A Geomorphic Map of the Riverine Plain of South-eastern Australia

B.E. Butler, G. Blackburn,
J.M. Bowler, C.R. Lawrence,
J.W. Newell, S. Pels

A Geomorphic Map of the Riverine Plain of South-eastern Australia

B. E. Butler, G. Blackburn, J. M. Bowler, C. R. Lawrence,
J. W. Newell, S. Pels

AUSTRALIAN NATIONAL UNIVERSITY PRESS CANBERRA 1973

First published in Australia 1973
Printed in Australia for the Australian National University Press, Canberra
United Kingdom, Europe, Middle East, Africa and Caribbean: Angus & Robertson (U.K.) Ltd, London
North, South, and Central America: International Scholarly Book Service, Inc., Portland, Oregon
South-east Asia: Angus & Robertson (S.E. Asia) Pty Ltd, Singapore
Japan: United Publishers Services Ltd, Tokyo

Registered in Australia for transmission by post as a book
ISBN 0 7081 0093 7
Library of Congress Catalog Card no. 73-79254

Foreword

The publication of a geomorphic map of the Riverine Plain of south-eastern Australia on the scale and with the detail of that now issued by the six co-authors involved, not only highlights the outstanding advances that have been made in our knowledge of this remarkable region, but also constitutes a noteworthy achievement in interdisciplinary collaboration by dedicated scientists having the knowledge and enthusiasm, and moreover the objectivity and tact needed to ensure the success of such a joint project.

The aspects of geomorphology on which the map is based are not those that are expounded in any detail in standard texts, for many of the natural features of the plains are, especially in the great alluvial fans and fluvial complexes in the eastern sector, but minutiae in a broad natural system of river courses changing with time, and associated with a complex of deposits which vary rapidly both laterally and in depth. That it has proved possible to map these, even if only at the surface of the plains, and to categorise the associated fluviatile, lacustrine, and aeolian land forms so as to permit the development of a satisfactory legend for the map, is a considerable scientific and practical accomplishment.

The map itself is a first-class cartographic production as to draughting and printing, displaying in a striking way major landform patterns and a host of subsidiary details. Together with the explanatory text the map provides a sound and eminently usable base for the understanding, planning and control of land use in a region which is well known to be extremely sensitive physiographically to misuse. To ensure the long-term survival of rural and urban development in such a terrain, where the balance of nature is delicate and thus potentially unstable even with minor interference, is truly a national goal. Geomorphology, as well as all the accumulated knowledge derived from other surveys and studies – of soils, vegetation, climatology, groundwater and the like – affords the background against which the development of the region may be rationally evaluated, and the map now made available will be welcomed alike by geographers and all who are concerned with the problems of the Plains.

It is heartening to realise that the encouragement given in 1966 by the Australia-Unesco Committee for the International Hydrological Decade to the Symposium at which it was determined to compile the map, should have led to so satisfying an outcome.

Edwin S. Hills

Melbourne
January 1973

Preface

In August 1966 a Symposium on the Geomorphology and Palaeohydrology of the Riverine Plain was held at Griffith, New South Wales, and a report on this is given in the *Australian Journal of Science* Vol. 29, p.135, 1966.

The Symposium was sponsored by the Department of Geology, University of Melbourne, the Department of Geography, University of Sydney, and the Division of Soils, Commonwealth Scientific and Industrial Research Organisation. It was an approved Australian activity in the program of the International Hydrological Decade, having been endorsed by the Australia-Unesco Committee (see the *Australian Journal of Science* Vol. 28, pp.426-7, 1966).

A resolution of the Symposium created a committee, with Mr B.E. Butler as chairman, to compile a geomorphic map of the Riverine Plain. This committee comprises the authors of this paper and of the accompanying geomorphic map. Their task was to establish a mapping legend and procedure, and to prepare the map.

Contents

Foreword *v*
Preface *vii*
The Authors *xi*
Acknowledgements *xiii*
Introduction *1*
General Description of the Region *4*
Geomorphic Features *8*
Mapping Criteria *15*
Modification of the Environment due to Land Use *26*
Map Reliability *29*
Discussion *31*
References *32*

Plates

I Aerial photograph illustrating channel plain, plain with channels, confined stream trace, unconfined stream traces *16*

II Aerial photograph illustrating plain with drains, scalded plain, confined and unconfined stream traces *17*

III Aerial photograph illustrating confined stream trace, plain with scald, linear dunefield and normal plain of indistinct character *18*

IV Aerial photograph illustrating unconfined stream traces, confined stream trace, plains with depressions, drains, scalds, and channels *21*

V Aerial photograph illustrating unconfined stream traces, confined stream trace, plains with scalds, channels and depressions, and source bordering dunes *22*

VI Aerial photographs illustrating linear dunefield, irregular dunefield and normal plain *23/24*

Figures

1 Locality plan *2*

2 South-eastern Australia and the Riverine Plain *3*

3 Broadly defined vegetation regions *5*

4 Contours above sea level *6*

5 Reliability map *30*

The Authors

B.E. BUTLER, Division of Soils, CSIRO, Canberra
G. BLACKBURN, Division of Soils, CSIRO, Adelaide
J.M. BOWLER, Department of Biogeography and Geomorphology, Australian National University, Canberra
C.R. LAWRENCE, Department of Mines, Melbourne
J.W. NEWELL, Victorian Department of Agriculture, Melbourne
S. PELS, Water Conservation and Irrigation Commission, Deniliquin of New South Wales

Acknowledgments

The Authors acknowledge the support given this project by their employer organisations for travelling expenses, field work and compilation working time. Some of the travelling expenses for one author (J.M.B.) was met by the Australia-Unesco Committee for the International Hydrologic Decade.

The compilation of the map from working plans prepared by committee members was made in the Department of Mines, Victoria by Mrs Gwenda Short under the supervision of the Chief Draftsman Mr D.W. McInnes MAIC.

Printing costs were met by a grant from the Rural Credits Section of the Reserve Bank of Australia.

Dr J.N. Jennings and Dr C. Ollier read the manuscript and gave advice on it.

Introduction

Australia has numerous plains, and these are of diverse character. The fluvial plains include some of vast extent like those of the Diamantina and Darling rivers. The Riverine Plain of south-eastern Australia, a fluvial plain of medium size, has been more intensively used and studied than others in Australia, and a co-ordination and summarisation of its accrued data here would be of interest. Fig. 1 gives a general perspective of the study area.

The Riverine Plain of south-eastern Australia (Butler, 1950) comprises the fluvial plains of the Murray, Murrumbidgee, Goulburn, and Lachlan Rivers and their tributary and distributary streams in southern New South Wales and northern Victoria. It is about 76,800 km^2 (30,000 sq. miles) in area. The boundaries chosen for this mapping project are 143° and 147° east longitude and 32°30′ and 37° south latitude. This area is considerably greater than the Riverine Plain *(sensu stricto)* and was chosen so that the Plain could be seen in relation to adjacent landscapes – the hilly water-shedding regions of the east and south, and on the west and north-west the low, undulating, wind-worked semi-arid lands. The immediate surroundings of the mapped area are shown in Fig. 2.

Though many studies have been made in the Riverine Plain, including soil surveys, geologic mapping, geomorphic studies, and the contour and drilling work associated with irrigation development and groundwater appraisals, these have covered restricted areas, and overall perspectives of the Plain have been lacking. A primary objective in undertaking this geomorphic map project has been to establish such overall perspectives. This has been done in terms of riverine and aeolian features. Whilst it would have been desirable to provide a general coverage also in terms of soils, texture of sediments, contour levels, depth to groundwater and salinity of soils, this proved to be impossible because of the unevenness in availability of information, and its complete lack in some large areas. The features chosen for mapping – those of riverine and aeolian origin – have the advantage of being both of prime interest and of forming the framework of variation of many other characteristics and uses. The riverine and aeolian structures are generally visible on air photographs, and these, being available for the whole region, provided a uniform basis for mapping.

The objective in preparing this text has been to provide an introductory statement on the physical features of the Plain, and to present the criteria adopted in compiling the map. The bibliography has been extended beyond the references of the text, so as to give some further leads on the study of the region.

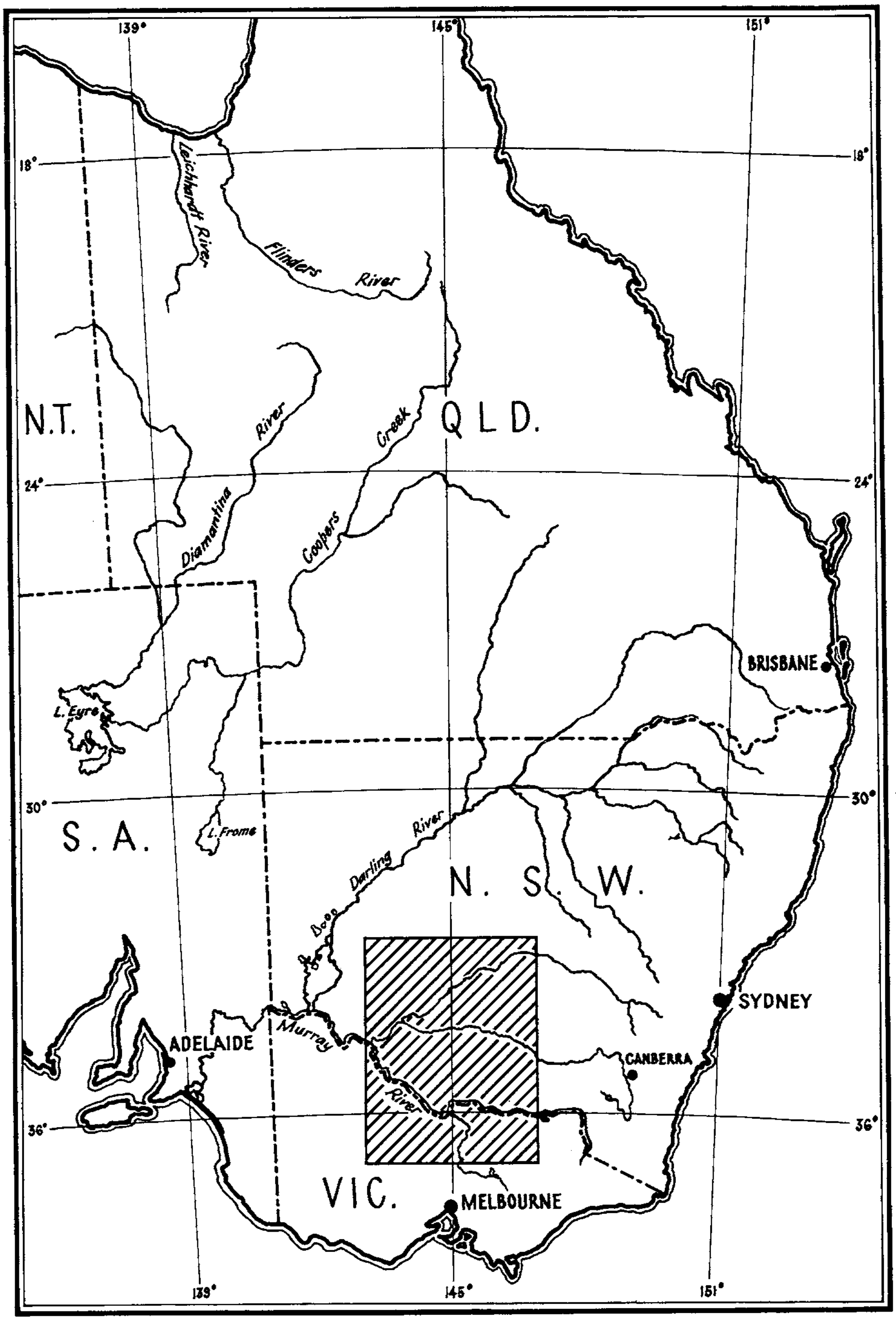

Fig. 1 *Locality plan, the mapped area in relation to eastern Australia*

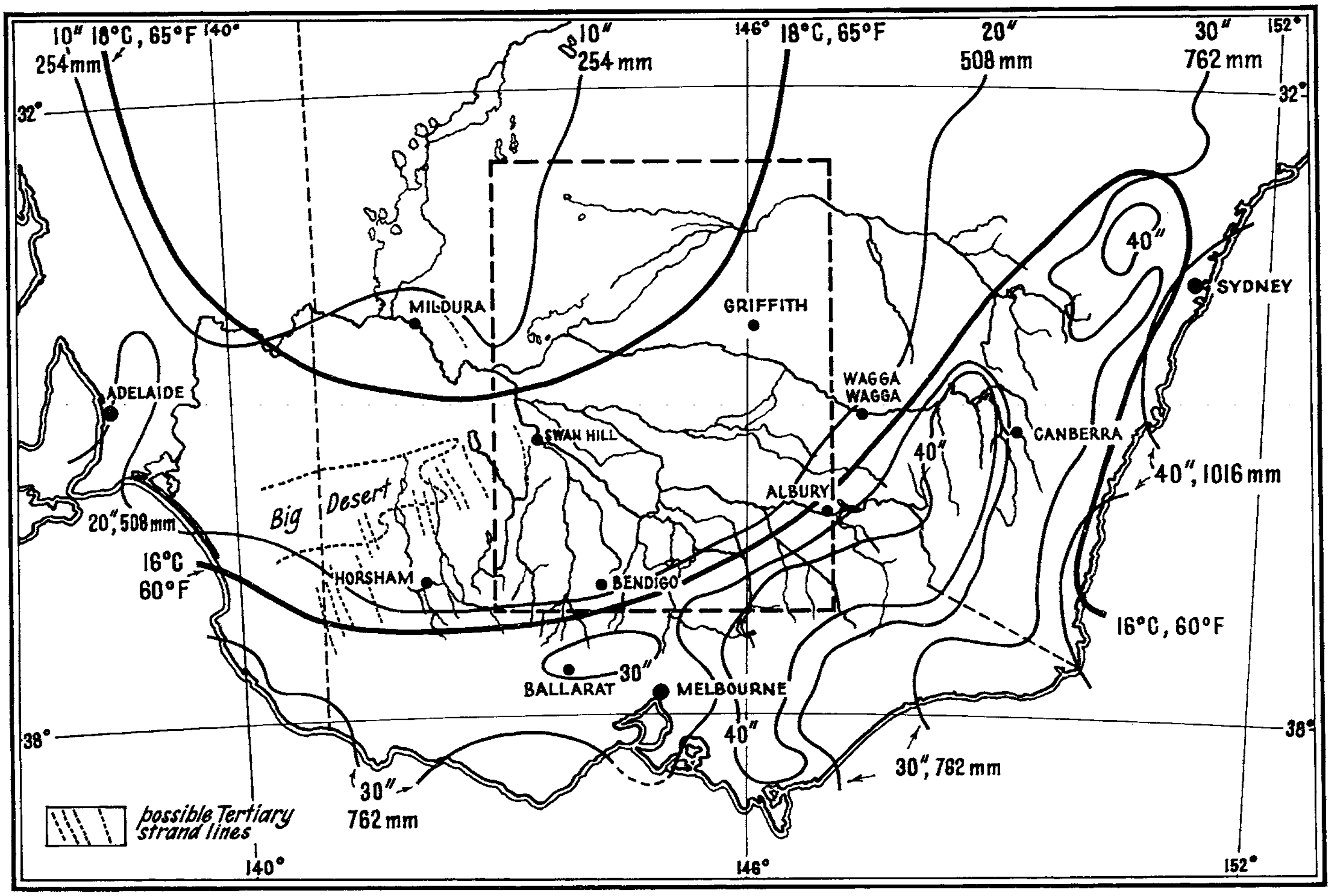

Fig. 2 *South-eastern Australia and the Riverine Plain. Rainfall is shown in mm and inches and mean annual temperature in °C and °F.*

General Description of the Region

Geology

The Riverine Plain covers the eastern part of the Murray Basin (Fisher, 1962; Lawrence, 1966; Pels, 1969b; and Geol. Soc. Aust., 1971) a Cainozoic sedimentary basin, rimmed on the east, south, and north by highlands of Palaeozoic geosynclinal sediments, comprising metasediments, glaciofluvials, lavas, and granite intrusives. These highlands are sparsely capped in places by Upper Tertiary lavas, gravels, and sands. The thickness of unconsolidated sediments beneath the Riverine Plain increases from 90m (300ft) near the highlands to about 305m (1000ft) towards the north-west of the Plain. At the base these sediemnts are Lower Tertiary lignites, sands, and gravels, and these are ovelain by Upper Tertiary and Quaternary sands, clays, and gravels, and lacustrine clays.

