THE GEOMORPHOLOGY OF THE MURRAY VALLEY IN SOUTH AUSTRALIA

by

R.M. Thomson B.A. (Hons)

Thesis submitted for the degree of
Master of Arts in the Department of Geography,
University of Adelaide.

1975

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Date 22/10/76 Signed R.M THOMSON

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LIST OF FIGURES (maps, diagrams and photographs) AND TABLES

STATEMENT OF ORIGINALITY

This thesis is based on original research carried out in the Department of Geography, University of Adelaide. It contains no material previously submitted for a degree at any University and to the best of my knowledge contains no material previously published or written by another author, except where due reference is made in the text of the thesis.

Robyn M. Thomson

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SUMMARY

Geomorphological mapping of the valley of the Murray River in South Australia and the interpretation of the geomorphic units selected for this mapping has yeilded an explanation for the present-day landscape in this region.

Intrenchment has produced a variety of valley-side slopes, related directly or indirectly to fluvial processes acting upon the combined effects of Pleistocene to Tertiary stratigraphy and jointing. Processes of subaerial weathering, erosion, and deposition subsequently modified the primary slopes.

The morphology of the intrenched valley is locally variable due to structural differences rather than to changes in discharge through the evolution of the river.

Discontinuous depositional units, resulting from fluctuations in baselevel of the river, are contained within the valley.

There are two types of river channel pattern: a meandering pattern occurs upstream from Overland Corner, whereas the river has an "angular meandering" form downstream from this locality. This difference in pattern suggests that the Murray River in its lower reaches is still in a period of adjustment to the lateral structure, as it flows across a deep floodplain.

The geomorphic units of the Murray valley in South Australia are chiefly the product of intrenchment, and minor baselevel changes. However, some of the present-day landforms are being modified by, or may be the result of, (1) chemical weathering, (2) mass movements, (3) normal fluvial processes, (4) aeolian processes, and (5) anthropogenically induced processes.

INTRODUCTION

. . . Most men are content only to see a river as it runs by them, and talk of the changes in it as they happen; when it is troubled, or when it is clear; when it drowns the country in flood; or forsakes it in a drought . . .

Sir William Temple's Netherlands
in Sturt, 1833

To a geomorphologist the approach implied by the above quotation is incomplete. A fluvial study is rewarding when, through analysis of landforms, an interpretation of the evolution of a river can be offered.

This thesis is concerned with analysis, involving description and explanation, of the landforms of the valley of the Murray River in South Australia. The term "Murray valley" is used throughout the text in a strictly geomorphic sense. It refers to that landform which has resulted from the combined action of fluvial and valley-side processes.

The Murray River flows for over 600 kilometres in South Australia. Since European colonization the river and immediate environs has been considerably modified by man. Since the Murray River is the life-line for the capital of the state there have been two proposals for dam sites to be constructed on the river, one at Teal Flat near Mannum, the other at Chowilla, north of Renmark. Such dam construction, if it were to eventuate, would obliterate landforms associated with the river, and any clues they might give as to the evolution of the river. Thus it was felt that it was expedient to map and explain the development fo these landforms. Furthermore,it was hoped that such research would enable the evolution of the Murray River in South Australia to be interpreted.

The landforms of the Murray valley were mapped as the following geomorphic units: valley-side slopes including cliffs, structural benches, slip-off slopes and sand deposits; terraces and pseudo terraces; the floodplain, both dissected and undissected, together with lakes, lagoons, clay pans and gypsum lakes; and the river channel (see Fig. A—I). Mapping was restricted to the region between the Victorian Border and Lake Alexandrina since a comprehensive account of the geomorphology of Lake Alexandrina and Lake Albert, based on soil associations, was completed by de Mooy (1959).

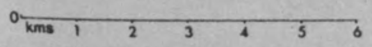
Two problems present themselves in the interpretation of the evolution of the river. First, how old is the valley produced by the Murray River? Such age determination necessitates consideration of the age of the surface into which the river has excavated the valley. An account of the evolution of the landforms on this surface is a necessary precursor to an estimation of its age. This forms the content of Chapter 1. Second, what are the factors and processes responsible for the valley of the Murray River in plan and cross-section? Identification of these factors and processes necessitates a consideration of the structure of the region through which the Murray River flows, slope behaviour and river dynamics. These are dealt with in the subsequent chapters, which describe the geomorphic units; Chapter II valley-side slopes, Chapter III floodplain and terraces, and Chapter IV river channel morphology.

Information obtained from mapping and explanation of the landforms in each geomorphic unit provides the substance for Chapter V, a discussion of the evolution of the Murray River in South Australia.

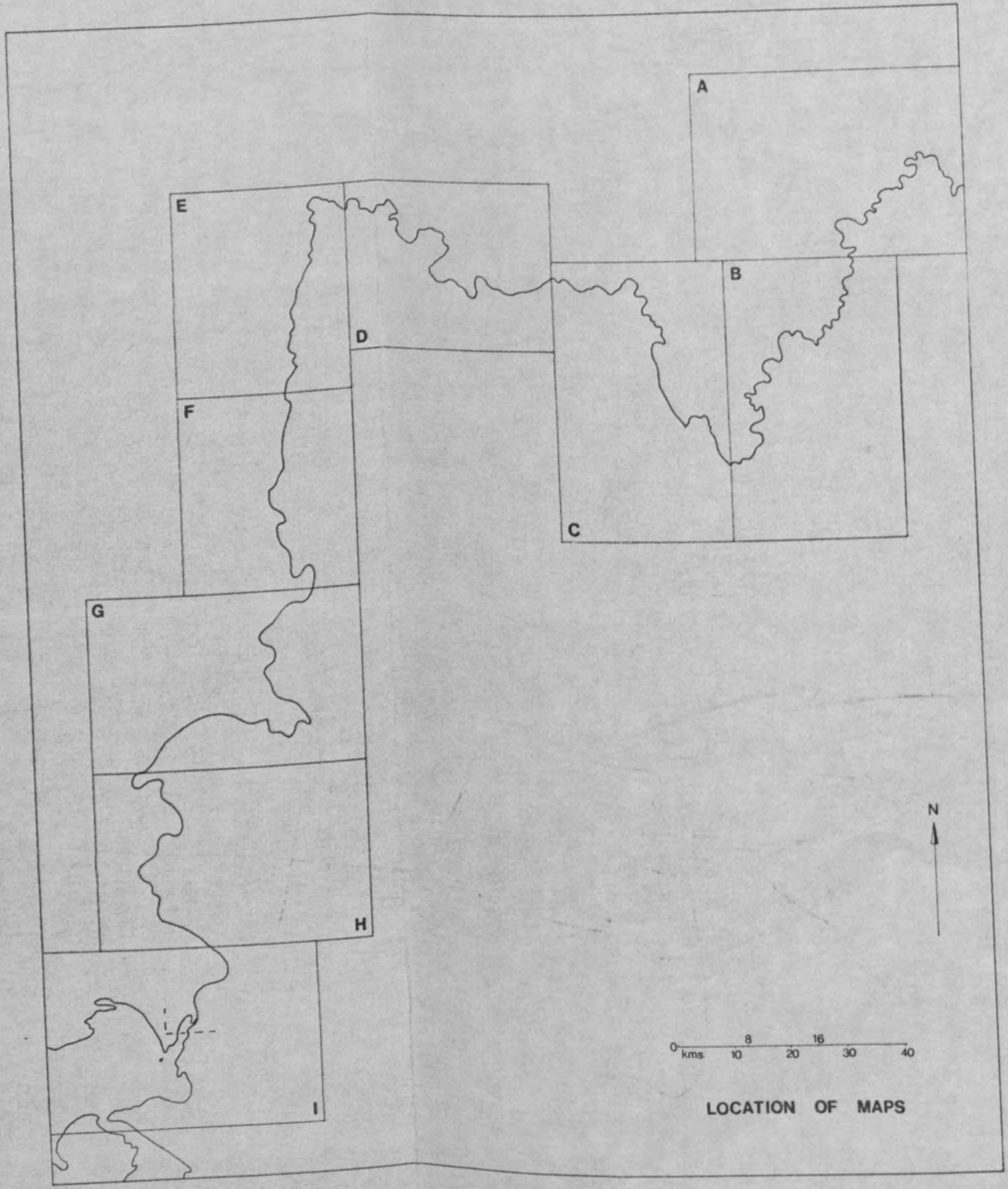
The data for this thesis was derived from a variety of sources, from field observations,aerial photograph analysis, topographic map interpretation, geological cross-sections, published and unpublished reports from the Mines, Lands and E. & W.S. Departments, and from personal contact with geologists and a soil scientist working in the field.

GEOMORPHOLOGICAL MAPS OF THE MURRAY VALLEY IN SOUTH AUSTRALIA

～	Murray River
■	lakes and lagoons
⁘	clay pans
▩	gypsum lakes
▤	floodplain - dissected
▦ 1 2	floodplain 1 low undissected 2 high undissected
▦	terrace
░	slip-off slope
■	structural bench
▥	cliffs
▒	sand
☐	Mallee Surface
cc	cliff channels
dc	disappearing cliffs
g	granite outcrops
tv-sf	triangular valley-side facets



source: stereoscopic analysis of aerial photographs
field work



LOCATION OF MAPS

FIG. A

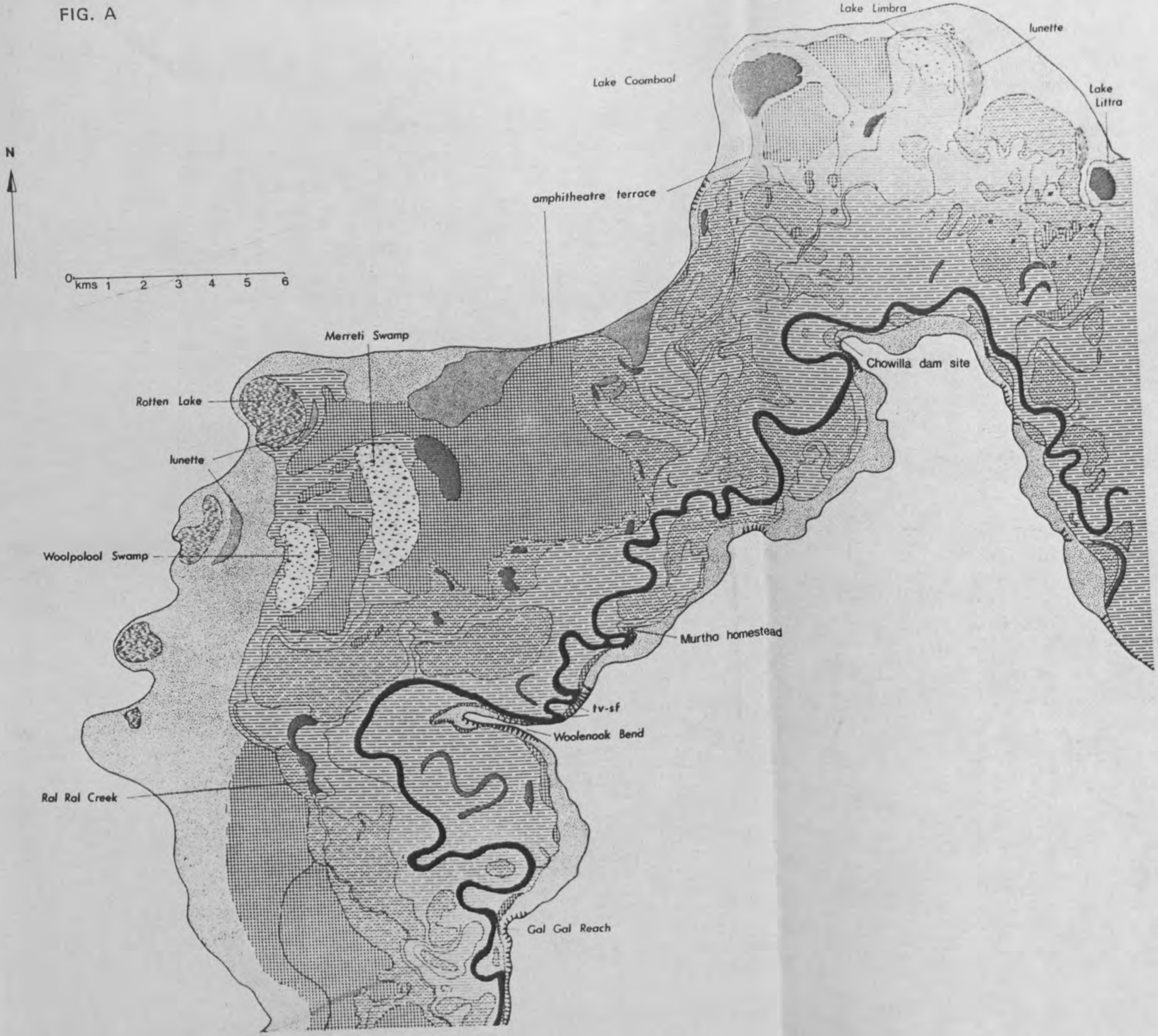

Lake Limbra
lunette
Lake Coombool
Lake Littra
N
0 kms 1 2 3 4 5 6
amphitheatre terrace
Merreti Swamp
Chowilla dam site
Rotten Lake
lunette
Woolpolool Swamp
Murtho homestead
tv-sf
Woolenook Bend
Ral Ral Creek
Gal Gal Reach

FIG. B

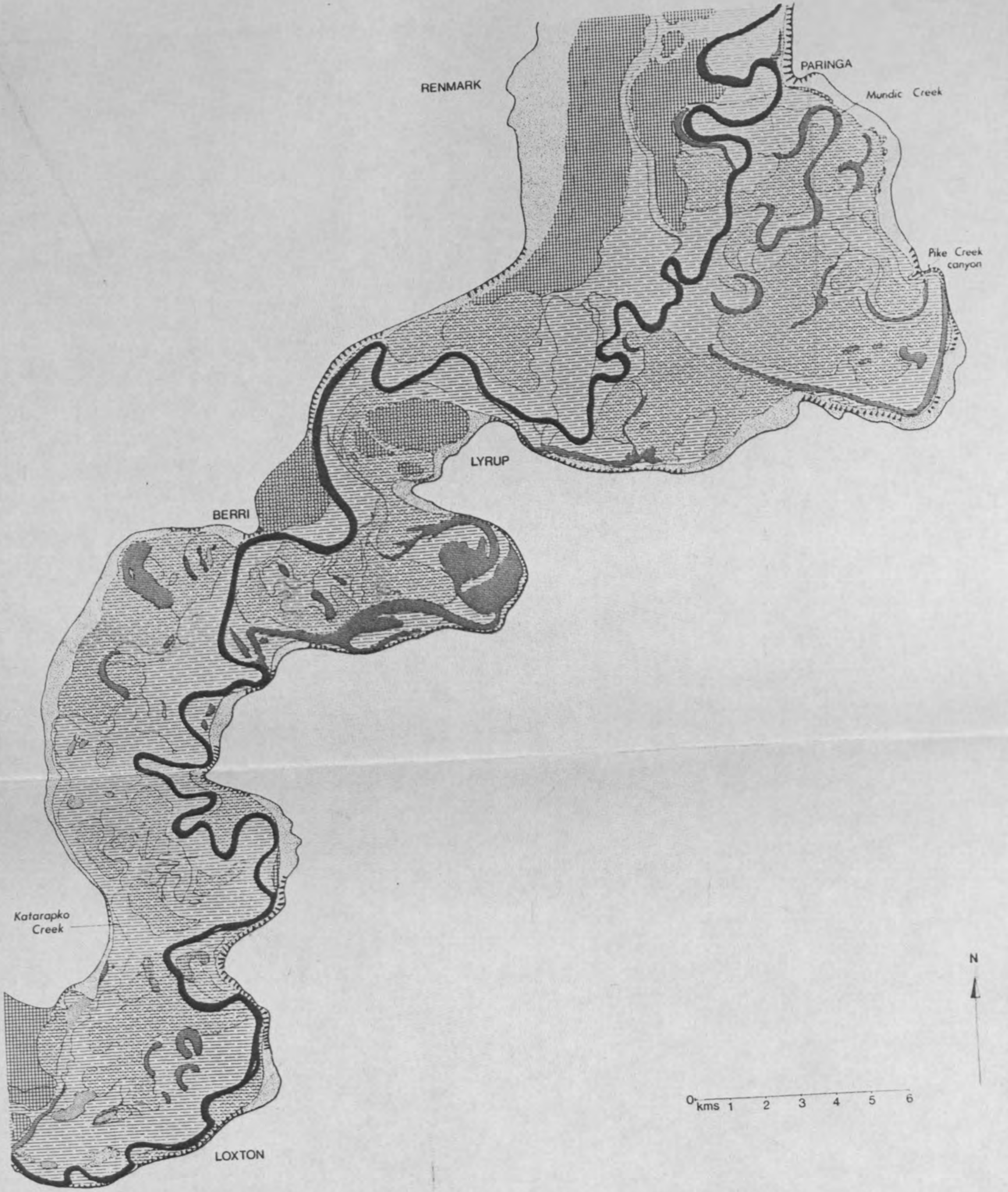

RENMARK
PARINGA
Mundic Creek
Pike Creek canyon
LYRUP
BERRI
Katarapko Creek
LOXTON
N
0 kms 1 2 3 4 5 6

FIG. C

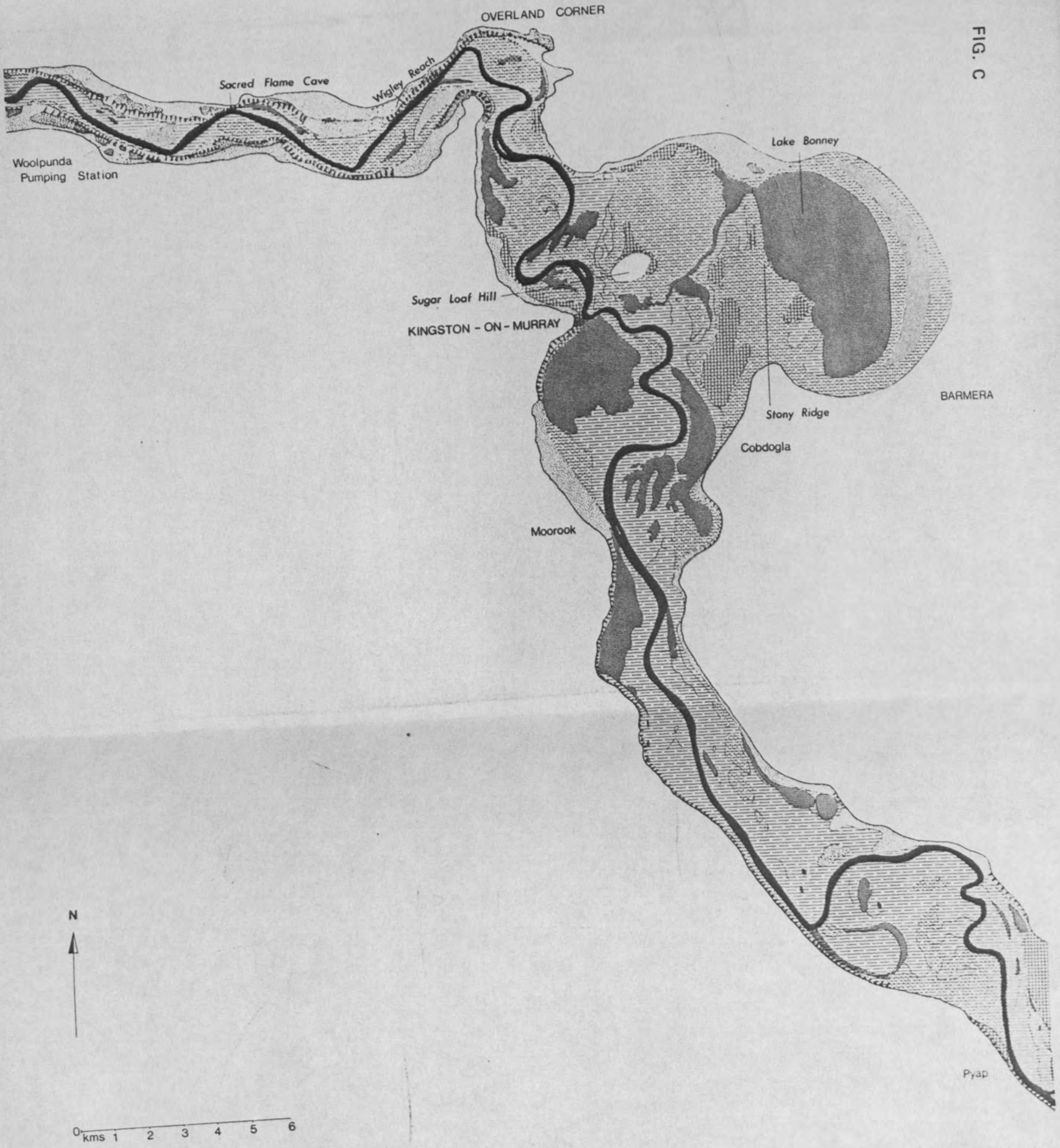

OVERLAND CORNER
Sacred Flame Cave
Wigley Reach
Woolpunda
Pumping Station
Lake Bonney
Sugar Loaf Hill
KINGSTON - ON - MURRAY
BARMERA
Stony Ridge
Cobdogla
Moorook
Pyap
N
0 kms 1 2 3 4 5 6

FIG. D

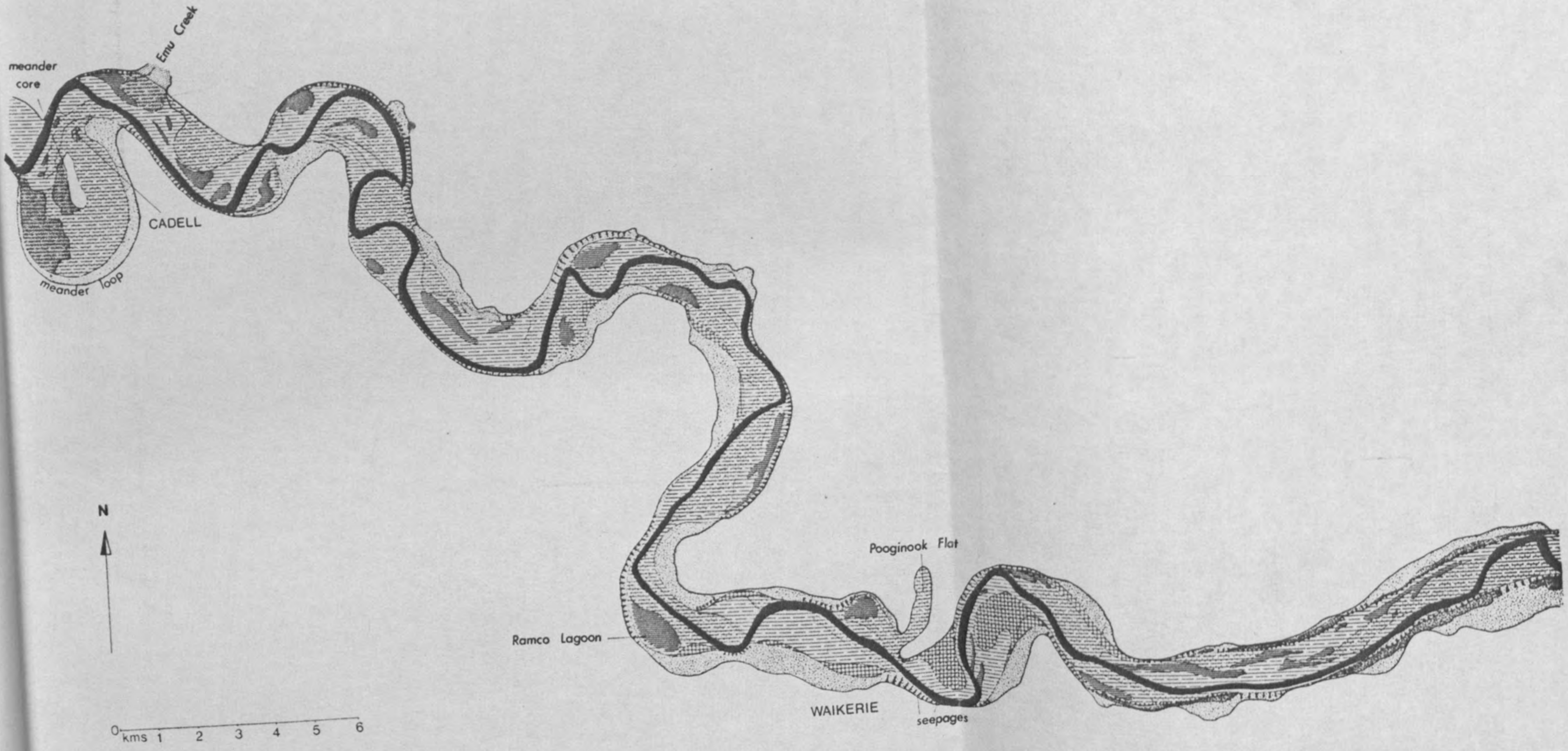

Emu Creek
meander core
CADELL
meander loop
Ramco Lagoon
Pooginook Flat
WAIKERIE
seepages
N
0 kms 1 2 3 4 5 6

FIG. E

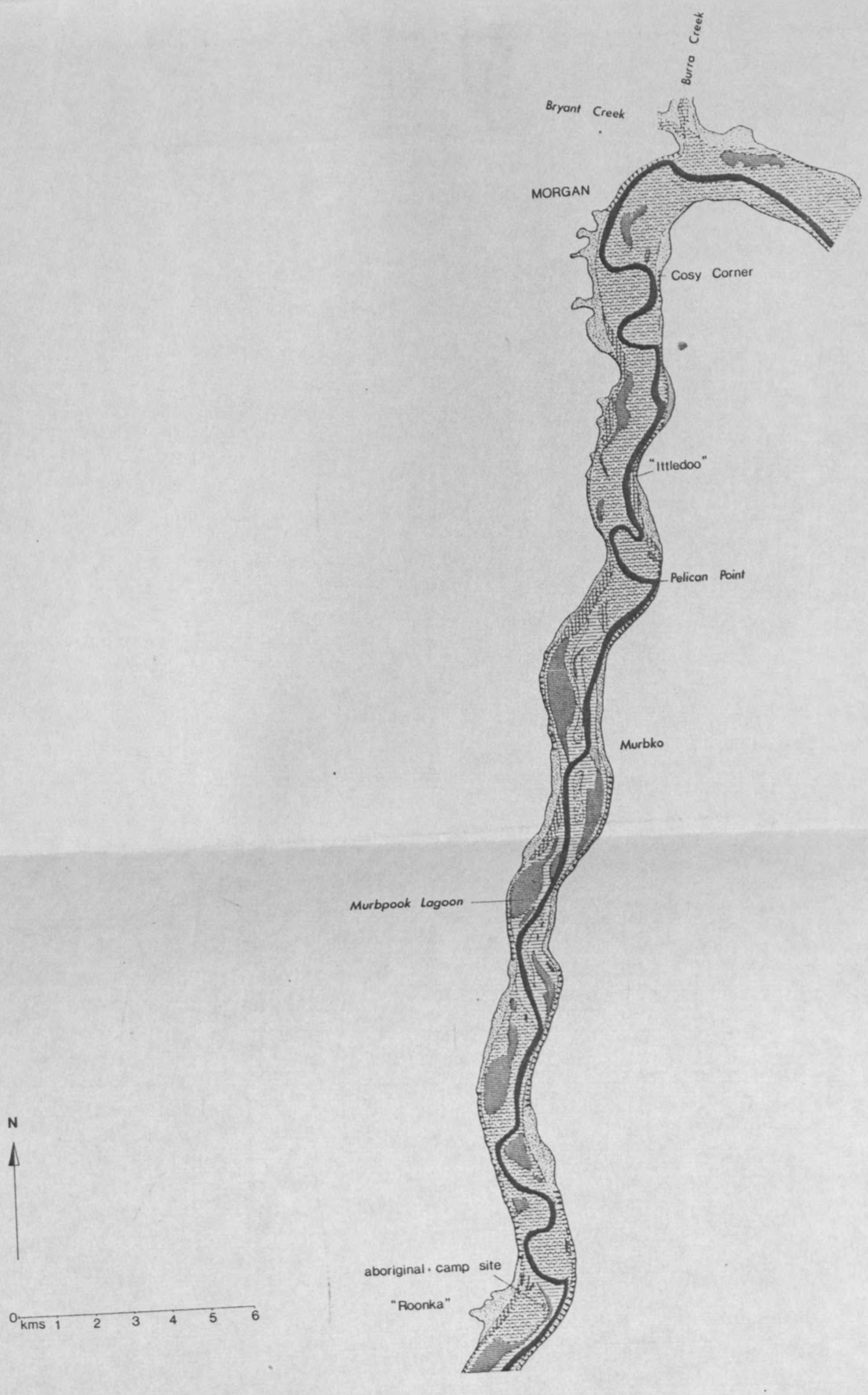

Burra Creek
Bryant Creek
MORGAN
Cosy Corner
"Ittledoo"
Pelican Point
Murbko
Murbpook Lagoon
N
aboriginal camp site
"Roonka"
0 kms 1 2 3 4 5 6

