terms of normative theories, and a simple spatial model is proposed as the framework for the rest of the analysis. But since it is beyond the
scope of this study to develop the new model rigorously, the formal models presented during the course of the thesis will be tested in terms of classical theory. This present chapter examines the relationships between resources and location theory, then introduces the spatial role of governments and, finally, reconsiders the aims of the thesis and its structure.

1.1 'Resource Creation' and the Non-renewable Resources

An examination of resource creation must be preceded by concise and unambiguous definitions, and the study industries, those extracting and processing metalliferous minerals, must be placed in this framework. A functional classification of resources is presented following a review of ways in which resources have been regarded by geographers, economists, and location theorists (sub-section 1.1.1). The process of resource extraction is considered in terms of simple economic models (sub-section 1.1.2), and in sub-section 1.1.3 the nature of extractive industries is considered in more detail, followed by a brief examination of the role of exploration (sub-section 1.1.4).

1.1.1 The nature of resources

In micro-economic theory, natural resources are usually absorbed into the set of market variables, in abstract, as 'land'. Under the determinist philosophy of geography a natural fund of materials sets strict bounds to economic endeavour and its location. Statistical analyses from the conservationists of the 1940s and early 1950s* made gloomy predictions about the future depletion of resources like metal ores, given accelerating rates of use. Many economic geography texts concentrated on inventories of global or national resources and not on the processes determining why some deposits became resources and others remained unused. This may have led the location theorist Beckmann to the

* This movement is summarized by Zobler (1962); Barnett and Morse (1963, pp. 72-97); and Zimmermann (1957).
conclusion that 'it may suffice in economic geography to list all resource deposits' (1968, p. 9). Few geographers would now regard such a listing as a major function for snapshot inventories reflect only the stock of knowledge about naturally occurring materials, the state of technology, and the level of productive activity in the society as a whole. Yet economic determinism has been questioned in some recent assessments of mineral resources; the optimistic analysis of the economics of resource availability by Barnett and Morse (1963) has been criticized by the biologist Ehrlich (1969) and by the geologist Lovering (1969). The highly aggregated global model proposed by Meadows et al. (1972) outlines the long-term limits to economic growth but ignores the spatial patterns of resource development and plant location, and cannot predict how the stock of useful earth materials will be converted into resources over time.

Theories of regional economic growth placed great emphasis on the resource base (North, 1955; Perloff et al., 1960) but usually considered this fixed or 'given'. Location theorists either neglected environmental inhomogeneities or assumed them away for the purposes of theory construction. Weber adopted a static inventory approach to resources; in establishing an isotropic plain, he assumed a given distribution of raw material sources, arguing that

this assumption is in accordance with the facts when we are concerned with materials... like minerals... which are simply dug out or mined -- which, in other words, exist at different places by nature (Friedrich, 1929, p. 37).

Such an argument overlooks the essential interdependence of resource development and plant location. Neo-classical theorists often examined extractive industry but regarded it as the simplest form of location problem. 'Extractive industries are, by definition, located at a source of their raw material; their location involves a mere choice among various possible sources' (Hoover, 1937, p. 7). Hoover presented no further analysis of the 'mere choice' and used these industries to illustrate the adjustment of mobile to
immobile factors, and to focus attention on market areas (1937, pp. 7-33). Similarly, Lösch (1952, pp. 36-7) used mining to illustrate basic location principles and, although he implied the existence of the resource creation process (1952, p. 35, footnote), it remained undeveloped in his theory of location.

Resources are the end products of economic processes, involving the technologies of extraction and industrial use*, transport economics, the size of demand in relation to supply, the spatial pattern of user industries, and the physical characteristics of the sources and their locations. A functional concept of resources was suggested by Zimmermann (1951), later by Wagner (1960, pp. 125-9), and was developed more formally by Barnett and Morse (1963, passim but especially pp. 126-47). Resources are an expression of human appraisal of the environment and are created (and destroyed) in the satisfaction of wants. 'The word "resource" does not refer to a thing nor a substance but to a function' (Zimmermann, 1951, p. 7), and different cultures, in sequential occupancy of a given territory, evolve different natural resources from their surroundings (see also Spoehr, 1956). In modern economies, the discovery of earth materials such as minerals is a necessary but not sufficient condition for the initiation of a resource creation process; they remain 'neutral stuff' (Zimmermann, 1951, p. 8) until it becomes profitable to invest capital in the investigation of their size and quality, and until circumstances involving market demand, entrepreneurial, and government structures allow their transformation into resources.

* Technological change can operate in both positive and negative directions. Improving extraction technologies can allow the exploration of previously difficult or inaccessible ore deposits, at the same time rendering resources of lower intrinsic quality marginal. Changes in processing or manufacturing technology can create a new set of material demands thus creating new resources but destroying others rendered unsuitable.
Despite wide acceptance of the functional concepts, ambiguous definitions remain a problem. Poor taxonomy simply increases the difficulty of comparing inventories over time and of estimating the life-span of global resources. Precise classification of resources would assist in the formulation of public policy, especially that relating to conservation and environmental protection. Yet recently, Manners (1971, pp. 236-43) has discovered little consistency in terminology between countries and organizations. A classification of resources should be based on functional definitions and take into account socio-economic processes.

Resources are often classified as 'exhaustible' and 'inexhaustible', although a taxonomy based on exhaustibility can be dangerous. Long before a particular deposit is entirely consumed it may be exhausted economically if long-run marginal extraction costs are greater than the long-run marginal revenues obtained. All factors which cause temporal changes in costs and revenue potentially influence the exhaustibility of a resource (Ciriacy-Wantrup, 1952, p. 33). Thus, individual resources may be 'created' or 'destroyed' by alterations in market factors and in production technologies. Exhaustibility is also influenced by the cumulative effects of resource use over time; depletion affects cost structures, but the accumulation of scrap also affects demand for primary materials. Most of the problems are surmounted by adopting the simple scheme proposed by Ciriacy-Wantrup (1952, pp. 33-5). Distinction is made between 'stock' (non-renewable) and 'flow' (renewable) resources. For the former, exploitation causes depletion of each individual occurrence which is not renewable by natural processes*

* For the total stock of materials, this is not strictly true over geological time; ores and hydro-carbons are forming continually but at a rate which is of no importance here. Clearly, there are physical limits to resource creation in non-renewable resources but, because of the critical importance of knowledge (collected only at a cost) and technologies, it is fair to say that these limits are not known. It is a plausible hypothesis that costs of pollution resulting from accelerating consumption of resources will constitute a crisis much sooner than the physical exhaustion of the more common earth materials.
The level at which the rate of use becomes zero is determined economically. Flow resources are those for which different units become available for use at different times (the resources are renewable), and, while high rates of use cause a decrease in flow for most resources, depletion is not a necessary concomitant of exploitation. Examples of each class of resource are given in Table 1.1. This scheme is unambiguous and its precepts simple; non-renewable resources are not necessarily exhaustible and renewable resources are certainly not inexhaustible.

Minerals form the most important variety of non-renewable resource, and this thesis concentrates on resource processes involving them. Manners (1969, pp. 158-9) has drawn attention to poor taxonomy for such resources; descriptions such as 'proven', 'potential', 'marginal', 'inferred', and 'possible', are used with little apparent consistency. In an attempt to reduce this, Manners proposed the system shown in Fig. 1.1.

![Fig. 1.1: A taxonomy of resources](After Manners, 1969, p. 159.

The most important distinction is that between resources and deposits; the former are the result of the processes outlined in this chapter and their spatial distribution
### TABLE 1.1: CLASSIFICATION OF NATURAL RESOURCES

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<th>Principal characteristics</th>
<th>Examples</th>
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<td>coal</td>
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<td></td>
<td>oil and gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>limestone</td>
</tr>
<tr>
<td>Flow (renewable)</td>
<td>Flow not diminished by use</td>
<td>Solar radiation</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>tides</td>
</tr>
<tr>
<td></td>
<td></td>
<td>snow (recreation)</td>
</tr>
<tr>
<td>II</td>
<td>Flow diminished by use but not subject to a critical zone(^a)</td>
<td>Water resources</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(under most circumstances)</td>
</tr>
<tr>
<td>III</td>
<td>Diminishing flow subject to critical zone</td>
<td>Natural forests</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pastures</td>
</tr>
<tr>
<td></td>
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<td>animal species</td>
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<td></td>
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<td>soil productivity</td>
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\(^a\) The critical zone is defined as a rate of diminishing flow beyond which the decrease is economically irreversible given existing technology.

**Source:** After Ciriacy-Wantrup, 1952, pp. 33-5.
is always different from that of deposits. Manners (1969, p. 154) recognizes this but does not distinguish between them in his classification. Nevertheless, his scheme is logical and would provide an unambiguous basis for global measurement of material stocks. It draws attention to the relationship between reserves and other types of ore deposit which make up these stocks. For the purposes of this study, however, the concept of potential resources adds little since known deposits seem to be potential reserves by definition. For spatial research into resource creation, current exploitation is critical and, at a point in time, potential reserves are simply deposits awaiting conversion. Deposits being mined are seldom synonymous with proven reserves, for much of the ore remains inferred until a more detailed analysis is necessitated. A more specific classification of non-renewable resources for spatial analysis is suggested in Fig. 1.2.

![World Earth Materials Diagram]

**Fig. 1.2:** Classification of non-renewable resources

1.1.2 The resource creation process

Rejection of the static inventory approach to resources pioneered by Zimmermann is obvious in recent geography textbooks such as Abler et al., (1971, pp. 455-88) and Haggett (1972, pp. 179-203). Dynamic interactions between man and nature have been incorporated into
location decisions using game theory; man plays against a vindictive environment of which he is uncertain. Gould (1963) has considered agricultural decision-making under conditions of extreme resource variability, while Langdale (1968) has considered the development of snowfields in Pennsylvania as a recreational resource. Decisions involving non-renewable resources have attracted less recent attention and there is still no generalised normative, or even descriptive, theoretical framework in which to analyse resources spatially. A non-spatial behavioural theory has been suggested by Firey (1960) and the basic economic processes can be approached through non-spatial models.

Nourse (1968, pp. 186-92) shows that factor inputs (including 'resources') are subject to derived demand, ultimately dependent on that for goods and services. The analysis of derived demand for metalliferous minerals is complicated by processing which creates intermediate stages of demand between extractive and manufacturing sectors. A sustained rise in demand for goods (services), evokes a supply response, through these stages, and increased resource inputs (causing an outward movement of the production possibilities function for the economy). New mineral resource creation is stimulated for two reasons: first, as existing sources increase production, accelerating rates of depletion necessitate detailed analysis of inferred resources and reserves (Fig. 1.2); second, new firms enter extractive industry as factor prices rise and marginal reserves become economic. Nourse's analysis of factor markets does not consider the employment of land, labour, and capital in the production of inputs themselves. Barnett and Morse (1963, pp. 101-25) have considered these costs, and the following analysis has been suggested by their models.

For simplicity, assume a closed economy with a single 'social product' (P) function and three factor inputs; R denoting natural resources, L labour, and K capital. If
continuous full employment of labour and capital is assumed they can be combined and a model developed with two factors, R and L+K. The production function is of the form

$$ P = f_1 (R, L+K) $$

Yet L and K are also employed in the production of R. Suppose $R_u$ represents deposits of useful materials which can be converted into standard factor inputs (R) according to the function

$$ R = f_2 (R_u, L_r+K_r) $$

The three-dimensional surface formed by $R$, $R_u$ and $L_r+K_r$ can be projected onto the axes $R$ and $L_r+K_r$ (Barnett and Morse, 1963, pp. 269-71) to yield a 'resource conversion path', which minimizes combinations of $R_u$ with labour and capital to produce R. In reality, such a conversion function would be very complex but could be represented by Fig. 1.3 under the restrictive assumptions that quality of $R_u$ varies continuously and, to minimize total costs, deposits are selected for conversion in strict quality order.

![Fig. 1.3: The resource conversion path](image)

The basic processes of resource creation can now be incorporated into the production function by substituting equation (2) for $R$ in equation (1):
The cumulative effects of depletion on currently exploited sources can be added to the resource conversion function, as in equation (4), by assuming a rate of depletion of $D_{ut}$.

$$R_{ut} = f_3 \left[ R_{ut}^t, (L_r + K_r)^t, \sum_{0}^{t} D_{ut} \right]$$  \hspace{1cm} (4)

These highly simplified resource conversion functions have little or no value as explanatory or predictive devices but are useful in emphasising that, while separate from the production function, resources are determined endogenously within the productive system. Deposits do not vary along a quality continuum in practice, and the actual selection of deposits is a complex process depending partly on cost structures (including technology and transport) and partly on knowledge gained through exploration. These two merit more detailed consideration for the extractive industries before resource creation is considered as a spatial process.

1.1.3 The extractive industries

While the history of mining has been considered by some members of the 'landscape school' (Pederson, 1966), geographers have paid little attention to its economics. Exceptions are Wilson (1968), who considered the temporal pattern of pit locations on a coalfield, and Aschmann (1970) who suggested a useful historical-descriptive framework for studies of mining. For a single underground mine, Aschmann suggested four stages of development (Fig. 1.4), each with a characteristic pattern of operating returns under depletion (described by Hotelling, 1931).

The first stage involves outlays on exploration and the proving of the deposit; the second is entered as mining commences with large investments of labour and capital. This stage is characterized by increasing returns to scale as output expands. During the third
stage, the net profitability of the mine falls as extraction costs rise (in an underground mine) and the quality of ore decreases. The mine is worked out until it ceases to be profitable and is abandoned (fourth stage). This model can be extended by postulating price fluctuations, which cause short-term peaks and troughs during the second and third stages, and periodic changes in knowledge and technology (Aschmann, 1970, pp. 175-8).

![Figure 1.4: Stages in the development of a mine](image.png)

Time intervals have been assigned arbitrarily and would vary considerably in practice.

It is easy to misunderstand the influence of physical geology on these development stages. While metallurgical technology largely determines which minerals will be considered as ores, differences in the relative crustal abundance of metal mineralization (Skinner, 1969, p. 22) strongly influence supply characteristics and the economic 'cut-off' grade that can be mined at a profit. The relatively abundant ores of iron and aluminium are rarely mined at grades of less than thirty-five per cent metal content, whereas minerals bearing copper, lead, and zinc can be successfully mined at grades of two per cent or less. Given these broad controls, 'the total physical yield of a mine is neither fixed nor naturally determined'
in the selection of deposits of a particular mineral, the mining firm makes interrelated decisions about the location of production, the rate of extraction, and the level of recovery. These decisions reflect the relationship between the anticipated stream of revenue and extraction costs.

The geological boundaries of a deposit are usually determinable, but it is seldom necessary to make such costly analyses once economic boundaries of proven ore are established. Hence the prospective mining company makes a decision ex ante about the total level of economically extractable material, and about the (annual) rate at which ore will be removed. There are several methods of estimating the value of the resource, discounted over the projected life of mining (Herfindahl, 1955, pp. 131-2; Soukoup, 1967). While the tonnage of material considered exploitable influences the choice of mining rates, these rates, and the grades developed, determine the tonnages realized. If short-term high profits are sought, or high unit extraction costs are faced, only richer seams may be exploited, reducing or even precluding the possibility of developing surrounding metal-bearing materials. Alternatively, large-scale mining techniques could be used to extract a lower average grade; tonnages mined are higher but production costs could be lower and a greater proportion of the total contained metal would be extracted in the long-run. For mining companies faced with ores of different grades and accessibility within a deposit, there is a choice between tonnages mined to achieve the required metal yield (Carlisle, 1954, p. 603)*. The optimal blend, determined by the firm's goals, is influenced by the costs of mining and transport, and even by rates of taxation. Thus, the total of all those mining

* Because of this important distinction between tonnage extracted and (theoretical) metal yield, many cost and production statistics are released in terms of contained metal units.
decisions determines the pattern of known deposits (Fig. 1.2), the geography of resources, and the size of a resource base at a given moment. The choice of grade determines the weight-loss to be incurred in processing.

In reality, the resource conversion functions of sub-section 1.1.2 are determined by a complex schedule of fixed and variable extraction costs which also shape the temporal behaviour of profitability (Fig. 1.4). While location determines transport costs, mining costs are controlled by geology. The nature and depth of mineralization and the character of seams and outcroppings constrains the choice of a method of extraction. Underground and open-cut mining possess distinct technologies, the former generally associated with higher unit costs, the latter with capital intensity and large-scale production. Because of the importance of fixed charges in mining (Herfindahl, 1955, p. 598), economies of scale provide an obvious means of lowering unit extraction costs. Such economies are assumed to exist, although little supporting evidence has been published (Ross, 1972, p. 1). Data for coal mining in Illinois suggest that scale economies in underground mining apparently cease above a capacity of 500,000 tons, but that productivity of open-cut mines increases almost continuously with scale of operations (Moyes, 1964, p. 105). The most important cost changes have resulted from technological progress in open-cut extraction. Although wide adoption of such innovations means that many small deposits become unsuitable for selection, the net result has been 'cost-induced' expansion of the resource base, aside from the results of exploration ('knowledge-induced' expansions). Improved extraction techniques are seldom useful without corresponding developments in metallurgy, especially in the beneficiation of poorer ores which has been a principal area of progress (McGann, 1961, p. 76; Aschmann, 1970, p. 174). Given economies of scale in mass-mining and beneficiation plants, poor ores have become highly competitive with rich
over the last decade.

Finally, a wide range of influences constrains the interaction of demand and supply to produce the pattern of extractive industries. The most important are 'institutional factors', such as the structure of markets for raw materials and products, the financial organization of firms, and the mining laws and mineral policies under which companies must operate (the theme of this study). Most firms to be discussed later in the thesis operate in oligopolistic markets, while monopoly also exists*. Natural resource industries are dominated by vertically-integrated, multi-plant firms and large quantities of mineral ores are transferred captively to processing plants within the same group. Such arrangements influence the way in which mines respond to changes in extraction costs, and low-profit operations can be cross-subsidized from within the corporation. International trade increases the possibilities for foreign investment and control, many firms becoming segments of international oligopolies. The importance of multi-national corporations in the mineral industries has been increasing (McNee, 1961; Penrose, 1968; Vernon, 1972, pp. 25-59; McKern, 1972) and will receive some attention in the empirical study.

1.1.4 The role of exploration

The level of knowledge is a principal determinant of an economy's resource base; in mineral industries, this knowledge is derived from a highly variable phenomenon known as exploration, the economic aspects of which have been neglected. McGann (1959, p. 101) attributes this neglect to the 'mystique' which surrounds the activity

* Monopsony, a single buyer of the resource, would also be important but not common. Such a buyer would be a monopolist in his (processing) industry, or a purchasing cartel representing several companies, and the monopsony situation could place a restraint on the size of the economy's resource base in the particular material.
but also to the great uncertainties (Grayson, 1960) and absence of published data. Discovery is widely regarded in economics as fortuitous (Aschmann, 1970, p. 172; Blainey, 1970, p. 298) but, as a result, 'the pattern and logic of mineral discovery have... been overlooked' (Blainey, 1963, p. v). Exploration properly includes not only the investigation of new areas by prospectors large and small, but also the collection of detailed information about known deposits, on the basis of which mining decisions will be made. The former type can be termed 'speculative' exploration and usually produces the more spectacular results. The latter, 'continuous' exploration, is a concomitant of depletion and is properly regarded as a production cost of mining.

Participants in speculative exploration range from individual prospectors, whose successes may indeed be regarded as fortuitous, to large exploration firms, often subsidiaries of major mineral corporations. While there seems little doubt that mineral discovery is partly endogenous to the system of economic activity, it is difficult to relate the activities of so disparate a group to the appropriate economic parameters. The spatial pattern of exploration is initially determined by the way in which the settlement pattern evolves. Blainey (1966, p. 138) has argued that the spread of the pastoral industry in Australia controlled most nineteenth century mineral discovery and the frontier became a later stepping-stone for the exploration of the arid interior.

A favourable economic and political climate is a precondition for the results of such exploration to become 'discovery' *. If 'seeing' is not necessarily 'believing' in mineral exploration, then believing is not necessarily

* Blainey (1970, p. 301) has argued that the distinction between exploration and discovery is akin to that between invention and the adoption of innovation.
'reporting'. Restricted market circumstances (such as monopsony conditions for the resource) can discourage exploration for particular minerals, while mining laws and government policies on the granting of leases are also important. Large corporations face a choice between alternative investments and consider both metal prices and corporate financial circumstances in seeking particular minerals. Their choice is also influenced by government policy since tax concessions and subsidies are sometimes offered to encourage exploration for certain 'strategic' minerals. Advances in exploration geology and technology during the last two decades have lowered the costs of surveying large areas, and governments have provided assistance in the form of basic geological surveys. As mineralized provinces like the Pilbara Region of Western Australia are identified, the pattern of exploration becomes more orderly and the chances of discovery increase.

Herfindahl (1955, p. 133) has suggested the simple hypothesis that exploration responds to above-normal profits in the extractive sector; successful exploration and resource creation become part of the equilibratory process in a standard supply model. Although this hypothesis is tenuous, costs are incurred in anticipation of adequate return and a large proportion of exploration is probably motivated by the profitability of extractive and processing industries at the time, and anticipated demand alterations. Some will remain purely speculative, especially during stock exchange booms*.

* Blainey (1970, pp. 306-10) has suggested the interesting (but untested) hypothesis that mineral discovery in nineteenth century Australia was related to the trough and initial upswing of the business cycle. Many gold and copper discoveries were made at times of low wool prices; low interest rates at the start of the upswing provide opportunities to high risk ventures and mineral share booms.
Currently exploited deposits face depletion, but the ultimate demise of mining at a particular location can be postponed either because of changes in economic and technological parameters allowing marginal reserves to become resources, or through periodic revision of resource inferences (Fig. 1.2) in the light of continuous exploration. Most mining companies* make outlays in revision of estimates to counteract depletion, assisted (or hindered) by market trends and technology. The results of this exploration may eventually cause a major change in extraction methods or, as profitability disappears, the deposit may be declared exhausted and mining transferred to another location. Continuous exploration often causes major revisions in published reserves (especially of ores at greater depths) and, sometimes, there is a fortuitous discovery; in 1930 a major copper lode was intersected during routine exploration of the Mount Isa lead-zinc deposit.

The importance of continuous exploration emphasises the dynamism and uncertainties influencing resource creation. Since information is costly to collect, exploration need only proceed until a decision can be taken. Viewed as a micro-economic problem in resource allocation (Vousden, 1971), and given constant demand and technical parameters, a mining company should cease continuous exploration when the marginal cost of additional information just exceeds the marginal discounted revenue that could be obtained from increments to the stock of proven ore. There are potentially useful techniques for analysing such problems; the question of how much information to collect before making a selection is a problem in sequential decision-making (Flood, 1960; Isard, 1969, pp. 344-69; Webber, 1972, pp. 110-14). In reality,

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* Small mining ventures will sometimes be established to work a given (small) deposit to economic exhaustion and will not invest in postponing it. Such a group would commonly have other business interests and may not find it possible to increase the scale of operations to extract poorer ores.
decisions about exploitation and future exploration are constrained by complex interactions between geological, economic, technological, and political circumstances.

1.2 Resources and Plant Location: A Least-cost Approach

There is a vital link between resource development and decisions about the siting of the intermediate processing stages between extraction and manufacturing. A two-way relationship exists between resources and processing: raw material sources help determine the location of plants, but the processing pattern itself exerts considerable influence on the subsequent geography of resource exploitation (Fig. 1.5). For the empirical work in this thesis, processing plants have been divided into first- and second-stage, the former rendering raw ores suitable as inputs for the latter, which produce metal ingot and thus include some of the basic industries of modern economies. Hence, the resource creation process begins with the selection of metalliferous mineral deposits and ends with the supply of ingot metal to manufacturing industries. A basic metallurgical industry is one '...which Weber might have regarded as a classic example of the utility of his system' (Haggett, 1965, pp. 142-3). Least-cost location theory, and essential modifications, will be reviewed (sub-section 1.2.1) as a framework for the study of processing, and an attempt will be made to express resource creation as a spatial process incorporating both resources and plant location decisions (sub-section 1.2.2).

1.2.1 Classical plant location theory

Critical surveys of the principal theories, models, and empirical studies of industrial location, such as those of McManmon (1959), Hamilton (1967), and Stevens and Brackett (1967), reveal the importance of the classical least-cost approach. The theory of Alfred
Fig. 1.5: Relationships between mines and processing plants

- Operating processing plant
- Abandoned processing plant
- Planned processing plant
- Currently exploited deposit
- Economically exhausted deposit
- Mine under development
- Plant located to serve mine
- Mine developed to serve existing plant
- Abandoned flow
Weber (Friedrich, 1929) has provided 'one of the continuing mainstreams of location analysis' (Webber, 1972, p. 11) and D.M. Smith (1970, p. 18) has argued that 'it seems too early to suggest the rejection of Weber as a starting point for industrial location theory'. A theory useful for industrial location is inevitably a partial analysis and could be excused for its inevitable failure as a general theory of location. Nevertheless, Weberian principles formed the basis for Isard's attempted theoretical synthesis (1956), and have provided a framework for empirical work in regional science, such as the examination of industrial complexes (Isard, 1960, pp. 375-410). For the purpose of this thesis, the theoretical approach chosen should be capable of producing generalized explanations of the location of processing plants, and of acting as a basis for examining resource creation. Since an attempt will be made to measure the parameters of this process, the theoretical framework should assist in the identification of principal spatial factors; a well-known approach is the generation of optimal location patterns, 'not to test the theory, but to test reality' (Lösch, 1952, p.4). (Optimality, in this sense, is principally a deductive hypothesis.) Classical least-cost theory seems a logical starting point for such an analysis.

Classical theories are normative in that they search for the best location under a set of simplifying assumptions taken from the theory of the firm. Their behavioural assumptions rest on the premises of perfect knowledge and rationality, plainly unrealistic for resource development and plant location. Yet classical theory is not concerned with individual behaviour, but with location patterns _ex post_, after the basic economic forces which it identifies have selected the most profitable decisions. Real firms may not make perfectly rational decisions in a certain environment but, for many purposes, it is useful to generate patterns on the
assumption that they do, and to compare these with reality. Retention of a normative system permits the generation of optimal patterns using simple location-allocation algorithms such as the transportation model of linear programming. As yet there is no completely effective bridge between classical theory and modern behavioural theories -- they approach location from different points of view.

Weber's theory, published in 1909, is now quite familiar. In the simplest form of the model, a firm faces a triangle formed by given sources of two factor inputs with fixed production co-efficients*, and a single punctiform market at which demand is inelastic. Profit is maximised by locating at the point of least cost which, under the assumption of spatially invariant production costs, is also the point which minimises total transport costs (on inputs and output). The transport surface is simple with freight rates per ton proportional to distance. Although this optimal point can be determined by analogues (Lösch, 1952, pp. 18-19; Abler et al., 1971, pp. 330-1), graphic solutions have been more common (Kennelly, 1968; Karaska, 1969). Weber's triangle is a special case of a general location polygon with a single market and m input sources. Although mathematical solution is difficult (Alonso, 1967), algorithms have been developed by Kuhn and Kuenne (1962) and Cooper (1963), and programming techniques are now widely used (Scott, 1970).

Locational orientation is determined by the production co-efficients for the localized inputs, and hence by the presence or absence of weight-loss in processing. In extensions of the simple model, Weber allowed some spatial cost variation although his analysis was highly simplified. Labour costs and agglomeration

* Production co-efficients are defined as the weight of input used per ton of output.
factors are examined separately; a firm chooses a low-
wage site (or an existing agglomeration) if the savings
gained exceed the extra transport costs incurred by
movement from the optimal point. Such choices are
regarded simply as deviations from a transport minimizing
location. Since processing in the mineral industry
involves generally considerable weight-loss, a simple
pattern of location is predicted with plants oriented
towards raw material sources unless drawn away by
substantial savings in labour costs at a special site*.

Aside from behavioural considerations, the simple
forms of least-cost theory have been subjected to
formidable criticism, producing some very important
modifications. The weakest parts of the system are its
assumptions about demand and market structures. The
assumption of perfect competition cannot be retained in
spatial analysis because the incorporation of space into the
theory of the firm immediately produces situations of
monopolistic competition and interdependence of location
decisions**. The assumption of inelastic, punctiform
demand severely restricts generality by excluding market
areas from consideration. Without this assumption,
however, least-cost analysis fails to generate optimal
(profit-maximizing) locations (Lösch, 1952, pp.28-9).
Although D.M. Smith has achieved 'some kind of
integration' (1971, p. 259) of revenue and cost surfaces,
retention of the Weberian scheme ensures that analysis
is biased towards costs.

* Presumably, any other variable input for which
production co-efficients are high (such as electricity)
could be substituted for 'labour' in the analysis.

** In reality, industrial structure is complicated by
the prevalence of oligopoly and vertical integration,
although these properly remain as institutional factors
exogenous to the simple normative models; optimal
location patterns for multi-plant firms do not
necessarily coincide with those for the economy as a whole
and normative predictions could be used to measure the
deviation.
There can be no resources without demand, and the location of processing plants would be unnecessary. Changes in market variables play an important part in the creation process but the spatial influence of demand is constrained in three principal ways. First, the end-product of the process is a 'producer good', in this case, metal ingot. While spatial competition between suppliers is plausible, metal is often produced under conditions of collusive oligopoly and various forms of non-price competition. Integration forwards into metal-fabricating industries is common, creating a stable marketing pattern through captive transfers, and metal distribution facilities are often concentrated at a small number of points on which c.i.f. prices are based. The assumption that these markets are punctiform seems reasonable. Second, mines and processing plants may sell in overseas markets and the demand impulse is without local spatial dimensions (although producers may compete with those in other countries). Finally, the prevalence of established c.i.f. prices in the principal market centres for ores and metals, especially through the formation of buying cartels, causes attention to be focused on transport and production costs.

When a mining operation cannot make a profit out of a given pattern of c.&f. prices less the relevant transfer charges... it is priced out of the market. Whether or not it can make a profit, of course, depends on its costs (Manners, 1971, p. 149). Hence, this study retains the least-cost framework, recognizing it as a cost-biased partial analysis.

Most of the modifications to Weberian theory have concerned its analysis of costs since the initial premises concerning spatial variations are too simple. Weber's attempt to reduce differences in input costs to 'ideal distances' involves a fallacy (Hoover, 1937, p. 40, footnote): in searching for the optimal point high cost sources cannot be regarded as 'further away' from the plant because its location has not yet been
determined. Consideration of the influences of cheap labour or agglomeration economies first required the point of minimum transport costs to be determined from which 'deviations' were then possible*. As a result of this indirect method, 'one of the most commonly accepted truisms is that industry will locate to minimize transport costs' (Alonso, 1967, p.28). The model over-emphasizes the weight-losing characteristics of localized inputs; although Hamilton (1967, pp. 371-2) shows that market orientation would be a common prediction of Weber's scheme, such solutions are dependent on characteristics of the raw materials relative to finished products.

Least-cost theory, then, must be generalized to the minimization of total costs of production, including transport costs on all inputs and outputs. Technological factors are thus incorporated and their spatial implications can be examined (Rawstron, 1958). An important contribution has been the development by D.M. Smith (1971, pp. 181-206) of 'space cost curves' which show how total costs vary over space for given levels of output. The derivation of these curves can be complex but the main features of the approach can be illustrated with a simple example (Fig. 1.6). Consider the simplest form of the Weber problem with fixed demand: the average revenue curve can be represented by AB. Suppose R is a single source of the principal raw material on the bounded plain OZ**. The curve XCY is the space cost curve

* While economies of agglomeration are important in the Weberian system, analysis of them is crude and no distinction is made between economies of scale, linkages between related industries, and general external economies associated with location in established centres. All of these are important in the location of processing plants and are not adequately represented by regarding agglomeration as a force promoting deviation from the point of minimum transport.

** Since this plain is really two-dimensional, the space cost curves are surfaces in three-dimensional space and are represented here in cross-section.
Fig. 1.6: The space cost curve and the spatial margins to profitability

and shows how the total cost of production varies spatially for a firm wishing to locate on the plain. If other inputs are ubiquitous and transport costs linear, this curve takes the simple form shown and costs are minimized at the source R. Two types of cost are suggested by D.M. Smith (1971, p. 191). Some costs are basic (the rectangle DOZE in Fig. 1.6) and include the minimum production charges regardless of location; they are related directly to technologies and their importance is determined by production co-efficients. Other costs are locational (XDEY) and include all transport inputs and other spatial premiums paid on production factors. The revenue and space cost curves delimit 'spatial margins to profitability' (F and G) beyond which the firm cannot make a successful location. The optimal location is R but any site between F and G may be preferred depending on the goals of the firm. The extent of these margins depends, in Fig. 1.6, on the cost of transporting the raw material and hence on weight-loss*. Smith's modified least-cost model is capable of considerable extension. Revenue curves can be allowed to vary with distance from established market centres and a more realistic space cost curve can be postulated as a composite of all spatially variable charges including more complex transport functions.

Weber's over-simplified transport notions can be readily modified. Hoover (1948, pp. 15-26), recognizing that terminal costs and overheads are independent of length of haul, showed that precision is gained if transport costs are made a degressively increasing ('tapering') function of

* Smith (1971, p. 185) claims that 'sub-optimal' behaviour is possible within these margins, but here the utility of the model seems doubtful. The concepts of 'sub-optimal' behaviour have been questioned by Webber (1969). Least-cost theory is not required to incorporate behaviour, and should remain normative. The question of uncertainty places doubt on the concept of spatial margins to profitability as perceived by the individual.
distance. The actual structure of freight rates is poorly represented even by Hoover's model; government regulations and competition between transport sectors remove the orderly progression of costs, while transport itself is subject to economies of scale, relating to volume rather than distance. Serck-Hanssen (1970, p. 9) has concluded that normative models should retain transport simply as a surrogate for distance since the inclusion of scale economies would make it difficult to obtain solutions to least-cost problems* . With tapering freight structures, the model predicts location at either raw material sources or markets rather than at intermediate points. It is often contended that transshipment (modal interchange) points can act as minimum transport locations but this is true only under special circumstances of little importance to manufacturing activity. Hoover has argued recently that much of the emphasis on transshipment locations has been 'quite misleading' in terms of transport advantages, and that 'we must explain the observed concentrations of activity at ports and other modal interchange locations on the basis of other factors' (Hoover, 1971, p. 54).

Modification should also be made to the classical theory to incorporate economies of scale and substitution between inputs since these have important locational implications. Weber's assumption of fixed production co-efficients is retained, for simplicity, in using programming models to generate least-cost solutions, although methods are available for including scale economies**. Moses (1958) has illustrated the dangers of

* It would require continuously altering cost surfaces with rates changing as a differentiable function of distance and each time different volumes are allocated to potential production points, input sources, and markets.

** Isard (1956) has retained fixed production co-efficients in his 'substitution' analysis of transport as a variable input. He considers substitution of money outlays (such as extra freight for low wages) rather than quantities of factor inputs.
predicting locational orientation in a framework which
denies scale and substitution (such as capital for labour).
In the theory of the firm, the least-cost combinations for
two factor inputs in producing each level of output are
derived from points of tangency between isoquants (loci
of technical input combinations) and isocosts (lines of
total expenditure, with a slope equal to the given input
price ratio). Suppose only two possible plant locations
exist and that there is a single source of each input.
For a given total outlay, the firm faces a different
family of isocosts at each location; transport costs
from sources to production points produce different input
price ratios. Isocosts for each location at a single
level of expenditure are shown in Fig. 1.7.

![Diagram](image)

Fig. 1.7: Derivation of a locational isocost for a
given level of total expenditure

The line CFG now becomes a 'locational isoscost' (Moses,
1958, p. 261), segments CF and FG representing location at
different sites. There exists, for each level of total
expenditure, a segmented locational isocost, and the
optimal production combinations for each level of output
now also specify a location, determined by the segment
which is tangent to an isoquant*. Mosès (1958, p. 267) has demonstrated that the optimal location depends on the level of output; the orientation of small plants within an industry can be different to that for large plants. This important modification shows that scale should be incorporated as an endogenous variable, and emphasizes the importance of the least total cost approach. Optimal location for a given scale of plant is only at the point of minimum transport costs as a special case, and locational orientation is determined by interactions between transport costs, the variability of production costs, and technical production possibilities.

The critical role assigned to raw materials and their weight-losing characteristics has been demonstrated, but Weber's theory ignores the processes of resource creation. Sources of inputs are not 'given' and weight-loss is controlled by the grade of the material processed; it has been shown in sub-section 1.1.3 that grade is an endogenous variable. Lösch (1952, p. 21) illustrated the operations of Weberian theory using the iron and steel industry while Goldman (1958, p. 92) has recognized the utility of the least-cost approach in generating optimal patterns of such plants (with homogeneous outputs). Beckmann (1968, p. 81) claims that second-stage processing comes closest to fitting Weber's model. This is partly because the restrictive demand assumptions are less serious for these industries than for most others. Thus, the least-cost theory, as modified, seems appropriate as a basis for examining the metalliferous mineral industries and for generating optimal patterns. Differences between the normative results and actual patterns will be partly explained by institutional factors such as market and industrial structures, but some might be due to constraints imposed by government policy. Extended models,

* There are n segments for n possible locations. If the number of sites is infinite, the locational isocost (for each level of total expenditure) becomes a smooth curve; each point on it specifies a unique location.
especially the space cost curves, suggest that empirical analysis of location patterns should investigate the structure of production costs, concentrating on the main components which vary spatially. Transport is regarded as a vital input to the production process. The importance of scale factors suggests an examination of technologies and the fixed capital costs of plant, equipment, and infrastructure. The empirical study in this thesis (Part II) is carried out within this least-cost framework.

1.2.2 Resource creation as a spatial process

Spatial theory might be improved by the inclusion of resource creation as an endogenous process, and this may be attempted using the models reviewed in this chapter. Yet it is not easy to adequately incorporate resources into a normative framework and it is difficult to avoid the restrictive assumption that society faces an inventory of known material stocks. More powerful treatment of exploration would require models such as those based on sequential decision-making, and it would be difficult to link an ex ante model of resource development to the ex post classical location theory. Nonetheless, the least-cost premises can be used to deduce a spatial pattern of resource creation, and the validity of the notions can be tested informally following the empirical analysis of the metalliferous mineral industries. Refinement of the model and a more rigorous presentation await later work.

In considering agriculture in the United States, Schultz (1953) argued that development takes place within specific locational matrices focused primarily on urban centres. The developing institutional framework is most effective in the vicinity of such nodes, and the availability of services declines with distance from them. Schultz's data suggest that differences in the regional productivity of agricultural resources were determined by the way in which the space-economy evolved, and not primarily by intrinsic qualities of the land itself. These
findings are important in considering the evolving spatial pattern of resources and processing plants.

The following analysis is presented in terms of a grossly simple model (Fig. 1.8) assuming a closed economy on a largely unpopulated island continent, with a single sea port and an evolving settlement pattern radiating from this node. It is further assumed that potentially useful earth materials of different physical quality are distributed randomly over this continent at discrete locations. The least-cost framework would predict a zonation of agricultural land-use around this node as shown in the model of von Thünen (Abler et al., 1971, pp. 346-53). The location of economic activity on this continent is influenced by distance from the principal market (the sea port), and by distance from service nodes in the developing network. Demands for metal commodities arise (and are concentrated) in this node, giving rise to derived demand for metalliferous minerals.

The use of Weberian polygons to predict the location of processing plants is difficult because only one vertex, the market, is known. Blainey (1966, pp. 137-9) has argued that information about potential mineral deposits would have been accumulating as agriculture and settlement expanded. Firms make use of this information in their assessment of sources for processing industry but their searching procedure is strictly bounded by knowledge and costs; only a small amount of exploration can be supported without a production decision. The remaining vertices of the location polygon are fixed to achieve least total cost (including that of discovery)*. Distances from the urban

* If only inadequate or poor quality deposits had been encountered, input prices would be high and demand for metals would be restricted. Resource creation in the closed economy would be stifled and abandoned, and the economy would be 'poor in resources'. The critical relationship is that between costs of obtaining information and the expected profitability of mining (itself dependent on demand). Lack of entrepreneurs and shortage of risk capital may exacerbate the paucity of resources.
Fig. 1.8: Resource development and plant location on a hypothetical island continent
node remain small and plants are located either at the mines or the market although, at small outputs, those at the market may be more profitable (Fig. 1.8a). Known deposits in more remote locations do not bear the cost of exploration once market demand is satisfied, and the size of the resource base is determined by market demand and the state of transport and facility networks.

Although information about remote areas may increase, there is no incentive for organized exploration while the domestic market remains small (and closed), except for that by established companies seeking to offset depletion. Further resource creation might be stimulated by population growth and changes in tastes, as urbanization increases and the settlement network expands. New mines are established in response to increased demand and the exhaustion of some initial sources, and large but remote deposits may be developed in preference to closer ones if they offer substantial cost advantages. The pattern of plant locations tends to be relatively stable -- it may be difficult for new firms to enter the industry. New locations are likely for large plants, exploiting economies of scale, at major inland mines, and at transshipment points for new sources if the port location offers lower total costs than the mine. Some plants which now appear 'market-oriented' were initially 'material-oriented' (Fig. 1.8b). Resource creation is controlled by the level of demand and the components of total production cost.

If the economy is now opened to foreign trade, analysis of optimal location becomes more difficult since much now depends on international comparative advantage (Isard and Peck, 1954). Demand for metal commodities may be satisfied by low-cost imports, although distance from exporting countries and government tariff protection encourage local manufacturing. Demand opportunities increase substantially for both metal commodities and unprocessed minerals. If metals are exported, some of the
established plants may increase their output and a new mining and processing firm may be developed solely for export. The location of the export plant involves a choice between the mine and its outlet port (which operates as the 'market' vertex in a Weberian polygon). In addition, new deposits are likely to be brought into production to supply plants located overseas. The possibilities of foreign trade stimulate new exploration and resource creation, and there is now no necessary nexus between mining development and the location of domestic processing plants (Fig. 1.8c).

1.3 Governments and the Resource Creation Process

This study has been set in a framework of normative location theory with the argument that optimal location patterns will tend to evolve as a product of basic economic forces. The importance of institutional constraints on resource creation has been implicit in this chapter; an understanding of the influence of governments is essential in specifying the links between resource development and plant location. The first step in the analysis of governments is to identify types of spatial influence and the problems involved in measuring it (sub-section 1.3.1). This leads to an examination of the structure of the thesis and a re-statement of its aims.

1.3.1 Analysing the spatial role of governments

Although the importance of governments in location is widely recognized, 'very little effort appears to have been made to bring this type of influence adequately into the framework of spatial analysis' (Linge, 1971, p. 25). Chisholm (1966, p. 215) has argued that 'one reason for this lack of interest has been the difficulty of devising techniques of analysis' and established methods of identification and measurement of government influence are absent. As a result, less direct government influences have been neglected, including constraints on private decision-making.
Geographers have largely ignored the mechanics of policy formulation and have seldom considered optimality of spatial policy (Tinbergen, 1956). Such analysis would be facilitated by the development of a more general behavioural theory of location, with public policy-makers as actors in spatial games attempting to maximize a social objective function both by direct participation, and by influencing the behaviour of other players by legislative processes. A prerequisite for such theoretical development is an improved understanding of the spatial results of policy, and Oxtoby (1970, p. 463) has commented that 'few studies pertain specifically to the impact of public policy on the locational patterns of industrial activity'. A first step is to identify types of government spatial involvement*.

Three types of influence are investigated in this study: first, governments act as direct spatial decision-makers; second, they act to delimit the area of choice of private decision-makers; and third, they have indirect influence through other location factors. State-owned industrial enterprises are commonly established during wartime (Peck, 1961) and these plants often become nuclei for peacetime industrial development by private entrepreneurs. In Australia, activities like public utilities which would operate as 'natural monopolies' (Nourse, 1968, pp. 228-9) are controlled directly, and both the prices charged and the siting of establishments can influence the location of processing industry. Private decisions in resource development and plant location are constrained directly by the legislative framework established under 'mineral policies', while firms are also directly influenced by a variety of more general policies. Control over trade is common (Manners, 1971, pp. 84-91) both by regulation of exports and tariff protection against imports (Oxtoby, 1970).

* Since Australian governments are the focus of attention in this thesis, centrally-planned economies are ignored here. Hamilton (1970; 1971, p. 78) has reviewed the basic principles of industrial location in socialist countries.
Mines and processing plants must operate under mineral agreements, and mining is subject to heavy taxation as society attempts to maximize the return from its resource base. Finally, governments influence the operation of other location factors such as freight rates, the cost of infrastructure, and regional production costs.

Accurate measurement of these types of influence on resource patterns would be a formidable task. Long-established policies do not produce the expected result in every situation, and the influence of other factors can be wrongly attributed to the government. The evaluation of policy instruments used in relation to extractive industries, has attracted much interest among economists (Gaffney, 1967), and economic models can be manipulated readily to predict the influence of government measures. This practice is less developed in spatial analysis, although Richardson (1969, pp. 67-8) and D.M. Smith (1971, pp. 210-11) have examined some government influences on industrial location using space cost curves. The testing against reality of patterns generated from normative models offers a preliminary means of analysing institutional influences, yet government policy does not act only to constrain the evolution of economically optimal patterns; the least-cost solution itself would be influenced by governments since policy affects the parameters from which such a solution is generated. The quantification of the indirect influences of government is a most difficult task and Chisholm (1966, pp. 220-1) implies that such measurements involve a considerable degree of subjectivity.

1.3.2 A reconsideration of the aims of the study

The aims of this thesis are twofold. In Part II, the spatial parameters of the resource creation process are examined in Australia in relation to metalliferous minerals; the aluminium industry forms a case study but comparative data are drawn from the metals, copper, iron, lead, and zinc. In Part III, the principal ways in which governments influence the operation of this process are identified and
some form of preliminary measurement is attempted. It is difficult to develop the empirical study in terms of formal tests of hypotheses. Geographers and economists have made a large number of empirical studies of industrial location, but most have sought to identify and measure the influence of spatial parameters. Stevens and Brackett (1967, p. 7) have argued that 'it has been difficult to generate testable hypotheses from the existing theory'. In its present form the resource creation model investigated in this chapter provides notions rather than formal hypotheses. Hence, the study of resource development and plant location seeks to identify the basic economic forces which would produce optimal location patterns under the least-cost framework, and will pay particular attention to the structure of demand (Chapter 2), production costs (Chapter 3), and the costs of distance including transport (Chapter 4), and extra capital costs incurred at isolated locations (Chapter 5). The empirical study is completed (Chapter 6) by a consideration of the interaction of all spatial factors, and the least-cost location pattern for the aluminium industry is generated by linear programming. The influence of governments is detailed in Chapter 7, and Chapter 8 reconsiders resource creation as a spatial process in the Australian metalliferous mineral industries.
PART TWO

THE AUSTRALIAN METALLIFEROUS MINERAL INDUSTRIES:

RESOURCE CREATION PROCESSES
The empirical part of this thesis examines resource creation with respect to five metals: the Australian aluminium industry forms the main case study but comparative data are drawn from the domestic iron and steel, copper, lead and zinc industries to illustrate aspects of resource development and plant location. Hence, there is no attempt in this Part to analyse in detail the growth of these industries, the value of foreign trade in mineral commodities, the precise contribution of mineral industries to Gross National Product, the costs and benefits of overseas capital inflow, or the role of mining and processing in regional economic growth. Rather, the individual chapters attempt to measure the spatial factors involved in local resource development and plant location processes as the basis for an examination of the influence of governments in shaping resource creation. The Part begins with an industry-specific analysis of location patterns and demand, develops a systematic study of resource creation, focussing on costs of product, transport and infrastructure, and returns to individual industries to conclude the survey.

The course of the mineral 'boom' in Australia since the mid-1960s has remained largely undocumented apart from the regular summaries released by the Bureau of Mineral Resources, Geology and Geophysics. Non-spatial analysis has been published by the Committee for the Economic Development of Australia, for example by Tsung (1970) and Subocz (1971); financial aspects have been studied by Rose (1969); and summaries of development have been made by Raggatt (1968) and Coghill (1971). More specific research has been carried out by McKern (1972) and Bambrick (1972) but substantive results are as yet unpublished.

The relative simplicity of domestic location patterns in the copper, lead and zinc industries suggests the major metals, aluminium and steel, for spatial analysis. The
aluminium industry has been chosen as the case-study in Part II for three main reasons. First, it constitutes an integrated domestic production system and the resource creation process can be traced from bauxite exploration through to sales of ingot to domestic metal-using industries. Second, little work has been done on spatial patterns within the industry apart from introductory surveys by Duncan (1961) and Dowie (1967). Third, considerable work has been done elsewhere on the domestic iron and steel monopoly, for example Wills (1963) and Hughes (1964), while in the most recent study, Allen (1971) has considered the location economics of the entry of a second domestic steel producer. Hence, for the aluminium industry, an attempt is made in this Part to measure location factors quantitatively and to draw them together into a formal spatial equilibrium model.

Much of the data for this empirical study were collected during 1970 and, unless specified otherwise, are correct to the end of that year. Yet events move rapidly in the mineral industry, projections from these data were generally of limited use, and some of the conclusions drawn were beginning to appear dated by 1972. Developments since the end of 1970 that have a bearing on the arguments and conclusions of this Part, therefore, have been indicated in footnotes where appropriate. Data for the aluminium industry were derived primarily from fieldwork and, for other minerals, from the Bureau of Mineral Resources, Geology and Geophysics, the Australian Mining Industry Council, personal communication with the major mineral companies, and published sources. Because of confidentiality problems, mineral companies approached were seldom prepared to release actual data, especially on production and transport costs, and estimation techniques were developed following fieldwork.
The wealth of Moria was not in gold and jewels, the toys of the Dwarves; nor in iron, their servant. Such things they found there it is true, especially iron; but they did not need to delve for them: all things they desired they could obtain in traffic (J.R.R. Tolkien, 1966, p. 335).

For the metalliferous minerals, an analysis of resource creation within a framework drawn from classical location theory presupposes a fund of knowledge about the extent and quality of deposits and, in addition, the availability of production technology, a set of demands for metals, and a series of market structures through which these demands can be satisfied. Deficiencies in the theoretical models arise partly because of the assumptions of inelastic, punctiform demand. Yet demand is important in resource creation, for the feasibility of particular mining developments depends on trends in the prices of ingot and, therefore, on the character of metal marketing. Rising prices can stimulate exploration and render economic deposits previously though to be uneconomic; falling prices do not necessarily discourage resource development processes although mines and processing plants whose profitability is marginal are placed under great pressure and may be abandoned. The importance as a location factor of demand for metals is related to the relative transportability of ores, processed materials, ingot, and fabricated products.

The resource creation process ends in sale, or captive transfer, of unwrought metal to user-industries, but this generates a system of demands for the output of mines and first-stage processing plants. Location decisions by metal producers simultaneously create a series of flow patterns involving earlier production stages. In a (hypothetical) closed economy, all production and commodity flows in the resource creation process would be shaped by
this link with the domestic manufacturing sector. In reality, the structure of demand is more complex because of overseas trade. Imported metals often compete against local products in supplying metal-using industries, and the domestic system of demand becomes more complicated when materials are exported from some (or all) levels of production. Foreign trade exerts a very strong influence on the location patterns of both mines and processing plants, but a complete assessment awaits the analysis of production and transport costs. Industrial structure is also important and the prevalence of vertical integration in the domestic aluminium, steel, and copper industries partially obscures the commodity flow patterns.

It is convenient to commence the study of the Australian industries by examining the location of mines and processing plants in 1970 in relation to the spatial parameters of demand. Following a general survey of the metalliferous minerals, this chapter considers the aluminium industry (section 2.2) and iron, copper, lead, and zinc (section 2.3) concentrating on the relationships between demand at each production level, the location patterns, and the industrial structure. The importance of demand factors in resource development and plant location processes is reviewed in section 2.4 and the retention of the least-cost location framework for the study is evaluated.

2.1 The Australian Metalliferous Mining and Processing Industries

The location of mines and processing plants operating in 1970 is shown in Fig. 2.1*, and distance relationships

* Installed production capacities have been mapped to show relative scales of operation of mines and processing plants. Actual output levels for a given year are less reliable, varying with seasonal price fluctuations and with periodic abnormal circumstances (such as prolonged drought or industrial disputes).
Fig. 2.1: Australia - production capacities at principal metalliferous mines and processing plants: 1970

between the various production points are summarized in Table 2.1. This information forms a basis for much of the analysis in Part II. While large processing plants exist adjacent to some of the mines, seaboard location appears to be predominant and long haulages of mineral commodities are common. The overall location pattern depicted in Fig. 2.1 reflects the complexities of resource creation, but is merely a stage in an evolutionary process and, although relatively stable during the 1950s, it has been subject to rapid change since 1960. A general increase in the level of exploration activity was followed by some major discoveries, especially of bauxite, iron ore, and nickel, and this stimulated further searching and a 'boom' on the Australian stock markets in exploration and mining shares. While much of this activity was speculative, there have been major changes in the contribution of metalliferous minerals to the overall economy as a result of dramatic increases in the production of ores and processed materials, the development of new mines, and the location of additional processing facilities. The five metals chosen for study have played different roles in the boom.

The mining industry contributed only about six per cent to Gross National Product in 1970, compared with one per cent in 1965 (Tsung, 1970, p. 1). Yet its principal contributions have been the support of growing mineral processing industries, a sharp increase in State governments' revenue from mining royalties, the establishment of basic infrastructure in remote areas and, perhaps most important, the attainment not only of self-sufficiency in the major metalliferous minerals (a long-established political goal), but also of large exportable surpluses and significant additions to foreign exchange earnings. While Australia remains a significant producer of gold, mineral sands, tin, tungsten, and manganese, the five metals chosen
### TABLE 2.1: DISTANCES BETWEEN MAJOR MINES, OUTLET PORTS, AND PROCESSING PLANTS

**SHOWN IN FIG. 2.1 (BY INDUSTRY GROUPS)**

(Statute miles)

<table>
<thead>
<tr>
<th>Origin - destination</th>
<th>Commodity flow</th>
<th>Transport mode</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aluminium</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weipa - Gladstone</td>
<td>bauxite</td>
<td>sea</td>
<td>1,540</td>
</tr>
<tr>
<td>Weipa - Bell Bay</td>
<td>bauxite</td>
<td>sea</td>
<td>2,800</td>
</tr>
<tr>
<td>Jarrahdale - Kwinana</td>
<td>bauxite</td>
<td>rail</td>
<td>28</td>
</tr>
<tr>
<td>Gladstone - Bell Bay</td>
<td>alumina</td>
<td>sea</td>
<td>1,410</td>
</tr>
<tr>
<td>Gladstone - Newcastle</td>
<td>alumina</td>
<td>sea</td>
<td>790</td>
</tr>
<tr>
<td>Newcastle - Kurri Kurri</td>
<td>alumina</td>
<td>road</td>
<td>28</td>
</tr>
<tr>
<td>Kwinana - Point Henry</td>
<td>alumina</td>
<td>sea</td>
<td>1,950</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tom Price - Dampier</td>
<td>iron ore</td>
<td>rail</td>
<td>182</td>
</tr>
<tr>
<td>Paraburdoo - Dampier</td>
<td>iron ore</td>
<td>rail</td>
<td>247</td>
</tr>
<tr>
<td>Newman - Port Hedland</td>
<td>iron ore</td>
<td>rail</td>
<td>265</td>
</tr>
<tr>
<td>Mount Edil - Cape Lambert</td>
<td>iron ore</td>
<td>rail</td>
<td>104</td>
</tr>
<tr>
<td>Goldsworthy - Port Hedland</td>
<td>iron ore</td>
<td>rail</td>
<td>71</td>
</tr>
<tr>
<td>Middleback Range - Whyalla</td>
<td>iron ore</td>
<td>rail</td>
<td>37</td>
</tr>
<tr>
<td>Whyalla - Newcastle</td>
<td>iron ore and pellets</td>
<td>sea</td>
<td>1,360</td>
</tr>
<tr>
<td>Whyalla - Port Kembla</td>
<td>iron ore and pellets</td>
<td>sea</td>
<td>1,240</td>
</tr>
<tr>
<td>Yampi Sound - Newcastle</td>
<td>iron ore</td>
<td>sea</td>
<td>3,440</td>
</tr>
<tr>
<td>Koolyanobbing - Kwinana</td>
<td>iron ore</td>
<td>rail</td>
<td>306</td>
</tr>
<tr>
<td>Savage River - Port Latta</td>
<td>iron ore</td>
<td>pipeline</td>
<td>53</td>
</tr>
<tr>
<td>Koolanooka - Geraldton</td>
<td>iron ore</td>
<td>rail</td>
<td>140</td>
</tr>
<tr>
<td>Frances Creek - Darwin</td>
<td>iron ore</td>
<td>rail</td>
<td>105</td>
</tr>
<tr>
<td>Mount Bundey - Darwin</td>
<td>iron ore</td>
<td>road/rail</td>
<td>68</td>
</tr>
<tr>
<td><strong>Copper</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Isa - Townsville</td>
<td>blister copper</td>
<td>rail</td>
<td>605</td>
</tr>
<tr>
<td>Mount Morgan - Port Alma</td>
<td>blister copper</td>
<td>rail</td>
<td>61</td>
</tr>
<tr>
<td>Queenstown - Burnie</td>
<td>copper concentrates</td>
<td>road/rail</td>
<td>90</td>
</tr>
<tr>
<td>Burnie - Port Kembla</td>
<td>copper concentrates</td>
<td>sea</td>
<td>570</td>
</tr>
<tr>
<td>Cobar - Port Kembla</td>
<td>copper concentrates</td>
<td>rail</td>
<td>470</td>
</tr>
<tr>
<td>Tennent Creek - Port Augusta</td>
<td>copper concentrates</td>
<td>road/rail</td>
<td>1,052</td>
</tr>
<tr>
<td><strong>Lead and Zinc</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken Hill - Port Pirie</td>
<td>lead and zinc concentrates</td>
<td>rail</td>
<td>247</td>
</tr>
<tr>
<td>Broken Hill - Cockle Creek</td>
<td>lead and zinc concentrates</td>
<td>rail</td>
<td>740</td>
</tr>
<tr>
<td>Port Pirie - Risdon</td>
<td>zinc concentrates</td>
<td>sea</td>
<td>1,250</td>
</tr>
<tr>
<td>Cobar - Cockle Creek</td>
<td>lead and zinc concentrates</td>
<td>rail</td>
<td>500</td>
</tr>
<tr>
<td>Rosebery - Burnie</td>
<td>lead and zinc concentrates</td>
<td>rail</td>
<td>70</td>
</tr>
<tr>
<td>Burnie - Risdon</td>
<td>zinc concentrates</td>
<td>sea</td>
<td>370</td>
</tr>
<tr>
<td>Mount Isa - Townsville</td>
<td>zinc concentrates lead bullion</td>
<td>rail</td>
<td>605</td>
</tr>
</tbody>
</table>

*a In the Newcastle urban area.*

Source: See Fig. 2.1 from which this table is derived.
for study in this thesis accounted in 1970 for more than four-fifths of the ex-mine value of metalliferous mineral production*.