Adjoining the western side of the Riverine Plain is the marine section of the Murray Basin comprising over 300m (1000ft) of sediments, capped by wind-worked littoral sands and loams. Marine formations extend eastward to Balranald and Kerang.

The Murray Basin results from regional subsidence; however, there has been upwarping of the marine section of the Basin in Quaternary time (Hills, 1939) and this appears to have contributed significantly to fluvial deposition on the Riverine Plain. In the upwarped section the Murray River is entrenched about 30m (100ft) below the general level, and there are several north-south ridges which are attributed by Hills (1939) to faulting in the basement. However, Blackburn (1962a) proposes that some of these ridges are stranded coastal ridges.

The western margin of the Plain is drawn at the boundary between the aeolian and fluviatile landforms, soil, and vegetation. The aeolian country is associated with a stunted eucalypt shrub called mallee, and for convenience this country is referred to here as the Mallee.

Climate, soils, and vegetation

The main rivers of the Plain rise in the mountains of the Great Divide in south-eastern Australia where the annual rainfall at points above 1524m (5000ft) elevation exceeds 1143mm (45in) and snow lies seasonally.

Generalised maps of climate (Fig. 2) vegetation (Fig. 3) and elevation (Fig. 4) show that the full range of environmental change is expressed along a traverse from Mt Buffalo in the south-east to Manara in the north-west – a distance of 580km (360 miles). In the south-eastern corner, in the Mt Buffalo National Park (Rowe, 1971), rainfall exceeds 1905mm (75in) and elevation reaches 1724m (5654ft). Here alpine meadow vegetation and soils occur. Passing to lower altitudes through steep forested land to more open woodland in the foothill zone, the boundary of the Plain occurs at an elevation of about 150m (500ft). Here the rainfall is about 508mm (20in), the annual temperature about 16^{0}C (61^{0} F) and the soils are red-brown earths.* The woodland zone extends some distance onto the Plain and, being well suited to mixed farming, much of it has been cleared of timber and sown to pastures and crops.

Continuing towards the north-west, the traverse passes across that part of the Plain, e.g. between Deniliquin and Jerilderie, characterised by savannah vegetation with grass and scattered trees, rainfall of about 406mm (16in), and an assortment of soils including grey, brown, and red clays, and red-brown earths. The savannah zone is well suited for raising livestock, notably merino sheep, but agricultural production unaided by irrigation succeeds only in the wetter parts. This country is prone to wind erosion of its

* The classification of soils follows Stace *et al.* (1968).

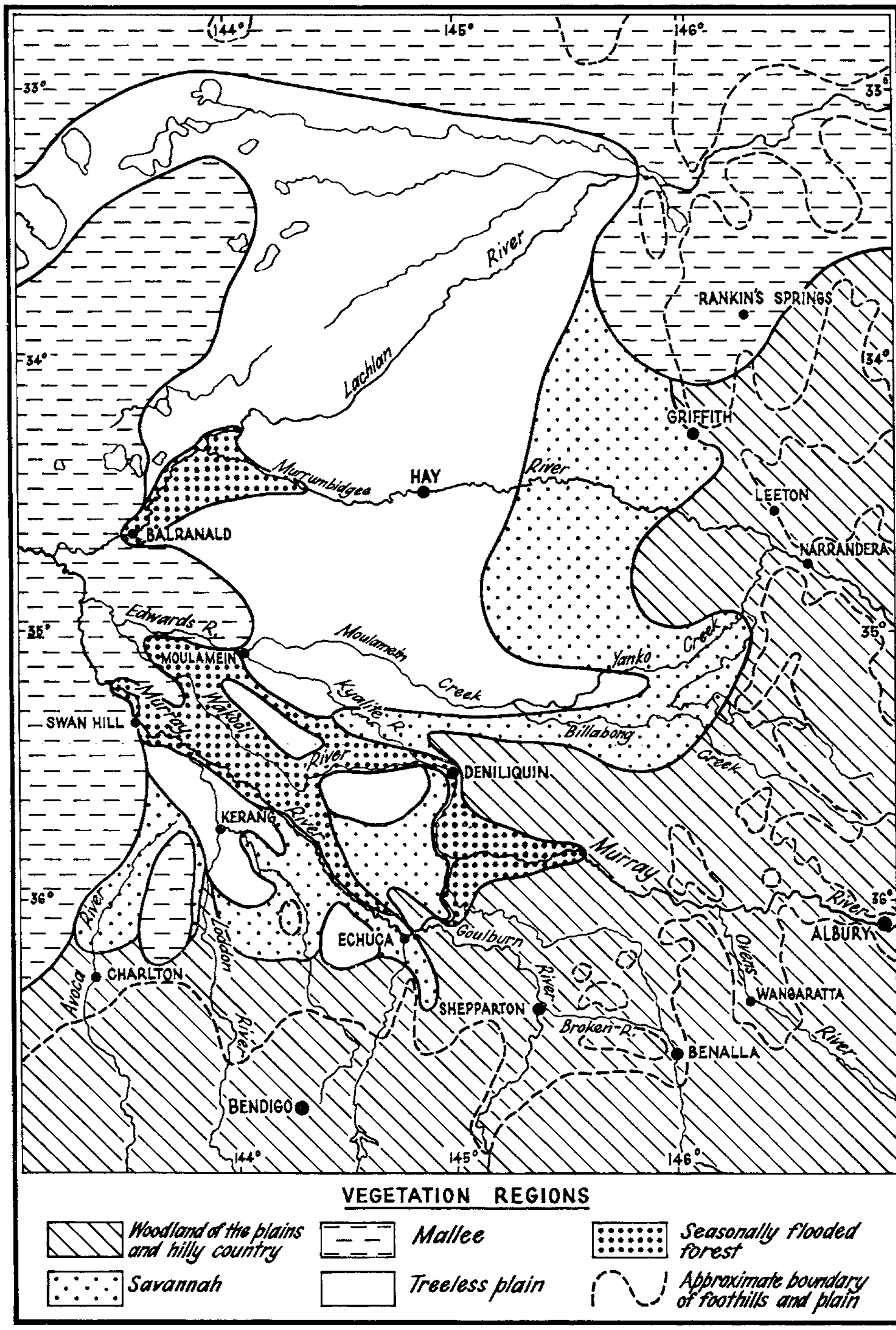

Fig. 3 *Broadly defined vegetation regions of the mapped area*

more sandy soils especially in times of drought and continued grazing. The phenomenon is referred to as 'scald' and has been studied by Beadle (1948) and others. Further out on the Plain, e.g. near Hay, the country is drier, with rainfall of approximately 305mm (14in). It is treeless except along the rivers, and is dominated by saltbush (*Atriplex* and *Kochia* spp.). The soils are grey, brown, and red clays, often of high salinity. This country has a long and favourable pastoral history in spite of its low stocking rate and its susceptibility to drought and scald.

The transect then continues across parts of the Plain with lower rainfall before reaching the Mallee (aeolian plain) in the most arid portion of the region. At Manfred the annual rainfall is approximately 254mm (10in), and the lowest rainfall in the whole region is 225mm (8·8in) recorded at Karpa Kora between Panban and Darnick. This north-western quarter is distinguished by its summer heat and low, unreliable rainfall.

In this district there are extensive tracts of scrub, typically including mallee. This Mallee country shows its aeolian nature in scattered sand dunes on a more loamy, undulating plain. The soils are solonized brown soils, generally of sandy texture and prone to erosion if cleared. Sparse grazing is the only land use in the north-west of the area,

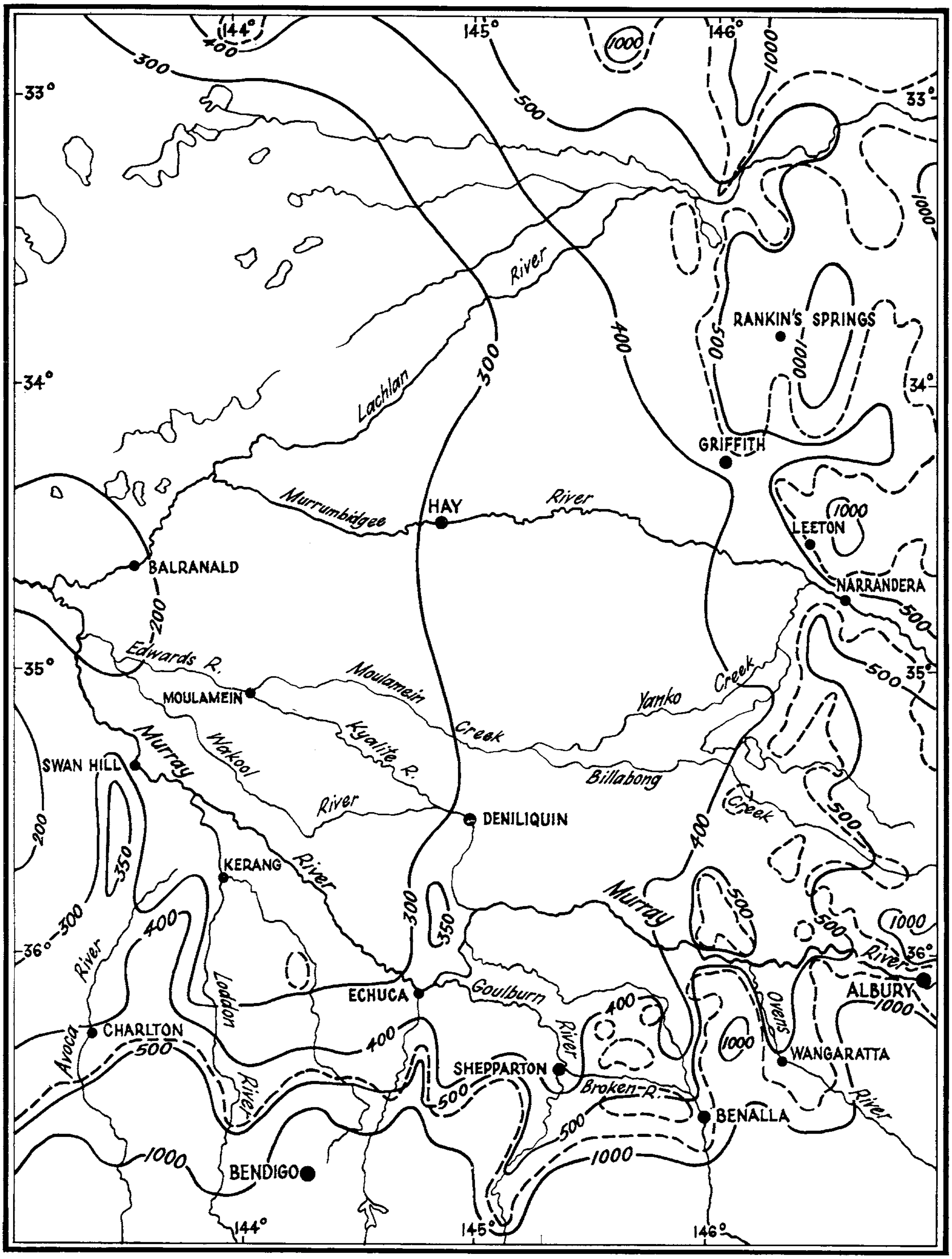

Fig. 4 *Contours in feet above sea level of the mapped area. Level data are more sparse in the north and west. Contours at 1000 ft (305m), 500 ft (153m), 400 ft (122m), 350 ft (107m), 300 ft (92m), 250 ft (76m), 200 ft (61m).*

but further south, in north-western Victoria, the rainfall is higher, and similar country has been cleared and used for wheat growing.

While the main patterns of vegetation, soils, and land use show a relationship to relief and climate, there are special vegetation associations on those sections of the Plain formerly subject to annual flooding after the melting of snow on the high catchment. These areas occur on the Murray River upstream of the Cadell Fault, and downstream of the same feature along both the Murray and the Edward Rivers; a large flooded section also occurs along the Murrumbidgee River below Maude. The flooding extends beyond the immediate terrace section and out onto the plain. The flooded country carries forests of *Eucalyptus* trees or beds of reeds, and the soils are grey clays and silty clays, low in salts, contrasting sharply in both vegetation and salinity with the adjacent, unflooded plains. The main flooded forest areas are shown in Fig. 3.

A more comprehensive statement of the soils of the Plain will be found in the Atlas of Australian Soils (Northcote, 1960, 1962, 1966), Stace *et al.* (1968) and the soil surveys of the region. More detailed statements of the vegetation are given by Beadle (1948), Moore (1953), and Leigh and Mulham (1965).