FIG. F

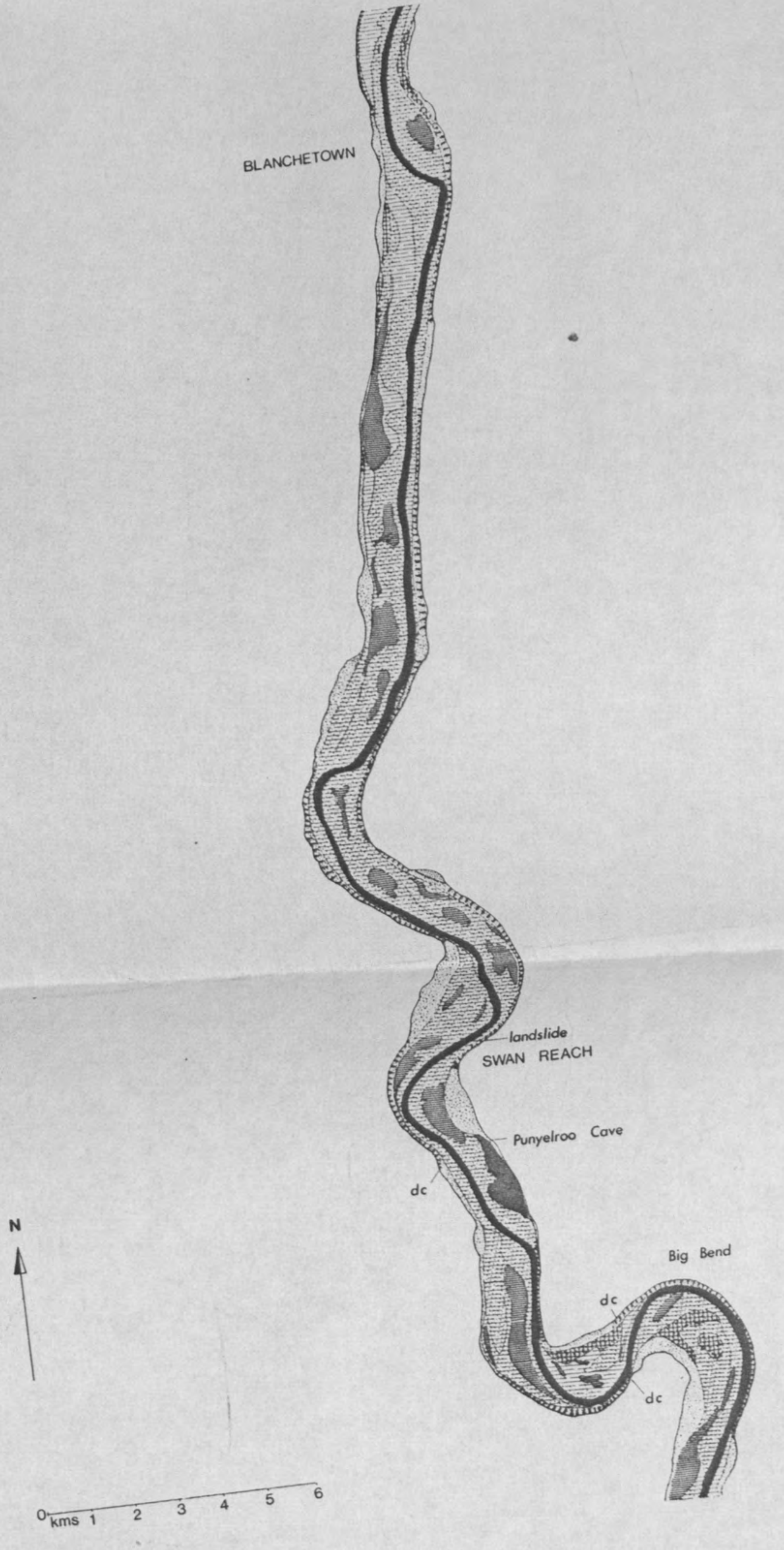

BLANCHETOWN
landslide
SWAN REACH
Punyelroo Cave
dc
Big Bend
dc
dc
N
0 kms 1 2 3 4 5 6

FIG. G

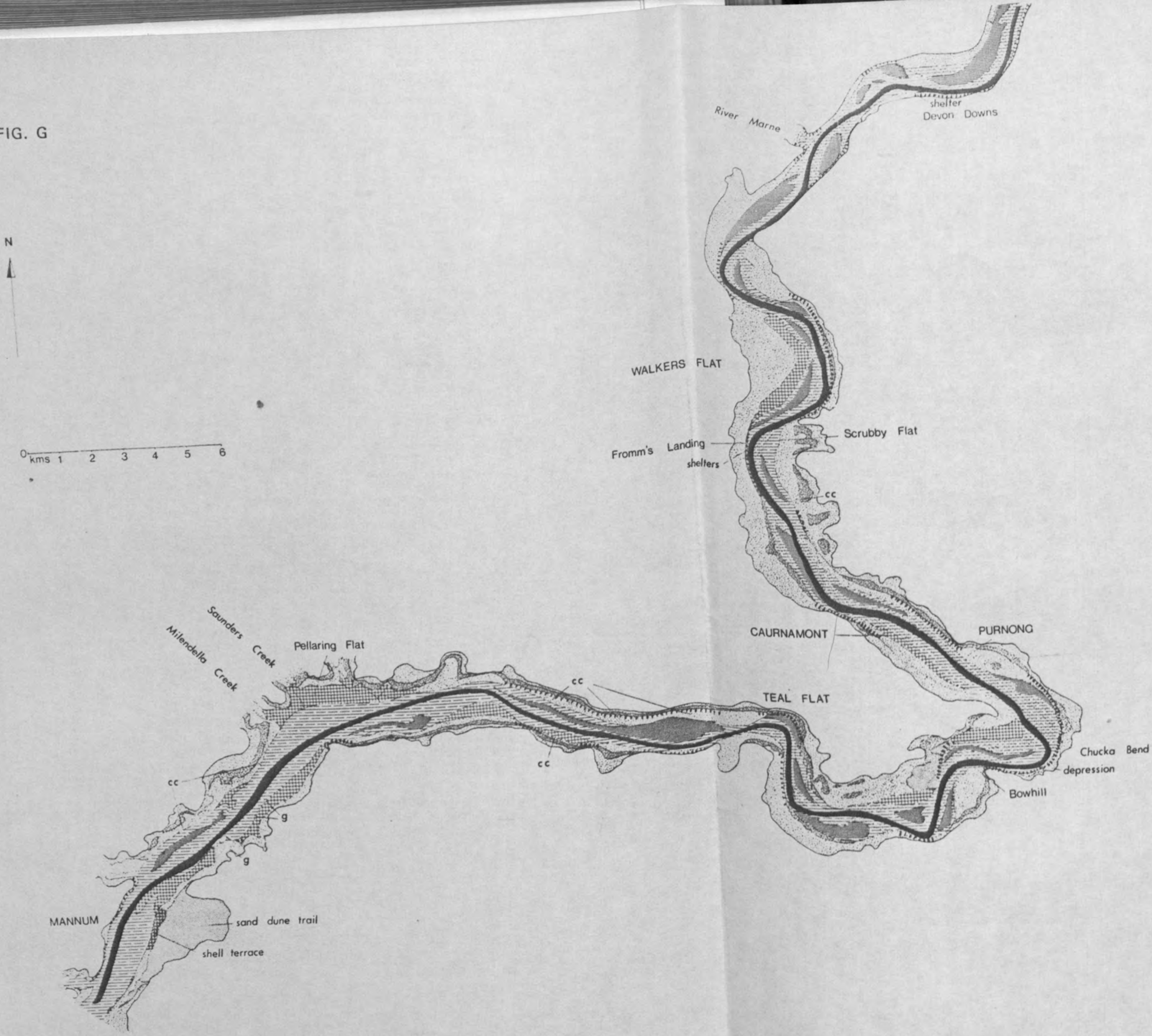

shelter
Devon Downs
River Marne
N
WALKERS FLAT
Scrubby Flat
Fromm's Landing
shelters
cc
0 kms 1 2 3 4 5 6
CAURNAMONT
PURNONG
Saunders Creek
Milendella Creek
Pellaring Flat
cc
TEAL FLAT
Chucka Bend
depression
Bowhill
cc
cc
g
g
MANNUM
sand dune trail
shell terrace

FIG. H

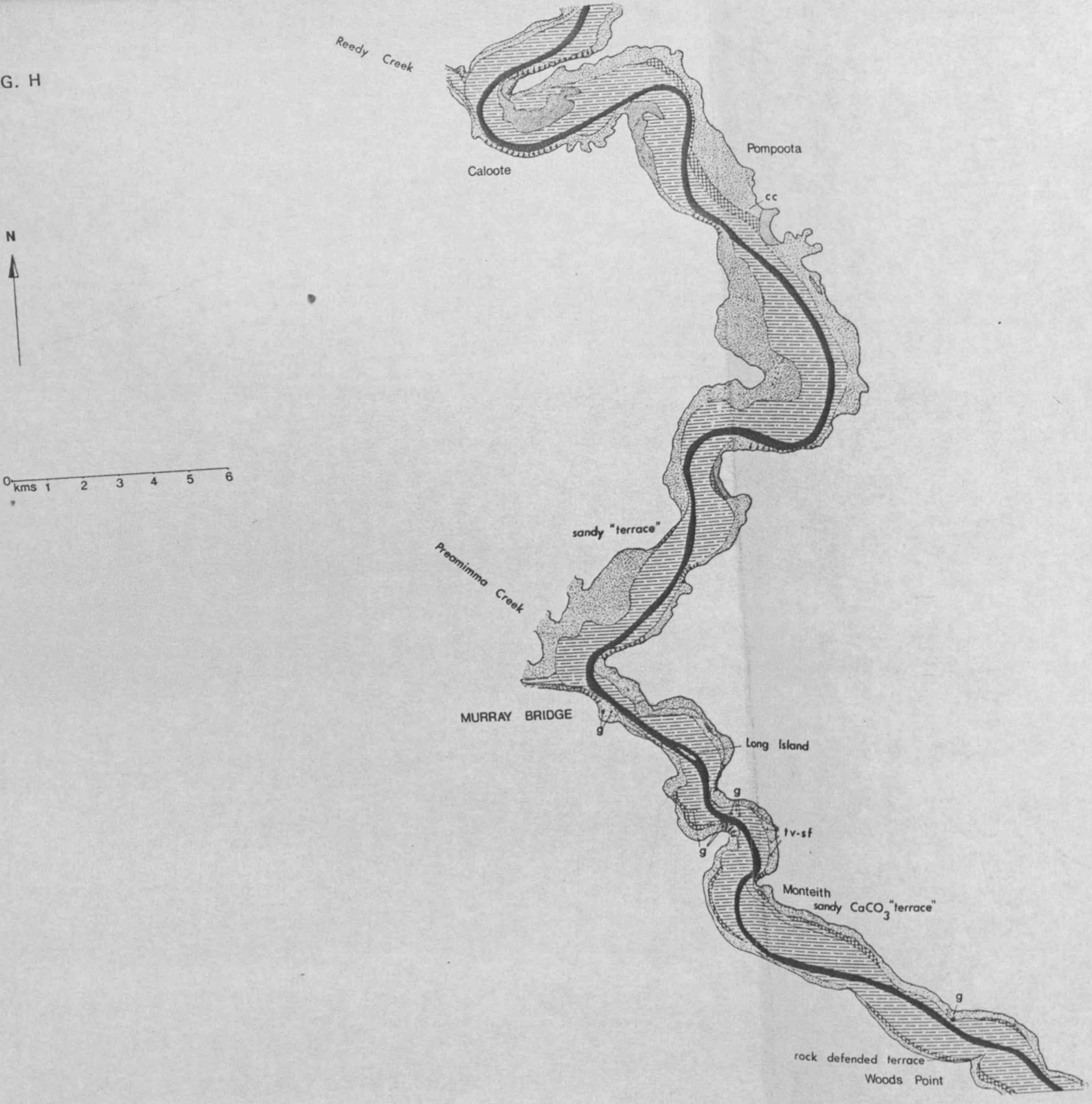
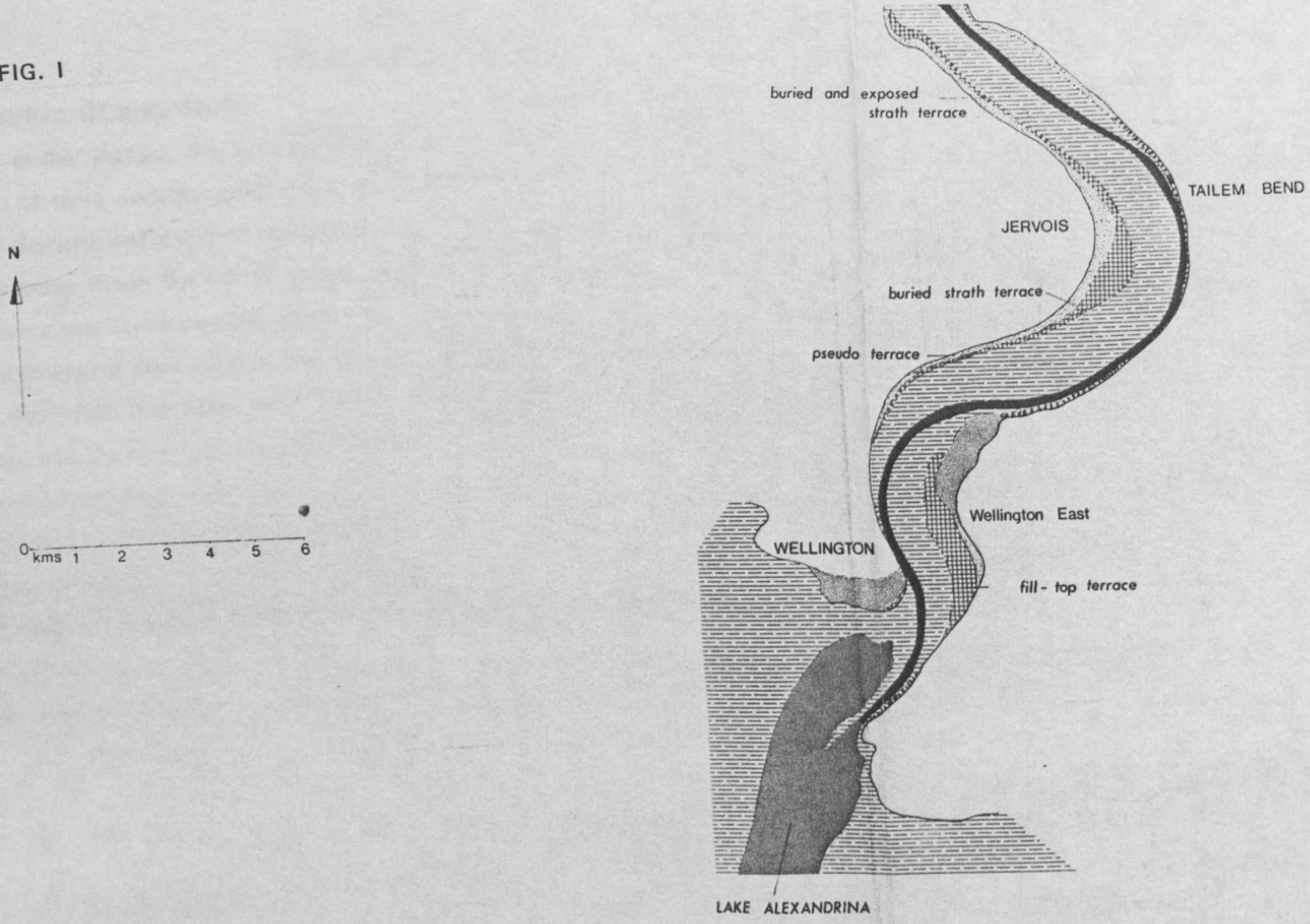

Reedy Creek
Caloote
Pompoota
cc
N
0 kms 1 2 3 4 5 6
sandy "terrace"
Preamimma Creek
MURRAY BRIDGE
g
Long Island
g
tv-sf
g
Monteith
sandy CaCO3 "terrace"
g
rock defended terrace
Woods Point

FIG. I


buried and exposed strath terrace
TAILEM BEND
JERVOIS
buried strath terrace
pseudo terrace
Wellington East
WELLINGTON
fill- top terrace
LAKE ALEXANDRINA
N
0 kms 1 2 3 4 5 6

CHAPTER I

THE MALLEE SURFACE

1. GENERAL DESCRIPTION

The Mallee Surface, the topographic surface into which the Murray River has incised, consists of three mapable units: a unit characterized by thick calcrete, a unit of extensive aeolian deposits, and a unit characterized by gypsum deposits. Beneath the first two units lies the extensive Ripon Surface of middle Pleistocene age (Firman 1964). Below the Ripon Surface is a post-Tertiary surface whose origin is problematical.

The following description of the evolution of the landscape through which the Murray River flows falls into three parts, the post-Tertiary surface, the middle Pleistocene Ripon Surface, and the Mallee Surface. The stratigraphy mentioned in the text is presented in the stratigraphic table (see Table 1.1).

2. THE POST–TERTIARY SURFACE

(1) Description

Throughout the Murray Mallee, i.e. the area mappped on the Renmark Geological Sheet 1:250,000 (Firman, 1971d), and along the cliff sections of the valley, this surface can be seen transecting strata of varying age and composition.

a. Quaternary — Pleistocene Blanchetown Clay and Bungunnia Limestone
b. Late Tertiary — Loxton Sands, overlain in places by Norwest Bend Formation and Parilla Sand, and
c. Middle Tertiary — Morgan Limestone and Mannum Formation

From the Mount Lofty Ranges to the vicinity of the Murray valley the surface slopes 2–3° across Miocene limestone. Borelog data shows the Miocene limestone is essentially horizontally disposed except where faulting post Miocene deposition has dislocated the limestone. On either side of the present Murray valley the Miocene limestone is eroded into a valley form in which Pliocene limestone, the estuarine Norwest Bend Formation, has been deposited. Upper Pliocene sand, Parilla Sand, is found from the centre of the Murray Mallee towards the Victorian Border. The Pleistocene Blanchetown Clay and Bungunnia Limestone occur discontinuously on the eastern side of the present valley, and less extensively on the western side.

(2) Origin

A lack of field evidence makes interpretation of the origin of the post–Tertiary surface difficult.

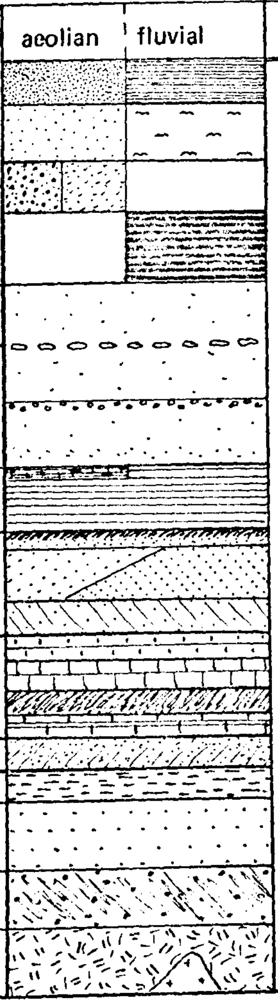
Borelog evidence suggests that the surface is erosional, but insufficient evidence is available to classify with certainty the type of erosion surface. However, it can be argued that the surface is not a plain of marine erosion, which is a plain of subcontinental extent developed by the sea as a planation agent. In the region of South Australia it seems doubtful whether there was sufficient stillstand of the sea to allow the narrow zone of wave attack to penetrate inland as far as the Murray Mallee. Furthermore there is no geological evidence to suggest a transgression of the whole region during the late Cainozoic. Only local estuaries were developed during the Late Tertiary (O'Driscoll, 1960).

Also it can be argued that the surface is not a structural plain, a plain formed by the stripping or near stripping of weak strata exposing a resistant stratum, since the surface clearly truncates rocks of varying resistance. The truncation of these sediments of the Murray Basin also negates the suggestion that the surface is a sediplain, a plain of deposition, the sediments of which have suffered little or no weathering and erosion since emergence. Furthermore, the nature of the sediments of the Murray Basin precludes the possibility of the surface being a panplane (Crickmay, 1933), a plain formed by the coalescence of floodplains, which are the product of lateral erosion by streams.

There is little evidence to suggest that the erosion surface is an etch plain (Wayland, 1934). This surface is formed when the original subdued surface with a deeply weathered regolith is uplifted and the regolith removed to expose the weathering front. Similarly, there is no evidence to suggest that the surface is a resurrected or exhumed surface, a surface produced by re-exposure of a buried erosion surface.

It is suggested that the erosion surface may be an uplifted peneplain that is a gently undulating surface, produced close to baselevel by fluvial processes, which then suffered uplift so as to be unrelated to the present baselevel of erosion, or sea level. Unfortunately, the Davisian term "peneplain" is used loosely in geomorphic literature. With its inherent genetic connotations its use should be restricted to surfaces which are the penultimate stage of a geomorphic cycle. There is no conclusive evidence to suggest that the post-Tertiary surface was formed in this way. If the surface is morphologically but not genetically consistent with Davis' description, alternative definitions should be devised. Geomorphologists have resolved this problem by qualifying the term "peneplain" for example "partial peneplain" and "apparent peneplain". A partial peneplain (Thornbury, 1969) is a surface which has not been completely reduced to baselevel, i.e. the areas which have been graded are of limited extent. In this study

TABLE 1.1: STRATIGRAPHY



AGE			DESCRIPTION see Renmark Sheet 1:250,000
			Murray Mallee and valley
QUATERNARY	Recent		grey and white sand spreads; halite crusts kopi- lunnettes; Coonambidgal Formation clays silts and sandy light grey alluvium (Qrs) Bunyip Sand (Qrp) Molineaux Sand (Qrm) with carbonate; Yamba Formation gypsum Monoman Formation (Qrs) course grained sandy quartz with Nototherium fossils
	Pleistocene	upper	Woorinnen Formation (Qpw) with Loveday Soil calcrete Bakara calcrete } Bakara Soil (Qca)
		middle	Ripon Calcrete } Bakara Soil (Qca) marl loess } Bakara Soil (Qca)
		lower	Bungunnia Limestone (Qpu) Blanchetown Clay (Qph) fluvia-lacustrine red brown and green mottled clay
TERTIARY	Pliocene		Norwest Bend Formation (Tpn) thick oyster shells and sand Parilla Sands (Tpp) bright micaceous sands cross bedded Loxton Sands (Tpl) bright micaceous sands cross bedded Bookpurnong Beds glauconitic marl
	Miocene		Pata Limestone Morgan Limestone Finnis Clay Mannum Formation
	Oligocene		Ettrick formation glauconitic marl
	Eocene		Renmark Beds carbonaceous sediments
PRE-TERTIARY	Lower Cretaceous		Ottway Group sandstone
	Permian		claystone sandstone erratic pebbles
	Palaeozoic		dolomite shale sandstone schists phyllites granite intrusion

after Firman 1969, and
Ludbrook, 1957

Fig. 1.1 (a) Field notes, (b) soil sample, and (c) photograph of the calcrete surface, Murbko.

(a)

PIT NO. 38

EXAMINER: Ken Wetherby

DATE: 29/8/68

LOCATION: Section $2A^1$ Hundred Murbko
Gravel pit on east side of Murbko road

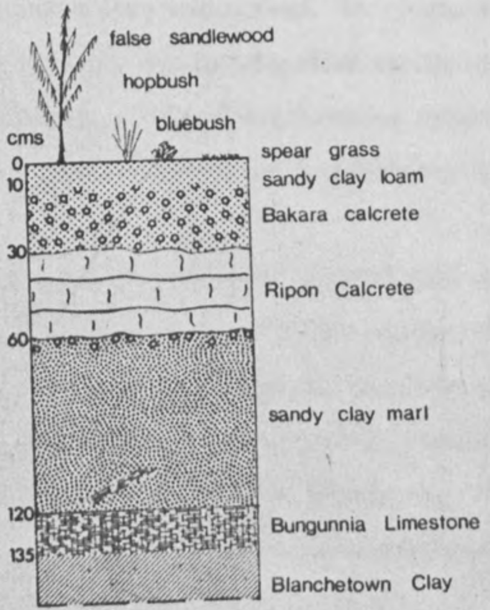
VEGETATION: Sparse mallee, hopbush, bluebush

LANDFORM: Very gently undulating (almost flat)

SOIL DESCRIPTION

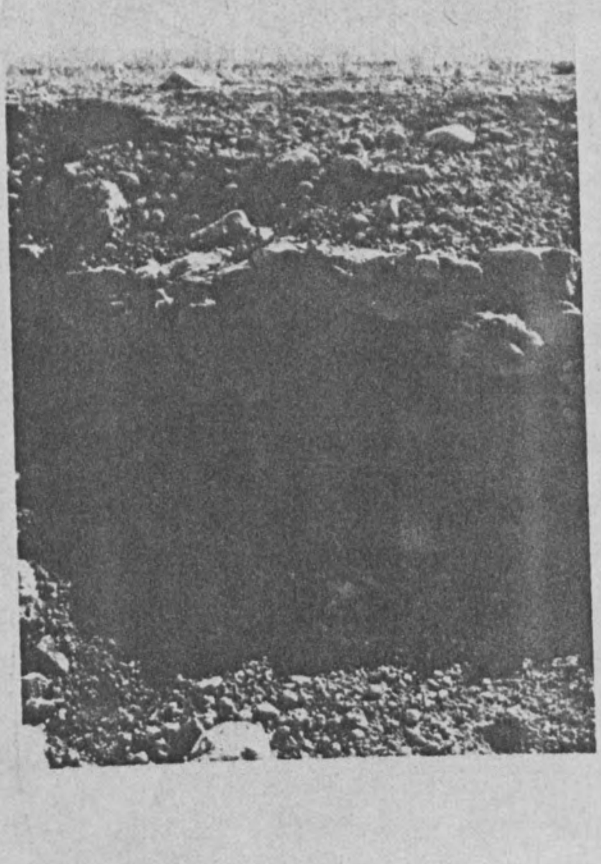
Depth in inches and cm	Colour	Tex	pH	$CaCO_3$	Fabric	EC		Stone	Remarks
						Mr 1:5	Ece cal.		
0"-4" 0cm-10cm	7.5 YR 4/4	Sandy clay loam	8.5/8.0	Highly					
4"-12" 10cm-30cm	7.5 YR 4/4	Sandy clay loam	8.5/9.0	Highly					2.5-3.75 cm oolitic $CaCO_3$ gravel. Bakara (50% of matrix).
12"-24" 30cm-60cm	–	Kunkar Indurated		Highly					30-45 cm thick Ripon. Very limey matrix, with many nodules. Just below the Ripon grades into
24"-48" 60cm-120cm	–	Sandy clay	9.5	Highly					
48"-45" 120cm-135cm	–	Poorly expressed Bungunnia Limestone							
54" + 135cm +	Greenish with red mottling	Clay with some sand		High High					Blanchetown clay.

Principle Profile form Um $5^{\underline{11}}$ (as per Northcote)
General Comments: Very similar to part east of Mantung. Associated pits in section C Cadell, section C^3 Cadell, and pit 73. Note large flat fragments of Bungunnia Limestone found at random in these two layers; must indicate solifluction type movement. Fragments are true dolomitic micrite.



b) solonized brown soil

c)



region the undulating surface is very widespread. An apparent peneplain (Trendall, 1962) is a surface of erosion, which is largely due to subsurface evacuation of material, primarily, though not wholly in solution (Twidale, 1968). The calcareous nature of the bedrock of the erosion surface, Miocene limestone, Pliocene limestone, and Pleistocene limestone presents a matrix for such a process.

Since there are problems of definition with erosion surfaces, especially with the use of the term peneplain, and since there is a scarcity of field evidence, classification of the post-Tertairy erosion surface is at best tentative. It is suggested that the term "simulant peneplain" (from the Latin "simulate, simulacrum" meaning image of something; shadowy likeness; deceptive substitute; mere pretence – Concise Oxford Dictionary, 1963) be used as a tentative classification for the erosion surface into which the Murray River has incised.