Lead-zinc and copper provided the mainstays of metalliferous mineral industries until the mid-1960s. The production of copper ores has fluctuated, but the installed capacities for blister copper and refined metals have increased steadily (Table 2.2) and, while the most rapid developments took place during the 1950s (Raggatt, 1968, pp. 191-214), the annual output of refined primary metal exceeded 100,000 tons for the first time in 1970**. Australia has long been one of the world's main sources of lead and a large producer of zinc; these metals are generally mined together from the same ore bodies although extraction of the metals from their concentrates involves sharply different processes (investigated in Chapter 3). Production of refined lead at Port Pirie (Fig. 2.1) has been relatively stable, but the output of lead bullion has increased following a rise in exports and that of refined zinc has risen substantially since 1960.

Increases in the production of copper, lead, and zinc have been overshadowed by developments in iron and aluminium. Installed capacities for smelting iron, copper, and zinc rose by about one-third between 1965 and 1970, but the aluminium industry more than doubled its ingot capacity over the same period (Table 2.2). Since 1965, iron ore has become the leading metalliferous mineral (in terms of ex-mine value of output); both the number of mines and the installed production capacity have increased rapidly and


** Production patterns for the major minerals, in various forms, over the last decade are summarized in Appendix I(a).
<table>
<thead>
<tr>
<th>Commodity</th>
<th>Number of plants</th>
<th>Capacity (thousand tons)</th>
<th>Number of plants</th>
<th>Capacity (thousand tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>2</td>
<td>3,800</td>
<td>2</td>
<td>10,750</td>
</tr>
<tr>
<td>Alumina</td>
<td>2</td>
<td>450</td>
<td>3</td>
<td>2,565</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2</td>
<td>94</td>
<td>3</td>
<td>229</td>
</tr>
<tr>
<td>Iron ore</td>
<td>4</td>
<td>7,000</td>
<td>12</td>
<td>57,200</td>
</tr>
<tr>
<td>Iron ore pellets</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>6,500</td>
</tr>
<tr>
<td>Pig iron</td>
<td>4</td>
<td>4,500</td>
<td>4</td>
<td>6,500</td>
</tr>
<tr>
<td>Crude steel</td>
<td>3</td>
<td>5,500</td>
<td>3</td>
<td>7,250</td>
</tr>
<tr>
<td>Copper concentrates</td>
<td>7</td>
<td>500</td>
<td>8</td>
<td>600</td>
</tr>
<tr>
<td>Blister copper</td>
<td>4</td>
<td>90</td>
<td>3</td>
<td>120</td>
</tr>
<tr>
<td>Refined copper</td>
<td>3</td>
<td>90</td>
<td>2</td>
<td>120</td>
</tr>
<tr>
<td>Lead concentrates</td>
<td>7</td>
<td>610</td>
<td>7</td>
<td>720</td>
</tr>
<tr>
<td>Lead</td>
<td>3</td>
<td>300</td>
<td>3</td>
<td>345</td>
</tr>
<tr>
<td>Zinc concentrates</td>
<td>7</td>
<td>650</td>
<td>7</td>
<td>920</td>
</tr>
<tr>
<td>Zinc</td>
<td>2</td>
<td>200</td>
<td>3</td>
<td>265</td>
</tr>
</tbody>
</table>

output rose from 6,700,000 tons in 1965 to more than 50,000,000 tons in 1970. Bauxite has recently displaced lead-zinc mining in value, and production, negligible before 1963, reached 9,000,000 tons in 1970. Installed capacities in alumina production have increased, and output rose from 30,000 tons in 1960 to more than 2,000,000 tons in 1970.

Despite significant increases in the domestic consumption of metals (especially aluminium), a rise in exports has been the principal characteristic of the mineral boom since 1965. The contribution of the study minerals to total export earnings had risen to eighteen per cent by 1970 and is expected to reach one-quarter by 1975*. The total value of exports of these minerals (in all forms) was $697,000,000 and could be about $1,250,000,000 by 1980**. Lead, copper, and zinc remain the most important ingot metals exported, although crude steel has been exported since 1966 and overseas sales of aluminium rose from sixteen per cent of total output in 1969 to forty per cent in 1970. The importance of exports of ores and processed raw materials, however, is reflected in Table 2.3. The majority of lead and copper concentrates is processed into ingot but the Mount Isa mine (Fig. 2.1) presently exports its entire output of zinc concentrates. Only about one-third of iron ore produced in 1970 was processed and a large proportion of this was used in manufacturing iron pellets for sale to Japan. Iron ore, indeed, has become Australia's principal mineral export commodity; exports grew from zero (1963) to 9,000,000 tons in 1967 and 35,400,000 tons in 1970. On available projections from currently-producing mines and those under development, exports could reach 70,000,000 tons per annum by 1975. More than two-thirds of bauxite produced was further processed (Table 2.3) but

* Between 1965-66 and 1970-71, the contribution of wool to the total value of exports fell from thirty per cent to nineteen per cent.

** Australian Mining Industry Council, pers.comm., October 1970.
**TABLE 2.3: EXTENT OF DOMESTIC PROCESSING OF MINERAL COMMODITIES - AUSTRALIA**
(per cent of tonnage produced)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1970</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ores and concentrates</strong></td>
<td></td>
</tr>
<tr>
<td>Bauxite</td>
<td>68</td>
</tr>
<tr>
<td>Iron ore</td>
<td>33</td>
</tr>
<tr>
<td>Copper concentrate</td>
<td>80</td>
</tr>
<tr>
<td>Lead concentrate</td>
<td>85</td>
</tr>
<tr>
<td>Zinc concentrate</td>
<td>40</td>
</tr>
<tr>
<td><strong>Processed materials</strong></td>
<td></td>
</tr>
<tr>
<td>Alumina</td>
<td>20</td>
</tr>
<tr>
<td>Iron ore pellets</td>
<td>15</td>
</tr>
</tbody>
</table>


four-fifths of the resulting alumina was exported.

The timing of the mineral boom of the 1960s, therefore, was strongly influenced by trends in international trade, especially in iron ore and bauxite. The major industrialized nations of the Northern Hemisphere (the Soviet Union aside) began to face increased scarcity of established ore supply sources during the 1950s, both because of the cumulative effects of depletion and rapid increases in metal production. Although Australian ores are now sold in Western Europe and North America, much of the overall demand has come from Japanese industry; financial participation in new ventures has involved multi-national corporat-
ions from North America and the United Kingdom. This rapid growth has led not only to modifications of the location pattern, but also to radical changes in the structure of the mineral industry and the degree of equity owned by foreign enterprises.

The proportion of Australian equity differs considerably between metals and between mining and processing stages. Local participation is strongest in the steel and lead-zinc industries*, although there are strong British interests in the latter. About half of total equity in the copper industry is held by Australians, and the balance by the United States and the United Kingdom. Only one-third of total equity in the export iron mining ventures is owned locally, the remainder being shared between the United States, the United Kingdom, and Japan. Less than one-quarter of the Australian aluminium industry is owned directly by Australian companies and individuals, and this consists principally of large (minority) shareholdings in two of the three ingot producers. The increase in foreign capital and ownership in the metalliferous mineral industries has some important spatial implications apart from other political and macro-economic considerations. McKern (1972) has argued that the present situation is the outcome of a bargaining process between local entrepreneurs, Australian governments, and multi-national corporations, in which the relative strengths of the participants depend on international marketing arrangements, capital requirements for resource development and plant location, the complexity of technologies (especially of processing), and Australia's resource endowment relative to other countries. The

* Indices were derived by applying the equity shareholding for the relevant companies, listed in Appendix I(b), to total company assets at the end of 1970. The resulting data were very approximate but allowed broad comparisons. Bambrick (1972) has commented on the difficulty of making sound measurements of ownership and control on an industry-wide basis.
importance of industrial structure forms a recurrent theme throughout this thesis because both location theorists and governments must grapple with such institutional influences.

2.2 The Aluminium Industry

The aluminium industry has been the fastest growing among the metalliferous minerals; since 1966, Australia has become a major exporter of bauxite and alumina, while a local smelting and fabrication industry has grown rapidly with the development of two fully-integrated corporations since 1960, and the entry of a third smelter in 1969. The growth of domestic smelting has been based on an expanding, and fully protected, local market, and the export of raw materials has followed the development of some of the world's largest bauxite deposits discovered and tested during the late 1950s. Following a brief consideration of location and industrial structure (sub-section 2.2.1), this section considers in turn the demand for bauxite and alumina (sub-section 2.2.2), and for ingot (sub-section 2.2.3).

2.2.1 Location and industrial structure

At the beginning of 1960, the Australian aluminium industry consisted of a single smelter at Bell Bay (Fig. 2.1) with an annual capacity of only 12,000 tons, and a small adjacent alumina refinery using imported bauxite. By 1970, two vertically-integrated corporations had been established based on bauxite mines in contrasting environments. The world aluminium industry is characterized by vertical integration and Fig. 2.2 reflects its importance in the Australian industry. Bauxite has been mined since 1963 at Jarrahdale, in the Darling Ranges east of Perth (Fig. 2.1) by Alcoa of Australia Ltd, and the entire output (3,240,000 tons in 1970) is refined at Kwinana. Most of the alumina is exported, but about one-fifth is smelted at Point Henry in Victoria. Expansions of mining by this company will support
**Fig. 2.2: The structure of the Australian aluminium industry**

* Denotes flow between plants of the same company or group
an additional refinery at Pinjarra*.

The second integrated producer, Comalco Ltd, exploits the large high-grade bauxite deposit at Weipa on Cape York Peninsula and about 6,000,000 tons were extracted in 1970. An expansion programme completed in 1972 raised mining capacity to 10,500,000 tons making it the largest single bauxite mine in the world. About half its output is exported, a small amount is processed at the company's refinery-smelter complex at Bell Bay, and the remainder refined at Gladstone by a refining consortium of which Comalco Ltd is a member. Comalco Ltd plans to establish an alumina refinery at the mine-site although the timing remains indefinite. The Gladstone plant, established in 1967, produced 1,200,000 tons of alumina in 1970, more than four-fifths of which were exported, and annual production capacity is being raised to 2,000,000 tons. The smelter at Bell Bay consumes a small amount of alumina produced at Gladstone.

A third smelter was established at Kurri Kurri in 1969 by Alcan Australia Ltd and alumina is drawn from the Gladstone refinery in which the company participates financially. The total installed ingot capacity in Australia has thus risen to 229,000 tons. Alcan Australia Ltd holds bauxite leases on Cape York Peninsula but there are no firm plans to develop mining. A third bauxite mine has operated at Gove, at a latitude similar to Weipa, since 1971 and ore is exported to provide a cash flow for an adjacent alumina

* This was completed in 1972.
refinery under construction *.

The resource development and plant location patterns just outlined cannot be understood fully without knowledge of industrial structure. The Australian metalliferous mineral industries as a whole are dominated by a small number of large firms, many of which are subsidiaries or associates of overseas mining groups. Neither the multi-plant firm nor the multi-national corporation is adequately digested by location theory or micro-economics in general (Penrose, 1968, p. 25). Internationalism, especially vertical integration across national boundaries, means that production costs and even transfer costs can be internalized and comparative advantage then depends partly on accounting procedures. A multi-national corporation can distribute its profit-earning capacity for taxation purposes and according to non-economic criteria so as to better withstand local political pressures or the activities of international competitors (Odell, 1963, p. 2). In host countries such as Australia, the multi-national corporations enter various company structures including wholly-owned subsidiaries or, more commonly, new companies with (minority) shareholding by local entrepreneurs or governments. In some instances, two or more major corporations have formed joint ventures with local participants, and the formation of the consortium has become popular.

* Additional bauxite-alumina projects have been planned but some remain speculative. An Amax Consortium (see Appendix I(b)) has commenced developing a bauxite mine on the Mitchell Plateau in the Kimberley Region following the signing, in 1969, of an agreement with the Western Australian Government to construct an alumina refinery in the area. In August 1972, however, Amax announced that it was considering joining Alcoa of Australia Ltd in the development of the Pinjarra refinery south of Perth. An agreement to establish a further refinery near Bunbury was signed by Alwest Ltd in 1970 and mining will be carried out in the South Darling Ranges within the next five years.
The aluminium industry provides a classic example of the influence of industrial structure on location patterns. More than three-fifths of the world's primary ingot capacity is controlled by the six largest producers, namely, Aluminum Company of America ('Alcoa'), Alcan Aluminum Ltd of Canada, Reynolds Metals Incorporated of the United States, Kaiser Aluminum and Chemical Corporation of the United States, Pechinéy Compagnie de Produits Chemique et Electrometallurgique (France), and Swiss Aluminium Ltd. These corporations have also integrated forwards into semi-fabrication facilities both in their parent countries and internationally. All of the North American members of the 'big six' have smelting interests in Europe. The development of the world oligopoly has been reviewed by Peck (1961) and the industrial structure is reviewed by Brubaker (1967, pp. 99-117) and Brown and Butler (1968, pp. 23-8); tight control at the second-stage processing and manufacturing levels has exerted a strong influence on world patterns of production of alumina and bauxite.

There is no world market price for alumina and captive transfers are common, since much of the productive capacity is controlled by the oligopolists. Thus independent smelting companies in the United States, Western Europe, and Japan have been encouraged either to maintain their own refineries or enter joint ventures with the multi-national corporations. Bauxite is sold at negotiated prices to 'independent' refineries in Europe and Japan, but the 'big six' now have large interests in bauxite mining in the major production areas to secure supplies for their alumina plants*. The Japanese smelting firms operate their

* A vertically-integrated industrial structure becomes self-perpetuating. Independent producers find themselves becoming dependent on raw material purchases from producers financially associated with the main vertically-integrated corporations and so either enter raw material production directly, or combine with the large companies in joint ventures.
own refineries but domestic expansion is becoming difficult, especially in view of strict pollution controls, and some of these producers are considering joint ventures with Australian entrepreneurs for the future production of alumina (for example, in the Amex Consortium and the Alwest Ltd project, and possibly with Comalco Ltd at Weipa). This world industrial structure has profound locational implications, one of which is the prevalence of captive transfers considered later in this section; in addition, locational decision-making is influenced not only by production economics and transport costs, but also by global corporate strategy*.

Captive transfers of bauxite, alumina, and ingot are indicated in Fig. 2.2. Alcoa, Alcan Aluminum Ltd, and Kaiser Aluminum and Chemical Corporation are all involved in local vertically-integrated production, including the control of some metal-using establishments. Alcan Aluminum Ltd has operated a semi-fabricating subsidiary since 1936 and has expanded its local activities since 1960; the other two multi-national corporations were invited to participate in resource development and plant location by local entrepreneurs seeking access to the tightly-controlled world markets and processing technologies, and large-scale borrowings for capital-intensive mining and processing ventures. Since 1965, Swiss Aluminium Ltd and Pechinéy Compagnie have entered alumina refinery projects. The participation of overseas companies has been a prerequisite for the development of the Australian aluminium industry to its present size but as a result, control, a proportion of the profits, and ultimate locational decision-making have passed out of domestic hands.

* For example, alumina refineries processing Caribbean bauxite were, for many years, concentrated along the Gulf coast of the United States for strategic reasons and have only recently been constructed near the mines, the simple least-cost locational solution. Bauxite from Weipa has been transported, since 1972, to an international refining consortium in Sardinia which is inside the European Economic Community. The transfer of alumina to smelters inside the E.E.C. attracts much higher tariff than that of bauxite.
2.2.2 The demand for bauxite and alumina

The degree to which bauxite and alumina are processed locally is shown in Table 2.3. If the aluminium industry operated as a closed system, the output of mines and first-stage processing plants would be strictly determined by the external relations of the vertically-integrated producers (see Fig. 2.2), and resource creation processes would be constrained by the size of the market. To meet local metal demands, the total requirements of alumina in 1970 would have been 260,000 tons (the actual output was 2,104,000 tons) and requirements of bauxite 600,000 tons instead of 9,000,000. The development of bauxite resources has been conditioned by foreign trade.

Although two-thirds of the total bauxite output are processed domestically, only fourteen per cent forms the basis for second-stage processing and the remainder is exported as ore or alumina *. While the relationships between scale of operations, production costs, and the feasibility of mining developments is properly the concern of Chapter 3, it is obvious that local markets could sustain only restricted resource developments and that the spatial pattern of bauxite and alumina production would be quite different to that which developed during the 1960s. A mine producing 600,000 tons of bauxite per annum would be small by present Australian standards; remote deposits may not have been exploited, and it is possible that alumina requirements could be produced locally from (captively transferred) imported bauxites at prices competitive with c.i.f. prices from small local mines.

Second only to Jamaica in 1970, Australia is expected to become the world's largest bauxite producer during the

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* If additional alumina refineries proposed in 1970 are brought into production on schedule, only about six per cent of locally-produced bauxite will find its way into domestic ingot production by 1975 despite increased exports of metal and a rapid growth-rate of local consumption.
In the 1970s, Comalco Ltd has been able to export large quantities of bauxite from Weipa, a high-grade deposit close to tidewater. In 1970, 3,400,000 tons were sold under long-term contracts at a price of about $6.00 per ton f.o.b.*. Japanese alumina refineries process imported bauxite which was largely obtained from Southeast Asia until 1963; by 1970, nearly half was purchased from Weipa. Contracts with such refineries in 1970 involved a shipment of 1,300,000 tons and, in addition, more than 1,500,000 tons per annum are now shipped to European refineries and 500,000 tons to the United States. The mine at Gove commenced exports of bauxite to Japan in 1971 at an annual rate of 2,000,000 tons.

Australia's present alumina refineries, with the exception of the small one at Bell Bay, depend on exports to overseas smelters, and, under a series of complex 'sales' relationships, about 1,700,000 tons were exported in 1970 (four-fifths of output). This may rise to 7,500,000 tons by 1975 involving the establishment of four additional domestic plants and three new bauxite mines. Only three of these seven plants would supply local smelters. Japanese smelters have outgrown the capacity of their domestic alumina refineries** and have become dependent on Australia for virtually all of their imports. A majority of exports, however, leave Australia as captive transfers to smelters in North America and Europe. Exports from the Gladstone plant are divided among the parent companies in strict accordance with their equity shareholding; Alcoa of Australia Ltd transfers alumina to its American parent but

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* These bauxite contracts are the longest yet negotiated for any Australian mineral. Comalco Ltd has contracted to export 194,000,000 tons of bauxite between 1970 and 1997 and a further 176,000,000 tons to the year 2041. Further contracts are sought for the period 1971 to 2008.

** Expansion of alumina refining has become difficult in Japan; plants are generally located on shallow harbours, suffer from obsolescence, and increasing concern over pollution makes re-location unlikely.
also sells under contract to independent smelting corporations in Japan, the United States, and Europe*. Swiss Aluminium Ltd will dispose of the entire output of the refinery at Gove, while Japanese smelting firms are expected to take equity participation in future planned refineries.

2.2.3 The demand for ingot: the semi-fabrication industries.

Rising domestic demands for a metal could be expected to result from population increases, and from economic growth generally; faster growth-rates of consumption can be achieved where these trends are accompanied by changes in tastes, such as the development of new uses and substitution for other metals. In this regard, aluminium has overshadowed other metals in Australia (Fig. 2.3) and domestic consumption has grown at twelve per cent per annum since 1960. Local demand for ingot was satisfied by imports until 1955 when the smelter at Bell Bay commenced production; annual consumption was less than 20,000 tons, about five lbs per capita. Quantitative import restrictions provided for selling the total output from Bell Bay at a guaranteed price, but imports satisfied more than half of total consumption until the entry of Alcoa of Australia Ltd in 1963. The domestic industry has since been protected by total quantitative restriction; import licences have been granted only for the difference between local production and demand and, therefore, only in exceptional circumstances since 1963 (Australian Tariff Board, 1964, p. 5; 1967, p. 43). This form of protection was renewed in 1967, but expired in 1971 pending a further Public Enquiry. In 1970, with three smelters operating, domestic consumption of

* These companies have either financial association or long-established relationships with the Aluminum Company of America.
Fig. 2.3: Growth in domestic consumption of the study metals

Source: derived from Appendix I (a)
primary metal approached 130,000 tons or twenty-four lbs per capita*.

Domestic metal prices reflect industrial structure and the influence of world supply conditions. Price stability is most common for aluminium and steel, metals still produced largely for domestic sale. Although most aluminium is transferred captively, ingot is sold at the market price to independent semi-fabricators, and was purchased by Alcan Australia Ltd from its local competitors until smelting began at Kurri Kurri in 1969. From 1960 a domestic price of $542.00 was guaranteed but Alcoa of Australia Ltd, on entry into the industry, initiated a price of $502.00 per ton which was immediately adopted by Comalco Ltd. Further changes have been promulgated by both producers and price has increased gradually, under import protection, to its present level of $577.92 per ton despite the entry of the third smelter.

In Australia, aluminium is used in building and construction**, in the electrical, transport, and packaging industries, and in the production of consumer durables. Metal-manufacturing industry is highly concentrated in State capital cities (especially Sydney and Melbourne), and the major industrial ports of Newcastle, Port Kembla, and Geelong. These are the principal markets and distribution points for both capital- and consumer-goods. Aluminium must pass through semi-fabricating plants before fabrication, and such plants are the direct consumers of ingot. Because of the relatively high costs of transporting products such as extrusions and sheeting, semi-fabricating is generally located at these major markets; economies of scale are

* Local producers anticipate continued growth of domestic demand; in the United States, the world's largest consumer of aluminium, annual per capita consumption is currently forty-five lbs.

** The building and construction materials industry now consumes about forty per cent of the total aluminium produced.
exploited in the larger centres and there are other economies of locating close to the principal consumers.

Vertical integration has been increasing and the three smelting firms operate wholly-owned semi-fabrication subsidiaries; the larger plants are located in Sydney and Melbourne, with smaller installations in Brisbane and Adelaide, while Alcoa of Australia Ltd operates its facilities adjacent to the smelter at Point Henry. Alcan Australia Ltd produced at least three-fifths of the total domestic output of semi-fabrications until 1961, principally from ingot transferred from its overseas parent. Its market share has been progressively eroded by the combination of quantitative import restrictions, the development of the two local ingot producers and, particularly, their establishment of captive semi-fabrication facilities. Comalco Ltd has captured thirty per cent of the market, and Alcoa of Australia Ltd a somewhat smaller share. The balance of domestic demand is met by six independent metropolitan companies*. Comalco Ltd has recently extended captive transfer even further by purchasing a number of metropolitan metal-using firms, a form of non-price competition in an attempt to capture a larger share of the growing market (Fig. 2.3). The increases in forward integration and captive transfer lend stability to domestic marketing of both ingot and semi-fabrications and must perpetuate the high concentration of domestic demand for aluminium in the larger seaboard centres.

Despite the rapid growth of local demand, excess capacity had appeared in the Australian aluminium industry by 1970 principally because of the entry of Alcan Australia Ltd into smelting, and the decisions made by Alcoa of Australia Ltd and Comalco Ltd to match each other's size increases during the year. In 1970, local sales accounted for little more than half of the installed capacities at

* Within the last few years, however, Comalco Ltd and Alcoa of Australia Ltd have bought major shareholdings in two of their larger customers.
Point Henry and Bell Bay, while locational decisions involving the plant at Kurri Kurri were made with large annual export sales in mind. Exports rose sharply to about 66,000 tons in 1970 and, as the need for metal export increases, the domestic industry will become increasingly influenced by world market conditions and its ability to manufacture metal at competitive prices becomes critical. The possibilities for trade in primary aluminium have been reviewed by Brubaker (1967, pp. 119-44) who emphasizes the importance of periodic excess capacity among North American producers, and the influence of industrial structure. The Australian companies have made several 'spot' sales of aluminium, principally in Japan and Southeast Asia; sales to the United States and Europe are rendered difficult by the tight control exercised by the 'big six' producers and the incidence of marginal cost pricing from excess capacities by very large overseas producers (Morgan, 1965, pp. IV-6). Spot sales have been difficult to obtain in these principal markets and the prospects for significant exports in this form were poor in 1971*.

Two of the domestic producers sought to minimize uncertainties by securing export contracts in the late 1960s. Alcoa of Australia Ltd has commenced exporting under contract at an average annual rate of 29,530 tons, while Alcan Australia Ltd arranged to supply Kobe Steel Ltd of Japan with 45,000 tons per annum, about half the planned capacity of its new smelter. Plant expansion to meet this contract was to be financed by a loan from Kobe Steel Ltd repayable during the tenure of the contract. In mid-1971, amid general excess capacity in world markets, the contract was cancelled. (Presumably Alcan Australia Ltd may attempt to replace it with another in the near future.) Comalco Ltd is attempting to deal with the problem of export markets partially by purchasing large shareholdings in

* Comalco Ltd have reported that returns on exports of ingot were low in 1971 and that spot sales were limited by over-supply in world markets (Comalco Ltd, 1972, p. 8).
metal-using industries in Asia. With the development of
the smelter at Bluff, New Zealand, the plant at Bell Bay
will no longer supply ingot to captive semi-fabricators in
New Zealand but, at least in the short-run, will supply
semi-fabrication affiliates in Hong Kong and Indonesia.
Long-term export markets for Comalco Ltd will be supplied
from the Bluff smelter in which it has a fifty per cent
share, and Bell Bay will meet principally domestic sales by
1975.

2.3 Other Metalliferous Minerals

The mines, blast furnaces, and steel-works of The
Broken Hill Proprietary Co. Ltd, the monopoly producer of
iron and steel in Australia, constitute the principal
domestic metalliferous mineral industry. Output of crude
steel has risen from 1,432,000 tons in 1950 to 6,725,000
tons in 1970. The most important spatial changes in the
industry have involved iron ore mining for export, and the
iron and steel industry provides a good example of the
marriage of two systems of resource development and plant
location since 1960 (investigated in sub-section 2.3.1).
Changes in the location patterns of copper, lead, and zinc
have been less dramatic but provide interesting contrasts
to the developments in aluminium and iron (sub-section
2.3.2).

2.3.1 The iron and steel industry

Iron ore was extracted from twelve mines in 1970 and
two more were under construction. The spatial distribution
of production has changed radically during the last five
years; before 1966, more than two-thirds of national
output was extracted in South Australia from mines of The
Broken Hill Proprietary Co. Ltd at Iron Monarch and Iron
Prince (Middleback Ranges). These deposits have supported
local blast furnaces and steel-making since 1915, and remain
the principal source of supply for integrated steel-works
at Newcastle, Port Kembla, and Whyalla (Figs. 2.1 and 2.4).
producing a total of 7,000,000 tons of ore in 1970. Other sources are mines at Cockatoo Island in Yampi Sound (2,000,000 tons), and Koolyanobbing (1,000,000 tons), the latter supplying a blast furnace at Kwinana established in 1968.

By 1970 three-quarters of total output of iron ore was produced in Western Australia following the development in 1966 of mines at Goldsworthy and Tom Price in the Pilbara Region, and at Koolanooka, joined in 1969 by a large mine at Newman (Fig. 2.1). Smaller ventures were established in 1967 at Savage River in northwestern Tasmania, and in the Northern Territory (Frances Creek and Mount Bundey)*. Two additional mines were under construction in the Pilbara Region in 1970 at Paraburdoo and Mount Enid. All of these new installations have been developed to serve overseas markets, and the Middleback Ranges now contribute only fourteen per cent of the total Australian output of iron ore. This spatial change in iron mining has resulted from one of the most rapid phases of resource development in Australia's history involving eight new mining companies in a total capital investment (to 1970) of almost $1,000,000,000. The largest mine in the Pilbara Region, at Tom Price, produced 16,800,000 tons of direct shipping ore in 1970.

These recent resource creation processes have involved little processing. The pelletisation of iron ore had not been carried out locally before 1968 when plants were established at Port Latta (Tasmania), Dampier, and Whyalla, each producing about 2,000,000 tons per annum. A fourth processing plant is under construction at Cape Lambert in the Pilbara Region. Yet the new mining developments will exert little influence on the location of steel-making facilities in the near future. Differential growth-rates have been recorded by existing plants and the steel-works at Port Kembla has grown faster than those at

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* The mine at Mount Bundey ceased operations in 1972.
Fig. 2.4: The structure of the Australian iron and steel industry
Newcastle and Whyalla. The Broken Hill Proprietary Co. Ltd is obliged to convert its Kwinana blast furnace into an integrated steel-works before 1980 and may use some ore from the Newman mine in which it has equity interest. It also has a half share in a project involving the construction of steel-fabricating facilities at Westernport (Victoria), and an integrated steel-works is planned for this site during the 1980s. The entry of a second (independent) domestic steel producer remains highly conjectural but suggested sites have been Jervis Bay (New South Wales), about which there has been considerable debate (Butterfield, 1971; Van Dugteren, 1971), and an ore port in the Pilbara Region.

Resource developments in iron can be understood only in terms of the securing of export markets. About seventeen per cent of ore produced is presently consumed by local blast furnaces. The Broken Hill Proprietary Co. Ltd remains a local monopsonist for iron ore and, indeed, subsidiary mines and quarries provide all the basic materials required for iron- and steel-making. Since exports of iron ore were prohibited before 1960*, resource creation in iron operated as a closed system and, within it, there would have been little incentive for developments in iron mining except for gradual expansion of the existing mines or the establishment of new captive mines to diversify supply sources or mitigate resource depletion. An entrant into the domestic steel industry would have to develop its own iron mines.

Most of the export of iron ore is made from mines established since 1967 and exporting their entire output; only two per cent of the total is exported by The Broken Hill Proprietary Co. Ltd from its captive mines. In 1965 Japanese steel mills, which now import nearly all of their

* The embargo on exports is considered in detail in Chapter 7.
requirements, purchased ore largely from South America, India, and Southeast Asia. While maintaining supply relationships with these areas the mills now obtain thirty-five per cent of their total ore imports from Australia; this proportion should rise to forty per cent by 1975. The growth in iron mining therefore, has been facilitated by the demands of the Japanese steel industry. The parameters of demand facing prospective Australian suppliers have been conditioned by the structure of world markets for iron ore, and by the bargaining strategies adopted by Japanese steel mills.

With many disparate sources of supply, buyers' market conditions have existed in the world iron ore market since about 1965. As a result of collusion among buyers and competition among sellers, the iron ore market can be divided into a number of discrete geographic sectors in which the aggregate demands of regional blast furnaces, given the structure of ocean freight rates, generate ruling c.i.f. prices for ores of similar quality (Manners, 1971, p. 146). A prospective supplier thus faces a range of c.i.f. prices, and obtains variable f.o.b. prices for identical ores depending on the markets in which he sells, the transport costs to those markets, and the ruling prices at the time of signing the supply contract. Prices in the market are inherently unstable. Thus, for resource developments geared to export markets, the c.i.f. prices and transport costs determine at which deposits resource creation proceeds. If a mine cannot operate profitably, given the f.o.b. prices realized from sales in accessible markets, it will not be developed in the absence of extra-market intervention by, for example, governments or captive transfer arrangements.

As a result of almost complete reliance on imported iron ore, a buying cartel of the ten largest Japanese steel producers was formed in 1964, under the stimulus of the Ministry of International Trade and Industry, to negotiate
contracts and eliminate competition between buyers. Part of the strategy of bargaining has been to encourage a large number of sellers to compete for long-term contracts. For mining companies in Australia, these contracts offered a firm basis on which to raise capital and make development decisions, especially for large projects. Yet the bargaining position of the steel mills was strengthened by increasing the number of intending suppliers and constraining the average prices paid for ore. The result has been a downward trend in the f.o.b. prices received by Australian producers since 1967; Jay (1969, pp. 49-51) has claimed that c.i.f. prices paid by Japan for Australian ores have been lower than those for many other ores consumed, regardless of their source. By 1969, ore from mining companies in the Pilbara Region was arriving in Japan at an average c.i.f. price of sixteen cents per unit compared with an average ore price of nineteen cents in 1965*. Direct shipping ore realized an average of $8.40 per ton f.o.b. and fines sold at $6.86 f.o.b.**. Additional contracts have obtained lower prices and Tsung (1970, p. 28) has argued that this 'may be taken as the cost of entry into the industry'.

In 1970 the Japanese steel mills purchased more than ninety per cent of Australia's iron ore exports. Hamersley Iron Pty Ltd has six contracts with Japan requiring the sale of 248,000,000 tons of unprocessed ore over the next two decades, while the Mount Newman Consortium has contracts involving 200,000,000 tons of ore. Not all the new mining companies have negotiated to produce at this scale; the first venture to obtain an export contract (1966) was the mine at Koolanooka, and the single agreement involved the

* Calculated from data in Australian Financial Review, 1 April 1966, p. 3. Prices for iron ore are expressed in terms of iron 'units' where a unit is one per cent metal content per ton of ore.

** Calculated from data in Tsung (1970, pp. 31-62); and Manners (1971, p. 256).
export of 5,000,000 tons over eight years. At the end of 1970 Australian iron ore mines had entered contracts to sell a minimum of 600,000,000 tons of ore to Japan over the next two decades. Future entrants to the iron mining industry would have to contend with both falling prices and the threat of excess capacity in the domestic industry; sales expansion in the immediate future can probably be accommodated by existing producers and Japan is unlikely to rely on a single country for much more than forty per cent of its ore requirements. While sales of ore to European and North American steel producers seem highly desirable, little progress has been made in the diversification of export markets. Because of the existence of several well-established regional suppliers and the influence of transport costs, the f.o.b. prices realized from sales of ore in Europe and North America would be presently profitable to few Australian producers. Only the largest producer, Hamersley Iron Pty Ltd, has negotiated significant sales to markets other than Japan.

Iron pellets are sold as for iron ore under long-term contracts with the Japanese steel mills. About 6,000,000 tons were exported in 1970 and this could rise to 10,500,000 tons in 1975. Pellet contracts have faced the same downward pressure on prices and were sold, in 1970, at an average price of $10.40 per ton f.o.b.. The largest contract yet signed has been for 88,000,000 tons of pellets over twenty-one years secured by the Robe River Consortium which will manufacture pellets from low-grade ores. The most interesting marketing arrangement involves the Savage River venture which annually exports 2,250,000 tons of pellets to Japan. Half of this quantity is transferred at cost to two of the parent companies and the remainder is sold under a contract to the steel mills at very favourable prices, beginning at about $12.00 per ton and falling to $11.00 per ton between 1973 and 1975. Thereafter, prices are to be negotiated on the basis of
the ruling c.i.f. prices in Japan*. Hamersley Iron Pty Ltd, one of the four pellet manufacturers, has been investigating the possibility of producing *metallized agglomerate*. No firm sales arrangements had been obtained by mid-1972, and no definite works will be commenced on the proposed plant site at Dampier until a long-term contract can be signed.

Despite recent increases in the price of steel, domestic markets have exhibited marked stability and the spatial pattern of demand has changed little over the past decade. Markets for basic steel products are located broadly in accordance with population distribution and are concentrated in the steel-producing centres and State capital cities with much semi-fabrication of steel being carried out by subsidiaries of The Broken Hill Proprietary Co. Ltd. Domestic consumption has experienced an almost linear growth-rate of about five per cent per annum since 1960 (Fig. 2.3). Under tariff protection, imports of basic steel were small until the years immediately following the Second World War**. The growth of domestic output was matched by increases in demand during the 1950s but a significant exportable surplus had appeared by 1966.

The Broken Hill Proprietary Co. Ltd has met few problems in disposing of small surpluses of pig iron and basic steel products to meet seasonal shortages in Japan, Europe, and Southeast Asia. As early as 1963, Wills (1963, p. 234) argued that the company would have to seek large export markets to justify increased investment in productive capacity and commitments to the development of steel-

* The average f.o.b. price realized on the total annual sale would have been about $10.00 per ton in 1970, although this estimate is strictly notional; only half of output is subject to 'sale'. This will fall to $9.50 per ton by 1975.

** Tariffs on all except special steels are now nominal (Australian Industries Development Association, 1970, p. 11).
making at Kwinana. Since then, exports of pig iron (largely from Kwinana) have increased to 305,000 tons in 1970. Most of this has been the subject of spot sales although contracts were signed with Japan in 1970 and Mainland China in 1971. Exports of steel have increased slowly since 1966 but fluctuate depending on the company's ability to correctly estimate local demand. About 540,000 tons of basic steel products were exported in 1969 but only 220,000 tons in 1970. The principal customers were the Philippines and New Zealand. Large-scale exports of steel will be difficult to achieve in the immediate future; Manners (1971, p. 117) has reviewed the emergence of excess capacity in the major steel-producing countries, mainly because of over-estimation of the growth of consumption, of rapid enlargement of production units, and of technical and locational obsolescence of some of the oldest plants. In the absence of the development of captive sales of basic steel products*, markets in Japan and Southeast Asia offer the best prospects for continued export sales.

2.3.2 The copper, lead, and zinc industries

While significant exports of aluminium and steel ingot have begun only within the last five years, the copper, lead, and zinc industries have been developed to serve both local and overseas markets. Most mining firms are heavily involved in second-stage processing and can produce both ingot and concentrates for export depending on seasonal price fluctuations. Copper ores have been extracted for more than a century, but annual production of primary metal remained below 20,000 tons before the Second World War. At that time, the largest copper mines were at Queenstown and Mount Morgan (Figs. 2.1 and 2.5) with additional production from numerous small-scale ventures.

* This could be achieved by the formation of an international consortium led by The Broken Hill Proprietary Co. Ltd and including North American and European producers, for the development of the proposed steel-works at Kwinana.
Fig. 2.5: The structure of the Australian copper industry

* Denotes flow between plants of the same company or group
About one-third of the domestic demand for refined copper was satisfied by imports. The industry was transformed in 1952 with the entry of Mount Isa Mines Ltd, and this company is now Australia's largest producer of concentrates and operates the largest copper smelter, producing three-quarters of the national output of blister (110,000 tons in 1970)*. Since 1959 all copper from Mount Isa has been refined by a wholly-owned subsidiary at Townsville. Blister copper was produced at Queenstown between 1896 and 1969 when smelting ceased following a re-organization of the mining operations. An electrolytic refinery also operated until 1965, and blister was processed on a custom basis at Port Kembla until 1969. The majority of copper concentrate from Queenstown is now exported, although 20,000 tons per annum are smelted at Port Kembla. A small smelter still operates at Mount Morgan. Copper mining commenced at Tennant Creek in 1953, and abandoned mines were re-opened at Cobar in 1965.

The semi-fabrication of copper is partially integrated with primary refining facilities at Townsville and Port Kembla, but a large proportion of refined metal is consumed in the major coastal industrial centres by independent extrusion, semi-fabrication, and cable-making firms. Domestic consumption fluctuates considerably, but has grown at an average rate of four per cent per annum since 1960 to the present level of 70,000 tons (1970). Copper prices are the least stable among those of the study metals, and are set collusively, based on prices at the London Metal Exchange, with upward adjustments for the freight that would be payable between Australia and the United Kingdom. During a world shortage, a record domestic price of $1,653 per ton was reached in 1970, but excess supply conditions

* During the Second World War, at the request of the Commonwealth Government, copper ore was extracted from the Mount Isa copper lode (adjacent to the already exploited lead-zinc lode), and blister copper smelted in temporary premises.
caused a rapid fall soon afterwards. Such price instability increases uncertainty in both production and locational decision-making. During periods of low prices, smaller (marginal) processing plants have been placed under great stress, while larger producers have delayed new investments. Such market factors influenced the decision to close the smelter at Queenstown in 1969, rather than replace obsolete plant. In an attempt to reduce market uncertainties, Mount Morgan Ltd secured a long-term export contract for the entire annual output of its small smelter. About one-third of the national output of refined copper is now exported to Japan, principally from Townsville. Concentrates are exported from Queenstown and Tennant Creek.

Australia has long had a large proportion of the world's reserves of high-grade lead-zinc ore, and much of the technology of lead-zinc mining and processing has been developed in Australia. There has been relatively little change in the location of mines and processing plants since the Second World War. The lead-zinc lode at Broken Hill (Figs. 2.1 and 2.6) has been one of the world's most productive and supported four large mines, and nearly three-fifths of the total domestic output of concentrates, until the closure of the Broken Hill South Ltd mine in 1972. The largest (single) lead-zinc mine is now at Mount Isa (one-third of total output) and a small operation is located at Rosebery. Most lead concentrates from Broken Hill have been smelted at Port Pirie since 1897, in a plant now owned by some of the mining companies, while a small proportion is processed at Cockle Creek (Newcastle)*. Lead concentrates produced at Mount Isa are smelted at the mine. Zinc ingot has been produced electrolytically at Risdon since 1916; the operating company purchases concentrates from the Broken Hill mines under long-standing supply

* The parent company of the smelter at Cockle Creek also owns a half share in the Broken Hill Associated Smelters at Port Pirie.
Fig. 2.6: The structure of the Australian lead and zinc industry

- BROKEN HILL (N.S.W.)
  - Lead
  - Zinc
  - (Four mines)
  - Slag dumps

- COBAR (N.S.W.)
  - Lead
  - Zinc

- PORT PIRIE (SA)
  - Zinc smelter
  - Lead smelter and refinery
  - Export (Slab zinc), (Refined lead)

- COCKLE CREEK (N.S.W.)
  - Lead and zinc smelter
  - Lead bullion
  - Zinc
  - Export (Lead bullion, slab zinc)

- ROSEBERY (Tas)
  - Electrolytic zinc smelter
  - Zinc

- BELTANA (SA)
  - Zinc

- MOUNT ISA (Qld)
  - Lead smelter
  - Export

- MOUT ISA (Qld)
  - Lead smelter
  - Export

- DOMESTIC MARKETS

a One mine has now closed (1972)

* Denotes flow between plants of the same company or group
relationships, but an increasing proportion of ore is obtained from the company's own mine at Rosebery. Lower-grade zinc metal is produced at Cockle Creek and, since 1968, at Port Pirie.

Domestic sales of lead depend on the automotive and chemical industries, and in 1970, two-fifths of the lead bullion produced and four-fifths of the refined lead were exported. Lead has been the worst performer of the non-ferrous metals in recent world trade and prices have been declining. Some of the effects have been a reduction of annual output from the lead smelter of Mount Isa Mines Ltd, and the postponing of plans to develop a new mine at its Hilton deposit. Zinc is consumed locally in galvanising and die-casting, and domestic consumption has grown steadily at three per cent per annum since 1960. About fifty-five per cent of the total zinc produced has been exported each year since 1960, world consumption is rising slowly, and prices have been relatively stable. The emergence of differences in marketing prospects between lead and zinc will undoubtedly cause future imbalances in this part of the metalliferous mineral industry.

2.4 The Demand for Metalliferous Minerals: Institutional Effects and the Two-system Model

This chapter has shown that the local demand for metals creates a series of domestic flow patterns for the products of mines, first-stage, and second-stage processing plants. In the absence of foreign trade, the number, location, and scale of mines and plants would be determined by the size of the Australian market and would change only in response to population growth (and changes in its distribution), economic growth, and changes in tastes. The prevalence of captive transfers of mineral commodities between processing plants, and of ingot to semi-fabricators in the aluminium and steel industries, constrains the importance of demand as a factor in resource creation.
Spatial price competition is virtually eliminated by forward-integration into the metal-using industries. While the present growth-rates of consumption will probably ensure that smaller State capital cities will develop as semi-fabricating centres, the pattern of final consumers of the study metals is relatively stable. The spatial influence of demand in the resource creation process is ultimately conditioned by the concentration of the metal-using industries in capital cities and major industrial ports. A geographical analysis of resource development and plant location, especially in the aluminium industry, could well concentrate on spatial cost variation and regard markets as given. Stability in spatially concentrated markets suggests that Weberian demand assumptions are not unreasonable for second-stage processing in Australia.

In practice, another system of demand is superimposed on these domestic marketing arrangements (Fig. 2.7) since exports are made from all levels of production. Some mines and plants serve only overseas markets; others export, but supply primarily local consumers. There are considerable differences between the study metals in internal and external marketing arrangements, and in the relative importance of foreign trade in ores, processed materials, and ingot. While copper, lead, and zinc are exported mainly in the form of refined metal, overseas sales are critical in the production of bauxite, alumina, and iron ore; exports of aluminium and steel are modest. The importance of the two-system model of demand can be illustrated by considering the extraction of bauxite and iron ore; if the total output of bauxite in 1970 were refined and smelted locally, production capacity of 2,000,000 tons of ingot would be required (ten times the present capacity) and Australia would be one of the major producers of primary aluminium. The output of iron ore in 1970 would yield at least 25,000,000 tons of crude steel (four times the present output). Disregarding comparative production costs, the analysis in this chapter suggests that disposal
FIG. 2.7: The two-system model of demand parameters in resource development and plant location.
of these quantities of metal on world markets might be very difficult under present arrangements.

Interactions between the two systems of demand influence the location and volume of output. At production level, the spatial influence of demand on plants serving overseas markets is determined by the location of feasible outlet ports and the quantities to be exported. Although distance from overseas markets plays an important part in determining the competitiveness of mineral exports, it exerts little real influence on the choice of location within Australia beyond that of favouring tidewater sites*. Plants serving domestic markets are influenced by the location of more advanced levels of production, but domestic prices of ores are strongly influenced by the magnitude of overseas sales. The relationship between scale of operations, production costs, and location will be explored in the following chapters.

* While Port Latta (Tasmania) is somewhat further from Japan than the Pilbara ore ports, such differences appear insignificant, especially given the economics of ore shipment (to be examined in Chapter 4).
CHAPTER 3: PRODUCTION COSTS IN METALLIFEROUS MINING AND PROCESSING

The location of any particular coal mine, for instance, cannot be fully explained by the presence of coal. Only the whole relationship between production and demand that results in profits will make clear why coal is mined at just this spot and no others (Lösch, 1954, p. 35 fn.)

Differences in regional costs of production help to explain the spatial pattern of both mining and processing industry in an economy; factors, like government policies, which affect regional costs thus themselves exert an important influence on location. This chapter presents a survey of such factors for mining and first- and second-stage processing and investigates the structure of production costs. Yet a mere recital of this structure is inadequate; interpretation of the results requires knowledge of the ways in which technology and geology interact to affect production costs at various scales of output. Information on the production input 'weights' is essential for the measurement of location factors.

After identifying the production cost parameters and their relationship to location through regional cost variation (section 3.1), the chapter presents an empirical survey of metalliferous mining and processing in Australia, and precise production co-efficients, derived from material collected in the field, are given where possible (section 3.2). Since actual production costs in the Australian metal industries remain closely guarded secrets, they are derived from the production co-efficients for the study minerals using a standard estimation model. The principal conclusions are summarized in section 3.3.
3.1 Production Costs, Location, and the Mining and Processing of Metalliferous Minerals

Spatial analysts have often asked representatives of various industries to rank the importance in locational decision-making of production inputs, and to include spatial influences like government policy and 'personal choice'. (Such a questionnaire technique is used by Greenhut, 1956, and an example of the 'quantitative' analysis arising from this technique is Doerr, 1954.) This approach is rejected here for two reasons. First, the outputs of mining and processing industries are homogeneous, and the nature of demand for them (discussed in the previous chapter) suggests that the principal production factors would achieve highest ranking. Yet it proves difficult to separate factors that are given a similar rank, such as 'raw materials', electricity, and fuels. Second, the structure of the study industries, dominated by multi-plant (and often multi-national) corporations, makes it difficult to identify the actual levels of decision-making and to collect information. It seems more constructive to adopt a Weberian approach and attempt to establish basic locational forces which condition decisions made about individual plants by large firms.

The factor-ranking approach is unlikely to provide much insight into locational decision-making for these industries, and conclusions about the orientation of processing plants on this basis could be trivial or misleading. Instead, the structure of production costs for ores, processed materials, and metal ingot, must be considered in some detail. In the most recent exposition of his location theory, Hoover (1971, pp. 1-8) argued that such a cost analysis is essential to an understanding of industrial location. Production costs are linked to location through spatial variability in the prices of inputs; those factors which are important in the unit cost of output and exhibit spatial variation because of transport, infrastructure, or regional factor endowment, are likely to exert
the strongest influences on locational decision-making and, hence, receive most attention in this study.

Not all factor prices vary significantly over space. Depreciation allowances, patent charges, and the cost of product research and development would not be expected to vary regionally. Differences among regional costs can arise through three (strongly interrelated) sets of causes. First, transport costs produce the most obvious differences between regions since they help determine the costs of assembling raw materials and fuel inputs at the selected plant sites; they are also included in selling expenses. Given the national transport networks and the relative economics of haulage by various media, transport costs set limits to the maximum differences in production costs which can occur between regions. Yet the variability of production costs over space is complex and distance costs can produce regional differences in other ways (discussed in Chapter 5).

Second, factor costs show 'intrinsic' regional differences. Included here are the regional factor endowment of adjunct raw materials and, particularly in Australia, the availability and price of water and power. Such differences can be partially offset by transport economies, which tend to reduce differences in 'landed' or C.I.F. prices between regions, especially of commodities which can be shipped in bulk. Third, policy differences between governments exert an important influence over factor variability. Local bodies, usually under the surveillance of higher authority, determine property taxes, land rents, and the price of some utilities, while State governments control the cost of certain transport services and of electric power.

While the existence of regional factor price differences can be established relatively easily, actual production costs for Australian mining and processing could not be obtained. In this chapter, therefore, a cost estimation
model (discussed at length in Appendix II) is applied to production co-efficients for the aluminium industry and the results, discussed where possible with industry representatives, provide a consistent base from which to attempt the measurement of location factors. Comparative cost data from the other metals are drawn largely from published sources, industry technical reports, and Buchanan and Sinclair (1964).

3.2 A Survey of Production Costs in Australia

This section presents estimates of production costs for ores, processed materials, and metal ingot, using the Australian aluminium industry as a case-study. Particular attention is paid to the relationship between unit costs and the scale of output, and to the influence on total costs of physical geology and geochemistry; the technologies of mining, beneficiation, and metallurgy; the allocation of funds between exploitation and exploration; the variability of production co-efficients for labour and utilities; and the required levels of establishment capital. Data are presented separately for mining and first- and second-stage processing, largely to facilitate the construction of location models in Chapter 6. The mining of metalliferous minerals is considered in sub-section 3.2.1 which draws a comparison between open-cut and underground methods. Then, cost structures are established for first-stage processing, including simple ore beneficiation as well as the production of processed materials (sub-section 3.2.2). The section concludes with a consideration of the production of metal ingot, including electrolytic refining (sub-section 3.2.3).

3.2.1 The mining of metalliferous ores

(a) Geological controls

In Chapter 1 attention was drawn to differences in scarcity between the principal metalliferous minerals. Bauxite and ores of iron are not crustally scarce, whereas
copper and lead-zinc ores do not occur in such abundance and almost any mineralization in such metals will bear investigation. Such differences are reflected in Tables 3.1 - 3.4, which show the economic size of deposits currently exploited in Australia, the grades of material extracted, and the dates when production commenced. Lead ores are mined at grades of from 1.8 to 14.6 per cent metal content, zinc ores at 5.6 to 17.7 per cent, and copper ores from 0.5 to 4.0 per cent. Average grade varies considerably with the size of deposit, the scale of operations, and the date of establishment. By comparison, there is relatively little variation in the grades of iron ore and bauxite mined. Most iron deposits exploited are haematites (average grades are high by world standards at sixty to sixty-eight per cent iron), and the only low-grade ores of present importance are the magnetites at Savage River and the limonites of the Robe River area. Although grades of bauxite are variable, the average alumina content will vary between forty-five and fifty per cent by 1975. The much higher average grade at Weipa has some implications noted later.

The outcome of these geological differences is that the iron ore and bauxites available for processing, mostly from mines developed since 1960, are of broadly similar grades and geo-chemical characteristics and the unit production costs of these raw materials can be standardized into quite narrow ranges, freight charges sometimes becoming the principal variable in c.i.f. prices. For the scarce metal ores, especially those of copper, the range of grades and qualities exploited from mines developed before 1950 is remarkably wide; there is little standardization of the costs per unit for such ores. These differences between metalliferous minerals are critical to the subsequent analysis of the costs of processing.
TABLE 3.1: PRINCIPAL AUSTRALIAN LEAD AND ZINC MINES - 1970a

<table>
<thead>
<tr>
<th>Mining company</th>
<th>Location of mine</th>
<th>Date production commenced</th>
<th>Proven ore reserves (million tons)</th>
<th>Average grade (per cent metal content)</th>
<th>Lead</th>
<th>Zinc</th>
<th>Silver (oz/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1950</td>
<td>1970</td>
<td>1970</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken Hill South Ltdb</td>
<td>Broken Hill (N.S.W.)</td>
<td>1885-(1972)</td>
<td>2.0</td>
<td>0.5b</td>
<td>10.0</td>
<td>9.0</td>
<td>6.5</td>
</tr>
<tr>
<td>North Broken Hill Ltd</td>
<td>Broken Hill (N.S.W.)</td>
<td>1888-1894 1904-</td>
<td>5.0</td>
<td>4.5</td>
<td>13.3</td>
<td>10.6</td>
<td>6.6</td>
</tr>
<tr>
<td>E.Z. Industries Ltd</td>
<td>Read-Rosebery (Tas.) and Farrell (Tas.)</td>
<td>1900-C 1936-</td>
<td>1.5</td>
<td>9.1</td>
<td>5.3</td>
<td>17.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Zinc Corporation Ltd</td>
<td>Broken Hill (N.S.W.)</td>
<td>1923-</td>
<td>5.5</td>
<td>6.0</td>
<td>12.0</td>
<td>10.0</td>
<td>2.8</td>
</tr>
<tr>
<td>M.I.M. Holdings Ltd</td>
<td>Mount Isa (Qld)</td>
<td>1924-1942 1946-</td>
<td>9.7</td>
<td>52.0</td>
<td>7.9</td>
<td>5.9</td>
<td>5.0</td>
</tr>
<tr>
<td>New Broken Hill Consolidated Ltd</td>
<td>Broken Hill (N.S.W.)</td>
<td>1936-</td>
<td>2.0</td>
<td>6.0</td>
<td>9.5</td>
<td>13.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Cobar Mines Pty Ltd</td>
<td>Cobar (N.S.W.)</td>
<td>1965-</td>
<td>-</td>
<td>n.a.</td>
<td>1.8</td>
<td>6.3</td>
<td>-</td>
</tr>
<tr>
<td>M.I.M. Holdings Ltd</td>
<td>Hilton mine (Qld) under development</td>
<td>-</td>
<td>35.0</td>
<td>7.7</td>
<td>9.6</td>
<td>5.8</td>
<td></td>
</tr>
</tbody>
</table>

a Arranged chronologically.

b In addition, this company produced zinc concentrates from tailings, residue dumps which accumulated as waste products from the concentrators. In 1970, 285,000 tons of tailings were treated. This company ceased operations at Broken Hill in 1972.

c Mining was sporadic from this date.

TABLE 3.2: PRINCIPAL AUSTRALIAN COPPER MINES - 1970

<table>
<thead>
<tr>
<th>Mining company</th>
<th>Location of mine</th>
<th>Date production commenced</th>
<th>Proven ore reserves (million tons)</th>
<th>Grade (per cent metal) 1970</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1950</td>
<td>1970</td>
</tr>
<tr>
<td>Cobar Mines Pty Ltd</td>
<td>Cobar (N.S.W.)</td>
<td>1871-1921</td>
<td>-</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1938-1952</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1965-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Lyell Mining and Railway Co. Ltd</td>
<td>Queenstown (Tas.)</td>
<td>1893-</td>
<td>30.0</td>
<td>36.6</td>
</tr>
<tr>
<td>Mount Morgan Ltd</td>
<td>Mount Morgan (Qld)</td>
<td>1902-1927</td>
<td>7.4</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1932-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.I.M. Holdings Ltd</td>
<td>Mount Is (Qld)</td>
<td>1942-1946</td>
<td>3.0</td>
<td>120.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1953-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peko Mines N/L</td>
<td>Tennant Creek (N.T.)</td>
<td>1953-</td>
<td>-</td>
<td>0.9</td>
</tr>
<tr>
<td>-Peko mine</td>
<td></td>
<td>1953-</td>
<td>-</td>
<td>0.9^c</td>
</tr>
<tr>
<td>-Orlando mine</td>
<td></td>
<td>1962-</td>
<td>-</td>
<td>0.1^c</td>
</tr>
<tr>
<td>-Ivanhoe mine</td>
<td></td>
<td>1965-</td>
<td>-</td>
<td>0.2</td>
</tr>
<tr>
<td>-Juno mine</td>
<td></td>
<td>1965-</td>
<td>-</td>
<td>0.1^c</td>
</tr>
<tr>
<td>-Warrego mine</td>
<td></td>
<td>1968-</td>
<td>-</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>under development</td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Arranged chronologically.

b Main copper ore body only. Lead and zinc grades are given in Table 3.1

c Worked principally as a gold mine.