Geomorphic Features

General setting

The Riverine Plain consists of a series of very gently sloping alluvial fans, and the floodplains onto which they merge. The apices of the fans are at points such as Murchison, Albury, Narrandera, and Hillston, where the rivers leave the foothills. Comprehensive contour data are not available for the whole Plain, but the available data for sections of it – State Rivers & Water Supply Commission (1966) and Schumm (1968a) – show fan forms for the Goulburn, Loddon, Murrumbidgee, and Lachlan Rivers. These show gradients of 1 in 2000 on the fans. Fig. 4 presents the contours for the whole area as well as sparse data allows, and this suggests that all of the fans merge to form one, with the lowest gradients (down to 1 in 7000) on either flank of this, along the Loddon and the Lachlan Rivers respectively. The map also shows that the rivers from the south have a steeper gradient immediately above the 92m (300ft) contour than those from the east.

Several isolated hills occur on the Plain at 36km (20 miles) or more from the main highland areas. These rock outcrops include Mt Wycheproof (approximately 46m (150ft) above the plain), Pyramid Hill (101m (330ft)), Mt Terrick Terrick (95m (310ft)), Mt Boomanoomana (143m (470ft)), the Darnick Range (24m (80ft)), and Manara Hills (122m (400ft)).

Though seasonal snow occurs in the highlands, evidence of Pleistocene glaciation is limited to 50km^2 (20 sq. miles) in the vicinity of Mt Kosciusko (Peterson, 1971) and with an aggregate of 2300km^2 (907 sq. miles) affected by periglacial processes. The highlands adjacent to the Riverine Plain show three old erosion surfaces (Singleton, 1965) the lowest of which is pre-Tertiary in age and carries Older Basalts. Uplift of the highlands occurred intermittently through the Mesozoic and Cainozoic and has resulted in valley incision to depths of 1000m (3000ft) and with associated narrow alluviated plains within the highlands. The long continued action of the streams is signified both by the depth of alluvium accumulated on the Plain and by the presence, close to the present courses, of Upper Miocene to Pliocene buried channels (paleochannels), which were extensively worked for their content of placer gold and tin, and are referred to as 'deep leads' (Hunter, 1909).

The early Tertiary surface is largely confined to the flanks of the highlands, occurring at elevations below 610m (2000ft) and toward the western, less elevated extension of the highlands, it is recognised by its gentle topography and deep weathering.

To the west of the Riverine Plain, in the Mallee, Currey (1966) proposes that the remnants of a peneplain landscape with laterite surface can be seen on the Gredgwin and Cannie Ridges. He suggests this surface may be traced more extensively at about the 116m (380ft) contour to the flanks of Pyramid Hill, to the north of Charlton, and and to Dunbulbalane. Macumber (1969a) has examined the Gredgwin Ridge and found that its core of Upper Tertiary sands and sandstone has been tectonically elevated. From the apparent absence of fluvial sediments on the surface of this block he concludes that the uplift probably occurred early in the Quaternary evolution of the region.

Fluviatile elements

The most widespread geomorphic features of the Plain are fluviatile in character. Stream deposition, and to a lesser degree erosion, have given the Plain its form, besides responding to changes in form such as those due to tectonics. The pattern of modern streams has a number of interesting features, but there are also many geomorphic features which are attributed to earlier stream systems of different character.

Table 1: Discharge of streams of the Riverine Plain. *Source:* Australian Water Resources Council, 1965.

River drainage basin	Possible mean discharge		Variability of flow based on particular gauging stations	
	$ft^3 sec^{-1}$	$m^3 sec^{-1}$	Maximum as percentage of average	Minimum as percentage of average
Avoca	90	2.5	510	6
Broken	332	9.4	425	7
Campaspe	304	8.6	247	9
Goulburn	3430	97.1	189	27
Kiewa	1023	28.9	158	45
Lachlan	1487	42.1	700	3
Loddon	318	9.0	247	9
Murray (upper)	4564	129.3	280	26
Murrumbidgee	4204	119.1	350	17
Ovens	1867	52.8	245	20

Modern drainage

The streams of the Riverine Plain form a tributary system with all tributaries joining to form the Murray River before it leaves the Plain to cross the Mallee region on its way to the sea. The most general form of the rivers is meandering in belts of country 1·5 to 5km (1 to 3 miles) wide and 1·5 to 5m (5 to 15ft) below the level of the plain. Occasionally, as for the lower Loddon River, the meander belt is not entrenched and the meandering river bed is simply incised into the plain.

The variation in stream flow, both from season to season and from year to year, is considerable. The early explorer Oxley (1820) was so misled by extensive flooding on the Lachlan River near Booligal, and on the Macquarie River, that he concluded there was an inland sea in the region. Generally, however, such flooding is of brief duration and is associated with rainfall and meltwater from the highlands bringing peak flow in spring. After periods of low rainfall the smaller streams temporarily dry up, and during widespread droughts even the main streams have almost disappeared at times. A common experience recorded even from the earliest explorers (see Sturt, 1833) was that very low rivers were often associated with saline inflows from the groundwater.

Stream gauging records were begun more than 100 years ago and are now available for many points in the region (Australian Water Resources Council, 1965). Table 1 gives a summary of the mean annual flow of the rivers of the mapped area.

A notable feature of the Murray River system is the common occurrence of downstream branching and anastomosing stream channels. Several major streams have smaller channels branching from them. A case in point is Yanco Creek, which branches away from the Murrumbidgee River about 24km (15 miles) downstream from Narrandera and flows strongly when the main stream floods. It was first referred to by the explorer Sturt (1833).

Two kinds of stream branchings are distinguished on the Plain. One involves the occurrence of an anabranch (Jackson, 1834) in which a stream divides into two channels which subsequently re-unite downstream. Mitchell (1839) applied this term to several streams in eastern Australia, and a good example is provided on the Edward River, which at 8km (5 miles) downstream from Deniliquin branches to form the Edward and the Wakool Rivers, with approximately parallel courses for 113km (70 miles) before their reunion near Kyalite. The other type of stream branching concerns those channels referred to as effluents (Hills, 1940b) and distributaries (Bowler, 1971). These divert flow from the main channels without return to the general tributary system; they terminate in lakes, salt-pans, or dunefields. Several examples occur in the drainage system of the Lachlan below Hillston, where the river breaks into the complex system of creeks described by Mitchell (1839). These include Willandra Billabong* Creek, in the north, and the Umbrella and Moolbong Creeks. Other channels discharging water away from the main tributary system are associated with the Avoca and Loddon Rivers (Hills, 1940b).

Meanders are strikingly apparent on many aerial photographs and on maps, and there is great variation in their dimensions between different stream traces. Abandoned channel remnants and traces of meander scrolls are visible in many meander belts; they mark stages in the evolution of drainage. Changes in the pattern of the Goulburn River near the southern margin of the area and in the positions of its meanders over the period 1841 to 1902 have been described by Gregory (1903).

River channels are generally deep and narrow in cross section with steep banks cut in the clays of the Plain. Details concerning the Murrumbidgee River are given by Sturt (1833) and Schumm (1968a). Evidence of erosion on the outer banks of meanders and of deposition on the inner concave banks is known from the Murray River between Tocumwal and Corowa, but elsewhere the channels do not appear to have changed their position since the surveys were made along this river in the 1920s. The rivers carry a relatively large proportion of their sediment load in suspension, i.e. their load is mainly silt and clay, with only a small component of sand.

Changes due to the Cadell Fault

A striking feature of the Plain is the deflection of streams by the Cadell Fault (Harris, 1939) which extends from Echuca to Deniliquin. The Murrary River, which previously flowed east-west through Mathoura, was defeated there and flowed round the northern end of the Fault in the course now occupied by the Edward River. At the same time a large lake formed near Echuca (Bowler and Harford, 1966) and the Goulburn River maintained this while an overflow channel was cut between Echuca and Swan Hill. A large sandy lunette which developed on this lake was eventually cut through when the Murray River reverted to its present, more southerly course. Bowler (1967) interprets a radiocarbon date near Barmah as indicating faulting about 20,000 years B.P.

Pels (1964a) studied the stream forms associated with the movement of the Cadell Fault. He found that the prior streams (described below) pre-dated the establishment of the fault, and his ancestral rivers (described below) post-dated it and could be subdivided into three stages by evidence adjacent to the fault. Pels (1969a) gives radiocarbon dates for his ancestral river stages as varying between 30,600 and 4200 years B.P.

The Cadell Fault is an extension of the Heathcote-Colbinabbin Axis, and downward movement east of the Colbinabbin Range established a depressed area of internal drainage with its centre at Lake Cooper.

Ancient streams

The surface of the Riverine Plain shows much evidence of relict stream channels, re-

* The term 'billabong', first recorded by Mitchell (1839) in the region and later in common use – e.g. Collins (1943) – has been translated as 'dead river' (billa = river; bong = dead). It has been used as a proper name, e.g. Billabong Creek, as a synonym for creek, and in reference to a cutoff meander or oxbow lake.

ferred to here as ancient streams. These were called *prior streams* by Butler (1950) who later (1958) made a distinction between prior streams and a younger system of stream structures which he called Coonambidgal. Langford-Smith (1960a) mapped out prior streams, which he referred to also as dead river systems, in the Murrumbidgee area. Pels (1964a) proposed the concept of *ancestral rivers* as a further development of Butler's (1958) Coonambidgal Formation, and still clearly distinguished from the prior streams. Schumm (1968a) studied both the prior streams and the ancestral rivers in terms of their channel and meander characteristics, giving them the general designation of 'paleochannels'. The relative place of the Coonambidgal and the prior streams (Mayrung and Quiamong) in regional stratigraphy has been formalised by Lawrence (1966).

Usage has tended towards a separation of ancient streams into prior streams and ancestral rivers on the basis of their form. The prior streams are indicated by low, winding, sandy ridges on the clay flood-plain, and associated with this may be found the winding depression 1 to 2m (2 to 6 ft) deep which marks the old stream-bed. Near these ridges may be found low, fixed sand dunes formed by redistribution of the coarse stream-bed deposits. Generally these were aggrading streams with natural levees. They have been modified until today, the bed levels are higher than the adjacent flood-plains. Skene and Freedman (1944), Stannard (1962), and Schumm (1968a) show that these stream systems were underlain by 6 to 12m (20 to 40 ft) of coarse sands and gravels entrenched in the clays of the plain. Pels (1964b) examined prior streams near Griffith and found several phases of deposition, the youngest of which was older than 36,000 years B.P.

Ancestral rivers are represented by belts of sediment at a level of approximately 3m (10ft) below the general level of the adjacent plain. These strips commonly carry water during floods and are postulated to be remnants of channels much larger than those of the modern rivers (Pels, 1964a). Ancestral rivers form a tributary system which overlaps with parts of the Murray and Murrumbidgee Rivers. Detailed studies of those associated with the Murray are reported by Pels (1964a, 1969a), Bowler and Harford (1966), and Bowler (1967).

Newell (1970) has been able to relate four terraces on the Ovens River at Wangaratta where the river joins the Plain, to the ancient stream traces on the Plain. He finds that the highest terrace becomes the prior stream plain, the others being entrenched in it.

In mapping the ancient streams the authors have decided against mapping prior streams and ancestral rivers *as such* because of the implied association between form and age. As this association may not always occur, mapping is on the criterion of form alone, and only on those aspects observable on air photographs.

Lacustrine elements

The dry basins of shallow lakes, occasionally referred to elsewhere as playas, are distributed widely in the region. They are more numerous in the western part of the Riverine Plain along the lower courses of the Loddon and Lachlan Rivers, and in the eastern fringe of the Mallee zone. There are comparatively few lakes in the accepted sense of the term – permanent, extensive bodies of water – and most of these owe these characteristics to incorporation in systems of irrigation or drainage, in which they serve either as reservoirs or evaporation basins.

Generally the outlines of the lakes are subcircular, elliptical, or kidney-shaped, with a long axis trending north and south. The region accordingly presents an array of oriented lake beds, mainly dry. The western shoreline may be irregular or indented, but that at the east is commonly a smooth crescent, and parallel with it is a dune ridge. The lakes are usually very shallow, and their flat floors often have the characteristics of the adjacent plain.

The dry basins of lakes and swamps vary according to the salinity of their surfaces. Most basins are not perceptibly saline – they support vegetation not characteristically salt-tolerant. However, there are several saline basins (salinas) near and in the Mallee zone. Mitchell (1839) discovered several of these in the Kerang district and believed that they had no connection with the Murray River. Common salt is concentrated at the dry surfaces of several lakes but there are also a number on which 'copi' – flour gypsum – occurs in low dunes, and selenite beds occur below the surface of others, as in the Manara district.

In regard to the origin of the lakes, Macumber (1970) proposed that some lakes were created by deflation of salt-affected areas. Lawrence (1971) has suggested the origin of lakes with saline water as points of groundwater discharge. It appears that some lakes occur as drainage terminals.

Aeolian elements

Landforms of aeolian origin occur only in lowland portions of the region. They are ubiquitous in the Mallee zone but are much less frequent on the Riverine Plain. The most common are those which involve accumulation, especially of sandy material, occurring as dunes or sand-ridges. Deflationary forms are represented by the occurrences of sheet erosion known as scalds, and may also be represented by the occurrence of dry lake basins.

All early reports of the Mallee zone, for example by Mitchell (1839), indicate that the dunes were fixed by native vegetation; they are therefore relict features. It is possible, however, that the deflationary features are largely modern, because the scalds appear to have become much more widespread since exploration, and the explorers scarcely referred to experiences of wind-borne dust in the region. It is true that Charles Darwin commented on a dust-storm he experienced in the Bathurst district in January 1836, that Paul Strzelecki (1845), the explorer, observed deposition of dust from strong winds when he was 96km (60 miles) out to sea from Sydney in 1845, and that dust was seen from ships near Port Phillip in 1856 (Lewis, 1950). Nevertheless only Sturt (1833) made reference to dust in the air, from an area north of Hay.

Tracts of land showing a widespread and distinctive pattern of dunes are referred to here as dunefields. Bowler *et al.* (1970) refer to two types of dunefield in the Mallee zone: a common type characterised by parallel ridges; another showing an irregular dune pattern. The parallel ridges vary in height, being commonly 6m to 10m high (18ft to 30ft). They have an open spacing with approximately 0·5km (0·3 mile) between adjacent ridge crests. The ridge sides curve smoothly and have slopes which generally do not exceed 6^0, according to data given by Hills (1939), Churchward (1960), and Rowan and Downes (1963). This slope gradient is much less than those recorded for parallel dunes still active in Australia (Madigan, 1946) and is consistent with the relict character of the Mallee ridges. The fairly common trend of the ridges in this region is west-east, a direction common to other parts of the Murray Basin, though not to many other parallel ridge formations in Australia (Jennings, 1968).