3. THE RIPON SURFACE

(1) Description

The middle Pleistocene Ripon Surface (Firman, 1964) is an extensive surface developed on top of Ripon Calcrete, a pedogenic calcium carbonate which on exposure forms a crust. The Ripon Calcrete was developed on Miocene limestone (Morgan Limestone and Mannum Formation), Pliocene sand (Loxton Sand), Pliocene limestone (Norwest Bend Formation), and Pleistocene limestone (Bungunnia Limestone).

Ripon Calcrete in the Murray Mallee is a fossil soil characterized by moderately hard to massive nodular or sheet-like calcium carbonate, 16 cm thick (see Firman, 1971d and Fig. 1.1). It has been dated at about 30,000 B.P. (Firman, 1969).

(2) Origin of the Ripon Surface

The source of carbonate for calcrete formation is problematical. According to Firman (1969), the Murray Mallee consisted of a widespread system of valley lakes during the Pleistocene. The Blanchetown Clay, and the Bungunnia Limestone represented two sediments deposited on the floor of these lakes. An arid period followed and the lakes dried out. A subsequent period of aeolian activity resulted in the deposition of loess. This mixed with weathered Tertiary sediments, and the now exposed lacustrine/estuarine sediments along the present Murray valley, produced a whitish, but heterogenous marl. Stable climatic conditions seem then to have prevailed, resulting in the development of a soil profile in which the thick accumulation of Ripon Calcrete developed in the B horizon. Removal of the A horizon by wind exposed the calcrete surface referred to as the Ripon Surface by Firman (1964).

Alternatively, it could be argued that the carbonate source for the Ripon Calcrete was simply weathering products of the Miocene limestones, Pliocene limestone, fossiliferous

Pliocene sands, and Pleistocene limestone. The extensive area of calcrete capping, and the obscure source of the loessic marl support the hypothesis for this *in situ* source of the carbonate.

There is still much controversy over the formation of calcrete, and many writers have differed in their interpretation of the pedogenic processes involved (see for example Teakle 1937, Crocker 1946, Bretz and Horberg 1949, Reeves 1970, Wetherby 1971, Williams and Polach 1971 and Goudie 1973).

It appears from evidence in Australia and overseas that calcrete formation, usually regarded as a pedogenic process, is due to a two-stage movement of soil water in a calcareous environment. These movements include a downward leaching of rainwater, resulting in solution of calcium carbonate from the source material (which may be loessic marl, or calcareous sands) to form a calcium carbonate rich solution; and a subsequent precipitation of calcium carbonate around nuclei, such as quartz grains, or the remains of shelly organisms as ground water is drawn upwards, through capillary action when the soil dries out. The depth of the soil profile would be a reflection of the interaction of the downward and upward movement of water, the existence of a relatively stable climate characterized by seasonal fluctuations, and time.

4. THE MALLEE SURFACE

The present topographic surface, the Mallee Surface, is the result of the modification of the Ripon Surface by aeolian and weathering processes.

(1) Description

Today the Mallee Surface consists of three major geomorphic units.

(i) Calcrete (kunkar) developed on the Ripon Surface.

(ii) Mallee sands, These can be divided into five sand dune types, classified according to morphology. These include longitudinal or seif dunes with an east-west orientation, parabolic or jumbled dunes with an east-west orientation, parabolic dunes with a northeast orientation, and lunettes on the eastern side of claypans or gypsum lakes.

(iii) Kopi plain country of gypsum flats located to the southeast of Renmark and east of Blanchetown.

These three units, i.e. the calcrete capping, the Mallee sands, and the kopi plains can be mapped (see the geological map of the Renmark Sheet 1:250,000). The calcrete capping is equivalent to Qca, the Mallee sands to Qrm, and Qrp, and the kopi plains to Q1o. The landforms in these three mapable units will be described in turn.

(i) *The calcrete units*

Calcrete developed above the Ripon Surface is referred to as Bakara calcrete (Firman, 1971d), and is essentially nodular, ranging in size from 0.6 cm – 3.8 cm in diameter.

Bakara calcrete has been dated at about 16,000 years B.P. (Firman, 1971d) A younger calcrete, the Loveday calcrete dated about 6,000 years B.P. (Firman, 1971d) is a chalky white calc which hardens on exposure to the atmosphere. Younger, but similar calc can be observed in both the Molineaux Sand and Bunyip Sand (see page 7). Field evidence suggests that carbonate is still forming in these sands, and also in the present Mallee soil developed on top of the Ripon Surface.

The calcrete developed on the Ripon Surface can be distinguished morphologically and chronologically (see Table 1.2) and chemically (see Table 1.3) from the underlying Ripon Calcrete.

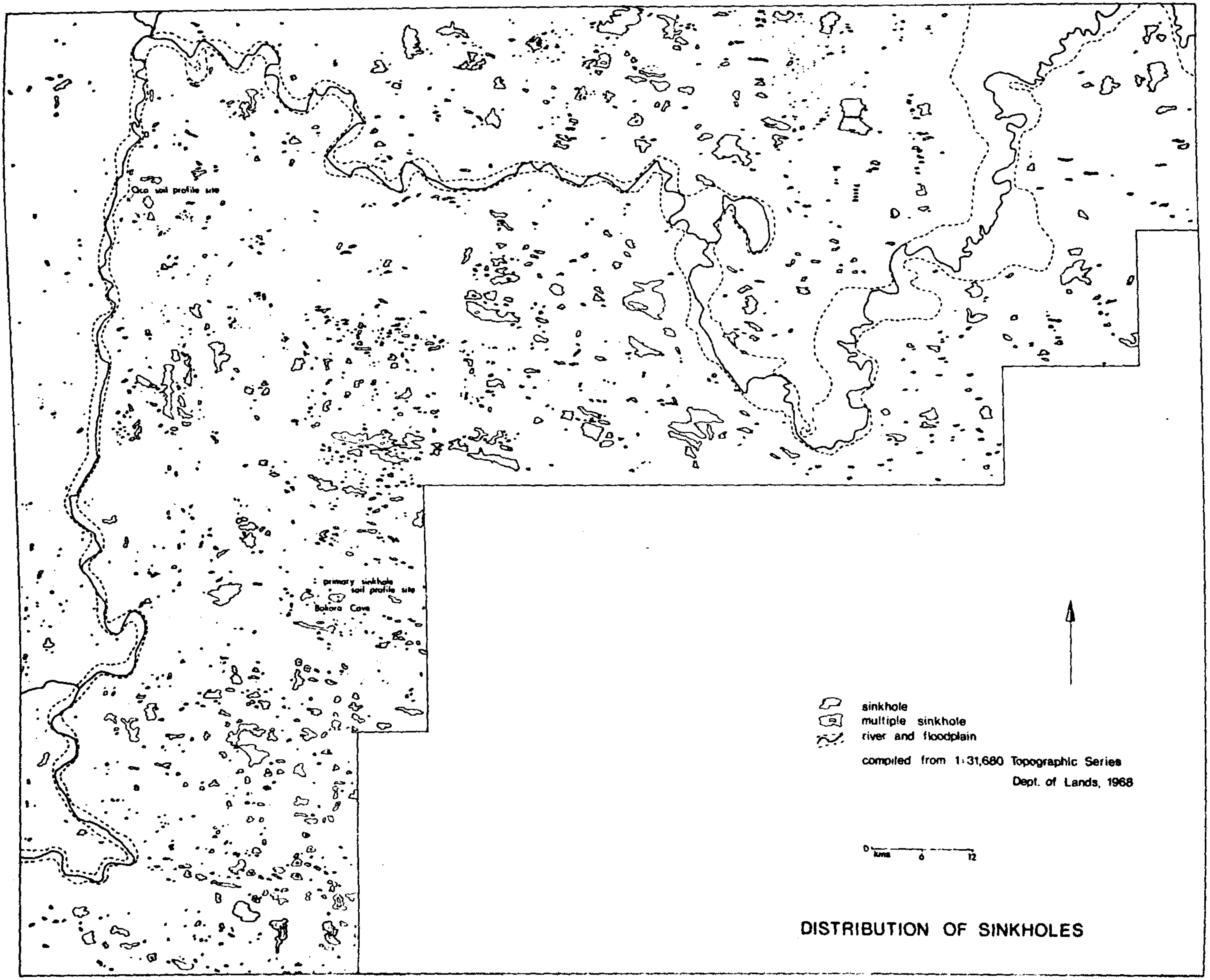
The calcrete unit of the Mallee Surface can be described as the modified Ripon Surface, modified by pedogenic processes which have produced the Bakara calcrete and Loveday soil calcrete, and by weathering processes producing solution features such as sinkholes. The sinkholes are located at the intersection of joints, or topographic lows in the overall undulating surface of the Ripon Calcrete.

The sinkholes are essentially rectangular in outline (see Fig. 1.2) although this pattern is often not readily discernible due to the presence of scree derived from the collapse of the caprock into the underlying Blanchetown Clay (Firman 1971 and see Fig. 1.3). This shape is suggestive of joint control.

Primary and secondary sinkholes can be distinguished. The primary sinkholes (1), are large scale features, ranging from 805 m–18.3 m in diameter, with side walls modified by scree and soil development (see Figs. 1.4, 1.5, 1.6). The map (see Fig. 1.2) compiled from data on the topographic maps of the Lands Department, 1:31,680, shows the variation in size of these. The apparent, approximate north-northwest/south-southeast and south-southwest/north-northeast orientation may be related to the joint pattern developed within the Bungunnia Limestone, and/or Tertiary limestones. The secondary sinkholes (2), represent more recent collapse (see Fig. 1.3, 1.5).

The primary sinkholes seem to have been developed prior to the formation of Ripon Calcrete; the secondary, or younger sinkholes, have been developed prior to the younger calcrete in Bakara Soil. There is evidence of solution features forming actively today, for example on the property of Mr. K. Gibbs, near Myrla, Section 13, Hundred of Holder, in the spring of 1973 (Wetherby, 1974. Similar solution features are reported in O'Driscoll (1960).

The majority of the primary sinkholes contain small internal single or multiple collapse features (2A) (see Fig. 1.3), ranging in size from 1 m to 10 m. These are developed within a



DISTRIBUTION OF SINKHOLES

Fig 1·2

FIG.1·3

SINKHOLES DEVELOPED WITHIN THE MALLEE SURFACE

Bakara Well

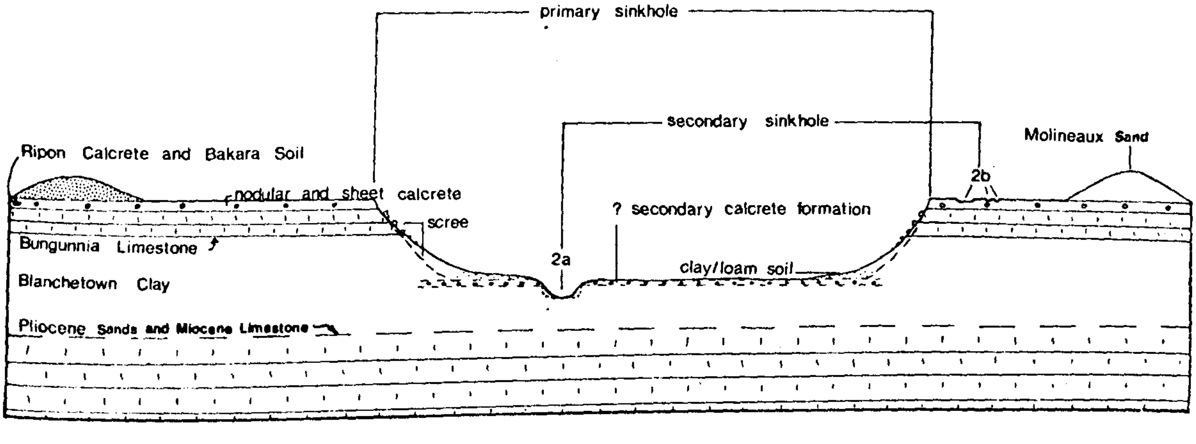


TABLE 1.2 CALCRETE IN THE MURRAY MALLEE

AGE (relative)	NAME (Firman 1971d)	DESCRIPTION
"Old" c? 30,000 B.P. mid-Pleistocene (Firman, 1964)	Ripon Calcrete	Thick, 15.2 cm-0.9 m, extensive zone of cemented $CaCO_3$, carbonate breccia and clastic material (Firman 1969), usually overlying marl, but resting on Pliocene Norwest Bend Formation (oyster beds) at Swan Reach, and granite (Wetherby pers. comm.). A well jointed caprock, showing some variations in texture, resulting from differing amounts of detrital impurities, and manganese oxide stainings. The uppermost surface consists of a laminated zone, with a skin, usually a few mms in thickness, with occasional solution features, e.g. onion weathering. The transitional zone below consists of a mixture of marl, (parent material) and small nodules – the oldest carbonate in the profile.
Mature – c. 16-12,000 B.P. Firman, 1971b)	Younger calcrete in Bakara Soil	Essentially nodular, ranging in size from 0.6 cm-3.8 cm in diameter, sometimes cemented by competent carbonate. Profile 7.6 cm-30.4 cm in depth grades upwards into thin Mallee soil, 10 cm – terra rossa – (Crocker, 1946), downwards to palaeosol, and/or Ripon Calcrete.
Young, c. 9,000-6,000 B.P. (Gill, 1973)	Loveday calcrete	Chalky, and white calc, no cementation between the carbonate powder and the parent material. Infilling of vertical desiccation cracks, in the Loveday Soil (palaeosol) of the Woorinen Formation, and accumulation in aeolian sands, Bunyip and Molineaux. The surface of precipitation is undulating, a distinct boundary between the zone of illuviation: eluviation – "the wetting front." Calc tends to harden on exposure. Suggest still forming today.

Classification based on the criteria of Reeves (1970)

TABLE 1.3

CHEMICAL ANALYSES FOR CARBONATE LAYERS OF THE MALLEE SURFACE (after Wetherby)

younger

decreasing hardness

Carbonate Layer	Summary
I Bakara Soil	SiO_2 values approximately $\frac{2}{3}$ of those for class II and $\frac{1}{2}$ of those for class IIIb, in Bunyip Sand.
II Loveday Soil – Woorinen Formation	SiO_2 counts are greater than class I but less than class IIIb in Bunyip Sand. Fe_2O_3 count is roughly $\frac{1}{2}$ that of class IIIa, in Molineaux Sand.
III(a) Molineaux Sand	Fe_2O_3, TiO_2, K_2O, and Al_2O_3 counts are high in relation to classes I, II and IIIb (Bunyip Sand): CaO counts are lower than these classes.
III(b) Bunyip Sand	SiO_2 counts are high in relation to classes I, II, and IIIa, in Molineaux Sand.

Source: chemical analyses carried out for Wetherby by the Waite Agricultural Research Institute.

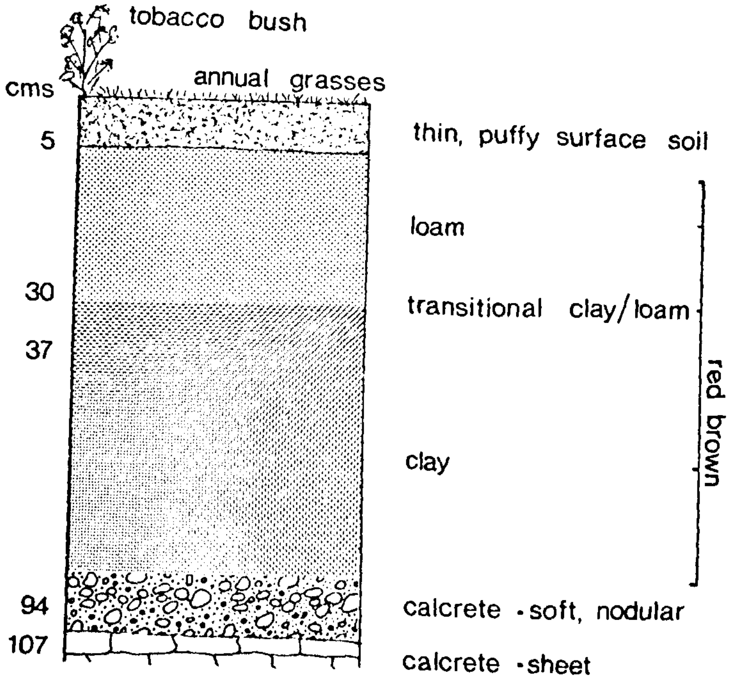
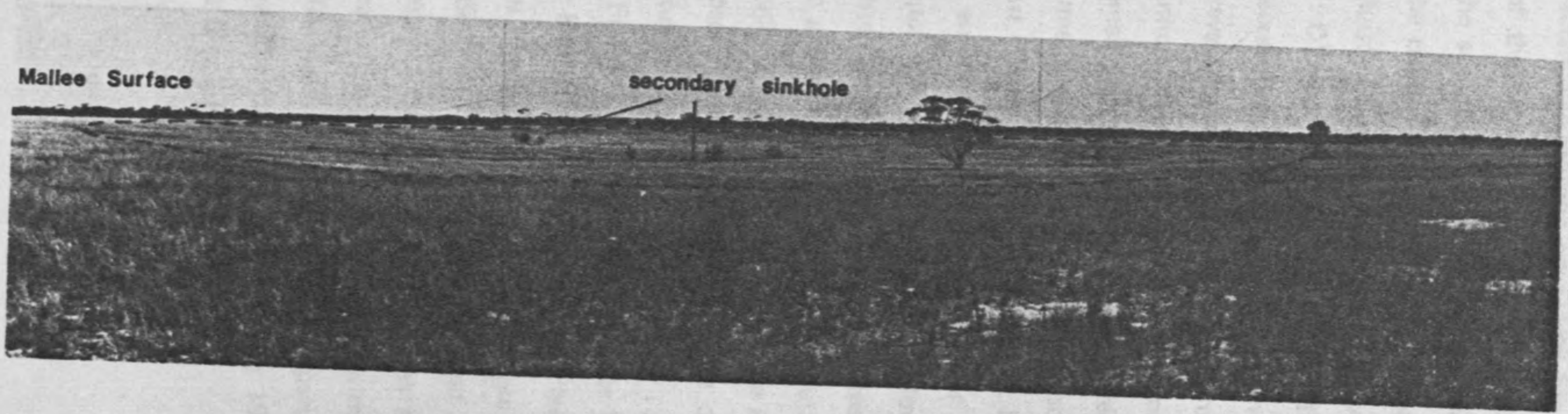


FIG. 1·4 Soil profile of a primary sinkhole

Fig. 1.5 A primary sinkhole Bakara Well, diameter 604 m, depth 7.6 m.

Fig. 1.6 A secondary sinkhole developed within the primary sinkhole Bakara Well.


Mallee Surface
secondary sinkhole


primary sinkhole

layer of sheet calcrete within the primary depresssion, which could represent the collapse of the Ripon Calcrete from the original topographic horizon onto the marl or Blanchetown Clay, or secondary precipitation of $CaCO_3$ forming a younger horizon. Solution cups (2B), represent secondary sinkholes on a minor scale (see Fig. 1.4). These may be circular or rectangular solution cups, (see Fig. 1.7, 1.8). Their depth varies depending on the thickness of the caprock, but is usually between 2.5 cm–45.7 cm. At Bakara Cave (Figs. 1.9, 1.10) the secondary sinkholes represent entrances to subterranean passageways, and elsewhere in the region may indicate former aboriginal waterholes (see Fig. 1.7). Along the cliffs of the Murray River such sinkhole development contributes to the overall cliff recession.

O'Driscoll (1960) and Barnes (1951) described the primary sinkholes as "clay pan" like depressions. Minor irregularities in the surface of the interdune flats have the effect of preventing surface runoff and promoting internal drainage into the depressions. These two authors claimed that numerous small depressions dotted over the Mallee Surface are the remains of sinkholes connected directly to the Morgan Limestone aquifer below. They cited numerous specific examples, and suggested that others now blocked, have existed in the past. There is one graphic account by O'Driscoll (1960) of a cloud burst in 1913 resulting in an enormous suction effect over 20.2 hectares of Section 5C in the hundred of Pyap. A crater was reported to have "swallowed" up much farming equipment as the water entered subterranean passageways. These features are also recorded in aboriginal legends, in which the presence of an alleged west-southwest/east-northeast passage between Loxton and Swan Reach is expressed by a large cave in the cliffs of the Murray valley. The cave at Loxton appears to have collapsed because of vibrations from irrigation practices (J. Chilman pers. comm.).

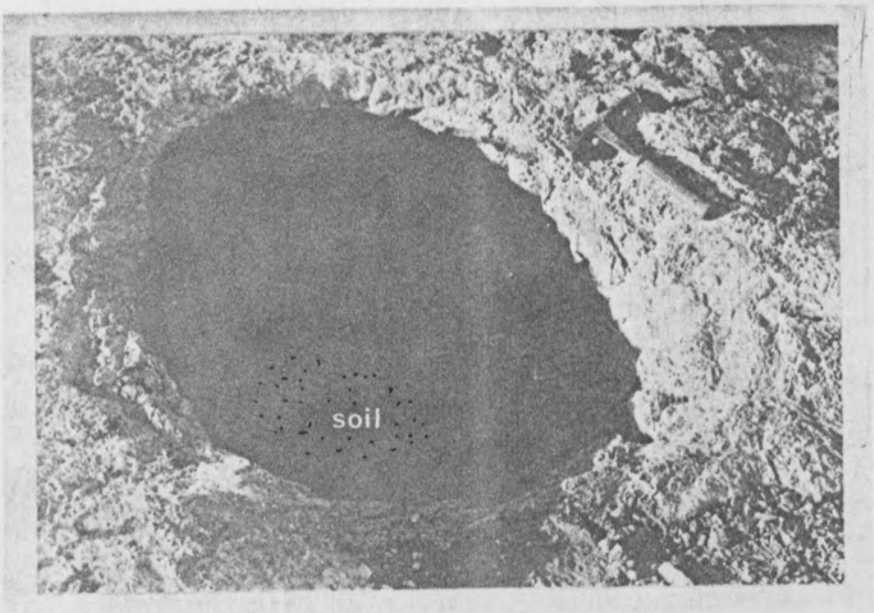
Frahn (1971) suggested that cave formation due to erosion of limestone took place when the Murray River flowed at higher levels than today. Subsequent collapse of the caves could have formed the sinkholes which are mapped as depressions throughout the Murray Mallee.

Sinkholes are in part fossil and in part actively forming. The fossil are described as primary forms, the more recent as secondary. However, it cannot be said with certainty whether the latter are associated with original calcrete or a reprecipitated, secondary form.

The only evidence of possible pseudo anticline development with arching of the calcrete formation (Jennings and Sweeting 1961) is located on the eastern slope of the valley, at Lock 6 (see Fig. 1.11).

Fig. 1.7 A large solution hollow developed within Ripon Calcrete, Maggea. It is 30 cm deep, 75 cm long, and has a diameter of 30 cm. A distinct overlying lip encircles this solutional feature. It was a former aboriginal water hole.

Fig. 1.8 A solutional cup, developed in sheet Ripon Calcrete, at Bakara Cave.


soil


calcrete

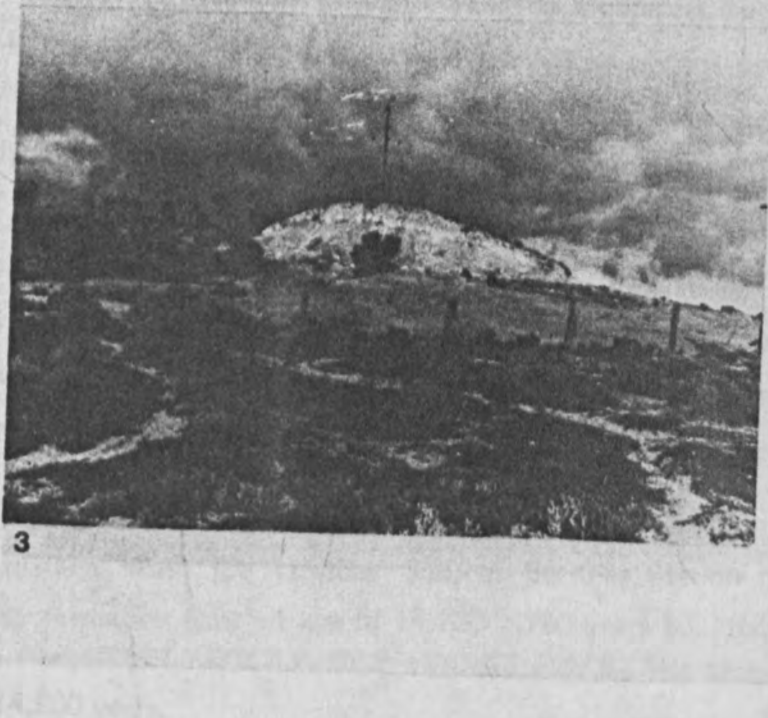
Fig. 1.9 Bakara Cave, the entrance to a subterranean passage. A small gully leads into a deep and extensive network of passageways.

Fig. 1.10 Looking into a "tributary" passage from the main chamber at Bakara Cave. Excellent exposures of the stratigraphy are present in this cave.

Fig. 1.11 A pseudo-anticline in the valley-side slope at Lock 6.

1

2



3

Thus this first unit of the Mallee Surface, the calcrete unit, is the modified Ripon Surface, modified by weathering and erosional processes producing sinkholes and subsurface drainage, as well as pedogenic processes, which have resulted in younger calcrete accumulations.

(ii) *The Mallee Sands*

There are five sand dune types mapped on a basis of their morphological characteristics (see Fig. 1.12).

(a) *East-west trending dunes* (see Fig. 1.13)

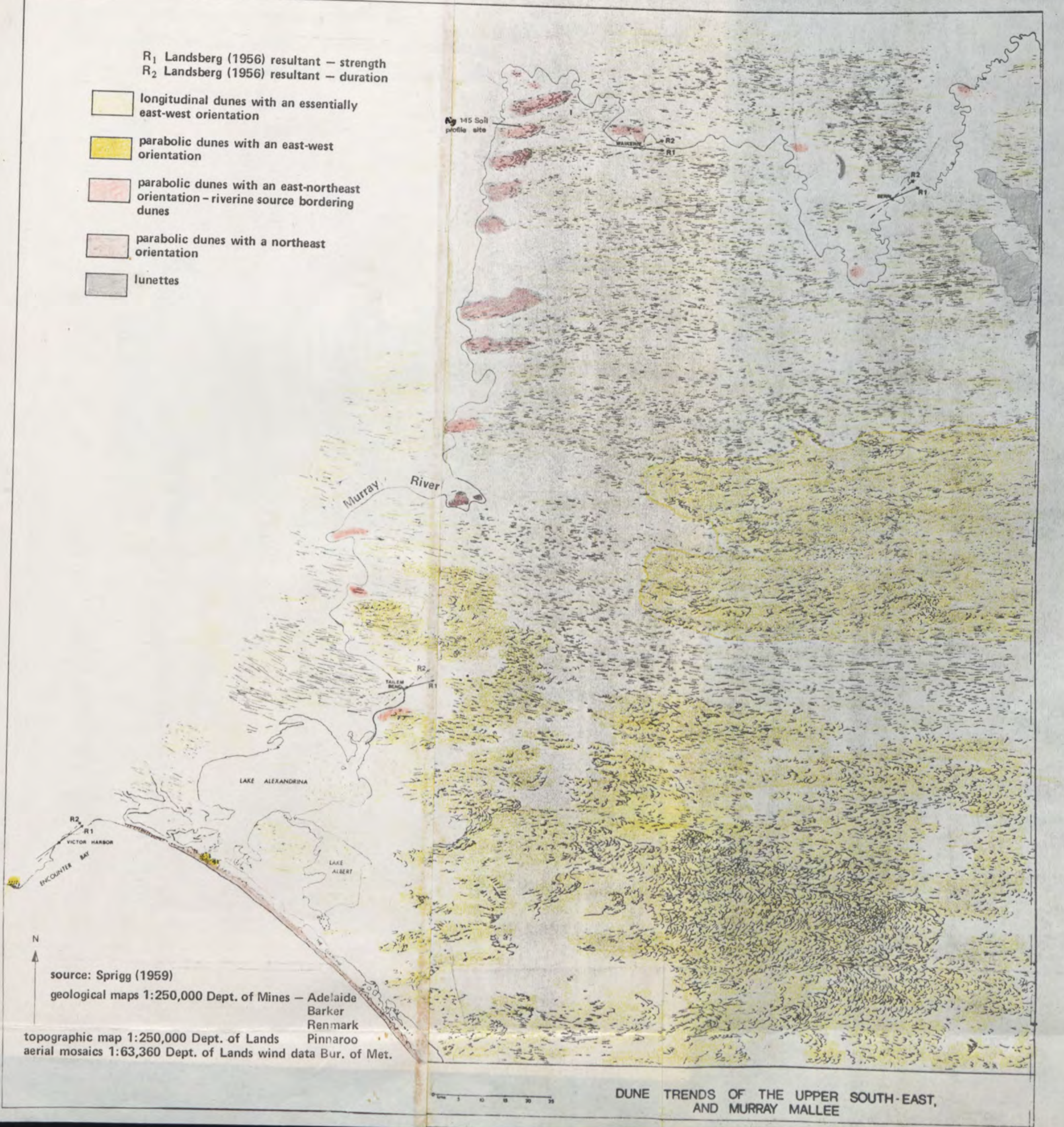
In the northern and central Murray Mallee these low rounded, discontinuous parallel dunes consists of Molineaux Sand developed from the Woorinen Formation as described by Firman (1969). The widespread Woorinen Formation consists of aeolian material derived from the deflation of the A horizon of the Bakara Soil. With the exception of Gill (1966, 1973) published descriptions of this formation are consistent with this suggestion. The Woorinen Formation has been reworked to form the east-west parallel sand dunes, consisting of Molineaux Sand with mobile crests.