Source: As for Table 3.1.
<table>
<thead>
<tr>
<th>Mining Company</th>
<th>Location of mine</th>
<th>Date production commenced</th>
<th>Proven ore reserves (million tons)</th>
<th>Average grade of proven reserves (per cent iron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Broken Hill Proprietary Co. Ltd</td>
<td>Middleback Ranges (S.A.) - Iron Monarch - Iron Baron</td>
<td>1899&lt;sup&gt;b&lt;/sup&gt;</td>
<td>200.0</td>
<td>63.0</td>
</tr>
<tr>
<td>The Broken Hill Proprietary Co. Ltd</td>
<td>Yampi Sound (W.A.) - Cockatoo Island - Koolan Island</td>
<td>1951-1963</td>
<td>50.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Western Mining Corporation Ltd</td>
<td>Koolanooka (W.A.)</td>
<td>1965</td>
<td>2.0</td>
<td>60.3</td>
</tr>
<tr>
<td>Hamersley Iron Pty Ltd</td>
<td>Tom Price (W.A.)</td>
<td>1966-1968</td>
<td>166.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Goldsworthy Mining Ltd</td>
<td>Goldsworthy (W.A.)</td>
<td>1966-1968</td>
<td>100.0</td>
<td>65.5</td>
</tr>
<tr>
<td>Frances Creek Iron Mining Co. Ltd</td>
<td>Frances Creek (N.T.)</td>
<td>1967</td>
<td>20.0</td>
<td>62.0</td>
</tr>
<tr>
<td>The Broken Hill Proprietary Co. Ltd</td>
<td>Koolyanobbing (W.A.)</td>
<td>1967</td>
<td>110.0</td>
<td>60.0</td>
</tr>
<tr>
<td>North-western Iron Co. Ltd</td>
<td>Savage River (Tas.)</td>
<td>1967</td>
<td>100.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Morgan Mining and Industrial Co. Ltd</td>
<td>Mount bundy (N.T.)</td>
<td>1968-1972</td>
<td>0.8</td>
<td>64.0</td>
</tr>
<tr>
<td>Mount Newman Consortium</td>
<td>Mount Whaleback (W.A.)</td>
<td>1968-1969</td>
<td>610.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Hamersley Iron Pty Ltd</td>
<td>Paraburdoo (W.A.)</td>
<td>under development</td>
<td>403.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Robe River Consortium</td>
<td>Mount Enid (W.A.)</td>
<td>under development</td>
<td>175.0</td>
<td>57.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> Arranged chronologically.

<sup>b</sup> Iron ore was extracted as fluxing material for an associated lead smelter until 1915.

<sup>c</sup> Production has now ceased.

<table>
<thead>
<tr>
<th>Mining company</th>
<th>Location of mine</th>
<th>Date production commenced</th>
<th>Proven ore reserves (million tons) 1970</th>
<th>Average grade of proven reserves (per cent)</th>
<th>Average silica content (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comalco Ltd</td>
<td>Weipa (Qld)</td>
<td>1963</td>
<td>520</td>
<td>52-60</td>
<td>2-12</td>
</tr>
<tr>
<td>Alcoa of Australia Ltd</td>
<td>Jarrahdale (W.A.)</td>
<td>1963</td>
<td>5</td>
<td>44</td>
<td>22</td>
</tr>
<tr>
<td>Nabalco Pty Ltd</td>
<td>Gove (N.T.)</td>
<td>under development</td>
<td>166</td>
<td>49</td>
<td>5</td>
</tr>
<tr>
<td>Amax Bauxite Corporation Ltd</td>
<td>Mitchell Plateau (W.A.)</td>
<td>under development</td>
<td>200</td>
<td>47-50</td>
<td>3</td>
</tr>
<tr>
<td>The Broken Hill Proprietary Co. Ltd</td>
<td>East Darling Ranges (W.A.)</td>
<td>under development</td>
<td>100</td>
<td>45</td>
<td>?</td>
</tr>
</tbody>
</table>

a The grade of bauxite is expressed as the proportion of contained alumina rather than the proportion of contained metal. The aluminium content of the bauxite would be approximately half the proportion of alumina.

(b) Mining and processing technologies

Geological factors are related to production costs through the technologies available for extraction and beneficiation of ore, and the commercially feasible techniques of extracting metals from minerals of various chemical characteristics. Developments in the technologies of mining and processing often allow formerly uneconomic mineral deposits to be developed as resources by reducing the unit mining costs, by reducing impurities or simply the weight-loss in subsequent processing through improved beneficiation, or by the development of new smelting techniques that cause a change in the competitive position of the metals. On the other hand, some resources have been effectively 'destroyed' by technological progress if their geological or geographical characteristics are not suited to new techniques.

Open-cut mining is usually practised for superficial deposits and for those occurring in hills or ridges with seams exposed. In the latter case, mining over long periods produces a characteristic pit, the depth of which depends partly on the dip of the mineralized strata. Copper ores have been extracted in this way at Mount Morgan and Mount Lyell for more than seventy years. The deeper the pit, the greater vertical movement of mined product and the higher the unit extraction costs.

Underground mining is essential where the mineralization has much greater vertical than horizontal dimensions; for example, the deepest shaft at Broken Hill in 1965 was 4,239 feet (Woodward, 1965, p. 69). The deposits at Mount Isa and Broken Hill are exploited by underground methods although, at the latter, superficial silver-rich ores were extracted from open-cuts before 1900. Cost structures, and especially production co-efficients for timber, power, and labour, vary widely between different methods of underground extraction and with depth and nature of seams. The method chosen partly determines the economic life of the
deposit. Before 1900 silver-lead ores formed the main-stay of mining at Broken Hill and were extracted from shallow mines, a large number of small-scale mining firms being encouraged by high-grades near the surface. Later mining required the sinking of deeper and more elaborate shafts, the development of extraction techniques suitable to the narrow seams of the Barrier lode, and the disappearance of all but four mining companies (Woodward, 1965, p. 55).

Under suitable geological circumstances, the development of open-cut mining methods, especially for iron ore and bauxite, has allowed very low unit production costs to be achieved, principally by the substitution of capital for labour, the exploitation of economies of scale, and the minimization of other variable inputs. Mining becomes a problem in earth-moving and (surface) product conveyance (see Gray, Owen, and Taylor, 1970). Where underground mining must be carried out, improvements in the generally much higher unit production cost have been achieved by increased mechanization, developments in ventilation and haulage, and reduction of waste in the extraction of mineralized strata. At Broken Hill, there was a steady modification of underground mining technology as depletion caused increases in mining depth and a fall in the grades of ore available (summarized by Woodward, 1965, pp. 55-74). Yet techniques of beneficiation (first-stage processing) have more often been critical to the survival of mining at particular locations. During the 1890s, as surface ores approached exhaustion at Broken Hill, it became clear that the survival of mining depended on the exploitation of vast lead-zinc sulphide mineralization known to extend to depths of more than 1,000 feet. The evolution of an economically feasible flotation process for the separation of lead or zinc concentrates from these geo-chemically complex ores was one of the most important innovations in the history of metalliferous mining in Australia as is well documented by Woodward (1965, pp. 79-103).
Improvements in first-stage processing techniques have also been important for iron ore and bauxite. Iron ores can be subjected to two types of processing, the first to increase the metal content and reduce the weight-loss in second-stage processing, and the second to produce a saleable product at competitive cost from fines either by agglomeration or the production of sinter. Overseas, particularly in the United States, the introduction of pelletisation has caused changes in the spatial distribution of iron ore mining (Mason, 1969; Earney, 1969, pp. 512-15), and encouraged the development of large deposits of relatively low grades to maximize scale economies in open-cut mining. In addition, the production of alumina from bauxite (usually by the Bayer Process) is an essential and advanced form of chemical processing to produce a raw material suitable for the production of aluminium by electrolysis. A modification of the standard Bayer Process has recently enabled the treatment of mixed monohydrate and trihydrate bauxites; This was essential before the large bauxite deposits of the Caribbean, India and tropical Australia could be developed as resources.

(c) The cost of continuous exploration

All active mining companies must invest in exploration and discovery usually results in 'knowledge-induced' resource development. Unfortunately, there are no reliable data on the costs of exploration in Australia and, in any case, it would be very difficult to isolate the funds spent on continuous exploration (see Sub-section 1.1.4). Nevertheless such outlays add to total mining costs since exploration expenses are levied against the total revenue from the sale of ores and concentrates.

While, in absolute terms, outlays on exploration may appear quite significant, they form an important component of total production costs only under certain conditions of resource depletion. In Chapter 1 it was suggested that, given constant demand and technology, a mining company
should continue (or expand) continuous exploration to the point where the marginal cost of additional information about the deposit just exceeds the marginal net revenue that could be obtained from increments to the stock of proven ore. Since no useful data exist for sound empirically-based conclusions, only very tentative inferences can be drawn from the history of mining in Australia. It seems that the costs of exploration would form a small component of total mining costs unless the effects of cumulative depletion warrant an investment switch away from extraction into exploration. This is suggested by Vousden (1971, p. 2).

Since the First World War, most of the important knowledge-induced expansions in the Australian resource stocks of copper, lead, and zinc ores have resulted from the continuous exploration of well-established mining companies. Such exploration has been essential to the survival of mining at Broken Hill, Mount Lyell, and Mount Morgan. Expansions in the resource stock following successful exploration of this kind have usually required the development of new extraction and beneficiation techniques (considered above). Proven reserves of copper and lead-zinc ores at Mount Isa are comparatively large (Tables 3.1 and 3.2) so that little investigation has been made of even larger volumes of low-grade mineralization known to exist both in the exploited deposits and on unexploited leases held by the mining company.

Despite the recent rapid increase in Australia's resource stocks of iron ore and bauxite as a result of speculative exploration, continuous exploration has been undertaken by the new mining companies, especially those mining at high rates of output and committed to vigorous expansion in the export of processed and unprocessed ores. Continuous exploration at the Tom Price iron ore deposit has indicated 337,000,000 tons of high-grade haematite in addition to the proven reserves (Table 3.3), while at Paraburdoo exploratory drilling has revealed a further
104,000,000 tons of ore (Hamersley Holdings Ltd, 1970, pp. 10-12)*. Similarly, at Newman more than 1,000,000,000 tons of high-grade ore have been discovered on the leases since the development of the Mount Whaleback deposit in 1968. Exploration costs presently make little impact on the production cost structures of these large-scale mining operations**. Bauxite deposits currently exploited, or under development, are similarly large but continuous exploration is vital to the Jarrahdale venture (Table 3.4) which was commenced when proven reserves were only 37,000,000 tons of relatively low-grade bauxite. Preliminary drilling of other parts of the leases has suggested at least 500,000,000 tons of variable grades.

(d) The structure of mining costs

Production costs in mining are determined by the interactions of geological factors and extraction technology, given the life of mining and the economic size of the deposit. Actual data for these costs were not available for any metalliferous mining in Australia so that, to gauge the importance of individual production factors, the cost estimation model (outlined in Appendix II) was applied to production co-efficients for the mining of bauxite in Australia. To emphasize differences between open-cut and underground mining, this model is compared with data from the mining of iron, lead-zinc, and copper ores, obtained

---

* The potential reserves (see Fig. 1.2) held by Hamersley Iron Pty Ltd in the Pilbara Region of Western Australia total about 1,600,000,000 tons of high-grade ore and 3,500,000,000 tons of limonite and low-grade haematite, much of which may never be developed, at least under foreseeable circumstances (Hamersley Holdings Ltd, 1970, p. 12).

** Speculative exploration, coupled with the continuous exploration of the companies rapidly expanding their rates of output, has dramatically reduced the 'scarcity' of iron ore in Australia. Apart from the large potential reserves discovered by the mining companies listed in Table 3.3, temporary reserves held by the Hancock and Wright prospecting partnership in Western Australia are believed to contain about 7,000,000,000 tons of haematite iron ores.
principally from published sources. Given the limitations of the estimation method, which tends to underestimate overhead and intangible outlays, the costs for bauxite mining are submitted as reasonable bench-marks for measuring the relative importance of production factors; in the absence of precise technical production data, the analysis of underground mining is presented for broad comparative purposes only. Particular attention is paid to the effects of both scale of operation and cumulative depletion on unit costs. The most important factors in determining the choice of deposits to be developed are isolated since the location of mining is partially determined by these decisions.

The events leading to the discovery in 1955 of the very large deposit of bauxite at Weipa need not be documented again (see Australian Mining, 1967; Dowie, 1967, pp. 10-12; Raggatt, 1968, pp. 85-90)*. Suffice it to say that one of the largest single bauxite deposits in the world was discovered with current proven reserves of 520,000,000 tons of high-grade bauxite and 1,700,000,000 tons inferred by geological reconnaissance (Fig. 3.1). A unique combination of geological and geographical factors, coupled with a capital-intensive mining technology, determine production costs and have encouraged large-scale development.

Three main geological factors influence the structure of production costs at an open-cut mine: first, the nature and depth of overburden in relation to the depth of mineralized stratum; second, the hardness, form, and grade of ore; and third, the nature of landscape 'restoration' (if required). At Weipa, ground cover consists of light tropical woodland, and bauxite occurs in a flat or gently

* Unless otherwise acknowledged, data on which this analysis of bauxite mining is based were collected, during fieldwork, from Commonwealth Aluminium Corporation Ltd (a wholly-owned subsidiary of Comalco Ltd) at Weipa (Qld) in July 1970.
Fig. 3.1: Weipa: bauxite leases and mining developments
dipping layer from ten to twenty feet deep covered by less than two feet of overburden. The preparation of areas for mining, therefore, is very simple and, apart from reclamation of the overburden, there are no effective costs of reclamation.

Bauxite occurs in pisolitic form and can be loaded directly into trucks at mine-faces; no blasting or major excavation is required*. The distribution of grade in the deposit exerts a direct influence over production costs. Weipa bauxite is of a very high grade by world standards (fifty to sixty per cent alumina) and, although alumina content varies (Raggatt, 1968, p. 90), the principal spatial variable is the proportion of silica. Since acceptable ranges of silica are specified in sales contracts, ores from different parts of the deposit are blended to achieve close control over grade and this requires a number of mine-faces to be worked simultaneously. Only elementary beneficiation is necessary, principally the removal of organic matter and some of the silica, by washing and screening at Lorim Point (Fig. 3.1).

Hence, mining is highly capital-intensive with a minimum of direct labour. The capital cost to the company of installing a capacity of 7,000,000 tons per annum was $34,000,000, of which $29,000,000 was the cost of plant and equipment and the remainder was the company's contribution towards infrastructure (considered separately in Chapter 5). Open-cut mining depends heavily on relatively small items of capital equipment (such as heavy vehicles), as well as the plant and ship-loader; mining efficiency depends on the selection of an internal conveyance system, presumably that which minimizes total extraction costs. At Weipa, the extraction costs, changes in total costs with increasing

* According to Raggatt (1968, p. 86 fn), 'pisolite' is derived from the Greek word for pea. Pisolithic bauxite is easy to mine because it occurs in the form of a coalescence of small pebbles.
output, and changes in the spatial pattern of mining within the leases, all depend on the conveyance of crude ore from mine-faces to the wharf-side plant area (Fig. 3.1).

There are five principal methods of conveying crude ore. An internal railway is the most expensive in terms of capital investment, provides no route flexibility once installed, and requires long-term use. It provides fast and economic carriage of large volumes where distances of more than about twenty miles are involved. A pipeline system, similarly inflexible and requiring large volumes of water, is competitive with rail over difficult terrain. Less expensive and more flexible are aerial ropeways and conveyor belts; the former are usually too slow for large-scale mining and systems of conveyor belts are common over relatively short distances. Such a system is used for the transport of crude bauxite over eighteen miles on the Gove Peninsula. Given the high rate of output at Weipa and the geological characteristics of the deposit, lateral advance of mine-faces is very rapid and flexibility of ore conveyance is critical to mining efficiency. This requirement is met by the use of heavy diesel trucks and unsealed haulage roads connecting the mine-faces with Lorim Point. The area of mining is circumscribed by the economic range of these vehicles which depends both on technical factors and the rate of production. It has been found that, under present circumstances, 50-ton and 75-ton trucks have a maximum operating range of 18,000 feet (3.4 miles) from the crushing and screening plant, and mining on the Weipa Peninsula (to 1971) has taken place within this radius of the wharf.

The combination of favourable geology and proximity to tidewater on all areas of the Weipa Peninsula has permitted a high rate of output and very low unit production costs. This is illustrated in Table 3.5 which gives an estimate of production costs in 1970. Direct extraction costs constitute only twenty-nine per cent of total unit cost, partly because of the scale of operations, but
TABLE 3.5: ESTIMATED MINING COSTS AT WEIPA: 1970

<table>
<thead>
<tr>
<th>Cost component</th>
<th>$ per ton output&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Per cent of total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct extraction costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- utilities</td>
<td>0.14</td>
<td>8</td>
</tr>
<tr>
<td>- direct labour</td>
<td>0.11</td>
<td>6</td>
</tr>
<tr>
<td>- maintenance</td>
<td>0.18</td>
<td>11</td>
</tr>
<tr>
<td>- royalty</td>
<td>0.07</td>
<td>4</td>
</tr>
<tr>
<td>- Total</td>
<td>0.50</td>
<td>29</td>
</tr>
<tr>
<td><strong>Indirect costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- overheads</td>
<td>0.28</td>
<td>16</td>
</tr>
<tr>
<td><strong>Fixed mining costs</strong></td>
<td>0.75</td>
<td>45</td>
</tr>
<tr>
<td><strong>Non-mining costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- administration and exploration</td>
<td>0.07</td>
<td>4</td>
</tr>
<tr>
<td>- financial expenses</td>
<td>0.10</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total production cost</strong></td>
<td>1.70</td>
<td>100</td>
</tr>
</tbody>
</table>

<sup>a</sup> Calculated for an output of 5,000,000 tons of dry bauxite.

**Source:** Calculated by applying the estimation model in Appendix II to production data collected at Weipa, Queensland, in July 1970.
principally because of the mining technology. Electricity, the principal variable input (eight per cent of total cost), is generated at Lorim Point, and oil-fired engines provide power most economically in remote locations (in the absence of hydro-power potential or nearby coal); fuel oil can be shipped in bulk from Australian refineries (Buchanan and Sinclair, 1964, pp. 1022-3). Because of the high degree of mechanization, production co-efficients for direct labour are very low (0.05 man-hours employed in mine and plant operations per ton)*: each shift requires only fifty-two men, five employed at mine faces, seventeen in stripping, clearing and road maintenance, fifteen in ore conveyance, and fifteen at the plant. Labour requirements have been reduced to a technologically-determined minimum and, as extra units of mining equipment are employed, labour is required in proportion.

Direct labour, however, comprises only one quarter of the total work force (407 persons); the cost of mine and plant maintenance (eleven per cent of total cost) is composed of sixty per cent labour and forty per cent replacement parts and equipment. Apart from the administrative staff, the remainder of the work force is employed in the township and other facilities. When total employment at Weipa is included, the labour co-efficient rises to 0.21 man-hours per ton of bauxite, still low by world standards, but becomes a very important component of production costs.

The importance of overheads and fixed charges is emphasized by Table 3.5. Most plant overheads in remote locations are related to infrastructure and can be sustained economically only when the scale of operations is large. The difficulties involved in measuring this component are

* Production co-efficients for direct labour of up to 0.50 man-hours per ton are reported for efficient but much smaller bauxite mines in the United States. Labour inputs of 1.60 man-hours per ton are reported for less-developed countries such as Ghana (United Nations, 1966, p. 4).
discussed in Appendix II; suffice it to say here that twenty-eight per cent per ton of bauxite is probably an underestimate, but that if the provision of infrastructure were shared by public and commercial organizations overhead costs per unit of output would fall. A better estimate is difficult to suggest because most of the overhead expenses are related only indirectly to mining operations, and the cost of providing the various services (and the achievement of scale economies) depends on the size of the Weipa township and, ultimately, on the absolute size of the labour force. Despite a large annual output, fixed costs related to the level of capital investment comprise nearly half the unit costs of output, with the principal element being depreciation of mining equipment, plant, and buildings. Yet despite the high capital cost of establishment at Weipa, bauxite probably costs no more than $2.00 per ton to extract from this mine. It is very likely, however, that the estimates in Table 3.5 represent the lowest attainable unit costs, and that both the maintenance of present rates of output and the expansion required to meet long-term contracts, will involve cost increases despite economies of scale.

Direct extraction costs have remained low principally because of favourable geology and location, and economies of scale have been achieved by spreading the considerable fixed costs over an increasingly large output. During 1972, the Andoom area (Fig. 3.1) was brought into production: annual mining capacity was to be raised to 10,500,000 tons so that future contract requirements could be met, and bauxites of acceptable silica content were already becoming scarce within the economic radius of the port facilities. Extensions of mining throughout the leases required a change in the internal conveyance system and, as a result, a heavy-duty railway has been constructed from Lorim Point fifteen miles to a loading station within the new mining area from which trucks can again operate within their economic range. Further extensions to this system will be made in the future, and the possible spatial pattern of mining expansion is
shown schematically in Fig. 3.2.

The cost of installing this railway, including the construction of a bridge across the Mission River and the purchase of locomotives and rolling stock, form the principal component in the considerable capital investment of the expansion programme. Power and plant facilities at Lorim Point have been duplicated with additional investment in infrastructure (especially in housing). The capital cost of raising production capacity by half has been $43,000,000. Despite the higher output of bauxite, fixed costs per unit will rise from $0.75 (Table 3.5) to at least $1.00. Overhead costs per unit will probably fall because of the greater spreading of infrastructural expenses, but there will be little change in the direct extraction costs. Direct labour requirements rise in proportion, and a slight fall in the importance of other inputs will be offset by maintenance costs and the upkeep of the new conveyance system. At optimal rates of output, unit costs of a little more than $2.00 per ton can be expected, the increase almost entirely due to capital costs of plant, equipment, and the ore conveyance system. Expansions to the railway, once installed, can be made at lower marginal costs but further rises in the unit production costs of bauxite can be expected in the future if the present high rates of output are maintained, given the rapid advance of mine-faces and distance from the port. In spite of increasing costs, the mining of Weipa's high-grade bauxite will remain a comparatively low-cost operation in the foreseeable future.

Open-cut mining at Weipa has been considered in some detail and acts as a model against which to compare other mining in Australia. Unfortunately, production data were not available for bauxite mining at Jarrahdale but certain geological characteristics, including lower average grades (Table 3.4), would seem to preclude the achievement of the economies gained at Weipa. Mining methods are similar although ground-cover is heavier and, while overburden is
Fig. 3.2: Weipa -- Possible growth of internal conveyance system with depletion and increases in production capacity

Based on material collected at Weipa, July 1970.
shallow, the ore body must be loosened by blasting in most parts of the lease. Extraction costs, particularly those of conveyance, are increased by the discontinuity of the deposit; laterites in the Darling Ranges occur in patches over a distance of more than 200 miles and exploited areas are similarly patchy within the leases. Some of the mining has been carried out by earth-moving contractors. These deposits can be exploited economically because of their proximity to the metropolitan area; fixed costs and overhead expenses are much lower per unit than at Weipa and infrastructure costs have been minimal. Utilities are provided by State authorities and no mining settlement need be supported. At an annual output of nearly 3,000,000 tons, total mining costs are probably between $3.50 and $4.50 per ton*.

The structure of mining costs for copper, lead, and zinc ores in Australia illustrates the differences between open-cut and underground techniques. Underground mining involves materials such as explosives and timber, while electricity has become the most important utility as mechanization has advanced. Inland mining companies operate their own power stations but the cost of power produced remains high because of low load factors (Woodward, 1965, p. 235). Despite mechanization, direct labour is still the most important variable input and the costs are amplified by rigid industrial conditions imposed by mining unions and the frequency of strikes. Manners (1971, p. 150) argues that the higher cost of labour is the principal factor accounting for the difference between unit costs of iron

* The Gove bauxite deposit, at which mining commenced in 1971, is geologically similar to that at Weipa, although of generally lower grade, and is mined with the same capital-intensive techniques. Capital investments in the Gove project are higher than at Weipa although costs are shared with the coastal alumina refinery which will come into full production in 1974. The principal difference in extraction costs, apart from those arising from the much smaller annual output, is the transport of crushed ore to the port by conveyor belt.
ore produced by open-cut and underground methods. In 1959, ore of shipping grade was produced in Minnesota at an average cost of $5.00 per ton from open-cut mines, and labour comprised about eighteen per cent of the total. Ore from underground mines cost an average of $8.68 per ton, of which labour comprised about sixty per cent; mechanization has considerably reduced this proportion in the last decade. It is almost axiomatic that labour costs form the major restraint on the reduction of underground mining costs for the world as a whole (Aschmann, 1970, p. 180), and this is strongly implied for Australia by Raggatt (1968, p. 168).

Fixed costs from a large component even in underground mining with heavy investments in shafts, ventilation systems, underground conveyance networks, and in the replacement of hand-mining by mechanical methods*. Yet the regional variation in capital costs is determined largely by the level of investment in utilities, townships, and transport systems outside the mine itself. Economies of scale in underground mining, no less than in open-cut extraction, are primarily the result of spreading these charges over increasing rates of output. Where geological conditions are suitable, greater scale economies can be achieved with open-cut methods and low-grade deposits are often rendered competitive because of savings in mining costs. The relationships between grades, scale economies, and mining techniques are suggested by a comparison of Australian copper mines in 1969-70. At Mount Isa, more than 3,000,000 tons of copper ore were raised in 1970, whereas at Mount Morgan, a similar tonnage of material was economically extracted from an open-cut mine to produce

* For long-established underground mines, some of the capital stock would be fully depreciated without replacement, and, despite falling grades of crude ore, mining remains profitable because of the considerable capital tied up in the mine and plant. Diseconomies associated with obsolescence, however, often act as a restraint on the development of low-grade ores at high rates of output to achieve economies of scale.
only one-tenth of Mount Isa's output of copper concentrates. At Queenstown, the 2,000,000 tons of crude ore extracted from the open-cut yielded only one-fifth of this concentrate output. The rates of extraction at Australia's largest lead-zinc and copper mines are dwarfed by those at iron ore and bauxite mines where open-cut techniques are used exclusively.

Cost structures for the mining of iron ore are analogous to those for bauxite, although geological characteristics of the iron ore deposits are often sharply different and the spatial extent of mining is quite restricted. Scale of operations, and distance from the coast are critical in the structure of production costs, the former because of the high establishment costs, the latter because the f.o.b. prices of direct shipping ore for export are quoted at the outlet port. It is estimated in Table 3.6 that the cost of transport of lump ore to the port comprises one-third of the total cost of ore from the Mount Whaleback mine in Western Australia. Despite the high level of capital investment (about $10.00 per ton of installed mining capacity for the Mount Newman Consortium), direct shipping ore can be produced from large-scale mines at a total cost of about $3.00 per ton of which more than half is fixed cost and twenty per cent is the mining royalty.

3.2.2 The first-stage processing of ores

(a) Beneficiation and the production of concentrates

As noted earlier in the chapter, it is usually difficult to separate this type of processing from mining. The structure of production costs for copper, lead, and zinc concentrates sold on the open market includes the costs of mining the crude ore, just as that of iron ore and bauxite should include the costs of simple washing and screening. The concentration of copper and lead-zinc ores is essential before these minerals can be fed into a blast furnace, and the flotation method is one of the most
TABLE 3.6: WESTERN AUSTRALIA -- ESTIMATED AVERAGE PRODUCTION COST\(^a\) FOR HIGH-GRADE LUMP IRON ORE:

1970

<table>
<thead>
<tr>
<th>Cost component</th>
<th>$ per tpn output(^b)</th>
<th>Per cent of total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extraction costs:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- royalty(^c)</td>
<td>0.60</td>
<td>13</td>
</tr>
<tr>
<td>- other direct costs</td>
<td>0.46</td>
<td>10</td>
</tr>
<tr>
<td>- overheads</td>
<td>0.20</td>
<td>5</td>
</tr>
<tr>
<td>- total extraction costs</td>
<td>1.26</td>
<td>28</td>
</tr>
<tr>
<td><strong>Fixed costs</strong></td>
<td>1.68</td>
<td>37</td>
</tr>
<tr>
<td><strong>Non-mining costs:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- administration and exploration</td>
<td>0.06</td>
<td>1</td>
</tr>
<tr>
<td>- transport of lump ore to outlet port</td>
<td>1.50</td>
<td>33</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td>4.50</td>
<td>100</td>
</tr>
</tbody>
</table>

\(^a\) Production cost is defined, for the purposes of this Table, as the total cost of direct shipping ore in the product stockpile at the outlet port.

\(^b\) Estimates here are based on the operations of the Mount Newman Consortium at Newman and Port Hedland. The mine is located 265 miles from its port, has an annual capacity of about 20,000,000 tons of crude ore, and total capital investment in plant, equipment, and infrastructure, of $200,000,000.

\(^c\) Prescribed in the Special Mineral Agreement at 7.5 per cent of the f.o.b. value per ton (direct shipping ore for export).

Sources: Cameron (1968, p.82); Tsung (1970, p.21); and The Broken Hill Proprietary Co. Ltd (pers. comm., August 1969).
basic forms of first-stage mineral processing.

Simple processing is dominated by the input of crude ore for which production co-efficients are very high. For example, the copper concentration plants at Mount Morgan require fifty tons of crude ore for each ton of output, at Queenstown twenty-six tons, and at Mount Isa thirteen tons. At Broken Hill, six tons or more of lead-zinc sulphide are used for each ton of concentrate produced, while at Mount Isa eleven tons are needed. Other important inputs are chemicals and direct labour, but production co-efficients are low. Fuels and electricity are the main variable inputs other than crude ore. Buchanan and Sinclair (1964, p. 710) have shown that for an ore treatment plant operated in conjunction with a mine, direct manufacturing costs account for ninety-five per cent of total production costs; the total cost of winning the crude ore comprises up to ninety per cent*. Low-grade iron ore is upgraded in Australia only at Savage River (Table 3.3), but iron concentrates will be produced on a large scale at the Robe River project.

(b) The production of iron agglomerates and alumina

Iron ores can be agglomerated by pelletization or sintering, and the production of pellets has become very important since the mid-1950s. Despite the costs of processing, agglomerates are competitive with most un-processed ores because they have high iron content (usually between sixty and sixty-five per cent for pellets) and their f.o.b. price per unit of contained metal is competitive with all but very high-grade lump

* Accounting convention is important in these calculations. The capital costs of the concentration plants are low and highly divisible. Items of fixed capital, such as infrastructure and warehousing, as well as shared items such as maintenance, administration, and overheads, would be charged principally as 'mining costs' against units of crude ore.
ores from large-scale mines, such as those of the Pilbara Region; they are easily transported and are technically very suitable as a blast furnace feed. The development of pelletization, and the increasing proportion of pellets and sinter in world furnace charges, are reviewed by Earney (1969, p. 512-15) and Manners (1971, pp. 161-2). The production of sinter does not usually involve 'beneficiation' since high-grade fines are the principal raw material. Iron pellets, however, are made either by processing fines, or as the final step in the concentration of low-grade ores. Both types of pelletization are carried out in Australia.

The scale of operations is the critical determinant of the structure of production costs in pelletization (Manners, 1971, pp. 165-6). Large plants can process large tonnages of crude ore from open-cut mines exploiting economies of scale. Processing costs per unit must be minimized if pellets are to compete with unprocessed ores and a large annual output is essential because of the high capital costs of establishment. Fixed costs in pellet production are difficult to estimate because many of the plants are integrated with mining operations, and power, water supply, and other infrastructure is charged against ore output. At Dampier, the capital cost of the pellet plant was $31,400,000 (Madigan, 1969) for an annual capacity of 2,000,000 tons ($15.00 per ton). This cost includes only plant and equipment used in pelletizing, and costs of up to $40.00 per ton have been reported elsewhere (Manners, 1971, p. 167). Reasonable economies of scale can be achieved at this output.

Production co-efficients for the ore input vary considerably. If pelletization is the end product of a concentration process, weight loss is involved and at Port Latta it takes about two tons of low-grade magnetite from Savage River to produce a ton of pellets. At Dampier and Whyalla, however, pellets are produced from fines, some of which are generated during primary crushing, and in the
transport of direct shipping ore to outlet ports. There is very little weight-loss in processing these fines. The main inputs (apart from ore) in the production of pellets are electricity and fuel oil. Direct labour co-efficients are very small for large plants, and the costs of ore comprise about two-thirds of total production costs. It is estimated that pellets are produced at Dampier for between $6.00 and $7.00 per ton, including the notional cost of fines generated in the mining and transportation activities (processing costs are thus about $3.00 per ton).

Alumina is the only technically feasible raw material for the production of aluminium by electrolysis, and bauxite is the ore from which alumina can be most economically produced. A detailed measurement of production factors is attempted here, based on data collected in the field*. As in other mining and processing activities considered so far, the scale of operations is critical to the structure of production costs because of the high levels of capital investment necessary. Economies of scale accrue principally through the spreading of fixed costs, although significant economies are possible in the use of production inputs. Table 3.7 illustrates changes in the production co-efficients for two plant sizes, the larger worked at two actual rates of output.

Between two and three tons of bauxite are required to produce a ton of alumina regardless of the scale of operations. The precise production co-efficient depends on the grade of ore, especially the silica content, and the efficiency of the digestion plant. All bauxite consumed at Gladstone is shipped in bulk carriers from the mine of Comalco Ltd at Weipa, shown in sub-section 3.2.1(d) to be a low-cost operation. Partners in the refining consortium

* Unless specified otherwise, data on which this section is based were collected from Queensland Alumina Ltd, Gladstone, in July 1970.
### Table 3.7: Alumina — Production Co-efficients for Various Inputs: Gladstone

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>Plant size 'A'</th>
<th>Plant size 'B'</th>
<th>Plant size 'C'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Annual output</td>
<td>Annual output</td>
<td>Annual output</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(tons) 600,000</td>
<td>(tons) 900,000</td>
<td>(tons) 1,000,000</td>
</tr>
<tr>
<td>Raw materials:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- bauxite</td>
<td>ton</td>
<td>2.100</td>
<td>2.200</td>
<td>2.500</td>
</tr>
<tr>
<td>- caustic soda</td>
<td>ton</td>
<td>0.170</td>
<td>0.170</td>
<td>0.150</td>
</tr>
<tr>
<td>- starch</td>
<td>ton</td>
<td>0.005</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>- limestone</td>
<td>ton</td>
<td>0.100</td>
<td>0.100</td>
<td>0.050</td>
</tr>
<tr>
<td>Utilities:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fuel oil</td>
<td>ton</td>
<td>0.130</td>
<td>0.170</td>
<td>0.150</td>
</tr>
<tr>
<td>- coal</td>
<td>ton</td>
<td>0.420</td>
<td>0.440</td>
<td>0.400</td>
</tr>
<tr>
<td>- electricity</td>
<td>kilowatt-hour</td>
<td>250.000</td>
<td>266.000</td>
<td>240.000</td>
</tr>
<tr>
<td>- water</td>
<td>thousand gallons</td>
<td>1.166</td>
<td>1.110</td>
<td>1.000</td>
</tr>
<tr>
<td>Direct labour:</td>
<td>man-hours</td>
<td>0.800</td>
<td>0.560</td>
<td>0.552</td>
</tr>
<tr>
<td>Total labour:</td>
<td>man-hours</td>
<td>2.400</td>
<td>1.730</td>
<td>1.680</td>
</tr>
</tbody>
</table>

**Source:** Calculated from data collected at the Gladstone plant of Queensland Alumina Pty Ltd, Queensland, July 1970.

---

a Rated plant capacity 600,000 tons of alumina per annum.

b Rated plant capacity 900,000 tons of alumina per annum.

c Annual output from the Gladstone plant has consistently exceeded the rated production capacity.
(see Appendix I(b)) purchase their bauxite requirements under long-term contracts and f.o.b. prices remain secret*. For present purposes a notional cost estimate is required, based on the estimates made in Table 3.5, and it seems reasonable to suggest an overall c.i.f. price of $5.00 per ton, including $2.00 sea-freight. (The low level of this transport cost is discussed in Chapter 4**). Caustic soda is the principal and most costly adjunct material, and production co-efficients are little influenced by the scale of operations (Table 3.7). The Gladstone plant is supplied from I.C.I.A.N.Z. Ltd (Sydney), but more than half is currently imported from Japan at an estimated c.i.f. price of $50.00 per ton of fifty per cent solution. Starch and limestone are minor inputs, both available locally, which assist in flocculation and effluent disposal.

After caustic soda, steam is the most important adjunct input and this requires the consumption of large quantities of fuel and water. At Gladstone, coal is used in steam-raising since it is available regionally at an estimated $6.00 per ton c.i.f. on a long-term contract***. There are some economies of scale in the use of steam, but the addition of boiler capacity for large increases in alumina production can cause production co-efficients for coal to rise (Table 3.7). To avoid contamination of the

* Each member of the consortium is entitled to alumina output in proportion to his equity share-holding in the venture, and bauxite contracts are written accordingly.

** There is no reason to suppose that bauxite is sold to the consortium partners at cost. Extensions of contracted supplies are probably accompanied by revisions of f.o.b. price to take account of any changes in mining costs (with adjustments for grade). The pricing of captive transfer of Comalco Ltd's share of the bauxite input (sixteen per cent in 1970) depends entirely on group accounting practice, but the transfer is probably not made at cost.

*** This is probably an overestimate since, under the long-term contract with Theiss-Peabody-Mitsui Pty Ltd, coal may be priced at less than $3.00 per ton f.o.b.
alumina, heat for the calcination kilns is provided from fuel oil, bulk-shipped from the Amoco Ltd refinery (Brisbane) at about $25.00 per ton c.i.f.. The large annual water input is provided from a local government scheme in which the company is financially involved, a small addition to total capital costs. Crushing mills for bauxite, limestone, and coal, as well as the product conveyance system and the stockpiling facilities, are electrically operated. Power is provided at bulk concessional rates from the State power station at Callide, at an estimated cost of 0.8 cents per kilowatt-hour. An increase in the scale of operations often results in a large increase in power consumption. In fact, Table 3.7 suggests that economies in the use of utilities are obtained only if it is possible to work a plant of a given rated capacity at higher levels of output.

Direct labour requirements are minimal in capital-intensive processing industries, and scale economies are considerable (Table 3.7). Yet plant labour constitutes only one-third of the total employment; an equal number of employees is concerned with maintenance, an important expense in larger-scale chemical processing. The remaining employees form the administrative staff, and most of the economies of scale occur in this section. Production coefficients for total labour fall by thirty per cent with a two-thirds increase in annual alumina output. The absolute size of the work-force is more important than the production coefficients for a large industrial plant and, at an output of 600,000 tons per annum, the Gladstone plant employed 600 persons, while 950 persons will be required when annual output reaches 2,000,000 tons. Overheads are inflated by site allowances and special employee facilities necessary to attract and retain labour.

In addition to maintenance and plant overheads, land is another very important non-production input in processing at this scale. A large, flat site is essential for a refinery of 1,000,000 tons per annum and, since most inputs
and all outputs are transported by sea, tidewater location is highly desirable. Such land was available at Gladstone on the site of an abandoned meat-works and situated at least four miles from populated areas. An even more important space requirement is an effluent disposal area, since an alumina refinery producing 1,000,000 tons per annum generates at least 1,500,000 tons of red mud each year; disposal of this material, which is of no economic value, is difficult because it does not consolidate and cannot be used for reclamation purposes. Queensland Alumina Ltd obtained large areas of tidal mud-flats and mangrove swamps, four miles from the refinery, for which opportunity costs were zero.

This investigation of production co-efficients suggests that economies of scale in capital investment are of most importance in lowering production costs. The capital investment required to increase the size of the Gladstone plant is shown in Table 3.8. The initial plant investment included port facilities, and items of an infrastructural nature, warehouses, workshops, and administration facilities. In the first and second expansions, only certain sections of the plant needed duplication and most installed equipment could be worked at higher rates of output. Marginal capital costs fell as the plant was increased to an annual capacity of 1,275,000 tons (1971). The third expansion (under construction) adds more than the capacity of the original plant but at a marginal cost still lower than the initial capital investment per ton, although many items are being expanded for the first time during this phase.

Application of the cost estimation model (Appendix II) to the data in Tables 3.7 and 3.8 yields Table 3.9 which estimates total alumina production costs for three levels of output. A decrease in the unit cost of output can be achieved either by increasing the size of the plant (an 'expansion phase'), or by working plant of a particular rated capacity at higher rates of output. The cost structure of
<table>
<thead>
<tr>
<th>Investment phase</th>
<th>Rated annual alumina capacity added (thousand tons)</th>
<th>Total capital cost (million dollars)</th>
<th>Marginal capital cost (dollars per ton)</th>
<th>Total capital investment per ton of capacity (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial plant</td>
<td>600</td>
<td>115</td>
<td>-</td>
<td>192</td>
</tr>
<tr>
<td>First expansion</td>
<td>300</td>
<td>45</td>
<td>150</td>
<td>178</td>
</tr>
<tr>
<td>Second expansion</td>
<td>375</td>
<td>53</td>
<td>142</td>
<td>167</td>
</tr>
<tr>
<td>Third expansion</td>
<td>725</td>
<td>125</td>
<td>172</td>
<td>169</td>
</tr>
<tr>
<td>Final plant totals</td>
<td>2,000</td>
<td>338</td>
<td>-</td>
<td>169</td>
</tr>
</tbody>
</table>

Source: Calculated from data obtained from Queensland Alumina Pty Ltd, Gladstone, in July 1970.
## Table 3.9: Alumina -- Estimated Production Costs at Gladstone

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Plant size 'A'</th>
<th>Plant size 'B'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual output</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(tons) 600,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dollars per unit of output</td>
<td>per cent of total cost</td>
</tr>
<tr>
<td>Raw materials:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- bauxite</td>
<td>10.00</td>
<td>19</td>
</tr>
<tr>
<td>- caustic soda</td>
<td>8.33</td>
<td>15</td>
</tr>
<tr>
<td>- others</td>
<td>0.40</td>
<td>1</td>
</tr>
<tr>
<td>Utilities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fuel oil</td>
<td>3.33</td>
<td>6</td>
</tr>
<tr>
<td>- coal</td>
<td>2.50</td>
<td>5</td>
</tr>
<tr>
<td>- electricity</td>
<td>2.00</td>
<td>4</td>
</tr>
<tr>
<td>- water</td>
<td>0.23</td>
<td>-</td>
</tr>
<tr>
<td>Direct labour:</td>
<td>2.00</td>
<td>4</td>
</tr>
<tr>
<td>Operating supplies:</td>
<td>0.17</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance:</td>
<td>3.83</td>
<td>6</td>
</tr>
<tr>
<td>Total direct costs</td>
<td>32.63</td>
<td>60</td>
</tr>
<tr>
<td>Process control</td>
<td>0.27</td>
<td>-</td>
</tr>
<tr>
<td>Overheads</td>
<td>2.25</td>
<td>4</td>
</tr>
<tr>
<td>Total indirect costs</td>
<td>2.52</td>
<td>5</td>
</tr>
<tr>
<td>Depreciation</td>
<td>15.33</td>
<td>29</td>
</tr>
<tr>
<td>Property tax, insurance etc.</td>
<td>1.40</td>
<td>3</td>
</tr>
<tr>
<td>Total fixed costs</td>
<td>16.73</td>
<td>31</td>
</tr>
<tr>
<td>Total manufacturing costs</td>
<td>51.88</td>
<td>96</td>
</tr>
<tr>
<td>Selling expenses</td>
<td>0.13</td>
<td>-</td>
</tr>
<tr>
<td>Administration</td>
<td>1.05</td>
<td>2</td>
</tr>
<tr>
<td>Financial expenses</td>
<td>1.10</td>
<td>2</td>
</tr>
<tr>
<td>Total Cost</td>
<td>54.16</td>
<td>100</td>
</tr>
</tbody>
</table>

*a* Capital cost of plant and equipment $115,000,000.

*b* Capital cost of plant and equipment $160,000,000.

Source: Calculated by applying the estimation model of Appendix II to the data in Table 3.6.
alumina is dominated by direct costs taken together. The most important are raw materials and fuels, and their contribution increases with the scale of output, principally because of the decline in the importance of fixed costs and overheads (Table 3.9). With an annual production of 1,000,000 tons, bauxite comprises one-quarter of the total production cost, total raw materials comprise forty per cent, and fuels add another twelve per cent. Direct labour contributes only three per cent, rising to about ten per cent when total employment is considered. With increases in the size of plant and rate of output, fixed costs fall both absolutely and in relative importance, but still constitute the largest single production factor (twenty-seven per cent of total cost). The importance of indirect costs also falls somewhat as output increases.

Four conclusions emerge from this analysis of production costs. First, relatively low-cost alumina is produced at Gladstone because of the large scale of output, the low c.i.f. price of bauxite from Weipa, and the generally favourable site for assembly of raw materials and fuels*. Second, any factor increasing capital costs per ton of installed capacity, such as heavy infrastructural expense, makes alumina less competitive unless the scale of operations is considerably increased (with, however, additional demands for labour, water, and power, and greater effluent disposal). Third, because of the importance of raw materials, transport costs are a significant but 'silent' production factor. The spatial variability of input prices is sometimes determined by local factor

* Table 3.9 suggests that alumina was produced at Gladstone in 1970 at about $50.00 per ton. Buchanan and Sinclair (1964, p. 807) have estimated that alumina could be produced in Australia, in a plant of 200,000 tons per annum capacity, at $64.00 per ton despite the fact that many of their cost estimates appear too low under the 1970-71 conditions. United Nations (1966, p. 10) estimated a production cost of about $60.00 per ton in a plant of 330,000 tons per annum. Metals Week (1968, p. 200) reported that the 'Free World' cost of alumina varied between $45.00 and $70.00 per ton.
endowment but, in most cases, by the cost of transport from distant sources. At an output of 900,000 tons per annum, freight contributes $7.20 per ton or thirteen per cent of total unit production cost*. Fourth, Table 3.8 has considerable spatial implications. Despite the high capital costs of plant expansion, the marginal cost per ton is less than that required to establish a separate plant of the extra capacity at another location. A very large plant can, however, suffer diseconomies, especially raw material bottlenecks and difficulties with power and water supply. In addition, industrial stoppages can have very serious consequences in a large, continuous-process plant. An even greater restraint on plant expansion in these industries might be site restrictions and the increasing real costs of effluent disposal at high rates of output. These two factors may have been the most important in the decision by Alcoa of Australia Ltd to establish its second alumina refinery rather than to expand the Kwinana plant beyond its present annual capacity of 1,230,000 tons.

Australia's two other operating alumina refineries show dissimilar cost structures. Relatively low-cost alumina is produced at Kwinana in a plant only slightly smaller than that at Queensland Alumina Ltd. While bauxite inputs are of lower grade, proximity to the mining leases reduces the freight component and the total c.i.f. price of bauxite is comparable to that at Gladstone. In addition, the plant benefits from its tidewater location in the State Government zoned 'industrial area', and purchases fuel oil from the adjacent oil refinery of B.P. (Australia) Ltd. Overhead costs are reduced by location near the State capital city, although land prices are high and the disposal of effluent is a serious problem. A refinery of 60,000 tons annual capacity is located adjacent to the smelter at Bell Bay and the locational decision-making can be under-

* This makes transport the third most important input after fixed cost, and bauxite at f.o.b. price.
stood only in the light of historical circumstances. Cost reduction is inhibited by the very small rate of output but integration with a large (and expanding) industrial plant reduces actual capital costs and most indirect operating charges. With no expansion planned, most plant and equipment is fully depreciated. It is (generously) estimated here that alumina can be produced at a cost of about $60.00 per ton mainly because of the low capital charges, and because of advantages of integration with the adjacent smelter. Thus, it seems fair to assert that the refinery could not remain in production as a separate entity, and may do so only because of special circumstances to be considered in Chapter 7.

3.2.3 The production of metal ingot

Second-stage processing includes the most advanced activities in the mineral industries, such as the production of primary metal by blast furnace techniques, steel-making, the production of electrolytic zinc or aluminium, and the refining of metals such as lead bullion and blister copper. Some second-stage processing plants also produce significant quantities of secondary metal from scrap. Partly because the basic industries of modern economies are included here, and partly because of the apparent usefulness of classical location theory in explaining their spatial distribution, economic geographers have devoted a great deal of research to second-stage mineral processing, particularly the iron and steel industry. (A typical work is Pounds and Parker, 1957; Manners, 1971, reviews the structure of production costs for iron and steel production, the changes in technology, and the location of the world steel industry). It would serve little purpose for this subsection to consider the domestic iron and steel industry in detail; instead, a rapid survey of the principal production factors for iron and steel, copper, lead, and zinc, provides a background for a detailed examination of domestic aluminium smelting. There is very little published material on the structure of production costs in the Australian
aluminium industry. Overall, companies in the metalliferous mineral industries proved most reluctant to divulge information about their second-stage processing activities; it was possible, however, to develop a reasonably detailed analysis of production co-efficients for the production of aluminium at Bell Bay.

In producing pig iron, the relatively uniform ore grades and the increasing importance of high-grade agglomerates have allowed standardization and the continuous improvement of furnace techniques (Manners, 1971, pp. 34-41). In producing aluminium ingot, the essential alumina refining stage acts as a buffer against the variability of ore costs. Copper smelting provides a complete contrast; few smelters operate on the same process flow-sheet, and much depends on the character of the concentrate input for which production co-efficients are high. At Mount Isa for example, about 3.5 tons of concentrate are required for each ton of blister copper produced. While there are virtually no reliable data on copper smelting and refinery (Brown and Butler, 1968, p. 14), it is clear that fixed cost components are high because of the relatively small size of smelters* (Fig. 2.1).

The structure of costs for blister copper is dominated by the costs of the concentrate inputs which reflect either the high costs of underground mining, or the low grades of ore produced by open-cut methods. Brown and Butler (1968, p. 5) have drawn an interesting comparison between the structure of production costs for refined copper and primary aluminium (Table 3.10). For copper production, raw material inputs account for half of the total cost, while variable and semi-variable costs of

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* Even the smelter at Mount Isa is small compared with those of the world's major copper producers. Most plants in the United States are at least three times its size, and five furnaces have annual production capacities of more than 1,000,000 tons.
TABLE 3.10: COPPER AND ALUMINIUM

AVERAGE PRODUCTION COST COMPONENTS FOR PRIMARY METAL
(per cent per ton)

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Copper</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore extractiona</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Beneficiationb</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Principal raw material input</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Smelting costs (variable and semi-variable)</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Refining costs (variable and semi-variable)</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Fixed cost, freight, royalty</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

a Assuming copper ore extracted by underground methods and bauxite from open-cut mine.

b Includes production of copper concentrates and alumina.

Source: After Brown and Butler, 1968, p.5.
smelting in the blast furnace contribute only an additional ten per cent. The greater importance of fixed costs reflects the generally small scale of plants, and total smelting costs comprise forty-five per cent of total production cost. By contrast, some seventy per cent of the cost of aluminium ingot is composed of the cost of electrolytic smelting.

Production economies at the Port Pirie lead smelter-refinery have been summarized by Woodward (1965, pp. 159-71). Concentrates from Broken Hill are of generally high grade, and only 1.5 tons are required for each ton of lead bullion produced. Nevertheless, the smelting process involves considerable weight-loss with the assembly of other raw materials such as coal (for coke), iron ore (for fluxing), sand, lime, and caustic soda. With an annual production capacity (1970) of 200,000 tons of refined lead, fixed costs are minimized and the cost structure is dominated by raw materials and fuels. Ores of lower grade are processed at Mount Isa.

Steel in Australia is produced by The Broken Hill Proprietary Co. Ltd at relatively low cost in the large-scale integrated works at Newcastle and Port Kembla. Most adjunct raw materials are available locally, and expansive tidewater locations are now linked to a wide range of allied industries with a high degree of market accessibility. The smaller integrated plant at Whyalla, meeting higher infrastructural requirements and higher overheads, enjoys economies of coal back-loading at the company's principal iron ore outlet port*. The blast furnace at Kwinana processes low-cost iron ore from Koolyanobbing on a tidewater block in the State Government's industrial area. In all of these plants, raw materials and labour costs are the most important production factors, while

* An interesting, if parochial, defence of its production economics has been made by Dickinson (1956).
transport inputs are significant depending on the sources of iron ore and coking coal. The high degree of vertical integration means that accounting practice is critical in a statement of total production costs for either pig iron or ingot steel. Recently, The Broken Hill Proprietary Co. Ltd has published an estimated break-down of steel costs to illustrate the difficulties associated with the costing of iron ore, coal, and limestone, obtained from wholly-owned subsidiaries and transported by the company's own coastal fleet*. There is no domestic market for iron ore, the principal input. These cost estimates are the first published by the company and, despite the difficulties associated with their interpretation, they throw some light on the cost structure for Australian ingot steel.

Direct manufacturing costs accounted for about three-quarters of total costs, and raw materials (including coal) and labour were the principal cost factors (twenty-four per cent and twenty-five per cent respectively of the total). Fixed costs were surprisingly low (twelve per cent) reflecting the scale of operations of the principal steel plants and, perhaps, the age of some plant and equipment. The policy of pricing steel c.i.f. capital cities produced an outward freight cost of eight per cent of the total. It is interesting to compare these estimates with those given by Manners (1971, pp. 11-14), although the latter are somewhat out of date. In the production of ingot steel in the United States, most of the cost factors were similar except that the relative importance of iron ore and coal inputs was much greater, and labour lower, suggesting generally higher prices for the basic raw materials. Manners shows that capital cost components are highest in steel rolling and semi-fabrication.

Electricity is important in all second-stage processing industries, principally for motive power, but is

virtually a 'raw material' in some electro-processes. The electrolytic production of aluminium involves very large power input; high-grade zinc is also produced by electrolysis, while blister copper is refined electrolytically before semi-fabrication. Steel can be produced in electric-arc furnaces, and other metals produced by electro-process include magnesium and ferro-manganese. The relationship between power cost and product value is shown in Table 3.11 which suggests that aluminium, for example, could not be produced economically at the normal rates for industrial power (commonly well above 0.6 cents per kilowatt-hour). Although power co-efficients are very much lower than for aluminium smelting, the economic production of electrolytic zinc requires electricity at below 0.8 cents per kilowatt-hour. Low-cost hydro-electricity is available at Risdon, Tasmania (Fig. 2.1). The combination of economies of scale with efficient use of electric power results in the production of zinc at low cost (Woodward, 1965, pp. 204-26). About two tons of concentrate are required for each ton of metal but, although a fifty per cent weight-loss is involved, valuable by-products are obtained from the 'waste', including sulphuric acid, lead, silver, cadmium, and cobalt. The two smaller plants in Australia now produce zinc of lower purity by the Imperial Smelting Process, similar to conventional lead blast furnace production (Woodward, 1965, pp. 194-204).

Primary aluminium is produced exclusively by electrolysis, and despite high establishment costs, smelters throughout the world remain relatively small with satisfactory economies of scale achieved with an annual capacity of 100,000 tons. Requirements for the commercial viability of aluminium smelting are rigidly determined by the standardized technology of the Hall-Heroult Process. Changes in production co-efficients for three different smelters are shown in Table 3.12; the smallest (Plant 'A') is hypothetical, while Plant 'B' is that of Comalco Aluminium (Bell Bay) Ltd and Plant 'C' that of New Zealand Aluminium Smelters Ltd at Bluff (in which Comalco Ltd has a fifty
<table>
<thead>
<tr>
<th>Product</th>
<th>Power requirement per ton (kilowatt-hours)</th>
<th>Approximate value per ton (dollars U.S.)</th>
<th>Electricity costs per ton at various power prices (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.2 cents per kwh</td>
</tr>
<tr>
<td>Aluminium</td>
<td>17,000</td>
<td>520</td>
<td>34.00</td>
</tr>
<tr>
<td>Magnesium</td>
<td>20,000</td>
<td>720</td>
<td>40.00</td>
</tr>
<tr>
<td>Electrolytic copper</td>
<td>2,500</td>
<td>720</td>
<td>5.00</td>
</tr>
<tr>
<td>Electrolytic zinc</td>
<td>3,700</td>
<td>268</td>
<td>7.40</td>
</tr>
<tr>
<td>Iron</td>
<td>2,200</td>
<td>66</td>
<td>4.40</td>
</tr>
<tr>
<td>Steel (electric)</td>
<td>600</td>
<td>80</td>
<td>1.20</td>
</tr>
<tr>
<td>Ferromanganese</td>
<td>4,500</td>
<td>240</td>
<td>9.00</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>13,000</td>
<td>370</td>
<td>26.00</td>
</tr>
<tr>
<td>Chlorine</td>
<td>3,000</td>
<td>60</td>
<td>6.00</td>
</tr>
</tbody>
</table>

Source: After a Table compiled by Ivan Bloch and Associates of North Pacific Consultants, Portland, Oregon (U.S.A.) (supplied to the author by Plant Location International Ltd, Sydney, December 1970).
## TABLE 3.12: ALUMINIUM — PRODUCTION CO-EFFICIENTS FOR VARIOUS INPUTS

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>Plant size 'A'</th>
<th>Plant size 'B'</th>
<th>Plant size 'C'</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw materials:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- alumina</td>
<td>ton</td>
<td>1.90</td>
<td>1.90</td>
<td>2.00</td>
</tr>
<tr>
<td>- petroleum coke</td>
<td>ton</td>
<td>0.30</td>
<td>0.28</td>
<td>0.30</td>
</tr>
<tr>
<td>- pitch</td>
<td>ton</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>- cryolite</td>
<td>ton</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>- fluorides</td>
<td>ton</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Utilities:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fuels</td>
<td>ton</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>- electricity</td>
<td>kilowatt-hour</td>
<td>18,600.00</td>
<td>16,500.00</td>
<td>16,360.00</td>
</tr>
<tr>
<td><strong>Direct labour:</strong></td>
<td>man-hours</td>
<td>12.00</td>
<td>10.00</td>
<td>9.60</td>
</tr>
<tr>
<td><strong>Total labour:</strong></td>
<td>man-hours</td>
<td>18.00</td>
<td>15.10</td>
<td>14.43</td>
</tr>
<tr>
<td>Capital cost of plant and equipment</td>
<td>dollars</td>
<td>1,200.00</td>
<td>860.00</td>
<td>900.00</td>
</tr>
</tbody>
</table>

- ^a^ Annual production of 20,000 tons primary aluminium.
- ^b^ Annual production of 70,000 tons of primary aluminium.
- ^c^ Annual production of 110,000 tons of primary aluminium.

**Sources:**
For Plant size 'A': United Nations (1966);
for Plant size 'B': data collected at Bell Bay, December 1969, and
Melbourne, July 1970;
for Plant size 'C': data for the Bluff smelter, New Zealand, supplied
per cent shareholding). It is assumed that these plants have no significant excess capacity, a feat seldom achieved in the industry over the last few years.