The sand ridges of the Mallee region are typically brown in colour, contain soft lime and/or calcrete, and contain a significant amount of clay in the subsoil.

In the second type of dunefield, that with irregular dunes, a comparatively large proportion of the land is covered by dunes. They are generally higher and steeper than the parallel ridges, and their crests wind about and intersect. Frequently the soil is paler and contains less clay and calcrete. Although they are irregular by comparison with parallel ridges, it is possible to distinguish features of parabolic dunes, and Bowler (1971) referred to irregular sub-parabolic dunes to the east of several drylake basins of the Willandra Creek drainage system.

The aeolian features on the fluviatile plains are more isolated than those in the Mallee zone, and comprise lunettes and source-bordering dunes. Lunettes generally have a regular crescentic shape, exactly fitting the curvature of the lake basin immediately to their west, but there are some situations where erosion has reduced a continuous ridge to several segments. The length varies from 200m to 30km (650ft to 10 miles) and the height from 3 to 50m (10 to 160ft). Lunettes vary in composition from clays to sands; they may be gypseous or saline or free of these salts. Adjacent lunettes may show very different soils (Sargeant and Newell, in press) and degrees of leaching, indicating their continued formation over a long period.

These landforms were first reported by Mitchell (1839) from several parts of the region, and were later described by Harris (1939), Hills (1939, 1940a), and Bowler and Harford (1966). Prior to their designation as lunettes by Hills (1940a), these landforms were referred to as loam or clay ridges, in distinction from sand ridges. Lunettes have been considered by Price (1968) as an expression of clay dunes, but the terms are not synonymous in view of several descriptions of sandy lunettes. Furthermore, observations by Bowler (1971) indicate that the sandy sediments of lunettes correspond with a full lake condition in contrast with the dry lake condition generally associated with the deposition of clayey sediments on the lunette. Bowler (1971) found the last lake-full stage of the lunettes along the Willandra Creek was dated 24,000 to 17,500 years B.P., and the saline, drying phase 17,500 to 15,000 years B.P. This site has yielded human remains dated at 26,000 B.P., the oldest yet established from Australia (Barbetti and Allen, 1972; Bowler, Thorne and Polach, 1972).

Sand dunes, fixed by vegetation and varying in height from 3 to 15m (10 to 50ft), are to be found in many parts of the Riverine Plain and are thought to be derived from the sandy deposits of ancient streams. Those near the Murrumbidgee River system were identified by Langford-Smith (1960a) as source-bordering sand dunes. The dunes are often complex in form but basically ovoid. Linear dune development contiguous with some source-bordering dunes has been reported from the Coleambally district by Pels, Stannard, and Talsma (1968). Most of the source-bordering dunes are associated with prior streams but there are also examples of similar dunes associated with ancestral rivers, as shown by Pels (1964a) and Bowler and Harford (1966).

The third aeolian landform of importance on the Riverine Plain is the scald, a deflationary feature. According to Beadle (1948), scalded country has existed in western New South Wales for 50 years or more. He defined the scald (p. 55) as a bare area produced by the removal of the surface soil by the wind, with the consequent exposure of the subsoil which is or becomes relatively impervious to water. The loss of soil varies from small patches a few feet in diameter to vast areas of several square miles. The association of scalds with prior stream levees in New South Wales has been stressed by Pels (1964b) and Jones (1969). Occurrences of scalds in the Victorian portion of the region are reported by Rowan and Downes (1963), particularly from sites on the Riverine Plain.

Parna, the aeolian clay deposit named by Butler (1956), is claimed to be widespread in the region (Butler and Hutton, 1956). Besides occurring as the 'loam lunette' it occurs as a thin mantle 1·5 to 4 ft thick over much of the Plain and the fringing foothills.

Churchward (1963a) has reported detailed studies on sand dunes at Swan Hill which indicate both a source and an addition of parna in these dunes. Detailed studies of the distribution of parna on the Plain and in the Mallee are not available, and its mapping in these regions is likely to be difficult since the parna has no geomorphic form of its own, but mantles other forms.

Mapping Criteria

Of recent years attention has been given to mapping country in geomorphic categories. Instances of this work are published by Klimaszewski (1963) and Tricart (1965), and the objective is to provide a comprehensive geomorphological statement by identifying all geomorphic processes in operation, and mapping geomorphic elements in terms of these processes throughout all parts of the area under consideration. In the present undertaking the authors doubt if research on the Riverine Plain has developed far enough to allow mapping of this kind. Nevertheless they believe that the understanding of some of its fluvatile and aeolian features has gone far enough to make their mapping interesting. But even when restricted to these elements it is felt that the interpretative aspect should be reduced to a minimum, and the mapping criteria stated in objective photo-patterns.

In keeping with this stand 'prior streams' and 'ancestral rivers' are not mapped as such, since their identification is an interpretation of evidence; but all evidence of streams is classified and mapped as *confined* or *unconfined* stream traces (as defined below). It is probably true that most ancestral rivers are confined, and most prior streams are unconfined, but where relative age is a criterion, as it is between ancestral rivers and prior streams, other evidence is needed, and this is not generally available for mapping. Objective mapping of photo-patterns has the advantage of allowing new extrapolations to be made when new relationships are discovered. Some of the differentiations which have been made on the map have as yet no proven geomorphic significance; such would be the difference between 'plain' and 'plain with depressions', or the difference between 'plain with channels' and 'plain with drains'. These can be objectively distinguished and mapped from the air photographs, and being based on landscape elements, they have been included; their interpretation, however, is not attempted here.

The mapping operation here has comprised two parts: the delineation of *features* of a fluviatile, aeolian, and lacustrine nature, being of a restricted form and extent; and the *plain classification* or the identification and.demarcation of the broad areas on which these features occur.

Mapped features

Stream traces
These are all features on the aerial photograph indicative of stream flow. They are classified first into either 'confined' or 'unconfined'. The confined stream trace (symbol C) has a clearly marked boundary, other than the bank of the channel, separating it from the plain on either side. The unconfined stream trace (symbol U) is one having no boundary, except the channel bank, separating it from the plain.

Confined stream traces – CS and CO The confined stream traces run in belts separated from the plain by visible boundaries. Their character within the confining boundaries is the basis for further subdivision of this group; if outlines of meander scrolls are discernible the classification is CS; if not it is classified CO. These are illustrated in Plates I, II, and III.

The confined stream traces have a further categorisation: where it appears that one depositional pattern has been partly cut out and replaced by another pattern, the symbol II is added to the CS or CO. Where a third pattern again is replacing a second, the symbol III is added.

The confined stream traces, CS and CO, are quite frequently wider than 650m

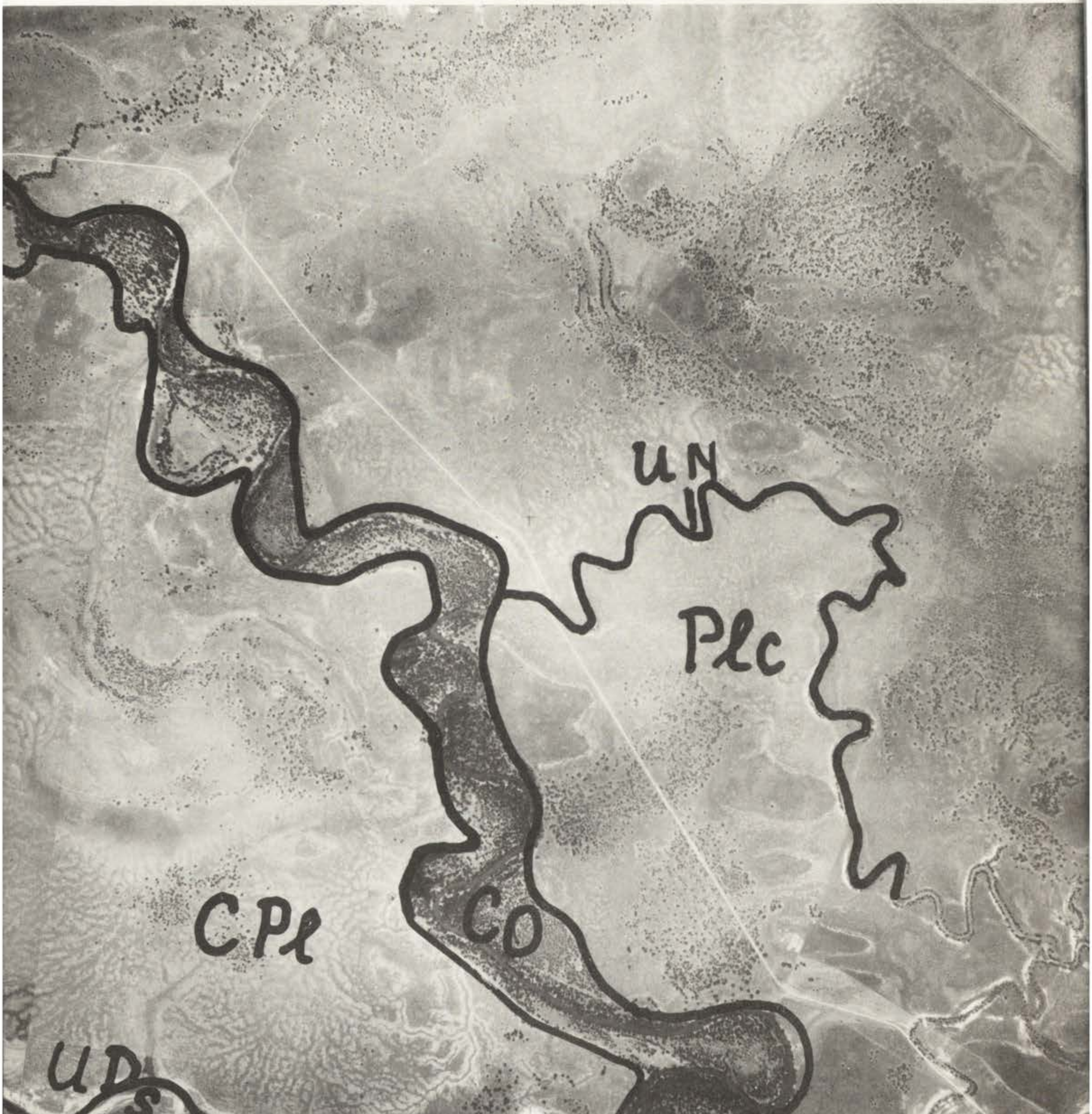

Plate I *Aerial photograph illustrating channel plain (CPL), plain with channels (Plc), confined stream trace with other than scroll bar deposition (CO), unconfined stream trace without deposition (UN), and unconfined stream trace with small amount of deposition (UDs)*

(2,130ft) and their width is shown to scale and printed in a characteristic colour. However, where they are narrower than 650m they are indicated by a characteristic line which is not to scale.

Unconfined stream traces – UD, UDs and UN The unconfined stream trace has no visible boundary, other than the channel bank, separating it from the plain. These stream traces are subdivided into UD with deposition, and UN with no deposition. They are illustrated in Plates I, II, IV, and V.

On the air photograph a faintly shaded zone on either side of the stream trace indicates deposition, and this merges imperceptibly into the plain without showing a boundary. This stream trace has the symbol UD. The stream bed only can be marked on the

Plate II *Aerial photograph illustrating plain with drains (Pldr), scalded plain (SPL), confined stream trace with scroll bar deposition (CS) and unconfined stream trace with deposition (UD). The two upper plain sections are not characteristic enough to be labelled in this photograph.*

map, and since it is always less than 650m wide it cannot be shown to scale. Rarely, and as an informative designation, UDs is used to denote a *smaller* amount of deposition than usual.

The separation of stream traces into the two classes, confined and unconfined, seemed to work unambiguously. However, the nearest call to an ambiguous case is in the stream trace lying south-south-east from Nathalia. This is mapped as confined, but it does show some of the vagueness of outer boundary which is associated with UD stream traces, and is elevated above the plain level.

The UN stream trace is a stream bed without any shading or other indications of deposition, and without any boundary separating it from the plain. Since the UN and UD stream traces are to be regarded as geomorphologically very dissimilar, their design-

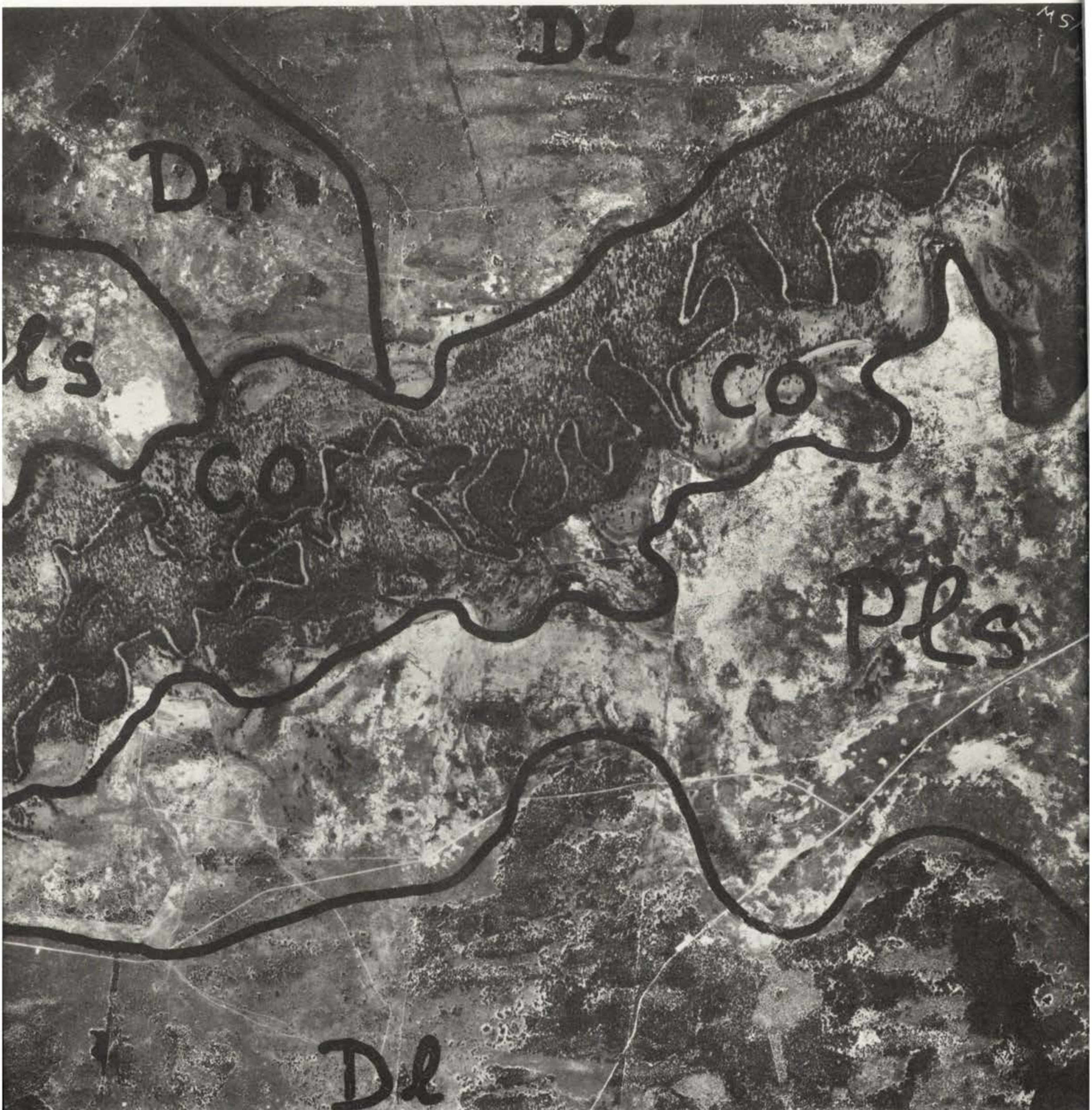

Plate III *Aerial photograph illustrating confined stream trace with deposition other than scroll bars (CO), plain with scald (Pls), linear dunefield (Dl) and normal plain of indistinct character (Dn)*

ations on the map are contrasting. The UN map inscription is made alongside a stream trace which is a blue line, identical with that used on the base map for streams and rivers generally. Neither the UN stream trace nor the river beds exceed 650m in width so this attribute is not shown to scale. In many cases the UN inscription identifies the form of a stream already existing on the base map; at other times it is a stream trace drawn on the map from the air photograph.