In the northern Murray Mallee the low, rounded, discontinuous parallel dunes are formed from the Woorinen Formation. The Woorinen Formation consists of sandy loam with moderate amounts of free lime, 1 m–6 m thick (Potter, Wetherby and Chittleborough, 1973). A soil profile the Loveday Soil, was developed on this stratigraphic unit. The Loveday Soil consists of a sandy loam grading to sandy clay loam over a weak calcrete found between 60 cm and 76 cm (Potter, Wetherby, Chittleborough, 1973). The A horizon of the Loveday Soil was reworked at a later date to produce the east-west low rounded discontinuous parallel dunes. These dunes have been mapped by Firman (1971b) as Molineaux Sand i.e. quartz sand with pale yellow upper layers overlying dark yellow layers possessing soft columnar carbonate nodules (see Figs. 1.12 and 1.13), and Bunyip Sand of light red-brown and red quartz sand with lower layers containing soft ropy or columnar carbonate nodules. The Bunyip Sand will be discussed in the following section dealing with parabolic dunes of an east-northeast orientation.

Molineaux Sand is found in sand dunes of differing morphology. These are east-west sub-parallel dunes in the northern Murray Mallee, and parabolic dunes in the southern Murray Mallee and the Upper South East. We are concerned here with only the east-west sub-parallel ridges.

The dunes of Molineaux Sand in the northern Mallee post date the Woorninen Formation. Dating of the material from the Loveday Soil, at Berribee Station northwest Victoria, developed on this formation gave an age of 14,200 ± 790 years B.C. (N.Z.) by Gill (1973). Younger than 14,200 years.

FIG 12



source: Sprigg (1959)

geological maps 1:250,000 Dept. of Mines – Adelaide
Barker
Renmark
Pinnaroo

topographic map 1:250,000 Dept. of Lands

aerial mosaics 1:63,360 Dept. of Lands wind data Bur. of Met.

DUNE TRENDS OF THE UPPER SOUTH-EAST, AND MURRAY MALLEE

Fig. 1.13 A deflated dune of Molineaux Sand, Hampton Well, showing columnar carbonate accumulations formed by exposure to the atmosphere. Aboriginal hearths have been exposed.


calcrete
hearth stones

(b) *Parabolic dunes with an east-west orientation* (see Fig. 1.12)

These occur in the southern Murray Mallee and the Upper South East. The source for the sand for these dunes of Molineaux Sand is reported to be reworked Woorinen Formation (Firman 1971b). However, Sprigg (1959) in his paper on the Upper South East considered an alternative source of sand for the dunes to have been derived from sediments deposited in previous courses of the Murray River. He also claimed that additional source of sand may have been derived from coastal erosion of Encounter Bay, and weathering of granite and/or pre-Tertiary sedimentary rocks. This material would then have had to be transported a great distance inland by westerly winds. It seems unlikely that material can be transported such distances from its source.

The Bridgewater Formation, occurring to the southwest of Lake Albert and Lake Alexandrina (see Firman 1964) consists of coastal dunes developed on an exposed continental shelf during Pleistocene low sealevels then uplifted and stranded. Crocker (1946) and Sprigg (1958) concluded that what was called the Lowan Sand of western Victoria (Lawrence, 1966) is the A horizon of former dunes of the Bridgewater Formation transported by wind during an arid period. However, in agreement with Lawrence (1966) there is no field evidence to support Crocker's and Sprigg's suggestion for the origin of the Lowan Sand in Victoria, and the Molineaux Sand in South Australia. Furthermore, it seems unlikely that sand could be transported the distance to Victoria. It is suggested that the Molineaux Sand is reworked Woorinen Formation.

Why are sand dunes of the Molineaux Sand in part longitudinal, and in part parabolic in morphology? This morphological difference may be the result of varying amounts of material available for dune construction, and variations in time before the dunes became stabilized by vegetation. It would be expected that in the wetter, southern areas the Woorinen reworked Formation would be stabilized in an early dune form, before there was sufficient time for the parabolic form to be blown out into parallel ridges.

(c) *Parabolic dunes with an east-northeast orientation* (see Fig. 1.12)

This dune type is found adjacent to the Murray valley in South Australia. Without exception these dunes are located on the eastern side of the valley.

These east-northeast trending dunes consist of Bunyip Sand, a coarse red to orange siliceous sand (see Fig. 1.20). Tongues of sand finger onto the Woorinen Formation, and/or calcrete surface. These tongues, however, do not have the east-west orientation of the parabolic dunes of Molineaux Sand, or of Woorinen Formation. Instead they have an approximate west-southwest/east-northeast trend. They occur between Swan Reach and Cadell regularly spaced between calcrete surfaces (see Figs. 1.12, 1.15). Bunyip Sand has been reported by both Wetherby (1972 pers. comm.) and Firman (1971) from Loxton and Gill (1973) from the Coonambidgal Creek, New South Wales.

The source of sand for these east-northeast trending dunes (See Figs. 1.15, 1.16, 1.17, 1.18, 1.19, 1.20) is considered to be fluvial. This is contradictory to Firman (1971b) who suggested that Bunyip Sand of which they are composed, is derived from aeolian reworking of the upper Woorinen Formation. A study of the geological sections of the Murray valley (see Fig. 5.7) suggests that source of Bunyip Sand may infact be fluvial. The Monoman Formation, not the Coonambidgal Formation is the valley-fill contributing to the supply of sand (see page 35). Pseudo terraces (see page 40) perhaps derived from the Monoman Formation, are actively being deflated, and are supplying additional sand to these east-northeast trending dunes.

It is suggested that these dunes can be designated riverine-source bordering dunes, a term used by Page (1971), (see page 35) and originated by Melton (1940).

(d) *Parabolic dunes with a northeast orientation* (see Fig. 1.12)

These dunes are found on Sir Richard and Younghusband Peninsulas, in the vicinity of the Murray mouth and the Coorong. The sediments for dune construction are made available by longshore drift processes operating along the coast of Encounter Bay and the Upper South East (see page 60). The parabolic dunes are superimposed on older east-west trending dunes (see page 61).

(e) *Lunettes* (see Fig. A and 1.13)

Lunettes (the yellow parna dunes of Gill, 1966) are found on the kopi plains, to the east of Loxton (see Fig. 1.21). They also occur within the Murray valley (see Fig. A). Lakes Limbra and Littra near Chowilla are two examples.

The kopi dunes are low and winding, and composed of gypsite, (flour gypsum) interfingering with the Woorinen Formation, as for example at Rotten Lake. The ridges are no higher than about 4.5 m with .3 m—.9 m of flour typsum covering seed gypsum. On the Blanchetown Plain low dunes have blown up at the edges of the gypsum depressions. In agreement with other writers a post-Pleistocene age is assigned to these dunes, since the lakes and lunettes are developed within Late Pleistocene Blanchtown Clay and Bungunnia Limestone.

Parna, consisting of wind blown clay aggregates, occurs as sheets, dunes, and lunettes (dune parna). Field evidence suggests that these deposits lying to the east of the existing dune systems in South Australia, must post-date the formation of the Molineaux Sand. Since the Bunyip Sand has little or no clay content then parna deposition may also pre-date Bunyip

Fig. 1.14 (a) Field notes, (b) soil profile, and (c) photograph of Bunyip Sand, Murbko.

(a)

PIT NO. 45

EXAMINER: K. Wetherby

DATE: 21/7/71

LOCATION: Section 36 Hundred Murbko
Hills in centre of section

VEGETATION: Mallee scrub – spinifex, hopbush = dune
" " " = flat

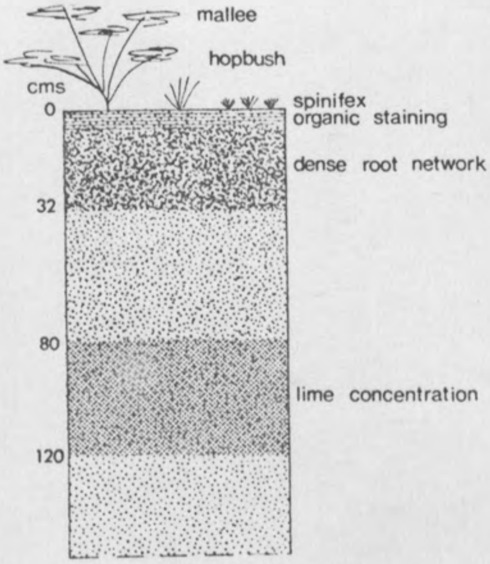
LANDFORM: Barchan dune Murbko high sand h.71
small sandy flats between (deep sand)

SOIL DESCRIPTION

Depth in inches and cm	Colour	Tex	pH	$CaCO_3$	Fabric	EC		Stone	Remarks
						Mr 1:5	ECe cal.		
Sample 1 0"-13" 0cm-32cm	7.5 YR 3/4 estimated	Coarse sand rounded	$7^{\underline{5}}$	N	S		1	N	
II 13"-32" 32cm-80cm	7.5 YR 4/4	Coarse sand rounded	$9^{\underline{0}}$	M/H	S		1½	N	
III 32"-48" 80cm-120cm	7.5 YR 4/4 chroma increasing	Coarse sand rounded	$9^{\underline{0}}$	H	S		2	N	Area of lime conc.
No sample 48" + 120cm +	7.5 YR 4/4 chroma increasing	Coarse sand rounded	$9^{\underline{0}}$	H	S		–	N	less compact than 32"-48" layers

Principle Profile form Uc $5^{\underline{12}}$ (deep)

General Comments: lime rubble is often on surface of flats.

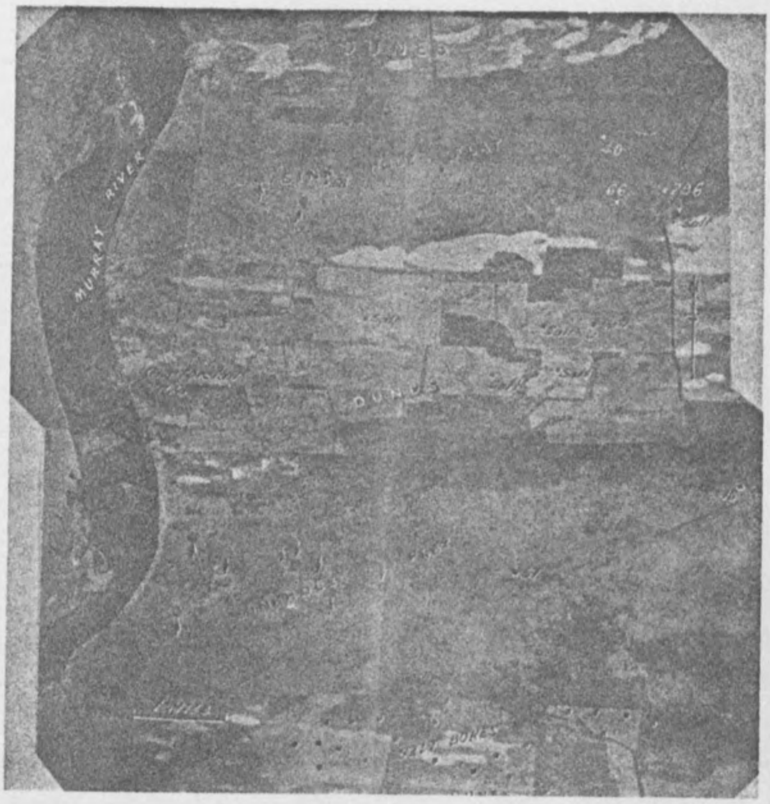


b) **Bunyip Sand**

c)

Fig. 1.15 East-northeast trending dunes northeast of Blanchetown, showing the tongues of Bunyip Sand, in this case a detached cliff-top dune trail, (see p. 33) separated by calcrete or sinkhole flats. (after O'Driscoll 1960).

Fig. 1.16 Bunyip Sand, at the eastern end of the Blanchetown Bridge. The coarse red sand possesses a distinct carbonate horizon.


DUNES
MURRAY RIVER
20
66
DUNES


carbonate

Fig. 1.17 Deflation of dunes of Bunyip Sand. This is a detached cliff-top dune, which has been isolated from its former riverine sand source. This dune field is actively migrating to the northwest under the present wind régime. It was an aboriginal camp site, and this may have contributed to deflation of the dune.

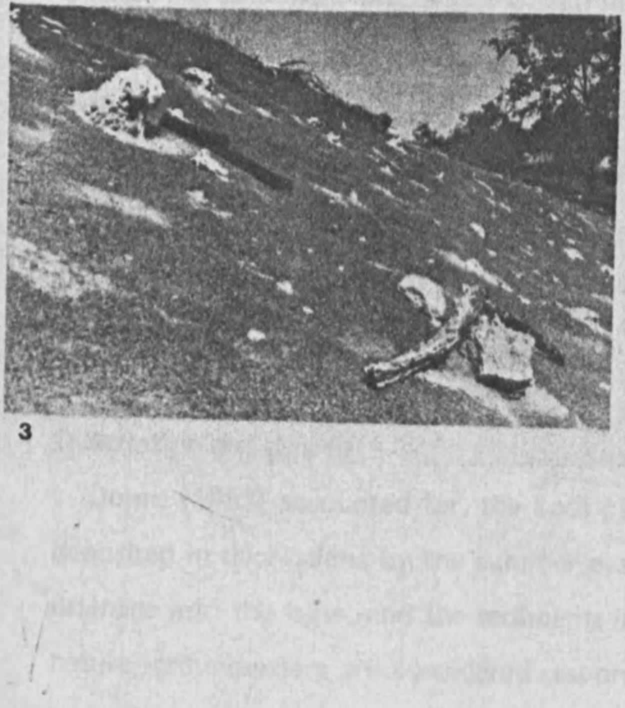
Fig. 1.18 Mobile dunes of Bunyip Sand are migrating into the valley along the Waikerie—Cadell road.

Fig. 1.19 Carbonate hardening on exposure to the atmosphere, along the roadside, north of Blanchetown. Very coarse quartz grains form a "gibber lag" over finer Bunyip Sand.

Fig. 1.20 Micro-relief on a partially deflated sand dune of Bunyip Sand. Recent strong winds have created a ripply pattern of the coarser quartz grains.

1

2



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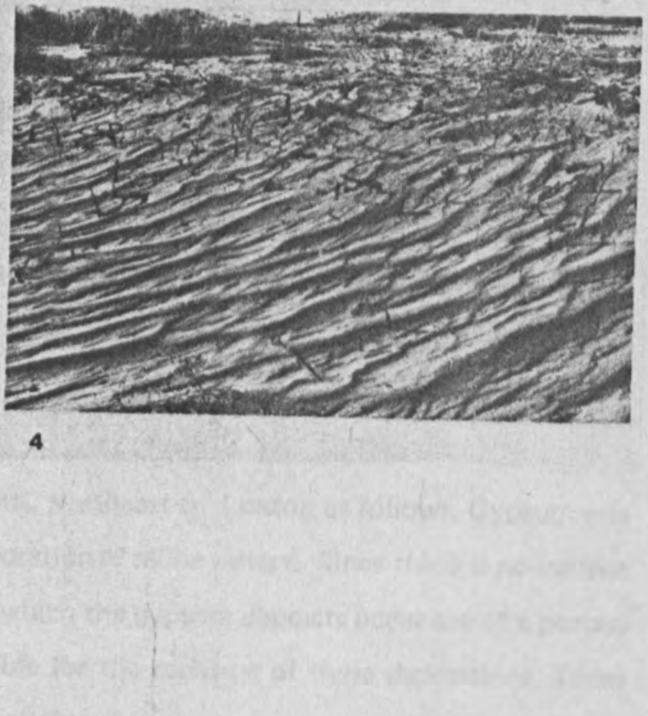


4

Sand deposition. There seems to be confusion over the time of deposition of parna through much of western Victoria. Butler (1956) considered that there was more than one period of deposition during the Pleistocene. The ultimate retention of the material in any one place was determined by the nature of the surface and the vegetation. Crocker (1946), and Sprigg (1959) maintained the wind transport of this loessal lime, its deposition, and the formation of lunettes took place during glacial phases. Lawrence (1966), and Campbell (1968) suggested that this could take place equally well under the present climatic conditions.

From field evidence it appears that because of the easterly shift of flour gypsum during strong winds, off bare surfaces, especially roads, that these sand dunes are being enlarged by deflation, as for example at Rotten Lake. Alternatively on the kopi plains the dunes show obvious signs of being reduced by deflation (see Fig. 1.21).

Having discussed the five dune types of the Mallee Surface, it can be concluded that the Mallee sands appear to be characterized by a variety of sources, ranging from the reworking of palaeosols derived from weathering of Miocene limestone, Pliocene sands and limestone, and Pleistocene limestone, inland and coastal dunes, and lacustrine deposits. It is suggested that the variation in the orientation of the dune system compared with present wind régimes may reflect differences in age, and a change in dominant wind direction. However, dating of soil carbonates from the Loveday Soil of the Woorinen Formation, the Molineaux Sand, and the Bunyip Sand is necessary to substantiate the hypothesis. European occupation and fluctuations in water level of the Murray River may have been other factors contributing to the development and/or extension of the dunes.

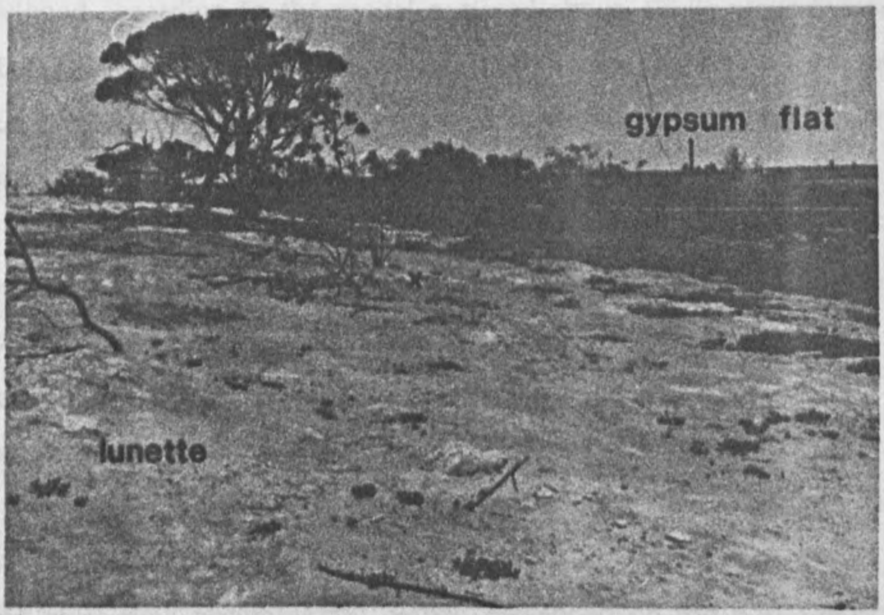
(iii) *Gypsum—Flats*

Description and genesis

Johns (1953) accounted for, the kopi plains, southeast of Loxton as follows. Gypsum was deposited in depressions by the summer evaporation of saline waters. Since there is no surface drainage into the lakes, and the sediments in which the gypsum deposits occur are of a porous nature, groundwaters are considered responsible for the recharge of these depressions. There seems, however, a need for a shallower water table than at present. Johns (1953) suggested that apart from the calcium and sulphate being derived from leaching of the Tertiary sediments, material of cyclic origin may have been introduced into the area. However, he gave no indication of the source of the aeolian material. Under continuing arid conditions the gypsum formation has ceased. In part the crystals have weathered to seed and flour gypsum. Halite crusts characterize the area now.

Fig. 1.21 A gypsiferous dune, the Kopi Plains, east of Loxton. These lunette-like accumulations lie to the lee-side of gypsum flats. X is the location of Fig. 1.22.

Fig. 1.22 Similar to the carbonate of the Bunyip and Molineaux dunes, the gypsum hardens on exposure to the atmosphere. This results in local hardening on the surface of the dune. Subsequent deflation produces micro-yardang features.


gypsum flat
x
lunette


x

On the Blanchetown Plain several kilometres east of the Murray River is another outcrop of gypsum. Here the gypsum is crystalline and banded, and Johns (1952) suggested that this occurrence developed according to the model outlined above. While groundwater is present today 21.3 m below the surface, calcium sulphate still makes up 14% of the total dissolved saline matter. Seed gypsum, weathered to flour has again built up into high lunettes on the margins of the gypsiferous depressions. (see Fig. 1.21).

This model of a high watertable-precipitation effect for gypsum formation is supported. Over time, subsequent weathering of crystalline gypsum occurs and this produces gilgai-like flour gypsum which may in turn become lunette material. On exposure the gypsum of the dunes hardens to form a "capping" (see Fig. 1.22).

(2) Origin of the Mallee Surface

The Mallee Surface, the present topographic surface, was developed on and through modification of the Ripon Surface. The Ripon Surface was formed on top of the Ripon Calcrete, a fossil pedogenic accumulation, which developed on the post-Tertiary erosional surface, tentatively classified as a simulant peneplain. It is suggested that the soil profile for the Ripon Calcrete was derived predominantly from the weathering of Miocene limestone, Pliocene sand and limestone, and Pleistocene limestone. The A horizon of this soil profile was subsequently deflated and reworked by aeolian processes to produce the Woorinen Formation, which in turn developed a soil profile, the Loveday Soil. The A horizon of this profile has been reworked too, to produce the Molineaux Sand contributing the material of the east-west longitudinal and parabolic dune patterns of the study area. Post-dating the Woorinen Formation, but pre-dating the Molineaux Sand, gypsum lakes were developed in localized areas, and subsequently developed lunettes.

There is evidence to suggest that calcrete has continued to develop since the deflation of the A horizon of the Bakara soil. Today it is forming in many places in a shallow soil developed on the Ripon Calcrete.

The occurrence of calcrete and Woorinen Formation on both sides of the Murray valley, seems to suggest that the incision of the Murray River into the Mallee Surface occurred post Ripon Surface development in the late Pleistocene. Dunes consisting of Molineaux Sand can be seen today growing into the valley in an east-northeast direction suggesting that incision occurred pre Molineaux Sand development. The east-northeast parabolic dunes of Bunyip Sand can be seen to have grown outwards from the valley. Thus the formation of the valley would pre-date Bunyip Sand development. Absolute dating of the age of the valley of the Murray River is not available because of the lack of C14 data.

CHAPTER II

THE VALLEY-SIDE SLOPES

1. INTRODUCTION

In this chapter a description of sample valley-side slopes, and processes active on these slopes, is presented to establish a framework for a subsequent interpretation of the evolution of the Murray River.

The characteristic slope of valley-sides differs within any one region, in micro-morphology and from region to region in macro-morphology. Qualitative and quantitative descriptions of the variations in valley slope morphology have been carried out systematically along the entire valley of the Murray River in South Australia. This has entailed detailed field work from cliff top and river channel, slope measurements, aerial photograph analysis, and cross-section construction.

The framework for the analysis of the valley-side slopes is based on the relative lengths of the slope segments, their maximum slope angle, and the stratigraphic and altitudinal position of the breaks in slope. A given slope is divided into zones, each of which has morphological characteristics distinguishing it from adjacent zones above and below. The first criterion for slope classification is numerical, i.e. the number of zones are recorded as unizonal, bizonal etc. Each zone in turn consists of two subunits, segments, in which the angle of inclination and length of the zone is recorded, and elements, in which curvature, measured as a rate of change of angle with length of the zone is described.

The scheme for the description of the erosional slopes for selected type localities is as follows:

vertical profile (a) number of zones
(b) segments – relative length
– maximum slope angle
(c) elements – uniform, convex, or concave
lateral profile – the degree of uniformity of the slope either side of the vertical profile.

Often the vertical profile is accompanied by a section and the lateral profile by a photograph. If the genesis of the slope occurs in only one locality, the general description and location is accompanied by a discussion of the origin of the slope. However, where the slopes occur repeatedly their genesis is discussed in separate topic studies.

Stream channels and valley-side slopes are complementary. Since there is this interaction it is necessary to establish the dominant slope processes before an interpretation can be made of the overall evolution of the river and its valley.

The valley-side slopes of the Murray valley were formed initially by vertical and/or lateral incision of an intrenching river (see Chapter V). These slopes are referred to as primary slopes. Subsequently, modification by weathering, especially chemical weathering, mass movements, minor tributary development, and wind deposition have altered the form of the original slope, and a secondary slope is developed. The following analysis of typical and atypical slopes suggests that the Murray valley in South Australia is characterized entirely by secondary slopes.

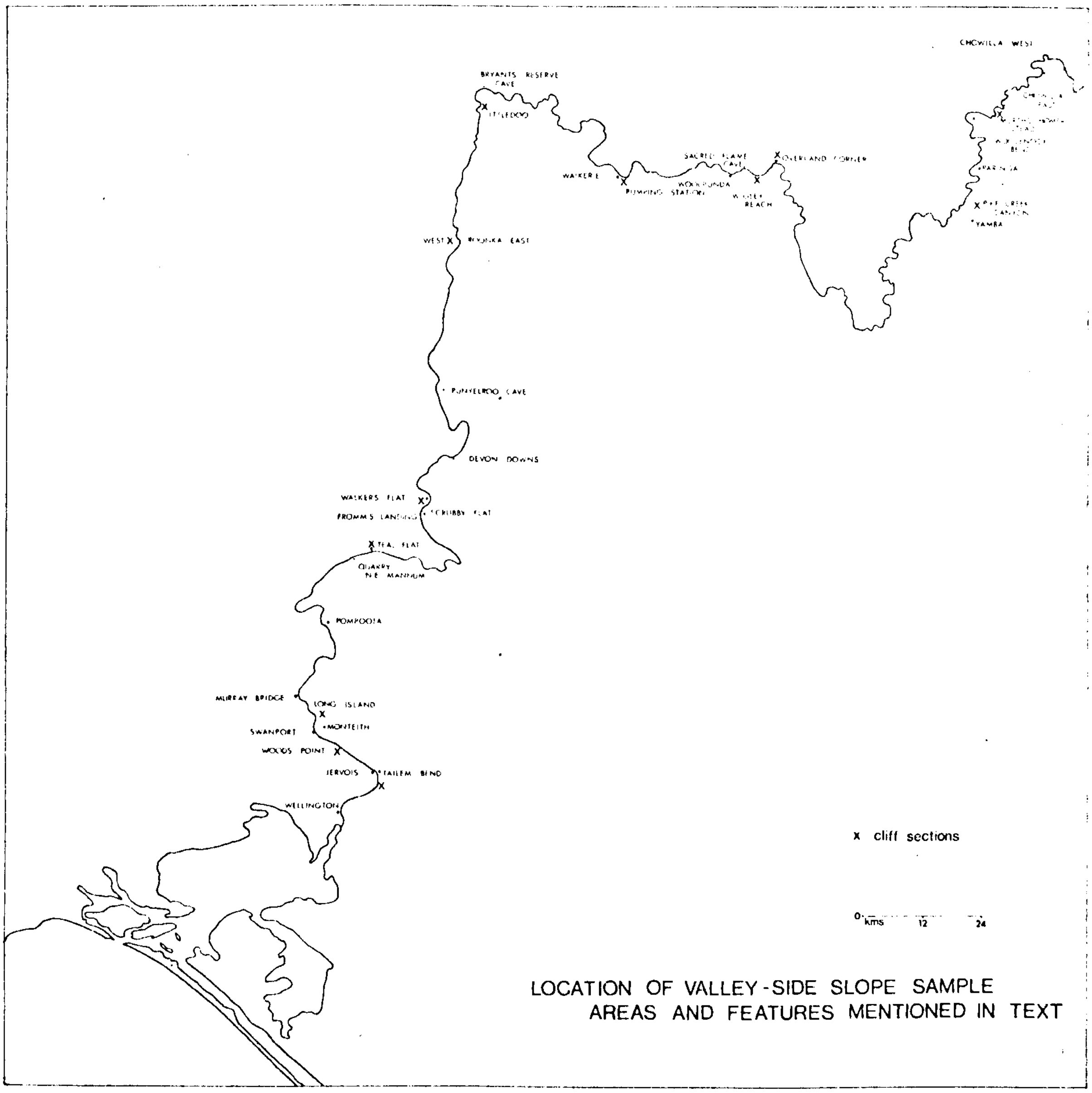
2. SELECTED TYPE LOCALITIES (for location see Fig. 2.1)

a. Murtho Homestead South (see Figs. 2.2, 2.3, 2.4, and 2.5)

This cliff form occurs more or less continuously from Chowilla to Woolenook Bend. As illustrated by sections and photographs, there is an assemblage of slope forms depending on the degree of modification. Some of the slope exposures are masked with sand spillage from the Mallee Surface. The triangular valley-side facets (see p. 17) possess a variety of upper surface form ranging from a flat top, to a pinnacle, to a much modified surface. There appears to be a gradual reduction of form with distance downstream. A dense columnar gullying, "pseudo-jointing" in Parilla Sand is outstanding at Murtho Homestead south. This represents channels from drainage lines where there is an absence of sandstone capping. Cliffs are restricted to two situations. Firstly, they occur where the river is impinging against the valley wall at Woolenook Bend, and against the terraces at Murtho Homestead. The river during its incision has increasingly migrated towards the eastern valley side. Secondly, they are located where there is the development of structural benches and cappings, for example within the deep Blanchetown Clay, capped with calcrete, the Parilla sands with a sandstone cap, and the Loxton Sands with ferruginized sandstone layers. The latter are particularly well developed south of Woolenook Bend, and at the rifle range at Paringa.

b. The Western Slopes Opposite Chowilla (see Fig. 2.6)

This slope form is continuous from the Victorian Border to Berri. Parallel sand dunes are growing into the valley. Cliff forms are absent except where the river has swung westwards as it meandered across a higher flood plain, now amphitheatre terraces (see p. 38). The slope represents a primary slip-off slope, and has become isolated from the channel as the river has migrated to the south and east.