Aluminium production is a continuous process requiring large quantities of alumina, electricity, and labour, and small quantities of other inputs. For raw material inputs there are no significant economies of scale, at least for a plant with electrolytic cells of given size. The optimal size of the cell is quite small, the largest at Bell Bay producing 1,330 pounds of aluminium every twenty-four hours. Production co-efficients for alumina and the adjunct materials are standard (Table 3.12) regardless of the rate of output, principally because of the upper limit to cell size. Electrolytic cells are arranged in series, 'potlines', and an increase in the rated production capacity simply requires the addition of new lines. The weight-loss of about half the input of alumina is determined chemically (there are no 'grades' of alumina) and, for Bell Bay, about forty-two per cent of this input was produced in 1970 in the adjacent refinery considered in sub-section 3.2.2(b). The remainder is bulk-shipped from Gladstone at an estimated notional price of $58.00 per ton c.i.f., including $5.00 freight. The principal adjunct inputs are petroleum coke and pitch from which pre-baked carbon anode blocks and cathode paste are produced for use in each cell. Coke, the basic material, is imported from the United States at an estimated price of $50.00 per ton, while pitch is available domestically at about $40.00 per ton.

The consumption of cryolite, the medium in which electrolysis takes place, is small once the potlines are operating continuously; this is important since imported cryolite costs approximately $300.00 per ton. Fuel requirements in the smelting process are very small, although much larger quantities are consumed in the adjacent refinery. Production co-efficients for both direct
and total labour are very much higher than for alumina refining (Table 3.12), although potlines can be expanded with a less than proportionate increase in operating staff. At Bell Bay in 1970, a total of 1,000 persons was employed (including refinery labour), with about 500 in the pot-rooms, 50 in the carbon plant, 35 in the casting shop, and 200 in maintenance. Production at the full capacity of 94,000 tons (1971) would require about 1,200 employees.

After alumina, electricity is the most important input and it was shown in Table 3.11 that price differences of 0.1 cent per kilowatt-hour make a considerable difference to total production costs. Economies of scale are very important (Table 3.12) and, while lower production coefficients can be achieved by increasing the size of individual cells, the most important factor is the increase in the efficiency of transmission as the total plant capacity is increased. Aluminium smelting does not provide opportunities for the generation of electricity as a by-product, and the peak-load requirements are such that power must either be purchased from the State grid (and preferably with a large power station nearby), or generated by the smelting company in a large, efficient station, from which excess power can be sold to the regional power authority. At Bell Bay, power from the Tasmanian Hydro-electricity Commission can be obtained for about 0.4 cents per kilowatt-hour which enables ingot to be smelted economically in a reasonably large plant*. Electricity is so important that the optimal scale of smelting operations is often determined by the economics of the power source, especially if there are few other potential users of power in the region. The importance of hydro-electricity in world aluminium smelting is well-known; hydro-stations

* The actual and potential spatial variability in the cost of electricity is high. In Australia, industrial rates for power from State grids vary between 1.8 cents and 2.5 cents per kilowatt-hour, although substantial concessions for bulk purchase can be negotiated.
alone can supply the requirements of a relatively small smelter at less than 0.6 cents per kilowatt-hour. Yet production economies of electricity generation have changed markedly in the last decade, and very large coal-fired stations at or near coal-fields can reduce power costs to about 0.3 cents per unit. In addition, sites for major hydro-schemes allowing reasonable transmission costs to large-scale industrial users are scarce. Where they exist, however, they usually give their region some cost advantage for aluminium production (for example, the Lake Manapouri Scheme in New Zealand). Hence, while changes in production co-efficients for electricity are unlikely, improvements in power generation will influence future aluminium cost structures.

This investigation of production co-efficients suggests that, apart from economies in electricity use, scale economies in capital investment are most important if aluminium is to be produced competitively. Establishment costs are considerable; smelters need very large production sites and, with most inputs (and often output) transported at some stage by sea, tidewater blocks provide positive advantages. Infrastructural development of the Bell Bay region was undertaken by the Tasmanian Government and 'inherited' by Comalco Ltd (at virtually no cost) when that company purchased in 1960 the Commonwealth Government's controlling share in the smelter-refinery complex. In order to establish a smelter of only 12,000 tons per annum and a refinery of 30,000 tons per annum, the Commonwealth Government had incurred a capital cost of $19,400,000 by 1960. The Tasmanian Government contributed only $3,000,000 towards plant and equipment but invested at least $20,000,000 in regional facilities (including the Trevallyn power station) which, of course, remain public. The total capital cost of plant and equipment was $1,866 per ton of ingot for so small a production capacity. With the initiation of a new potline, Comalco Ltd immediately raised production capacity to 20,000 tons and total invest-
ment fell to $1,300 per ton. By 1967, the total capital cost (including the initial investment in plant and equipment) had risen to about $60,000,000 for an annual production capacity of 73,000 tons ($822 per ton). During 1970, capacity was raised by 21,000 tons per annum at a capital cost of only $9,000,000*. A United Nations report (1966, p. 12) has argued that new potlines can be added to existing smelters at marginal capital costs considerably less than the costs per ton of establishing a new smelter. This argument can be overstated easily, however, for aluminium smelting, especially in view of the potential importance of power restraints in certain locations.

The cost estimation model has been applied to the data of Table 3.12 first, by applying input prices at Bell Bay to the co-efficients for Plant 'A' and, second, by estimating the actual costs of production at Bell Bay during 1970. The production cost of primary metal (Table 3.13) is dominated by the cost of alumina (twenty-nine per cent of the total cost) and electricity (seventeen per cent). Total raw materials contribute thirty-seven per cent and direct labour only seven per cent (rising to about twelve per cent for all labour). Considerable unit cost reduction is involved by increasing annual rates of output from 20,000 tons to 70,000 tons per annum. Direct costs per unit fall, because of economies in the use of electricity and labour, but their relative importance in the cost structure increases as output rises. The

* During 1971, however, world markets for aluminium slumped and excess capacity appeared in most producing nations. In fact, Huggins (1965, p. 61) has claimed that 'the history of the aluminium industry is one of lumpy capital investment providing, in periods of optimism, capacity ahead of requirements which later catch up only to have production take another leap forward'. At Bell Bay, production has been cut back by the partial closure of the original potline, suggesting that the recent expansion of plant capacity will have little beneficial influence on production costs, at least in the short-run.
TABLE 3.13: ALUMINIUM -- ESTIMATED PRODUCTION COSTS OF PRIMARY METAL

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Plant size 'A', a</th>
<th>Plant size 'B', b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dollars per unit output</td>
<td>per cent of total cost</td>
</tr>
<tr>
<td>Raw materials:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- alumina</td>
<td>114.00</td>
<td>24</td>
</tr>
<tr>
<td>- petroleum coke</td>
<td>15.00</td>
<td>3</td>
</tr>
<tr>
<td>- pitch</td>
<td>8.00</td>
<td>2</td>
</tr>
<tr>
<td>- cryolite</td>
<td>6.20</td>
<td>1</td>
</tr>
<tr>
<td>- other fluorides</td>
<td>4.00</td>
<td>1</td>
</tr>
<tr>
<td>- total raw materials</td>
<td>147.20</td>
<td>31</td>
</tr>
<tr>
<td>Utilities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fuels</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>- electricity</td>
<td>74.40</td>
<td>16</td>
</tr>
<tr>
<td>Direct labour:</td>
<td>36.00</td>
<td>8</td>
</tr>
<tr>
<td>Operating supplies:</td>
<td>3.00</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance and repair:</td>
<td>18.00</td>
<td>4</td>
</tr>
<tr>
<td>Total direct costs</td>
<td>279.60</td>
<td>59</td>
</tr>
<tr>
<td>Process control</td>
<td>6.00</td>
<td>1</td>
</tr>
<tr>
<td>Overheads</td>
<td>42.00</td>
<td>9</td>
</tr>
<tr>
<td>Total indirect costs</td>
<td>48.00</td>
<td>10</td>
</tr>
<tr>
<td>Depreciation</td>
<td>96.00</td>
<td>20</td>
</tr>
<tr>
<td>Property tax, insurance etc.</td>
<td>12.00</td>
<td>3</td>
</tr>
<tr>
<td>Total fixed costs</td>
<td>108.00</td>
<td>23</td>
</tr>
<tr>
<td>Total manufacturing costs</td>
<td>435.60</td>
<td>92</td>
</tr>
<tr>
<td>Selling expenses</td>
<td>10.00</td>
<td>2</td>
</tr>
<tr>
<td>Product distribution</td>
<td>4.00</td>
<td>1</td>
</tr>
<tr>
<td>Corporate administration</td>
<td>22.00</td>
<td>5</td>
</tr>
<tr>
<td>Total cost</td>
<td>471.60</td>
<td>100</td>
</tr>
</tbody>
</table>

a Production of 20,000 tons per annum; capital cost of plant and equipment $24,000,000.
b Production of 70,000 tons per annum; capital cost of plant and equipment $50,000,000.

Source: Application of the estimation model of Appendix II to the data in Table 3.11.
principal cost reduction is in fixed costs which fall from twenty-three to sixteen per cent of the total cost. Bearing in mind the assumptions on which Table 3.13 is based (see Appendix II), and ignoring possible effects of excess capacity, it seems clear that aluminium ingot can be produced competitively at Bell Bay, largely because of favourable electricity costs. The unit cost estimated, however, is above the median of world cost estimates quoted by Metals Week (1968, p. 203).

The structure of production costs at Australia's two other aluminium smelters is undoubtedly similar, although a few differentiating characteristics are important. The smelter of Alcoa of Australia Ltd at Point Henry, with an annual capacity of 90,000 tons, was developed at a capital cost of $90,000,000. While the relative importance of the production factors would be the same as at Bell Bay, and most operating costs similar*, there have been considerable differences in the supply of electricity to the plant. For the first six years of its operation, power was obtained solely from the Victorian State Electricity Commission at rates which are unlikely to become public knowledge. As a result of the analysis in this sub-section, however, the order of concession necessary to make production economic is clear. If power were supplied at half or even one-third of the standard industrial rate, production in Victoria would not have been feasible unless the company could immediately construct a large low-cost power station. If a rate of 0.6 cents per kilowatt-hour were offered, power

* Differences in the cost of alumina are conjectural. The movement of alumina from Kwinana to Point Henry is a captive transfer and 'pricing' depends on internal accounting; nevertheless, unfavourable freight rates of up to $8.00 per ton for alumina between these ports (discussed in Chapter 4) may produce a higher real c.i.f. price at Kwinana than at Bell Bay. This apparent disadvantage is partially offset by the relatively higher cost of alumina produced at Bell Bay and supplying forty-two per cent of that smelter's requirements.
costs of $100.00 per ton would be incurred (compared with less than $70.00 at Bell Bay). Although unsatisfactory in the long-run, such a concession would have been sufficient to facilitate the establishment of the smelter both because of the 'umbrella effect' of import protection and, particularly, the captive transfer of ingot to semi-fabricators removing the possibility of domestic price competition, at least at this stage of production. For the long-term, a rate of between 0.4 and 0.5 cents was desirable, close to the average cost of producing electricity from brown coal in the Latrobe Valley. In 1969, the company completed its own power station on a brown coal deposit at Angelsea. The peak load generating capacity of 150 megawatts means that any excess power needs must still be purchased from the State Electricity Commission at the concessional rates.

The entry of Alcan (Australia) Ltd into domestic aluminium smelting was to be assisted by the securing of a large export contract, for up to half of the annual output of the plant at Kurri Kurri. Satisfactory economies of scale could be achieved in a plant with a plant capacity of 88,300 tons per annum. The loss of this contract in 1971 has placed this project in difficulties, although the plant was still 'tooling-up' in 1970 with attendant diseconomies*. For the immediate future, installed aluminium capacity is likely to remain at 44,460 tons. At this scale of output, the costs of both alumina and electricity become critical. Labour and certain adjunct materials are available locally but imported raw materials must be transshipped at Newcastle and transported twenty-eight road miles to the plant site. Transport costs for low-cost alumina from Gladstone are increased by the relatively short sea voyage and small size of annual flow,

* Substantial losses have been borne by Alcan (Australia) Ltd during this tooling-up period. In 1970, a net loss of $1,300,000 was sustained, $2,000,000 having been written-off in 1969 for plant establishment.
and, most importantly, by the cost of transshipment and carriage to Kurri Kurri. Once again, electricity is obtained at (secret) concessional rates from the State Government and there is no immediate plan for the substitution of an alternative generation scheme for these concessions. With somewhat higher input costs than the other smelters, a power rate at least as low as 0.4 cent per kilowatt-hour seems essential if unit production costs are to be brought into line with those of the tidewater plants.

3.3 Conclusion

The survey of production costs in Australian mining and processing allows some important generalizations, the locational significance of which will be explored in Chapter 6. The production of ores is dominated by the fixed cost components related to the capital costs of establishment and expansion, especially in open-cut mining where production co-efficients for variable inputs are low. Capital costs are also critical in first- and second-stage processing, particularly in the production of iron agglomerates and alumina where economies of scale are essential if materials are to be supplied competitively to second-stage plants. The relative factor weights for adjunct materials (such as coal and fuel oil), labour, and power, are greater for second-stage processing than for earlier stages of production. The analysis of aluminium smelting indicated that a considerable degree of government involvement is possible in the pricing of critical production factors, in this case electricity. Raw material costs were found to be important for all metalliferous processing plants, particularly those with high rates of output, or those using materials of variable quality. Transport components in some of the c.i.f. prices are considerable. The determination of the spatial variability of raw material costs and capital costs, therefore, requires a detailed analysis of transport (Chapter 4) and establishment costs, particularly investment in infrastructure at isolated locations (Chapter 5).
A basic premise of spatial analysis is that distance acts as an ordering mechanism. Transport costs have central importance in resource creation and in the theory of location, and are characteristically used as a surrogate for distance in miles. It is not surprising that 'the taming of distance is essential before minerals can be found and mined' (Blainey, 1966, p. 138) and this chapter examines the influence of transport on the pattern of mines and domestic mineral processing plants. After briefly considering the relationship between transport costs and distance, the magnitude of the flows of mineral commodities is determined, with particular attention being given to the choice of transport system available to the shipper in each case (section 4.2). The argument is drawn together (section 4.3) into an analysis of freight rates and a measure of transportability as a development and location factor. In this section, data are generated for the empirical models, based on freight rates in operation during 1970 wherever possible.

4.1 Transport Costs, Distance, and Transportability

It becomes apparent when dissecting the spatial arrangement of the metalliferous mineral industries that transport costs provide only one measure of the importance of distance. The costs of isolation can considerably inflate capital costs, labour costs, and total production expenses of both mining and processing. The costs of
transporting inputs and outputs are seldom determined by absolute geographic distances because freight rates are only loosely related to the length of haul. Rather, they reflect product characteristics, transport technologies, the costs (particularly the time costs) of loading and unloading, tonnages moved on individual consignments, ownership of the transport media, and the pricing policies adopted. In practice, the geographer must deal with dynamic surrogates for distance in which notions of spatial 'proximity' can be defined only in terms of the relative transportability of commodities under consideration and of their total costs (expressed as c.i.f. prices) at points of consumption.

The problem of measuring transport influences on various macro-economic phenomena in a national economy is well-known (Hirst, 1963, pp. 65-7). So far, in this study, transport charges have been included in production costs without comment; they have simply been a component in the delivered prices of raw material inputs at each stage of activity. As such, it is not easy to isolate the influence of transport costs in locational decision-making. Moreover, it is difficult to assess the relationship between f.o.b. prices at sources, and c.i.f. prices at consumption points when commodities move between plants of the same integrated firm for then much depends on internal accounting practices. Measurement is further complicated by differences in ownership of the various transport media.

Some companies, notably The Broken Hill Proprietary Co. Ltd and the export iron ore miners, own railway lines and rolling stock, maintain fleets of road transports, and operate maritime bulk carriers. Such transport activities are ancillary to the principal operations of the companies and are seldom recorded separately. In Australia, private transport media carry very large tonnages of metalliferous minerals and sell their services in various ways depending on the particular means of conveyance and its ownership.
Services may also be purchased from a public carrier (such as a State railway system) at established commodity rates or at concessional rates negotiated for individual consignments or a particular commodity flow. In such cases, transport costs depend on government pricing policy, and on the structure of concessional rates which may be granted because of transport economies (such as bulk long-haul shipments) or for political reasons.

Private transport companies may sell carriage to mineral producers at market prices, the result of competition or collusion or, as is more likely, at negotiated rates depending on the type of cargo, tonnage, length of haul, and the regularity of demand. A vessel, such as a bulk carrier, may be chartered for exclusive use over a negotiated time period. The private sector is influenced in its operation by an elaborate framework of government controls causing differences between media, and further obscuring the relationship between cost and distance.

The transportability of a commodity is sometimes thought to be its ability to bear freight. For example, transport costs form a significant component of the c.i.f. price of mined products (ores and concentrates) since most have a low f.o.b. value per unit weight. It would thus be expected that the transportability of semi-processed and processed metals is increased since the value added by processing is usually large. Yet, as early as 1924, Engländner argued that 'the transportability of goods does not depend on their value' (Lösch, 1954, p. 45 fn.), and Lösch himself showed that the nature of demand schedules and volume of flow could be of greater importance (1954, p. 45). The determination of the effective transportability of a commodity over a given route depends on a complex set of interactions including such characteristics as perishability, the stowage factor, and weight-loss during processing.
It has been shown earlier in this study that the concept of weight-loss is basic to Weberian location theory. Industries whose principal input suffers considerable weight-loss in processing are optimally located at or near the source. In practice, the weight-loss principal is often counterbalanced by the multiplicity of factors which determine freight rates. Over the last twenty years the economies of bulk shipment have been increasing, especially for materials of low value per unit weight, following the installation of bulk handling facilities at terminals and the introduction of vehicles and vessels with much greater carrying capacities. Also important are the pricing policies of the various transport operators which generally favour the transport of unprocessed goods rather than semi-finished, higher value goods such as metal ingots and shapes. Weber's 'material index' is not a reliable guide to the least-cost locational arrangement except under the more extreme conditions of weight-loss (such as in the concentration of complex copper, lead, and zinc ores).

Thus, for the flow of a particular commodity, the interactions of geographical distance, volume, f.o.b. value, commodity and route characteristics, and carrier pricing policy determine transportability and the effective or 'economic' distance between the source and the point of consumption. For instance, a processing plant on tidewater able to obtain its principal input from a single, large producer and able to negotiate special freight rates for regular bulk shipments by sea is effectively 'nearer' its raw material source, regardless of the actual distance involved, than a plant using a number of disparate sources served by small volume, less regular shipments. It is not surprising that several types of 'optimal' location orientation can be discovered within a single industry if actual distance between plants is used as the yardstick.

Transport costs are important in foreign trade and help determine international comparative advantage. The relationship between freight rates and competitiveness in
international markets for metal ores is given detailed treatment by Manners (1967, pp. 272-6, and 1971, pp. 173-200). Drysdale has argued that 'geographical proximity was ... easily the most important among the three factors which favoured growth in Australian exports of minerals and metals to Japan' (1970, p. 200), and also that proximity can be measured through transport costs which are held to be the most important determinant of export trade bias towards Japan in these commodities (1970, p. 203). While the actual relationship between transport costs (Australia to Japan) and comparative advantage is yet to be demonstrated, geographical proximity at least partially explains the direction of Australia's foreign trade in metalliferous minerals.

4.2 The Movement of Metalliferous Minerals on Australian Transport Systems

The modal choice in commodity flow depends on the availability of services to particular locations and the relative economics of transport on each system over the required distance. This section considers the transportation of metalliferous minerals around Australia between sources and consumption points at each production level (Fig. 2.1), culminating in the distribution of ingot metal to metal-using industries. Sub-section 4.2.1 considers the structure of the Australian transport systems as a background to the choice, both of transport media and, ultimately, of processing location. Air transport is, under foreseeable circumstances, not feasible for the shipment of metals and metal ores although Dubnie (1961, pp. 11-14) has forecast that this may not always be the case. The importance of transport on internal systems is considered in sub-section 4.2.2 which also presents data on actual flows for 1970*.

* Mineral commodity flow data were calculated from the latest available statistics published by Bureau of Mineral Resources, Geology, and Geophysics.
4.2.1 The choice of transport mode

The modal choice partially determines the transportability of, for example, a metal ore from a particular source, and is thus a decisive factor in the effective distance between that source and the locations of its consumers. In this way the proportion of traffic moved by each sector influences the importance of distance as a locational factor. Australian coastal shipping seems to hold a virtually impregnable position for the movement of bulk mineral cargoes in ship-load consignments, especially where hauls of more than 1,000 miles are involved. An increasing proportion of mineral traffic is borne by bulk carriers, the introduction of which has greatly influenced the coastal flows of metalliferous ores such as iron ore and bauxite, but a considerable tonnage of ingot metal is still distributed to domestic metal-users by general cargo freighters.

Freight rates increase less than proportionately with distance because of economies of long haulage*. In addition, shipping has some technological advantages for bulk transport: bulk loading and discharging facilities can be installed on the wharves to reduce turn-round time, and economies of scale can be exploited by the introduction of larger vessels specializing in the movement of a single type of commodity. Bulk carriers of 10,000 deadweight tons (d.w.t.) appeared in Australian coastal shipping in 1955 and soon others were introduced of 20,000 d.w.t. followed, in turn, by vessels of more than 50,000 d.w.t. Internationally, bulk carriers above 100,000 d.w.t. were introduced for the mineral trade but the first vessel of this size to operate on the Australian coast did not appear until 1972. Despite the capital costs of these ships, a high level of vessel can ensure that line-haul costs per ton carried

* Obviously, transport costs per ton rise as length of haul increases, but seldom proportionately. Falling costs per ton mile (one ton carried for one mile) indicate a tapering of freight rates with increasing distance.
remains low. Bulk commodities such as iron ore, bauxite, and alumina are particularly suitable for transport in these vessels since they usually have high weight-to-volume ratios and are suitable for bulk handling at terminals, thus reducing the time ships spend in port and improving the relationship between capital costs per ton carried and operating costs*. Larger vessels allow a reduction of ton-mile costs through economies of scale because of the lower capital costs per ton transported and because terminal, labour, and maintenance charges can be spread. Bulk carriers of greater than 30,000 d.w.t. capacity become uneconomic for hauls of less than 1,000 miles, due principally to the predominance of terminal over operating expenses (Manners, 1967, p. 268 and 1971, pp. 180-1).

Mineral companies in Australia can choose between several coastal shipping operators, although only some of these have bulk carriers. The two leading coastal carriers are the Australian National Line (sixteen bulk carriers in 1970), which is owned by the Commonwealth Government but operates virtually as a private shipping company**, and The Broken Hill Proprietary Co. Ltd (six bulk carriers), which operates its own coastal fleet for the movement of iron ore, coal, limestone, manganese ore, ferro-alloys and steel

* The critical factor for bulk cargoes is the relationship between the total amount of hold space, in cubic feet, and the maximum deadweight lifting capacity of the vessel. Commodities with stowage factors of thirty-five cubic feet per ton or less are very suitable since, in these cases, a vessel's capacity tonnage is unlikely to exceed the available hold space. Iron ore stows at between twelve and fifteen cubic feet per ton, bauxite between twenty-six and twenty-eight cubic feet, and alumina at thirty-two cubic feet per ton.

** Bulk carriers operated by the Australian National Line are in considerable demand for shipments of coal, gypsum, and salt, as well as bauxite and alumina. The availability of carriers for individual voyage charters, therefore, is often restricted.
products. Coastal shipping has long enjoyed protection under the Commonwealth Navigation Act 1919-1968; licences are granted only to ships meeting certain conditions and most ships not registered in Australia are precluded from regular operation around the coast (when local bottoms are available) despite the much lower operating costs achieved by many international shipping companies. Developments in Australian coastal shipping since the Second World War have been summarized by Lowndes (1956), Hirst (1963, pp. 73-80), and Rimmer (1967). Suffice it to say here that, despite a large decline in the movement of coal, the bulk carrier trade has provided most of the expansion in the Australian coastal shipping industry over the last two decades. The relative contribution of the bulk trades is certain to increase (Table 4.1), corresponding with a world trend towards the bulk carriage over long distances of unprocessed raw materials based on falling real costs of bulk sea transport (Manners, 1967, pp. 260-2).

There are practical limits to the introduction of very large carriers into the coastal trade. First, only plants located on tidewater and with very large input requirements can keep carriers of 50,000 d.w.t. economically occupied in a specialist trade and, second, the number of ports capable of handling such vessels is limited. There are relatively few ports in the world (as yet, three in Australia) capable of accommodating fully-loaded vessels of more than 75,000 d.w.t. and, in a majority of established harbours, the provision of adequate draught and, especially, terminal facilities for unloading large bulk carriers would prove difficult. There has been a corresponding search, no less in Australia than overseas, for deep-water port sites which would provide adequate docking facilities and plentiful foreshore space for the installation of high-speed handling equipment with attendant stock-pile areas. The changing port requirements necessary to take advantage of the economies of bulk mineral shipment have, over the last ten years, exerted a profound influence on the location
TABLE 4.1: INTERSTATE MOVEMENTS OF COMMODITIES BY COASTAL SHIPPING

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1955-56</th>
<th>1963-64</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tons (thousand)</td>
<td>Per cent</td>
</tr>
<tr>
<td><strong>Bulk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude oil and petroleum products</td>
<td>2,005</td>
<td>15.6</td>
</tr>
<tr>
<td>Iron ore</td>
<td>3,488</td>
<td>27.1</td>
</tr>
<tr>
<td>Limestone</td>
<td>329</td>
<td>2.6</td>
</tr>
<tr>
<td>Coal</td>
<td>2,193</td>
<td>17.1</td>
</tr>
<tr>
<td>Coke</td>
<td>252</td>
<td>2.0</td>
</tr>
<tr>
<td>Sugar</td>
<td>265</td>
<td>2.1</td>
</tr>
<tr>
<td>Other bulk</td>
<td>758</td>
<td>5.9</td>
</tr>
<tr>
<td><strong>Total bulk cargo</strong></td>
<td>9,290</td>
<td>72.3</td>
</tr>
<tr>
<td><strong>General cargo</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Steel ingot and products</td>
<td>760</td>
<td>5.9</td>
</tr>
<tr>
<td>Bagged sugar</td>
<td>148</td>
<td>1.2</td>
</tr>
<tr>
<td>Bagged wheat</td>
<td>53</td>
<td>0.4</td>
</tr>
<tr>
<td>'Sea road' cargo</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other cargo&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2,600</td>
<td>20.2</td>
</tr>
<tr>
<td><strong>Total general cargo</strong></td>
<td>3,561</td>
<td>27.7</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>12,851</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> Shipped as bulk cargo after 1957.
<sup>b</sup> For 1955-56 items classed as 'other bulk' are included as 'other cargo' in this Table.

Source: After Rimmer (1967, p. 21).
of mineral processing plants, a phenomenon which will be investigated in more detail later in this study.

Rail transport dominates the overland movement of unprocessed and semi-processed metalliferous minerals, both from outback mines to coastal processing centres and from inland sources to outlet ports. Distances involved range from 30 miles to more than 700 miles. On railways, the ton-mile costs fall with increasing distance because terminal costs, difficult to reduce for rail carriage because of technological limitations on the unit size of conveyors, can be spread further. Line-haul costs depend on distance, traffic density, stowage factors, and track conditions, all of which impose speed and safety limits. Application of a formula suggested by the South Australian Transport Advisory Council indicates that rail rates under local conditions taper rapidly with increasing distance up to about 200 miles, after which they fall very slowly, and scarcely at all for distances over 1,000 miles (Hirst, 1963, p. 88).

The most important requirements to bring about a reduction in the ton-mile rail freights is large volume; it is the tonnage rather than the mileage which allows the greatest spreading of capital charges on the railways. Extra mileage causes some increase in the fixed capital investment in track, whereas large consignments allow reduction in the unit costs of track, rolling stock, and terminal facilities (Smith, 1967, p. 2). Modern rail developments also allow economies of bulk handling, and the capacities of individual train hauls have been increasing. Nevertheless, the railways have met competition from road transport for the movement of metal ingot to the metal-using industries in southeastern Australia.

While rail transport seems particularly suited to the movement of metals, the actual rates paid on public railways reflect so many factors that cost-based analysis of
railway transport can be misleading. Ownership of the railways is critical to the movements of metalliferous minerals in Australia. Many miles of publicly-owned railway track have been maintained largely because of the carriage of metals and metal ores from remote areas. In addition, in 1970, companies in the metalliferous mineral industry owned and operated six private railways, with route distances ranging from 12 to 265 miles. The existence of such lines complicates the structure of rail transport costs. The construction and maintenance of railway track and the operation of rolling stock increase the capital costs incurred by mining companies; yet, for large ventures, the ownership of railways often allows lower variable transport rates to be obtained compared with public railways since they represent only the costs of carriage on the particular line concerned*.

Road transport is of little importance in the transfer of metalliferous minerals since it is poorly suited to the transport of ores and concentrates in bulk, except for short distances from a mine to a rail siding (where it almost becomes part of the mining operation), or for remote locations not served by railway and where the scale of operations justifies neither the construction of a private track nor the extension of the State rail network. For the distribution of metals, however, road transport is becoming highly competitive over shorter distances, principally because of its flexibility, speed, and handling efficiency for commodities of higher value-for-weight, and partly because of long-established railway pricing policies. Road transport is being used for the transport of both bulk alumina and finished ingot between the aluminium smelter at Kurri Kurri and the port of Newcastle. Recently, the mining companies at Broken Hill have claimed

* The costs along a line within a State-owned railway system are not independent of the operations (and particularly the traffic densities) of all other lines in the system.
that competitive freight rates have been offered for the road transport of concentrates over 240 miles, traffic presently carried by the South Australian Railways*.

There is only one instance of the movement of metal ores in slurry form by pipeline, a choice largely determined by difficult terrain for bulk movements by other media in northwestern Tasmania. For a large, regular flow, transport by pipeline requires little labour and no return carriage of empty conveyors, although it considerably inflates the capital costs of the mining operation.

4.2.2 The transport of metalliferous minerals during 1970**

In 1970, 60,380,000 tons of such minerals (in various forms) were moved over Australian transport networks; some 32,426,000 tons were transported for domestic use, and 27,954,000 tons moved between inland sources and the nearest export port (Table 4.2). More than ninety per cent of minerals moved for export were unprocessed ores and concentrates, reflecting the predominantly seaboard location of Australia's major processing industries as well as its infancy as a metal exporter. The movement of 8,235,000 tons of metal to domestic consumers is accounted for largely by the distribution of finished metal ingot*** to metal-using industries. Only 104,000 tons represents the movement of unrefined metals to domestic metal refineries****.

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* North Broken Hill Ltd, pers. comm., August 1969.
** Iron, aluminium, copper, lead, and zinc.
*** This was mostly of iron and steel over relatively short distances, although movement of aluminium and zinc ingot are increasing.
**** Most of this traffic consisted of blister copper from Mount Isa to Townsville.
### Table 4.2: Destinations of Metalliferous Minerals Moved on All Australian Transport Systems During 1970 (thousand tons)

<table>
<thead>
<tr>
<th>Class of commodity</th>
<th>Delivered to domestic plants</th>
<th>Delivered to ports for export</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ores and concentrates</td>
<td>19,389</td>
<td>32,286</td>
<td>51,675</td>
</tr>
<tr>
<td>Processed materials&lt;sup&gt;a&lt;/sup&gt;</td>
<td>330</td>
<td>-</td>
<td>330</td>
</tr>
<tr>
<td>Metals (unrefined and refined)</td>
<td>8,235&lt;sup&gt;b&lt;/sup&gt;</td>
<td>140</td>
<td>8,375</td>
</tr>
<tr>
<td>Total</td>
<td>27,954</td>
<td>32,426</td>
<td>60,380</td>
</tr>
</tbody>
</table>

<sup>a</sup> Iron ore pellets and alumina.

<sup>b</sup> Included are 8,131,000 tons of unwrought metal distributed to domestic metal-using industries.

**Sources:** Calculated from statistical information in various mineral companies' 'Annual Reports', 1970; from personal communications with mineral companies; and from information in Commonwealth of Australia, Bureau of Mineral Resources, Geology and Geophysics, Australian Mineral Industry 1970 Review, Canberra, 1971.

(a) Flows of minerals for export

Mineral export can be considered briefly. Table 4.3 summarizes the tonnages moved and the ton-miles performed during 1970: ninety per cent of both the total tonnage moved for export and of the ton-miles were performed by privately-owned railways. This reflects the transport operations of the Western Australian iron ore exporters since all this traffic consists of unprocessed ores. The three principal railways involved are those linking Dampier to Tom Price (182 miles), and Port Hedland to Newman (265 miles) and Goldsworthy (71 miles). In addition, twelve
TABLE 4.3: TRANSPORT OF METALLIFEROUS MINERALS FOR
EXPORT BY VARIOUS SECTORS DURING 1970
(thousand)

<table>
<thead>
<tr>
<th>Transport sector</th>
<th>Tons moved</th>
<th>Ton-miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public railway</td>
<td>2,345</td>
<td>437,773</td>
</tr>
<tr>
<td>Private railway</td>
<td>30,760</td>
<td>5,879,600</td>
</tr>
<tr>
<td>Road</td>
<td>600</td>
<td>17,260</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33,705</strong></td>
<td><strong>6,334,633</strong></td>
</tr>
</tbody>
</table>

a The total tonnage of metalliferous minerals moved in 1970 was 32,425,600 tons: this does not equal the sum of tonnages moved by the various media because some of the shipments are carried on more than one of them.

Source: As for Table 4.2.

miles of private line connect the mine at Koolanooka with the State railway to Geraldton. Only seven per cent of the tonnage of ores exported from Australia in 1970 was carried on State railways, reflecting the operations both of the long-established lead, zinc, and copper miners, and of the small iron ore export projects, which have been able to make use of a pre-existing transport system -- usually at concessional rates. Government railways in Queensland carry lead bullion for export from Mount Isa to the port at Townsville, and blister copper from Mount Morgan to Port Alma. Road transport carried only 580,000 tons in 1970, mostly along the road linking Mount Bundey and the Commonwealth Railway to Darwin.
(b) The movement of minerals for domestic processing

For domestic purposes, ores and concentrates are transported from mines to first-stage processing plants (bauxite) or direct to second-stage plants (copper, lead, and zinc). Iron ore can also be transported direct to blast-furnaces, although some passes through the pelletization process. Processed raw materials, such as alumina, move to second-stage plants. In addition, blister copper and lead bullion are transferred to other second-stage plants for refining prior to sale to the metal-using industries. The magnitude of flows between sources and destinations for domestic processing reflects the spatial arrangement of plants; the distance between the plants reflects freight costs and the transportability of minerals at various stages of metallurgy.

Table 4.4 is based on a detailed analysis of the transport of metalliferous minerals for domestic use on intra- and inter-state transport networks. The transport of finished metal to domestic metal-using industries could not be included because it is extremely difficult to obtain separate data for road and rail shipments. In effect, then, Table 4.4 quantifies the transport of ores and metals to plants which carry out further processing. About 8,000,000 tons of metal were distributed to local users in 1970, about one-quarter of which was moved by coastal shipping*. The remainder was transported by road and rail over relatively short distances.

Railways (forty-four per cent of tonnage moved) and coastal shipping (thirty-eight per cent) dominate the movement of metalliferous minerals to domestic processing plants. The very long hauls undertaken mean that coastal

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* This represents about 1,700,000 tons of iron and steel products (a majority transported in bulk); more than 50,000 tons of aluminium ingot; 70,000 tons of refined copper shapes; 75,000 tons of refined zinc; and 36,000 tons of refined lead.
TABLE 4.4: TRANSPORT OF METALLIFEROUS MINERALS FROM SOURCES TO DOMESTIC PROCESSING PLANTS DURING 1970

(thousand)

<table>
<thead>
<tr>
<th>Transport sector</th>
<th>Unprocessed ores and concentrates</th>
<th>Processed materials</th>
<th>Metals (unrefined and refined)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tons</td>
<td>ton-miles</td>
<td>tons</td>
<td>ton-miles</td>
</tr>
<tr>
<td>Road</td>
<td>20</td>
<td>400</td>
<td>100</td>
<td>2,800</td>
</tr>
<tr>
<td>Public railways</td>
<td>4,209</td>
<td>552,619</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Private railways</td>
<td>6,210a</td>
<td>318,800</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pipeline</td>
<td>4,200</td>
<td>222,600</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coastal shipping</td>
<td>9,629</td>
<td>17,703,950</td>
<td>330</td>
<td>500,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>24,268</td>
<td>18,708,669</td>
<td>430</td>
<td>503,300</td>
</tr>
</tbody>
</table>

a In addition, 500,000 tons of unprocessed material were carried as 'incidental cargo' (see text for explanation). This amount is excluded from the table.

b The total tonnage moved in 1970 was 19,823,400 tons: this does not equal the total tonnage moved by the various sectors since some shipments travelled on more than one sector.

Source: As for Table 4.2.
shipping performs ninety-three per cent of the ton-miles. Much of the volume transported by rail is carried on company-owned tracks although a substantially greater ton-mileage is performed by State railways compared with private railways. The two operating company lines were both established before the First World War. The longer, of seventy miles, connects the lead-zinc and copper mines in north-western Tasmania with the outlet port of Burnie*; two shorter tracks are operated by The Broken Hill Proprietary Co. Ltd to carry large quantities of iron ore from Iron Knob and Iron Baron to Whyalla. Haulage distances on State railway lines are generally much greater; for example, concentrates are carried 247 miles from Broken Hill to Port Pirie, 740 miles from Broken Hill to Newcastle, and 605 miles from Mount Isa to Townsville. The shortest haul is the movement of 2,500,000 tons of bauxite from Jarrahdale to Kwinana less than thirty miles away. The new company railways played little part in the domestic industry in 1970: 500,000 tons of iron ore fines were generated during the handling and transport of lump ores for export and were processed into pellets for export at Dampier. This is regarded as 'incidental cargo' and is not included in Table 4.4**. Other fine ores from the crushing mills at Tom Price are transported for pelletization and are included in the Table.

* The Emu Bay Railway Co. Ltd is a subsidiary of E.Z. Industries Ltd. Its principal business is the transport to Burnie of lead, zinc, and pyrite concentrates from the mines of Electrolytic Zinc Co. of Australasia Ltd, an associated company, and copper and pyrite concentrates from the mines of Mount Lyell Mining and Railway Co. Ltd at Queenstown (E.Z. Industries Ltd, pers. comm., October 1971).

** The Broken Hill Proprietary Co. Ltd will take increasing quantities of high-grade iron ore from the mine at Mount Whaleback operated by the Mount Newman Consortium of which it is a member. This ore, which may be used ultimately to supply a large integrated steelworks at Kwinana, is transported to Port Hedland on the railway owned by the Consortium. Shipments for domestic processing will rise to 8,000,000 tons per annum by 1977 (The Broken Hill Proprietary Co. Ltd, pers. comm., October 1971).
Coastal shipping is of primary importance for the long haulage of unprocessed ores and concentrates, and the bulk carriage of processed materials such as alumina is increasing. The Broken Hill Proprietary Co. Ltd transports iron ore from Whyalla to its east coast steelworks: in 1970, 4,500,000 tons were shipped in its own bulk carriers. In addition, 1,000,000 tons of iron ore per annum are carried from Cockatoo Island to these steelworks but the Australian National Line carries about two-fifths of the mine output on a voyage charter basis at negotiated freight rates*. A third large flow (2,600,000 tons) is of bauxite from Weipa to Gladstone. For such regular shipments of commodities suitable for bulk handling and stowage, the companies concerned can achieve the lowest freight costs by employing the largest bulk carriers available on the Australian coast**. Under these circumstances, iron ore and bauxite become highly transportable commodities and the effective distances between these sources and the processing plants which they support are considerably reduced.


** The largest carriers available on the Australian coast in 1970 were Iron Endeavour (69,000 d.w.t.), used by The Broken Hill Proprietary Co. Ltd; Howard Smith (58,000 d.w.t.), a bulk oil/ore carrier operated by a private shipping company; Tolga (57,000 d.w.t.), operated on a long-term charter by the Australian National Line; Iron Hunter (55,000 d.w.t.), operated by The Broken Hill Proprietary Co. Ltd; Yarra River (55,000 d.w.t.), operated by the Australian National Line for the carriage of iron ore; and Clutha Oceanic (55,000 d.w.t.), operated by Clutha Developments Pty Ltd and chartered exclusively for the carriage of bauxite from Weipa to Gladstone (this ship travels to Weipa in ballast, the round trip taking about ten days). In addition, a carrier of 81,000 d.w.t. has been constructed for Clutha Developments Pty Ltd and, in late 1972, the Broken Hill Proprietary Co. Ltd introduced Iron Somersby of 106,000 d.w.t.
Shipments of alumina are increasing in response to the rise in domestic aluminium production, but employment of large bulk carriers is inhibited by the relatively small annual flows that in 1970 ranged from 50,000 to 180,000 tons, and by draught restrictions at loading and discharging ports (particularly Point Henry). Bulk carriers of 11,000 d.w.t. are also used for the transport of more than 220,000 tons of zinc concentrates per annum from Port Pirie to the smelter at Risdon. In 1970 smaller freighters carried copper concentrates from Burnie to Port Kembla and zinc concentrates intra-state from Burnie to Risdon. Both the volume carried (20,000 and 90,000 tons respectively) and the distances are small compared with bulk shipments.

Over the past decade, the development of deep-water ports, having a draught of at least forty feet, has exerted a strong influence on the ability of metallurgical industries in Australia to take advantage of the economies of bulk shipment*. The leading ports, Port Hedland and Dampier, handling iron ore for export in international bulk carriers, are soon to be joined by another bulk iron ore port in the Pilbara Region. In 1970 there were eight other ports which handled more than 1,000,000 tons of metalliferous minerals. Of these, five were specialist bulk ports handling either iron ore or bauxite and alumina, and the others were Port Kembla and Newcastle (where large iron ore shipments are discharged) and Darwin (which has been expanded recently to enable the bulk loading of iron ore for export).

* The maximum draught in Sydney Harbour is about forty feet while at Newcastle it is only thirty-six feet. At the bulk shipment port of Gladstone, maximum draught is fifty-three feet. The draught in Torres Strait (barely forty feet) is probably the most important factor governing freight rates achievable for the transport of bauxite between Weipa and Gladstone in large bulk carriers. A vessel of 80,000 d.w.t. and a draught of fifty feet could negotiate Torres Strait only if carrying less than three-quarters of its lifting capacity (Comalco Ltd, pers. comm., October 1971).
4.3 Freight Rates and the Importance of Transport as a Location Factor

Freight rates can be estimated for the movement of selected metalliferous minerals: these will be incorporated in the empirical models of Chapter 6, but are also used here to make a realistic assessment of the importance of transport and distance. In the previous section it was argued that the interactions between distance, freight rates, and transportability determine the effective distance between any mineral source and the point at which it is processed. Here, an assessment is made of the transportability of specific minerals by sea and land for the more important commodity flows. Special emphasis is placed on the movements of bauxite and alumina since the spatial pattern of the aluminium industry, considered in some detail in Chapter 3, forms the basic model to be tested later in the thesis.

4.3.1 Estimating freight rates

No exact measurement of transportability or effective distance is possible unless actual freight rates paid in the assembly of inputs are known. The Commonwealth Department of Shipping and Transport publishes freight rates which are said to represent average prices paid for individual consignments of particular commodities; it is possible, therefore, to assemble a list of likely transport costs for the movement of iron and steel products in various forms, and for copper, lead, and zinc metals. Such published sources give little or no insight into the price of the bulk shipment of ores and intermediate producer goods.

It should always be realized that for large quantities it is almost always necessary to negotiate the price, since special rates can usually be given after careful analysis of such factors as back-loading possibilities, speed of loading and unloading, and so on (Buchanan and Sinclair, 1964, pp. 1304-5).

Such negotiations are the rule for the bulk movement of minerals by coastal shipping services in Australia. Neither
the shipping companies nor the mineral companies concerned were prepared to divulge their actual transport costs for raw materials so that it has been necessary to make reasoned estimates. Data on rail transport are relatively easy to obtain from State Railway Departments, and specially negotiated rates for the mineral industry are usually listed in the Special Mineral Agreements. Yet Table 4.4 demonstrated that private railways move a large part of the tonnage transported by rail: those transport costs cannot be determined precisely not only because they are regarded as confidential but also because internal accounting practices differ.

Estimates in this section have been based on published international data for commodity movements of a similar nature, modified as necessary for Australian conditions using information released by various transport bodies and the crude estimation techniques outlined in Buchanan and Sinclair (1964, pp. 1301-16)*. Data obtained in this manner are suitable for an overall assessment of the importance of transport costs and of the relative transportability of metalliferous minerals on different media. They can take little account of rapid changes in macro-economic circumstances and, even less, of the vagaries of private negotiations between large mineral corporations and the major shipping operators.

* In order to test the validity of these cost estimates, a range of opinion has been sought on appropriate modifications to freight rates as derived by these crude techniques. Wherever possible, they have been discussed with representatives from both governments and the mining industry. They remain estimates, and are intended only to suggest the correct orders of magnitude and so to strengthen the results of the model-building of Chapter 6.
4.3.2 The costs of transportation by sea

The cost of freight per ton-mile is a useful indication of the way in which rates are determined, and helps to expose the existence of economies of bulk handling and long haulage. Freight rates per ton are important in assessing the contribution of transport to the c.i.f. prices of commodities at various processing locations. For coastal shipping in Australia, bulk freight rates are at least comparable with those of the coastal trade in North America; during the early 1960s rates for bulk cargoes varied between 0.17 and 1.70 cents per ton-mile for medium to long haulage distances (Buchanan and Sinclair, 1964, p. 1305). Charges are considerably higher for small consignments in coastal freighters (Dubnie, 1961, p. 1). In the mid-1960s, freight rates for the ocean shipment in bulk carriers of iron ore over distances greater than 1,000 miles averaged 0.10 cents per ton-mile rising to 0.40 cents and above for shorter hauls and smaller vessels (Manners, 1967, p. 262). There is no doubt that the lowest rates per ton-mile for the transport of mineral ores and concentrates are achieved by the employment of bulk carriers*. The size of the vessel has become critical to the reduction of freight rates, and the tonnages available for specific flows thus become critical to the transportability of a commodity between its sources and destinations.

Because of the sizes of shipments, the regularity of flows, and the installation of bulk handling equipment on wharves, iron ore and bauxite travel at the lowest rates per ton-mile in Australia. Loading and discharging facilities are usually owned and operated by the mineral companies as part of plant operations; carriers can thus quote rates 'free-in-and-out' (f.i.o.). One of the lowest

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* The importance of scale economies, and the relationship between vessel size and the unit costs of shipping bulk cargoes, are shown graphically by Manners (1971, p. 181).
privately negotiated rates in Australia has been obtained for the shipment of bauxite from Weipa to the alumina refinery at Gladstone. Rates are quoted f.i.o. and rapid loading and unloading facilities minimize the turn-round time. Three bulk carriers now handle this flow and freight rates (which closely reflect the line-haul operating costs) are much lower than 0.20 cents per ton-mile. Because of the specially negotiated long-term charter arrangements and the virtual absence of terminal expenses, it is estimated that freight rates are as low as $2.00 per ton (approximately 0.12 cents per ton-mile). Bauxite is less transportable from Weipa to the small refinery at Bell Bay despite the favourable haulage distance; the small annual demands of the refinery, draught restrictions in the Tamar River, and the high demand for bulk carriers, have inhibited the use of larger vessels. It is estimated that a freight rate of about $5.00 to $5.50 per ton f.i.o. is obtained depending on the size of the vessel (an average of 0.20 cents per ton-mile).

Iron ore is also highly transportable as a bulk cargo although terminal charges are slightly higher than for bauxite. Rates for the carriage of iron ore between Whyalla and blast furnaces on the east coast by vessels of the Australian National Line have been reported as $3.10 per ton, about one-quarter of a cent per ton-mile (Rimmer, 1967, p. 19); this is best regarded as an average since there is some variation in the size of vessel which can be employed. It is likely that freight rates per ton-mile f.i.o. for the transport of ore from Yampi Sound (3,500 miles from the furnaces) fall to about 0.20 cents because of the economies of long haulage in bulk carriers.

Alumina is also suitable for bulk shipment since it has a stowage factor similar to bauxite although it requires more sophisticated handling equipment. Despite the moderately long haulages of alumina to Australian smelters, the small size of present shipments prevents the use of large bulk carriers on time charter, and the
demand for coastal carriers presently available for individual consignments is high. Because of these factors, coupled with draught restrictions at Point Henry, the rate for the movement of alumina from Kwinana to Geelong (1,950 miles) is between $7.00 and $8.00 per ton f.i.o. (an average of about 0.36 cents per ton-mile) for individually contracted, bulk consignments in 'Lake'- or 'Mount'-class ships operated by the Australian National Line. 'Lake'-class vessels also carry alumina from Gladstone to Newcastle at an estimated rate of $4.00 per ton.

Copper, lead, and zinc concentrates are not generally moved at low rates by Australian coastal shipping, and only the transport of zinc concentrates from Port Pirie and Burnie to Risdon justifies the use of bulk vessels. Apart from the relatively small size of consignments (in carriers of only 10,000 d.w.t.), outlet ports are relatively poorly equipped compared with those modern bulk ports dealing with iron ore and bauxite. It is likely that such concentrates can rarely be transported by sea for less than 0.50 cents per ton-mile, and rates for small shipments of copper concentrates from northwestern Tasmania are probably higher. Hence, iron ore and bauxite are the most easily transportable metalliferous minerals by coastal shipping to domestic processing plants; alumina also transports well as a bulk commodity but freight rates are not as favourable; the concentrates of lead, zinc, and copper are the least transportable because of relatively small and, in some cases, irregular shipments. The effective distances between metallurgical plants located on tidewater and their respective raw material sources, where they are within easy access to tidewater, are considerably reduced by the economies of bulk shipment for the steel and aluminium industries.
4.3.3 Transport over land

Rates charged per ton-mile are much higher for railway transport than for coastal shipping especially at distances greater than about 750 miles; rail freights in Australia are generally higher than those in North America and Europe where rates of 1.10 cents per ton-mile for bulk ores were common during the 1960s (Manners, 1967, p. 262). It was suggested in sub-section 4.2.1 that large volume is the most important requirement for low rail freights in Australia. This principle has been recognized in the freight schedules negotiated for the shipment of iron ore and bauxite to processing plants at Kwinana which are set out in the Special Mineral Agreements. Bauxite, for example, is transported by the Western Australian Railways from Jarrahdale to the refinery at Kwinana, and the mining company agreed to use only rail transport in return for concessional freight rates (Table 4.5). These rates allow considerable reductions in transport costs for large shipments: in 1970, 2,500,000 tons of bauxite were transported at the rate of only $0.42 per ton.

In offering a schedule of freight charges to The Broken Hill Proprietary Co. Ltd for the development of their Koolyanobbing iron ore deposit, the Western Australian Government specified that rates were to be tied to the costs of providing the service on the standard gauge line between the mine siding and Kwinana, rather than to the normal pricing policy*. Reductions in the ton-mile rates for the 306-mile journey were based on increases in the volume transported. For the present shipment of 1,119,000 tons per annum, the rate is 1.19 cents per ton-mile ($3.64 per ton); for 2,000,000 tons, 1.07 cents per ton-mile will be charged ($3.27 per ton) and for 3,000,000

**TABLE 4.5: SCHEDULE OF FREIGHT RATES FOR RAIL TRANSPORT OF BAUXITE FROM JARRAHDALE TO KWINANA**

<table>
<thead>
<tr>
<th>Tonnages (thousand)</th>
<th>Rate per ton (dollars)</th>
<th>Rate per ton-mile (cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 150</td>
<td>2.33</td>
<td>8.33</td>
</tr>
<tr>
<td>150 - 299</td>
<td>1.00</td>
<td>3.54</td>
</tr>
<tr>
<td>300 - 499</td>
<td>0.87</td>
<td>3.13</td>
</tr>
<tr>
<td>450 - 599</td>
<td>0.70</td>
<td>2.50</td>
</tr>
<tr>
<td>600 - 749</td>
<td>0.62</td>
<td>2.22</td>
</tr>
<tr>
<td>750 - 1,459</td>
<td>0.53</td>
<td>1.88</td>
</tr>
<tr>
<td>1,460 - 2,159</td>
<td>0.48</td>
<td>1.70</td>
</tr>
<tr>
<td>2,160 - 2,159</td>
<td>0.42</td>
<td>1.50</td>
</tr>
<tr>
<td>2,860 - 3,559</td>
<td>0.38</td>
<td>1.35</td>
</tr>
<tr>
<td>Greater than 3,560</td>
<td>0.34</td>
<td>1.20</td>
</tr>
</tbody>
</table>

*a* Twenty-eight route miles.


Tons of 0.96 cents ($2.93 per ton). The rates offered for the transport of bauxite and iron ore in this State were clearly designed to encourage the development of large-scale mining and must be among the lowest in Australia for bulk shipments on public transport, given the distances involved. It seems likely that the operating costs for the movement of bulk ores by company railways are comparable with those encountered in the special cases already discussed and that ton-mile rates of 1.00 cent would be a reasonable estimate for large volume shipments.
Freight rates on copper, lead, and zinc concentrates are not always so favourable. Collectively, the mining companies at Broken Hill are the largest paying customers of the South Australian Railways because of the movement of lead and zinc concentrates both for domestic processing and for export. In 1968 the rate charged for these concentrates was 3.50 cents per ton-mile for the 218-mile haul from Cockburn to Port Pirie* ($7.70 per ton). The mining companies claim that this rate is based on the principal of 'what-the-traffic-will-bear' and that a reasonable rate based on the most common railway pricing policy should be 1.60 cents per ton-mile ($4.60 per ton) because of the large tonnages transported. They have asked the South Australian Government for a special rate of 1.20 cents per ton-mile ($2.70 per ton) based only on the cost of providing the service**. The New South Wales Railways charge concentrates from Broken Hill at the rate of 1.48 cents per ton-mile ($11.56 per ton) for relatively small shipments over the 740-mile haul to Newcastle.

Finally, a pipeline has proved competitive with other forms of bulk transport for the movement of about 4,200,000 tons per annum of low-grade iron ore from Savage River to Port Latta. On the basis of a procedure suggested by Buchanan and Sinclair (1964, p. 1315-16), it is estimated that operating costs of about 1.50 cents per ton-mile have been achieved ($0.80 per ton), considerably lower than transport costs attainable on road or railway services extended into the rugged terrain of northwestern Tasmania.

* Concentrates, carried until 1970 on a thirty-mile private 'tramway' to Cockburn, are now transported direct from Broken Hill to Port Pirie by the South Australian Railways on the new Standard gauge track.

** North Broken Hill Ltd, pers. comm., August 1969.
4.3.4 Transport as a location factor

Freight rates, transportability, and distance combine to determine the importance of transport as a factor in the location pattern of metal processing industries. It has been shown that the ores of copper, lead, and zinc are generally much less transportable than those of iron and aluminium, and a simple locational arrangement would be expected, at least for copper and lead smelting*, with plants at mine sites or at their nearest outlet ports. Bauxite and iron ore can be transported long distances in bulk carriers at low rates, and the importance of actual distance is reduced in the location of the processing plants. To illustrate the operation of transport as a location factor for these minerals, an example is given from the aluminium industry which forms the basis for the model discussed in Chapter 6.

First, let it be assumed that the optimal location pattern is the one that minimizes transport costs. In this case, the weight-loss of materials during processing becomes important, as suggested by Weber, although its effect is partially offset by differences in transportability (reflected in Table 4.6). Since there is a weight-loss of approximately half in both refining and smelting, each ton of aluminium ingot produced requires two tons of alumina obtained from four tons of bauxite. These proportions can be used as weights in the calculation of total freight costs paid in the production of one ton of metal at the three existing smelters.

At present, there are four spatial arrangements of mines and processing plants. In terms of total transport costs, the least favourable involves the movement of bauxite from Weipa to the refinery-smelter complex at Bell.

* The case of zinc smelting is a little different because of the large quantities of electric power consumed in processing (see Sub-section 3.3.2).
<table>
<thead>
<tr>
<th>Journey</th>
<th>Medium</th>
<th>Commodity</th>
<th>Volume (thousand tons)</th>
<th>Distance (statute miles)</th>
<th>Freight rates per ton (dollars)</th>
<th>Freight rates per ton-mile (cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weipa-Gladstone</td>
<td>sea</td>
<td>bauxite</td>
<td>2,630</td>
<td>1,540</td>
<td>2.00</td>
<td>0.12</td>
</tr>
<tr>
<td>Weipa-Bell Bay</td>
<td>sea</td>
<td>bauxite</td>
<td>140</td>
<td>2,800</td>
<td>5.00</td>
<td>0.18</td>
</tr>
<tr>
<td>Jarrahdale-Kwinana</td>
<td>rail</td>
<td>bauxite</td>
<td>2,500</td>
<td>28</td>
<td>0.42</td>
<td>1.50</td>
</tr>
<tr>
<td>Gladstone-Bell Bay</td>
<td>sea</td>
<td>alumina</td>
<td>50</td>
<td>1,410</td>
<td>5.00</td>
<td>0.35</td>
</tr>
<tr>
<td>Gladstone-Newcastle</td>
<td>sea</td>
<td>alumina</td>
<td>100</td>
<td>790</td>
<td>4.00</td>
<td>0.20</td>
</tr>
<tr>
<td>Kwinana-Point Henry</td>
<td>sea</td>
<td>alumina</td>
<td>180</td>
<td>1,950</td>
<td>7.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Newcastle-Kurri Kurri</td>
<td>road</td>
<td>alumina</td>
<td>100</td>
<td>28</td>
<td>1.80(^a)</td>
<td>6.50</td>
</tr>
</tbody>
</table>

\(^a\) Estimated cost of carrying alumina in company-owned trucks.