Obscure stream traces – UO Mapping with the foregoing classification and using air photographs gave satisfactory results over most of the region. However, for the unconfined stream traces it became apparent that there is a zonal difference in the air photographs. They have the 'typical' appearance in the lower rainfall sectors but in the higher rainfall sectors they are more obscure. In the lower rainfall areas the sparser ground cover and the natural zoning of plant species according to soil and slopes make the air photographs very revealing. But in country of higher rainfall, and especially where the sowing of crops has imposed its own pattern and uniformity on the land, unconfined stream traces are traced on the air photographs with diminished confidence.

To increase confidence of recognition of UD traces in these areas, other means of mapping are needed. Soil surveys on the Plain have revealed an association between soil types and the unconfined streams, and this enables one to draw stream traces from the soil map. The soil types of the unconfined stream trace are red-brown earths with 20cm (8in) sandy loam A horizons and sandy textures again below about 75cm (29in). They occur as elongated, more or less continuous ridges which are slightly raised above the more clayey soils of the plain, and they are often associated with sand dunes and a weakly depressed, sandy 'stream bed'. The vegetation is characteristically different from that of the adjacent plain; *Callitris glauca*, *Eucalyptus melliodora*, and *Hakea leucoptera* being common. The stream traces so derived from soil maps in this way are associated with the unconfined stream traces but because of their different definition they are mapped UO in place of UD.

Soil maps are not, however, available over the whole area where unconfined stream traces are difficult to discern on the air photograph, so field traversing has been used to complete the mapping. In the field the unconfined stream traces are recognised by the soil and topographic characteristics described above. Though to the uninitiated unconfined stream traces are rather subdued features in a subdued landscape, and therefore hard to detect, a little experience enables most interested observers to identify them. Stream traces so mapped are also inscribed UO.

The obscure stream traces, UO, whether identified from soil maps or from field traversing, are inscribed along the same symbol line as the UD stream trace because of their close relationship; however, the different symbol informs the reader which criteria of identification have been used in each case.

The problem of identifying unconfined stream traces in the higher rainfall regions does not extend to the identification of the confined stream traces, which are therefore treated uniformly across the whole map.

The symbols CS, CO, UD, UO, and UN, whichever is appropriate, printed along the stream traces at intervals, designate the characteristics of the stream trace at that section; the designation does not necessarily refer to the whole length of the stream and is changed according to the evidence on the photograph. Where changes of designation occur along the stream the point of change cannot always be shown; it may be obscure, or scale may not permit.

In cases where changes in designation occur along the length of a stream, and the feature is less than 650m wide, the symbol for all classes of stream is a line, though differing in colour according to the classification. This calls for the reader's particular attention to the finer detail of the map in these cases, and where a modern stream of some magnitude is involved, a continuous underline of blue has been retained to aid the appearance of continuity in the stream.

Lacustrine features

In mapping lacustrine features distinction is made between lakes and swamps; the latter having the more vague and irregular borders. Lakes are sub-divided as permanent on the one hand, and intermittent or dry on the other. No distinction is made between permanent lakes which are naturally so and others which are artificially maintained by channel supply or drainage.

Some intermittent or dry lakes, especially if very large, have the usual characteristics of plains. Where this is so the plain classification (see below) is applied to them. Where lakes contain deposits of gypsum this is shown by the symbol G.

Only lakes and swamps larger than 650m (2130ft) diameter are shown on the map; they are drawn to scale.

Aeolian features

Aeolian activity is expressed in the region as dunes and dunefields on the one hand, and as areas of wind-eroded, or scalded land on the other. Where dunes occur individually they are classified and mapped separately; but where they occur repetitively in a recognisable pattern they are classified as a plain type dunefield, the subdivision of which is discussed below. Wind erosion – scald – is used as a criterion for subdividing the alluvial plains, and this also is discussed below.

The individual mapping of dunes is on the following bases: *(i)* Source-bordering dunes: usually occurring along certain stream traces; they are often ovoid or poly-ovoid in shape. Shown by shape and map colour if larger than 650m (2130ft), otherwise by the symbol 'D'. Individual dunes of this type are not always recognisable on the aerial photograph, and it is possible that some dunes have not been recorded. *(ii)* Lunettes: crescentic dunes primarily on the eastern side of lakes. Shown by shape and map colour if larger than 650m, otherwise by the symbol L.

Plain classification

The plains and backgrounds on which stream traces and aeolian features are drawn are classified according to features showing on the air photograph. The primary classification is: *(1)* Alluvial plains *(2)* Dunefields *(3)* Plains of indistinct character *(4)* Marginal highlands.

The alluvial plains are readily identified on the air photograph by patterns of water-marked depressions, channels, and depositional features such as levees or scrolls. Dunefields are also easily identified from their regular pattern of dunes. However, the group called plains of indistinct character are less readily defined, though their most consistent features are evidence of windwork – small, widely separated dunes and wind eroded scalds. But even these tend to disappear in the higher rainfall zones. Nevertheless these are plains of loamy soils and sands, and are distinct from the outcrops of folded and indurated rocks of the marginal highlands.

Alluvial plains

These are subdivided according to natural features present on them – depressions, channels, scalds, or drains – and each class is subdivided again according to the extent to which the feature modifies the plain – negligibly, moderately, or strongly. These degrees of effect are broad classes only, and their expression as percentage of the area affected should not be construed precisely. The classification used in mapping is:

(i) Plains, Pl. These have a negligible proportion of depressions, scalds, channels, or drains.

(ii) Plains with depressions, Pld. These are influenced in 10 to 50 per cent of their area by depressions which are regular in shape, usually circular, and seem to accumulate water for very short periods. They are remarkably consistent in appearance and are shown in Plates IV and V.

(iii) Plains with scalds, Pls. The scalds – wind erosion of the surface soil – seem to

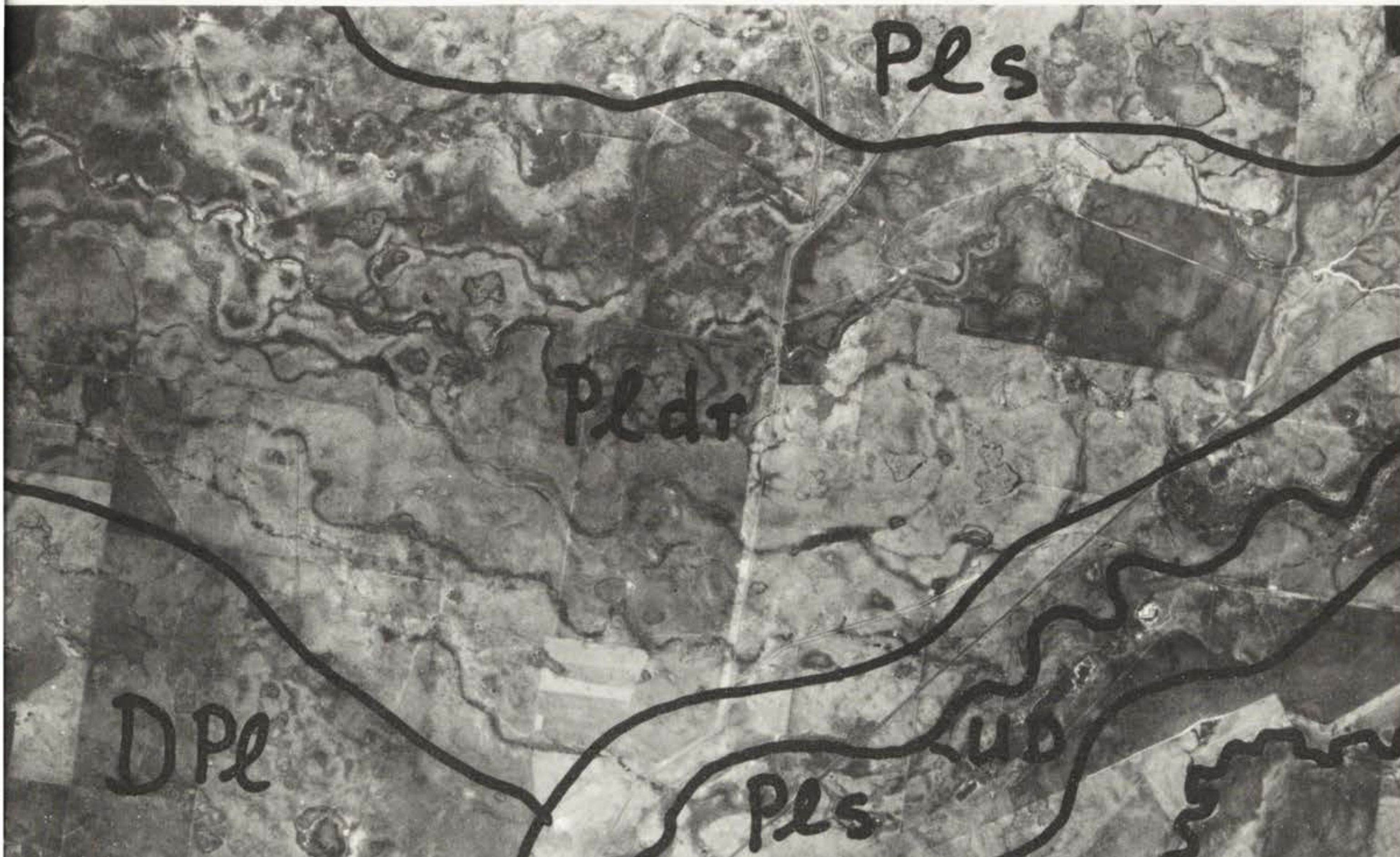

Plate IV *Aerial photograph illustrating unconfined stream trace with deposition (UD), unconfined stream trace with no deposition (UN), confined stream trace with other than scroll bar deposition (CO), plain (Pl), plain with depressions (Pld), plain with drains (Pldr), plain with scalds (Pls) plain with channels (Plc) and depression plain (DPL)*

underline the aeolian nature of the present geomorphic environment; however, the alluvial character of the plain is emphasised in so far as the levees are conspicuously more susceptible to erosion than the adjacent floodplain. In this class 10 to 50 per cent of the area is affected by scalds, as in Plates III, IV, and V.

(iv) Plains with channels, Plc. These are influenced in 10 to 50 per cent of their area by channels or gutters, often in an anastomosing pattern. These plains seem to be prone to occasional flooding, and forests may be present. They are shown in Plates I, IV, and V.

(v) Plains with drains, Pldr. The features called drains are wider and straighter than those called channels. An example is shown in Plates II and IV. In this class 10 to 50

Plate V *Aerial photograph illustrating unconfined stream trace with deposition (UD), unconfined stream trace without deposition (UN), confined stream trace with scroll bar deposition (CS), plain with scalds (Pls), plain with channels (Plc), plain with depressions (Pld), and source bordering dunes (D)*

per cent of the area is affected by drains.

(vi) Depression plains, DPL. This carries the character of plains with depressions a stage further; more than half the area is affected by depressions. Plate IV gives an example.

(vii) Scalded plains, SPL. This carries the character of plains with scalds a stage further; more than half the area is affected by scalds, and thus the case for regarding this as an aeolian rather than an alluvial landform is strengthened. However, depositional features of the aeolian regime are lacking whereas alluvial deposition patterns are very conspicuous. Plate II gives an example.

(viii) Channelled plains, CPL. This carries the character of plains with channels a stage further; more than half the area is affected by channels. Plate I gives an example.

Plate VI A & B *Aerial photographs illustrating linear dunefield (Dl), irregular dunefield (Dr) and normal plain of indistinct character (Dn)*

Dunefields

These are characterised by sand dunes so spaced that the tracing of every fourth dune on the air photograph presents a recognisable pattern. Dunefields are clearly the result of wind action, and they are classified on the map as: *(i)* Linear dunefields Dl. The dunes are linear and parallel. See Plates III and VIB. *(ii)* Irregular dunefields, Dr. The dunes have an irregular to sub-parabolic form. See Plate VIA.

The frequency and form of the dunes is indicated on the map by the fact that every fourth dune has been traced. Tracings of this kind are general for the dunefield classes, but will also be found occasionally on plains of indistinct character (Dn) and on alluvial plains, when applicable.