LOCATION OF VALLEY-SIDE SLOPE SAMPLE AREAS AND FEATURES MENTIONED IN TEXT

FIG. 2·1

Fig. 2.2 **Murtho Homestead south.** Lateral profile, section and photograph showing the triangular valley-side facet, north of Woolenook Bend.

CHOWILLA TO MURTHO HOMESTEAD

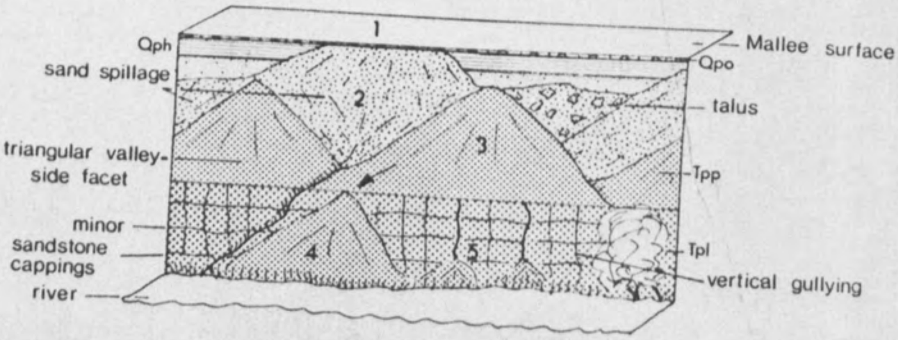


Fig. 2.3 Murtho Homestead south. Vertical profile, section and photograph.

1 (a) quadrizonal

(b) i – 3 x 90°

ii – 2 x 90°

iii – 8 x 40°

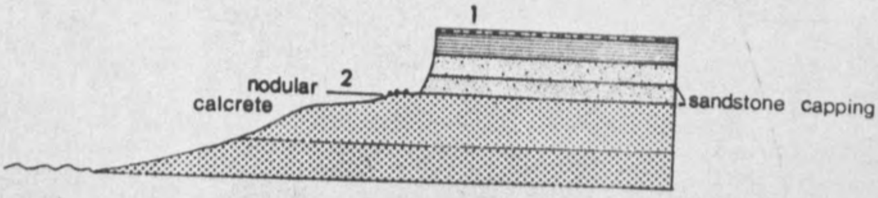
iv – 7 x 85°

(c) i uniform

ii uniform

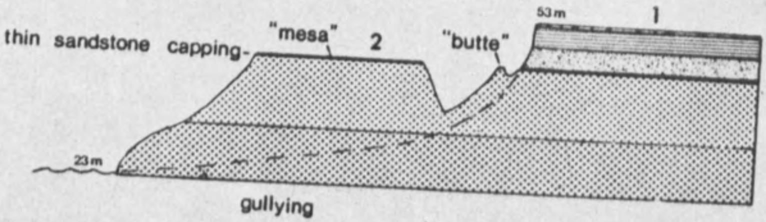
iii uniform

iv uniform


1
2
nodular
calcrete
sandstone capping


1
2

Fig. 2.4 **Murtho Homestead south**—flat topped triangular valley-side facet, north of Woolenook Bend. Section and photograph.



field work
Roberts (1967)

Fig. 2.5 **Murtho Homestead south.** Triangular valley-side facets viewed from the Mallee Surface, at Woolenook Bend. A sand dune trail can be seen in the background.

Fig. 2.6 **The western slopes opposite Chowilla.**

I a unizonal
  b variable X x 7°
  c uniform

II continuous, masked with sand dune formation. Sand dunes are spilling into the valley. A dust storm can be seen towards the right hand side of the photograph. The lagoon (Lake Merreti) in the middle ground has been drained to provide land for pasture.


sand dune trail
river
triangular valley-side facets


Lake Merreti
river
Chowilla dam site
dust
sand

c. Chowilla–micro-form (see Fig. 2.7)

At Chowilla dam site a conspicuous zone of scalding is developed at the contact of the Mallee Surface with the valley-side slope and at the head of a major gully. Scalding, a micro pediplanation process, has created a "plateau," "mesa," "butte," "sugar-loaf," assemblage of landforms. There is ample evidence here to support the role of water in scalding, and in agreement with Warren (1965), the wind erosion hypothesis is negated. There are numerous micro drainage lines, and the scald is not oriented in the direction of the prevailing wind.

d. South of Paringa (see Fig. 2.8, 2.9)

South of Paringa to Yamba there is an extensive slope form possessing a wide break of slope. Two possibilities exist to explain the development of this slope unit. Firstly, the primary slope formed by intrenchment is modified by a pediplanation process. There is evidence of weathering and removal of material in the scarp foot zone, and slope 11 (see Fig. 2.9) appears to cut across bedrock, and to slope gently towards the river. Secondly, the slope represents a valley-in-valley form, the result of a two stage period of intrenchment. Evidence for this suggestion includes an erosion surface sloping gently to the centre of the valley, and a marked break of slope leading to the terrace. There is little other supporting evidence. However, the generally localized nature of this form may be attributable to its destruction elsewhere by the lateral migration of subsequent river channels. (For further discussion on stepped slopes see p. 21.)

e. Pike Creek Canyon (see Fig. 2.10)

This unique landform in the Murray valley is found to the east of Pike Creek (see Fig. 2.1). In this locality, the Loveday Soil of the Woorinen Formation forms a distinct capping to the Blanchetown Clay. Scalding is apparent on the Mallee Surface but there is no surface drainage. Immediately below the soil capping, with a reinforcement of thin rubbly calcrete, tunnel erosion dominates. In the zone of headward erosion, at the source areas of the gullies, the slopes have often lost the capping and rounded forms, "sugar loaf" forms, predominate. Slumped blocks of Blanchetown Clay and soil capping are numerous within the confines of the canyon.

The sandstone cap, of yellow siliceous sandstone with dendrites, of the Parilla Sand forms a capping, a marked structural bench (see p. 22) at the entrance to the canyon. A similar feature near Chowilla dam site was referred to as the Karoonda Surface by Firman (1966). Small cavernous forms are developing beneath this feature. A minor structural bench occurs within the Loxton Sand, resulting in a change in slope morphology. Slumped blocks of Blanchetown Clay occur in the bottom of the "v" shaped gorge.

Fig. 2.7 **Chowilla:** micro-form—vertical and lateral profiles, and photograph.

I a bizonal
  b i – 1 x 90°
    ii – 6 x 20°
  c i – uniform
    ii – slightly convex

II i – uniform, soil capping effect in the Loveday Soil Formation, producing a mesa-butte-sugar loaf micro-landform assemblage (Thomson 1969), and hummocks (Warren 1965).
  ii – dissected, dendritic gullying, micro-pediment surface.


"sugar loaf"
"mesa"
"butte"

Fig. 2.8 **South of Paringa:** vertical profile, section and photograph.

I (a) trizonal

(b) i – 12 x 18°

ii – 55 x 4°

iii – 8 x 10°

(c) i uniform, except where subsequent streams are present

ii very slightly concave upwards

iii uniform

SOUTH OF PARINGA

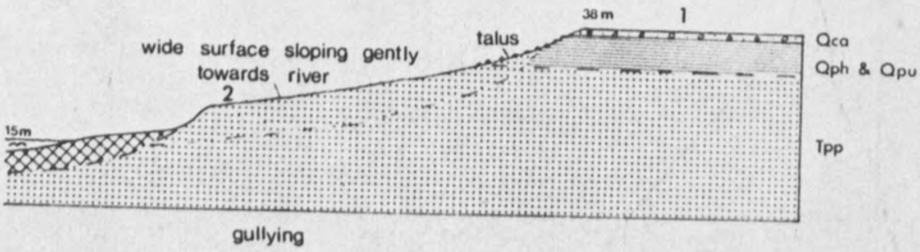


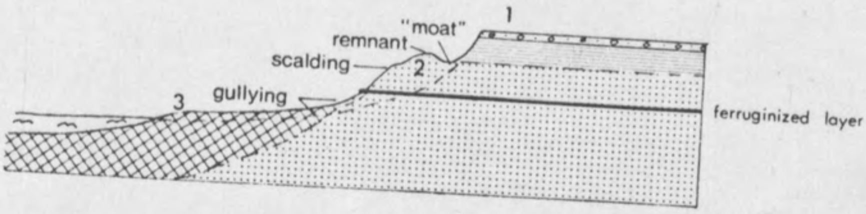
Fig. 2.9 **South of Paringa:** lateral profile, section and photograph.

II i generally uniformly continuous, strata masked by talus lag.

ii variations exist in the degree of dissection. Some dissection developed to a stage where the surface is no longer planate, a more convex form results.

Variations also exist in the degree of modification by scalding, gullying, and infilling of the gullies. A ferruginized layer outcrops locally, for example at Yamba.

iii uniformly continuous. The lower edge is masked with an alluvial terrace deposit.


1
"moat"
remnant
scalding
2
3
gullying
ferruginized layer

field work

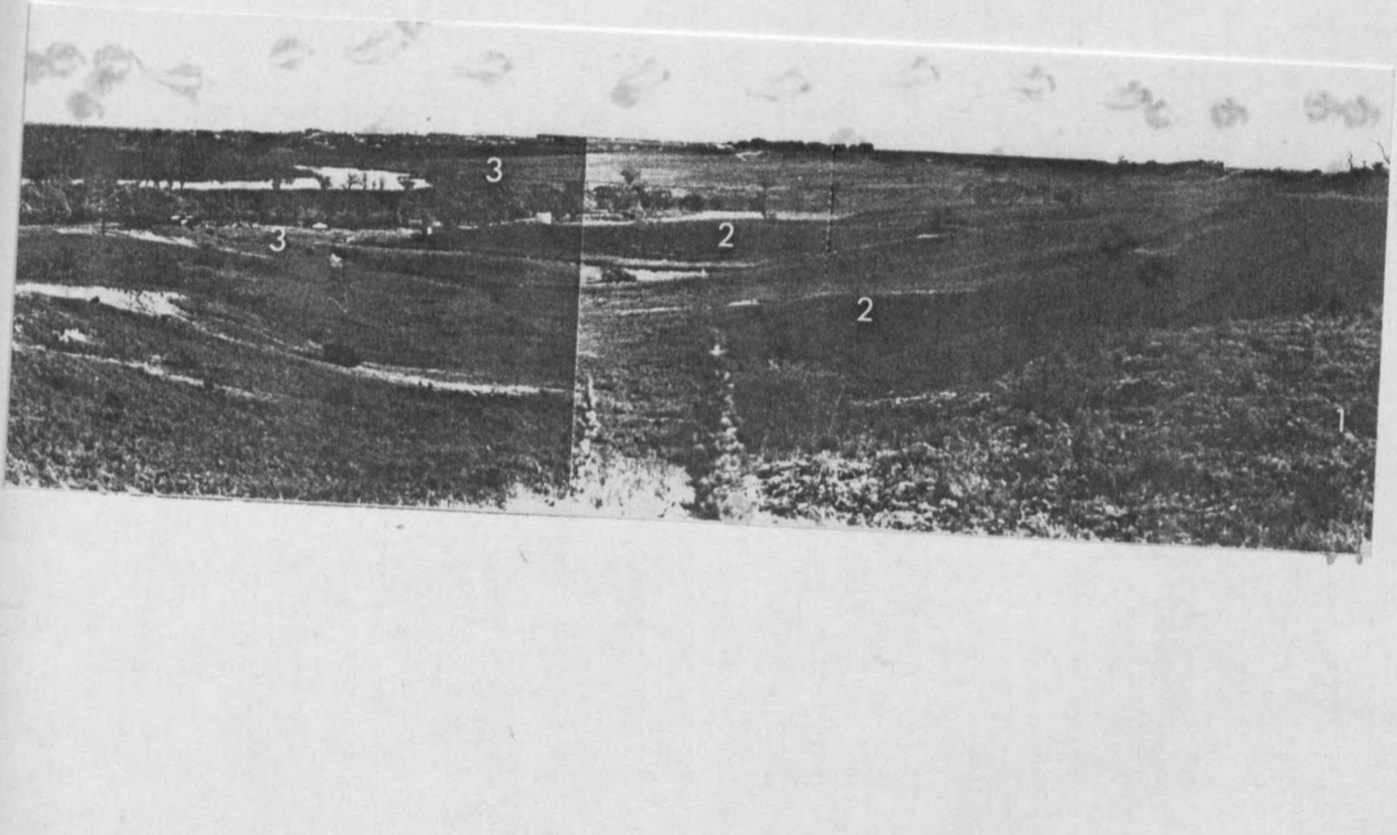
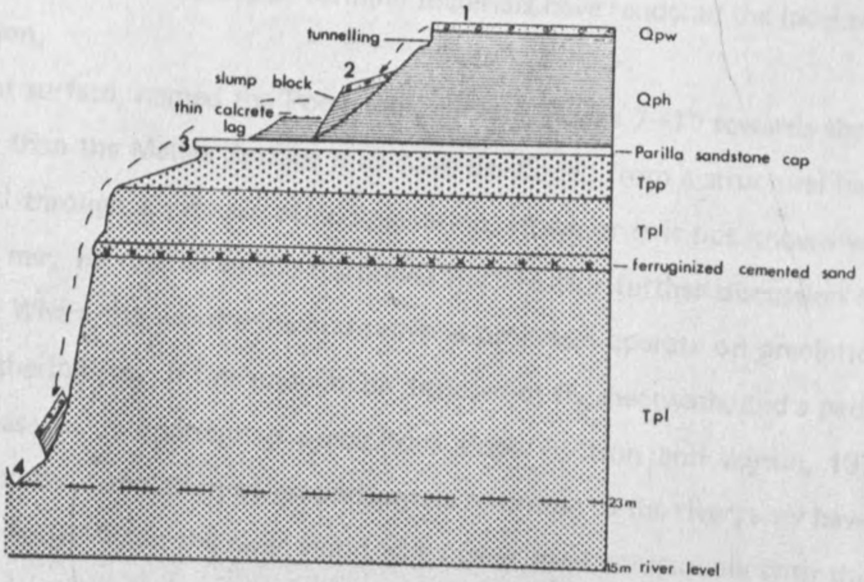

3
3
2
2
1

Fig. 2.10 **Pike Creek Canyon:** vertical and lateral profile and photograph.

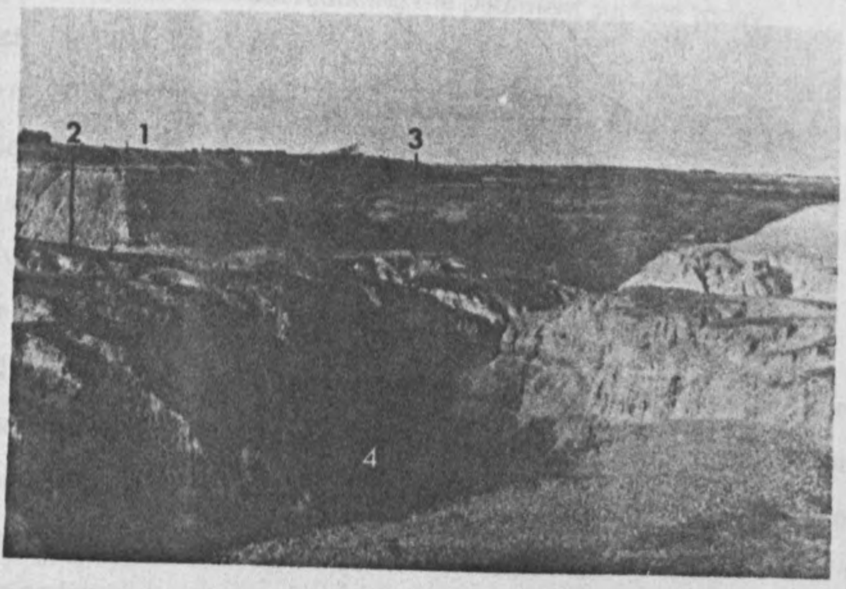
- I
  - (a) quadrizonal
  - (b)
    - i – 6 x 45°
    - ii – 8 x 0°
    - iii – 6 x 25°
    - iv – 9 x 80°
  - (c)
    - i – uniform/concave
    - ii – uniform
    - iii – slightly concave
    - iv – uniform
- II
  - i – a soil capping, Loveday Soil, thin carbonate horizon.
  - ii – uniformly planate where exposed.
  - iii – slightly concave, with capping.
  - iv – uniformly densely gullied, with minor cappings of ferruginized cemented coarse sands.

PIKE CREEK



section through canyon

field work



f. Overland Corner (see Figs. 2.11, 2.12, 2.13)

This is a complex area being actively dissected by headward erosion into the Mallee Surface. Isolation of residuals, one capped by calcrete, the other by a ferruginized layer, has occurred where local concentrations of caprock forming materials have rendered the local surface more resistant to erosion.

The dominant surface, named the Pooginook surface, slopes 7–1° towards the river. This surface, younger than the Mallee Surface may have developed from a structural bench, which became extended through a process of pediplanation. However it is not known whether the structural bench may be related to the Karoonda Surface (for further discussion on stepped slopes see p. 21). Where the weathering and removal processes operate on precipitous slopes, the debris of weathering may, if fine enough, be disposed of by sheetwash, and a pediment will develop at the base of the retreating precipitous slope (Cotton and Wilson, 1971). Basal sapping, weathering by percolation of ground waters returning to the river, amy have been the dominant process active when the river stood at a higher level comparable with this surface, i.e. about 30 m a.s.l.

The break of slope at the Mallee Surface, and Pooginook surface (see Fig. 2.11) contact may represent a rectilinear denudation slope, ramp, or "richter" (see Cotton and Wilson, 1971). Incision by the river has resulted in the lowest cliff formation, a "truncated spur". Gully and valley widening processes are reducing the pediment surface today.

g. Wigley Reach (see Fig. 2.14)

This slope form is continuous along the entire east-west Murray valley from Overland Corner to Waikerie. A marked break of slope is located high in the valley-side wall of both the north-facing and south-facing slopes. However, there is a variation in width of this slope segment. The valley asymmetry is the result of aspect (see p. 17).

h. Ittledoo (see Figs. 2.15, 2.16, 2.17, 2.18)

The slope locality lies to the south and east of Morgan. This complex valley-side slope area results from an interaction of weathering and erosion processes. It is suggested that the initial cause of the stepped valley-side slope was variation in resistance of the strata (see p. 21). A major structural bench was formed subsequent to intrenchment. Lateral retreat of the Mallee Surface is now by a pediplanation process into the Blanchetown Clay. The pediment surface is in turn being dissected. The gullies themselves actually display a cut and fill sequence. Nodular calcrete layers are present, occurring either as an accumulation due to pedogenic processes, or more likely as a colluvial or terrace deposit. The next small surface cut into the Loxton Sands has a local baselevel in the form of a structural bench of Norwest Bend Formation. The case

Fig. 2.11 **Overland Corner:** vertical and lateral profile, and photograph.

I (a) quadrizonal

(b) i – 4 x 30°

ii – 3 x 7°

iii – 12 x 3°

iv – 4 x 40°

(c) i – concave upwards

ii – concave upwards

iii – uniform

iv – uniform

II i – uniform, but suffering dissection, headward erosion, gullying into weathered Pliocene sands. A calcrete mesa-like residual 6 m x 4 m is located to the west of the town. It has a 1° slope to the river, and a 15° slope covered with a coarse angular lag. A ferricrete residual 3.5 m x 4.5 m, lies 6 m below the Mallee Surface. This residual surface slopes 4° to the river. Its sides possess a 25° slope.

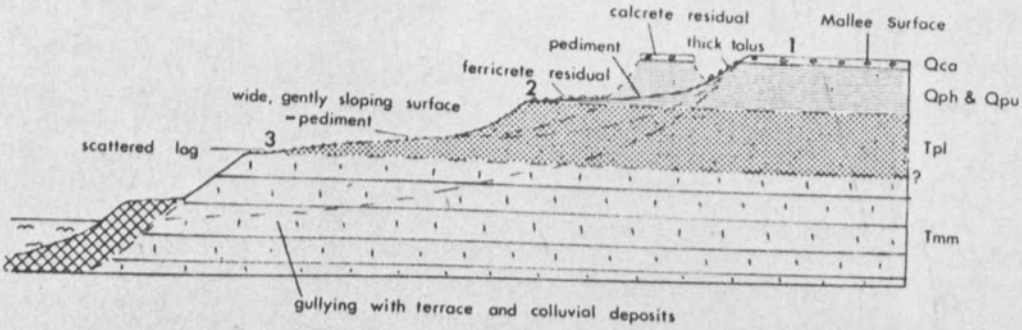
ii – a more common debris slope where the residuals are absent.

iii – a planate pediment surface, uniform, with a coarse lag of calcrete fragments. It is dissected by straight joint-controlled gullies, which contain a cut and fill sequence.

iv – uniform trucated spur-like feature, deeply pitted, into fossiliferous Morgan Limestone.

2

OVERLAND CORNER



field work

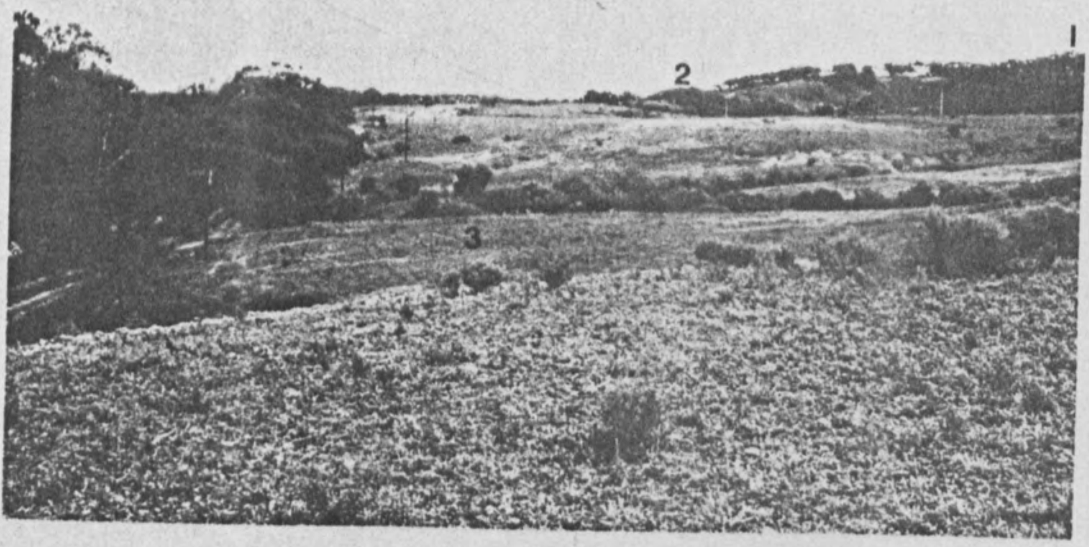


Fig. 2.12 Overland Corner west—calcrete residual.

Fig. 2.13 Ferruginized residual, Overland Corner. This local surface is still attached to the slope of the Mallee Surface by a shoulder. There is a coarse lag protecting the surface.


calcrete

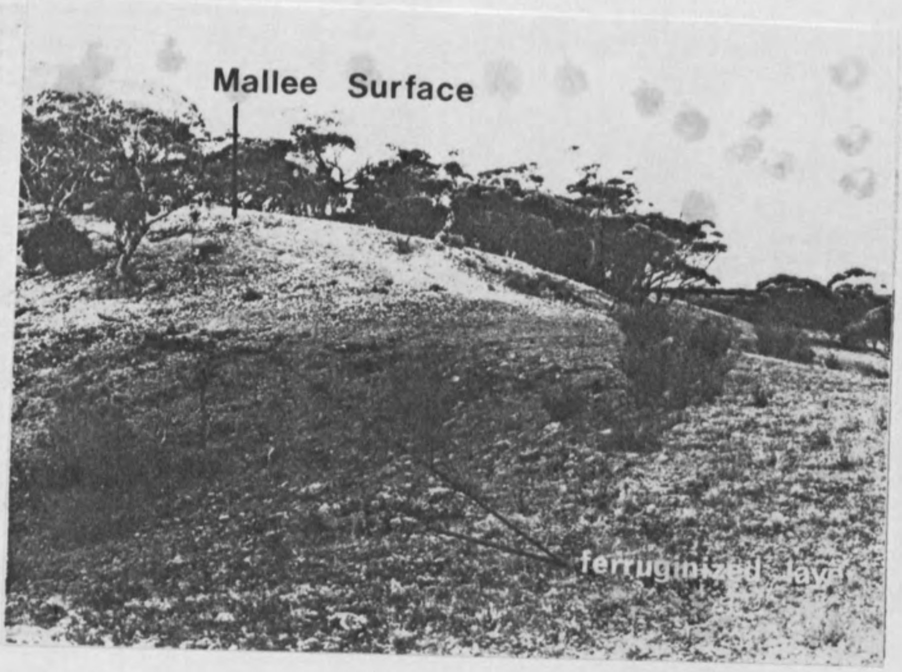
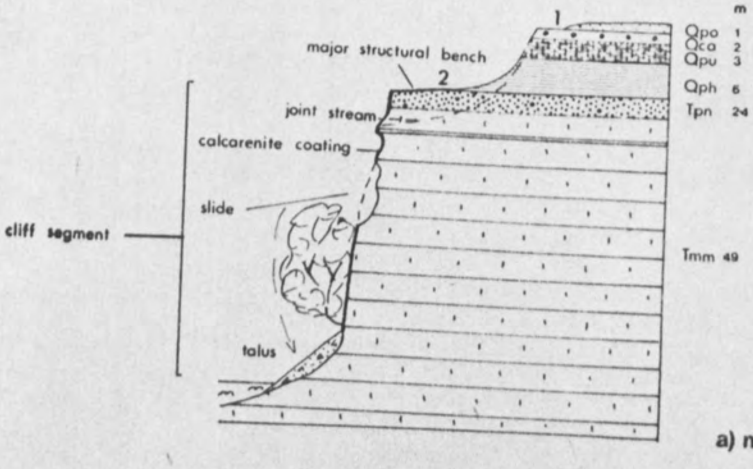

Mallee Surface
ferruginized layer

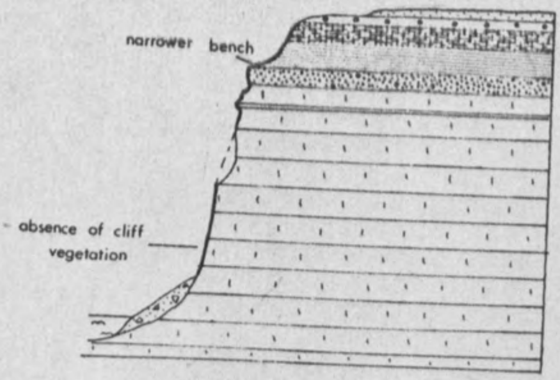
Fig. 2.14 **WigleyReach/Woolpunda Pumping Station:** (a) vertical and lateral section and photograph of south facing slope, (b) section of south facing slope.