Source: Estimates made in sub-sections 4.3.2 and 4.3.3.
Bay; each ton of ingot produced from this raw material costs about $20.00 in freight, depending on the size of vessel employed*. The smelter at Bell Bay also purchases alumina from the refinery at Gladstone and total costs in this case fall to $18.00 per ton of ingot. A reduction in total transport costs is gained by processing at an intermediate location and shipping alumina instead of bauxite. Alumina from Gladstone is also supplied to the smelter at Kurri Kurri; total transport costs are $19.60 per ton of ingot of which $3.60 represents the cost of haulage by road transport from the port of Newcastle to the smelter site. The most favourable arrangement is that from Jarrahdale through Kwinana to Point Henry; although it attracts higher freight rates per ton, alumina is more efficient to transport than bauxite because of weight-loss, and in this instance total transport cost of only $17.68 per ton of ingot is achieved. If minimal total transport costs are sought, therefore, alumina refineries are best located near the bauxite mines -- a solution suggested by Weber's weight-loss principle.

The empirical models to be considered in this study seek to minimize total costs in which transport is only one input. In this case, production costs at various sources and processing locations, and transportability, become important. When the principal raw materials can be considered highly transportable, the importance of transport costs is better gauged by the proportion of freight in the

* The total transport costs for each spatial arrangement are calculated by:

\[ T = a(X) + b(Y) \]

where \( T \) = total transport cost per ton of metal; \( X \) = total freight paid per ton of bauxite \( (X = x_1 + x_2 + \ldots + x_n) \); \( Y \) = total freight paid per ton of alumina \( (Y = y_1 + y_2 + \ldots + y_n) \); \( a \) and \( b \) are production co-efficients taken here as 4 and 2 respectively. This involves a simplification especially for bauxite inputs. A production co-efficient greater than 4 (such as that experienced in the use of bauxite from Jarrahdale) serves only to increase the advantage of refining the ore close to the mine.
The importance of freight is determined by the low f.o.b. price per ton of the raw material and, in this case, by the very low production cost of bauxite mined at Weipa. At the estimated freight rates (Table 4.6), transport contributes about seventy per cent of the c.i.f. price of bauxite from Weipa delivered to Bell Bay. At Jarrahdale bauxite is mined at higher cost than at Weipa and is of lower grade but, with the refinery located nearby and concessional rates offered for transport of large volumes by rail, freight contributes only about ten per cent of the delivered cost of bauxite at the refinery. Since it has been estimated that the prices of bauxite at Gladstone and Kwinana would be similar, it is clear that, disregarding the weight-loss during processing, refineries are best located at or near the mine sites (unless bauxite can be mined in large quantities at low cost), because of the potentially high contribution of transport costs to the c.i.f. prices of the principal input. Given the combination of low f.o.b. prices and low freight rates by bulk sea transport, bauxite from sources such as Weipa can be delivered to processing plants more than 1,000 miles away at competitive c.i.f. prices*.

* Clearly, the individual producer makes a choice (if there is one) between raw materials at a range of c.i.f. prices. If a distant source of supply is chosen, there is a substitution, for the system as a whole, of transport inputs for other production inputs.
Alumina is somewhat less transportable than bauxite (Table 4.6) but aluminium smelters face a very different set of input costs. It is estimated that the c.i.f. price of alumina from Gladstone at Bell Bay is $60.00 per ton to which freight contributes only eight per cent. The relative importance of transport costs in the total price of alumina is much smaller than in total bauxite price because of the considerable value added to the raw material during first-stage processing. This provides further evidence that, except in cases where bauxite has a very low f.o.b. price, total costs are minimized if first-stage processing plants are located at or near source mines and alumina is transported in bulk -- even though it is less transportable than bauxite -- to aluminium smelters close to final markets. Such a solution is produced without reference to the weight-loss of inputs during processing. This 'raw material' locational orientation will be considered in the following chapter in relation to other costs of distance.
So that, looking out onto constructions, and curved bridges made by the hand of man, we can simply breathe: 'Nature!' -- and feel ourselves saved and clean. (Yevtushenko, 1966, p. 155)

The cost of transport is but one reflection of the importance of distance in explaining the location of economic activity. Decision-making is considerably influenced by the perceived costs of 'isolation'. Some locations within the settlement and transport networks of the space-economy are remote from major nodes providing essential services; others effectively exist outside the networks. This chapter examines the importance of distance from major population centres in production and location decisions.

A detailed examination of capital expenses seems justifiable for four reasons: first, the magnitude of capital requirements determines the minimum economic scale of operations and influences industrial structure; second, Chapter 3 established that capital costs constitute one of the most important production factors in both mining and processing, and significant spatial variation would strongly influence location patterns; third, isolation plays a critical role in the location of processing facilities, principally because such plants require greater quantities of power, water, and labour than mining operations; and, fourth, this thesis attempts to identify the spatial importance of government policies and, in the settled areas of the continent, investment in infrastructure is normally regarded as the responsibility of public authorities.

After a brief consideration of the nature of isolation and the importance of infrastructure, a survey is made in
section 5.2 of investments made in remote locations by companies in the metalliferous mineral industries, concentrating on variations in capital costs with the scale of operations and distance from populated areas. The relationship between infrastructure and the location of processing at or near mine sites is explored in section 5.3, based on production costs estimated in Section 3.2. The final section considers isolation as a factor in resource development and plant location, and suggests that traditional distance costs alone are an inadequate measure of the influence of space.

5.1 Isolation and Investment in Infrastructure

There are several ways in which remoteness from population centres influences mining and manufacturing costs, even setting aside for the moment the capital investment in infrastructure at isolated locations. Most of these are well known and are applicable to all manufacturing activity located outside the State capital cities. Direct manufacturing costs* tend to be higher in remote locations because of increased maintenance expenses and the need to stockpile adjunct materials. In a survey of 228 firms in New South Wales, Webber (1967, pp. 127-30) found that those located outside Sydney, Newcastle, and Wollongong were forced to carry large stocks of operating supplies, especially spare parts and maintenance materials. Similar conclusions can be drawn from the mining industry. In extracting bauxite at Weipa the operating company employs a maintenance staff of 114 persons (about a quarter of the total work-force), and this forms the largest single

* The reader is referred again to Appendix II in which total production cost is divided into its components and the relationship between total capital investment and the unit costs of output is illustrated.
employment category. Because Weipa is so remote*, it is necessary for this mine to be entirely self-sufficient in engineering and maintenance facilities, and for large stocks of replacement parts to be held. In Sub-section 3.2.1(d) it was estimated that maintenance expense forms about ten per cent of total mining costs and is the largest single direct extraction cost.

The alumina refinery at Gladstone provides a useful comparison from the mineral processing industries. This is a capital intensive, continuous chemical process plant so that breakdowns are serious. More than 200 persons are employed in maintenance at this refinery (one-third of the total work force). In addition, a considerable amount of repair is contracted to local businesses** allowing the full-time staff to concentrate on engineering and maintenance. Problems arising because of the distance from metropolitan centres are important***; in particular the absence of machine-tooling establishments and fitters and turners in Gladstone (population 15,000 in 1971) makes it essential for the plant to operate a machine-shop and to carry large stocks of spare parts. Nonetheless, maintenance expenses comprise only five per cent of the unit cost of the alumina produced; by far the most important production input is the cost of raw materials and fuels.

Firms located outside the capital cities incur greater costs of communication. Webber (1967, pp. 130-7) found that such firms claim this to be a real cost of distance and that many firms had offices in capital cities and held larger

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* Weipa is served only by sea and air and is about 400 miles by air northeast from Cairns (population 32,570 in 1971), the nearest major town.

** Especially for electrical fitting and basic tasks such as painting, carpentry, and vehicle servicing. The diversity of tradesmen employed by the alumina refinery is considerably less than at Weipa.

*** Gladstone is 390 miles from Brisbane.
stocks of finished products at country factories. In the mineral industry communication expenses are considerable and most firms maintain office staff at both the mining and processing location and in a State capital city. Although costs of maintenance and communication increase considerably with distance from the major centres, they are relatively small compared with those for labour and infrastructure.

In most Australian manufacturing industries, firms find little spatial variation in wages (Buchanan and Sinclair, 1964, p. 407) and they are not generally important as a location factor. Yet real costs of labour are often stated to be higher in the mining industry than for many other forms of economic activity (Raggatt, 1968, p. 168-70; Hibberd, 1968; and Aschmann, 1970, p. 180). The principal causes seem to be high turnover, increased payroll overheads (such as site allowance), and the frequency of industrial disputes. During his survey of manufacturers in New South Wales Webber found that plants in some non-metropolitan locations regarded recruitment as a problem, although employer-employee relations were very good (1967, pp. 124-7). It is likely that the real costs of labour, in the long-term, are often lower in non-metropolitan areas than in the cities (Distribution of the Population Committee, 1961, pp. 64-5 and 1962, p. 455; Linge, 1963, p. 50; Webber, 1967, p. 124). Labour difficulties, especially industrial disputes, in the metalliferous mining and processing industries are brought about at least partially by the remoteness of many of the operations*. Poor communications and lack of variety in social facilities often make recruitment difficult and turnover high despite the considerable site allowances offered. These allowances are based

* The remoteness of Weipa has been noted previously. Gove is 430 miles due east of Darwin, Mount Isa 605 miles from Townsville, and the Pilbara region of northwestern Australia is 800 to 900 miles from Perth.
on distance from other centres, climatic factors, and the nature of operations. It seems that

the cumulative effect of these factors is frequently enhanced by psychological repercussions brought about by family separation, culture shock, and disorientation; these are also commonly reinforced by real or imagined physiological difficulties. The combined effects of these and other factors upon the attitudes of management, workers, and their families to permanent settlement is not known, but must be related to high employment turnover rates in the mining industry (Webb, 1969, p. 172).

Mining companies contacted indicated that high labour turnover increases their real costs. At Weipa, while no severe restrictions have been caused by recruitment difficulties, a large section of the work-force is in a continuous state of flux and the current rate of turnover in the total employment is about twenty per cent per month, rising to thirty-five per cent among single males*. Labour turnover at the alumina refinery at Gladstone has not often exceeded the national average of about four per cent per month**. Although difficult to establish quantitatively, it is tempting to assert that, since wages are comparable at Gladstone and Weipa, this lower rate is principally a reflection of reduced isolation.

It is apparent that many of the difficulties and much of the real cost of labour to the mineral industry are related to the degree of isolation of many of its plants. Despite the relatively small direct contribution of labour to total production expenses in both mining and processing, the attraction and support of a work-force in remote locations is one of the more important causes of high capital costs. Labour forms one of the principal links between production and investments in infrastructure since a large proportion of such expenses are incurred in the construction and maintenance of settlements.

* Comalco Ltd, pers. comm., Weipa, July 1970.

** Queensland Alumina Pty Ltd, pers. comm., Gladstone, July 1970.
Attention has been drawn in this study to the importance of costs based on the level of capital investment. In the mining of iron ore in the Pilbara Region fixed charges contribute about forty per cent of the total unit production cost, while at Weipa such charges comprise half the unit cost of mining bauxite. At the Gladstone alumina refinery fixed charges form the most important item in the cost structure (twenty-eight per cent), and at Bell Bay they form a quarter of the cost of producing aluminium ingot*. Fixed charges depend on the level of investment and represent mainly the allowance for depreciation of the capital stock; this includes productive plant and equipment, and company investment in power supply, transport, and employee facilities, all of which have different depreciation periods. (Depreciation and its relationship to production cost is discussed in more detail in Appendix II.) Other fixed charges include financial expenses which not only depend on the size of the capital stock but also on the sources of investment funds.

Few studies have been made of spatial variations in the capital requirements of mining or manufacturing activities in Australia. A survey of capital costs by Buchanan and Sinclair (1964, p. 407) noted that prices for equipment are similar in Australian capital cities, and argued that freight on materials, construction plant, and labour, causes progressive increase in establishment costs with distance from the metropolitan centres. Their survey did not investigate the relationship between construction costs and isolation, which depends not on transport but on the maintenance of temporary community facilities at remote locations and on site allowances for labour. A detailed analysis of such expenses is beyond the scope of this study: suffice it to say that cost associated with temporary facilities inflates the capital charges for plant

* These estimates were made in Sub-sections 3.2.1, 3.2.2 and 3.2.3.
and equipment just as investment in 'permanent' infrastructure at remote locations causes high establishment costs in the mineral industries under consideration. In fact, spatial variation in capital requirement per unit of output is principally determined by the degree of private infrastructural investment necessary to maintain the activity and its work-force. Since such expenses are not readily apparent from a survey of production costs, this chapter concentrates on infrastructural investment as a measure of isolation and as a factor in the location of processing industry.

'Infrastructure' is defined in The Concise Oxford Dictionary (1964, p. 625) as a 'system of airfields, telecommunications, and public services forming a basis for defence'. From this rather specific meaning the term has become widely used in the last decade for the basic services at a settlement or plant location, especially where they are provided privately to maintain a particular economic activity. Hence, the Australian Mining Industry Council includes as part of a location's infrastructure the transport systems outside the industrial site, airfields, power generation and reticulation, water supply and sewerage disposal, housing and community facilities such as medical, educational, and recreational services. At coastal sites it also includes the development and maintenance of harbours and wharves*. Such facilities are usually government responsibilities, and in incorporated areas they are administered under Local Government Acts. In Australia, public facilities are administered under the control of various State government departments; with minor exceptions, such as administration of airfields, the Commonwealth Government is not directly involved.

Private investment in infrastructure has been common in Australia particularly, but not exclusively, in the case of mining activity in the outback. In the latter part of the nineteenth century most companies mining gold, silver, copper, and lead had to establish not only a mine but also a small community, and to provide transport and communication links to the outside world without the assistance of colonial governments. From small beginnings most of the surviving settlements were subsequently incorporated under the responsibility of local government authorities, and State governments took over the operation and maintenance of transport and port services. The majority of such settlements, especially those remote from the populated areas have retained their character as 'mining towns' and are often dominated by one or two large companies as is the case at Kalgoorlie, Mount Isa, Broken Hill, and Mount Morgan*. Older mining towns on the coalfields of southeastern Australia, such as Cessnock, Kurri Kurri, and Lithgow, have subsequently broadened their functional role as indicated in the summary of the characteristics of Australian mining towns made by Wilson (1962, pp. 125-32).

To a much lesser degree, large manufacturing enterprises have taken part in the development of infrastructure such as at Whyalla, Port Pirie, and Bell Bay. In addition, a number of so-called 'decentralized' industries have taken part in capital investment projects in their host towns**.  

* The principal mining firms still take part in infrastructural expansion programmes or make loans to local government bodies for capital works in the towns.

** Perhaps the majority of manufacturing industries located outside major Australian cities have invested in town infrastructure by directly financing, and less frequent-operating, power and water supply schemes, extensions to sewerage works, and the development of housing estates. Such investments for the textile industry, considerably decentralized by Australian standards, have been summarized by Fagan, 1968, pp. 44-74.
In most cases, manufacturers have been able to co-operate with pre-existing local authorities in the expansion of infrastructure to serve their industrial plant or work-force. Since the Second World War, State governments have promoted 'industrial areas' on tidewater within their bailiwicks, and have endeavoured to provide a range of infrastructure at these sites in order to attract large-scale manufacturing concerns; examples are Kwinana, Geelong, Wollongong and, in the 1960s, Westernport and Gladstone.

During the last ten years a new phase of massive infrastructural investment by the metalliferous mining industry has begun, although its characteristics are unlike those of early mining developments, particularly because of the scale of operations. It is important to note that these developments have been the subject of Special Mineral Agreements (with State governments) which have firmly established the principle that mining companies should be obliged to establish their own infrastructure in remote locations. These obligations are enacted as law and default may result in the loss of mining rights. The policies relating to infrastructure and the mining industry are considered later in the thesis; here the magnitude of such investment is determined since it forms the principal cost of isolation.

The nature of infrastructural investment means that there is no regular relationship between distance and capital costs in the industries under consideration*, yet it is not difficult to suggest a simple model for the relationship between company infrastructural investment and isolation. As distance from major urban centres increases,

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* For most items of infrastructural capital, the concept of marginal increments to the capital stock is not useful; shopping facilities, ex-mine transport services and, especially, port installations and power stations are extremely 'lumpy' investments and often require large capital works if expansion of capacity is necessary.
such investments rise progressively as population density becomes lower and the capacity of local government bodies to undertake capital works decreases. In very sparsely populated or unpopulated areas, infrastructural investments differ in kind as well as degree, and depend on the willingness of State governments to participate in the knowledge that the companies concerned will, at least initially, effectively constitute the local government 'authority' in the new settlements. In these areas capital costs per unit of planned capacity rise steeply to a plateau where companies are responsible for all necessary infrastructure. In Australia, with the exception of the more populous southeast, this investment plateau occurs little more than 200 miles from the State capitals for large-scale mining or industrial undertakings. Thus, the relationship between isolation and company capital investment is irregular since many of the infrastructure costs will either be 'present' or 'absent' depending on the scale of operations and the location of the project, given the extreme spatial concentration of Australia's population, and the sparseness of public facilities in inland areas.

5.2 A Survey of Infrastructure Costs in the Australian Metalliferous Mining Industries to 1970

Many firms considered in this thesis, particularly those mining copper, lead, and zinc, have been operating in remote locations for more than twenty-five years. In such cases it is not possible to present meaningful data on infrastructure costs; many investment projects have been fully depreciated or are now administered by local authorities, and the present valuations for property, plant, and equipment give no indication of the real costs of isolation during the development of mining and processing. Thus, the infrastructural investments made by these firms have been considered qualitatively in sub-section 5.2.1.
The remainder of this section presents company investment data for 1960 to 1970: since there was little new activity in the metalliferous mineral industries during the 1950s, all the important projects are thus included. They are considered first by scale and then by location (degree of isolation). Mines capable of extracting less than 2,000,000 tons of ore per annum by 1970 are considered in sub-section 5.2.2 and the larger ones in sub-section 5.2.3*.

5.2.1 Infrastructural development before 1960

The development of older mining settlements and their infrastructure is outside the scope of this study and, in any case, has been considered at length by Blainey (1954, 1960, and 1963) and Woodward (1965). Nevertheless, a summary of the principal investments required to establish these mines and plants is warranted if only because the data to be presented later in this section may give the false impression that the costs of infrastructure have been important merely in the recent metalliferous mineral developments. Infrastructural investments by the long-established copper, lead, zinc, and iron mining companies have depended on distance from the populated areas at the time of development and, subsequently, on the scale and complexity of operations. Table 5.1 shows characteristics of settlements serving the mines and processing plants established outside major urban areas before 1960. With the

* Aggregate data on infrastructural investments made by companies were obtained from company reports and by personal communication where necessary. A detailed breakdown (Table 5.2) has been possible using a variety of published sources and the results of a survey released by the Australian Mining Industry Council in March 1971. If data were not available for publication (for example, the detailed findings of the Australian Mining Industry Council survey), or could not be given in a form comparable with other statistics, estimates have been made and are thus indicated in the text.
TABLE 5.1: CHARACTERISTICS OF SELECTED METAL MINING AND PROCESSING SETTLEMENTS

<table>
<thead>
<tr>
<th>Locations</th>
<th>Distances over land (miles)</th>
<th>Approximate date of foundation</th>
<th>Population 1954</th>
<th>Population 1971</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>To outlet port</td>
<td>To nearest capital city</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken Hill</td>
<td>247</td>
<td>390</td>
<td>1885</td>
<td>31,390</td>
</tr>
<tr>
<td>Queenstown</td>
<td>90</td>
<td>120</td>
<td>1896</td>
<td>3,460</td>
</tr>
<tr>
<td>Cobar</td>
<td>500</td>
<td>450</td>
<td>1871</td>
<td>2,220</td>
</tr>
<tr>
<td>Rosebery</td>
<td>70</td>
<td>130</td>
<td>1900</td>
<td>1,460</td>
</tr>
<tr>
<td>Tennant Creek</td>
<td>1,052</td>
<td>600</td>
<td>1945</td>
<td>660</td>
</tr>
<tr>
<td>Mining and processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Morgan</td>
<td>60</td>
<td>380</td>
<td>1902</td>
<td>4,150</td>
</tr>
<tr>
<td>Mount Isa</td>
<td>605</td>
<td>1,400</td>
<td>1924</td>
<td>7,430</td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Pirie</td>
<td>0</td>
<td>140</td>
<td>1892</td>
<td>14,220</td>
</tr>
<tr>
<td>Whyalla</td>
<td>0</td>
<td>240</td>
<td>1937(^b)</td>
<td>22,120</td>
</tr>
</tbody>
</table>

\(^a\) A smelter operated at Queenstown until December 1969.  
\(^b\) Before 1937 Whyalla was an outlet port only for iron ore.

exceptions of the small communities at Tennant Creek and Cockatoo Island, all towns have been incorporated and infrastructural development shared, in varying degrees, by local authorities and mining companies. Examples from the larger mining towns*, Broken Hill and Mount Isa, illustrate the continuing importance of investment in infrastructure.

Electric power for all industrial and domestic purposes is generated in both towns by privately-owned stations, although reticulation for non-industrial uses is the responsibility of local government bodies which purchase power at negotiated rates. At Broken Hill a centralized power station was established in 1931 by the mining companies which had previously operated small coal-fired generators each working inefficiently and at high cost on very low load factors (Woodward, 1965, p. 235-6). Diesel generators were installed in the new station, mainly because of severe water supply problems and shortages during prolonged drought. The power station is still privately-owned and operated (at relatively high cost according to Woodward, 1965, p. 237). Mount Isa Mines Ltd operates a large thermal power station to serve not only mine and all non-industrial uses but also its two large smelters. Current water supply at both towns has been developed jointly with local authorities and uncertainty related to droughts has caused some modifications of the production processes. The Broken Hill Council is heavily subsidized by the mining companies which also provide three-quarters

* For convenience, a 'mining town' is defined as having greater than fifteen per cent of its work force employed in mining (Wilson, 1962, p. 126). Thus, from Table 5.1, all settlements except Cobar and, of course, Port Pirie and Whyalla, are classifiable as 'mining towns'. At Mount Isa, an even larger proportion of the work-force is engaged in mineral processing.
of the municipal income from rates (Hibberd, 1958, pp.24-5)*. The companies have made many investments in community facilities, especially housing, although with some State government assistance. In 1969 Mount Isa Mines Ltd started to develop a satellite town at the new Hilton mine in co-operation with the Mount Isa Council, although construction has now been postponed.

The development of Whyalla and Port Pirie** accelerated when they became sites of large-scale processing industries, although both still remain outlet ports for inland mining operations. Port Pirie, the less isolated (Table 5.1), is now served by public utilities, State transport systems, and a harbour board, although until 1952 power for all industrial and domestic purposes was generated by the lead smelting company. This power station was closed permanently in 1955 and the State grid substituted***. Whyalla remains a company town with most facilities (including the harbour and shipyards) maintained by The

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* The effect of infrastructure cost on charges for utilities in remote locations has been examined by Hibberd. The industrial rate for water at Broken Hill is $0.50 per 1,000 gallons. Hibberd (1958, p. 25) claimed that the average real cost for water consumed by the mines, when subsidization and direct capital investment are added, has been as high as $2.25 per 1,000 gallons. Typical industrial rates (per 1,000 gallons) in Australian cities are $0.27 (Sydney, Newcastle, Brisbane) and $0.10 (Hobart).

** Whyalla is now the largest non-metropolitan town in South Australia and Port Pirie the third largest.

*** It should be added that many mineral processing plants can generate electricity as a by-product of various exothermic chemical reactions or where steam is an important input. Such power is rarely sufficient to meet all industrial requirements although the costs are low and reliance on the State grid reduced at peak loads. The lead smelter at Newcastle, for example, generates electricity in its sulphuric acid plant, itself a by-product activity. Such power developments do not represent infrastructure costs.
Broken Hill Proprietary Co. Ltd: it is not served by the State railway system and sea transport remains the principal freight link with other centres. The railway tracks connecting Whyalla to the iron mines of the Middleback Ranges (established in 1901) are owned and operated by the company*. Direct private investment in community facilities at both industrial towns is still important**.

Most of the remaining mining settlements shown in Table 5.1 support smaller operations. Isolation at Queens-town and Rosebery in northwestern Tasmania results from rugged terrain rather than physical distance, and the narrow-gauge railway linking the area to the outlet port of Burnie is still owned by one of the mining companies. Mount Morgan is only twenty-five miles from Rockhampton. In these towns, the provision of basic infrastructure by State and local governments has gradually replaced company ownership although the communities still retain their distinctiveness as mining towns (Wilson, 1962, p. 130). The settlements at Tennant Creek and Cockatoo Island remain two of the most isolated communities in Australia, and with small-scale mining operations requiring small work-forces, levels of infrastructural investment have been relatively low (although high per unit of production capacity installed).

5.2.2 Investments in small mining ventures after 1960.

The infrastructural investments made since 1960 by mining companies can be compared with the capital investment in mining and processing developments from the data set out in Table 5.2. There are five mining operations, all

* Two small settlements are maintained by The Broken Hill Proprietary Co. Ltd in the Middleback Ranges; these are Iron Knob (750 persons in 1971) and Iron Baron (260 persons).

** Since 1945, Broken Hill Associated Smelters Ltd claim to have invested more than $1,000,000 in parks, gardens, and playing fields in Port Pirie (The Australian Financial Review, 7 December 1970, p. 28).
TABLE 5.2: CAPITAL INVESTMENTS IN METALLIFEROUS MINING AND PROCESSING PROJECTS ESTABLISHED SINCE 1960\(^a\) (notes on following page).

(millions of dollars)

<table>
<thead>
<tr>
<th>Code</th>
<th>Locations</th>
<th>Products</th>
<th>Annual production capacity (b) (million tons)</th>
<th>Investment in plant</th>
<th>Investment in infrastructure</th>
<th>TOTAL CAPITAL INVESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mine</td>
<td>Process plant</td>
<td>Railway</td>
<td>Rolling stock</td>
<td>Power station (mine)</td>
</tr>
<tr>
<td>1</td>
<td>Weipa</td>
<td>bauxite, calcined bauxite</td>
<td>7.00</td>
<td>20.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.10</td>
<td>-</td>
<td>3.20</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Gladstone</td>
<td>alumina</td>
<td>1.28</td>
<td>-</td>
<td>213.00</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Koolan Island</td>
<td>iron ore</td>
<td>1.75</td>
<td>10.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Koolyanobbing</td>
<td>iron ore</td>
<td>2.00</td>
<td>8.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Goldsworthy, Port Hedland</td>
<td>iron ore</td>
<td>6.00</td>
<td>18.00</td>
<td>-</td>
<td>7.00</td>
</tr>
<tr>
<td>6</td>
<td>Tom Price, Dampier</td>
<td>iron ore, iron pellets</td>
<td>17.50</td>
<td>61.10</td>
<td>-</td>
<td>63.00</td>
</tr>
<tr>
<td>7</td>
<td>Newman, Port Hedland</td>
<td>iron ore</td>
<td>14.00</td>
<td>48.86</td>
<td>-</td>
<td>80.00</td>
</tr>
<tr>
<td>8</td>
<td>Savage River, Port Latta</td>
<td>iron ore, iron pellets</td>
<td>4.30</td>
<td>15.00</td>
<td>-</td>
<td>10.00 (^m)</td>
</tr>
<tr>
<td>9</td>
<td>Mount Bundey</td>
<td>iron ore</td>
<td>2.50</td>
<td>-</td>
<td>35.00</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Koolan Island</td>
<td>iron ore</td>
<td>0.80</td>
<td>6.10</td>
<td>-</td>
<td>0.80</td>
</tr>
<tr>
<td>11</td>
<td>Frances Creek</td>
<td>iron ore</td>
<td>1.00</td>
<td>n.a.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>Mount Bundey</td>
<td>iron ore</td>
<td>0.25</td>
<td>n.a.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>Gove</td>
<td>bauxite, alumina</td>
<td>3.00</td>
<td>12.50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>Kimberleys</td>
<td>bauxite, alumina</td>
<td>3.00</td>
<td>10.00</td>
<td>-</td>
<td>5.00</td>
</tr>
<tr>
<td>15</td>
<td>Mount Enid, Cape Lambert</td>
<td>iron ore, iron pellets</td>
<td>10.00</td>
<td>20.00</td>
<td>10.00</td>
<td>8.00</td>
</tr>
</tbody>
</table>

\(^a\) Includes investment in 1960 and 1961 projects.

\(^b\) Capacity for 1960 and 1961 projects.

\(^c\) The term 'port' refers to the town facility.

\(^d\) The term 'all town facility' refers to the total capital invested including all town-related facilities.

\(^e\) Figures include the investment in infrastructure.

\(^f\) Figures include the investment in the town facility.

\(^g\) Figures include the investment in other utilities.

\(^h\) Figures include the investment in railway and rolling stock.

\(^i\) Figures include the investment in power stations.

\(^j\) Figures include the investment in other utilities.

\(^k\) Figures include the investment in infrastructure.

\(^l\) Figures include the investment in the town facility.

\(^m\) Figures include the investment in railway and rolling stock.

\(^n\) Figures include the investment in power stations.

\(^o\) Figures include the investment in other utilities.

\(^p\) Figures include the investment in railway and rolling stock.

\(^q\) Figures include the investment in power stations.

\(^r\) Figures include the investment in other utilities.
NOTES TO TABLE 5.2

a Includes investments up to 1 January, 1970, but not capital extensions to mines and processing plants in existence before 1960. Data for the operations of Alcoa of Australia Ltd are not available for publication.

b At 1 January, 1970.

c Includes harbour and approaches and handling equipment, but not utilities serving port installations.

d Includes all infrastructural investment not elsewhere included and is labelled 'town facility' for convenience. It includes the cost of housing, community facilities (but not utilities), airfields, and all ex-mine roads.

e Financed by the Queensland State Government.

f In addition, the Queensland State Government has invested $3,783,000 in the Weipa township.

g Principally loans to local government authorities for water and sewerage.

h Pier and handling facilities. Harbour and approaches are operated and financed by Gladstone Harbour Board.

i Extensions to existing company power station at Yampi Sound.

j Includes a loan of $7,400,000 to the Western Australian State Government for capital works associated with the Millstream water supply scheme for the towns of Dampier and Karratha.

k Includes grants to Port Hedland local government authority.

l Represents the total cost of product pipeline connecting the mine and the processing plant at Port Latta.

m All data refer to announced production capacity at plant start-up, not to ultimate or planned capacity.

Code

1 Comalco Ltd 2 Queensland Alumina Pty Ltd 3 The Broken Hill Proprietary Co. Ltd 4 Goldsworthy Mining Ltd 5 Hamersley Iron Pty Ltd 6 Mount Newman Consortium 7 Northwest Iron Co. Ltd 8 Western Mining Corporation Ltd 9 Frances Creek Iron Mining Corporation Ltd 10 Morgan Mining and Industrial Co. Ltd 11 Nabalco Pty Ltd 12 'Amax' Consortium 13 Robe River Consortium

Sources: Aggregate capital investment data for all projects (to 1 January, 1970) have been obtained from company reports and public relations material, checked where necessary with the Australian Mining Industry Council, pers. comm., September, 1971. Details of infrastructural investment have been obtained from Department of Industrial Development (1969a, pp. 8-12); Comalco Ltd (1970, p. 7) and pers. comm., June, 1970; Madigan, (1969), Hamersley Holdings Ltd (1970b, pp. 9-14) and pers. comm., June, 1970. Where detailed break-down of infrastructural costs has not been possible from published data, it has been estimated from known data from projects of similar scale and location. Costs of pipeline for the Savage River project have been estimated from Buchanan and Sinclair (1964, p. 1315). Totals for each item of infrastructural expenditure shown in the Table were compared with aggregates drawn from a survey of infrastructure costs made by the Australian Mining Industry Council, released in a press statement on 14 March, 1971, and close correspondence was found.
extracting iron ore from open-cuts, with annual production capacities of 2,000,000 tons or less. Mining at Koolanooka was developed solely for export, while Koolyanobbing, the largest of the five, was developed principally for domestic processing by The Broken Hill Proprietary Co. Ltd. Mines at Koolan Island, Frances Creek, and Mount Bundey were developed as export ventures. Such small-scale capital-intensive mines have low labour requirements, thus reducing the burden of community infrastructural expenses through payroll (and plant) overheads and direct capital investment. In ventures of this type most of the infrastructural investment has been needed to support mine production directly, especially where power stations and deep-water harbour facilities were required. The capital costs of these five mining projects have depended on distance from settled areas and on the degree of government assistance. This has itself depended on the distance of the mine from the existing public facilities, but the cost of extending them for the use of single companies has seldom been regarded as economically justifiable. In Western Australia, direct government involvement has often been approved where the bulk of the ore mined is to be processed within that State.

The Western Mining Corporation Ltd's venture at Koolanooka is the least isolated of the iron ore mines developed for export since 1960. In 1962 the company signed a Special Mineral Agreement with the Western Australian Government for the Koolanooka Hills reserves near the town of Morawa in the hinterland of the regional port of Geraldton. The State railways and a company branchline carry iron ore using company owned rolling stock. An export wharf was constructed by the State Government. Hence, this small-scale operation, served by public power and water supplies, was established at low private capital cost, principally that of a short railway branch, rolling stock, and a small investment in the pre-existing township of Morawa. Infrastructure formed less than one-quarter of the capital cost of this project (Table 5.2).
For the large deposits of iron ore at Koolyanobbing, The Broken Hill Proprietary Co. Ltd signed an Agreement (1960) in which it undertook to establish a blast furnace in Western Australia in return for the mining leases. These deposits are 300 miles east of Perth but in an area served (albeit sparsely) by public utilities from the town of Southern Cross (130 miles west of Kalgoorlie). The Mineral Agreement is concerned principally with the establishment of secondary processing at Kwinana and, ultimately, an integrated steelworks. To stimulate mining the State Government guaranteed power and water supply and housing assistance for the accommodation of married personnel*. The remaining infrastructure developments were the responsibility of the company but, with a small labour requirement (at least initially), the capital costs were low**. The most important government contribution, a direct attempt to encourage heavy industrial development in Western Australia, was the construction of the standard-gauge railway from Kalgoorlie to Kwinana, with a branch line serving the mining leases; processing obligations were binding only on the completion of this railway***. As a result of these government contributions, the infrastructure costs of installing mining capacity of 2,000,000 tons per annum are estimated (Table 5.2) to have comprised only one-fifth of the total capital expenditure. It is interesting to compare investments at Koolyanobbing with those required for the large-scale export ventures considered in sub-section 5.2.3.


** The mining settlement at Koolyanobbing had a population (1971) of only 310 persons.

*** The standard-gauge line was completed (1968) in a joint venture with the Commonwealth Government as part of the transcontinental railway link and at a cost of $132,000,000 (Department of Industrial Development, 1969 A, p. 8).
Since 1960 The Broken Hill Proprietary Co. Ltd has provided all infrastructure at Koolan Island where a new settlement with a diesel power station, an airstrip, and shiploading facilities have been constructed. The port installations and utilities accounted for eighty per cent of the estimated total investment in infrastructure which itself comprised one-third of the total capital cost of the project (Table 5.2). The small iron ore mines in the Northern Territory were established largely without assistance from the Administration, although the Commonwealth Government rehabilitated the 105-mile railway line from Darwin to Frances Creek and extended a sealed road from the Humpty Doo rice project to the mining site at Mount Bundey. It seems certain that competition for export contracts was successful only because of the small capital costs of development and, particularly, the existence (or provision) of the Commonwealth-owned and operated transport facilities. Until the closure of the Mount Bundey mine, the mining companies shared wharf facilities at Darwin developed by the Commonwealth Government.

5.2.3 Investments at the principal mining ventures

Examples in this sub-section are drawn from the large bauxite and iron ore mines developed since 1960 both for export and to support domestic mineral processing. Bauxite mines operating in 1970 illustrated large-scale capital-intensive mining, but in very different environments at different levels of capital cost. Comalco Ltd established its Weipa mine in a virgin forest area remote from all public infrastructure: this venture is considered in some detail to illustrate the relationship between development costs, isolation, and the extent of government assistance.

In Sub-section 3.2.1(d) attention was drawn to the small direct labour input in bauxite mining at Weipa*. Yet

* Except where indicated otherwise, all information was collected during the visit to Weipa (July 1970).
the absolute size of the labour-force is a principal determinant of the level of infrastructural investment in community facilities, and direct labour comprises only twenty-two per cent of the total employment. A further 130 persons are employed indirectly in plant and port installations; and eighty-six in scientific, administrative, and managerial work. Thus, about 280 employees* (about half of them married) must be supported in a company township. There are no private commercial businesses at Weipa, and the company supports a small hotel and a shopping centre (and subsidizes some retail prices), as well as functions normally the responsibility of a town council. These town facilities require a further ninety-two employees, one for every three in mining, maintenance, and administration.

It is tempting to postulate an 'infrastructural multiplier', applied to the direct and indirect mining work-force, to estimate the level of total employment and the approximate size of the town, especially for the subsequent analysis of processing industries with their greater direct labour requirements. Yet, as with all models of 'basic' and 'non-basic' functions, such a multiplier is fraught with conceptual and technical problems. First, it is very difficult to separate non-basic (town-serving) employment in maintenance and the provision of utilities. Second, non-basic functions such as retail trade** bear a lagged and irregular response to changes in the production

* About forty aborigines were employed (1970), most of them as direct labour in mining and plant operations. These employees live at Weipa Mission Station which was relocated by the company a short distance from the plant area at Lorim Point.

** Such commercial facilities at Weipa are entirely non-basic. They serve only the population of the Weipa township and the construction camp at Evans Landing (which has its own subsidiary facilities); there was no evidence that a significant trade is done with inhabitants of the nearby Mission station.
capacity of the basic functions (the mining operation). It is difficult to determine a relationship between employment in mining and the level of town facilities supported; services provided by the company need not respond to changes in demand in the same way as private businesses, or even a town council, elsewhere. Third, the requirements of basic community facilities are influenced by the fluctuating proportion of single males, receiving full board, in the work-force. Finally, the company indicated that non-basic functions would be gradually taken over by local government and commercial establishments, but the 'take-off' point will be determined largely by company policy. The eventual development of non-company services at Weipa should result in a decline in the size of the work-force of Comalco Ltd.

In addition to community facilities, the power and water supply at Weipa was provided by the company at an estimated cost of $9,000,000 (Table 5.2). Yet such expenditure has been conditioned by the juxtaposition of the bauxite deposit and tidewater (see Fig. 3.1). Since the port is adjacent to currently exploited leases a single township can serve both mine and harbour installations and the duplication of power stations and utilities has been unnecessary. Direct contributions towards infrastructure by the Queensland Government have been considerable. As a condition of the Mineral Agreement the State Government undertook to provide hospital and education facilities and has contributed directly towards the cost of company-owned facilities. The capital cost of the harbour and shipping channel was shared by Comalco Ltd and the State, assisted by a loan from the Commonwealth Government (Raggatt, 1968, p. 74), and the two existing wharves are publicly-owned (at a capital cost of $8,224,000). About $9,000,000 have been invested in the Weipa township, but the State Government owns buildings worth $345,000, and provided $3,783,000
towards the cost of company owned facilities*. Hence, Comalco Ltd invested $13,800,000 in infrastructure at Weipa but, despite the need to support a town of 2,130 persons (1971), power and water supply accounts for two-thirds of this investment. Table 5.2 shows that infrastructure comprised forty per cent of the total capital cost of the project (about $0.66 for each $1.00 spent on plant and equipment).

In the establishment of the bauxite mine at Jarrahdale, investments in infrastructure have been slight**. The Mineral Agreement with the Western Australian Government is similar to that involving the Koolyanobbing iron ore deposits, and recognizes the decision to establish processing facilities within the State. To encourage this local industry, the Government constructed the railway line from Jarrahdale to Kwinana, guaranteed the reticulation of electricity and water at standard industrial rates, and undertook to provide sealed roads into the mining leases. The capital costs of this mining project were largely accounted for by mine and plant.

The three export iron ore mining ventures in the Pilbara Region (Fig. 5.1) provide a contrast in scale of operations and levels of infrastructure cost***. This region is remote from public facilities and only a handful of small nucleated settlements existed in a sparsely populated pastoral area, for example, Wittenoom, Marble Bar.

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** Details of investments at Jarrahdale were not released by the company, and the project could not be included meaningfully in Table 5.2.

*** During 1966 constructions in the Pilbara Region by Hamersley Iron Pty Ltd and Goldsworthy Mining Ltd were the two largest capital investment projects in Western Australia, rivalled only by State Government expenditure on the Ord River Scheme (Department of Industrial Development, 1969B, p. 5)
Fig. 5.1: Infrastructural investments by mining companies: Pilbara Region

Derived from data in Table 5.2.
Roebourne, and Port Hedland. No railways served the region, there were no deep-water harbours, and utilities were adequate to serve only the small populations (most of them provided privately by pastoral and mining concerns). In the Special Mineral Agreements, the Western Australian Government made companies mining for export responsible for all necessary infrastructure* in the Pilbara Region, including ports, railways, and power stations, of which the capital costs are high. (Such investments are illustrated in Fig. 5.1.)

The State Government accepted the responsibility for staffing police, school, and hospital facilities in buildings provided by the companies. The Agreements gave rights to 'third parties', wishing to carry out 'legitimate private business', for the use of company installations (at rates negotiated privately); this provision was aimed principally at railways and port facilities although there have been no practical examples of such use. The companies were given the status of local government authorities for their townships, and of water boards and electricity supply authorities. Although Kerr (1967, pp. 110-11) claims that the Government reserved the right to incorporate company towns in the future, a procedure is not set out in the Agreements and no provision was made for the ultimate purchase of company-owned infrastructure by public authorities.

Goldsworthy Mining Ltd, the first and smallest of the three projects, has developed a mine of similar production capacity to the bauxite venture at Weipa. Table 5.2 shows that because of infrastructure costs the total capital

investment has been nearly twice that at Weipa. There are three principal reasons. First, the Mount Goldsworthy deposit is seventy miles from Port Hedland and the company constructed a railway line and provided rolling stock at a total cost of $11,000,000 (twenty-seven per cent of the total investment in infrastructure). Second, the largest single item of expense was the port established on Finucane Island (forty-two per cent of investment). The pre-existing harbour could only accommodate vessels up to 5,000 d.w.t. and an approach channel was dredged to accept bulk carriers of 70,000 d.w.t.. Third, the company was obliged to invest in infrastructure at two locations without government assistance; two diesel power stations were constructed (Table 5.3) and settlements were established at the mine and port sites, although a narrow range of community facilities already existed at Port Hedland*. Infrastructure costs amounted to sixty-eight per cent of the total capital investment, or $2.22 for each $1.00 invested in the mine and plant.

Hamersley Iron Pty Ltd and the Mount Newman Consortium have established much larger mines at their extensive deposits further inland. Capital costs have been higher (in both absolute and relative terms) than those incurred by Goldsworthy Mining Ltd since the larger scale of output has required greater investment in plant and equipment, and in utilities, rolling stock, and harbour installations. The smaller mine, at Newman, is linked to Port Hedland by a 265-mile railway line, and the total cost of the railway system alone amounted to $90,000,000 (Table 5.2), half the total investment in infrastructure. The company developed separate facilities at Cooke Point, east of Port Hedland, where deep-water wharves and an extensive stockpiling area

* In 1966, before the major iron ore developments were underway, Port Hedland had a population of 1,900. By 1971, this had risen to 7,170 following the growth of communities maintained by Goldsworthy Mining Ltd and the (much larger) Mount Newman Consortium. In 1971, Goldsworthy mine township had a population of 1,000.
could be constructed at a cost of $40,000,000*. Power stations were installed at both mine and port, and the larger labour requirements necessitated the establishment of settlements at Newman** and Port Hedland. The total cost of infrastructure was $179,000,000, seventy-eight per cent of the total capital investment.

Infrastructural investments at the Tom Price mine of Hamersley Iron Pty Ltd have been similar to those at Newman. The company constructed a 180-mile railway over difficult terrain (at a cost of $63,000,000), and the large mine output has required the purchase of 14 locomotives and 776 ore waggons bringing total investment in railways to $82,000,000 (Madigan, 1969, and Hamersley Holdings Ltd, 1970, p. 8). Investments at the port of Dampier, developed at an estimated cost of $50,000,000, have been enlarged by the construction of the pelletizing plant which has increased the requirements of power, water, and labour. The power station, at Dampier is the largest in the Pilbara Region, and with a peak load capacity of sixty megawatts is the only thermal turbine station in the North West***. Thus, up to 1 January 1970, Hamersley Iron Pty Ltd has invested $223,000,000 in infrastructure, seventy per cent

* The railway lines of Goldsworthy Mining Ltd and the Mount Newman Consortium cross about six miles outside Port Hedland. Because of the scale of operations the sharing of port facilities was not considered feasible, and it is extremely doubtful whether Finucane Island could have accommodated another large export wharf and stockpiling area.

** Newman had a population of 3,900 in 1971.

*** The current expansion programme to raise mining capacity to 22,500,000 tons per annum has necessitated a large increase in infrastructural investment. A new town is being developed at Paraburdoo, sixty-five miles south of Tom Price (population 3,370 in 1971), and a new port is under construction on East Intercourse Island, offshore from Dampier. The company regards Dampier as 'full' with a present population (1971) of 3,560 and is investing in a new 'open town', Karratha, being developed jointly with the State Government a few miles east of Dampier (Hamersley Holdings Ltd, 1971, p. 8).
of the total capital cost (including the pellet plant), or $2.35 for every $1.00 invested in mine and plant.

The results of this survey are in general agreement with the claim made by the Australian Mining Industry Council that mining companies developing 'virgin' areas since 1960 have been obliged to spend an average of nearly $2.00 on infrastructure for each $1.00 spent on plant and equipment*. In the Pilbara Region, company investments in community facilities (excluding utilities) totalled $85,000,000 to 1970 for a total population of about 17,000. The magnitude of community investment is not directly related to the population supported. Five towns existed in 1970 (three more are under construction), and investments are partly determined by the desire to attract and stabilize a work-force. Data presented in this section of the chapter suggest that the cost of infrastructure depends on the planned scale of operations, which influences the necessary sizes of port, utilities, and community facilities; on the distance of the mining area from the selected port site; and on the degree of State government assistance in the establishment of such facilities. In general, government assistance has been important only where a considerable proportion of the mined output is to be processed within the particular State, or where the costs of extending public facilities to mining areas have been low. The example of Hamersley Iron Pty Ltd suggests, further, that capital investments are raised by the location of processing plants in remote areas, and the remainder of this chapter considers the importance of infrastructure in such locational decisions.

* Australian Mining Industry Council, press statement, 14 March 1971. Details of the survey on which this press statement was based were not available. Such average figures must be treated carefully in comparing projects since they refer to units of installed mining capacity. Infrastructural investments are very 'lumpy'; for example, the 'capacities' of community facilities are only loosely related to the level of output and variation could partly reflect differences in company policies.
5.3 Infrastructure Costs and the Location of Processing Plants since 1960

It was argued in Chapter 3 that some of the more attractive locations, particularly for second-stage metal processing industries, are those areas ear-marked by various State governments for heavy industrial development; Gladstone, Westernport, Kwinana, and Jervis Bay are suggested by Buchanan (1970, pp. 68 and 73) as possible locations for future industrial complexes. Jervis Bay is considered in detail by Butterfield (1971). At such sites, governments would attempt to provide maximum infrastructure at minimum public expense by serving a number of (linked) secondary industries. Kwinana, south of Freemantle on Cockburn Sound, has been developed since 1950 (Government of Western Australia, 1968), and two metalliferous mineral processing plants have been located on tidewater blocks since 1960. These establishments are the subject of special agreements with the Western Australian Government involving the mining leases already discussed. For example, the Alumina Refinery Agreement Act, 1961, guaranteed to a subsidiary of Alcoa of Australia Ltd a large industrial site fully served with infrastructure, although wharf facilities are company-owned under the supervision of the Freemantle Harbour Trust.

More recently, the Queensland State Government has assisted in the development of foreshore industrial sites at Gladstone. It was found in Sub-section 3.2.2 that the alumina refinery at Gladstone, producing about 1,000,000 tons of alumina per annum, requires 650 employees or twice the total labour-force at Weipa (excluding employment in the township). With a population at Gladstone of about 8,000 at the time of establishment, it was possible to support a large labour-force with relatively minor company

infrastructural investments. In addition, the town was near a thermal power station of 120 megawatts on the Callide coalfield*, was well served by road and rail systems, and was under development as an export port for the coalfields of central Queensland. The largest infrastructural investment by the company (Table 5.2) was the purchase of wharf facilities on Green Trees Island, constructed by the Gladstone Harbour Board. The company also met some of the capital costs of expanding local facilities, although the State Government lent $8,000,000 to the Town Council for the expansion of the water supply. Queensland Alumina Ltd guaranteed the loan and pays the interest. The State Housing Commission provided 350 homes for the refinery labour-force and the company instituted a building society**. Direct infrastructural investments by the company have amounted to less than four per cent of the total capital cost of the project.

The establishment of processing industries in remote locations requires much higher levels of infrastructural investment; production co-efficients for electricity, water, and labour are much greater than in mining, as was shown in Sub-section 3.3.3, and capital costs are considerably raised where electric power and water supply must be provided entirely at company expense. Once more, the level of such investment depends on distances from settled areas and scales of operation, but also on input requirements for each type of processing. This can be illustrated with reference to the four ventures in which mining has been developed largely to support a first-stage processing plant either at

* In November 1969, the Queensland Government announced plans to establish a power station of 1,100 megawatts at Gladstone to encourage future industrial development.

** The remaining infrastructural investments have been small, but reflect some of the less apparent costs of isolation. For example, the company subsidizes the salaries of senior medical staff at the local hospital in an attempt to alleviate a serious recruitment problem (Queensland Alumina Ltd, pers. comm., Gladstone, July 1970).
the mine site or at an outlet port; only one such development, Northwest Iron Co. Ltd in Tasmania, was in operation by 1970, the remainder being under various stages of construction* (Table 5.2). In all cases, the mineral deposits on which the plants are based are not of a sufficiently high grade to support the export of unprocessed ores.

Northwest Iron Co. Ltd established their iron pelletizing plant at Port Latta, thirteen miles east of the pre-existing town of Smithton. With public utilities available most of the non-plant capital charges were incurred in the port and ore conveyance facilities**. The total infrastructural investment, $25,000,000 was one-third of the total capital cost of the project. In contrast, the location of the pelletizing plant at Cape Lambert in the Pilbara Region, and the development of mining at Mount Enid (nearing completion in 1972), has incurred an infrastructure cost of $153,000,000, sixty-two per cent of the total capital expense. Under the terms of a Special Mineral Agreement, the company was held responsible for the construction of a port, a 104-mile railway, and townships (at mine and port), but the largest category of infrastructural expenditure has been the cost of utilities, especially

* The iron pelletizing plant established at Dampier is not considered here. While its power, water, and labour requirements have increased the investments in infrastructure at Dampier, it is strictly ancillary and its operations are dwarfed by the export of more than 15,000,000 tons of unprocessed ore through the port each year.

** The Tasmanian Government, anxious to encourage the development of the Savage River iron ore deposits, which had been regarded as uneconomic for many years, and to secure employment opportunities in the northwest region, provided a loan of $4,000,000 towards port expenses.
power and water to serve the processing plant (Table 5.2)*. For the alumina refinery under construction at Gove, the costs of infrastructure will be high despite the (initially) relatively small scale of mining operations and the proximity of the bauxite deposits to the coast. To the high costs of utilities and ports are added the expenses of large townships; the direct labour requirements of an alumina refinery are about three times those of even a large mining operation. Although the costs of plant and equipment in alumina refining are high, infrastructure will account for about half of the total capital cost of the Gove venture (Table 5.2).

To complete this analysis of infrastructural investment and the location of processing, the bauxite and alumina developments associated with Comalco Ltd are reconsidered. It has been argued in Chapters 3 and 4 that, under a strict application of Weber's least-cost location theory, alumina refining would be optimally located at the bauxite mines. Such a locational arrangement was considered by Comalco Ltd but rejected in favour of organizing a refining consortium at Gladstone, 1,540 miles by sea from the mine at Weipa**. While reasons for this decision have been investigated

* Strictly speaking, the Robe River development was not remote from infrastructure but existing railways, ports, and townships, were owned by the earlier mining companies in the Pilbara Region. The company has been obliged to develop its own facilities including a third major export port in the northwest at Cape Lambert, east of Dampier; the railway crosses that of Hamersley Iron Pty Ltd (see Fig. 5.1). The Mineral Agreement did specify that railway and port facilities were to be developed jointly with The Broken Hill Proprietary Co. Ltd, which holds an iron ore lease over the Deepdale area, adjacent to Robe River. The Deepdale project, however, has been postponed indefinitely.

** Comalco Ltd still intends to establish an alumina refinery at Weipa, by the formation of a consortium similar to that operating Queensland Alumina Ltd at Gladstone. The timing of this major processing development is still subject to considerable doubt.
earlier in terms of comparative input costs, there is no doubt that infrastructural factors were very important.

Consider now the infrastructural implications of a decision to establish an alumina refinery at Weipa with an annual capacity of 1,000,000 tons. The examples already given suggest that the capital costs of processing in a remote location are high principally because of utilities and, in absolute terms, the high labour requirements (which determine the size of the township to be supported)*. The integration of mining and processing at Weipa would allow the sharing of some production inputs, such as maintenance labour, plant overhead, and administrative staff, and some items of infrastructure such as the port. Yet total labour requirements would rise considerably. Suppose bauxite production capacity was the same as that shown in Table 5.2**. About 120 persons are currently employed in mining and wharf operations, while the alumina refinery requires 210 plant workers. Allowing a maintenance section of 260 persons and 250 in administration***, total employment would rise to 840 for an integrated development. Applying the crude analysis suggested in sub-section 5.2.3, a further 250 employees would be required to support the township bringing the total employment to 1,090, almost three times the present employment at Weipa. The population

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* Input co-efficients on which these calculations are based were developed in Sub-section 3.2.2.

** This is a reasonable assumption since considerably more than half of the output of bauxite would be required to meet long-term export commitments.

*** This is about the size of the administrative staff at Gladstone. It is assumed here that no extra administrative staff would be required at an integrated mining and processing development, except for a small number of mining engineers.
of the township would then rise above 3,000, requiring additional investment in housing and community facilities, and greater demands for power and water for domestic purposes.

Electricity consumption at the Gladstone refinery peaks at a load of thirty megawatts, more than twice the generating capacity of the present power station at Weipa. To provide power for the mine, the refinery, and an enlarged township, a station of at least sixty megawatts would be required. The refinery at Gladstone consumes 1,110,000,000 gallons of water per annum while at Weipa, more than 1,000,000,000 gallons are required for plant operation and domestic purposes. It is very doubtful whether the bore water supply scheme at Weipa, presently under considerable strain, could have yielded up to three times the present capacity and an alternative scheme would be essential, using bores only as supplementary sources. Rights to the waters of Wenlock River, north of the mining leases, were guaranteed in the Mineral Agreement with the Queensland Government, and a scheme to dam this river has been under consideration by Comalco Ltd for some time. Such a project would have been essential if a large-scale refinery and a township of 3,000 persons were to be established at Weipa.

Thus, because of the additional costs of community facilities and utilities, a greater level of infrastructural investment is necessary to support both mining and a processing plant. A power station of sixty megawatts capacity would cost about $25,000,000 and the Wenlock River scheme could require a further $10,000,000. Excluding government contributions, investment in the township could rise to $25,000,000. Even allowing for State Government assistance with housing and water supply, and public ownership of the port, expenditure on infrastructure would rise to $60,000,000, three times the combined comparable investments at Weipa and Gladstone up to the beginning of 1970.
With the costs of plant and equipment shown in Table 5.2, the total capital investment in an integrated mining and refining complex would be at least $300,000,000. Apart from these considerable capital expenses, isolation could also raise the operating costs of a refinery; payroll overheads would be increased by the need to pay site allowances to a much larger work-force. Reference was made earlier in this chapter to the high labour turnover at remote mining locations. Difficulties in recruiting tradesmen have been regarded as a minor restraint on the expansion of the refinery at Gladstone* and such problems are multiplied in remote locations such as Weipa.

5.4 Isolation as a Location Factor

From this survey of establishment costs since 1960 in the mineral industries, it is clear that isolation is a critical factor in resource development and plant location. It has been defined in terms of distance from populated areas of the continent, and its influence is conditioned by the degree to which governments assist with the provision of infrastructure, either by extending pre-existing facilities or, less often, by taking part in the construction of new communities. For resource development, this depends largely on the destinations of mined products. Isolation, the corollary of distance, is not expressed by a relationship with transport inputs (ton-miles), but is related to the presence or absence of public (and non-company commercial) facilities. Kerr (1967, p. 301) has argued

In some cases, the economic prospects of a region do not reveal themselves as attractive until a large amount of public capital has raised its infrastructure development... to the point where expected returns from production, manufacture, and distribution compare favourably with costs... It is in the sphere of infrastructure development, therefore, that government probably has its biggest contribution to make to regional development.

* Queensland Alumina Ltd, pers. comm., Gladstone, July 1970.
Government policy affecting infrastructure is examined in more detail in Part III of this study.

It was argued in Chapter 3 that high capital costs in remote locations favour the development of large-scale mines by large organizations, especially where the product has a relatively low value per unit. The examples in this present chapter show that the cost of infrastructure is often the most important component especially where ports, railways, and townships must be provided without government assistance. These expenses encourage the selection of substantial mineral deposits from which high grade ore can be sold without further processing, although a few small-scale ventures have been feasible where infrastructure requirements are low. Because of the high capital requirements, most of the recent developments have been undertaken by major corporations and the possibility of majority Australian equity participation in remote ventures is considerably reduced. Yet, despite the nature of establishment costs, the mining of bauxite and iron ore from large-scale operations has yielded high (short-run) profits (Tsung, p. 27 and pp. 74-84; Cameron, p. 82).