Plains of indistinct character

These seem to be nearest in character to the dunefield class, but lack the frequency of dunes. They also lack the fluviatile markings of both the alluvial plains and the highlands. Indications of wind action are often present in the form of small scalds, and of coppice dunes (Melton, 1940). However, the proportion of these runs down to nil es-

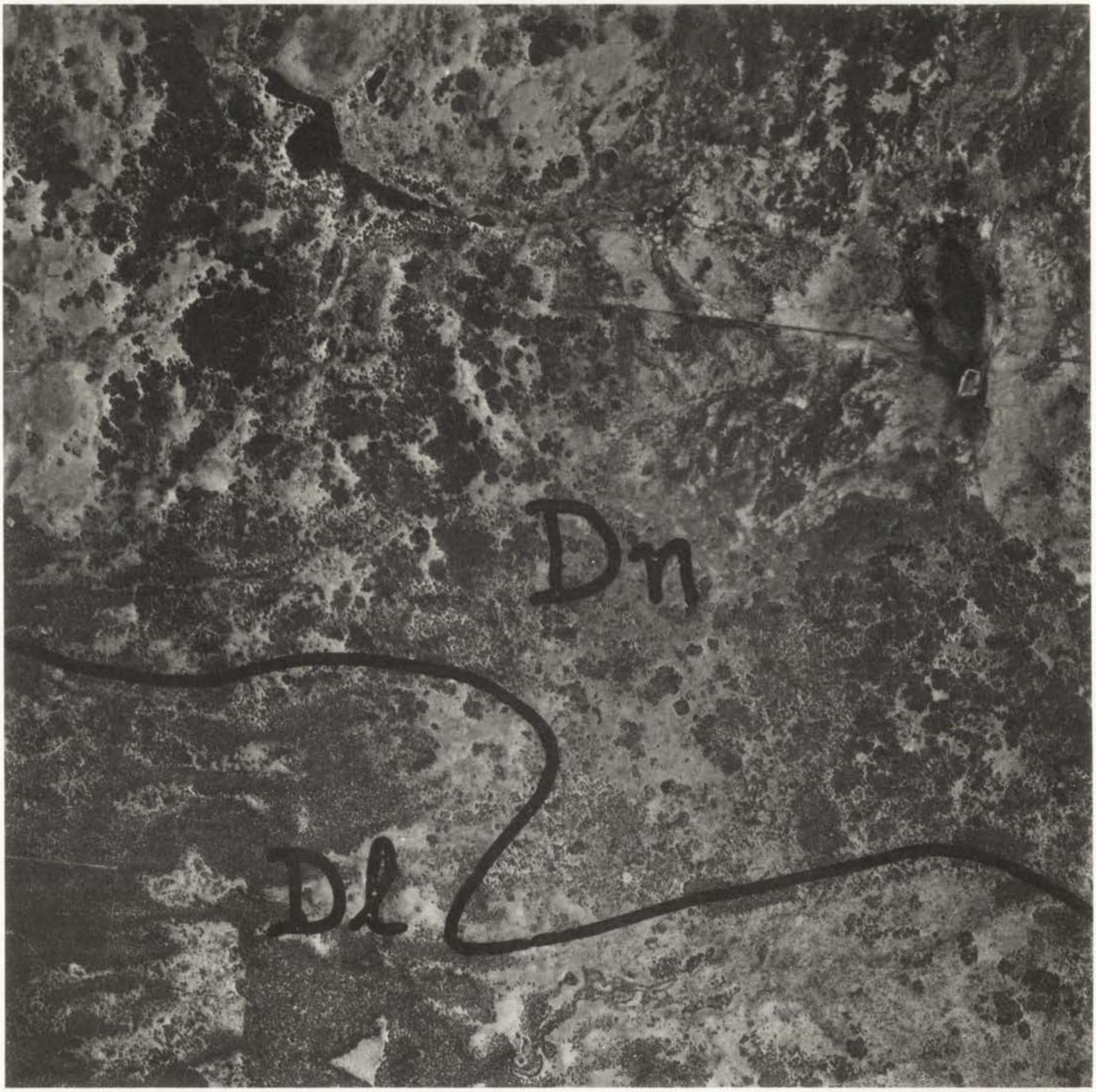

Plate VI A & B *Aerial photograph illustrating linear dunefield (Dl), irregular dunefield (Dr) and normal plain of indistinct character (Dn).*

pecially in the south-west of the mapped area.

This class is subdivided: *(i)* Normal to this class, Dn. See Plates III and VIB. *(ii)* Separated from this class, Plx. This subdivision corresponds with those areas, in the south-west of the mapped area, where Tertiary marine sands are close to the surface. It is a gently undulating landform with few or no dunes, and some fluviatile dissection.

Marginal highlands

In this project interest in the marginal highlands is limited to a few features. The occurrence of flights of terraces is shown by spot information as to the number of terraces T_2, T_3, but they cannot be delineated on the map at the scale used. It is likely that this information is very incomplete.

The boundary of the highlands, outlying hills, and embayed plains is taken from geological maps of the Victorian Geological Survey and the New South Wales Geological Survey Branch. The boundary is modified in appropriate places by the interpolation of a class, alluvial apron (symbol AA), between the plain proper and the outcrop. This is always of minor extent and is recognised by an intermediate drainage pattern occurring between that on the hills and that on the general alluvial plain. It also includes the smaller tributary valley fills.

The geologic units of the highland areas are taken from the maps of the Victorian Geological Survey and the New South Wales Geological Survey Branch, the details of which are greatly condensed for the present mapping. Tertiary formations are distinguished and grouped as Tertiary basalts (Tv) and Tertiary sands, gravels, and conglomerates (Tg). The remaining area is Palaeozoic and this is subdivided into Palaeozoic granites (Hg) and Palaeozoic sediments (Hp).

Modification of the Environment due to Land Use

Evidence on the environment at the time of the early explorers is uneven though explicit. Sturt (1833), when travelling down the Murrumbidgee River at Maude, remarked on the great extent of the plains there, their treelessness, and the fact that the grasses of further east were replaced by 'misembrianthemum and salsolae' *(sic)* (*Dysphyma* spp. and saltbush or *Atriplex* spp.). He wrote 'it appeared as if the river was decoying us into the desert'. Nearer to the foothill margin of the Plain conditions were much more salubrious, as reported by Mitchell (1839) for the country south of Pyramid Hill. He wrote glowingly of the park-like setting of trees and grasses.

Considerable changes affecting the surface of the land and the drainage of water have occurred in the period of nearly 150 years since the first explorers traversed this region. Some changes occurred early, and some late, and it is convenient to discuss the changes in three periods.

1830 to 1880

In the period 1830 to 1880 the principal effect of land use was on the vegetative cover, and it was due to grazing. The first settlers followed closely behind the explorers with sheep and cattle, following the water courses and moving away from these as the seasons permitted. Significant changes in the vegetation were observed as early as the 1840s as reported by Williams (1962) and Buxton (1967). It seems there was a general reduction in the proportion and regional distribution of saltbushes (*Atriplex* spp., *Kochia* spp.). The more palatable species were eaten out, and grasses, mainly indigenous species, spread in their place. Though ecologists now tend to regret this change (Williams, 1962) contemporary evaluation of it seemed to be otherwise. Buxton (1967, p.25) records John Phillips of Warbreccan (Deniliquin) stating 'the old wild herbage had disappeared, giving rise to a better and more uniform description of grasses'.

Williams (1962) mentions other vegetative changes as possibly involving an increased distribution of pine (*Callitris* sp.) and boree (*Acacia pendula*). The latter is a major tree of the savannah zone in the central part of the Plain, and its increased spread would mean an effective expansion of the savannah zone at the expense of the treeless zone (Fig. 3). As against this trend of increasing tree cover, the practice of 'ringbarking' – killing trees so as to increase the growth of grass – was general.

Reports of extreme pasture depletion and soil erosion occur for the lower rainfall portion of the Plain quite early after settlement. These events were associated with the incidence of cumulative droughts, and often with certain vicissitudes of the livestock markets.

The reed beds in the seasonally flooded sections of the plain proved to be of great value for fattening cattle, so much so that they were rapidly depleted (Williams, 1962, p.425) and now only those below Maude on the Murrumbidgee river still have this reputation.

1880 to 1930

The period 1880 to 1930 is marked by three important changes: the spread of rabbits throughout the plain, widespread development of arable farming, and the initiation of irrigation. Rabbits spread northward from Geelong, Victoria, in 1862, crossed the Murray River about 1879, and by 1885 had infested many parts of the region, with widespread damage to herbage. They spread along streams and patches of sandy ground.

Almost one million rabbits were killed on one pastoral holding in 1880, and some holdings were temporarily abandoned (Buxton, 1967). The infestation of rabbits further aggravated the inroads of soil erosion and pasture depletion.

The opening up of the Plain for selection by small farmers became an issue in the 1860s. However, arable farming did not become widespread until about 1880, even though by that time it was well established near Albury and in several districts of Victoria. These developments were most successful in the areas of higher rainfall on the foothill fringe where the native vegetation was woodland. With the introduction of farming most of the trees were removed and indigenous grasses were replaced by crops, weeds, and introduced pasture species. Insufficiency of rainfall proved a limitation to farming success, but later subdivision plans after World War I were nevertheless pushed beyond the then boundary to Finley, Wakool, Urangeline, Rennie, Stony Crossing, and Benanee. Some of these plans failed, but much land was cleared and ploughed during the period of trial.

Irrigation of small sections of land by simple stream diversions was occasionally practised from the earliest times and Buxton (1967, p.46) gives some account of this. By the 1890s small community projects or trusts had passed through early failures to an effective form of intensive irrigation farming (see Martin, 1955, for experience at Shepparton in this period). Large scale irrigation enterprises for the production of fodder crops, cereals, and fruit were established by 1890 on the Goulburn, Campaspe, Loddon, and Murrumbidgee Rivers. Davidson (1969) estimates that by 1920 the total area under irrigation was 42,000 hectares (350,000 acres), most of it south of the Murray River.

Problems of salinity and waterlogging made their appearance soon after irrigation began. Baldwin, Burvill, and Freedman (1939) mention extensive salting and waterlogging in the Kerang district about 1910. Concern over these and similar problems elsewhere in the Murray system caused a committee to be set up by the Council for Scientific and Industrial Research in 1926 (Taylor, 1970) to advise on reclamation. This committee proposed that soil surveys should be made as a step towards a better understanding of the problem. Soil surveys have been made in later years over a considerable part of the Plain, and have assisted in handling its irrigation problems as well as contributing largely toward an understanding of its geomorphology.

Since 1930

Since the 1930s the major development in the region has been the further expansion of irrigation and of the effects of irrigation. By 1970 (Gutteridge, Haskins, and Davey, 1970) the total irrigation in the region was estimated at 931,000 hectares (2,300,000 acres). Storage dams have been built on all the significant rivers so that control of the river flow can be managed to suit irrigation needs. Very low flows and cessations of flow have been effectively eliminated, and only major floods would now pass along the river, normal flood crests being retained by the dams. The river regime now is thus very different from that under which the current stream beds developed.

Experience has revealed a marked interaction between geomorphology and irrigation development. The sandy loam soils along the prior streams have proved suitable for a wide range of crops, whilst the heavier soils of the flood-plains have proved of limited suitability, being restricted to rice and annual pastures.

Continued irrigation of the older areas and its introduction to new areas has led to further extensions of waterlogged and salty conditions, resulting from rising water tables. The broad picture of groundwater levels and its salt levels is given by Gutteridge, Haskins, and Davey (1970). It shows extensive areas of shallow saline groundwater in the Kerang and Wakool districts, and it indicates that groundwater levels will continue to rise both in these districts and in other irrigated areas. Pels's unpublished data are cited to show that groundwater levels and salting are strongly influenced by the aquifer systems of both the prior streams and the ancestral rivers. Their effect is to aggravate the seepage and salinity problems by excessive intake over the lighter textured soils.

Reclamation of salt-affected areas has involved both surface and subsoil drainage, the latter including deep tube-well pumping with the purpose of lowering groundwater levels. Many extensions of these practices are foreshadowed by Gutteridge, Haskins, and Davey (1970). In some districts, especially those on the apices of the prior stream alluvial fans, where groundwater is of low salinity, drainage water could be re-used for irrigation, and the prospects of efficient, permanent irrigation are good. However, in other districts where groundwaters are saline the problem is more serious. Both the natural groundwater discharge and the artificial drainage finds its way into the rivers, and causes a serious decline in the quality of water in their lower reaches. It is proposed to meet this problem by pumping the saline drainage to evaporating basins, either artificial or suitably placed dry lakes.

Map Reliability

The base map was prepared from plans by the Department of Mines, New South Wales, and the Department of Crown Lands and Survey of Victoria. The standard of reliability of the geomorphic mapping is set by the fact that boundaries were drawn from air photographs and photomaps of scale 1:50,000 or 1:100,000. This gives sufficient detail on all points except for some uncertainty in the recognition of some vegetated dunes. There is also some variability in the recognition of UD stream traces (unconfined with deposition); as explained above there is diminished confidence in the recognition of UD stream traces in the higher rainfall country where trees and the blanketing effects of agriculture obscure the evidence which is adequate elsewhere. An effective boundary in this respect is that between the savannah vegetation and the woodland. This boundary is repeated from Fig. 3 on the Reliability Map Fig. 5.

Soil surveys have been made in many areas, and their data have been used to indicate the location of UD stream traces. This improves the reliability of mapping these features, and consequently soil surveyed areas are shown on the Reliability Map. Soil surveys are particularly valuable in enhancing reliability of UD stream traces in the woodland country, but it must be taken that they also enhance reliability in the savannah country beyond that obtained by air photographs alone.

It will be seen that soil surveys cover a large part of the area where the reliability of UD stream traces would otherwise be inferior. Where no soil survey is available, but evidence suggested the extension of UD traces, field traverses were made to fill in the detail. Boundaries derived from field traverses should be regarded as of high reliability. The location of field traversing is shown on the Reliability Map.

The more general question of map reliability revolves around the question of stability of the data. The preceeding section on the modification of the environment since European settlement indicates that some background data may have changed considerably. The flow regimes of the rivers have been greatly changed by the construction of storage dams and diversion weirs, and the control of flow to meet the needs of irrigation. The response of the Plain to irrigation has also been strongly marked, with water and salt levels in a rapid state of flux and causing damage.

There seems little doubt that the extent and severity of wind erosion has increased in the last 100 years, and thus the aeolian features on the map, especially the state of scalds, are transient.

Changes in vegetation have been marked, both by the wholesale clearing of land in the argicultural areas, and by possibly major changes in the boundaries and content of plant communities in the savannah and treeless zones.

The present study has nevertheless revealed that a number of these conditions of flux are related to geomorphic features, and thus the geomorphic map will serve a valuable purpose in guiding the management and planning to overcome practical problems.