- (a) I (a) trizonal
  - (b) i 1 x 30°
    - ii 3 x 17°
    - iii 6 x 90°
  - (c) i concave
    - ii uniform
    - iii uniform, but with micro-variations
- II i uniform
  - ii variations in width
  - iii uniform

WIGLEY REACH



a) north facing slope



b) south facing slope

field work
bore log data from
1:250,000 Renmark geological map

Fig. 2.15 Ittledoo—vertical and lateral profiles, and sections.

I (a) sexizonal

(b) i – 3 x 20°
ii – 36 x 4°
iii – 2 x 17°
iv – 3 x ½°
v – 2 x 30°
vi – 6 x 60°

(c) i – slightly concave downwards
ii – uniform
iii – uniform
iv – uniform
v – uniform
vi – slightly concave upwards

II i—greatest development is at this site. Calcrete forms a caprock effect. The morphology is repeated on the mesa-like landforms. A rounding of the slope produces a convexo-concave profile. The degree of coarseness of the talus lag from this surface to the next decreases with distance from the Mallee Surface.

ii—a wide continuous surface except where dissected by several essentially straight gullies. However, some display an intrenched meander pattern into the talus material. The regular spacing of these features suggest a joint control location.

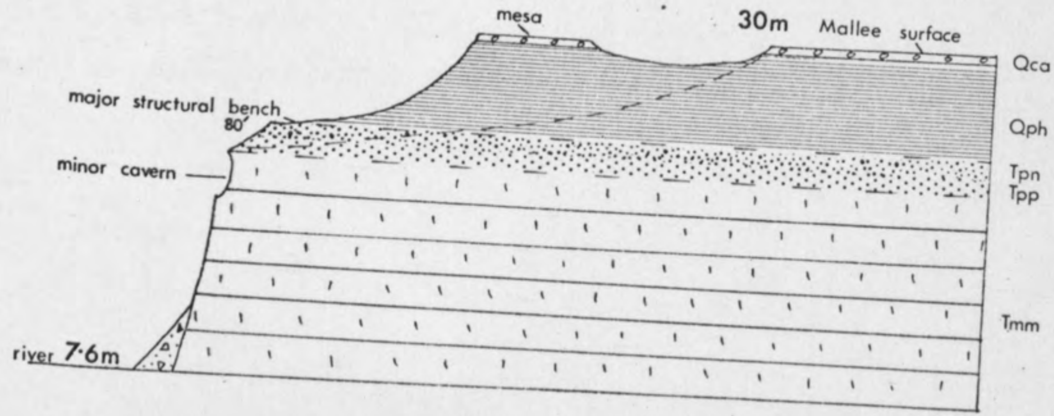
iii—a minor scarp feature located at the top of the limestone cliff, and along some of the larger, older gullies.

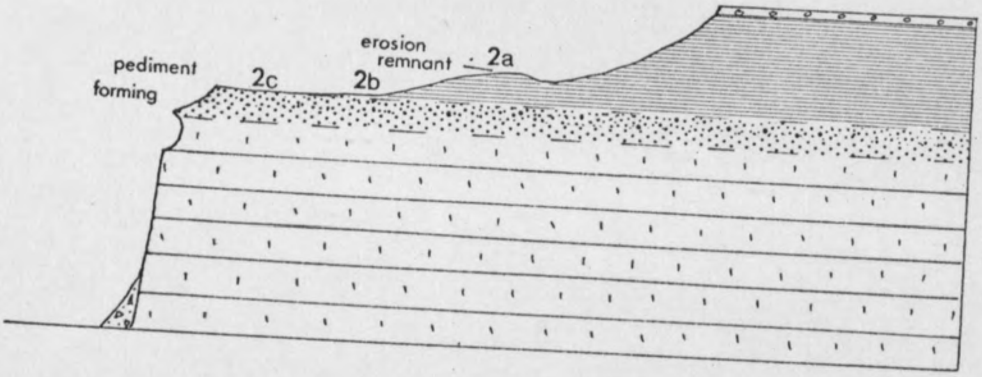
iv—variations in width occur in this generally planate surface.

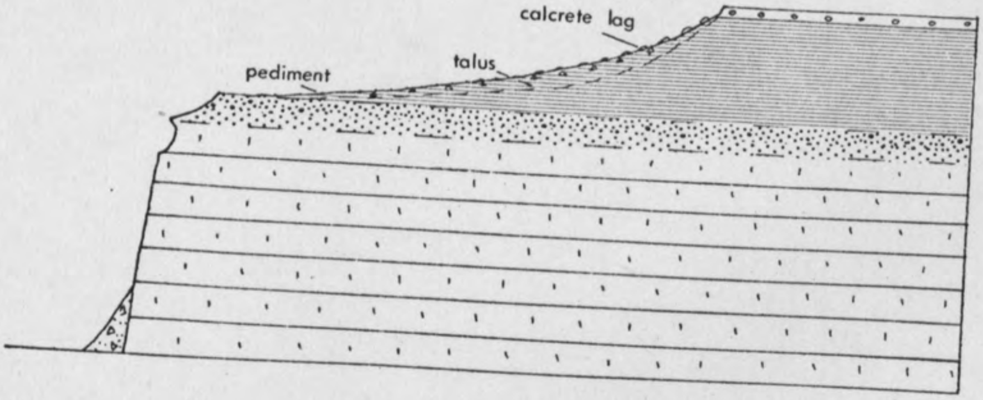
v—uniform regular narrow gully dissection.

vi—continuous cliff feature, possessing an overhang/prominent structural bench effect, at the highest point. It is made more obvious by a linear cavernous feature immediately underneath (see p.25). Gullying within the cliff is infilled by joint blocks of the structural bench material (collapsed Norwest Bend Formation), producing a kind of gully gravure (Bryan 1940). There is a noticeable variation in height of the cliff downstream from Morgan.

ITTLEDOO - SOUTH EAST OF MORGAN







field work
Whitten (1957)

Fig. 2.16 The valley-side slope profile at Ittledoo, (see Fig. 2.15).

Fig. 2.17 The scarp foot zone Ittledoo, showing intensive gullying, and weathering at the base of the Mallee Surface, which is capped with calcrete.

Fig. 2.18 Mesa at Ittledoo. The calcrete capping is distinct.

1

2

3

Fig. 2.19 **Roonka east**–vertical and lateral profiles, and photograph.

I (a) quadrizonal

(b) i – 4 x 90°

ii – 5 x 35°

iii – 4 x 90°

iv – 15 x 95°

(c) i – uniform

ii – uniform

iii – uniform

iv – concave downwards

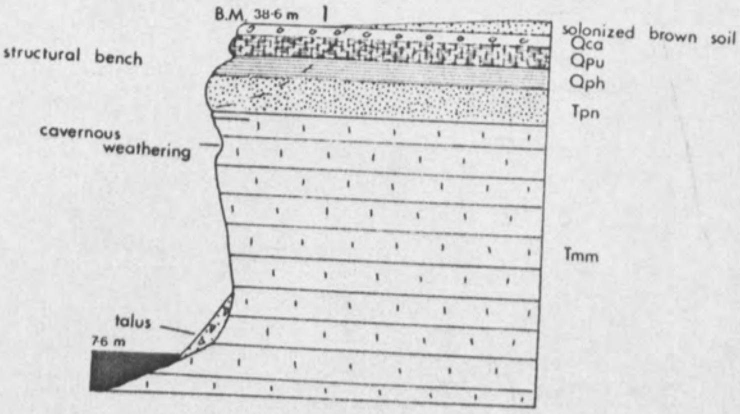
II i – calcrete capping, small cavernous forms beneath.

ii – uniformly continuous, a little masking with talus.

iii – continuous, very prominent bench form, with overhang.

iv – varied in microform, i.e. number of caverns, amount of sliding.

ROONKA



eastern side

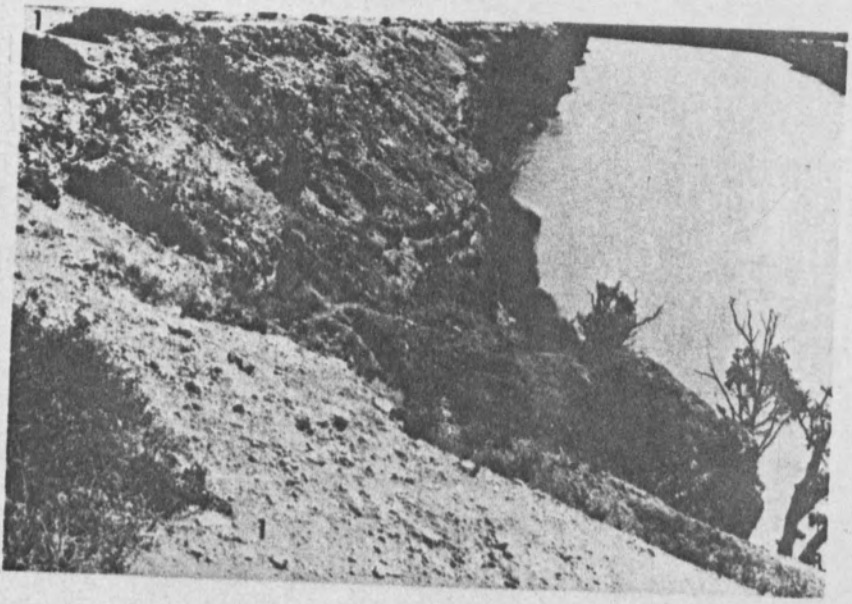


Fig. 2.20 Roonka west—vertical and lateral profiles, and photograph.

I (a) trizonal

(b) i – 4 x 10°

ii – 31 x 30°

iii – 6 x 12°

iv – 8 x 5°

(c) i – slightly concave

ii – uniform

iii – uniform

iv – uniform

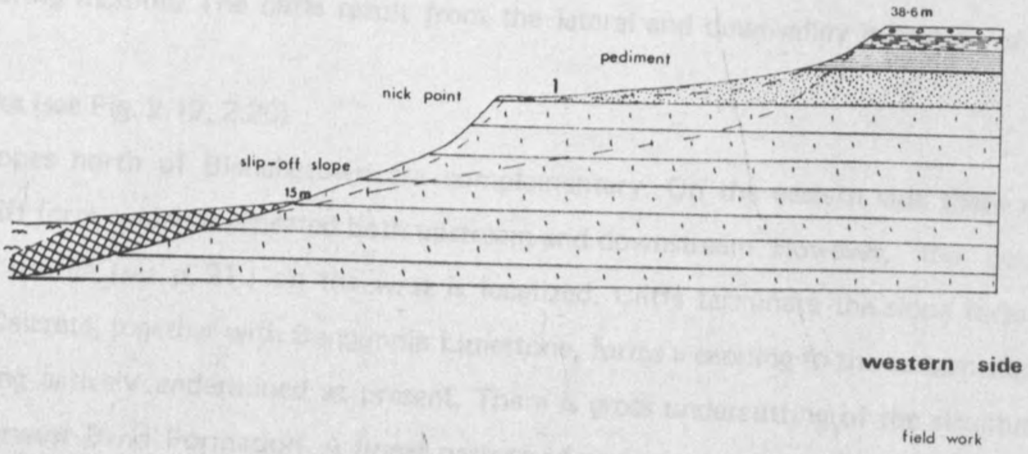
II i – uniformly continuous

ii – localized, marked variations in width, greatest development to the west of the southern homestead.

iii – uniform

iv – variable in the degree of masking by colluvium.

Immediately downstream from section site a joint stream flows across the structural bench. Norwest Bend Formation is outcropping in the foreground of the photograph.


38·6 m
pediment
nick point
1
slip-off slope
15m
western side
field work

hardened limestone and cavernous development of the cliffs are weathering phenomena (see p. 25). The variation in height of the cliff from Morgan south reflects a change in the course of the river during incision. The cliffs result from the lateral and downvalley migration of the meanders.

i. **Roonka** (see Fig. 2.19, 2.20)

These slopes north of Blanchetown are complementary. On the eastern side there is a dominant cliff form, which is repeated both upstream and downstream. However, the gentle but stepped profile (see p. 21) on the west is localized. Cliffs terminate the slope form at either end. Calcrete, together with Bungunnia Limestone, forms a capping to the eastern slope, which is being actively undermined at present. There is gross undercutting of the structural bench of Norwest Bend Formation. A linear pattern of caverns occurs beneath this layer of oyster shells. A talus line immediately below is evidence of recent sliding of cliff material. Small joint streams are eroding through the post-Pliocene formations and towards the Mallee Surface. The oyster bed stratum forms a temporary knick point. The western valley-side slope is restricted to the inside of the river and valley meander loop. There is also a dense network of small tributary streams eroding the slope. It is suggested that the present slope form is attributable to a pediplanation process and stream erosion, in an area not subjected to the major fluvial processes, which occur immediately to the north of this locality.

j. **Teal Flat** (see Fig. 2.21)

A more or less continuous stepped valley-side slope is the distinguishing feature of this area north of Mannum. It is suggested that this marked break of slope is a structural form, which has been subsequently modified by weathering and erosion processes (see discussion p.21). The localized outcrop of Kanmantoo greywackes is being exposed by fluvial erosion today.

k. **Monteith** (see Fig. 2.22, 2.23)

This slope is located north of Monteith, directly east of Long Island. The distinctive feature of the slope is a triangular valley-side facet developed in resistant rock (see p. 17).

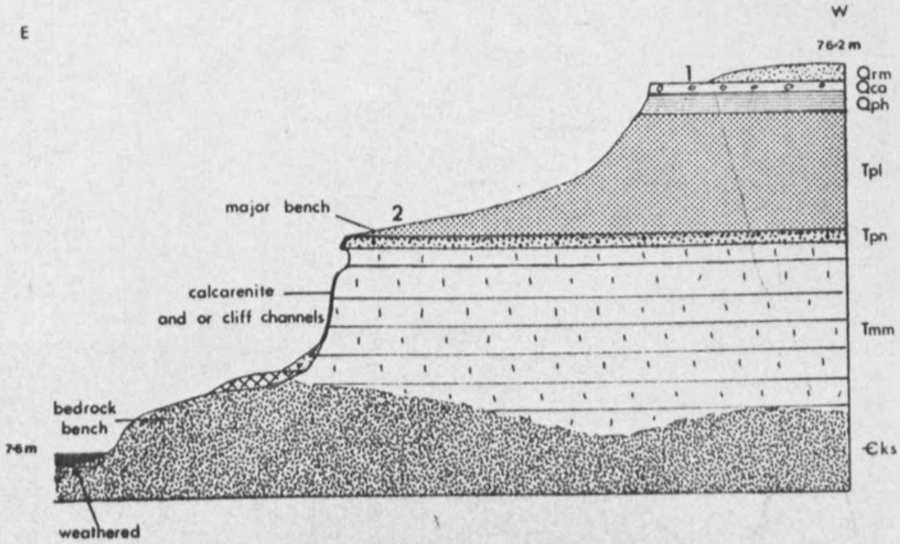
l. **Woods Points** (see Fig. 2.24)

This western valley-side slope is located between Swanport and Jervois, and is the only one of its kind in the Murray valley. This area, a western valley-side slope, is a slip-off spur feature developed in the Mannum Formation (cf. Monteith above), which has fortuitously resisted erosion by downvalley migration of the river. Some formation of calcrete has reinforced the internal resistance to erosion of this feature. Calcrete forms a capping to the valley-side slope, and it is thought that one of the upper benches, (ii) or (iv) may represent a structurally controlled break between Pliocene sands and Mannum Formation. (v) seems to be a fluvial

Fig. 2.21 **Teal Flat**—vertical and lateral profile and section. Photograph is to the southeast of the section.

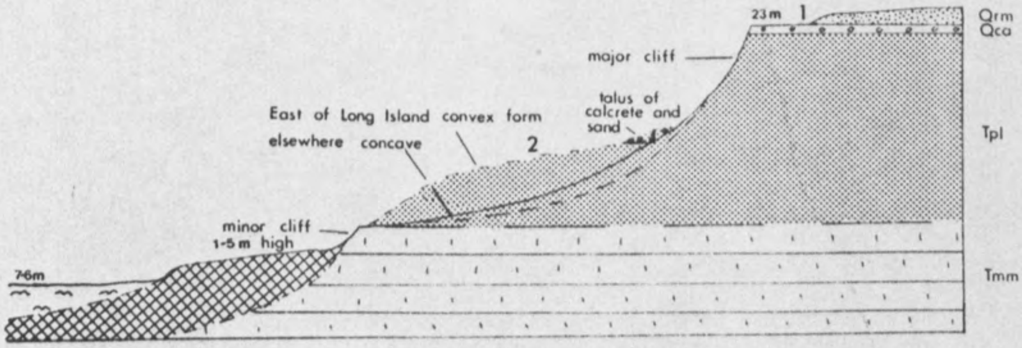
- I (a) quadrizonal
  - (b) i – 3 x 15°
    - ii – 6 x 4°
    - iii – 3 x 40°
    - iv – 1 x 1°
  - (c) i – uniform
    - ii – uniform
    - iii – concave upwards
    - iv – uniform
- II i – uniformly continuous but variation in the amount of sand masking the slope.
  - ii – variable in length and lateral extent.
  - iii – variable, depending on the amount of river impingement, the number and elevation of cliff channels, the uniform in linear cavernous development along the eastern bank, and in the joint dissection.
  - iv – a localized outcrop of Kanmantoo greywackes, or Palmer Granite.

TEAL FLAT



field work
Steel (1962)

NORTH OF MONTEITH



field work

Fig. 2.22 **Monteith**—vertical and lateral profile, section and photograph.

I (a) quadrizonal—typical

(b) i – 4 x 17°

ii – 45 x 7°

iii – 10 x 20°

iv – 3 x 45°

(c) i – uniform

ii – concavo-convex (valley edge to river)

iii – uniform

iv – uniform

II i – uniformly continuous.

ii – variable in width, dissection, and degree of masking with sand.

iii – variable in length and amount of gullying. Downstream a concave slope is present in these Pliocene sands.

iv – uniform, but there is a decrease in altitude and size of cliff expose downstream, i.e. to the south of Monteith. This takes the form of a regular, arcuate shaped outcrop of Mannum Formation. More continuous vestiges, of the strath terrace, can be seen at Jervois and Wellington.

Fig. 2.23 Monteith—convexo-concave valley-side profile to the east of Long Island.

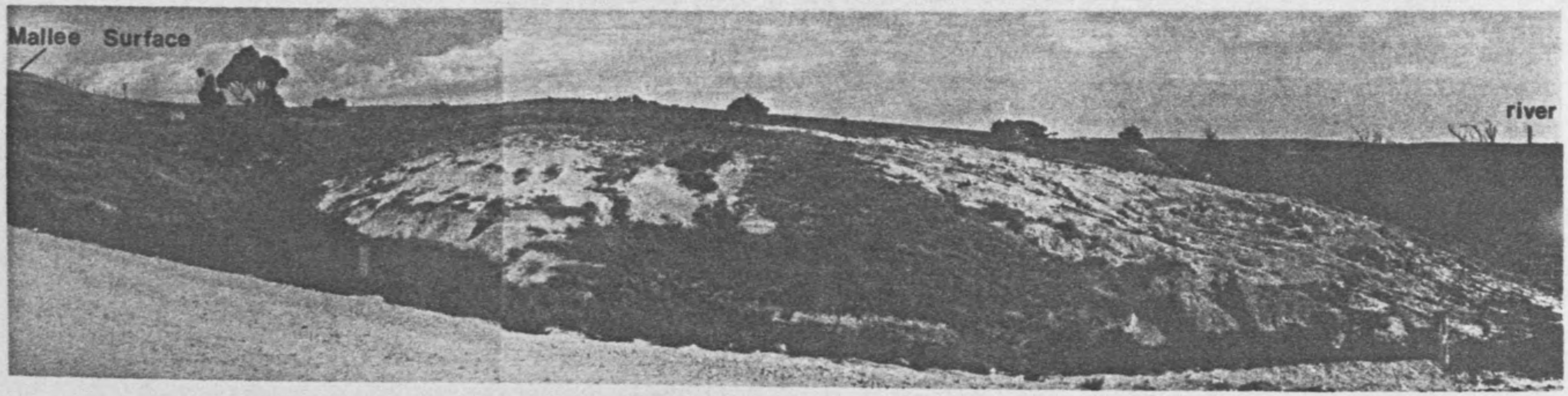
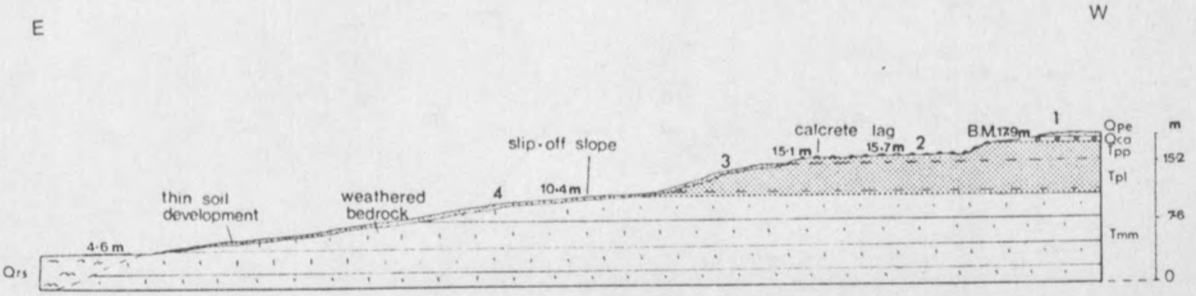

Mallee Surface
river

Fig. 2.24 Wood's Point—vertical and lateral profiles, section and photograph.

I (a) Septizonal
(b) i – 1 x 25°
ii – 7 x 1°
iii – 5 x 15°
iv – 2 x 2°
v – 3 x 20°
vi – 7 x 3°
vii – 12 x 8°
(c) i – uniform
ii – concave upwards
iii – uniform
vi – uniform
v – uniform
vi – uniform
vii – uniform

II i – continuously uniform
ii – continuously uniform
iii – local
iv – local
v – local
vi –)becoming uniformly narrower
vii –)until it disappears

WOODS POINT



proportional scale only

field work

Fig. 2.25 **Tailem Bend**—vertical and lateral profile, section and photograph.

I (a) quadrizonal

(b) i – 1 x 90°

ii – 10 x 30°

iii – 1 x 75°

iv – 30 x 35°

(c) i – uniform

ii – uniform

iii – uniform

iv – concave

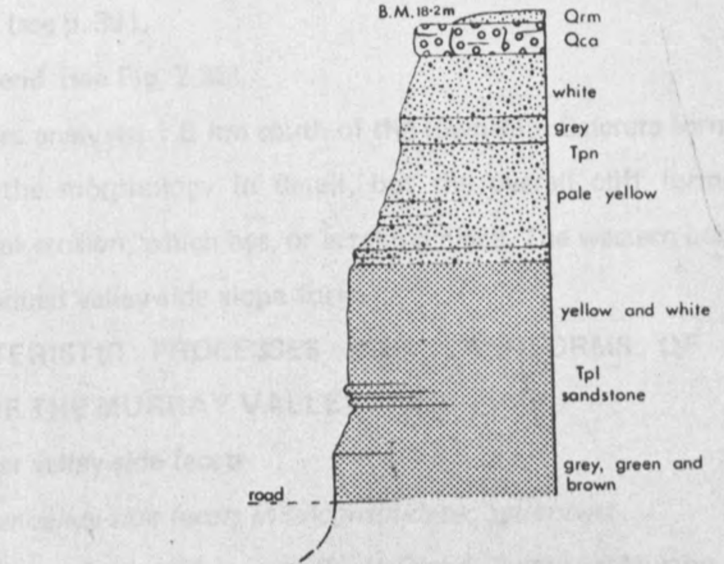
II i – uniformly continuous, calcrete capping.

ii – variable slope depending on the degree of river impingement.

iii – a continuous resistant stratum in Norwest Bend Formation.

iv – variable dissection due to gullying. The lower part of the slope may be masked by talus.

TAILEM BEND



field work
1: 63,360 geological map
Alexandrina
Johns (1961)

erosion surface, because of its elevational position relative to other similar features within the valley and its relationship with the terrace formation lying along the upstream, or northern side, of the spur (see p. 39).

m. Tailem Bend (see Fig. 2.25)

This slope was analysed 1.6 km south of the township. Calcrete forms a capping and minor benches affect the morphology in detail, but the overall cliff formation depends on the amount of fluvial erosion, which has, or is taking place. The western bank, at Wellington, has a much more subdued valley-side slope form.

3. CHARACTERISTIC PROCESSES AND LANDFORMS OF THE VALLEY-SIDE SLOPES OF THE MURRAY VALLEY

(1) Triangular valley-side facets

(a) *Triangular valley-side facets in unconsolidated sediments*

This slope form developed in soft Parilla Sand between Murtho Homestead south and Woolenook Bend could result from gullying action from small tributary streams with their "headwaters" in Blanchetown Clay. The easily eroded sands are dissected by deep "v" shaped gullies. Mass movements on the sides of these recently formed drainage lines have contributed to a widening of the gully in places. Many of the triangular valley-side slopes are capped with a sandstone, layer within the Parilla Sand but this is gradually being undermined by subsurface flushing.

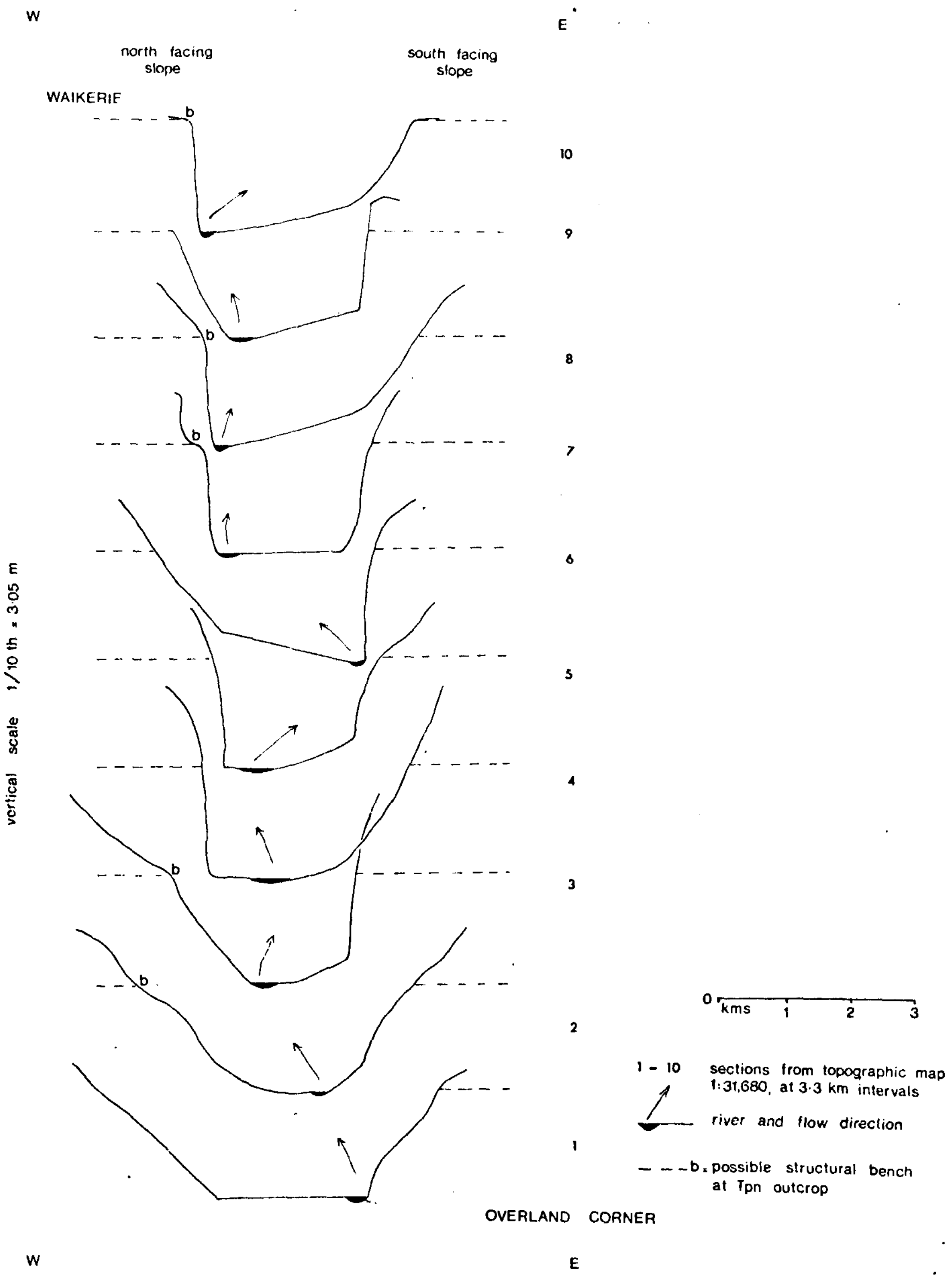
(b) *Triangular valley-side facets in consolidated sediments*

These slopes are developed in the resistant Mannum Formation south of Murray Bridge. They are very conspicuous north of Monteith (see Fig. 1.1). These could be primary cliff forms developed during intrenchment of the river. Subsequently they have been dissected by gullying of small tributary streams. The softer overlying sediments were removed by flushing out of the former upper bluff slope. This slope has subsequently retreated into the upper Mallee Surface. Again it is suggested that the gullies dissecting the Mannum Formation have been extended laterally by mass movements and chemical weathering.