Setting aside transport advantages and the comparative costs of production factors, higher capital costs are incurred if processing is located in remote areas because of the importance of utilities and labour (in absolute terms, if not in man-hours per unit of output). These contribute to higher operating costs, along with other non-capital expenses such as higher overhead, maintenance, and communication charges. With relatively slender profit margins obtainable in mineral processing, location in isolated areas appears less attractive to the companies than at industrial areas such as Gladstone and Kwinana, or sites close to final markets. If, as Webber implies (1967, pp. 123-37), uncertainties are increased with isolation,
established industrial areas attracting public infrastructure investments are much 'safer' locations, given high capital requirements. In assessing the strategy of site selection for processing industries, Buchanan has argued that

although some large mining companies prefer isolated sites to minimize labour disputes, land costs and effluent disposal problems, most processing companies opt for urban sitings where low-lying land can be provided at reasonable cost, recognizing that the advantages of being near a city for these capital intensive low-labour industries will usually outweigh the disadvantages (Buchanan, 1970, p. 72).

The analysis in this chapter supports the locational implications of such an argument; yet while production co-efficients for labour in mineral processing industries are certainly low, it is the absolute size of the labour-force which partially determines the cost of infrastructure in isolated locations. The following chapter attempts to resolve the locational forces exerted by comparative input costs, transport charges, and the high levels of capital investment associated with infrastructure.
It is not pretended that we have given more than an outline... but we must be content with that... for doubtless the proper way of going to work is to draw an outline and fill in the details afterwards -- when the sketch is well done, anyone can finish the picture (Aristotle in Thomson, 1953, p. 39)

Resource creation results from interactions between demand, production factors, the scale of operations, and distance costs, including both freight and the effects of isolation in general. This chapter concludes Part II by identifying the principal locational forces, the resolution of which has given rise to the present spatial pattern of metalliferous mining and processing. The empirical studies of earlier chapters have three important functions: they provide data on the spatial variability of parameters in the resource creation process; they allow an assessment of the empirical status of classical least-cost location theory with respect to the study industries; and they suggest reasons for differences between actual patterns and the optimal patterns generated by least-cost models.

The aim of this chapter is to develop generalizations about the principal spatial factors influencing the actual decision-making of companies in the mineral industries. These 'models' reflect only the basic locational forces in the evolution of the industrial pattern and, as in classical Weberian location theory, they do not represent the decision-making processes of individual firms. Most economic and geographic analysis has involved some form of model-building (defined in Harvey, 1969, p. 163 and pp. 148-9), but the relationship between 'theory' and models, especially those without a formal (mathematical) structure, is difficult to ascertain. The following analysis rests on the premise that models must be evaluated
according to the analytical purpose and that, in the absence of well-developed theory with sound empirical status, it is useful to proceed as though the processes operating in the model are, in fact, those governing the real world phenomena.

While the parameters of resource creation in the metalliferous mineral industries were derived systematically, the analysis now returns to a consideration of the study minerals individually since there are important differences between the forces shaping each pattern. The data generated for the aluminium industry are brought into a formal optimization model, the structure of which is reviewed in section 6.1. In section 6.2 the actual spatial patterns for the aluminium industry are used in a matched comparison test (Wolpert, 1964) against the optimal patterns to yield insights into the importance of the principal location factors; comparative conclusions are drawn from the iron and steel, copper, lead, and zinc industries. The results are used to re-assess the strength of locational forces and to indicate the importance of 'non-economic' constraints to resource creation processes in Australia (section 6.3).

6.1 Optimal Location: 'Matched Comparison' Testing of the Principal Spatial Factors

Within spatial analysis, the general location-allocation problem is still without a determinate solution: 'not only has the problem in its most general form never been solved, it has never even been stated in sufficiently precise terms to be approached mathematically' (Abler, Adams and Gould, 1971, p. 533). In its simplest form, the problem is to locate facilities, and allocate production capacities, so that either manufacturing or tertiary services satisfy a given pattern of final demands. Hence, it is distinctly analogous to the general resource creation problem considered, for the metalliferous minerals, in this
study*. The location-allocation procedure is usually performed to minimize total costs, and Scott (1970, p. 96) describes this system-state as 'socially optimal'. Other objectives include maximization of profits or simply the 'efficiency' of the spatial system. Part II of this thesis has been cast within a least total cost framework developed in Chapter 1 and, although the importance of demand factors was recognized, much of the analysis has concerned costs of production and transport. Models are sought for this study which can represent the resource creation process including mining, first- and second-stage processing, and the supply of ingot to final (spatially-concentrated) markets.

Approximate solutions can be obtained by controlling one or two of the principal variables; allocation models, for example, determine optimal number and size of plants, and the commodity flow patterns, for a given pattern of feasible locations. Serck-Hanssen (1970, p. 87) describes these as 'classic programming models'. Although complicated procedures have been developed to allow the number of plants, their size and location, to vary simultaneously (Scott, 1970; Abler, Adams and Gould, 1971, pp. 546-9) most spatial analyses of specific industries have used (modified) allocation models such as the transportation model and its variants.

The simplest form of transportation model allocates given supplies of a single commodity from m-origins to n-destinations with given (inelastic) demands, a problem which becomes difficult for numerous origins and destinations. Linear programming is most commonly used to solve this problem, although alternative algorithms have been investigated (for example, King, Casetti, Odland and Semple,

* For primary and secondary industries, it is convenient to establish the model as though the economy were closed; all demands are generated from the pattern of final domestic consumers and there are no export sales to render the allocation of production capacities more complex.
1971). Although linear programming was developed to solve non-spatial problems such as production scheduling (Symonds, 1955; Manne, 1963), it has been used widely in geographic research and has been assessed by Garrison (1959, pp. 471-82 and 1960, pp. 357-60) and Scott (1970). Variants of such spatial models have been used by Henderson (1955 and 1958) and Miller (1963) to investigate efficiency of commodity flow patterns in a specific industry, while Wolpert (1964) has used linear programming to derive maximum productivity of regional agricultural combinations. The optimal location of plants in industries where transportation of raw materials has been considered, for iron and steel, by Casetti (1966) and, for wood processing, by Barr (1970); Odland (1968) has used linear models to determine optimal increases in plant size.

For the aluminium industry, which has formed the case study in Part II, a model is required which solves the location-allocation problem with a series of intermediate (processing) stages between origins (mines) and destinations (metal-markets). A modification of the trans-shipment model suggested by King and Logan (1964), and extended by Hurt and Tramel (1965), is a suitable algorithm; this determines the optimal location, number, and size of processing plants, and allows flows of raw product and a processed material. Any locations included in the cost matrices, including origins, destinations, and intermediate trans-shipment points, are regarded as feasible sites for processing. Modifications to an existing spatial pattern are suggested by the possible allocation of zero output to high-cost or poorly-located plants and, here, the model has been used experimentally by the inclusion of a number of hypothetical intermediate plant locations in the problem matrix.

The objective function of the linear programming model used here is of the specific form

$$\text{Minimize } \sum_i \sum_j t_{ij} R_{ij} + \sum_i H_i p_i + \sum_i \sum_j T_{ij} x_{ij}$$
subject to the following constraints:

1) \[ \sum X_{ij} = w_i P_i \]
2) \[ P_i = S_i - \sum (R_{ij} - R_{ji}) \]
3) \[ \sum X_{ij} = D_j \]
4) \[ 0 \leq X_{ij}, R_{ij}, P_i \]

where \( X_{ij} \) = final product shipment from \( i^{th} \) processing plant;

\( T_{ij} \) = transport costs (final product);
\( H_i \) = processing cost per unit (excluding raw product at c.i.f. price);
\( P_i \) = quantity processed at \( i^{th} \) location;
\( R_{ij} \) = raw material shipment from \( i^{th} \) source;
\( t_{ij} \) = transport costs (raw product);
\( w_i \) = weight-loss in processing;
\( S_i \) = total supply of raw product to the \( i^{th} \) location;
\( D_j \) = total quantity consumed at \( j^{th} \) final demand point.

The costs of producing the raw product have rarely been included in standard trans-shipment problem matrices. Yet because this study is concerned with plant location as a stage in resource creation, the basic model has been extended to include the costs of extraction at various mines. This is accomplished by adding the element \( \sum \alpha_i E_i \) to the objective function in one of the models (where \( \alpha_i \) is the unit mining cost, and \( E_i \) the quantity extracted from the \( i^{th} \) mine). An additional constraint is necessary:

\[ P_i = E_i - \sum (R_{ij} - R_{ji}) \]
The element

$$\left[ \sum_{i} \sum_{j} t_{ij} R_{ij} + \sum_{i} \alpha_{i} E_{i} \right]$$

represents the effective cost to the economy of resource development at the various mining locations and is analogous to the function shown in Fig. 1.3.

With a single intermediate processing stage, the transshipment model is of the general form

$$\text{Minimize } \sum_{i-j}^{2N} \sum_{i-j}^{2N} c_{ij} x_{ij}$$

where $c$ is a cost parameter, $x$ a quantity transported or processed, and $N = m+n$ (where $m$ is the number of origins and $n$ the number of destinations). In the aluminium industry, there are two processing stages and a modification was necessary to compute optimal solutions in a single problem matrix. Any number of processing stages is possible between the origins and final product destinations, and in general terms the size of the problem matrix becomes

$$(M + \sum_{k} L_{k}) \cdot (\sum_{k} L_{k} + N)$$

where $M$ is the number of raw product origins, $L_{k}$ is the number of plants at the $k^{th}$ processing stage, and $N$ is the number of demand points for final product. A sample problem matrix, of the type constructed for the aluminium industry, is shown in Fig. 6.1. Sub-matrix A includes transport costs for bauxite shipments and, if included, mining costs at each origin. Sub-matrix E includes unit costs of refining plus transport costs for alumina shipments, while sub-matrix J includes the unit costs of smelting plus transport costs for shipments of aluminium ingot to demand centres. Sub-matrices D and H are used to record excess capacities at processing plants after the optimal allocation; sub-matrices B, C, F and G are not relevant to
### FIG. 6.1: SAMPLE PROBLEM MATRIX - BASIC TRANS-SHIPMENT PROBLEM

For $M = 3$, $L_1 = 5$, $L_2 = 4$, $N = 3$ (see text).

After Hurt and Tramel, 1965, p. 769.
this problem*. The row and column margins show supplies, demands, and plant capacities. The optimal solutions were computed using an IBM Transportation Programme** and the results are presented in sub-section 6.2.1.

The results of the linear programming analysis were used in 'matched comarison' test whereby the optimal patterns are compared with the actual patterns and the deviations assessed (Wolpert, 1964) to throw light on the behaviour of the system. The assumptions of linear programming influence the interpretation of the solutions. The models used here assume homogeneity of inputs, absence of scale economies in production (at least for model-building) and transportation, inelasticity of demand for final product, perfect marketing conditions, and a closed economic system. The homogeneity assumptions do not seriously violate reality with respect to the processing industries, and product flows in the aluminium industry can be readily expressed in terms of a single commodity. Once the model has been constructed, allowance can be made for economies of scale in production using an iterative procedure (explained by King and Logan, 1964). The demand assumptions are shared by Weberian least-cost location theory and have been assessed as reasonable for the study industries in Chapter 2.

The assumption of a closed system allows results to be interpreted more easily but a method for dealing with 'leakages' into exports is essential. Koch and Snodgrass

* In the computation of this matrix, very high values are assigned to items in sub-matrices B, C, F and G so that they are not considered in the calculation of the optimal solution. The diagonals of sub-matrices D and H contain zeros and the remaining values are very large to prevent their entry into the solution.

** This programme solves the transportation problem by the MODI method, described by Hadley (1962, pp. 273-322), and was obtained from IBM. Programming was carried out on the IBM 360/50 computer at the Australian National University.
(1959, pp. 157-60) have suggested the manipulation of the cost matrices to include not only regional cost variation (an integral part of the analysis of this section), but also product differentiation and market imperfections. Excessive manipulation of the matrices, however, serves little analytical purpose; an optimal solution close to the actual pattern can be produced, but not much can be said about the relative strengths of economic and 'non-economic' factors in producing the pattern. It must be remembered in matched comparison testing that a spatial pattern minimizing costs for the system as a whole has been generated. There is no reason why the decisions of multi-plant corporations should be system-optimal; the minimization of total firm costs may involve 'non-optimal' spatial arrangement of plants.

Repeated iterations of the models to allow for economies of scale in production and transport were not attempted in this analysis for two main reasons. First, the cost estimates made in Chapters 3 and 4 do not encourage a sophisticated analysis of production economics and, in any case, the extra computations required are beyond the purposes of this analysis. Hence, the first solutions obtained minimize total transport costs, holding production costs fixed, and abstract from the effects of plant size on location. Scale factors can be introduced qualitatively into the interpretation of results, and later models are modified to include production costs at present plant capacities. Second, even those activity analyses which attempt to include production economies rarely include those in transportation, and mathematical and computational reasons are given by Serck-Hanssen (1970, pp. 9-11). Yet such economies are equally important in location, especially in the domestic aluminium industry.

The use of individual (estimated) freight rates for particular flows raises an important conceptual weakness of static programming analysis. If an optimal solution
allocates a low output to a particular source, actual transport costs would probably rise, especially if coastal shipping were the transport mode involved. This cost increase could be sufficient to remove this source from a 'true' least-cost solution, especially if its competitive position depended principally on the economies of bulk shipping. If a greater output were allocated, lower actual freight rates might increase the competitive advantage of this location even further than suggested by the linear programming solution. Finally, the inclusion of hypothetical production points in the models involves another conceptual weakness. Even for companies making locational decisions, freight rates for a particular commodity flow are not known _ex ante_ and must be estimated from known rates; yet reliable estimates are difficult if the commodity flow does not actually exist, especially when bulk concessions are involved.

Hence, the solutions generated are optimal only under the stated assumptions and, in the following sub-sections, their interpretation is subject always to the conceptual and data difficulties discussed here. Economists have tended to evaluate (linear) spatial models pragmatically, based on their usefulness to policy makers, entrepreneurs, or consumers. Spatial analysts might reject such evaluation criteria and construct the models in an attempt to understand better the working of a space-economy. Tests for efficiency are not the concern of this chapter: rather, the model solutions are presented as 'bench-marks' against which to assess the interplay of location factors and to evaluate their relative importance in producing the spatial pattern. Linear programming provides a robust and mathematically simple system of establishing such bench-marks (Harvey, 1968).
6.2 The Resolution of Forces in the Selection of Mineral Deposits and the Location of Processing Plants

The multiplicity of primary, secondary and tertiary processing and manufacturing operations involved with each consumer product need to be carefully interrelated to give minimum costs and it generally works out best to have primary treatment at the source or at the nearest coastal site with secondary processing at integrated complexes near large cities and with the tertiary manufacturing at a multiplicity of nearby and district locations closer to the point of consumption (Buchanan, 1970, pp. 67-8).

A least-cost approach to the location of basic processing industry is implicit in this quotation; applied to the metalliferous mineral industry, Buchanan's model suggests the development of first-stage processing plants at mines and coastal trans-shipment points, with second-stage plants at a small number of heavy industrial centres. The fabrication and distribution of metals would take place at capital cities and then through regional centres. As a first approximation, this provides a reasonable descriptive model for the location of such processing in Australia especially that serving primarily domestic markets. Not all plant locations are satisfactorily explained by such simple models and an assessment of the degree to which 'non-optimal' location patterns have evolved is an essential prelude to the identification of government influences in Part III.

In sub-section 6.2.1 the principal factors influencing decision-making in the aluminium industry are discussed and the actual patterns tested against solutions developed using the linear programming model. The iron and steel industry is reviewed in sub-section 6.2.2 concentrating on criteria for selection of deposits during the 'boom', and the location of first-stage processing plants. In sub-section 6.2.3 the long-established copper, lead, and zinc industries are considered and the plant locations assessed in terms of classical theory.
6.2.1 The aluminium industry: optimal allocation solutions

(a) Actual locational decision-making

Decisions to develop bauxite mining in Australia have been integrated with the establishment of alumina refineries; unprocessed ore has been exported to provide short-term revenue flow during the construction of refineries (as at Gove), but long-term overseas sales will be made only from the high-grade deposit at Weipa which achieves low costs because of both high quality and economies of scale. There are strong economic reasons for the location of refineries close to the bauxite deposits. The most important of these were exposed in Chapter 4 and are the weight-loss of one-half in processing (the classic Weberian factor) and, despite the transportability of bauxite, the potentially high contribution of transport costs to the c.i.f. price of the ore, a commodity of low value per ton. Given the economies of large-scale, long-distance sea transport, only large producers located near tidewater and producing high-grade bauxite at low unit cost could deliver the ore competitively at distant refineries (whether in Australia or overseas). Since the domestic ingot capacity is low and four-fifths of alumina output is exported, the location of the domestic smelters and final metal markets is not necessarily important in the location of refineries. In 1970, two refineries were under construction near bauxite mines (Gove and Pinjarra) while an additional mine-site plant has been planned (Weipa). None of the refineries operating in 1970, however, (Bell Bay, Kwinana, Gladstone) was located at its bauxite source; each illustrates a different interplay of location factors.

The establishment of the refinery at Bell Bay in 1955 can be understood only in terms of historical circumstances, and its location was determined by that of its only proposed 'customer', the domestic smelter. The small scale of operations was determined by the ingot production capacity (and the diseconomies of production at
so small a scale were investigated in Chapter 3). The decision by the Australian Aluminium Production Commission to integrate refining and smelting was sound, given the structure of marketing in the world aluminium industry (considered in Chapter 2) and the very small bauxite resources of Australia at that time. Possible difficulties in alumina supply could be overcome by local production using bauxite imported from India and Malaysia. Under the circumstances of establishment as a State-owned corporation, production economies were not of primary importance, especially at the alumina stage, and Bell Bay was the best location for the small refinery. The sale of the refinery-smelter project in 1960 to a company with international affiliations, and the development of Australia's large bauxite resources, ensured location-obsolescence for this plant.

Kwinana was an obvious locational choice for a refinery to process bauxite from Jarrahdale. The tidewater block was suitable for the assembly of raw materials both by sea, and by rail from the bauxite leases, and for the despatch of alumina either overseas or to a local smelter near the east coast markets. Fuel oil could be obtained from the adjacent oil refinery and infrastructural investment at this site was minimal. The relatively low grade and high mining costs of Jarrahdale bauxite ensured that a least-cost locational arrangement would involve the shipment of alumina rather than of bauxite; if the refinery was to supply a local smelter, the foreshore of Cockburn Sound had considerable production cost advantages over the mine-site, especially with the concessional freight rates negotiated for the bulk transport of ore by rail.

For the developments at Weipa, the Weberian locational arrangement of refining at the bauxite mine was the first to be investigated by Comalco Ltd, especially because of the proximity of the mining leases to tidewater.
Yet the transport advantages of shipping alumina were weighed against the very much greater infrastructural cost of establishing a large plant at a remote location, and against cost disadvantages with respect to fuels, electricity, water, and labour. The selection of another site with more suitable production economics was encouraged by the high transportability of Weipa bauxite explained in Chapter 4. Since most of the output of alumina was to be exported, several sites on the Queensland coast seemed appropriate to minimize the haulage of unprocessed ore, and one of the first selection criteria was suitability for the development of bulk shipping facilities. Established ports offered several advantages over new sites: they were nodes in regional transport networks; they would involve lower site allowances for labour and less need for investment in community facilities even if little suitable man-power was immediately available; the reticulation of power and water could be undertaken by local government authorities*.

The final selection of Gladstone suggests the relative importance of the various factors in decision-making. Situated on a natural deep-water harbour, Gladstone was being developed as the export port for coal mines at Moura (1961) and Blackwater (1968); marine facilities were expanding under a local Harbour Board with State government assistance. The port was a suitable location for the assembly of raw materials by sea, both limestone and coal occurred in large quantities within 100 miles, and electricity could be reticulated from the nearby Callide

* Several sites considered were technically inappropriate. The establishment of a large-scale refinery near the Brisbane metropolitan area, for example, would have involved high land prices and a potentially serious effluent disposal problem. Poole, McDonald and Rowe (1971, p. 26) claim that the State Government had already forbidden location in Brisbane because of 'decentralization' policies. The technical and economic factors are likely to have been of much greater importance.
Aluminium smelting has been used commonly to illustrate the importance of regional cost variation in 'distorting' a location pattern away from that which minimizes transport costs (see for example Krutilla, 1955; Isard et al., 1960, pp. 242-3; and Isard and Whitney, 1952, pp. 112-33). Attention was drawn in Sub-section 3.2.3 to the importance of electricity in the total production costs of aluminium ingot. In the initial feasibility studies during the late 1950s for an aluminium smelter based on the newly discovered Weipa bauxites, Consolidated Zinc Pty Ltd considered the hydro-electricity potential of the Purari
River (Papua)* and Lake Manapouri (New Zealand), and also investigated the use of coal deposits in Central Queensland (Hibberd, 1958, pp. 20-1). At least for the hydro-schemes under consideration, electricity could have been generated for less than 0.3 cents per kilowatt-hour in large-scale plants. Yet, despite the large requirements of a smelter, the absence of regional alternative users would have made difficult the construction of a plant of the necessary scale. The feasibility studies were postponed when, in 1960, the company's offer to purchase the Commonwealth Government's share in the Bell Bay smelter was accepted. Since the terms of the sale included the guarantee of protection against imports, the consideration of other Australasian sites was shelved.

The smelter at Bell Bay had been established in 1955 to take advantage of Tasmania's low-cost electricity. Four sites in the Tamar Valley were considered by the Australian Aluminium Production Commission (Henty, 1960, p. 608): Trevallyn, the site of a power station; Dilston, a few miles north of Launceston; Nature Point on the west bank of the estuary; and Bell Bay on the opposite shore near Georgetown. Although near a major town, the first two sites were not on tidewater and were rejected. Since all material inputs and output were to be transported by sea, Bell Bay was chosen as the most feasible site for harbour facilities. Although the Commission could not show a profit during the six years of its operation (Australian Aluminium Production Commission, 1955-56 to 1959-60), the analysis in Sub-section 3.2.3 supports the conclusion that inadequate scale of operations rather than poor location was the main reason. It is extremely doubtful whether

* The selection of Delena, a site west of Port Moresby investigated by the company, may have changed subsequent locational decisions regarding the alumina refinery. If the smelter had been located in Papua, Weipa may have been chosen as the site for the initial refinery.
ingot could have been produced more cheaply in a plant of the same size elsewhere in Australia. Tidewater location, important in the assembly of raw materials, remained significant once Australian sources were substituted.

An integrated refinery-smelter complex at Kwinana had been considered by Alcoa of Australia Ltd but, since at least initially, the smelter was to produce for the domestic market in competition with Comalco Ltd, this location involved serious marketing disadvantages. While Kwinana would have been a feasible site for an export smelter, providing power could have been supplied at reasonable rates, the shipment of alumina in bulk to a smelter site in southeastern Australia was more economic than the transport of ingot to a semi-fabricator near Melbourne or Sydney. (The shipment of semi-fabricated products would have been out of the question.) While neither Western Australia nor Victoria could offer power as cheaply as the Tasmanian Hydro-electricity Commission*, industrial rates in Victoria, where brown coal is a principal fuel, are lower than those in the west. The company was able to lease a brown coal deposit west of Geelong, which could support a company-owned power station. Yet the market-oriented site in Victoria was made feasible only by concessional power rates offered by the State Electricity Commission. A tidewater block at Point Henry near Geelong was selected, and semi-fabrication facilities were integrated with the smelter. It was shown in Chapter 4 that the locational arrangement adopted by Alcoa of Australia Ltd of refining near the bauxite mine and smelting near the final market, is the most favourable in the Australian industry in terms of total transport costs per ton of ingot produced.

* The smelter at Bell Bay consumes at least one-quarter of the power output of the Tasmanian Hydro-electricity Commission and it is most unlikely that another large smelter could have been supported in that State.
Alcan Australia Ltd considered a number of locations in New South Wales for a smelter to supply its semi-fabricating works in Sydney. Alumina was to be drawn from the company's share of the output of the Gladstone refinery, and the New South Wales Government guaranteed sufficient electricity (at concessional rates) from large thermal power stations at Liddell, Lake Munmorah, and Vales Point near Newcastle. Although tidewater sites in the area were considered, the final choice of Kurri Kurri near the (inland) South Maitland coalfield is somewhat surprising. Large tidewater blocks in the Newcastle area were expensive and, at Kurri Kurri, a technically-suitable site was available, infrastructure adequate, and labour potentially available. It is possible, but unlikely, that regional cost advantages were sufficient to outweigh the extra transport costs of a non-tidewater location, particularly the trans-shipment of alumina at Newcastle and its haulage to the site by road. Even at concessional power rates, the smelter is at a cost disadvantage over Bell Bay; long-term arrangements for the supply of electricity are critical to its profitable operation but, at present, speculation would be purely conjectural. At an annual capacity of about 90,000 tons of ingot, and with large metal exports, much of the apparent disadvantage could be overcome by economies of scale. With the cancellation of the export contract and the present plant capacity of 44,000 tons per annum, however, the locational disadvantages of Kurri Kurri appear more serious; this location may not be predicted by the least-cost location models.

(b) The matched comparison test

Four linear programming models of the aluminium industry were investigated using the data generated in previous chapters. The first allows variation in transport costs but not in production costs and is called, for convenience, the 'Weberian solution'. The second, the 'least total-cost' solution, allows regional variation in refining and smelting costs, while the third includes
mining cost variation. These three consider the pattern of existing mines and plant locations*. The fourth model includes additional (hypothetical) locations for first- and second-stage processing and is thus called the 'location-allocation' model**. In computing an optimal solution, the programme first allocates ingot to the demand points and works backwards to refineries and mines. Exports are ignored, therefore, in the calculation but are considered when the results are interpreted.

Large-scale exports allow the achievement of economies of scale so that c.i.f. prices to local consumers are lower than they would be from smaller plants serving only domestic markets. The cost matrices assume annual rates of output for each plant of at least three-quarters of their production capacity in 1970. If the optimal solution allocates only a small output to a plant, two possibilities must be considered in interpreting the results: either export demand is sufficient to permit adequate economies of scale, or the solution is a highly suspect least-cost optimum because increases in unit costs at small outputs might remove the comparative advantage given to that location. Fortunately, the first possibility is reasonable for many plants, especially those producing alumina since four-fifths of annual production is now exported. Although the two larger smelters depend on exports to maintain high rates of output, and some sales are made under contract, spot sales depending on international market conditions are

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* Problem matrices for the Weberian and least total-cost models are of the same size and include three mines (Jarrahdale, Weipa, Gove), four refineries (Kwinana, Bell Bay, Gladstone, Gove), three smelters (Bell Bay, Point Henry, Kurri Kurri), and four final demand centres (Melbourne, Sydney, Brisbane, Adelaide).

** Cost matrices for these models are presented as Appendix III. Production capacities and final demands (for 1970) are expressed in terms of alumina equivalent.
important. Thus, it is dangerous to conclude that reduced domestic sales from any of the smelters can be readily converted into exports, unless quantities to be reallocated are relatively small.

The Weberian and least total-cost solutions are presented in Tables 6.1 and 6.2 in matched comparison with the actual situation. Interpretation of the results is easier from the optimal flow patterns (Table 6.1); the potential patterns of domestic and export sales, to maintain output levels for each plant under the optimal solutions, are given in Table 6.2. The actual industry pattern neither minimizes transport costs nor total costs for the economy as a whole. In the Weberian solution the pattern of ingot production is similar to the actual pattern, suggesting that at least two of the smelting companies have taken transport costs into consideration in supplying semifabricators. Kurri Kurri and Point Henry are good locations but the Bell Bay smelter supplies only a portion of the Sydney market and would rely heavily on exports. The Weberian solution allocates a majority of alumina production for domestic use to Kwinana because of the advantages of shipping alumina instead of bauxite, and the short distance from the mine to the processing plant. Both Point Henry and Bell Bay are supplied from this plant. Gladstone is not favourably located to make domestic sales, principally because of the long haulage of bauxite from Weipa, and it supplies Kurri Kurri alone. The principal function of this large plant would be as an exporter. The small refinery at Bell Bay, drawing bauxite supplies from Weipa, is the most unfavourably located and disappears from the optimal solution*. Gove is developed entirely for export markets because of remoteness from the metal markets

* Since this model does not include production costs, it seems clear that it is not only small scale which renders the refinery at Bell Bay locationally obsolete.
<table>
<thead>
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<td>Brisbane</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>ingot</td>
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Source: Computed by linear programming from cost matrices in Appendix III.
<table>
<thead>
<tr>
<th>Location</th>
<th>Product</th>
<th>Actual (1970)</th>
<th>Weberian solution</th>
<th>Least total-cost solution</th>
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<td>Output</td>
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<td>44</td>
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<td>-</td>
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</table>

*a Under development in 1970.

**Source:** Based on Table 6.1.
of southeastern Australia. Hence, Jarrahdale becomes the principal bauxite source for the Australian industry because of the advantages of nearby processing. The large deposit at Weipa would be developed largely to support export (of both alumina and unprocessed ore). The least total-cost solution, basic to this analysis, allows the substitution of production inputs for transport inputs and makes it unlikely that the optimal location pattern minimizes transport costs. The results reflect the interplay between transport and regional cost variation and the solution is quite different to that of the strict Weberian model (and from the actual pattern). In this case, the inclusion of mining costs made no difference to the optimal allocation made by the least total-cost model*. In the aluminium industry, sources of commodities with low f.o.b. prices possess significant comparative advantage. The inland smelter at Kurri Kurri disappears from the pattern. Despite its relative accessibility to markets, demonstrated in the Weberian solution, it cannot compete locally because of the relatively high costs of electricity and lack of scale economies at the present production capacity. Point Henry also loses much of its competitive position, although economies of scale reduce the disadvantage and the plant supplies the balance of the nearby Melbourne market. Without significant exports, this plant would probably not be locally competitive, according to the model. Because of low power costs and high rates of output, the Bell Bay smelter supplies Sydney, Brisbane, Adelaide, and a portion of the Melbourne market at lowest total cost. It has no excess capacity and does not export (Table 6.2).

* This is not necessarily the case, however, and the inclusion of mining costs could change the pattern of supply for first-stage processing plants. In this analysis, it was found that when mining costs were included in the model, the total cost savings by switching to the optimal pattern were even greater than for the basic least total-cost model.
The alumina refinery at Bell Bay disappears as in the Weberian solution; not only is it poorly located in terms of transport costs, but its unit production costs are unfavourable at so small a scale. Domestic sales from the Gladstone plant double because of the low unit costs of production at large scale, and the low c.i.f. prices of bauxite from Weipa. The smelters at Bell Bay and Point Henry are supplied from Gladstone, and this solution is reinforced by the transport economies of large-volume bulk shipment. In the total cost minimization solution, Kwinana and Jarrahdale would produce only to supply export markets. The deposit at Weipa supports greater domestic processing despite remoteness, and its local competitive position is encouraged by the high grade of the ore, and the strong export demand for bauxite of this quality. The matched comparison test of the actual pattern with that minimizing total costs suggests important differences. Reasons must be found, for example, for the survival of alumina production at Bell Bay, for the large local sales of the Jarrahdale-Kwinana development, and for the fact that actual domestic sales are similar for the three smelters (a solution far from optimal).

The results of the 'location-allocation' model are given in Table 6.3. Three additional locations for refining were considered (Weipa, Brisbane, Newcastle) and three for smelting (Kwinana, Newcastle, Gladstone)*. The estimated costs of alumina produced at Weipa were inflated by additional infrastructure, and costs at the other locations

* No additional bauxite mines were added. Deposits currently under investigation are either of too low a grade, or are too remote to feasibly take part in domestic sales and would be developed only for alumina export.
TABLE 6.3: SOLUTION OF 'LOCATION-ALLOCATION' PROBLEM: PLANT SIZES AND SALES (thousand tons)

<table>
<thead>
<tr>
<th>Location</th>
<th>Product</th>
<th>Actual (1970)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Domestic sales</td>
<td>Exports</td>
<td>Total</td>
<td>Domestic sales</td>
</tr>
<tr>
<td>Jarrahdale</td>
<td>bauxite</td>
<td>2,740</td>
<td>-</td>
<td>2,740</td>
<td>2,740</td>
</tr>
<tr>
<td>Weipa</td>
<td>bauxite</td>
<td>2,530</td>
<td>3,270</td>
<td>5,800</td>
<td>2,400</td>
</tr>
<tr>
<td>Kwinana</td>
<td>alumina</td>
<td>170</td>
<td>680</td>
<td>850</td>
<td>-</td>
</tr>
<tr>
<td>Bell Bay</td>
<td>alumina</td>
<td>62</td>
<td>-</td>
<td>62</td>
<td>-</td>
</tr>
<tr>
<td>Gladstone</td>
<td>alumina</td>
<td>180</td>
<td>1,000</td>
<td>1,180</td>
<td>340</td>
</tr>
<tr>
<td>Bell Bay</td>
<td>ingot</td>
<td>44</td>
<td>30</td>
<td>74</td>
<td>94</td>
</tr>
<tr>
<td>Point Henry</td>
<td>ingot</td>
<td>34</td>
<td>50</td>
<td>84</td>
<td>-</td>
</tr>
<tr>
<td>Kurri Kurri</td>
<td>ingot</td>
<td>44</td>
<td>-</td>
<td>44</td>
<td>-</td>
</tr>
<tr>
<td>Gladstone</td>
<td>ingot</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>26</td>
</tr>
</tbody>
</table>

Source: Computed by linear programming, and interpolation, from the cost matrix in Appendix III.
by relatively small scale*. Large smelters were envisaged at Kwinana and Gladstone, both potentially good sites for second-stage processing, while Newcastle was included to allow re-location to a tidewater site of the small smelter at Kurri Kurri. Kwinana, and to a lesser extent Newcastle, suffer electricity cost disadvantages but Gladstone has been selected as the site for a 'super' thermal power station based on low-cost coal. The potentially low cost of electricity from such a station is sufficient for the inclusion of a Gladstone smelter in the optimal solution (Table 6.3) to serve Brisbane and one-third of the Sydney market. Considerable exports would be essential suggesting that the plant could be operated feasibly by an international consortium (led by an Australian semi-fabricator), with at least half of ingot output transferred captively to overseas parents.

Smelting capacity was not allocated to Newcastle, Kwinana, or Point Henry. Newcastle is a marginally better location than Kurri Kurri, but a large plant at Gladstone would hold significant comparative advantage. A plant at Kwinana could survive only as an export smelter, in which case the costs of electricity would make other sites preferable, at least under foreseeable circumstances. Bell Bay supplies the remaining semi-fabricators including the entire Melbourne market at the expense of Point Henry. The remainder of the industry is organized as for the least total-cost solution with Weipa and Gladstone as the domestic sources, while Jarrahdale-Kwinana and Gove are developed only for export. Despite apparent transport advantages, the extra costs of infrastructure and high transportability of the bauxite discourage the location of the refinery at Weipa itself rather than Gladstone; a prerequisite for the

* At both Brisbane and Newcastle, it was not considered feasible to permit the allocation of plants with annual capacity greater than 600,000 tons per annum. At both locations, site factors and particularly the effluent disposal problem would make the establishment of large plants difficult.
establishment of such a plant would be the securing of export markets for about 1,000,000 tons per annum. Neither Brisbane nor Newcastle attracts refineries at the scales of output envisaged.

Hence, a survey of the actual industry patterns reveals that most bauxite is processed into alumina which is both exported and used in local smelting. Large overseas sales of bauxite and alumina encourage economies of scale and allow these commodities to be supplied at low cost to local processing plants. Exports of ingot, more difficult to arrange, are becoming increasingly important to maintain profitable operations and to avoid excess capacity now that three local smelters are operating. The matched comparison testing emphasizes the strength of the principal location factors, especially the high transportability and low cost of Weipa bauxite, but also suggests that the actual pattern is not adequately explained by the least-cost location theory.

6.2.2 Resource development and plant location patterns based on iron

Spatial patterns of resource creation in Australia involving iron and steel illustrate the constraints initially imposed by the small size of local markets, and the changes caused by the imposition of a second system of demand with the commencement of large-scale exports of iron ore after 1960. Early developments in the smelting of iron ores in Australia correspond roughly with the situation depicted in Fig. 1.8(a) with ore deposits close to settled areas discovered and tested before those at greater distance. High-grade ores from the Middleback Ranges could be economically transported by the emergent iron and steel monopolist to its east coast steel-works. Resource creation processes involving iron ore were, until 1960, dominated by the attempts of The Broken Hill Proprietary Co. Ltd to secure long-term supplies; once adequate reserves were proven, there was no incentive for further exploration.
As export markets for Australian iron ore developed during the 1960s, new selection criteria for resource development emerged. Most mining decision-making in Australia since 1960 has been conditioned by the need for low unit extraction costs and high annual rates of output from open-cut mines. In such circumstances the size of deposits, rather than the grade, emerges as a major location factor where infrastructural expenses are to be involved, and size becomes important as grades become lower, as the distance from outlet ports increases, and as government contributions towards infrastructure decline. The highest capital costs are incurred when a suitable port must be developed and operated by the mining company, involving the duplication of infrastructure at mine and port townships. As a result, there is a considerable difference between the minimum economic size of operations for mines facing little infrastructural expense, and those for which large scale is made essential by high capital costs. Large mining ventures require even greater (relative) capital investments especially in utilities and community facilities, making the minimum economic size very large indeed. For export developments, therefore, the expected pattern would include a number of small mines close to existing infrastructure, and several very large ones with few intermediate sizes.

The interactions of these selection criteria are complex and are influenced considerably by the capital reserves of the prospective mining company and by a variety of non-economic factors. If the minimum economic scale of operations is very large because of the locational factors already mentioned, the company would seek to develop a deposit which could sustain not only the high annual rate of output, but also one that could support mining long enough to justify the heavy initial investment in ports, townships, and railways. If, at the projected rates of output, the initial deposit would be approaching economic exhaustion before such a time had elapsed, mining might still be established if potential and inferred reserves
(perhaps of lower grades) or adjacent deposits could be brought into production with a minimum of duplication, or actual abandonment, of the initial infrastructure. Given the high capital costs, it is very unlikely that small deposits of haematite in the Pilbara Region (say of less than 50,000,000 tons) could be converted into resources under foreseeable circumstances; production from deposits of up to 100,000,000 tons could be integrated with that from existing mines depending on conditions of depletion of the higher grades, and the costs of developing larger but even more remote deposits. It is clear that none of the large but isolated deposits in the Pilbara Region could have been developed economically for local consumption alone.

Only two iron ore deposits with average grades of less than sixty per cent have been developed since 1960 to serve coastal processing plants. Profitable pelletization from low-grade ores usually requires the establishment of large-scale mining and small deposits are rarely selected for resource creation. The Robe River project has faced high infrastructure costs but production will become economic at an annual output of 10,000,000 tons of crude ore. The selection of the low-grade magnetite deposit at Savage River as the basis for the export of pellets is somewhat difficult to explain especially since the scale of operations is moderate (about 4,500,000 tons of crude ore per annum). Special pellet marketing arrangements (outlined in Sub-section 2.3.1) are very important, however, and, despite rugged terrain, private investment in infrastructure was low compared with the Pilbara developments.

Locational decision-making is easy to interpret for the pelletization plants, for there are strong economic reasons to locate such plants at or near the ore sources. Fines for pelletizing are generally much less transportable than lump ores or pellets (Manners, 1971, p. 170),
and weight-loss is involved where the pellets are the result of concentrating low-grade ores*. In Chapter 3, it was shown that energy and capital inputs are of most importance in pellet production, and locational disadvantage in remote areas can be minimized by integration of a large plant with either mining or port facilities. Production costs often favour port sites over inland mines because of economies in the generation of electricity; fuel oil can be delivered direct to the power stations from bulk carriers, although back-loading of oil is usually possible to the mine-sites. The locational problem is one of resolving the cost differentials against differences in the transportability of fines and pellets, and weight-loss in processing. The lower the grade of ore to be pelletized, the higher the likelihood of mine-site location, especially where mine and plant can be operated at very large scale, and where the deposit is located more than about 150 miles from a suitable bulk-port site. As yet, there are no examples of such inland plants in Australia, but Manners has presented some case-studies from North America (1971, p. 170).

The resolution of locational forces suggests three circumstances under which location at the outlet port minimizes total costs. First, the deposit may be located only a short distance from the coast, or else the concentration of the ore may involve relatively little weight-loss. (An example is the Robe River project.) Second (and as a special case of the first), a pipeline may have been the chosen method of linking the mine to its outlet port in which case the transport of ore becomes an integral part of the concentration process; the crushing of crude ore prior to concentration produces material ideal for

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* In addition, Earney (1969, p. 514) has suggested a technological reason. He claims that the long-distance transport of fines or concentrates renders them less suitable, in physical structure, for the standard pelletization process.
transport as a slurry (Savage River - Port Latta). The third case involves the agglomeration of high-grade fines rather than concentration. Such processing is strictly ancillary to the production and sale of shipping-grade ore, there is little weight-loss in processing, and a proportion of the fines is actually generated by the transport and port-handling systems. (Examples of such plant locations were found at the ports of Dampier and Whyalla.)

6.2.3 The copper, lead, and zinc industries

The location of domestic second-stage processing facilities had little or no influence on the initial development of Australia's largest lead-zinc and copper deposits, although the re-opening of old mine-workings at Read-Rosebery (1936) was undertaken by a company which had already located a smelter in Tasmania. The principal spatial variable has not been demand but, rather, the cost of isolation; in the light of previous chapters, it is reasonable to conclude that mining at considerable distances from outlet ports could survive only at large deposits*. While the relative scarcity of copper, lead, and zinc ores has allowed production from underground mines at relatively small scale even in remote areas, only large mining companies survived the rapid depletion of superficial high-grade ore which immediately followed early resource developments. As progressively lower grades are exploited, low unit extraction costs become increasingly important in the production of concentrates and this often results in the employment of more capital-intensive mining methods.

In spite of mechanization, the reduction of underground mining costs has been restrained by the costs of

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* The small mine at Tennant Creek in the Northern Territory provides an important exception to this rule. Mining and a vigorous programme of continuous exploration have been profitable largely because of the high gold content of the copper ore bodies.
isolation (principally those associated with labour), although infrastructural expense does not now exert so great an influence on extraction costs. The grade which can be mined profitably has depended partly on the cost of transporting concentrates to outlet ports, either for further processing or for export. It was indicated in Chapter 4 that concentrates of lead, zinc, and copper are generally less transportable than iron ores, bauxite, and alumina. High extraction costs and low transportability encourage the survival of large mining companies and the demise of small ones, especially those for which low financial reserves and high uncertainties discourage continuous exploration thus placing a constraint on the size of mineral resources at such locations. Hence, a large number of small copper mines have been worked in Australia since 1860, especially in times of high metal prices, but five mining locations now produce well over ninety per cent of the current domestic output of copper concentrates. Similarly, only four deposits are now mined for lead and zinc ores, although in the past significant quantities were extracted from mines at other locations (Raggatt, 1968, pp. 151-2).

The simplest plant location patterns are found in the production of concentrates; for copper, lead, and zinc, very high weight-loss ties this activity (without exception) to the mine-sites. In copper smelting, production coefficients for concentrates are very high and weight-loss averages sixty per cent. There are strong reasons, therefore, for the location of smelters adjacent to the concentrators and such an arrangement was universal during the later nineteenth century. The improvement of the rail transport of concentrates in bulk removed some of this mine-site advantage but, when copper mining began at Mount Isa during the Second World War, the smelter was developed at the mine, despite some cost disadvantages (especially infrastructural) over coastal sites. Problems of isolation were reduced by integration with existing developments
(including the lead smelter), by the back-loading of coal, and by the exploitation of economies of scale. Thus, by far the largest copper smelter in Australia is located more than 600 miles inland. Since the Second World War, other inland smelters have fared badly, partly because of locational disadvantages, but principally because of obsolescence and very small scale combined with fluctuating metal prices. In 1964, market uncertainties were removed for the tiny smelter at Mount Morgan with the signing of the long-term export contract for the plant's entire output of blister. The Queenstown smelter has not survived. Since 1965, primary smelting has been undertaken at Port Kembla, a location with many advantages for a small-scale plant; adjunct raw materials and power are readily available, the principal metal-using industries are within easy access, and concentrates can be received by sea.

According to Weberian theory, the refining of blister copper should show no such basic raw material orientation. Little weight is lost in processing and the removal of impurities by electrolysis releases 'waste' products such as gold which provide a supplementary income. It was shown in Chapter 3 that electricity consumption is relatively low in copper refining; with refined copper shapes, wires, and rods transportable only at relatively high cost, market orientation is common throughout the world for this form of second-stage processing. The Townsville copper refinery is apparently a classic case of locational advantage at the trans-shipment point, but in terms of a least-cost solution it is doubtful whether Townsville would be a better location than Newcastle or Port Kembla. Townsville is a good location for the export of refined copper but in fact only about thirty per cent of output is exported so that much must be explained by the large scale of operations. The smaller refinery at Port Kembla, one of a number of market-oriented refineries treating scrap metal, now refines an increasing quantity of blister copper since the commencement of primary smelting in 1965. Copper refining was
undertaken at Queenstown using low-cost power from the Tasmanian Hydro-electricity Commission but was abandoned in 1965 and blister shipped to Port Kembla.

Lead smelting and copper smelting are subject to a similar set of locational forces. There were obvious economies associated with a single integrated works at Port Pirie against which smaller mine-head smelters could not compete. This plant is apparently another example of the trans-shipment point location; high-grade concentrates could be railed in bulk and refined lead shipped out to local and export markets. Although processing involves weight-loss (especially when the coal and iron ore flux are considered), valuable by-products such as silver can be obtained from the lead concentrates and, since 1968, zinc has been produced from accumulated slag dumps. The relatively high transport costs from Broken Hill to Port Pirie have encouraged the diversion of some of the concentrate traffic to a market-oriented smelter on the New South Wales coast. In fact about eight per cent of the total production of lead concentrates and twenty per cent of zinc concentrates are railed to a small-scale smelter at Newcastle. Although its small scale precludes active competition with Port Pirie for the domestic lead market, the plant is well located to serve domestic markets for low-grade zinc. A mine-site location for the other large lead smelter at Mount Isa was chosen because of weight-loss in processing and a relatively poor transport connection to the outlet port at the time of establishment. (Since all bullion is exported, there has been no competition with Port Pirie for a share of the domestic market.)

The electrolytic zinc smelter at Risdon is an example of the simple comparative cost advantage of the chosen site at the time of establishment given the high electricity requirements, and the low cost of power from the Tasmanian hydro-electricity scheme.
6.3 The Strength of Locational Forces in Resource Creation

As a conclusion to this empirical Part, an overall framework can be constructed for the analysis of government spatial influence, which occupies the remainder of the study. The determinants of the locational patterns will be principal determinants of the effectiveness of particular policies, and governments must contend with 'non-optimal' choices related to the corporate structure of large firms. The linear programming analysis has provided some measurement of these factors and exposes some apparently non-economic choices for the case-study, the aluminium industry. Although often neglected in this cost-biased analysis, demand factors provide overall control to all resource development and plant location patterns. Because of the small size of the domestic market, many mineral deposits can be developed only for export, while overseas sales are critical to the achievement of scale economies in first- and second-stage processing. The competitive position of plants serving domestic markets often depends on the quantities exported. Where regional costs preclude the export of metal ingot, plants often become dependent on protection against lower-priced imports.

Geological differences between the metal ores partly explain the different spatial patterns of mining, the choice of extraction technology and the scale of operations. While deposits of bauxite, copper, and lead-zinc ores have been developed simultaneously with processing plants, much of the increase in iron ore production since 1960 has been for export in unprocessed form. Under a theoretical least-cost solution, the total Australian iron ore output of 50,000,000 tons in 1970 would be produced from four or five large mines (with low marginal costs) based on very large deposits of high-grade haematite, switching towards lower-grade ores, and pelletization, only as depletion advanced and mines faced increasing costs. This solution is encouraged by economies of scale in bulk transport. The spatial pattern of resource creation would be determined
by the distance of suitable deposits from tidewater and the relative capital costs of establishment. Regardless of grade or location, small deposits would not be developed. Yet, in fact, twelve iron mines currently operate in Australia, two of them based on low-grade deposits; this has resulted from a well-established pattern of captive ore transfer to the domestic blast furnace, and the addition of new companies competing for long-term contracts for export of ores and pellets to Japan.

High production co-efficients for the crude ore input produce very simple location patterns for much first-stage mineral processing, and Weberian theory has strong empirical status for concentrating, and for the processing of relatively low-value commodities such as bauxite and iron ore. Yet extending classical theory to the minimization of total costs increases its explanatory power still further. A large scale of operations is critical for plants producing alumina and iron pellets; regardless of production co-efficients the absolute requirements of power, water, and labour are high and least-cost locations become those which offer comparative production advantages, especially in the provision of utilities and in lower capital requirements. Ports of trans-shipment have become common locations for mineral processing although, in the case of the Gladstone alumina refinery, since most of the plant's external relationships involved sea transport, a technically suitable tidewater site, 1,500 sea-miles distant, was a profitable location.

The location of domestic metal markets, heavily concentrated in southeastern Australia, has had a significant influence on the location of second-stage mineral processing, especially in the steel and aluminium industries. Apart from the overall influence of markets, four principal factors have conditioned the spatial pattern of metallurgy. First, historical circumstances and subsequent geographical inertia have been important, especially in the production
of copper, lead, and zinc. Second, metal ingot from all types of second-stage processing industry has relatively poor transportability compared with ores and concentrates. Forces for market-orientation are strong for producers selling a majority of their output to local fabricators. Other things being equal, producers of metal for export would be best located on tidewater. Third, the scale of operations is very important in the profitable production of metals; large-scale smelters still operate successfully at considerable distances inland while small plants have seldom survived unless located near the markets or producing for long-term export contract. Fourth, production co-efficients for variable inputs are higher than in first-stage processing, especially for labour (which partly determines infrastructural expense). In addition, capital requirements per unit of output are large and remote locations are generally less safe as investment propositions than those nearer to final markets.

Institutional factors, particularly the corporate structure of industries, are vital in an understanding of location and the aluminium industry provides an example. With multi-plant metal-producing corporations operating under conditions of monopoly and oligopoly, there is little economic pressure to encourage the development of the least total-cost solutions. Industrial structure in the aluminium industry accounts for most of the deviation between actual and optimal patterns. With the prevalence of captive transfer of metal ingot to semi-fabricators, and the existence of a protected market, the three existing smelters make similar domestic sales regardless of plant location; this is definitely not a least-cost solution for the economy. Thus, the smelters of Comalco Ltd and Alcan Australia Ltd are supplied from the Weipa-Gladstone development with which the two companies are associated. Alcoa of Australia Ltd supplies its Point Henry smelter from its Jarrahdale-Kwinana project which, in the optimal solution, is developed only for alumina export. Given the
increasing importance of metal exports, it is reasonable to assume that the companies for competitive reasons attempt to minimize costs for their own operations. In all cases, however, the group economics are strongly influenced by the profitable export of alumina*, with additional exports of bauxite by Comalco Ltd. Second-stage processing is thus supported by cross-subsidization within each corporation, and by captive transfer of ingot arising from integration forwards into semi-fabrication and metal manufacturing. The evolution of system-optimal spatial arrangements is unlikely under these conditions.

Yet despite the existence of such an economic structure, and the importance of geographical inertia in spatial patterns, there are relatively few examples of non-economic locational choice in the Australian metalliferous industries. There is at least some economic rationale for the choice of both Whyalla and Kwinana as sites for blast furnace capacity. Alcoa of Australia Ltd has chosen the classic transport-optimal arrangement for its own processing plants while Comalco Ltd, in supplying a smelter well-located by its previous owners, chose an arrangement determined by regional production cost variation and the high transportability of its basic raw material. Yet in terms of classical theory, there is no adequate explanation for the continued existence of a refinery at Bell Bay, and in the selection of Kurri Kurri as the site for a smelter. The linear programming analysis illustrated the apparent

* Alcan Australia Ltd and Comalco Ltd share in the output of Queensland Alumina Pty Ltd. It is significant that export markets have been obtained by Alcoa of Australia Ltd for the Jarrahdale-Kwinana development. This reflects both captive international transfers, and the standardization of the product by first-stage processing. There are no 'grades' of alumina and, hence, successful marketing can be achieved by a plant processing low-grade and even relatively high-cost bauxite if the supporting mine is nearby.
disadvantages of location at Kurri Kurri, but the plant has been incurring 'tooling-up' losses. Firm conclusions about this plant location decision cannot be made until present uncertainties about future ingot markets have been resolved.
PART THREE

THE SPATIAL INFLUENCE OF GOVERNMENTS ON RESOURCE DEVELOPMENT AND PLANT LOCATION

Governments in Australia play an important part in the resource extraction process outlined in Part II, and much of their influence has been implicit in the analytical analyses of feasible production units, and optimal location. As indicated in Chapter 3, government spatial influence can involve direct governmental decision-making, direct controlling on the behavior of private entrepreneurs, and indirect influence on locations through the use of various fiscal and resource development and plant location incentives. An adequate understanding of economic theory and policy development is the importance of government in practice to the wide variety of populations and policy involved, but also indicates that in practice governments that government influence to change and such influence change in reality (Sellers, 1971, p. 41).

The models approach employed in Chapters 2 and 3 illustrated the importance of transportability for the optimization of 'optimal' location parameters with an economy as a whole, and the importance of considering transport into the empirical survey methodology and the basic locational factors. The addition of government policies as a result of the matched resources and processing models further highlighted the many roles in the infracture as an area for future development, and the location of activities. Chapter 2 also noted that the roles (states in which electricity is not available to the extent for industries in general), which was discussed in this present chapter.
CHAPTER 7: GOVERNMENT POLICY AND THE METALLIFEROUS MINERAL INDUSTRIES

Hang care, the parish is bound to save us
(Dorothy George, 1953, p. 28)

Governments in Australia play an important part in the resource creation process outlined in Part II, and much of their influence has been implicit in the earlier analyses of demand, production costs, and optimal location. As indicated in Chapter 1, government spatial influence can involve direct locational decision-making, direct constraints on the behaviour of private entrepreneurs, and indirect influences on location through the main parameters shaping resource development and plant location patterns. An adequate understanding of resource creation requires some measurement of the importance of governments, partly because of the wide variety of regulations and policy involved, but also because 'it is sometimes imagined that government influence is stronger and more relevant than it really is' (Linge, 1971, p. 47).

The models approach employed in Chapter 6 illustrated the importance of transportability in the determination of 'optimal' location patterns, both for the economy as a whole, and for individual, vertically-integrated companies; the empirical survey established the strength of the basic locational forces. For the aluminium industry, the results of the matched comparison test (based on the linear programming models) raise important questions about government roles in the continuation of alumina refining at Bell Bay, the entry of a third integrated producer in 1969, and the location of smelters in Victoria and New South Wales (States in which electricity is not provided at low cost for industries in general). These problems will be considered in this present chapter.
Yet the measurement of government influence is difficult within the framework provided by location theory. Industrial structure causes the survival of spatial patterns which may not be system-optimal, but best for the company concerned. A State-owned enterprise would probably seek to maximize a 'social' objective function in its decision-making (such as the removal of endemic regional unemployment), and location would not be predicted by least-cost theory. Direct government regulation of the spatial behaviour of others could distort the evolving location pattern and, setting aside inadequacies of the programming techniques, long-run non-optimal locations indicated by matched comparison testing would be explained by a combination of industrial structure, 'social' decision-making, and direct government regulation. Indirect influences of governments, including those unforeseen or unintentional, could change the values of the resource creation parameters and be incorporated into the derivation of least-cost patterns. Measurement using location models would require precise knowledge of all parameters having 'artificial' values as a result of public policy, and would be a very difficult task, not only because of the wide range of policy involved, but also because direct concessions for specific industries are generally highly confidential.

A first step towards the understanding of government spatial influence is to identify the more important government activities of each type, and to interpret the patterns of resource creation in the light of these policies. This is attempted following a review of the role of Australian governments and mineral policy (section 7.1). The Commonwealth Government is considered in section 7.2 and State governments in section 7.3. The importance of policy is reviewed in section 7.4.
7.1 Mineral Policy and the Role of Governments in Australia

Interactions between government and private sectors in a so-called 'free market economy', such as Australia, are shaped by individual political structures, the political philosophies of successive governing parties*, the prevailing macro-economic climate, and the character of the industries under consideration. The metalliferous mineral industries are the subject of public policy because of their strategic importance, but also because the resources they exploit are non-renewable and private decision-makers might not include 'conservation' motives in their cost-benefit calculus**. Societies have developed a variety of ways to maximize their return from the private exploitation of non-renewable resources, usually involving some form of taxation. This becomes particularly important when metalliferous ores are extracted for export rather than to support local processing industries.

In the market economies, direct government involvement is usually acceptable during times of national emergency, and for defence purposes, in the operation of public utilities, and in State-owned enterprises competing on equal terms in the market with private firms. (This is

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* Commonwealth Government policy since the Second World War has been shaped by the political philosophy of the Liberal-Country Party Coalition which held office continuously from December 1949 to December 1972. This chapter cannot consider the platforms of policies of the Australian Labor Party which now forms the Government; nor can it postulate spatial implications of likely changes in mineral policy.

** The argument for this type of government involvement is analogous to that concerning externalities of private decisions. Governments may seek to minimize the social costs of private locational decisions (such as noise pollution near a residential area), or maximize the social benefits of others (such as employment diversification in country towns).
common in sectors of the Australian transport industry.) Although there has been little direct government involvement in the Australian metalliferous mineral industry, it is common in many non-socialist countries; in Western Europe, national governments have often secured major shareholdings in fuel and metal corporations. Outright nationalization is much less common. State-owned enterprises rarely locate to minimize total costs or maximize profits, and plants can survive in unprofitable locations to fulfil policy objectives. Yet large, multi-plant corporations often maintain similarly unprofitable operations, by cross-subsidization within their group, to achieve particular corporate goals. Both governments and large firms exert 'institutional' influences on location patterns.

Australia's federal structure conditions national and regional economic policy, and the division of powers between the Commonwealth and State governments is controlled by the Commonwealth of Australia Constitution Act, 1900. The administration of 'lands' is vested in the State governments; such resources had been controlled by the independent colonies during the nineteenth century, and none would have willingly surrendered these powers. The Commonwealth Government is given little jurisdiction over land, except in relation to the Northern Territory and the Australian Capital Territory. Control over public utilities, including power stations and railways, is also vested in the States. The regulation of resource utilization is a State responsibility as are land-use conflicts and pollution problems. The limited role of the central government regarding resources is common in federations. According to Richards (1965, p. 205), Provincial boundaries in Canada have presented 'formidable barriers to the achievement of rational federal participation in resource planning'.