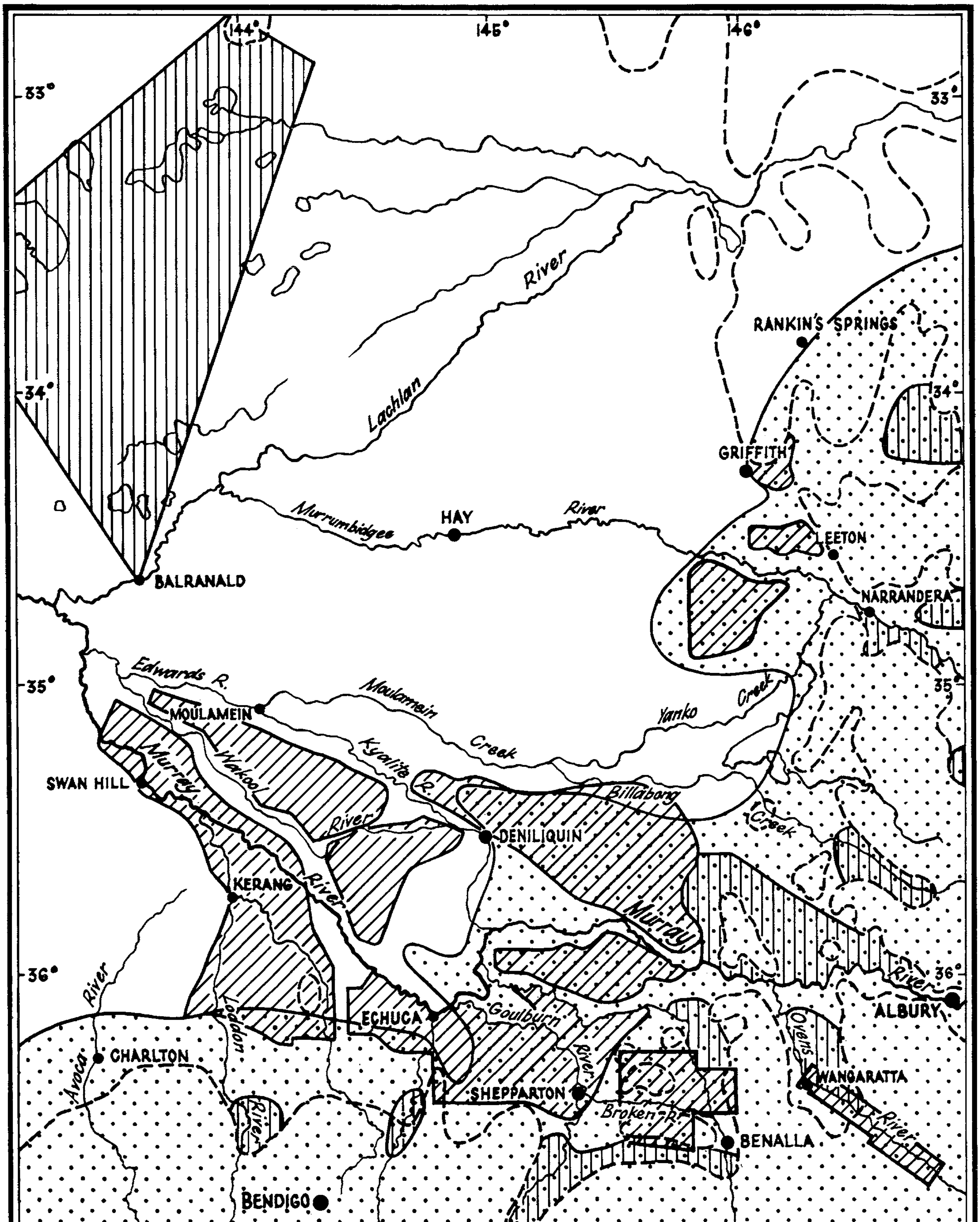

Fig. 5 *Reliability map. Reliability is indicated by visibility on aerial photographs, by the availability of soil maps and by recourse to field traversing. The stippled area is the woodland zone, diagonal hatchuring indicates soil surveyed areas, and vertical hatchuring covers areas where field traversing for this mapping project was done.*

Discussion

The map reveals some regional contrasts which could prove of interest. There is a relative absence of UD stream traces from the Lachlan River – though these are known by one author (B.E. Butler) to be well developed higher up that river. The difference between the Murray and Murrumbidgee Rivers in the form and extent of their UD systems is quite marked. The Murrumbidgee system is a perfect fan, whilst the Murray system, having several hilly sections to traverse, has two imperfect fan forms in downstream sequence.

A profusion of confined stream traces is associated with the Cadell Fault, with more on the downstream side than the upstream side. A number of confined stream traces are associated with the Lachlan distributary system, otherwise this type of stream trace has, for the Plain as a whole, a simple tributary pattern leading to the present rivers' exit from the Plain between Swan Hill and Balranald.

The UD stream traces in contrast have a distributary pattern and tend to dissipate before the Plain is crossed. It is interesting to note that many small streams, for example Mirrool Creek, are associated with characteristic UD stream traces, though these only occur at the first debouchment onto the Plain.

In a few instances the designation of a stream trace changes down its course, indeed allowance for this possibility was one of the main reasons for the particular classification of fluviatile features adopted.

References

All references in the foregoing text are listed below, together with a selection of other references covering the broader fields of physical science inquiries on the Plain. These include most of the published soil surveys, and papers on debated issues. A few unpublished reports are included.

Australian Water Resources Council (1965). *Review of Australia's water resources (stream flow and underground resources)* **1963.** Department of National Development, Canberra.

– (1971). *Stream gauging information, Australia – December 1969.* 2nd ed. Department of National Development, Canberra.

Baldwin, J.G., Burvill, G.H., and Freedman, J.R. (1939). A soil survey of part of the Kerang Irrigation District, Victoria. *Bull. Coun. scient. ind. Res. Melb.* No. 125.

Barbetti, M. and Allen, H. (1972). Prehistoric man at Lake Mungo, Australia, by 32,000 years B.P. *Nature, Lond.* **240**: 46.

Beadle, N.C.W. (1948). *The Vegetation and Pastures of Western New South Wales with Special Reference to Soil Erosion.* Govt Printer, Sydney.

Blackburn, G. (1962a). Stranded coastal dunes in North Western Victoria. *Aust. J. Sci.* **24**: 388-9.

– (1962b). The distribution of 'Wimmera' clay soils in relation to previous drainage of the southern Murray Basin. *Aust. J. Sci.* **25**: 95.

Bowler, J.M. (1967). Quaternary chronology of Goulburn Valley sediments and their correlation in Southeastern Australia. *J. Geol. Soc. Aust.* **14**: 287-92.

– (1971). Pleistocene salinities and climatic change: evidence from lakes and lunettes in Southeastern Australia, in *Aboriginal Man and Environment in Australia* (ed. Mulvaney, D.J. and Golson, J.). Australian National University Press, Canberra, pp. 47-65.

– and Harford, L.B. (1963). Geomorphic sequence of the Riverine Plain near Echuca. *Aust. J. Sci.* **26**: 88.

– and – (1966). Quaternary tectonics and the evolution of the Riverine Plain near Echuca Vic. *J. geol. Soc. Aust.* **13**: 339-54.

– , Jones, R., Allen, H. and Thorne, A.G. (1970). Pleistocene human remains from Australia: a living site and human cremation from Lake Mungo, western New South Wales. *World Archeology* **2**: 39-60.

– , Thorne, A.G. and Polach, H.A. (1972). Pleistocene man in Australia: age and significance of the Mungo skeleton. *Nature, Lond.* **240**: 48.

Bowmaker, A.E. (1968). *A Brief History of Leeton.* Rotary Club, Leeton.

Browne, W.R. (1969). Geomorphology. General notes, in 'The Geology of New South Wales' (ed. Packham, G.H.). *J. geol. Soc. Aust.* **16**: 559-69.

– and Raggatt, H.G. (1935). Buried rivers of eastern Australia. *Aust. Geogr.* **2** (6): 24-30.

Butler, B.E. (1950). A theory of prior streams as a causal factor of soil occurrence in the Riverine Plain of south-eastern Australia. *Aust. J. agric. Res.* 1: 231-52.

– (1956). Parna – an aeolian clay. *Aust. J. Sci.* **18**: 145-51.

– (1958). Depositional systems of the Riverine Plain of south-eastern Australia in relation to soils. *Soil Publ. CSIRO Aust.* No. 10.

– (1960). Riverine deposition during arid phases. *Aust. J. Sci.* **22**: 451-2.

– (1961). Groundsurfaces and the history of the Riverine Plain. *Aust. J. Sci.* **24**: 39.

– (1967). Soil periodicity in relation to landform development in Southeastern Australia, in *Landform Studies from Australia and New Guinea* (ed. Jennings, J.N. and Mabbutt, J.A.). Australian National University Press, Canberra, pp. 231-55.

– , Baldwin, J.G., Penman, F., and Downes, R.G. (1942). A soil survey of part of County Moira, Victoria. *Bull. Coun. scient. ind. Res. Melb.* No. 152.

– and Hutton, J.T. (1956). Parna in the Riverine Plain of south-eastern Australia and the soils thereon. *Aust. J. agric. Res.* **7**: 536-53.

Buxton, G.L. (1967). *The Riverina 1861-1891: an Australian regional study.* Melbourne University Press, Melbourne.

Churchward, H.M. (1956). The soils of the East Murrakool District, New South Wales, and their relation to land use under irrigation. *Soils Ld Use Ser. CSIRO Aust.* No. 19.

– (1958). The soils and land use of the Denimein Irrigation District, New South Wales. *Soils Ld Use Ser. CSIRO Aust.* No. 27.

– (1960). The Soils of the Woorinen Settlement, Swan Hill Irrigation District, Victoria. *Soils Ld Use Ser. CSIRO Aust.* No. 36.

– (1961). The soils of the Lower Murrakool District, New South Wales. *Soils Ld Use Ser. CSIRO Aust.* No. 39.

– (1963a). Soil studies at Swan Hill, Victoria, Australia, II. Dune moulding and parna formation. *Aust. J. Soil Res.* **1**: 103-16.

– (1963b). Soil studies at Swan Hill, Victoria, Australia, IV. Ground surface history and its expression in the array of soils. *Aust. J. Soil Res.* **1**: 242-55.

– and Flint, S.F. (1956). Jernago Extension of the Berriquin Irrigation District, New South Wales. *Soils Ld Use Ser. CSIRO Aust.* No. 18

Cockroft, B. (1965). Pedology of the Goulburn Valley Area, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 19.

Collins, T. (1943). *Such is Life.* Angus & Robertson, Sydney.

Commonwealth Bureau of Meteorology (1972). *Climatic Survey Central Murray Region 17 New South Wales.* Commonwealth Bureau of Meteorology, Melbourne 1972.

Condon, R.W. (1961). Soils and landforms of the Western Division of New South Wales. *J. Soil Conserv. Serv. N.S.W.* **17**: 31-46.

– and Stannard, M.E. (1956 and 1957). Erosion in western New South Wales. *J. Soil Conserv. Serv. N.S.W.* **12**: 192-202; and **13**: 17-26, 68-74, 122.

Cotton, C.A. (1963). Did the Murrumbidgee aggradations take place in glacial ages? *Aust. J. Sci.* **26**: 54-5.

Craft, F.A. (1934). The regimes and cyclical volume changes of the Upper Murray and Snowy Rivers, New South Wales. *Proc. Linn. Soc. N.S.W.* **59**: 314-32.

Currey, D.T. (1966). Features of the plains area, in *Contour Plans of the Northern Victorian Plains.* State Rivers & Water Supply Commission, Melbourne.

Davidson, B.R. (1969). *Australia Wet or Dry? The physical and economic limits to the expansion of irrigation.* Melbourne University Press, Melbourne.

van Dijk, D.C. (1958). Principles of soil distribution in the Griffith-Yenda district, New South Wales. *Soil Publ. CSIRO Aust.* No. 11.

– (1961). Soils of the southern portion of the Murrumbidgee Irrigated Areas. *Soils Ld Use Ser. CSIRO Aust.* No.40.

– and Talsma, T. (1964). Soils of portion of the Coleambally Irrigation Area N.S.W. *Soils Ld Use Ser. CSIRO Aust.* No. 47.

Downes, R.G. (1949). A soil, land-use and erosion survey of parts of the counties of Moira and Delatite, Victoria. *Bull. Coun. scient. ind. Res. Melb.* No. 243.

Dury, G.H. (1963). Prior stream deposition. *Aust. J. Sci.* **25**: 315-17.

– (1967). Climatic change as a geographical backdrop. *Aust. Geogr.* **10** (4): 231-42.

England, H.N. (1950). *Waterlogging, Drainage and Reclamation.* Tech. Conf. Irrigation, held at Griffith N.S.W. Sept. 1950. CSIRO Aust., Melbourne, pp. 58-64.

Fenner, C. (1934). The Murray River basin. *Geogr. Rev.* **24**: 79-91.

Fisher, N.H. (ed.) (1962). *Tectonic Map of Australia.* Department of National Development, Canberra.

Garland, K.R. and Jones, G.O. (1963). Kerang-Cohuna districts: distribution of subsoil sands. *J. Dep. Agric. Vict.* **61**: 507-10.

Geological Society of Australia (1971). *Tectonic Map of Australia and New Guinea. 1:5,000,000.* Geological Society of Australia, Sydney.

Gill, E.D. and Bethune, F.N. (1967). Radiocarbon dates from Narrandera, New South Wales, Australia. *Victorian Nat.* **84**: 125-7.

Gloe, C.S. (1947). *Underground Water Resources of Victoria.* Vol. 1. State Rivers and Water Supply Commission, Melbourne.

Gregory, J.W. (1903). *The Geography of Victoria: historical, physical and political.* Whitcombe and Tombs, Melbourne.

– (1910). Australia. Physical geography, geology, in *Encyclopaedia Britannica,* 11th ed.

Gutteridge, Haskins, and Davey (1970). *Murray Valley Salinity Investigation.* River Murray Commission, Canberra.

Harris, W.J. (1939). The physiography of the Echuca district. *Proc. R. Soc. Vict.* **51** (N.S.): 45-60.

Hawkins, C.A. and Walker, P.H. (1956). A study of layered sedimentary materials in the Riverine Plain, New South Wales. *J. Proc. R. Soc. N.S.W.* **90**: 110-27.

Hills, E.S. (1939). The physiography of north-western Victoria. *Proc. R. Soc. Vict.* **51** (N.S.): 297-323.

– (1940a). The lunette, a new landform of aeolian origin. *Aust. Geogr.* **3** (7): 15-21.

– (1940b). *The Physiography of Victoria, an introduction to geomorphology.* Whitcombe and Tombs, Melbourne.

Horbach, D. (1964). Ground waters of the Murray Basin, in *Dept Mines, N.S.W. Chem. Lab. Report* No. 12, pp. 1-6.