(2) Aspect and valley asymmetry

The Murray River with its low channel gradient flows in an approximate east-west trending valley between Overland Corner and Morgan, and asymmetry of the valley-side slope was observed in this part of the valley on topographic maps (Lands Department, 1:31,680), on aerial photographs and in the field. The cross-sections (see Fig. 2.26) show the relative variation in slope angle of the north-facing and south-facing slopes, the narrowing of the valley downstream, and the structural bench, Tertiary limestone to Pliocene sand. The maps of the

FIG. 2·26 VALLEY CROSS-SECTIONS SHOWING ASYMMETRY OF AN EAST-WEST REACH



scale 1:31,680 from Overland Corner, Sheet No. 6929 I–S, M.R. 328812 to Waikerie, Sheet No. 6929 IV–S, M.R. 041797 show the variation in areal dissection.

The results of a quantification study of the tributary streams between Overland Corner and Waikerie can be summarized as follows:

The ratios for south-facing slopes to north-facing slopes

(i) actual number of tributaries, first order to fourth 1:1.21

(ii) total lengths in kilometres 1:1.51

(iii) area in square kilometres 1:1.81

(iv) density 1:.9

It is concluded that in terms of actual number length of streams and dissected area, the north-facing slopes exceed the south-facing slopes. This is regarded as proof of valley asymmetry (see Fig. 2.27). However, there is a greater drainage density on the south-facing slopes. Therefore, factors other than tributary stream channeling may play a dominant role in the creation of valley asymmetry.

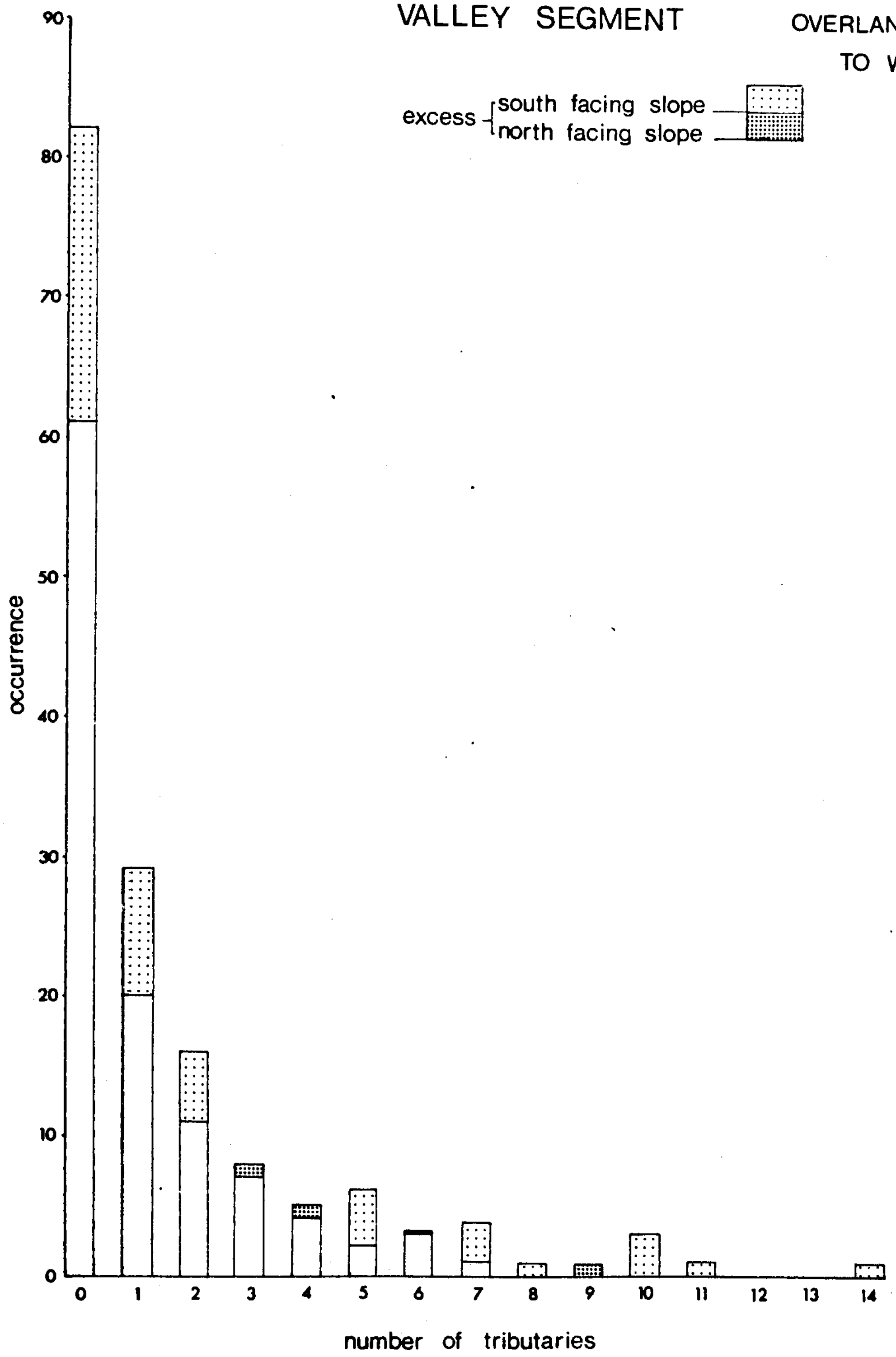
The location and orientation of the tributary valleys, especially where they enter the Murray River reflect the jointing pattern in the Tertiary limestone. These joint streams are producing lateral cliff recession. Variations in rates of such recession would be related to the length of time processes have been active, whether there has been river impingement, and/or how much subsurface return of water to the river has taken place. Expectedly, the north-facing slope might receive more infiltrated water because of a latitudinal increase in rainfall south of the river, and the presence of irrigation schemes favouring the south bank location, e.g. Waikerie.

Asymmetry in the valley profiles is reflected in the uppermost sections above 38 m in Pliocene sands. However, the height variation of the Tertiary limestone cliffs appears to be related to the length of time of river impingement against the formation. For south-facing to north-facing slopes today river impingement is occurring 8/12 times, but for established cliff forms 4/9. Therefore lateral corrasion/corrosion by former rivers, using cliff locations today as the evidence, seems to have been equally proportioned to either bank. Thus there does not seem to be supporting evidence for Melton's suggestion of basal corrasion (1968). It could be argued that incision of a later date could have destroyed this evidence, but from the map it appears that both valley sides have been subjected to equal amounts of reduction laterally. In 7 of the 10 profiles drawn regularly from Overland Corner to Waikerie, at 3.2 km intervals, valley asymmetry in the upper valley profile section was recorded. Nowhere was there a

FIG. 2·27

TRIBUTARY DEVELOPMENT OF AN EAST-WEST ASYMMETRICAL VALLEY SEGMENT

OVERLAND CORNER TO WAIKERIE



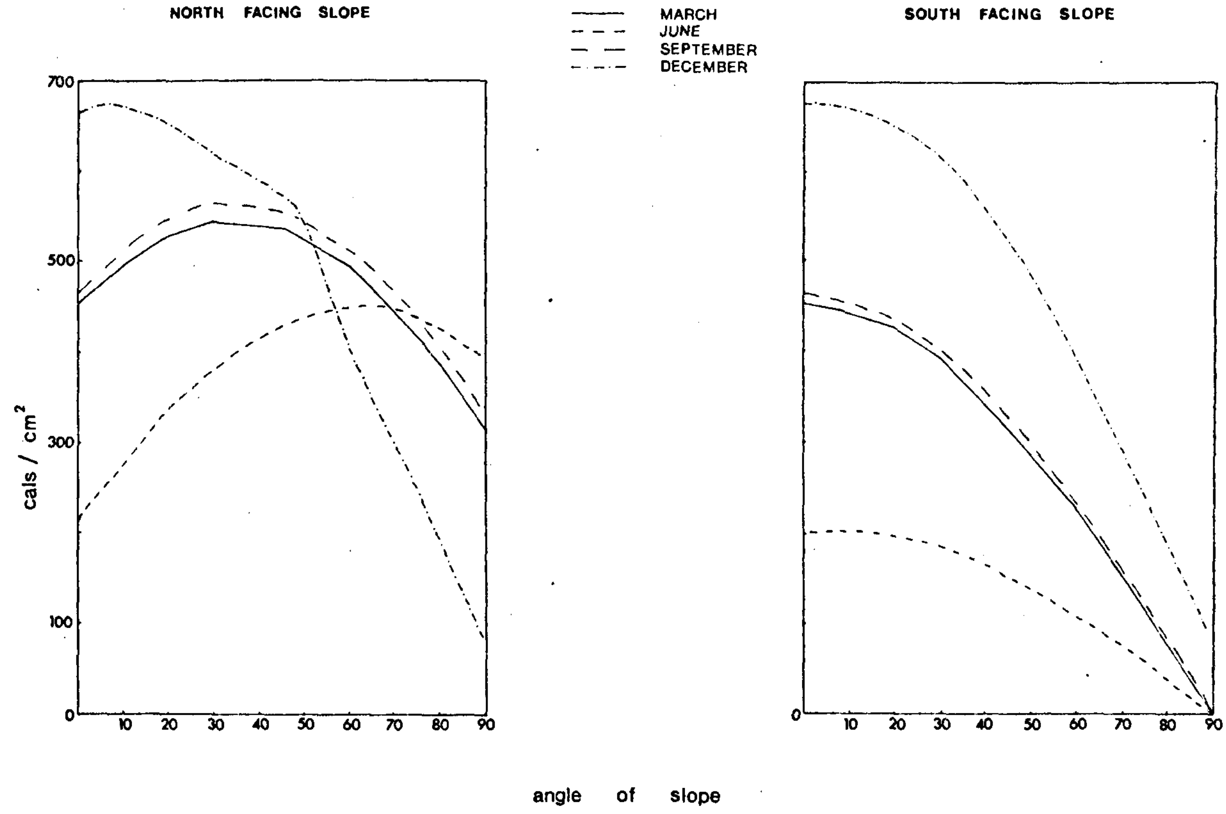
symmetrical valley profile. It seems that the upper slope (in Pliocene sands) asymmetry is related to post-incision processes. Subsequent processes, e.g. in the form of periglacial activity may have played a role, but it is suggested that today chemical and physical weathering are dominant. These processes are related to variations in micro-climate.

The graph (see Fig. 2.28) shows the amount of radiation in cal/cm^2 on both north and south-facing slopes at sea level from sunrise to sunset, at latitude 35°10'S, for the four seasons, with the angle of slope measured in from the horizontal. These figures are thought to be suitably representative since the latitude of this region is 34°10'S and the slopes range from 45.7 m to 7.6 m. Plotted onto the graph are a series of slope angles measured from the north and south facing slope. It can be seen that there is a marked variation in insolation received. For maximum weathering processes to occur, a combination of high temperatures and moisture is necessary. It has been suggested that the river and its lagoons represent a source of moisture, for example dew, contributing to high humidity on clear still winter nights (Mason pers. comm., and supporting evidence in Mason 1956). It is noteworthy that maximum insolation variation occurs at the season of greatest dew formation. Optimum weathering conditions result. The diurnal range of temperature is also important in its effect on weathering (see Fig. 2.28). It is expected that there would be an associated increase in mass movement on the slope with the greatest weathering, all other things being equal. With more weathering and more rapid removal of weathered material on one slope relative to another, valley asymmetry would result.

Micro-climatic variations could be expected to be reflected in the vegetation species, on either cliff face, but from field work and aerial photograph observations a general paucity of vegetation exists on either slope, possibly due to overgrazing resulting from European occupation, or to the steep slopes and resultant thin skeletal soils. However, a quadrat study of vegetation species would possibly help to substantiate even further the relationship between valley asymmetry and aspect.

Although the precise reason for valley asymmetry cannot be stated firmly, the results from the visual and statistical observations of this problem in the east-west valley section of the Murray River reaffirm the past observations of other geomorphologists' analyses that valley-side slopes are sensitive indicators of the gradational processes operating on their surfaces. Contrary to Melton's findings (1968), the role of the main channel seems to be only of secondary importance.

FIG. 2·28 AMOUNT OF RADIATION ON SLOPES AT SEA LEVEL, FROM SUNRISE TO SUNSET AT LATITUDE 35° SOUTH



source: Mason (1956)

(3) A study of valley-side slope change in a downvalley direction, Walkers Flat

By constructing profiles across the valley at close, regularly spaced intervals down a chosen reach, the change in slope morphology relative to changes in valley orientation, and location of the present river channel can be demonstrated.

Topographic maps of the scale 1:31,680 were expanded to the scale of 1:10,000, and used for the transverse profiles. Some indistinguishable slope elements onthe maps were checked in the field with the use of an Abney level.

The series of profiles so produced are represented in two ways: individually with a constant orientation for qualitative description; and superimposed with a constant orientation for quantitative description (see Fig. 2.29, 2.30). The differing results from this study help to explain the ancestral valley windings (see Chapter V) and the recent floodplain development. The profiles are constructed at right angles to the valley, nearly one kilometre apart.

For Fig. 2.6 the mid-point of the valley, between the 25′ contour lines is taken as the base point for the positioning of the profiles, and a vertical exaggeration of 8.4 is used. Variable asymmetrical profiles appear. Cliff and slip-off slope development are greatest where the river has been undercutting for the greatest length of time, (1) and (5). Marked breaks of slope, but of variable lateral extent, occur on those profiles with intermediate sized cliffs. The least asymmetrical profile (6) occurs where the river occupies, or has occupied, the mid-point position of the floodplain for the greatest length of time, and where there has been equal impingement on the eastern and western cliffs.

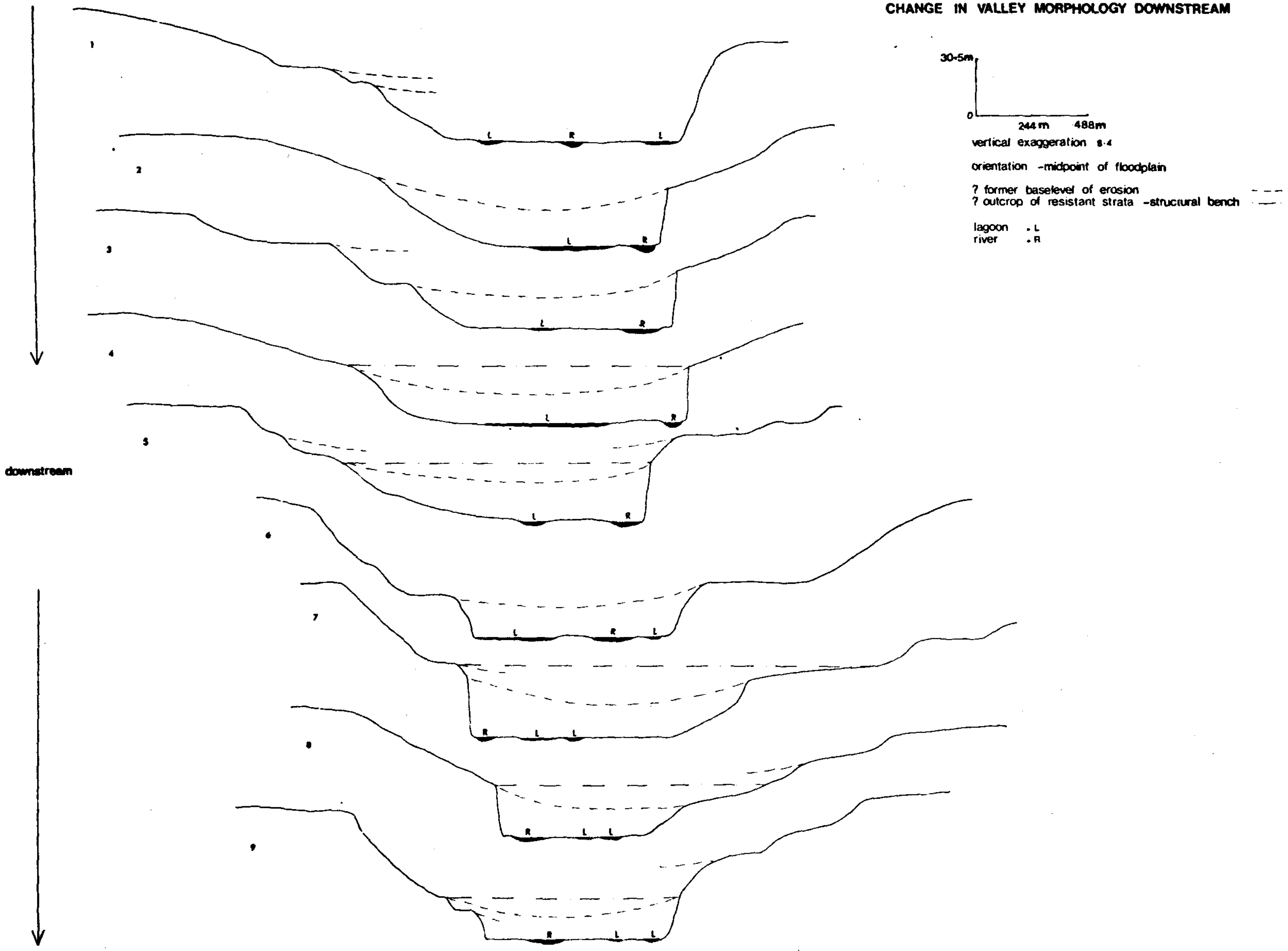
The superimposed diagram is used to compare and correlate the above profiles spaced at regular intervals, and plotted on a single frame (see Fig. 2.29). The results are as follows:

(i) Marked variations occur in the Mallee Surface; the highest elevation, 76.2 m above sea level, 68.6 m above flood plain level for (6), (7) and (9). Sand dunes are located here. The general elevation at 61 m, or 53.3 m, for (1), (5), (7) and (8) is an erosion surface cutting across Pliocene sands.

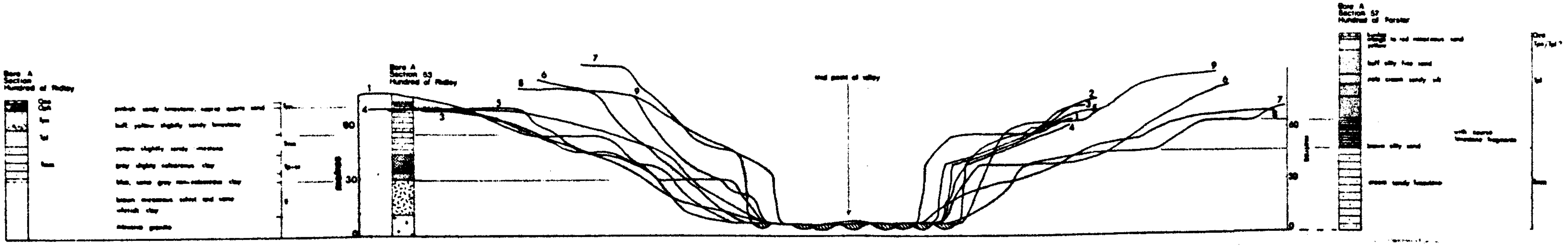
(ii) Marked variations occur in the height of the cliff; the highest 45.7 m, or 38.1 m for (1), the lowest 22.9 m or 15.2 m for (9). The highest are the site of the longest river impingement, and the lowest with the least fluvial contact. The most common occur at 38.1 m or 30.5 m, which from the borelog data appears to coincide with the geological boundary between the Miocene limestones and the Pliocene sands.

FIG. 2·29

CHANGE IN VALLEY MORPHOLOGY DOWNSTREAM



WALKERS FLAT - SUPERIMPOSED CROSS-SECTIONS 1 - 9 FIG. 2·30

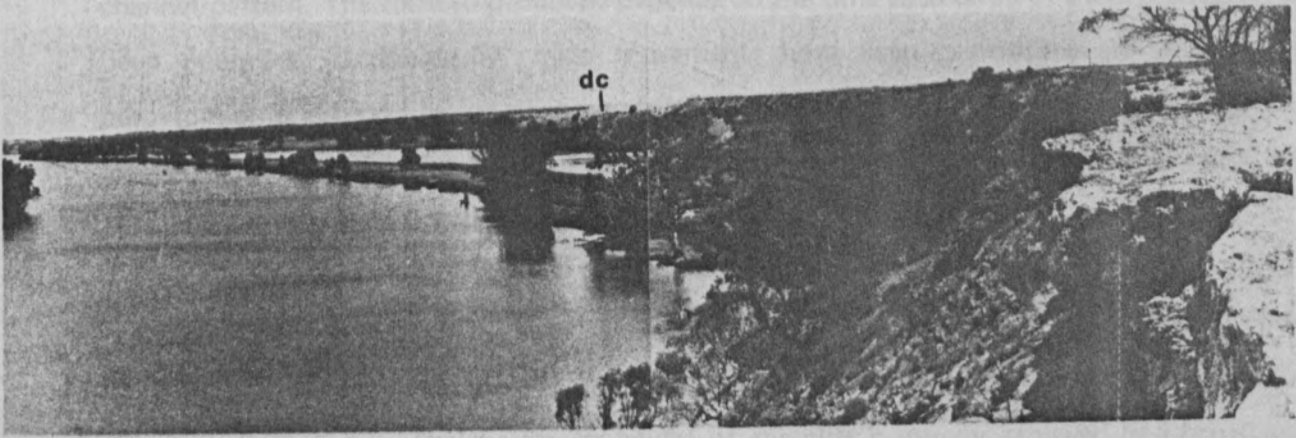


with bore-log data showing possible structural bench effect

1 Tpl - Tpn
2 Tmm - Tpl
3 E - Tp-er

Fig. 2.31 Disappearing cliff form, opposite Bowhill. Part of the crescentic scar is shown in the distance. A wide slip-off slope is in the foreground.

Fig. 2.32 Disappearing cliff (dc) at Big Bend. Ripon Calcrete forms the capping to the cliff.


dc

(iii) Planate forms are located at:

- 70.1 m or 62.5 m, (1), (3), (5),
  Pliocene Norwest Bend Formation, capping
- 61 m or 53.3 m, (7), (8), also
  Norwest Bend Formation
- 38.1 m or 30.5 m, (1), (6), (8),
  geological boundary of Tertiary Mannum Formation and Pliocene Loxton Sands
- 30.5 m or 22.9 m, Palaeozoic outcrop.

(iv) There is an apparent relationship between the width of valley and the width of floodplain. Wherever the floodplain is narrowest there is greatest development of slip-off slopes.

(v) The river has occupied all positions in the floodplain in a distance of 7 km.

The findings listed here will be used as evidence for the description of the evolution of the Murray River (see Chapter V). The processes active in this downvalley change in slope form are fluvial, for example, intrenchment, with lateral erosion, and downvalley migration of the channel pattern. The form so produced depends on the time each or all of these processes have been operative. Undoubtedly, mass movements have been responsible for enlargement, perpetuation and modification of some of the features. It is possible that structural differences are important in the initial stages of development of some of the planate forms, and/or have been solely responsible for structural benches *per se.*

(4) Disappearing cliffs

Many of the major cliffs developed in Miocene limestone possess "disappearing ends," i.e. there is a gradual reduction in height of the cliff over a short horizontal distance (see Fig. A–I, 2.31, 2.32). The maximum height of the cliff is usually achieved in a broad zone between the two ends. Disappearing cliffs occur at either end of the cliffs, but they appear to be dominant at the downvalley end. It is suggested that these represent downvalley migration of the stream, and a shift in channel location. Consequently, with migration of the river the channel forming processes change from erosional to depositional.

(5) Stepped valley-side slopes

During the discussion on sample valley-side slopes mention was made of marked breaks of slope in the valley-side slopes (see pages 14, 15, 16 and 17). Stepped valley-side slopes may reflect structural benches, or indicate rejuvenation.

Structural benches are produced by greater weathering and erosion of less resistant strata which exposes relatively resistant strata. Valleys which have suffered rejuvenation with lowering of the base level of erosion, possess a valley-in-valley form, i.e. rejuvenation may produce a gorge-like valley within an older and more open valley.

The extent of the areas of stepped valley-side slopes is shown on Fig. A–I. There is a concentration of these slopes from Teal Flat to the confluence of the River Marne and the Murray, and from Waikerie to Overland Corner. Specific localities mentioned previously occur at Paringa, Pike Creek Canyon, Overland Corner, Wigley Reach, Ittledoo, Roonka and Teal Flat. In many locations, however, accumulations of talus obliterates the stepped appearance of the valley-side slope.

Geological sections show that major breaks of slope occur where unconsolidated sands and clays appear above limestone sequences. Field evidence suggests that weathering and removal of weathered products by rainwash and mass movements produce the stepped valley-side slopes. Where stripping, or removal of younger, less resistant strata exposes an unconformity the surface exposed is described as an exhumed surface. At Wigley Reach the stepped valley-side slope could be considered as an exhumed Pliocene surface. Here the estuarine Pliocene Norwest Bend Formation is exposed.

Lateral extension of structural benches may occur through a pediplanation process. At Paringa (see p. 14) there is evidence of weathering and removal of material in the scarp foot zone of a gently sloping bedrock surface.

Alternatively, stepped valley-side slopes may be interpreted as valley-in-valley forms. Twidale (1968, p. 150) described the valley-side slopes between Mannum and Morgan as displaying a distinct valley-in-valley form. However, the breaks in slope are shown to occur in most cases where there is a change in the nature of the strata, they are absent from many of the valley-side slopes (see Fig. A–I), and most importantly the breaks of slope are most extensive where there is obvious upper valley-side slope weathering occurring today, or in the recent past (see aspect and valley asymmetry, p. 17). These processes would tend to modify and obliterate, not perpetuate a valley-in-valley form. On the other hand a structural bench would be extended by such processes. To date the evidence, i.e. geological evidence, topographic map analysis (see p. 20 and 21) and field work, suggests the stepped valley-side slopes can be described as structural benches.

(6) Weathering processes active on cliff forms

There are three forms of weathering active on cliff forms of the valley-side slopes.

(i) *Organic weathering*

A mechanical form of organic weathering is carried out by the germination and growth of species of *Eucalyptus* which penetrate and prize apart joint blocks of the cliff limestone (see Fig. 2.33). At Murbpook Lagoon 0.9 m–1.2 m caverns of the cliffs are now the haven of the

Fig. 2.33 Organic weathering of cliffs 1.6 km upstream from Woolpunda Pumping Station. The roots of *Eucalyptus camaldulensis* are prising open the joints in the Morgan Limestone.

Fig. 2.34 Organic weathering of the cliffs at Murbpook Lagoon. The cliffs form the habitat of the White Cockatoo (*Cacutua galerita rosinae*).

white cockatoo, *Cacutua galerita rosinae* (see Fig. 2.34). Their physical occupation of the hollows leads to organo-weathering and the enlargement of these cliff forms. Similar effects were reported by Parkin (1938) with bat guano in Punyelroo Cave, Swan Reach.