The Commonwealth Government has power over Australia's external relations including defence, foreign trade, customs and excise, and regulates all public borrowing; it
has *de facto* control over income tax. In addition, the Government can assume wide powers during wartime, and for defence purposes. While the centralization of tax collection has given the Commonwealth considerable strength in bargaining with the States, its spheres of influence are strictly constrained by the Constitution and unilateral action outside these fields can be challenged before the High Court. Apart from re-distribution of revenues from income tax, the Commonwealth can make grants to individual States for specific purposes, or enter joint agreements for specific regional projects*. Yet, defence powers aside, the spatial role of the Commonwealth Government remains quite restricted; while policies can be applied to specific industries, they cannot be used to influence particular locations**. Much of the Commonwealth influence on resource development and plant location is incidental or accidental.

The mining and processing of metalliferous minerals concern the Commonwealth Government principally because of their importance in defence capability, national economic growth, and foreign exchange earnings (determined by export prices), and in determining the volume and nature of capital inflow. Most spatial problems fall under the jurisdiction of State governments, and strategic implications, capital inflow, and export prices are likely to be less important.

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* The Snowy Mountains Hydro-electricity Act, 1949 instituted the large power scheme which was a joint venture between the Commonwealth and the governments of New South Wales and Victoria. The Commonwealth took the leading role by invoking its defence powers but, constitutionally, the grounds for its participation were weak until enabling legislation was passed in the three parliaments in 1958.

** Section 99 of the Constitution reads: 'the Commonwealth shall not, by any law or regulation of trade, commerce, or revenue, give preference to any one State or any part thereof over another State or any part thereof'.
in their policy-making than direct revenues from mining royalties and freight, employment opportunities, private capital investment in infrastructure, and the location of new processing plants*.

Apart from the administration of all mining under State regulations, much mineral policy before the Second World War was concerned with gold mining, although the iron and steel industry was assisted, first through the payment of bounties, and ultimately by tariff protection. Commonwealth involvement increased considerably during wartime and, for strategic reasons, self-sufficiency in metalliferous minerals became a primary aim of mineral policy. Government involvement has differed between minerals; there have been few direct attempts to control the copper, lead, and zinc industries although influence is exerted by the collection of income tax and royalty, and by the structure of freight rates on public railways. The recent mineral boom involving aluminium and iron among the study metals, and the entry of new firms with overseas affiliation, has increased interactions between governments and mining companies; the location of processing plants has become an important issue. A new pressure group, the Australian Mining Industry Council, has been formed and the channels of communication have been broadened by the formation of bodies such as the Aluminium Development Council.

Butterfield (1971, p. 255) has presented one view of the role of governments in Australia: 'initiative invariably comes from private industry with government following its accepted role of providing infrastructure, advising on location, and assisting the development as much

* Processing establishments provide greater employment opportunities than large, capital-intensive mines, as shown in Chapter 3, and are likely to play an important part in State regional development strategies.
as possible'. The achievement of structured national policy, whether concerned with regional development or the mineral industries in general, seems difficult under such a (reactive) role. Not only are there considerable differences between States, but between types of economic activity: governments have provided little infrastructure for large mineral export ventures developed since 1960 (examined in Chapter 5). Yet Livingstone (1972, p. 198) has claimed that 'a substantial body of mineral policy has been built up, particularly since World War II'. This survey concentrates on the spatial manifestations of this 'body of policy' and attempts to evaluate the influence of governments on resource creation.

7.2 The Role of the Commonwealth Government

The Commonwealth Government influences both mining and domestic processing industries; while a multi-national corporation seeking to mine metalliferous ores in Australia would negotiate directly with a State government, its choices, and the possible outcomes of negotiations, would be constrained by national policies, especially in relation to trade and taxation. This section examines the Commonwealth as a direct spatial decision-maker (sub-section 7.2.1), and considers the role of policy in constraining the behaviour of private spatial decision-makers (sub-section 7.2.2). Other influences are considered briefly in sub-section 7.2.3.

7.2.1 The Commonwealth Government as a direct spatial decision-maker

In the case of the aluminium industry the Commonwealth has acted as a locational decision-maker in its own right, the only example of such direct involvement in the Australian metalliferous mineral industries. During the Second World War, the Commonwealth Government decided to establish a local aluminium smelting industry for defence
purposes and in 1944, an Aluminium Production Commission was empowered 'in order to promote naval, military and air defence of the Commonwealth and its territories, to do all such acts and things necessary for the production of ingot aluminium'*. It is significant that this could be effected only under defence powers. An agreement was reached with the Tasmanian Government, which was able to guarantee the reticulation of sufficient electricity, at a suitable cost, to the proposed smelter. The two governments became equal partners in the Commission, and each undertook to provide $3,000,000 towards the capital cost of the smelter; the Tasmanian Government began the construction of the Trevallyn hydro-electricity scheme in the Tamar Valley near Launceston. The selection of Bell Bay as the site for this plant has been considered in Chapter 6; it suffices to say here that negotiations were protracted and the defence motive had become irrelevant by the time construction began. The initial plant capacities of 30,000 tons of alumina and 12,000 tons of ingot per annum were barely economic even in 1950. By 1952 it had become imperative for the Commonwealth to provide additional finance for the project (the cost of which had far exceeded $6,000,000) and it took a majority shareholding in the Australian Aluminium Production Commission. Production of ingot did not begin until September 1955. The total Commonwealth investment at Bell Bay was $19,400,000 but it must be borne in mind that the Tasmanian Government had invested $20,000,000 in power supply and regional infrastructure.

Under protection against imports the publicly-owned smelter supplied only two-fifths of the Australian demand for aluminium and was not operated profitably. For metal to be produced at a reasonable price, annual plant capacity had to be increased to at least 25,000 tons and the

Commonwealth was unwilling to finance such a major expansion. In the late 1950s, therefore, it began negotiations with Consolidated Zinc Corporation Ltd which had signed an agreement with the Queensland Government in 1957 to develop the Weipa bauxite deposit and was committed to establish an alumina refinery. The Commonwealth Government seized the opportunity to stimulate a fully-integrated domestic aluminium corporation and, without calling for tenders, sold its interest in the Bell Bay smelter to the company in 1960*. The operation of a State-owned enterprise had not been successful, but the two governments had played a critical role in the development of the Australian aluminium industry. Bell Bay proved to be a good location for a smelter, but there seems little doubt that the adjacent alumina refinery, although the plant has been fully depreciated, remains in production largely because the Tasmanian Government retains a shareholding. The refinery at Gladstone, presently the source of more than half of Bell Bay's alumina requirements, could supply the entire input at no extra cost, and total costs would be lower if the employment of a larger bulk carrier were facilitated between Gladstone and Bell Bay.

7.2.2 Commonwealth influence on private decision-making
(a) The development of mining

The Commonwealth Government has power to control Australia's foreign trade; it may seek to maximize the foreign exchange gains from overseas sales of mine products, to force a politically-desirable degree of

* The Commonwealth sold the smelter for $21,800,000 (Spooner, 1960A). Under the original offer by Consolidated Zinc Corporation Ltd, the Tasmanian Government was to be given a one-third equity in a new operating company. This was accepted on the condition that the State would have to invest no more than $6,000,000. The Government's share in Comalco Aluminium (Bell Bay) Ltd has fallen steadily and is now only 17.4 per cent.
mineral processing, to encourage the conservation of non-renewable resources, or to fulfil strategic objectives (such as the control of uranium sales). The most publicized example of such control is the embargo on iron ore exports which operated from 1938 to 1960, discouraged exploration for new deposits, and certainly retarded potential economic growth in Western Australia; the effects of the policy were unintentional and, presumably, undesirable. With the advantage of hindsight it could be argued that this embargo was ill-founded; nonetheless, an examination of its operation indicates the potential influence wielded by the Commonwealth through its export powers.

Before the embargo was imposed on 1 July 1938 Australia exported small quantities of iron ore (for example, 168,000 tons in 1937-38 were shipped with Japan and the United States each taking about half). The Broken Hill Proprietary Co. Ltd had adequate high-grade ore deposits in the Middleback Ranges, and there was little incentive for this company to carry out further exploration, especially after the securing of a lease over the Yampi Sound deposit in 1935. The testing time came in 1935 when the Western Australian Government, anxious to promote regional development based on known ore deposits, sought Commonwealth approval of a project by the Nippon Mining Company of Japan to export annually about 1,000,000 tons of ore from other leases in Yampi Sound. The Commonwealth raised no objections in principle but, within two years, expressed doubts about the long-term adequacy of Australia's iron ore deposits and, in the interests of the domestic steel industry, ordered a full investigation of reserves. The Commonwealth Geological Adviser submitted an interim report to Cabinet in 1938 and the full report was tabled in the Commonwealth Parliament in 1940 (Woolnough, 1940). On the basis of the former report, the Cabinet imposed a complete embargo on the export of iron ore from Australia. Woolnough assessed the deposits already considered to be 'resources' but gave scant attention to
other known deposits; thus, he estimated that the local steel industry could be supplied from indigenous sources for less than a century so that Australia would become an importer of high-grade ores in less than a generation unless resources were conserved (Raggatt, 1968, p. 106). The rationale for the embargo was, at least publicly, conservational with the Commonwealth Government arguing that it was essential to retain the Yampi Sound deposits for domestic use. With the information available this argument was sound enough but, in fact, Woolnough's projections were extremely pessimistic. The opposition to the embargo stemmed almost exclusively from Western Australia whose Premier claimed that the export of iron ore would stimulate regional development and the State would gain $1,000,000 in revenue and twice as much in wages (Willcock, 1938, p. 448).

Whether Woolnough's pessimistic report was the sole basis for the export embargo can be queried. Strategic considerations also probably played an important part because the presence of a Japanese company at Yampi Sound would have been embarassing in the event of a Pacific War: indeed, Blainey (1968, p. 471) has argued that anti-Japanese feeling was extremely important. Whatever the grounds for the decision, the embargo lasted more than twenty years, long after any strategic motives had been relevant.

It is easy now to criticize Woolnough's report: yet, even allowing for the paucity of knowledge (and a lack of capital, staff, and time to improve this knowledge), the report makes strange reading. To delay the development of the high-grade haematites in Yampi Sound by prohibiting exports was a short-run solution and only superficially conservational. Woolnough had neglected the process of resource creation; the total embargo ensured that The Broken Hill Proprietary Co. Ltd was in a monopsony position with respect to iron ore and that there would be no
incentive to outlay capital in the assessment of known deposits. In 1938 Australia's iron ore resources were large given the small local demand (by an industrial monopolist) and uncertain export opportunities. There was little or nothing to attract more capital into iron ore development. Woolnough's report dealt with physical entities alone and neglected the factors identified in this study as determining the resource process: no consideration was given to technological improvements and how they can influence the size of a country's resource base. In 1938 almost every mining field in Australia was extracting ores not considered as resources fifty years earlier. Thus, Commonwealth policy on iron ore had a negative influence on Australian resource development principally because of an apparent failure to understand the components of the resource development process. As Blainey (1968, p. 475) remarks, the tone of Woolnough's report was not categorical and he can scarcely be held responsible for its becoming dogma for the next two decades.

The partial lifting of the embargo in 1960 was a response to national economic and regional political pressures. In his statement to Commonwealth Parliament, the then Minister for National Development justified the long retention of the embargo on grounds that it had been 'conservational' (Spooner, 1960B). In 1959 a Bureau of Mineral Resources, Geology and Geophysics report showed that total reserves had risen by 110,000,000 tons despite the extraction of 50,000,000 tons since 1940. The new guarded optimism was based on exploration guided by the Bureau, principally in Queensland and Northern Territory; on the negotiations between the Western Australian Government and The Broken Hill Proprietary Co. Ltd to develop the Koolyanobbing deposits; and on the grounds that the Savage River deposits in Tasmania now seemed 'larger' than was estimated in 1938. The Minister's estimates (Spooner, 1960B, p. 1966) scarcely justify such a policy reversal. Apart from strategic considerations, the arguments for the
embargo would have been stronger in 1960 than in 1938. The 'reserves' would have lasted for a shorter time than those of Woolnough's report because of the large growth in demand by the steel industry. In effect, the iron ore resource base was smaller when the embargo was lifted than when it was imposed.

The Minister argued that because reserves seemed higher it was now possible for the Commonwealth 'to provide a stimulus to the discovery of new deposits and more detailed investigation of known deposits' (Spooner, 1960B, p. 1966). The Commonwealth policy was still conservational since export from Middleback Range, Yampi Sound, and Koolyanobbing was prohibited; export from other deposits was limited to 1,000,000 tons a year provided the total exports did not exceed half of the proven reserves of direct shipping ore. Special consideration was to be given to requests to export more than 1,000,000 tons 'having regard to the size and location of the deposit' (Spooner, 1960B, p. 1967).

The reasons for the relaxation of the long-standing embargo are difficult to discern. Latent political pressure existed for a policy change and reports of the Bureau of Mineral Resources, Geology and Geophysics were certainly influential, but the then current economic conditions, including both the 'credit squeeze' and balance of payments difficulties, must also be considered. Despite restrictions implicit in the new policy, the partial lifting of the embargo, together with some important State government policy changes, led to the investigation of ore mineralization in various locations and, in particular, to the release in 1962 of information about the huge deposits in the Pilbara Region. It was generally realized that the new export policy would prevent mining companies from exploiting economies of scale so that it was further liberalized in June 1963 (before any shipments had begun). Under the revised policy exports from the three deposits
already listed were still prohibited*, but virtually no restrictions applied elsewhere although the Commonwealth Government reserved the right to scrutinize export prices, which were to be 'reasonable', and to determine the effect of any request on Australian development. All applicants for iron ore export licences were expected to state their plans for secondary processing and, presumably, these might influence the Minister's willingness to grant them.

Thus, the Commonwealth's iron ore policy was marked by conservatism; 'incentive policies' resulted from successful resource creation processes rather than initiating them. The twenty-year export embargo illustrated problems inherent in using absolute controls to stimulate conservation of non-renewable resources in economies where massive exploration campaigns cannot be carried out by the government. The prohibition of exports postponed regional development in Western Australia and Tasmania but, more important, retarded the increase in knowledge about iron ore deposits, and placed an artificial constraint on the size of the resource base -- the very asset that the Commonwealth was ostensibly trying to conserve. An assessment of the costs and benefits to the nation of the rapid increase in exports of iron ore since 1966 is outside the scope of this study; rather, the example illustrates unintentional effects on resource creation of this Commonwealth policy.

The Commonwealth Government retained the power to inspect iron ore contract prices, a matter of potential conflict with State policies because of different primary goals. With its responsibility for the balance of payments and the volume of capital inflow, the Commonwealth seeks in the 'national interest' to secure the highest possible export price for iron ore; in contrast, State governments,

* The Broken Hill Proprietary Co. Ltd, however, has exported ore from Koolan Island, in Yampi Sound, since 1964.
anxious to ensure that their mineral deposits are exploited and to maximize regional development benefits and royalties, may be prepared to accept much lower prices. The inevitable decline in export prices, considered in Sub-section 2.3.1, prompted the issue of 'export price guidelines' late in 1965. Controversy developed over the second major contract negotiated by Hamersley Iron Pty Ltd for the export of iron ore pellets: the Commonwealth rejected the f.o.b. prices and, therefore, the contract -- probably the first time since Federation (1 January 1901) that it had directly curtailed an export contract under anything less than defence powers. Hamersley Iron Pty Ltd announced that it might be unable to locate the proposed pellet plant at Dampier and the Western Australian Government again charged the Commonwealth with retarding the State's development: relations between the two governments became strained. Maximization of export revenue was not, in this instance, compatible with the maximization of regional development.

Despite the influences of f.o.b. prices on the balance of payments, a more logical strategy for the Commonwealth might have been to consider c.i.f. prices as guidelines since these determine the competitiveness of various Australian ore deposits on the Japanese market. An unintentional result of using a minimum f.o.b. guideline is that such prices eventually become the basis on which future contracts are negotiated; the writing of long-term contracts in terms of f.o.b. prices ensures that any reductions in transport costs per ton benefit the purchasing country rather than the source.

The Commonwealth aroused much controversy because it did not adopt a consistent policy towards acceptable f.o.b. prices: it took location and developmental difficulty into consideration and was prepared to lower f.o.b. prices for the slow-starting operation at Mount Newman and for pellets produced from Savage River ores. The Minister for National Development claimed that the Savage River project should be
given special encouragement because it was based on low grades, and because it was the only deposit on which a future Tasmanian iron and steel industry could be based*. Yet, with lower marginal costs than other producers, Hamersley Iron Pty Ltd could afford to accept lower contract prices, achieving sufficient economies of scale to make a pellet plant at Dampier viable. The policy of the Western Australian Government was clear; the more contracts initially secured for the State's ore (despite falling prices), the sooner the chance would arise of establishing secondary processing facilities and, eventually, an integrated iron and steel works. After three months of heated debate the Commonwealth achieved a qualified victory when Hamersley Iron Pty Ltd's contract was re-negotiated. The Commonwealth Government had demonstrated its power to intervene in raw material export and in the resource development process: by being sympathetic about 'special problems', the Commonwealth could potentially influence the spatial distribution of feasible resource projects.

Yet although Australia's political stability, the size and quality of deposits, and proximity to the Japanese market had given the Government a degree of bargaining power, much depends on the structure of marketing and the activities of competing suppliers. In 1967 the price guideline policy was abandoned. To a limited extent, it had stabilized contract prices and controlled price competition between mining companies; but it was argued that in the face of competitive development of ore deposits in South America, West and South Africa, over-stringent price control would lead to loss of export income, and the Commonwealth once more found itself in a dilemma over its export policies.

The Commonwealth has paid little attention to export

prices for bauxite, while most alumina is transferred overseas under captive arrangements. The Government has been concerned periodically with overseas trade in copper, lead, and zinc. Although their world price has fluctuated considerably there have been few price stabilization or support schemes; the mineral industry has been less important to governments, in this regard, than the rural industries. However, copper scrap exports were banned in 1966 when a wide disparity between internal and world prices caused a rapid rise in shipments and a domestic shortage of copper. In effect, payments under the **Copper Bounty Act, 1958-1966** were made (when prices were low) to ensure the survival of communities based on the marginal producers at Mount Morgan and Mount Lyell -- Mount Isa Mines Ltd did not receive any benefit under this scheme. Finally, the Commonwealth Government is involved in some international agreements concerning metal minerals, such as the International Tin Agreement and the International Lead-Zinc Study Group*.

The Commonwealth Government has influenced the mineral industries through its income tax Acts. Taxation provisions relating to mining have not developed as a distinct body of policy and many of the current provisions relate to historical circumstances. Although various concessions are allowed, their locational influence has been minor, and it is doubtful whether they have determined the feasibility of developing any important metalliferous ore deposit. Taxation concessions usually take the form of exempting certain portions of income for tax, allowing various expenses as spatial deductions, and allowing rapid (or additional) depreciation of the value of plant and equipment. Such concessions could be given to encourage investment in exploration and mining (high-risk ventures) of both local and overseas capital. **The Income**

Tax Assessment Act, 1936 was amended in 1942 to allow tax exemption of one-fifth of the net assessable income derived from mining asbestos, bauxite, radio-active ores, rutile and zircon, and ores of copper, nickel, and tin*. Iron, lead, and zinc were omitted; this was a wartime measure designed to encourage the production of minerals in which Australia was then deficient and, in addition, the Government was unwilling to grant concessions that would benefit mining companies working rich ores at Broken Hill. This tax concession was formalized in 1960, but no account was apparently taken of the marked changes since the Second World War. Since 1947, exploration expenses have been allowed as deductions.

Infrastructural investment at mines and mine towns- ships has been granted special (rapid) depreciation allowances since the Second World War, although company-owned railways and port facilities are not included**. The magnitude of private capital investment in ports and railways has been determined in Chapter 5; it seems anomalous that community facilities at mines should receive special treatment and yet similar facilities at outlet ports should not. Recently, sections of the mineral industries have argued that special taxation concessions are justifiable for establishments located in remote areas and forced to bear high infrastructural costs. This is a debatable issue since, if profitable operation were not possible, mining would not have been developed at such locations. The claim must rest, therefore, on external

* This concession is a de facto depletion allowance; mining companies have long argued that special taxation provisions are justifiable to compensate them for resource depletion.

** In 1968 the High Court had ruled that ports and railways should be included as 'mine development expenses', but this decision was reversed following an appeal by the Commonwealth Commissioner of Taxation (Livingstone, 1972, p. 218).
economies and regional development benefits flowing from infrastructure provided by the companies. The analysis in Chapter 5 suggests that, at present, this claim may be weak. Very generous depreciation allowances for infrastructure would be necessary if it became policy to alter the selection criteria for suitable mineral deposits (as outlined in Chapter 6), and to encourage the development of smaller deposits situated a considerable distance from the coast.

(b) The location of processing

The Commonwealth Government's power to influence processing location is strictly limited. Assistance to processing and manufacturing industries generally has no spatial component, although income tax provisions can have an indirect influence on locational decision-making (Will, 1964; Williams, 1967). The Commonwealth could attempt to encourage domestic processing of metalliferous ores by allowing special taxation concessions for first- and second-stage plants; spatial influences could be exerted if special rates of depreciation were allowed for plants located at a mine or its outlet port. Yet while the Government has often claimed that encouragement of processing before export is a component of its mineral policy, such plants are given no special status for income tax assessment. Indeed, since 1968 plant and equipment for processing at or near a mine has not been permitted special depreciation as a 'mine development expense'. It was suggested in Chapter 5 that infrastructure costs are much heavier for firms processing at mines or outlet ports; yet special provisions are not allowed for port developments. It is unlikely that taxation concessions alone would give rise to further processing of mineral ores, but it is surprising that the Commonwealth Government has made no attempts to give encouragement by this means.

The Commonwealth's principal direct influence over decision-making about mineral processing emanates from its
control over imports and tariff policy. Import protection has some interesting spatial side effects. The locational decisions relating to the establishment of Australia's second and third smelters at Point Henry and Kurri Kurri can be understood only in terms of the 'umbrella-effect' of protection against imports by quantitative restriction on the sale of the State-owned smelter to Comalco Ltd in 1960. The new company had sought protection for the first four years of its operation, after which it would be requested in 'abnormal circumstances'. Duties on ingot provided little or no protection against imports (free British Preferential Tariff and 12.5 per cent ad valorem Most Favoured Nation), but an extension of the system of import licensing which had been adopted in 1955 ensured that only sufficient aluminium was imported to make up the difference between total domestic production and domestic demand. In 1962, ingot produced by Comalco Ltd had satisfied only one-third of the total domestic demand so that the domestic sale of ingot produced by Alcoa of Australia Ltd in 1963 was guaranteed and imports were eliminated the following year. The site selection for the smelter of Alcoa of Australia Ltd was considered in Chapter 6; the company was able to overcome short-run comparative cost disadvantages relative to Bell Bay, and the system of protection not only permitted the entry of the second smelter, but also (indirectly) influenced the feasibility of location in Victoria.

Quantitative import restrictions ended early in 1965 but the smelting companies immediately applied for the continuation of protection. This was to prevent the large semi-fabricator, Alcan Australia Ltd, importing ingot at low prices from its Canadian parent rather than purchasing metal from its two domestic competitors. The Tariff Board recommended the extension of quantitative restrictions until the end of 1971 to forestall such captive transfers (Australian Tariff Board, 1967, p. 18); this type of protection was the only way to effectively eliminate
imports since marginal cost pricing would allow captively-transferred ingot to absorb tariffs of up to seventy per cent ad valorem (Morgan, 1965, pp. VIII-4). The Commonwealth's decision to retain quantitative import restrictions made it necessary for Alcan Australia Ltd to establish the third smelter at Kurri Kurri in 1969. With the protected domestic market now shared between three integrated producers, all companies have concentrated on securing export sales to avoid considerable excess capacity.

7.2.3 Other Commonwealth Government influences

Aside from defence powers and control over foreign trade, the scope of Commonwealth influence on mineral development has been strictly circumscribed by the Constitution: in effect, its role has been passive and governments have not yet adopted the function of co-ordinator for Australia's diverse mineral policies. The establishment of the Bureau of Mineral Resources, Geology and Geophysics during the 1940s was an important step and systematic geological mapping and research has assisted in giving private exploration some spatial logic. This organization's reports have not only had a signal influence on government policy, but the Bureau itself has been involved in a number of significant discoveries of metaliferous minerals, notably bauxite in the Northern Territory and iron ore elsewhere.

Yet the remaining influences of the Commonwealth in metal resource creation processes have consisted of individual instances either under defence powers, or in special financial agreements with State governments. For example, during the Second World War the Commonwealth Government sought to revive the copper industry which had collapsed during the 1920s and 1930s. In 1942 it requested Mount Isa Mines Ltd to cease mining lead-zinc ores and to commence working the nearby copper lode (discovered in 1930) for the production of blister copper (aided by the loan of $100,000 from the Commonwealth towards the cost of a
Several special financial agreements have been entered with State governments (designed to facilitate mineral processing), for example, the Commonwealth provided seventy per cent of the capital cost of the standard gauge railway from Kalgoorlie to Perth which was expanded to connect the mine at Koolyanobbing and the blast furnace site at Kwinana, and in a joint venture with the Queensland Government, the line between Mount Isa and Townsville was upgraded (Mathews, 1967, pp. 99-100).

7.3 The Role of State Governments

State governments in Australia exert the most pervasive influence on the location of mining and processing. While the involvement of the Tasmanian Government in the Australian Aluminium Production Commission remains the only example of a direct public decision-making role, the States control the conditions under which private decisions in mining and processing can be made (considered in sub-section 7.3.1), and exert indirect influence over spatial patterns by affecting mining and processing costs at various locations (considered in sub-section 7.3.2).

Apart from the collection of revenue from the metalliferous mining industries, State governments have long been concerned to maximize regional development benefits and this has often involved attempts both to encourage the establishment of processing activities within their bailiwicks, and to influence the final site selection for such plants. Industrial location patterns in Australia as a whole can frequently be understood only in terms of the existence of six (competing) sovereign States.

7.3.1 State government influences on private decision-making

(a) Mining legislation

An assessment of the precise influence of mining legislation on the resource development process is
difficult. This legislation, administered by the various Mines Departments, prescribes the conditions, which differ between the States, under which the search for minerals must be carried out, and governs the pegging of claims and the rights to mine*. There have been few major problems in the dealings between the mining industry and the various Mines Departments. Yet this has depended largely on the existence of a 'gentleman's agreement' principle under which a mining company undertaking feasibility studies on temporary reserves would expect the granting of a mining lease to be virtually automatic. There is no co-ordinated policy between States on the granting of leases, and large sections of mining law have become out of date in relation to the heavy expenditures involved in modern exploration, and regarding growing public concern for environmental protection. Mining companies are entitled to security of their investments and this should be based on unambiguous legislation rather than precedents**. Yet wider societal goals should also be incorporated and mining legislation should aim to minimize potential land-use conflicts (for example, between recreation and the mining of mineral sands). State governments can influence the spatial distribution of mining by refusing to allow rights in certain areas.

An example will illustrate the importance of mining legislation as a framework for the resource creation process. The Western Australian Government had been moderately active in searching for iron ore within that State, but took a pessimistic view about the possibility of further discoveries and appeared to misunderstand the nature of private exploration and exploitation. Its policy had been to secure the maximum regional development benefit for

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* Information on Australian mining legislation and the differences between States is given by Lloyd (1966).

** This is the view of the Australian Mining Industry Council, pers. comm., Canberra, September 1970.
Western Australia (Blainey, 1968, p. 476), and before 1961 all iron ore deposits were reserved to the Crown and could not be pegged by individuals or companies. It seems that the Western Australian Government desired to retain control of the iron ore to attract industrial development since its ownership of the deposits enabled bargains to be made with potential users.

Although this policy enabled the Western Australian Government to ensure that part of The Broken Hill Proprietary Co. Ltd's iron and steel capacity was located in the State, it inhibited iron ore mining and stifled private exploration. It was not only the Commonwealth export policy, therefore, which retarded the discovery of iron ore in Western Australia. Lang Hancock (who became one of the leading entrepreneurs in the development of the Pilbara resources) discovered iron ore in the Hamersley Ranges in the early 1950s: he claimed in 1961 (quoted in Raggatt, 1968, p. 114) that

after making several trips [by air], I finally found a place to land in 1953. I took samples, made quantity estimates, and realized that this was a major discovery... Nothing could be done with it in view of the State Government blanket over all iron ore in Western Australia.

Hancock did not even report the discovery -- it was not politic to search for iron ore in that State. The lifting of the export embargo by the Commonwealth in 1960 apparently stimulated the State Government to change its leasing policy. A few months later, early in 1961, the Premier announced that tenders would be called for the development of known deposits not covered by lease agreements, and invited companies to apply for iron ore exploration permits (and temporary mining titles). This case study shows how, on occasion, changes in both Commonwealth and State policies allow the process of resource development to commence.
(b) Special Mineral Agreements

Since 1960 the development of deposits of bauxite and iron ore has been the subject of Special Mineral Agreements which simply add to the diversity of mining legislation. State governments have used these devices to impose obligations on prospective firms, especially where the minerals are not to be supplied to local second-stage processing, but exported as ores or processed materials. In return, the companies receive security of tenure and, often, a number of concessions. Direct government influence on resource development and plant location appears to be at its greatest through such Agreements which provide an overall framework for the development of the deposits, prescribe a timetable for their exploitation, stipulate minimum levels of investment, establish rents for leased areas, specify royalties to be paid to the State, and sometimes place conditions on the disposal of the mined product. The most important aspects of these Agreements, however, are the provisions relating to first- and second-stage processing, and the establishment of the principle that mining companies in remote locations are responsible for their own infrastructure.

Bauxite mining in Australia has been established under various Mineral Agreements but all regarded alumina refining as the principal concern; indeed, those signed in Western Australia are known as 'Alumina Refinery Agreement Acts' and bauxite is mentioned only if it is to be exported to provide a rapid cash flow to help finance the processing plant. All firms, then, intended to establish alumina refineries largely for export and the participation of Comalco Ltd in the Gladstone refining consortium was regarded as discharging its processing 'obligation'. Considerable assistance in the provision of infrastructure was provided for developments at Weipa, Jarrahdale, and Kwinana but most remained private responsibilities. Although all governments concerned have required the companies to investigate the feasibility of smelting within
the State, the agreements have recognized that this form of processing is dependent on the availability of large quantities of low-cost electricity. Some have guaranteed the companies first options should such power become available in the State concerned, but even the timing of the feasibility studies has become flexible and there is little the State governments could do if the firms involved submitted unfavourable reports.

The majority of Special Mineral Agreements signed since 1960 involve iron ore; there have been four basic types of agreement. The first includes the high-grade deposits of less than 10,000,000 tons at Koolanooka, Frances Creek, and Mount Bundey, but the leases have exerted little influence over the (small-scale) mining developments and no processing obligations were incurred. The second type relates to lower-grade ore deposits which could not be developed as direct export mining ventures and thus require first-stage processing such as pelletization. Thus, the agreement over the Robe River project recognizes that limonite is unsaleable as direct shipping ore and that a pellet plant was the principal concern of the operating company. Apart from making the firm responsible for its own infrastructure, no other promises were extracted. The Tasmanian Government placed no obligations on the developers of the Savage River iron ore leases.

In marked contrast are the agreements of the third type which apply to the large high-grade haematite deposits at Goldsworthy, Tom Price, Paraburdoo, and Newman in the Pilbara Region. Developments were divided into three 'phases': during the first phase the companies were obliged to spend $1,000,000 on detailed feasibility studies while the second phase required the construction of mines and all necessary infrastructure. Thus, Goldsworthy Mining Ltd, in developing the smallest of the deposits, was bound to spend $40,000,000 on mining and facilities, and Hamersley Iron Pty Ltd and the Mount Newman Consortium were
bound to invest $60,000,000 each. It was shown in Table 5.2 that these companies have invested much more than these prescribed minima principally because of infrastructure costs. The third phase, to commence after iron ore had been exported for about ten years, involved the location of processing plants within the State.

The simplest obligations involved the smallest of the three producers; Goldsworthy Mining Ltd is required to commence the beneficiation of ores after ten years have elapsed from the commencement of ore exports and, after twenty years, should submit proposals for the manufacture of metallized agglomerate. The larger mining companies incurred similar obligations involving both first- and second-stage processing. The announced policy was to 'turn Western Australia into an international steel-makers' warehouse' exporting crude steel, metallized agglomerates, ore pellets, and various forms of raw ore*. Conflicts between State and national 'optimal' locations for such processing plants are possible:

to have an individual State laying down development conditions from its own viewpoint can work against the overall national interest. The government of Western Australia, for example, has imposed developmental conditions which pre-suppose three or more steel industries in [that State] (Hibberd, 1968, p. 29).

Yet it has proved difficult to extract definite second-stage processing obligations and the aim of turning Western Australia into an exporter of steel ingot is a long-term possibility rather than a definite commitment. Although the contractual obligations on processing ore are detailed in precise schedules, the escape clauses are numerous and the powers of the government are more apparent than real.

Most success has been achieved with simple forms of first-stage processing such as pelletization, largely because there are often sound economic reasons for the establishment of such plants. For example, Hamersley Iron Pty Ltd constructed a pelletizing plant at Dampier, after only four years, in fulfilment of its 'third phase' obligations. For such a large producer of direct shipping ore, pelletization is a convenient means of producing an exportable commodity from the fines, generated by crushing and handling activities. Fines can be exported for use in blast furnaces with coke as a sinter, but are of relatively low value and do not bear the cost of transport as well as lump ore. By establishing a pellet plant, therefore, Hamersley Iron Pty Ltd not only satisfied its processing obligations but, at the same time, is able to produce from fines a processed material for which there is a stronger market demand. A similar obligation has been placed on the Mount Newman Consortium although plans have not yet been announced. The extension of the leases of Hamersley Iron Pty Ltd to include the large Paraburdoo deposit was accompanied by additional processing obligations involving the manufacture of metallized agglomerate whenever technically and economically feasible. While this obligation has encouraged the company to carry out detailed feasibility studies with this processed material, serious marketing problems have caused postponement of the venture.

Both Hamersley Iron Pty Ltd and the Mount Newman Consortium are required to present feasibility studies on the production of steel within twenty years from the commencement of mining. Yet, if Hamersley Iron Pty Ltd, for example, finds that steel production in Western Australia is uneconomic, the Government can do very little except call tenders for the establishment of such a plant and compel the company to supply a successful tenderer with raw material. The possibility of there being active independent tenderers seems remote. In short, the State Government can ensure the preparation of feasibility
studies on steel-making and, while this may be regarded as an important achievement in itself, it should be given no more significance than it deserves.

Agreements of the fourth type involve The Broken Hill Proprietary Co. Ltd and offer some interesting comparisons since they have influenced the geography of the Australian iron and steel industry considerably. In the mid-1930s the South Australian Government advised this company that the leases over its principal raw material source might not be renewed unless it undertook to establish a blast furnace in the State. At this time the Middleback Range was Australia's only known high-grade iron ore resource and The Broken Hill Proprietary Co. Ltd had little option but to sign an agreement and build a blast furnace at Whyalla (although its subsequent development has been shaped by other factors). In the second instance, the Western Australian Government offered (1952) to extend this company's Yampi Sound leases in return for the establishment of a steel rolling mill in the State. In 1960 The Broken Hill Proprietary Co. Ltd agreed to develop deposits at Koolyanobbing thought to be the largest in the continent; access to those leases was again used to oblige the company to locate a blast furnace, and ultimately an integrated iron and steel works, in Western Australia. No formal mining obligations were imposed and the agreement was not binding on the company until the standard gauge railway linking Koolyanobbing and Kwinana was completed. The Broken Hill Proprietary Co. Ltd undertook to use rail transport for at least thirty years, and the State Government promised that it would provide a complete transport service at concessional rates, and various other kinds of assistance such as the provision of housing at Kwinana and the mine site. It was relatively easy, therefore, for governments to influence this company's spatial behaviour since it was anxious to secure long-term supplies of ore. Most of the processing obligations were secured before the development of the very large resources of the Pilbara Region.
In summary, then, the policy of the Western Australian Government before 1960 was to offer considerable assistance to The Broken Hill Proprietary Co. Ltd's mining activities in return for the establishment of a local iron and steel industry (which may not have been optimal for the economy as a whole). The proposed export developments after 1960 brought about a change of policy with the Government apparently anxious to garner the maximum number of projects in the State. Simultaneously, the Government sought to discourage the processing of Western Australian ores in other States: all contracts imposed a penalty of one dollar per ton on Western Australian ores (except those mined by The Broken Hill Proprietary Co. Ltd) off-loaded elsewhere in the Commonwealth*. This provision, included in all iron ore agreements signed in Western Australia since 1960, hardly follows the spirit of Section 92 of the Commonwealth Constitution**. During the 1960s, the Western Australian Government preferred to deal with large corporations (Court, 1963, p. 1418). Since the highest return on capital was obtainable from the direct shipping of high-grade ores, firmly-established and profitable export mining companies would provide a sound basis for future secondary industry. Yet an implicit assumption in the Government's policy was that, since the iron mining corporations would earn very high short-run profits, the greatest possible regional benefit should be extracted in the form of transport facilities, ports, and townships in isolated locations. Although the State was attempting to ensure the establishment of mineral processing plants, the high private infrastructure costs are a strong disincentive for such developments.

* Excluded from this levy was any ore used by a company within Australia provided the tonnage processed did not exceed half the total quantity of ore processed by that company in any year within Western Australia.

** Section 92 of the Commonwealth Constitution reads, in part, 'intercourse among the States, whether by means of internal carriage or ocean navigation, shall be absolutely free'.
7.3.2 State government influences on mining and processing costs

(a) Royalties

Royalties levied by the States differ widely in their nature and historical background; they vary between States and between minerals within a single State. Indeed, it could be argued that royalties have been based on a notion of 'what-the-resource-can-bear'. Rates are based on profit, the f.o.b. value of production, or units of output (such as a ton of bauxite), and, as a variable cost of production (Sub-section 3.2.1) they play an important role in resource creation and can have distinct spatial implications. The only other form of economic activity to pay this form of taxation is sawmilling, and mining royalties remain a principal source of State revenues. (The Commonwealth levies royalties on mining companies in the Northern Territory.) Rates are published in the mining laws of each State but, in practice, the governments retain the right to negotiate special charges for individual projects; these are set out in Mineral Agreements and reviewed on each renewal of the lease.

Queensland and Tasmania appear to charge relatively low royalties while New South Wales, Western Australia, and the Commonwealth have adopted some high rates for specific purposes. Bauxite mining at Weipa is charged five cents per ton on domestically processed ore (about half of annual output) and ten cents on exports, yielding a total contribution of four per cent of total unit production costs (Table 3.5). In Western Australia bauxite was charged 7.5 cents per ton if processed in that State and ten cents per ton if processed elsewhere. In 1970, this system was modified and royalties are now levied on the output of alumina rather than bauxite, at twenty-five cents per ton; this forms a negligible fraction of the unit production costs of alumina. At Gove, the Commonwealth Government has used royalties for the purpose of compensating local aborigines for the mining of tribal lands and the
mining company must pay twenty cents per ton for bauxite processed locally and thirty cents per ton on exported ore.

Iron ore mining companies in Western Australia pay royalties based on value of sales, units of output, or the type of ore exported. Direct shipping ore (with an iron content greater than sixty per cent) is charged 7.5 per cent of the f.o.b. value of sales although the rate is not allowed to fall below sixty cents per ton which, even for large-scale mining companies, still represents a considerable impost*, and comprises more than one-tenth of the total cost of ore (at the outlet port) for the Mount Newman Consortium (Table 3.6). The existence of a maximum royalty discriminates against sales to Europe and North America rather than Japan since sixty cents is often greater than 7.5 per cent of the f.o.b. value realized from such sales. On fine ore, which is less valuable, the rate is 3.75 per cent f.o.b. value with a minimum of thirty cents per ton; fines, if exported, are charged fifteen cents per ton. Simultaneously, secondary processing is encouraged since iron ore concentrated or used in the production of pellets or metallized agglomerated in the State is charged only the base rate of fifteen cents per ton although most pellets, at present, are made from high-grade fines which carry the same royalty if exported. Different royalty scales were introduced for companies manufacturing pellets from low-grade ores: north of the twenty-sixth parallel of latitude the rate is only ten cents per ton for the first fifteen years and the basic rate of fifteen cents will not be charged until the twenty-sixth year of production. This is an incentive to produce pellets from low-grade ores and to locate the plant in the North-West. Thus, the Western Australian Government has used the royalty system principally to extract a considerable amount of revenue from export mining companies, but also in an attempt to encourage first-stage processing.

* For a company exporting 15,000,000 tons of high-grade ore a year the total royalty is at least $9,000,000.
Companies mining lead and zinc at Broken Hill in New South Wales pay royalties based on a graduated scale related to gross profit; under such a system, the greatest absolute burden falls on the most profitable producers and some of the rates levied on the Broken Hill companies seem to have been based on highly profitable operations of these firms before the Second World War. Until the 1960s each lease renewal was accompanied by increased royalty rates so that 'with no ceiling on the royalty charges, payments to the New South Wales Mines Department reached a level of 96 per cent of the upper brackets of mine revenue in excess of operating expenditure' (Raggat, 1968, p. 170). In 1965 a ceiling of fifty per cent was introduced but this still represented a heavy burden on the mining companies operating at Broken Hill, which will become dependent on the mining of low-grade ores within the next two decades. The royalty levy thus performs an important role in resource creation and can place an artificial restraint on the size of the resource base and on the potential life of a company's mines: it may also affect the spatial distribution of workable mineral deposits. Rates levied per ton of output can cause higher (more profitable) grades to be worked out first and the earlier abandonment of mining. Royalties based on profits allow marginal mines to survive longer than they might under rates per ton and do not act as a major disincentive to the use of lower-grade ores. High rates of royalty on any system, however, reduce incentive to undertake major re-organizations of mining such as a switch to mass-mining of low-grade material.

(b) Freight policies

State governments have often used freight policies on public railways as another means of raising revenue from mining, especially where they hold a monopoly over the movement of mineral commodities (for example, from an isolated mine to an outlet port). The effect of high freight rates on mining is similar to that of royalties levied per ton of output, and they can influence both the
feasibility of particular deposits and the life of mining. Lead-zinc miners at Broken Hill have persistently urged the South Australian Government to charge a freight rate for the haul from Broken Hill to Port Pirie based on cost rather than on the principle of 'what-the-traffic-will-bear'. The rate charged for concentrates ($7.70 per ton in 1966) has been very high and bears no relation to operating costs*. The base rate was established in 1937 and a cost variation was instituted to cover wage increases. In 1949, with the rate at $2.82 per ton, a freight variation was introduced based on changes in the cost of New South Wales coal used by the South Australian Railways. This was deleted on the introduction of diesel locomotives and a new base-rate of $6.60 per ton substituted. A rebate system was introduced based on the volume carried to deter companies from using road transport. The ton-mile freight rate for lead and zinc concentrates in South Australia (3.1 cents) is more than twice that charged in New South Wales, and nearly twice the rate for export coal in Queensland. Consequently, the Broken Hill mining companies have often threatened to divert a larger proportion of the concentrate traffic through the New South Wales system to the east coast. A more important result of these high transport costs is that the development of low-grade ores has been retarded.

(c) State governments and regional cost variation

There is an almost bewildering range of ways in which the States can cause regional cost variation and thus influence the location of mineral processing plants. Most of these plants are, at least by Australian standards, of a very large scale, occupy extensive sites (including land on

* The companies at Broken Hill have estimated that the cost of carrying concentrates on the Cockburn to Port Pirie line in 1966 was $3.26 per ton; the rate charged was $7.70 per ton. Even adding various levies for public works, the cost was only $3.47 per ton (North Broken Hill Ltd, pers. comm., August 1969).
which to dispose of effluent), and consume considerable amounts of fuel, electric power, and water. The location of smelting in the Australian aluminium industry provides a good example of the potential influence of governments in shaping location patterns by manipulation of regional costs.

Although electricity costs during the 1960s were lower in southeastern Australia than in Western Australia or Queensland, only the Tasmanian Hydro-electricity Commission could offer rates acceptable for the commercial production of ingot. The location of smelters outside Tasmania thus depended on the installation of efficient company-owned power stations linked to the plant, or on location close to a 'super' thermal power station, with a generation capacity greater than 1,000,000 kilowatts, offering rates similar to those from a hydro-scheme, or on semi-permanent concessional rates for power provided from the State grids. Both the Victorian and New South Wales Governments entered very generous, and strictly confidential, agreements with Alcoa of Australia Ltd and Alcan Australia Ltd over the provision of electricity, and the magnitude of concessions was suggested in Sub-section 3.2.3; offers of power at less than 0.6 cents per kilowatt-hour (close to the average cost of generation) must be the most generous arrangements ever reached with private firms in those States. Without such concessions, the smelters at Point Henry and Kurri Kurri could not have been established.

Low-cost power from the State grid was essential until Alcoa of Australia Ltd could afford to complete its own power station on its brown coal deposit at Angelsea. The smelter of Alcan Australia Ltd requires concessions for a longer period, and the analysis of Chapter 6 suggested that the plant is still at a locational disadvantage at its present scale of operations. The two State governments were prepared to offer the substantial concessions to encourage the location of smelters in their territories.
and, with the subsidies, these plants are well located to serve the principal Australian metal-markets. The New South Wales Government was also anxious to diversify employment opportunities on the South Maitland coalfield.

Recent announcements about the siting of future power stations could strongly influence the location of future mineral processing. In April 1970 the Commonwealth promised to help the Queensland Government establish a thermal power station of 1,100,000 kilowatt capacity of which 600,000 will be reserved for 'special industrial purposes' which must be approved by the Commonwealth. Two major industrial plants have been suggested by the Queensland Government (Department of National Development, 1969): a caustic soda plant could sell some of its output to the adjacent refinery, while the Government has frequently intimated its belief than an aluminium smelter will eventually be constructed at Gladstone. It has been suggested in Chapter 6 that, if the cost of generating power at the new station were favourable, Gladstone would be a good location should a fourth smelter be located in Australia to serve overseas markets. In this case, the construction of the large public utility rather than concessional rates would have exerted an important influence on plant location.

7.4 Government and Resource Creation in Australia

A simple inventory of policies relating to the metalliferous mineral industries reveals a large number of possible ways in which governments can delimit the areas of choice of private decision-makers, or attempt to modify the parameters of the resource creation process. Yet the importance of policy is severely constrained by the broad location factors discovered in Part II and, it appears, by conflicts between governments and even between the policies of an individual government. Although it has been contended that the resurgence of the Australian mineral
industry since 1960 has been a product of post-war mineral policy (Livingstone, 1972, p. 208), this view is not supported by the evidence given in this chapter. The timing of the boom was certainly influenced by overall controls, especially those exerted by the Commonwealth, but was largely conditioned by Australia's political stability, proximity to the fast-growing Japanese market and, it is tempting to assert, the non-policy on overseas capital inflow. Some of the more tangible government policies have resulted from the boom itself.

Attempts by either Commonwealth or State governments to directly influence the mining and processing of copper, lead, and zinc, have been relatively minor compared with recent concern over aluminium and iron. The role of the Commonwealth Government in constraining private decision-makers has broadly controlled the resource creation process, especially its powers over foreign trade. Import protection has been critical to the development of the aluminium industry but the spatial results of the Commonwealth policies have usually been incidental and some entirely unforseen.

The most important result of State mineral agreements has related to the provision of infrastructure; this not only determines the character of entrants into the industry, but also controls their selection of feasible deposits. Such costs discourage the location in remote areas of processing plants, generally expected to be raw material-oriented. The policy on infrastructure has been a way of extracting benefit to the economy from the export projects, rather than a positive step to encourage regional development. If use of the infrastructure by other activities remains low, and presently there is no facility for public takeover, the benefits are restricted to the multiplier effects of the investments. As yet there has been no study of such effects, but most of them probably accrue to State capital cities.
It would be optimistic to argue that private investments in the Pilbara Region will, in the short-run, be a force for decentralization in Western Australia. The Special Mineral Agreements have ensured the expenditure of large amounts on infrastructure but the additional population supported is less than that of a medium-sized Australian town. From a social viewpoint, it is possible that the duplication of infrastructure, with little public co-ordination, has involved a misallocation of resources. It is not feasible to equate the potential of the new Pilbara ports with that of Newcastle or Port Kembla during the 1930s since economic and geographic circumstances are sharply different.

The strongest locational influence has been exerted where the government can act indirectly through regional production costs. The ability of governments to exert such influence is controlled by the production co-efficients for the various factor inputs. The importance of the State government role in the aluminium industry has been determined by the unusually high co-efficient for electric power provided by public utilities. In two cases, direct subsidy has been a necessary condition for the establishment of smelters in otherwise feasible (market-oriented) locations. Few mineral processing industries could be influenced in this way. The provision of low-cost power would certainly encourage both alumina refining and steel-making but would not act as a determinant of location. In the majority of circumstances, the real influence of government in Australia remains indirect; a desirable pattern of location can be positively encouraged by the provision of necessary infrastructure, including community facilities, and the guaranteed supply of adequate utilities.

In the final analysis, the establishment of further mineral processing establishments in Australia, as a consolidation of present resource creation processes, will
be controlled by the size of the Australian market and, hence, by the ability of new plants to export the majority of their output at competitive prices. Most of the successful attempts by governments to 'enforce' processing through Mineral Agreements have involved first-stage plants, and there have usually been strong economic reasons for their establishment. The location of additional plants in Australia will be controlled by the factors identified in this study, and the actual spatial influence of governments would be strongest through the manipulation of these factors. Up to the present time, there have been no integrated State policies on mineral processing, and there is no co-ordinated plan for Commonwealth involvement except by special financial agreements for specific projects initiated by the States.
All one can do is to understand them better, to keep up with them; so that as the other changes you can understand the change as soon as it happens, though you could not have predicted it (T.S. Eliot, 1954, p. 67)

Resource development and plant location decisions in the Australian metalliferous mineral industries are commonly interrelated in space, and it seems useful to postulate the existence of 'resource creation' processes which have spatial ramifications. This thesis began with a review of normative, least-cost location theory which, as indicated in Part II, still has considerable explanatory power if applied to basic resources and their processing industries. The development of the resource creation notions, and their formal incorporation into the theory, could not be attempted in Chapter 1 since it requires a separate investigation that would include the collection of data on other resource industries. It is submitted that powers of geographical analysis are increased by considering resources in terms of a process beginning with resource-evaluation and culminating in the supply of a usable product to more advanced sectors of the economy. Such a framework emphasizes the essential interactions between extractive 'industries' and processing and, potentially, allows a more penetrating analysis of decision-making about resources. In this concluding statement, the empirical survey of the metalliferous minerals is reviewed (section 8.1), the influence of institutions considered (section 8.2), and the measurement of resource creation processes evaluated (section 8.3).
8.1 Processes of Resource Development and Plant Location

While it is convenient to establish the resource creation model in terms of a closed economy, the real world is complicated by the two systems of demand parameters identified in Chapter 2: interactions between the systems are important spatially because scale of operations partly determines location as has been demonstrated in Chapters 1 and 6. More weight has been given in this study to the domestic processes, and exports have been regarded almost as leakages from the local resource system. The relationship between Australian exporters of ore and overseas processing industries depends on international comparative advantage, world shipping conditions and, frequently, the activities of governments in other countries. These factors were outside the scope of this study and, as a result, the question of maximizing the domestic processing of ores before export could be considered only in the most general way.

The Australian aluminium industry provided the best vehicle for a study of domestic resource development and plant location largely because of the fully-protected local market for ingot, and the existence of vertically-integrated producers carrying out exploration, mining, and processing. Such a system was more difficult to identify for the lead and zinc industries, for example, because of Australia's well-established role as a world supplier of these metals. The iron and steel industry was an ideal case-study before 1960 but only a small proportion of the current output of iron ore is processed locally despite continued growth of domestic steel production.

The three domestic producers of aluminium ingot developed different spatial arrangements for their group operations. The location patterns for Comalco Ltd (based on Weipa bauxite) and Alcoa of Australia Ltd (based on Jarrahdale) minimize the total costs of producing ingot for each company. Alcan Australia Ltd carries out no mining or
independent refining, and the location in 1969 of its smelter was strongly influenced by both Commonwealth and State government policy; its location can be described as 'eccentric'. It is not surprising, therefore, that the overall spatial pattern fails to minimize costs for the economy as a whole. The least-cost solution, generated from the theoretical model, suggested that Weipa and Gladstone should supply the entire domestic smelting industry which is concentrated in southeastern Australia; in practice, Jarrahdale and Kwinana are equally important because of industrial structure, and the entry of the second smelter in 1963, facilitated by import protection, changed the course of resource development in this industry. Alumina refineries, such as the one under construction at Gove, exporting their entire output are added to the pattern and are generally located at the tidewater port nearest to the source mine. Since alumina is a chemically pure product (there are no 'grades'), the quality of ore becomes less important than the total production cost of alumina, and the feasibility of bauxite developments cannot be separated from the economics of refining. The addition of resource development costs to the model allows a better analysis of subsequent plant location decisions; the bauxite deposits at Weipa, the Darling Ranges, and Gove have different characteristics only partially represented by the 'weight-loss in processing'.

Before 1960 the Australian iron and steel industry provided a good example of a resource creation system constrained by the size of the domestic market. High-grade ores were best transported to east coast ports near the coalfields and the development of additional deposits by The Broken Hill Proprietary Co. Ltd was influenced by the location of its steel-works; Yampi Sound could be brought into production (1952) but not the inland deposits of the Constance Range in Queensland. The company also secured the high-grade Koolyanobbing deposit (although the
leases were signed before the discoveries in the Pilbara Region) and The Broken Hill Proprietary Co. Ltd involvement in the Mount Newman Consortium, brought into production in 1969, seems to have considerably reduced the importance of the Koolyanobbing deposit. State control over iron leases in South Australia and Western Australia allowed the governments to influence the location of the company's blast furnace capacity, but this power has been weakened by the discoveries made during the 1960s.

The development of iron resources has been made complex by Australia's recent emergence as the major supplier of ore to Japan, and the discovery of enormous iron reserves has raised hopes, if no definite commitments, of future integrated steel-works in Western Australia or even Tasmania. It is significant, however, that preliminary studies of the feasibility of steel-making by the Armco Corporation of the United States (now discontinued) involved Jervis Bay, only fifty miles south of Port Kembla, and the haulage of ore from an unexploited deposit in the Pilbara Region. Much of the analysis of possible second-stage processing is pure conjecture; suffice it to say that first-stage processing plants have been established profitably, subject to the availability of sales contracts, and that future plants producing pellets of iron or metallized agglomerate are likely.

The detailed analysis in Part II of the parameters of these resource creation processes was hampered by lack of adequate data, and much research on industrial patterns in Australia is restricted by lack of information or its confidentiality. Firms in the metalliferous mineral industries are reluctant to release 'real' data and it has been necessary to use a standard prediction model so that estimates are at least consistent if not precise. This procedure yields orders of magnitude only, and much of the measurement of parameter values becomes intuitive. The model used in this study has almost certainly underestimated intangible costs such as overheads and extra
labour costs in isolated locations. Despite the serious shortcomings, it is submitted that the detailed estimates made in Chapter 3 allow spatial analysis to proceed; they permit production factors to be correctly weighted, a vital task because the regional variability of the most important factors controls the development of long-run spatial patterns of mining and processing.

The most important production factor in open-cut mining was found to be the level of capital investment and spatial variability in this factor was determined largely by infrastructural requirements. Economies of scale are very important in both mining and first-stage processing plants but raw materials at c.i.f. prices are dominant in the cost structures of processing. Hence the location of most of these plants is explained adequately by the least-cost theory as modified in Chapter 1. It was shown in Chapter 4 that 'transportability' was a more useful concept that either distance or freight rates, and that it varies not only between mineral commodities, but also between shipments of the same commodity in different volumes over a range of distances. The economies of bulk shipment lend a high degree of transportability to large-volume flows of iron ore and bauxite.

The costs of infrastructure were found to be important for processing industry (Chapter 5) because of the large quantities of power, water, and labour required by large-scale plants. Extra capital costs can discourage the choice of transport-optimal locations such as the mine-site for first-stage processing although location elsewhere is most likely when the ore is of high quality, produced at low cost, and transported in large quantities. The costs of infrastructure would be even higher for second-stage plants in remote areas especially where economies of scale are important to the competitive production of the metal. Given the advantages of shipping raw materials rather than ingot, market-orientation is most common for smelters serving the domestic market. The high co-efficients for electricity in
the production of aluminium and electrolytic zinc give strong comparative advantage to cheap power sources, as predicted by Weberian theory.

8.2 Institutional Influences on the Metalliferous Minerals

The resource creation process cannot be understood properly without knowledge of institutional factors such as industrial structure and government policy. Normative location theory does not deal adequately with vertical integration (let alone with multi-national corporations) since it assumes the long-run equilibrium state of a spatial system is optimal for the economy as a whole. The optimizing decisions for multi-plant firms are likely to produce quite different, but stable solutions and the maximization of total group profit or sales, or minimization of long-run group costs might be important goals. The analysis in Chapter 6 suggests that the least-cost theory, together with modifications to allow for industrial structure, explain much of the geography of the Australian aluminium industry, although government influences were important in the location of smelters.

Governments influence the milieu in which resource development and plant location decisions are made. The direct influence of governments on private decision-makers could be regarded as a distinct parameter of the resource creation process. The Commonwealth has acted through its control over defence, foreign trade, and income tax but its spatial role is constrained by the Constitution and much of its influence on location occurs as a side-effect. The State governments have shaped resource creation through the policies on mining leases and infrastructure but, with the notable exception considered earlier, have exerted only limited influence over the location of processing plants through their power over leases. Governments play a part in the resource creation process through many of its other parameters, but measurement of this type of influence
becomes very difficult and requires precise knowledge of the importance of these parameters and access to information that is often inaccessible. It is a mistake to suppose that government influence always, or even commonly, works in the direction of 'non-economic' locational choice, although these effects can be measured more readily: if governments can manipulate regional cost variation, they can influence the development of spatial patterns even when non-economic choices have been unimportant.