Hunter, S. (1909). The deep leads of Victoria. *Mem. geol. Surv. Vict.* No. 7.

Jackson, Col. (1834). Hints on the subject of geographical arrangement and nomenclature. *J.R. Geog. Soc.* **4**: 72-88.

Jennings, J.N. (1968). A revised map of the desert dunes of Australia. *Aust. Geogr.* **10**: 408-9.

Johns, M.W. and Lawrence, C.R. (1961). Northern plains of Victoria. *Dept Mines Vic.,* *Geol. Survey Underground Water Invest. Report* No. 1.

Johnston, E.J. (1950). The morphology and evolution of the soils of 'Pine Lodge' Estate, New South Wales. *Bull. Coun. scient. ind. Res. Melb.* No. 259.

– (1952). The soils of the western part of the Murray Valley Irrigation Area and their classification for irrigation. *Soils Ld Use Ser. CSIRO Aust.* No. 4.

– (1953). Pedology of the Deniboota Irrigation District, New South Wales. *Soil Publ. CSIRO Aust.* No. 1.

Jones, R.M. (1969). Scald reclamation studies in the Hay district, Pt IV. Scald soils: their properties and changes with reclamation. *J. Soil. Conserv. Serv. N.S.W.* **25**: 104-20.

Klimaszewski, M. (1963). Problems of geomorphological mapping. *Polish Acad. Sci. Inst. Geogr. Studies* No. 46.

Langford-Smith, T. (1959). Deposition on the Riverine Plain of south-eastern Australia. *Aust. J. Sci.* **22**: 73-4.

– (1960a). The dead river systems of the Murrumbidgee. *Geogr. Rev.* **50**: 368-89.

– (1960b). Reply to Mr Butler. *Aust. J. Sci.* **22**: 452-3.

– (1962). Riverine Plains geochronology. *Aust. J. Sci.* **25**: 96-7.

– (1968). Murrumbidgee land settlement 1817-1912, in *Studies in Australian Geography* (ed. Dury, G.H. and Logan, M.I.). Heinemann, Melbourne, pp. 137-94.

Lawrence, C.R. (1966). Cainozoic stratigraphy and structure of the Mallee region, Victoria. *Proc. R. Soc. Vict.* **79**: 517-53.

– (1967). Hydrogeology of the Murray basin south-eastern Australia. *Mem. Assoc. Inter. des Hydrologues* **7**: 308-12.

– (1971). Occurrence and production of halite and gypsum in Victoria. *Min. Geol. J. (Vict.)* **7** (1): 17-19.

Leigh, J.H. and Mulham, W.E. (1965). *Pastoral Plants of the Riverine Plain.* Jacaranda Press, Brisbane.

– and Noble, J.C. (1972). *Riverine Plain of New South Wales: its pastoral and irrigation development.* CSIRO, Canberra.

Lewis, C.F. (1950). Sandstorms over Melbourne a century ago. *Victorian Nat.* **67**: 129.

Macumber, P.G. (1969a). The inland limits of the Murravian marine transgression in Victoria. *Aust. J. Sci.* **32** (4): 165-6.

– (1969b). Interrelationship between physiography, hydrology, sedimentation and salinization of the Loddon River plains, Australia. *J. Hydrol.* **7** (1): 39-57.

– (1970). Lunette initiation in the Kerang district. *Min. Geol. J. (Vict.)* **6** (6): 16-18.

Madigan, C.T. (1946). The Simpson Desert Expedition, 1939, Scientific Reports: No. 6, Geology – the sand formations. *Trans. R. Soc. S. Aust.* **70**: 45-63.

Marshall, T.J. and Penman, F. (1932). A soil survey of part of the Murrabit Irrigation Settlement (Vic.) and the Bungunyah Irrigation Settlement (N.S.W.). *J. Coun. scient. ind. Res. Aust.* **5**: 215-27.

Martin, C.S. (1955). (ed. J.L.F. Woodburn) *Irrigation and Closer Settlement in the Shepparton District, 1836-1906.* Melbourne University Press, Melbourne.

Melton, F.A. (1940). A tentative classification of sand dunes – its application to dune history in the southern highplains. *J. Geol.* **48**: 113-74.

Mitchell, T.L. (1839). *Three Expeditions into the Interior of Eastern Australia, with descriptions of the recently explored regions of Australia Felix and the present colony of New South Wales.* 2nd ed., T. & W. Boone, London, 2 vols.

Moore, C.W.E. (1953). The vegetation of the south eastern Riverina, New South Wales. 1. The climax communities. *Aust. J. Bot.* **1**: 485-547.

Morland, R.T. (1958-9). Erosion survey of the Hume Catchment Area, N.S.W. Pts I and II. *J. Soil Conserv. Serv. N.S.W.* **14**: 191-225; **15**: 66-99, 172-86, 208-26, 293-326.

Newell, J.W. (1970). Soils and land use in the Ovens and Buffalo River valleys, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 21.

Northcote, K.H. (1951). A pedological study of the soils occurring at Coomealla, New South Wales. *Bull. Coun. scient. ind. Res. Melb.* No. 264.

– (1960). *Atlas of Australian Soils, Sheet 1. Port Augusta-Adelaide-Hamilton Area.* With explanatory data. CSIRO Aust., Melbourne University Press, Melbourne.

– (1962). *Atlas of Australian Soils, Sheet 2. Melbourne-Tasmania Area.* With explanatory data. CSIRO Aust., Melbourne University Press, Melbourne.

– (1966). *Atlas of Australian Soils, Sheet 3. Sydney-Canberra-Bourke-Armidale Area.* With explanatory data. CSIRO Aust., Melbourne University Press, Melbourne.

Oxley, J.W.M. (1820). *Journals of Two Expeditions into the Interior of New South Wales, undertaken by order of the British Government in the years 1817-18.* Murray, London.

Pels, S. (1960). The geology of the Murrumbidgee Irrigation Areas and surrounding districts. *Bull. Water Cons. Irrig. Com., N.S.W., Groundwater and Drainage Ser.* No. 5.

– (1964a). The present and ancestral Murray River system. *Aust. Geog. Studies* **2** (2): 111-19.

– (1964b). Quaternary sedimentation by prior streams on the Riverine Plain southwest of Griffith, N.S.W. *J. Proc. R. Soc. N.S.W.* **97**: 107-15.

– (1966). Late Quaternary chronology of the Riverine Plain of south-eastern Australia. *J. Geol. Soc. Aust.* **13**: 27-40.

– (1969a). Radio-carbon datings of ancestral river sediments on the Riverine Plain of south-eastern Australia and their interpretation. *J. Proc. R. Soc. N.S.W.* **102**: 189-95.

– (1969b). The Murray Basin, in 'The Geology of New South Wales' (ed. Packham, G.H.). *J. Geol. Soc. Aust.* **16** (Pt 1), pp. 499-511.

– (1971). River systems and climatic change, in *Aboriginal Man and Environment in Australia* (ed. Mulvaney, D.J. and Golson, J.). Australian National University Press, Canberra, pp. 38-46.

– , Stannard, M.E., and Talsma, T. (1968). Environmental studies of the Coleambally Irrigation Area and surrounding districts. *Bull. Water Cons. Irrig. Com. N.S.W. Land Use Ser.* No. 2.

Penman, F. (1936). Soil conditions at Bamawm and Ballendella in relation to citrus growth. *J. Dep. Agric. Vict.* **34**: 399-432.

Peterson, J.A. (1971). The equivocal extent of glaciation in the south eastern uplands of Australia. *Proc. R. Soc. Vict.* **84** (2): 207-11.

Poutsma, T.J. and Skene, J.K.M. (1961). The soils of Rutherglen Research Station, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 12.

Price, W.A. (1968). Clay dunes, in *Encyclopedia of Geomorphology* (ed. Fairbridge, R.). Reinhold, New York.

Rowan, J.N. and Downes, R.G. (1963). Study of the land in north-western Vic. *Tech. Com. Soil Conserv. Auth. Vic.* No. 2.

Rowe, R.K. (1971). A study of land in the Mount Buffalo National Park. *Tech. Com. Soil Conserv. Auth. Vic.* No. 6.

Sargeant, I.J. and Newell, J.W. (in press). Soils and land use in the Torrumbarry Irrigation District, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 23.

Schumm, S.A. (1968a). River adjustment to altered hydrologic regimen – Murrumbidgee River and paleochannels, Australia. *Prof. Pap. U.S. Geol. Surv.* **598**: 65.

– (1968b). Speculation concerning palaeohydrologic controls of terrestrial sedimentation. *Bull. Geol. Soc. Amer.* **79**: 1573-88.

Singleton, O.P. (1965). Geology and mineralization of Victoria, in *Geology of Australian Ore Deposits,* (ed. J. McAndrew) 2nd ed., Vol. 1, Aust. Inst. Mining & Metallurgy, Melbourne, pp. 440-9.

Skene, J.K.M. (1951). Soil survey of the Robinvale Irrigation Area, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 10.

– (1963). Soils and land use in the Deakin Irrigation Area, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 16.

– (1971). Soils and land use in the Mid-Loddon Valley, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 22.

– and Freedman, J.R. (1944). Soil survey of part of Shepparton Irrigation District, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 3.

– and Poutsma, T.J. (1962). Soils and land use in part of the Goulburn Valley, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 14.

– and Harford, L.B. (1964). Soils and land use in the Rochester and Echuca Districts, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 17.

– and Sargeant, I.J. (1966). Soils and land use near Swan Hill, Victoria. *Tech. Bull. Dep. Agric. Vict.* No. 20.

Smith, R. (1945). Soils of the Berriquin Irrigation District, N.S.W. *Bull. Coun. scient. ind. Res. Melb.* No. 189.

– , Herriot, R.I. and Johnston, E.J. (1943). The soil and land-use survey of the Wakool Irrigation District, New South Wales. *Bull. Coun. scient. ind. Res. Melb.* No. 162.

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M. J., and Hallsworth, E.G. (1968). *A Handbook of Australian Soils.* Rellim Tech. Pubs., Glenside, South Australia.

Stannard, M.E. (1954). A study of soils and erosion in the Menindee district. *J. Soil Conserv. Serv. N.S.W.* **10**: 24-34.

– (1957 and 1958). Erosion survey of the south-west Cobar Peneplain. *J. Soil Conserv. Serv. N.S.W.* **13**: 176-86; **14**: 30-45, 137-56.

– (1962). Prior stream deposition. *Aust. J. Sci.* **24**: 324.

– (1962 and 1963). Erosion survey of the Central East-Darling Region. *J. Soil Conserv. Serv. N.S.W.* **18**: 145-53, 173-82; **19**: 17-28, 69-80.

State Rivers and Water Supply Commission (1966). *Contour plans of the Northern Victorian Plains.* State Rivers and Water Supply Commission, Melbourne.

Stephens, C.G. and Crocker, R.L. (1946). Composition and genesis of lunettes. *Trans. R. Soc. S. Aust.* **70**: 302-12.

Strzelecki, P.E. de (1845). *Physical description of New South Wales and Van Diemen's Land, accompanied by a geological map, sections, diagrams and figures of the organic remains.* Longmans, London.

Sturt, C. (1833). *Two Expeditions into the Interior of Southern Australia* . . . Smith, Elder and Co., London.

Taylor, J.K. (1970). *Development of Soil Survey and Field Pedology in Australia 1927 -67.* CSIRO Aust., Melbourne.

– and Hooper, P.D. (1938). A soil survey of horticultural soils in the Murrumbidgee Irrigation Areas, New South Wales. *Bull. Coun. scient. ind. Res. Melb.* No. 118.

– and Penman, F. (1930). A soil survey of the Woorinen Settlement, Swan Hill Irrigation District, Victoria. *Bull. Coun. scient. ind. Res. Melb.* No. 45.

– , – , Marshall, T.J., and Leeper, G.W. (1933). A soil survey of the Nyah, Tresco, Tresco West, Kangaroo Lake (Vic.) and Goodnight (N.S.W.) Settlements. *Bull. Coun. scient. ind. Res. Melb.* No. 73.

Thomas, D.E. (1947). Some gypsum deposits of Victoria. *Min. Geol. J. (Vict.)* 3 (2): 23.

Thorne, A.G. and Macumber, P.G. (1972). Discoveries of Late Pleistocene man at Kow Swamp, Australia. *Nature. Lond.* **238**: 316-19.

Tricart, J.L. (1965). *Principes et Mèthodes de la Gèomorphologie.* Masson et Cie, Paris.

Webster, A. (1957). Drainage in the riverine plains of northern Victoria, Australia with special reference to ground water hydrology. *Trans. Third Cong. Int. Comm. Irrigation & Drainage, New Delhi, Vol. 5:* 10.27-10.42.

Williams, O.B. (1962). The Riverina and its pastoral industry, 1860-1869, in *The Simple Fleece, studies in the Australian wool industry* (ed. Barnard, A.). Melbourne University Press, pp. 411-34.

Williamson, W.H. (1964). The development of groundwater resources of alluvial formations, in *Water Resources, Use and Management.* Melbourne University Press, Melbourne, pp. 195-211.

– (1964). Evidence of an abandoned course of the Lachlan River, New South Wales. *Aust. J. Sci.* **27**: 117-18.

– , Hinde, M.C. *et al.* (1962). 'A Review of Groundwater Resources of New South Wales.' Unpub. report, Water Conserv. Irrig. Com. N.S.W., Sydney.

The Riverine Plain of south-eastern Australia, which extends through parts of southern New South Wales and northern Victoria, is an area of outstanding economic importance. On it has developed a large part of Australia's irrigated agriculture, and the future will see further development of its soils and water resources.

The aim of this study is to bring together into a coherent whole the fragmented studies that have been carried out over the years and to amplify them by encouraging further investigation.

The map shows all the information presently available, including the fluviatile features of the plain, classified according to their form and as interpreted from aerial photographs, and some field traverses in areas where the features are indistinct. Aeolian features are also classified and mapped.

This map, with its accompanying detailed descriptive text, gives the first unified picture of the plain. It will be invaluable in the further development of the region, which can only be successfully carried out, and mistakes of the past avoided, if the formation and composition of the plain are fully understood by those responsible for planning.

The Authors

B.E. Butler, Division of Soils, CSIRO, Canberra
G. Blackburn, Division of Soils, CSIRO, Adelaide
J.M. Bowler, Department of Biogeography and Geomorphology, Australian National University, Canberra
C.R. Lawrence, Department of Mines, Melbourne
J.W. Newell, Victorian Department of Agriculture, Melbourne
S. Pels, Water Conservation and Irrigation Commission of New South Wales, Deniliquin

Australian National University Press Canberra

ISBN 0 7081 0093 7