The examination of mineral policy in Chapter 7 showed the importance of State governments, and the potential for conflicts of interest in mineral policy. Given the nature of public financing in Australia, State governments have tended to view metalliferous mineral resources as generators of revenue and harbingers of future regional development. Little direct policy has developed concerning copper, lead, and zinc but the more 'strategic' minerals aluminium and iron have become important in State policies for industrial development through processing, and in Commonwealth policies concerning the balance of payments and the long-run growth of Gross National Product.

To date there has been no co-ordinated policy on the further processing of mineral exports. State governments have been accused of ambivalence by sections of the mineral industry which argue that maximizing the degree of processing is incompatible with the infrastructure requirements set out in the Special Mineral Agreements. It has been suggested in Chapter 7 that the provision of infrastructure by the mineral companies was seen as one of the principal ways of extracting community benefit from the development of the State's resources for export. Mineral companies argue that the costs of infrastructure discourage the location of processing plants in Australia. While further research is needed to resolve this problem, there are few concrete examples of infrastructure costs being the principal factor working against further processing, although these costs
do produce some important results.

One such example has been investigated in detail in this thesis; the plant refining bauxite from Weipa was located at Gladstone partly because of its cost advantages (over the mine site) resulting from the higher infrastructure costs incurred by large-scale processing. The extent of this cost disadvantage was calculated in Chapter 5. Yet the Queensland Government assisted in the provision of infrastructure at Weipa and many of the advantages possessed by Gladstone were based on superior site factors and the availability of water and power. As emphasised in this study, the high transportability of Weipa bauxite allowed the mining and refinery operations to be separated spatially. Other alumina refineries will be constructed in remote areas such as Gove and, eventually, Weipa itself, despite the costs of infrastructure.

Location factors as a whole, of which capital costs are only one, condition the location of plants processing metalliferous minerals. It is very doubtful whether lack of publicly-provided infrastructure in the Pilbara Region has been the principal reason why so large a proportion of iron ore mined is exported in its raw state. Mining companies have been able to earn reasonable returns on capital and would not have accepted the risks involved in locating in such a remote region unless they had believed this would be possible. The necessity for companies to provide their own infrastructure has exerted some very important spatial effects; it has influenced the choice of suitable deposits, determined the scale of operations, and shaped the financial structure of participating companies. First-stage processing plants are able to operate profitably at large scale if markets can be found for alumina and iron pellets. Assistance towards infrastructure costs remains a means by which governments could encourage the establishment of processing plants, but considerations of this kind would be much more complex involving the inter-
action between the whole range of market, production, and transport cost factors examined in Part II.

The importance of these resource development variables implies, further, that governments have limited power to force the location of processing plants in particular areas: most of the 'successes' in this regard have involved first-stage processing plants which might have been located in the same places even in the absence of contractual obligations, although the timing may have been influenced by the Special Mineral Agreements. The plans by Hamersley Iron Pty Ltd to establish a metallized agglomerate plant, to fulfil a long-term contractual obligation, have been postponed for various technological and marketing reasons.

The analysis in Chapter 7 provides only an identification of the spatial roles played by governments in relation to the metalliferous mineral industries in Australia. Such a study should be extended by developing more suitable measurements of government attempts to manipulate other parameters of the resource creation process. Yet a better understanding of the spatial influence of governments awaits a consideration of spatial policy goals, and the bargaining strength of Commonwealth and State governments against private spatial decision-makers including local entrepreneurs, foreign developers, and the buyers of mineral exports. (It was shown in Chapter 2 that collective action and bargaining strategy on the part of buyers can exert considerable influence on resource development patterns.) The effectiveness of governments, given the Constitutional constraints, would depend on industrial structure, world marketing arrangements, and the principal location factors identified in this study, and would therefore be different for each of the study minerals. The role of policy might be better understood in terms of such a process which would also provide insights into government power to influence the evolution of spatial
economic patterns such as those of the Australian metalliferous mineral industries.

8.3 The Measurement of Resource Creation as a Spatial Process

If indirect government spatial influences are likely to be very important, as argued in this thesis, quantitative analysis of their role in resource creation becomes difficult. For industries dominated by a few large firms, many of the better-developed multivariate techniques of spatial analysis are of limited application. The Australian metalliferous mineral industries are controlled by a relatively small number of decision-makers, and penetration of these corporate structures to allow an ex ante study of spatial decisions would be extremely difficult. As a first step the patterns can be analysed ex post within the framework provided by location theory, and the linear programming technique was employed in this thesis to formally structure the theory of Chapter 1, and to generate bench-marks against which to test actual locations. Programming analysis seems appropriate, despite its deficiencies, for investigating spatial patterns dominated by vertically-integrated firms.

Programming models could be used experimentally to test alternative spatial arrangements, and to measure the strength of location factors. This can be done by varying the cost matrices to determine how much change in the value of a particular parameter is necessary to produce modification of the least-cost pattern. Such models could also be used to investigate the effectiveness of various combinations of government policies designed to produce socially- or politically-desirable location patterns. Such potentially useful applications were not attempted in this study for three main reasons: first, patterns in the aluminium industry are dominated by industrial structure
and a simple input (electricity); second, data inadequacies mentioned previously would have made useful interpretation of the results a formidable task beyond the limited aims of this study; and third, there is only a small number of feasible sources that could be used in the problem matrices. Although the aluminium industry proved suitable for detailing the parameters of the resource creation process, some of the subtleties of resource development, plant location, and government spatial influence are difficult to explore in terms of the Australian aluminium industry.

The employment of resource creation as an analytical framework allows a more penetrating study of industries such as those concerned with the metalliferous minerals. Yet without improved techniques of measurement it is difficult to fully understand resource creation as a spatial process and much of the problem hinges on analysing institutional factors. Such understanding would improve the contribution made by geographers to current debate about resource issues, whether they concern economic growth, future resource adequacy, environmental problems, or land-use conflicts.
A wide range of sources has been consulted in the preparation of this glossary of chemical expressions important both to the arguments of Part II and to the estimation of production costs for mining and processing. Individual references are made only for direct quotation but acknowledgment is made here to the following basic sources: the Shorter Oxford Dictionary for chemical terms; United Nations (1956) for terms relating to the aluminum industry; Hassler (1957) for the technology of the lead and zinc industry; and Woodward (1962) for the technology of lead and zinc processing.

**Glossary**

**Alumina**: Anhydrous aluminum oxide (Al₂O₃). One technically pure ore of aluminum yielding from bauxite by the Bayer Process. Under present technology, it is the only alumina suitable for the commercially feasible production of aluminum metal.

**Bauxite**: The principal commercial ore of aluminum composed of hydrated aluminum oxide mixed with various impurities, mainly silica, iron oxides, and titania oxide. Bauxite usually forms as the result of leaching of tropical and sub-tropical sediments. The grade of bauxite is given as the proportion of soluble alumina. Failures in bauxite are common, with- and included.

**Bayer Process**: The most economical process for producing alumina from bauxite. The metallurgical process involves the digestion of ground bauxite, at elevated temperatures and pressures, in a solution of potassium salts. The suspended impurities and pressure conditions differ in the treatment of hard bauxite and bauxite. Alumina aluminas used in the Bayer process are mixed with hard alumina and basic coke which are lost in the red mud. The sodium aluminate solution is cooled and upper aluminate crystals are precipitated, washed, and calcined at almost 7,000 degrees Fahrenheit. The resulting product, an anhydrous yellow-white powder, is essentially pure alumina oxide. Calculable coke is the most important raw material input but can be re-cycled during the process. There is an approximate fifty percent weight loss in the evaporation of high-grade bauxite or low-sodium content.
GLOSSARY

A wide range of sources has been consulted in the preparation of this glossary of technical expressions important both to the argument of Part II and to the estimation of production costs for mining and processing. Individual references are made only for direct quotation but acknowledgement is made here to the following basic sources: the Shorter Oxford Dictionary for common usage; United Nations (1966) for terms relating to the aluminium industry; Manners (1971) for the technology of the iron and steel industry; and Woodward (1965) for the technologies of lead and zinc processing.

ALUMINA: Anhydrous aluminium oxide (Al₂O₃), the chemically pure ore of aluminium yielded from bauxite by the Bayer Process. Under present technology, it is the only input suitable for the commercially feasible production of aluminium metal.

BAUXITE: The principal commercial ore of aluminium composed of hydrated aluminium oxide mixed with various impurities, mainly silica, iron oxide, and titanium oxide. Bauxite usually forms as the result of laterization in tropical and sub-tropical climates. The grade of bauxite is given as the proportion of contained alumina. Bauxite is mined in two forms, monohydrate and trihydrate.

BAYER PROCESS: The most economic process for producing alumina from bauxite. The conventional process involves the digestion of ground bauxite, at elevated temperature and pressure, in a solution of caustic soda. The required temperature and pressure conditions differ in the treatment of monohydrate and trihydrate. Hydrous aluminium oxide is dissolved into sodium aluminate. After this digestion process, insoluble components are separated to form an effluent, 'red mud', which is produced in large quantities, is of no commercial value and creates disposal problems. Reactive silica contained in the bauxite combines with both alumina and caustic soda which are lost in the red mud. The sodium aluminate solution is cooled and hydrous alumina crystals are precipitated, washed, and calcined at about 1,200 degrees Centigrade. The resulting product, an anhydrous greyish-white powder, is chemically pure aluminium oxide. Caustic soda is the most important adjunct input but can be re-cycled during the process. There is an approximate fifty per cent weight-loss in the refining of high-grade bauxite of low silica content.
BENEFICIATION: Defined by the United States Bureau of Mines as 'any process used to increase the value of the ore after it is mined, but before it is smelted' (Earney, 1969, p. 513). This is a broad and not very useful definition, however, and includes simple washing, screening, and gravity separation techniques of reducing detritus and waste-products in mined ore, regarded in this thesis as an essential part of mining. It also includes activity classifiable as first-stage processing, that is, the production of concentrates by chemical means and pelletisation. It is questionable whether the production of alumina, an important first-stage process, can be regarded as the beneficiation of bauxite although it takes place after mining and before smelting. Alumina and bauxite are quite distinct and production of the former is an essential step in the extraction of aluminium metal from its ore. Bauxite is 'beneficiated' where necessary by washing and screening to reduce the proportion of silica prior to its refining.

BLAST FURNACE: A vertical steel cylinder lined with refractory materials and used for smelting ores of iron, copper, lead, and zinc. A 'charge' is fed into the top of the furnace, often in the form of a sinter, and hot air is blown through the bottom. Coke in the charge burns fiercely in the oxygen generating both heat and reducing-gas which moves up through the furnace. The gas and heat reduce the metalliferous ore to metal which, however, usually contains impurities and, therefore, some undesirable qualities. A fluxing material in the charge assists in the formation of a slag, from the majority of the waste-products, which floats on the molten metal and can be separated at the base of the furnace. Blast furnaces are used to produce pig iron, blister copper, and lead bullion. Zinc proved metallurgically difficult to produce by blast furnace methods until the development of the Imperial Smelting Process.

BLISTER COPPER: Unrefined copper produced in a blast furnace from copper concentrates. It contains small amounts of other metals which are usually removed by electrolytic refining.

BOEHMITE: A form of monohydrate bauxite found in Western Europe and, mixed with gibbsite, in tropical Australia, India, and the Caribbean.

BULK CARRIER: 'A bulk carrier may be defined as a single-deck cargo vessel suitable to carry efficiently and economically various kinds of dry cargo in bulk with widely different stowage factors varying from fifteen to fifty-five cubic feet per ton' (Bes, 1965, p. 7). Thus, 'shipments in bulk' are substantial consignments in which the commodity is stowed in a ship's hold in loose form, depending on its stowage factor, and not in drums, containers, or other packing.
C.I.F.: In this thesis c.i.f. refers to cost-insurance-freight and represents a total landed price delivered to the factory for a particular commodity. (See f.i.o. and f.o.b.)

CONCENTRATES: Mineral ores which, as a result of first-stage processing, have a higher proportion of contained metal than the naturally occurring mineral. Concentration of lead-zinc and copper ores is usually essential because of the low intrinsic metal content of mineralization occurring in commercial quantities. The chemical process flotation, for example, has been developed to produce lead and zinc concentrates from complex lead-zinc sulphide minerals. Very low-grade copper ores are concentrated by similar means; for example, at Mount Lyell raw ore with an average grade of about one per cent copper is concentrated into a product bearing twenty-seven per cent copper, (theoretically) involving a weight-loss of about twenty-six tons for each ton of concentrate produced. Waste materials are known as tailings.

CONSORTIUM: Defined, for the purposes of this study, as any joint venture between two or more companies in which an agreement is made that output (or sales revenue) of the venture will be distributed for disposal by the participants in accordance with their equity share-holding. Conversely, when loans are raised to finance plant expansions, participants agree to service the indebtedness in proportion to their output shares. Management of the venture is usually delegated either to a subsidiary of one of the members, or to an operating company (not necessarily owned in the same proportions as the consortium). Members pay all costs of the operating company (plus an agreed mark-up). Under this arrangement, start-up losses can be used as tax deductions by each participant on profits earned elsewhere.

CRYOLITE: A catalyst used in the smelting of aluminium metal by the Hall-Héroult Process. It is a double fluoride of sodium and aluminium (Na₃AlF₆) which melts at 1,000 degrees Centigrade. It is used because alumina, which itself has a very high melting point, dissolves in it and dissociates into ions of aluminium and oxygen. Cryolite, very rare in natural form, is now produced synthetically; it is a very expensive input but only small amounts are consumed per ton of metal produced.

DIRECT SHIPPING ORE: A term used principally in the iron mining industry to denote ore sold without prior first-stage processing, usually as lump ore of relatively high grade which can be fed directly into a blast furnace. In Australia, the term refers to haematite of greater than sixty per cent iron content.
ELECTROLYTIC REFINING: A form of second-stage processing in which an electric current is passed through a (molten) metalliferous mineral yielding a 'pure' metal at the cathode by a process of electrolysis. This process is used to extract certain metals from their ores but, in this thesis, this is included in smelting. Remaining is the use of electrolysis to increase the purity of a metal extracted from its ore by other means, the most common example being the refining of copper.

ELECTROLYTIC ZINC: Zinc metal of high purity extracted from zinc concentrates by electrolysis (see also electrolytic refining). The concentrates are roasted (yielding sulphuric acid as a by-product), and then leached in a weak sulphuric acid solution to form zinc sulphate in solution plus impurities. Consumption of exogenous fuel is very low in this continuing process since heat produced is largely self-sustaining. Impurities are separated by flocculation in 'thickening' tanks and the residue, containing small amounts of silver, lead, and zinc, is removed as slag. Zinc metal is obtained from the clarified zinc sulphate solution by electrolysis; the process is less elaborate than the Hall-Héroult Process for aluminium production and the consumption of electric power is lower.

FINES: Iron ore, defined in Western Australian Iron Mining Agreements as that which will pass through a screen of half inch mesh. Fines thus include undersized material and 'dust' produced in iron ore crushing plants and in the handling of lump ore either in transportation or at the blast furnace. Much of this material formerly accumulated as waste until the production of sinter, and pelletization, were developed as economic means of utilizing the fines for which no market existed.

F.I.O.: The quotation of a freight rate so that the c.i.f. price does not include the cost to the factory of placing the commodity in stockpile, nor of loading, although these costs are strictly part of the total transport cost. These expenses are very difficult to separate from plant operating costs. (See also f.o.b.)

FLOTATION: A form of first-stage processing of metalliferous ores in which concentrates are produced from raw mined output involving considerable weight-loss. Flotation is a common method of concentration in which various chemical reagents are added to crushed ore in water. Differential surface tensions attract particles with different chemical composition and as much 'waste' as possible can be floated off leaving a material which, when agglomerated, has a much higher metal content than the original ore. Flotation methods for the concentration of complex lead-zinc sulphides were developed (and patented) in Australia at Broken Hill between 1900 and 1930.
F.O.B.: The price of a commodity quoted by the supplier at the point where 'transport' begins. It does not include loading and stowing costs unless specified. In some cases, the f.o.b. price is taken as being that realized after the deduction of all transport and handling costs from the c.i.f. price. This is a very simple definition but is adequate for the purposes of this study. There are numerous legal definitions of f.o.b. price (see also f.i.o.).

GALVANIZING: Refers in this study to the coating of steel products with zinc metal to protect them against corrosion. The most common process involves the dipping of products in a bath of molten zinc, and lower-grade zinc produced by the Imperial Smelting Process can be used.

GIBBSITE: The trihydrate form of bauxite found in North and South America and in temperate Western Australia. It also occurs in mixtures with boehmite.

HAEMATITE: One of the principal commercially exploited iron ores consisting of grey-blue iron oxide which turns red on crushing. It contains various impurities such as phosphorus and aluminium oxide. It can be formed through prolonged weathering of magnetite and contains a theoretical maximum of seventy per cent iron.

HALL-HEROULT PROCESS: Developed in 1886, it is the only commercial process for the extraction of aluminium from its oxide, alumina. Since alumina has a very high melting point it is processed electrolytically. Alumina is dissolved in a cell containing molten cryolite, and the passage of large amounts of electricity through the cell causes aluminium to be deposited at the cathode in molten form. The principal adjunct inputs are carbon (in the form of pre-baked blocks for anodes), cryolite and other fluorides (catalysts), and large quantities of electricity. Cells are arranged in continuous series known as potlines, and space needs are large even for a modest plant. Despite experiments with the direct reduction of bauxite, the Hall-Héroult Process is unlikely to be seriously challenged in the foreseeable future. A weight-loss of half is involved in the electrolysis of the alumina.

IMPERIAL SMELTING PROCESS: A process patented in 1930 for the smelting of zinc-bearing materials by blast furnace techniques rather than by electrolysis. Zinc and lead concentrates can be charged simultaneously as a sinter with coke and slag-producing fluxes. Vapour containing metallic zinc given off in the furnace is condensed above the furnace into the metal while lead bullion is separated from the slag at the base of the furnace in the usual way. Zinc produced in the blast furnace contains 2.3 per cent impurities (principally lead), a much higher proportion than in electrolytic zinc, but the metal is adequate for many purposes including galvanizing. High-grade zinc can be produced from this metal by a (more costly) re-fluxing process.
INGOT: A cast into which molten metal is poured after smelting, usually of a standard shape and often as a small bar or billet. Ingot metal is the basic input of metal manufacturing industry and is regarded (when refined, if necessary) in this thesis as final output from the metalliferous mineral processing industries.

LEAD BULLION: Unrefined pig lead produced in a blast furnace. The furnace charge consists largely of a sinter containing two-thirds lead concentrates, about one-quarter crushed slag, and small amounts of iron ore (used as a flux), sand, and lime. Sulphurous gases produced during sintering are often used to produce sulphuric acid as a by-product. The blast furnace is then charged with the sinter, coke, lead, and iron scrap, and small amounts of slag. Metal is separated from the slag (which usually contains recoverable zinc) as bullion. In this form, the metal contains small amounts of arsenic, silver, gold, bismuth, and sulphur, but the main impurity is usually copper (up to one per cent). This is removed in a copper drossing furnace and other impurities in a refinery which utilizes heat, agitation, and rapid cooling, followed by leaching with caustic soda to produce chemically pure lead.

LIMONITE: A form of lower-grade hydrous iron ore often produced as a result of weathering and stream deposition of haematites. It contains an average of one-half iron and one-tenth water, the principal 'impurity'.

MAGNETITE: A commonly occurring magnetic iron ore which theoretically has the highest proportion of contained iron of any of the ores (seventy-two per cent). In practice, grades of magnetite are very variable (for example, thirty-eight per cent at Savage River).

METALLIZED AGGLOMERATE: Sometimes called 'sponge iron', metallized agglomerate is pre-reduced iron ore processed by means other than the traditional blast furnace. It commonly contains a very high proportion of metallic iron ('Himet', an experimental sponge iron produced in Australia is ninety-three per cent iron), and is designed for direct feeding into steel-making by the electric arc method. The blast furnace step is thus eliminated from steel production. As yet, the use of metallized agglomerate is not common and there have been marketing problems partly related to the competitiveness of steel scrap.

MINING: Despite the apparent familiarity of this term, it is important to bear in mind its correct definition. The Concise Oxford Dictionary defines it as 'the extraction of material from a "mine"' which is any excavation in the earth for minerals (that is, substances extracted for use as raw materials and rarely for their own sake). It is thus clearly distinguished from a quarry. Mining can be an underground operation, in which material is extracted from a system of subterranean passages connected to the surface by shafts (principally, but not necessarily,
vertical), or open-cut, in which material is won from a pit or other open excavation. Since ore extracted from a mine can seldom be sold exactly as mined, 'mining' also includes such essential activities as crushing and screening, and washing (very simple beneficiation). In practice, the dividing line between mining and first-stage processing sometimes becomes arbitrary, especially for beneficiation activities normally tied to the mine site for technological reasons.

MONOHYDRATE: One of two forms in which aluminium oxide is found in nature as a component of bauxite. The oxide is present as $\text{Al}_2\text{O}_3\cdot\text{H}_2\text{O}$ and bauxites containing it occur as boehmite and diaspor.

PELLETIZATION: A form of first-stage processing of iron ore. Pellets have proved to be an efficient charge for the blast furnace because of uniform size, chemical composition, physical strength, and high reducibility. Since pelletization is a convenient means of agglomerating concentrates of iron ore, pellets have a higher metal content than the mined ore and thus compete very strongly with all the very high grade direct shipping ore. Pelletization is also used instead of the production of sinter as a means of producing a saleable product from fines of direct shipping ore. The process involves a balling of fines of crushed concentrate under controlled conditions of motion and pressure, and then the kilning of the pellets at high temperature. The major inputs in this physical process are fuel oil and electricity.

PIG IRON: Metallic iron produced in a blast furnace. In the traditional process, the furnace consists of iron ore, coke, and limestone (a flux) through which hot air is blown to reduce the ore to metallic iron which melts, picking up carbon from the burning coke. Most of the waste material and the coke ash are fluxed by the limestone to form slag. Impurities such as carbon (in unacceptable quantities), silicon, sulphur, and phosphorus are removed in steel-making although some pig iron is used directly for foundry purposes and special casting. One of the most important developments in blast furnace technology in recent years has been the improvement in the structure of the charge either by the use of pellets (see pelletization) and/or sinter in addition to, or instead of, lump ore.

PRIMARY METAL: Ingot metal obtained directly from metalliferous ores, concentrates, or agglomerates, by second-stage processing.

PROCESSING: Processing industry can be identified as a sub-set of the economic activity known as 'manufacturing', and includes all those industries concerned with 'a chemical and physical change of state' rather than with mechanical changes of form and position (Buchanan and Sinclair, 1964, p. vi). Processing industries are thus linked directly to the 'resource industries' of an economy.
(agriculture, forestry, mining) or to their by-products (such as the heavy chemical industries). In most types of processing, raw materials are transformed into useable inputs for secondary manufacturing industries concerned with semi-fabrication, fabrication, assembly, and construction. In metalliferous mineral industries, processing can be divided into first- and second-stage, the former producing marketable raw materials from mined output, the latter metal ingot. Vertical integration tends to obscure the boundaries of this classification and it is sometimes difficult to separate mining from first-stage processing, and metal refining from manufacturing.

QUARRY: Defined in the Concise Oxford Dictionary as an excavation from which stone (for example limestone and basalt) may be obtained for building and other purposes. Thus, mining and quarrying are distinct extractive industries, the latter producing materials principally for their own characteristics (limestone is the basic input in the manufacture of cement). Because of clear technical similarities, some open-cut mining is often incorrectly described as quarrying; yet the terms are defined on purpose rather than technology and, in practice, imply considerable differences in scale of operations.

SCRAP: Refined metal used in the production of secondary metal, and as an adjunct in the production of primary metal, by re-melting. Scrap metal is most important in steel-making, especially in electric furnaces, but is also used extensively in the production of (refined) copper metal.

SECONDARY METAL: Ingot metal obtained from the remelting of scrap.

SEMI-FABRICATING: Basic metal manufacturing in which ingot metals are converted into products useful as inputs for a wide range of metal fabricating industries. Semi-fabrication includes the extrusion of shapes by pressing, the rolling of sheets, and the manufacture of bars, rods, pipes, and wires. This activity is not considered in this thesis although vertical integration often leads to rather arbitrary separation. For example, the semi-fabricating of steel is strongly integrated with steel-making for technological and other reasons; copper refining is often accompanied by the manufacture of basic products; zinc products are often manufactured at electrolytic zinc works; and there are some instances of the integration of aluminium smelting and semi-fabricating, although this is by no means common.

SINTER: Material produced by sintering, a technique designed to improve the physical structure of blast furnace feeds in the smelting of iron, lead-zinc, and copper ores. In the production of iron sinter, for example, crushed ores and fines (either purchased or generated at the blast furnace during the handling of lump ores), are fused with coke and pyrites. Limestone can also be added to produce a
self-fluxing sinter. Fines must be sintered before they can be used as a blast furnace feed and the process was first developed in the iron and steel industry to utilize accumulated blast furnace dust and waste fines at steel-works. Because of the desirable qualities of sinter as a feed, however, sintering has now become a major element in ore preparation.

SMELTING: The basic form of second-stage processing, defined in the Concise Oxford Dictionary as 'the extraction of metal from ore by melting'. In this thesis, the term is used to describe the extraction of metal, not necessarily in pure or used form, either by the blast furnace method or by electrolysis, although in the latter method, the metal is not gained by reduction of melted ore.

STEEL-MAKING: One of the most important second-stage processing industries, steel-making removes impurities from pig iron and imparts a range of desirable qualities by the formation of alloys. Three principal techniques are used: the oldest is the Bessemer process in which hot air is blown through molten iron in a converter to oxidize carbon and impurities. Ferromanganese is often added to remove excess oxygen, and the process is fast but inflexible, and strict control over the composition of the steel is difficult. Open-hearth process is slower and involves the injection of fuels, and a charge of scrap, limestone, and iron ore, into a furnace where ignition of the fuel heats the charge strongly before molten pig iron is added. Impurities in the pig iron are removed and strict control can be exercised over the quality of the steel produced. Large quantities of scrap can be used if desired. The third method, the electric-arc furnace, involves the insertion of electrodes into a bath of molten pig iron, or pure scrap; an electric arc is struck between the metal and the electrodes on the passage of electricity, and very high temperatures are produced for the refining process. Addition of alloy metals is easy and high-quality steel can be produced. One of the advantages of this process, if electricity is available, is that steel can be produced economically in relatively small-scale plants.

STOWAGE FACTOR: This is the volume in cubic feet taken up by one long ton (2,240 lbs) of the commodity (compare lead ingot and foam rubber for an example of its importance to shipping).

TAILINGS: Waste materials produced in the concentration of complex metalliferous ores often accumulate in tailing dumps or are used as 'fill' for underground mining. Tailings often contain recoverable quantities of metal, not extracted in the original concentration process; for example, flotation to produce lead concentrates often produces tailings containing zinc. From time to time, tailings are treated to remove remaining metal content, usually when metal prices are very favourable (or in cases of severe depletion of primary ores).
TRIHYDRATE: One of the two forms in which aluminium oxide is found in nature as a component of bauxite. The oxide is present as Al\textsubscript{2}O\textsubscript{3}.3H\textsubscript{2}O and bauxites containing it are known as gibbsite. Trihydrate is the easiest to refine by the Bayer Process because of the relatively low temperatures and pressures required in the digestion of the bauxite.
# APPENDICES

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*Estimated from company records (actual data not available)*

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# APPENDICES

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*Estimated from company records (actual data not available)*
APPENDIX I(a): PRODUCTION, EXPORTS, AND IMPORTS OF THE MINERAL COMMODITIES UNDER CONSIDERATION

### Bauxite

(Thousand tons)

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\(^a\) Estimated from company reports (actual data not released)

### Alumina

(Thousand tons)

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\(^a\) Estimated from company reports (actual data not released)
## ALUMINIUM
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## IRON ORE
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### STEEL INGOT<sup>a</sup>

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<sup>a</sup> Including secondary steel
### COPPER CONCENTRATES
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### BLISTER COPPER
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### PRIMARY REFINED COPPER (SHAPES)
(thousand tons)

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### LEAD CONCENTRATES
(thousand tons)

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(thousand tons)

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* Total production figures for lead bullion are not separately released. These are author's estimates from individual company data and can give orders of magnitude only.

## PRIMARY REFINED LEAD
(thousand tons)

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### ZINC CONCENTRATES

(Thousand tons)

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### ZINC

(Thousand tons)

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**APPENDIX I(b): EQUITY STRUCTURE OF ALL DOMESTIC MINERAL COMPANIES MENTIONED IN THE TEXT**

Companies mentioned in the text are arranged here alphabetically, according to the following format:

**NAME OF COMPANY**

(m) mines: product (location); (f) first-stage processing plants: product (location); (s) second-stage processing plants: product (location).

* Ownership: name of parent or shareholder (country of domicile) - per cent equity.

Other comments.

Information has been obtained from published sources including 'Annual Reports' of companies concerned or their (controlling) parents. The data are correct as at January 1971.

**ALCAN AUSTRALIA LTD**

(s) aluminium (Kurri Kurri)

* Alcan Aluminium Ltd (Canada) - 70
  Australian finance houses (Australia) - 30

Alcan Aluminium Ltd of Canada formed Australuco Pty Ltd (a semi-fabrication firm) in 1936 with British Aluminium Ltd and E.Z. Industries Ltd (q.v.) but bought out the two partners. Australuco Pty Ltd is now a wholly-owned subsidiary of Alcan Australia Ltd in which Australian equity was taken up in 1963.

**ALCOA OF AUSTRALIA LTD**

(m) bauxite (Jarrahdale)
(f) alumina (Kwinana, Pinjarra)
(s) aluminium (Point Henry)

* Aluminium Co. of America (U.S.A.) - 51
  Western Mining Corporation Ltd (Australia) - 20
  Broken Hill South Ltd (q.v.) (Australia) - 17
  North Broken Hill Ltd (q.v.) (Australia) - 12

Alcoa of Australia Ltd also owns semi-fabrication facilities and has investments in fabrication affiliates.
ALWEST JOINT VENTURE

(m) bauxite (Southern Darling Ranges) - construction yet to commence.
(f) alumina (a site to be selected near Bunbury)

* Alwest Pty Ltd (Australia)
The Broken Hill Proprietary Co. Ltd (Australia)
Nippon Light Metal Co. (Japan)
Showa Denko Co. (Japan)
Sumitomo Ltd (Japan)

The financial structure of this venture is not final, but Australian companies will retain majority equity. The expected Japanese participants are major alumina and aluminium producers; Showa Denko Co. and Sumitomo Ltd are already joint venturers with Comalco Ltd (q.v.) in the Bluff aluminium smelter complex, New Zealand, and are committed to equity participation in the Amax Consortium (q.v.).

AMAX CONSORTIUM

(m) bauxite (Mitchell Plateau) - under development.

* American Metals Climax Corporation (U.S.A.) - 52.5
Sumitomo Chemicals (Japan) - 17.5
Showa Denko Co. (Japan) - 12.5
Holland Aluminium N.V. (Netherlands) - 10.0
Sumitomo Shoji Kaisha (Japan) - 5.0
Marubeni-Iida Co. (Japan) - 2.5

Australian equity will be offered up to ten per cent of the shareholding of American Metals Climax Corporation (giving 3.5 per cent of overall equity).

BROKEN HILL ASSOCIATED SMELTERS LTD

(s) lead (Port Pirie)

* Conzinc Riotinto of Australia Ltd (q.v.) (Australia) - 50
North Broken Hill Ltd (q.v.) (Australia) - 30
Broken Hill South Ltd (q.v.) (Australia) - 20

The smelter had been established in 1897 by The Broken Hill Proprietary Co. Ltd (q.v.).

BROKEN HILL SOUTH LTD

(m) lead and zinc concentrates (Broken Hill) - ceased April 1972.

* An Australian public company

This firm is becoming an important investment company but retains large interests in copper mining and refining, and lead smelting.
COBAR MINES LTD

(m) copper, lead, and zinc concentrates (Cobar)

* Broken Hill South Ltd (q.v.) (Australia) - 77
  Conzinc Riotinto of Australia Ltd (q.v.)
  (Australia) - 23

This company reopened long-abandoned mines at Cobar in 1965.

COMALCO ALUMINIUM (BELL BAY) LTD

(f) alumina (Bell Bay)
(s) aluminium (Bell Bay)

* Comalco Ltd (q.v.) (Australia) - 82.6
  Tasmanian State Government - 17.4

Formed in 1960 on the sale of the Bell Bay smelter by the Australian Aluminium Production Commission to Comalco Ltd.

COMALCO LTD

(m) bauxite (Weipa)

* Kaiser Aluminium and Chemical Corporation
  (U.S.A.) - 45
  Conzinc Riotinto of Australia Ltd (q.v.)
  (Australia) - 45
  Australasian public (Australia and New Zealand) - 10

Reconstituted in 1960 following withdrawal of British Aluminium Ltd. Now controls aluminium smelting at Bell Bay and participates in alumina refining at Gladstone and salt production at Dampier. It operates Australian semi-fabrication and fabrication facilities and has overseas equity participation in alumina refining (Sardinia), smelting (New Zealand), semi-fabrication (Indonesia, Hong Kong, New Zealand) and fabrication (Hong Kong, New Zealand).

CONZINC RIOTINTO OF AUSTRALIA LTD

Involved in a wide range of mining and mineral processing in Australia.

* Rio-Tinto Zinc Ltd (U.K.) - 84
  Australian public - 16

One of Australia's largest mining houses. Local subsidiaries and affiliates in iron, aluminium, lead, and zinc are listed separately here. In addition, it is financially involved in the domestic production of uranium (Queensland, Northern Territory), coal (Queensland, New South Wales), chemicals, timber, and is involved in exploration for oil and natural gas. It holds fifty-three per cent direct equity in Bougainville Copper Pty Ltd.
COPPER REFINERIES LTD

(s) refined copper (Townsville)
* M.I.M. Holdings Ltd (q.v.) (Australia) - 100

ELECTROLYTIC REFINING AND SMELTING CO. LTD

(s) blister and refined copper (Port Kembla)
* Broken Hill South Ltd (q.v.) (Australia) - 60
  North Broken Hill Ltd (q.v.) (Australia) - 40

E.Z. INDUSTRIES LTD

(m) lead and zinc concentrates (Rosebery), zinc concentrates (Beltana)
* Australian public company

Acquired, in 1956, all issued capital of Electrolytic Zinc Co. of Australasia Pty Ltd (registered as a public company in 1920). It has financial participation in sulphuric acid production.

FRANCES CREEK IRON MINING CORPORATION LTD

(m) iron ore (Frances Creek)
* Duval (Australia) Corporation Ltd (Australia) - 87
  private individuals - 13

GOLDSWORTHY MINING LTD

(m) iron ore (Goldsworthy)
* Consolidated Goldfields (Australia) Ltd (Australia) - 33.3
  Utah Mining and Construction (U.S.A.) - 33.3
  Cyprus Mines Corporation (U.S.A.) - 33.3

Consolidated Goldfields (Australia) Ltd is owned as to seventy-seven per cent in United Kingdom.

HAMERSLEY HOLDINGS LTD

(m) iron ore (Tom Price, Paraburdoo)
  iron pellets (Dampier)
* Conzinc Riotinto of Australia Ltd (q.v.) (Australia) - 54.0
  Kaiser Steel Corporation (U.S.A.) - 34.5
  Australian public - 11.5
M.I.M. HOLDINGS LTD

(m) copper, lead, and zinc concentrates (Mount Isa)
(s) blister copper, lead bullion (Mount Isa)

* American Refining and Smelting Co. (U.S.A.) - 54
  Australian public - 46

Formerly Mount Isa Mines Ltd. Operates a domestic copper refining subsidiary and a coal mine, and also a lead refinery in United Kingdom.

MORGAN MINING AND INDUSTRIAL CO. LTD

(m) iron ore (Mount Bundey) - ceased production in 1972.

* Peko-Wallsend Investments Ltd (q.v.) (Australia) - 100

Formally owned by Mount Morgan Ltd (q.v.); iron ore activities have now ceased.

MOUNT LYELL MINING AND RAILWAY CO. LTD

(m) copper concentrates (Queenstown)

* Consolidated Goldfields (Australia) Ltd (Australia) - 61
  Australian public - 39

The controlling share was purchased in 1964 by Consolidated Goldfields (Australia) Ltd, the majority of which is owned in United Kingdom. The company is financially involved in domestic production of tin, fertilizers, and sulphuric acid, and has large minority shareholdings in metal fabrication firms.

MOUNT MORGAN LTD

(m) copper concentrates (Mount Morgan)
(s) blister copper (Mount Morgan)

* Peko-Wallsend Investments Ltd (q.v.) (Australia) - 100

A long-established Australian public company, it was absorbed into the present parent group in 1968.
MOUNT NEWMAN CONSORTIUM

(m) iron ore (Mount Newman)

* The Broken Hill Proprietary Co. Ltd (q.v.) (Australia) - 30
  Pilbara Iron Pty Ltd (Australia) - 30
  American Metals Climax Corporation (U.S.A.) - 25
  Mitsui - C. Itoh Pty Ltd (Japan) - 10
  Seltrust Iron Ore Ltd (U.K.) - 5

Managed by The Broken Hill Proprietary Co. Ltd. Pilbara Iron Pty Ltd is owned as to sixty-eight per cent by The Colonial Sugar Refining Co. Ltd, an Australian public company.

NEW BROKEN HILL CONSOLIDATED

(m) lead and zinc concentrates (Broken Hill)

* Conzinc Riotinto of Australia Ltd (q.v.) (Australia) - 32
  British shareholders (U.K.) - 68

This firm was transferred from British to Australian registration in 1970. It has entered partnerships with its Australian management group, Conzinc Riotinto of Australia Ltd, in various domestic projects, and holds twenty-six per cent equity in Bougainville Copper Pty Ltd.

NORTH BROKEN HILL LTD

(m) lead and zinc concentrates (Broken Hill)

* Australian public company

Financially involved in domestic lead and copper smelting, and a significant minority shareholder in a domestic aluminium group. The company also maintains a wide variety of portfolio investments in mining and industrial enterprises.

NORTHWEST IRON CO. LTD

see Savage River Joint Venture.

PEKO-WALLSEND INVESTMENTS LTD

(m) copper concentrates and gold (Tennant Creek)

* Australian public company

Financially involved in a variety of other local enterprises including copper mining and smelting, coal mining and transport.
QUEENSLAND ALUMINA LTD

(f) alumina (Gladstone)

* Kaiser Aluminium and Chemical Corporation (U.S.A.) - 37.3
  Alcan Aluminium Ltd (Canada) - 22.0
  Péchiney Compagnie (France) - 20.0
  Comalco Ltd (q.v.) (Australia) - 11.3
  Conzinc Riotinto of Australia Ltd (q.v.) (Australia) - 9.4

An international consortium, its financial structure has been subject to periodic change with participants taking their share of output strictly in accordance with their equity holding.

ROBE RIVER CONSORTIUM

(m) iron ore (Mount Enid) - under development
(f) iron pellets (Cape Lambert) - under development

* Cliffs (Western Australia) Pty Ltd (U.S.A.) - 30
  Mitsui and Co. Ltd (Japan) - 30
  Garrick Agnew Pty Ltd (Australia) - 5
  Robe River Ltd (Australia) - 35

Robe River Ltd is owned by Australian financial institutions and the public following the collapse of its principal shareholder, Mineral Securities (Australia) Ltd, in 1971. The final equity structure is still uncertain.

SAVAGE RIVER JOINT VENTURE

(m) iron ore (Savage River)
(f) iron pellets (Port Latta)

* Dahlia Mining Co. Ltd (Japan) - 50
  Northwest Iron Co. Ltd (Australia) - 50

The Japanese partner is owned jointly by two steel manufacturers, while the 'Australian' partner is majority-owned by Pickands Mather Corporation of the United States.

SULPHIDE CORPORATION

(s) lead and zinc metal (Newcastle)

* Conzinc Riotinto of Australia Ltd (q.v.) (Australia) - 75
  New Broken Hill Consolidated (q.v.) (Australia) - 25
THE BROKEN HILL PROPRIETARY CO. LTD

(m) iron ore (Middleback Ranges, Yampi Sound, Koolyanobbing)
(f) iron pellets (Whyalla)
(s) pig iron (Kwinana)
(s) integrated iron and steel (Port Kembla, Newcastle, Whyalla)

* Australian public company

One of Australia's largest industrial groups -- a monopolist in the domestic iron and steel industry -- integrated backwards into the extraction of coal, limestone, manganese, and forwards into a variety of manufacturing industries. Also involved in oil and natural gas exploration and production.

WESTERN MINING CORPORATION LTD (JOINT VENTURE)

(m) iron ore (Koolanooka)

* Western Mining Corporation Ltd (Australia) - 50
  Hannah Mining Company (U.S.A.) - 25
  Homestake Mining Company (U.S.A.) - 25

The major shareholder is an Australian public company with domestic interests in gold and nickel, and a large holding in a local aluminium group.

ZINC CORPORATION LTD

(m) lead and zinc concentrates (Broken Hill)

* Conzinc Riotinto of Australia Ltd (q.v.)
  (Australia) - 100
A method of cost estimation was sought which allowed reasonable estimates of production cost as a basis for the study of regional variation. The choice of such a model depends on the purpose for which it is required and, in this study, an agglomerative rather than a divisive approach to total production cost was desirable. In most cases, it was not possible to commence with a known (or widely accepted) total cost estimate (or f.o.b. price); instead, an accurate picture of regional costs was sought in which the magnitude of factory profit is not of primary importance.

There were three principal requirements of the estimation procedure. First, consistency of estimation technique is essential for valid locational comparison. Second, it should make maximum use of available data; a set of production co-efficients for the principal variable inputs could be obtained either directly from plants or from technical and engineering studies. Third, the classification of cost elements should be complete and include all charges made against product revenue before the assessment of income tax. The location analyst is usually interested in factors which exhibit significant spatial variability, since these influence the relative economics of production in one location as against any other. Raw materials, utilities, and labour are of traditional concern to the economic geographer, but it serves very little analytical purpose to describe the residual factors as 'other'. In some presentations of production cost, this item contains some very diverse cost elements; for example, Carlson (1956, p. 150) has a 'miscellaneous' cost component and Huggins (1965, p. 117) has a similar residual. Brown and Butler (1968, p. 5) include overheads, fixed costs, and transport cost in one residual category. The creation of such a
component is not useful for measuring location factors, although it may serve admirably the purposes for which it was designed. Fixed costs are distinctly different from overhead costs (which are semi-variable) and are of such importance in the metalliferous mineral industries that they should not be included with other components. Both fixed costs and overheads vary spatially, and Part II of this thesis seeks to identify some of this variation.

The complete specification of a cost structure creates some difficulties. Some items will be very small or insignificant for mining and processing, but even if these items are ultimately presented as 'other' costs, a correct order of magnitude is obtained for the major factors. The accounting procedure adopted becomes critical, and it often proves difficult to cross-check estimates against published data based on different accounting conventions or incomplete cost specification.

The advantages of the method developed here are largely its simplicity and consistency. When 'raw materials' or 'maintenance charges' are mentioned in the text, they refer always to a defined set of cost elements and inter-plant comparison is valid. Differences between factor groups are not simply the result of different accounting procedures. The total production cost derived from this model can be regarded only as a first approximation since its calculation involves many gross assumptions and at least some arbitrary, but unavoidable guess-work, especially for the cost items for which production co-efficients cannot be derived. More sophisticated estimation, however, is clearly outside the scope of the thesis; it is sufficient to develop broadly reasonable cost estimates giving a sound measure of the relative importance of the production factors. It is submitted that the method outlined below develops such 'broadly reasonable' estimates.
The major problem with any cost estimation model is the accounting practice of firms; this is common to most economic analysis, especially that of vertically integrated structures. The main difficulty is in dealing with the 'pricing' practices for captive transfers of goods and services between plants of the same firm (or multi-plant corporation). If optimal location is under consideration, the analyst must adopt a system which reflects the actual competitiveness of particular locations. One assumption is that transfers are made at unit production costs, or that plants within the same group operate on a 'tolling' system (as Queensland Alumina Pty Ltd does for its consortium partners). Transfer at cost is a convenient assumption; at some point, a sale is made to a buyer outside the group and profit is made from the revenue. Yet this accounting device interferes with the profit maximization thesis of the firm's goals which clearly becomes inapplicable at the level of the individual plant. Many multi-plant firms find it more appropriate to adopt other accounting systems, especially for the analysis of production economics within their group.

The Broken Hill Proprietary Co. Ltd*, for example, uses the 'profit-centres' system to facilitate cost control and investment appraisal at plant level**. This system involves, for inputs transferred captively, at least the concept of opportunity costs, normally the price the firm could expect to pay (or receive) for the materials if


** Production inefficiencies at second-stage processing levels could be hidden if materials from efficient mines and first-stage plants were transferred at unit production cost, which might be very low for a large-scale operation. The industrial structure of manufacturing is one of the reasons why theoretical optimal location might fail to develop in an economy dominated by a small number of large firms but little research has been done into the importance of management accounting practices on locational decision-making.
purchased (or sold) on the open market. This is difficult if the firm is in a monopsony position with respect to its principal input, or if a rigid oligopolistic structure precludes the existence of an open market*. An indication is sometimes given if large exports of the material concerned are also made by the firm; export prices can usually be obtained or inferred**. Despite the difficulties, the profit-centres method of accounting is used in Chapter 3 for cost estimation purposes unless tolling arrangements are known to exist. For input prices, notional f.o.b. prices are established to which published or estimated freight rates are added to obtain a delivered price at the factory. Estimates of freight rates are often crude where the material is transferred by a company-owned transport system.

The development of an estimation technique in which mining is separated from processing serves no useful purpose. Mining firms are economic enterprises which can be subjected to the same form of economic analysis as manufacturing concerns; differences between the mine and the classical theoretical firm regarding pricing and output (noted in Sub-section 1.3.1) make no difference to the classification of production cost components. Hence, in

* Not only is there no open market for iron ore in Australia, for which The Broken Hill Proprietary Co. Ltd is the only buyer, but neither are local sales of bauxite or alumina made.

** Yet c.i.f. prices for ores in various consuming regions of the world tend to be standardized through buyers' market conditions and the competitive behaviour of suppliers. The f.o.b. prices realized at individual sale points depend on the market the ore is sold in, and the freight rate to that market. Much of the 'profit-centres' analysis involves conceptual weaknesses on the market side. Cost estimates for outside purchases cannot really be made unless some such purchases exist. In addition, very large purchases often cause reduction in price below the open market average, especially where long-term supply contracts are involved.
this thesis, the terms 'mining cost' and 'manufacturing cost' are synonymous. The accounting procedure adopted in this model is substantially that used by Buchanan, Sinclair, and others for cost estimation in the Australian process industries (Buchanan and Sinclair, 1964, pp. 701-21). The classification of cost elements is shown in Fig. 1. It must be emphasized that this is a model for production cost; it is based on a particular set of accounting conventions and is only one of many ways in which 'total production cost' could be disaggregated. It has been chosen for three main reasons: first, it appears to fulfill the criteria outlined above; second, it has been used with reasonable success in Buchanan and Sinclair (1964), and results of the estimation analysis of Chapter 3 can be compared, at least, with those published in their study; third, likely (absolute) cost increases since the publication of their study (1964) do not seriously affect the model since the principal components are estimated from present factor costs and production co-efficients.

The basic division is between 'manufacturing' and 'non-manufacturing' cost; the former is the basic unit production expense while the latter includes all items not involved either directly or indirectly as process inputs, but levied against the product before the profit margin, and the f.o.b. price, are determined. In Buchanan and Sinclair (1964, pp. 701-2) it is argued that the manufacturing cost is least dependent on company policy, the method of capitalization, and other external factors, and is thus a useful measure for inter-plant comparisons. There are three types of production components; 'variable' costs exist only when output is positive and are, in some way, proportional to its volume; 'semi-variable' costs would not disappear if production were zero and increase less than proportionately as output increases; 'fixed' costs are held to be independent of the rate of output. Hence, manufacturing costs can be divided into direct costs, variable and semi-variable costs precisely attributable to
Relationship between cost components – total production cost

After Buchanan and Sinclair, 1964, p. 702.

\( v = \text{variable} \quad s-v = \text{semi-variable} \quad f = \text{fixed} \)
the production process; indirect costs, variable and semi-variable costs which are related via other factors; and fixed costs. The methods adopted in Chapter 3 for the estimation of the various components shown in Fig. 1 are discussed in turn below.

1 **Direct Manufacturing Costs**

All direct variable costs are estimated using actual production co-efficients and input prices wherever possible. This gives a solid foundation to the estimate of total cost.

1.1 **Variable costs**

1 **Raw materials**

This item includes all materials consumed in the manufacturing (or mining) process at c.i.f. prices. It thus includes 'silent' transport inputs. Fuels are not included. The principal input is quoted at actual price if available, and otherwise at an estimated price based on cost estimates for the supplier plus an appropriate margin (since the profit-centres system is used), plus the freight rate. Adjunct materials are priced at a commonly quoted regional supply price, although actual prices paid are probably lower on materials purchased under long-term bulk contracts. The raw material component is usually negligible for mining activity.

2 **Utilities**

Sources of energy (fuels, electricity) are included in this item. Fuels such as coal and oil are priced at common regional c.i.f. prices and overestimates are likely again where long-term supply relationships have been obtained. Electricity is priced at the actual rate if known, or else estimates are made in the text of Chapter 3. Power generated in company-owned stations is not included here; fuel costs for the power station are charged to utilities and capital costs of the generators to those of plant and equipment generally. Water is charged at the regional industrial rate where purchased.
3 Direct labour

For comparative purposes, it is useful to include only the labour employed in the plant itself (or actually involved in mining and raw product conveyance). The estimation of this item involves some gross assumptions about award wages, but a reasonable cost estimate can be made given the actual number of plant workers and the shift patterns. An addition to total direct labour cost is made to cover the costs of supervision (Buchanan and Sinclair, 1964, p. 713).

4 Royalties, patents, etc.

These are important variable costs in mining and, since they are usually specified as a rate per ton, they can be included as actual values. Patent charges in processing are not estimated.

1.2 Semi-variable costs

1 Operating supplies

Production co-efficients can seldom be derived for this item, the first of the 'other' categories. It includes materials purchased continuously but not consumed in the manufacturing process or in the generation of electricity. These expenses, however, are often more important than raw materials in the mining industry. On the basis of Buchanan and Sinclair (1964, p. 711), this cost is estimated as ten per cent of the direct labour cost (excluding supervision).

2 Maintenance and repair

This vital expense is difficult to estimate accurately because there is no clear relationship between labour employed, the value of parts held, and the variety of operations carried out internally. The costs of outside contracting should be added. The actual value depends on the age of the plant, the type of process (or mining technique), and company policy. It also depends on the degree of isolation of the plant. Buchanan and Sinclair
(1964, p. 713) found that the ratio of labour cost to materials-value was remarkably constant for Australian processing industries surveyed at 3:2. A first estimate is obtained, therefore, by applying this ratio to the cost of labour employed in the maintenance division of the plant concerned; the derived cost is then compared with four per cent of the total capital cost of plant and equipment, and the higher value accepted.

2 Indirect Manufacturing Costs

These components are very difficult to estimate because they are not related to output by production co-efficients. For consistency, they have been estimated from the direct costs of plant labour.

2.1 Variable costs

1 Process control

This is the second expense in the 'other' category and is incurred in both mining and processing for the routine testing of inputs and outputs. Its costs are principally those of labour and the component is estimated as fifteen per cent of total direct labour cost for relatively simple, continuous mining and processing.

2 Packaging

This cost is virtually zero for all firms in the metalliferous mineral industries and was not estimated.

2.2 Semi-variable costs: plant overhead

Included in this item are both payroll and plant overhead, the latter expense (of greater importance) is a summation of all factory (mine) expenses not directly related to the productive process but essential in its operation. Overheads are always important in large-scale plants, and are considerably inflated in isolated locations where entire communities and semi-variable infrastructural costs must be supported. Overheads are impossible to estimate accurately but an attempt is made because of their
importance, especially in the attainment of economies of scale. Because many of the charges are labour-dependent, overheads are estimated roughly as 120 per cent of direct labour cost with an additional twenty per cent if site allowances for location are paid to the plant's work-force.

3 Fixed Manufacturing Costs

3.1 Depreciation allowance

This cost is related directly to the total capital investment in plant and equipment (and infrastructure where important), and is the charge made against output as a method of compensating for the inevitable degradation of the stock of plant, equipment, buildings, and infrastructure, through physical wear and tear, obsolescence, and other factors. There are various methods of depreciating capital investments and some are discussed in detail in Buchanan and Sinclair (1964, pp. 1201-13). Some, but not all, of this depreciation is recognized by the Commonwealth Taxation Department as a tax deduction, and various depreciation allowances are granted. Thus, two depreciation rates exist, one for taxation purposes, the other an internal rate designed to write-off assets in a way which approximates their actual rate of decline over time. The depreciation allowance is basically, therefore, an accounting device but one of such importance that it must be estimated as a production factor. Its estimation involves rough approximations: plant, mobile equipment, buildings, and infrastructure, depreciate at different rates and different allowances are made. The easiest way of including these items is to adopt a fixed proportion of the total capital investment necessary to install the given annual production capacity, including infrastructure. Buchanan and Sinclair (1964, p. 715) suggest that a rate of eight per cent of the total is appropriate for all capital investment.
3.2 Property taxes and insurance

Buchanan and Sinclair (1964, p. 715) found that a value of one per cent of the total capital investment adequately covers these expenses.

3.3 Rent

This item is rarely significant as a cost per unit because of the high rates of output at most mines and plants.

4 Non-manufacturing Costs

4.1 Variable cost: outward freight

Actual values are used, or estimates based on common ton-mile rates for the particular transport medium concerned. The magnitude of this item depends on selling policy, and is zero in cases where the product is sold f.o.b.. In this thesis, however, it is found that many companies quote their prices f.o.b. at the nearest outlet port so that the costs of overland freight are 'internalized'. The cost of this transport is included here as non-manufacturing cost. Outward freight is also incurred where some form of freight-equalization is practiced, for example, the quoting of prices c.i.f. at capital cities in Australia.

4.2 Semi-variable costs

1 Selling costs

These expenses are minor for most plants under consideration. For second-stage processing plants, they are estimated very roughly at three per cent of the total manufacturing cost of the product (Buchanan and Sinclair, 1964, p. 716).

2 Exploration and research

Included here is a rough estimate of the cost of continuous exploration by mining companies and, for processing plants, the cost of product research and development other than routine process control. Buchanan and
Sinclair (1964, p. 716) recommend that three per cent of the total manufacturing cost is a reasonable estimate for processing industry, and this is likely to cover adequately the costs of exploration (other than speculative), at least where the company's reserves are not in a serious state of depletion (see Sub-section 3.2.1(c)).

3 Corporate administration

This cost item depends as much on company policy as on the location and size of plant, and the structure and size of the parent group. Operating plants of large, multi-plant corporations have to bear the costs not only of on-site administration, but also of maintaining a head office. Buchanan and Sinclair (1964, p. 1401-11) suggest that the value of this element varies between three and six per cent of total manufacturing cost, depending on the organizational complexity of the parent group.

4.4 Fixed cost: financial expense

This item includes interest payments on borrowed capital and depends on the methods used to finance capital investment. Since there is virtually no basis for estimating this cost component (Buchanan and Sinclair, 1964, p. 716), interest payments are usually ignored in preliminary cost estimation.
APPENDIX III: COST MATRICES FOR THE LINEAR PROGRAMMING ANALYSIS

The two basic cost matrices for the linear programming analysis of Chapter 6 are presented here. All cost data have been derived from the analyses in Chapters 3 and 4. Hypothetical locations have been included by modifications to the basic cost data to allow for changes in transport costs, scales of operation, and variable production costs. The reader is referred to Fig. 6.1 for conventions used in the setting out of these matrices. Asterisks indicate irrelevant links (flows between plants at the same level of processing) and non-feasible links (for example, a flow from a bauxite mine to an aluminium smelter). Zeros along the diagonals of 'identity matrices' allow excess capacities to be shown in the optimal allocation solution.

The first matrix ('Weberian') includes only transport costs between origins and destinations. It forms the basis for two other matrices used, 'least total cost' and 'Minvar'; the former incorporates processing costs in the relevant sub-matrices, and the latter both mining and processing cost. Since the matrices are identical in structure to the Weberian, they have not been included here.

Key to origins and destinations

<table>
<thead>
<tr>
<th>Origins</th>
<th>Destinations</th>
</tr>
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<tbody>
<tr>
<td>1 Jarrahdale</td>
<td>1 Kwinana</td>
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<tr>
<td>2 Weipa</td>
<td>2 Bell Bay</td>
</tr>
<tr>
<td>3 Gove</td>
<td>3 Gladstone</td>
</tr>
<tr>
<td>4 Kwinana</td>
<td>4 Gove</td>
</tr>
<tr>
<td>5 Bell Bay</td>
<td>5 Bell Bay</td>
</tr>
<tr>
<td>6 Gladstone</td>
<td>6 Point Henry</td>
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<td>7 Gove</td>
<td>7 Kurri Kurri</td>
</tr>
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<td>8 Melbourne</td>
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<tr>
<td>9 Point Henry</td>
<td>9 Sydney</td>
</tr>
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<td>10 Kurri Kurri</td>
<td>10 Brisbane</td>
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<td></td>
<td>11 Adelaide</td>
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## Weberian Cost Matrix

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<th>Destinations</th>
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<tr>
<td>$R_j$</td>
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<td>62</td>
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The next cost matrix is the 'Location-allocation' problem and was designed to allow consideration of some hypothetical locations in the optimal patterns. The present pattern of final demands was retained. The matrix includes all costs (transport, mining, and processing) and hence includes both the 'least total cost' and the 'Minvar' matrices.

Key to origins and destinations (Location-allocation matrix)

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<td>Point Henry</td>
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APPENDIX IV: PARLIAMENTARY ACTS FROM WHICH EVIDENCE HAS BEEN DRAWN


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