(ii) *Weathering (and erosion) resulting from the presence of seepages*

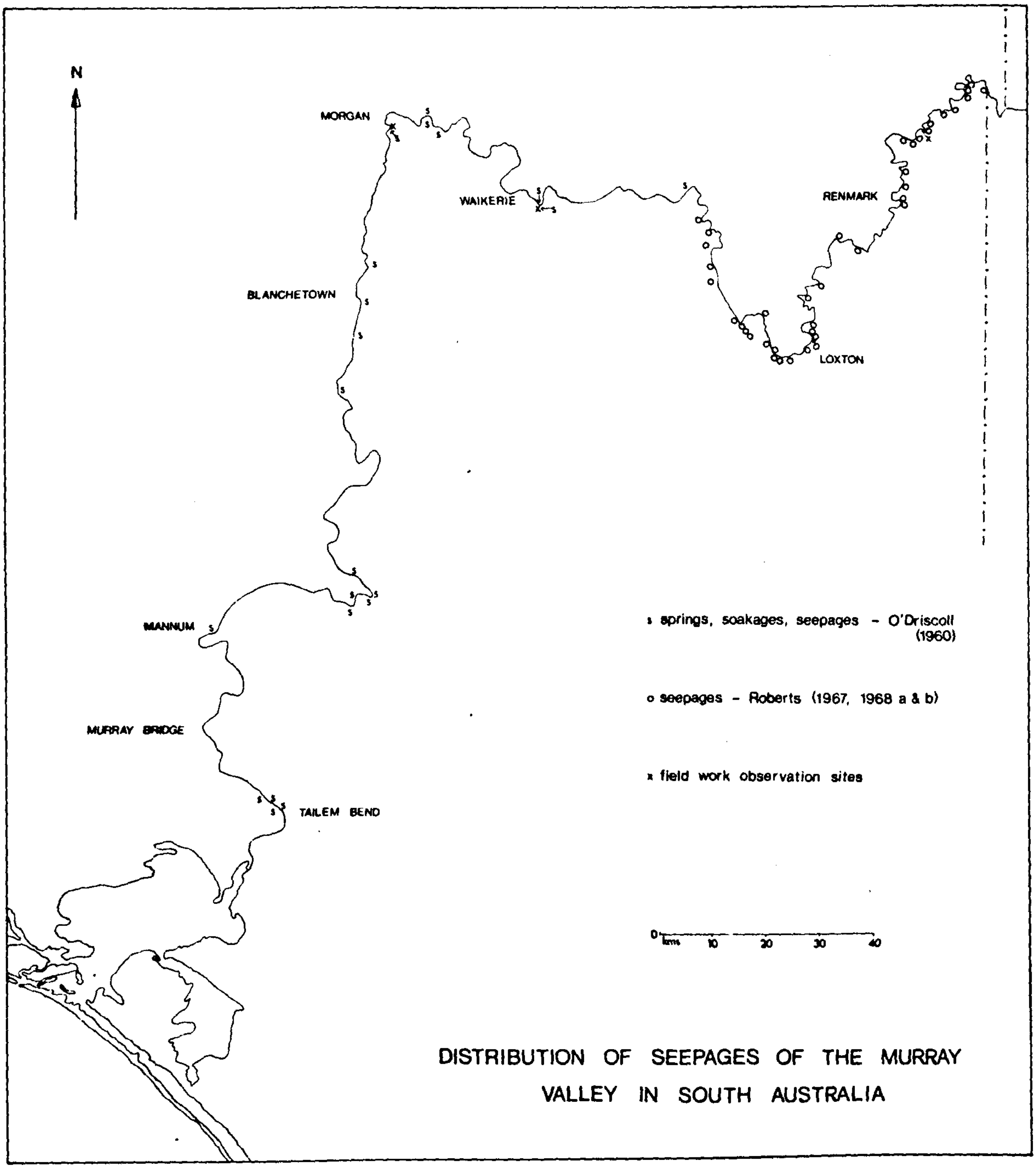
Seepage is a slow, often discontinuous movement of water from a rock or soil onto a land surface, or into a body of water.

Distribution: Natural seepages or exsurgences, i.e. springs fed solely by rain falling on karst rocks and infiltrating directly (Jennings 1971), are not commonly noticeable along the valley-side slopes of the Murray River. However the observational field work was carried out in January and February when discharge is low because of negligible precipitation, and high evaporation (Mason 1957). Furthermore, storage of moisture in the soil and rock strata is at a minimum. Roberts (1967), after a very careful survey of the river bank between Chowilla and Renmark, reported no evidence of natural seepages. He attributed this to the general level of the water table being close to the floodplain level of the river, and the diffuse nature of the seepage. This occurs mainly at the toe of the cliff lines, or in the recent deposits now masking old cliffs at some distance from the present river course. However natural seepages have been reported by O'Driscoll (1960) and Roberts (1968a), (see Fig. 2.35).

The only natural seepages found during field work were at Cosy Corner (see Fig. 2.36), but it could be argued that these might be attributable to the irrigation practices at Cadell. This may result in a long more or less horizontal translocation of water through the Loxton Sands aquifer, westwards to the Murray valley.

The two main areas of artificial seepages discussed here lie to the north and east of Renmark, and to the east of Waikerie.

a. Renmark: Roberts (1968a) has made a comprehensive study of this area reporting three main outlets. At Murtho Homestead south irrigation is well developed several hundred metres back from the cliff edge (see Fig. 2.37). Seepages are within the Parilla Sand. Elsewhere they are controlled by Blanchetown Clay, which outcrops along the upper valley-side slope. Water is moving along the surface of the clay from the irrigation block to the cliff edge and white salt encrustations mark the site where water is evaporating before reaching river water level. However, in winter when irrigation practices are negligible the seepages do not flow! By the end of summer perched water tables on the Blanchetown Clay and other impervious layers build up and result in a steadily increasing discharge at the valley-side slope.



DISTRIBUTION OF SEEPAGES OF THE MURRAY VALLEY IN SOUTH AUSTRALIA

FIG. 2·35

b. Waikerie: The location of the seepages occur to the east of the township of Waikerie, in the cliff formations (see Fig. 2.38). There are two seepage lines, on top of a blue clay horizon of Miocene age, and the Loxton Sand, a major aquifer above the Blanchetown Clay.

A sequence from dormant to active seepage forms has been recognized (see table 2.1, Figs. 2.40, 2.41, 2.42). As this morphological description indicates vegetation plays an important role in the assessment of the age of the seepage. With the development of a sere, the volume and the flow of the seepage can be determined. Furthermore, vegetation is of importance in trapping and building up the curtains or mats of colourful precipitates (see Figs. 2.43, 2.44). This deposit is characterized by organic material, boulders of sandy limestone talus and other colluvial material, and nodular growths with stratification or layering resulting from precipitate crystallization.

The net effect of localized artificial seepage activity is to weather and erode limestone. This results in the undermining of certain cliff strata and the creation of an assemblage of micro-landforms. The cliffs then take on a distinctive micro-morphology. Extensive slumping and land-sliding of the cliff by the lubricating action of the seepage water for a distance of 160 metres has occurred in the Waikerie cliffs, and lateral cliff recession has resulted (see Fig. 2.39). The absence of any vegetation suggests this is a recent occurrence. The progression from seepage dampness and salt encrustation, to pitting and weakening of the Morgan Limestone results in a "decalcification" of the limestone.

(iii) *Chemical weathering and the formation of surfaces case-hardened by carbonate* (see Fig. 2.45)

Solutional weathering processes determine micro landforms of the limestone cliffs from Overland Corner to Monteith. This weathering is of two types.

(a) Rocks rich in calcium carbonate are readily attacked by water. The calcium carbonate combines with weak carbonic acid to form a calcium bicarbonate, which is soluble in water.

$$CaCO_3 \; + \; \frac{H_2O + CO_2}{HCO_3} \; \rightarrow \; Ca(HCO_3)_2$$

Twidale (1964) described this process as honeycomb weathering. Innumerable holes and cavities up to 2.7 cm in diameter, and .6 m deep result. Honeycomb weathering consists of selective weathering of the non-shelly parts of the calcarenite. Carbonic acid dissolves the calcareous matrix, and gradually eats further back into the bedrock. This process is coupled with groundwater penetration through the rock along joint planes (Twidale, 1964). Development of micro forms from such weathering is not even in the Miocene limestones. Certain strata are more susceptible to the weathering than others, though few are entirely devoid of such forms.

Fig. 2.36	Cosy Corner, 1.6 km upstream from Ittledoo. Seepage lines appear in the cliff of Morgan Limestone. A flat topped residual can be seen on the skyline.
Fig. 2.37	Pseudo vertical jointing, resulting from seepage cutting gullies into soft Pliocene sands.

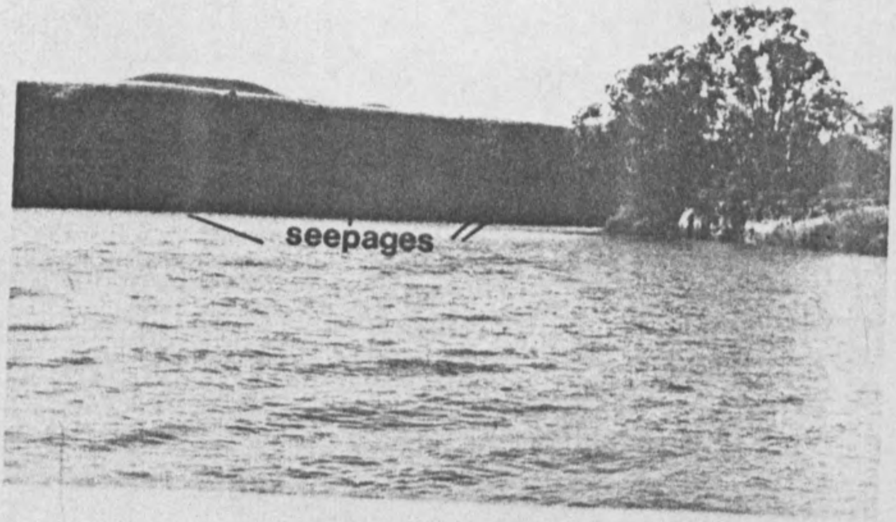

seepages

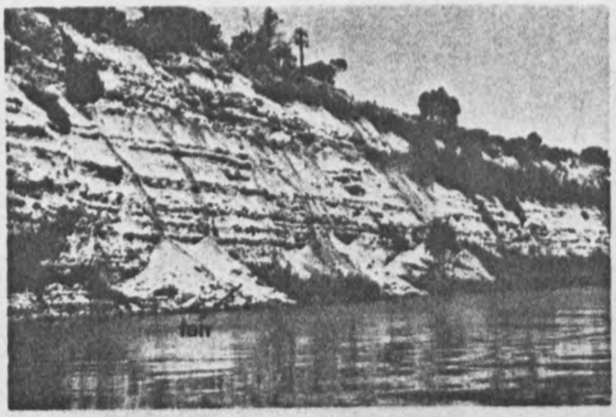
Fig. 2.38 Seepage at Waikerie. The two lines of *phragmites* indicate the two aquifers. At the base of each major flow there is an alluvial fan.

Fig. 2.39 A major slump, 183 m long, at Waikerie. This is the result of continued seepage from irrigation waters draining into the river. The cliff form becomes unstable, and local cliff recession occurs.

Fig. 2.40 A seepage in the Waikerie cliffs, which is drying up. There is no free flow of water.

Fig. 2.41 A seepage "stalactite", 2.4 m in length.

Fig. 2.42 Seepage curtain, Waikerie cliffs.

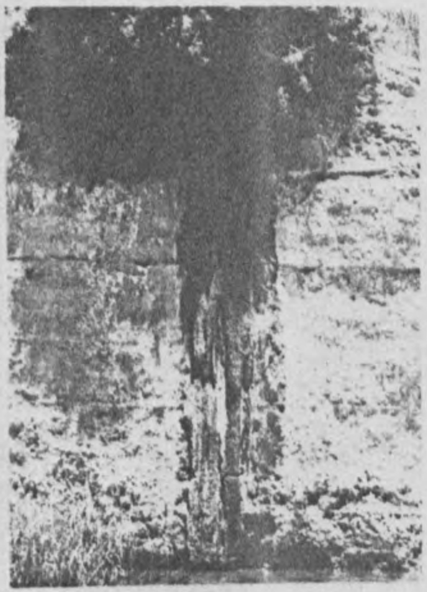


1

2

3

4



5

Fig. 2.43 Seepage curtain from a distinct seepage line. X is the location of the close up photograph, Fig. 2.44.

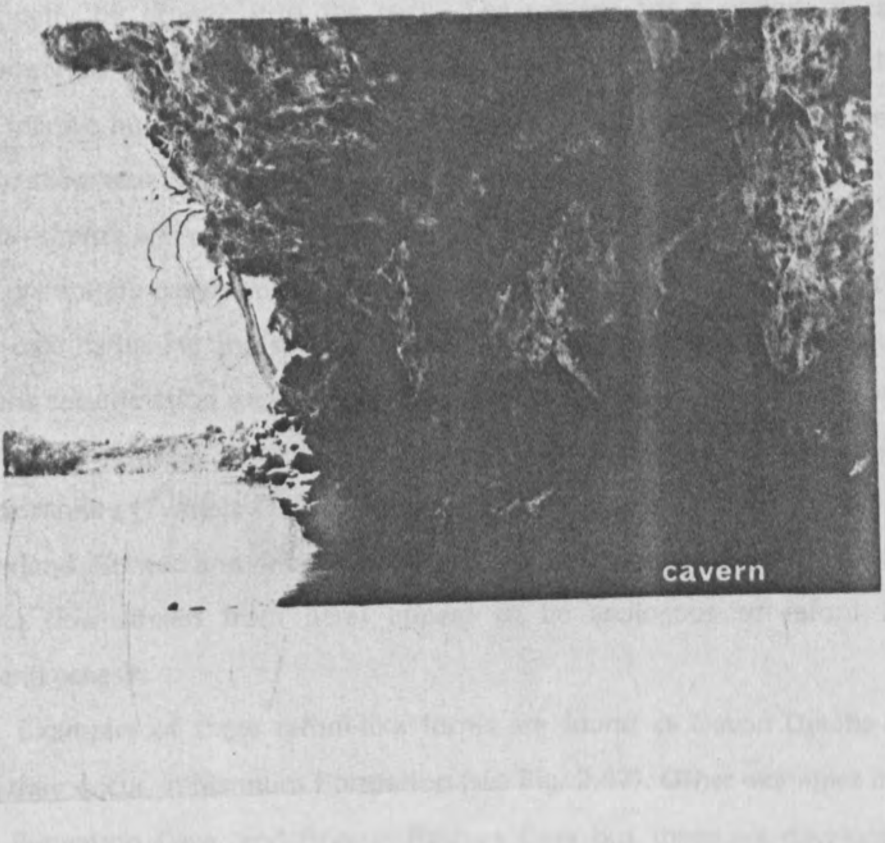
Fig. 2.44 A close up of a segment of the seepage curtain, Fig. 2.43, with micro-"stalactite" forms. It consists of a mat of *phragmites*, and precipitates.

TABLE 2.1 SEQUENCE OF SEEPAGE FORMS, WAIKERIE CLIFFS

Type			Water Movement	Landform Evidence
dormant			no free flow	small vertical grooves, degenerating fans, dead vegetation
active	(a)	young	oozing	widespread damp patches, no defined channel, but knick point forming in Morgan Limestone at outlet, phragmites growth
	(b)	mature	free flow	single channel flow, but may be some lateral dampness, fan or bajada forming at the base of slope, at river level. Similarity of dimensions indicate equal discharge, age, time of seepage. Some large scree from landslides
	(c)	old	oozing	general dampness of country rock, curtain deposits and stalactites (drip "stone"), up to 2.4 m in length. Dense phragmites and bushy vegetation growth

Fig. 2.45 A 33 m cliff in Morgan Limestone, possessing a surface case-hardened by carbonate, and cavernous forms. View from Sacred Flame Cave.

Fig. 2.46 Cavern development at the water-atmosphere contact at the base of the cliff, Waikerie. The caverns are 1.3 m deep and 3.6 m in height.



cavern

Since most weathering is accomplished in locations where there is alternate wetting and drying, the water/atmosphere contact at river level represents the site most susceptible to weathering (see Fig. 2.46). The lap of waves from the river would result in an increase in this zone of weathering activity. Sturt (1883) described this process:

> The constant rippling of water against the rock had washed out the softer parts, and made hollows and cavities that gave the whole formation the precise nature of a catacomb.

Today wash from power boats would surely act as a catalyst for such a weathering process. Fluctuating river levels, especially in time of flood would provide similar conditions.

Innumerable holes and cavities up to 2.7 cm in diameter, and .6 m in depth result from honeycomb weathering. However, variation in size is a function of time, the duration over which there were optimum conditions for this type of weathering to occur.

b. Soft or brittle limestone may become quite hard on contact with the atmosphere.

$$Ca(HCO_3)_2 \leftrightharpoons CaCO_3 + H_2O + CO_2$$

This reaction is reversible until H_2O and CO_2 escape. The evaporation of H_2O and the loss of CO_2 results in a superficial hardening of the limestones (see Fig. 2.45).

This chemical process seems to post-date the incision of the Murray River into the Miocene limestones. The discontinuous coating is found from cliff top to river level. Cavernous forms are gradually reducing this surface hardened by carbonate. These solution holes, or pitting, enlarge principally by growth into the rock. The reasons for a period of case hardening followed by a period of honeycomb weathering are obscure. Perhaps climatic change with an alteration of relative humidity, or a change in volume or supply of water on the cliff face are responsible for these alternate processes.

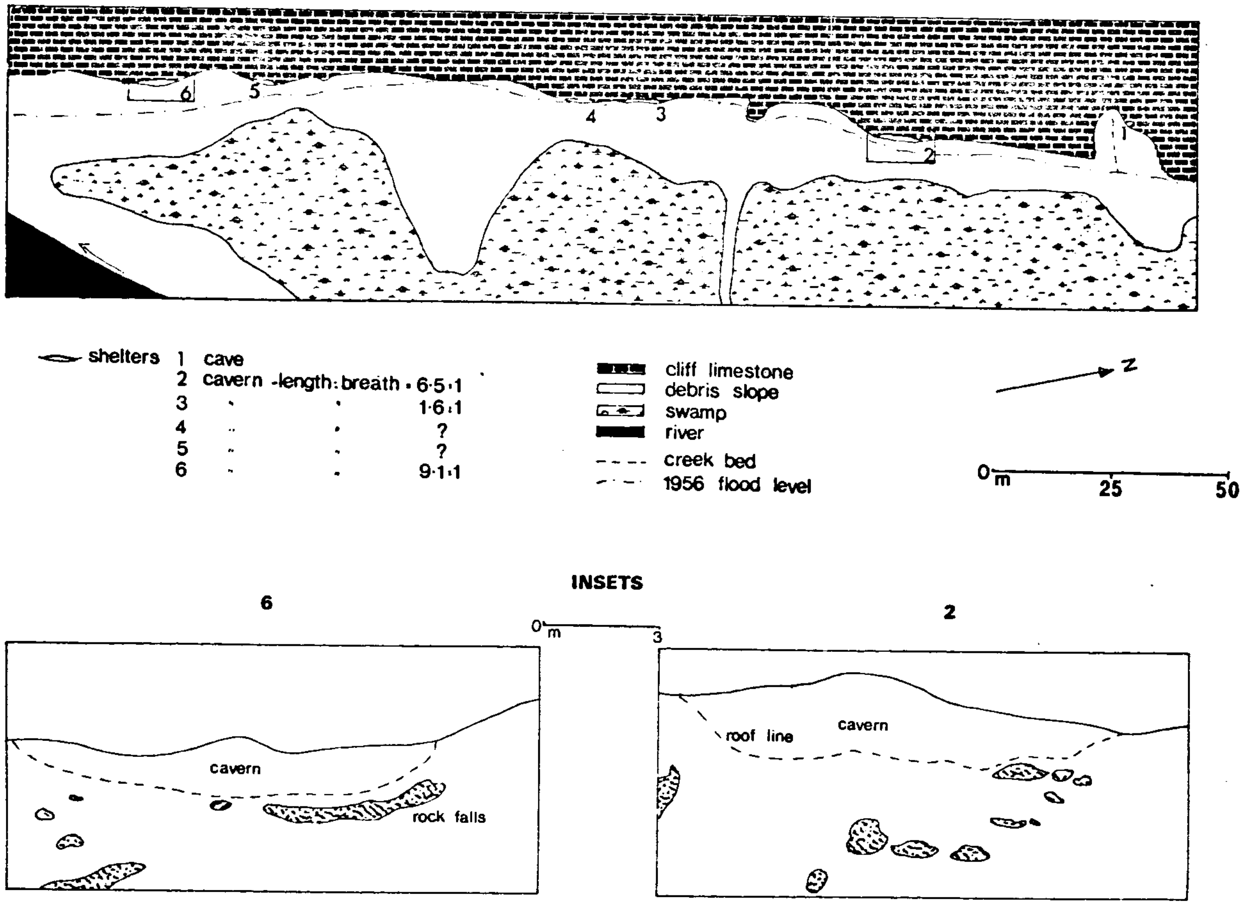
(iv) *Tafoni—shelter and cave*

Tafoni in granite are cavernous hollows, which result from the combined processes of the formation of case hardening and soil layer weathering. Moisture is retained along joint planes or in soil debris accumulation causing pronounced disintegration of the lower sides of the joint blocks (or sheet structures). A hollow is formed which expands with the tough outer case weathered less rapidly (Twidale 1971). The cavernous hollows in the cliffs of the Murray River between Overland Corner and Murray Bridge (Pliocene sands become the dominant cliff forming strata downstream from here) appear to be analogous to tafoni in respect to morphology and genesis.

Location: Examples of these tafoni-like forms are found at Devon Downs and Fromm's Landing and they occur in Mannum Formation (see Fig. 2.47). Other examples include Sacred Flame Cave, Punyelroo Cave, and Briants Reserve Cave but these are developed in Morgan Limestone (see p. 27).

FIG. 2·47

FROMM'S LANDING CLIFF SHELTFR DISTRIBUTION AND MORPHOLOGY



source: PRICE (1952)

Morphology: The term shelter has been used to describe these cliff landforms. In the literature they have been reported as aboriginal shelters and display evidence of occupation by these indigenous peoples from 4850 ± 100 years B.P. (Grenfell-Price 1952); and rock shelters (Mulvaney 1960, and Mulvanney, Lawton and Twidale 1964). Since not all these landforms of the Murray River cliffs have been occupied by the Aborigines the term rock shelter will be used in preference to the term aboriginal shelter or cave (see p. 28). "Caverns" will be used to describe these features in miniature.

Fig. G shows the location of the six rock shelters at Fromm's Landing, and the one at Devon Downs. The cross-sections illustrate the morphology of the bedrock walls, and the sequence of sedimentation on the floors (see Fig. 2.48). As can be seen they occur at a variety of elevations above river level, e.g. 9.7 m, 7.3 m, and 6.3 m. However, they are always at the junction of the debris slope, and bluff (cliff), which may be vertical or inclined. The depth varies from 4.8 m, 4.5 m, 3.9 m, to 3 m, but it is always considerably less than the width of the entrance, e.g. with ratios of 1:9.2, 1:6.2. The subunits of the rock shelters include, (1) a bedrock floor, with single or multiple steps, and usually covered with debris layers, (2) side, roof, and back walls displaying honeycomb weathering, and (3) at the bedrock/atmosphere/debris contact, especially at the back wall numerous caverns often coalesce (Twidale 1968). Large talus blocks may be scattered in front of the entrance or incorporated into the sediments on the floor of the rock shelters.

Twidale (1968) considered the following processes responsible for rock shelter formation:

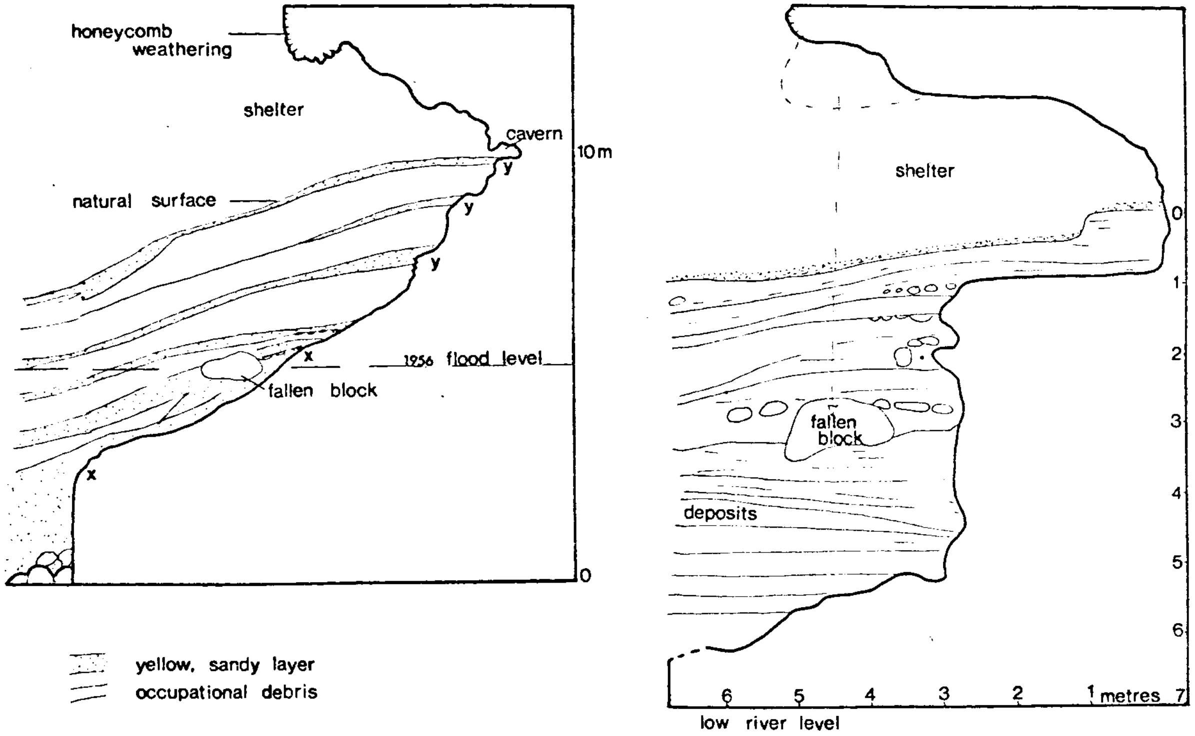
(1) Anthropogenic shaping of the bedrock slope.

(2) Chemical weathering.

(a) The development of minor caverns. This is the principal means by which the shelter undermines the bluff.

(b) Slower weathering of the ceiling. This occurs simultaneously, and differentially to produce an inverse mammilation. This may lead to total collapse of the wall and bluff recession (cf. meander cave and cliff channel formation, p. 31).

Intense weathering is confined to a zone several cms either side of the line of contact between the debris surface and the bedrock back wall. Here moisture percolating through the bedrock tends to concentrate where this horizon of porous country rock emerges from below an impermeable blanket of debris. No springs or evidence of springs have been observed at this junction, but there is some evidence of water seeping from the bedrock in this vicinity. A washing action (subsurface flushing?) is thought to contribute to the removal of debris from



FROMM'S LANDING - SHELTER 6

after Twidale (1964)

DEVON DOWNS - EXCAVATION C

after Hale and Tindale (1930)

FIG. 2·48 SHELTER PROFILES

this contact zone. Alternate wetting and drying by the irregular subsurface seeping would hasten the process. Twidale (1964) suggested that these weathering processes may be the initiating factors in the development of the sequence from cavern to rock shelters to undermining of the bluff, which would lead ultimately to cliff recession.

An interesting weathering form described in detail is the series of steps of the bedrock floor of the shelter at Fromm's Landing (see Fig. 2.48). The angularity and distinctiveness of the steps is said to diminish downslope, i.e. towards the river. The steps terminate in a near vertical cliff 2.7 m above present river level. The steps do not seem to be related to any internal resistances in the Mannum Formation. The major break of slope (x) is interpreted by Twidale (1964) as probably an old river cliff dating from a period when the Murray River flowed closer to the eastern bank. Twidale considered the minor breaks of slope (y) to be the result of soil layer weathering.

Alternatively, water layer weathering could be responsible for these steps. It is suggested that the minor steps (y) may represent small periods of stillstand in the river when water layer weathering occurred (see p. 25). The river level continued to fall until it reached the level of the major break of slope (x). Here the river was in contact with the bedrock for a greater length of time and receded only slowly producing a steep vertical cliff. These steps must predate the oldest sedimentation on the bedrock floor, i.e. be older than 4,850 ± 100 years B.P.

The stepped morphology is definitely a weathering phenomenon due to either soil layer of water layer weathering. The height of the steps reflect the length of time for weathering on the bedrock slope. Once formed the shelter became increasingly filled with sediments.

Sketch profiles (Fig. 2,48) showing a clear and consistent relationship between the bedrock morphology and the sediments of the shelter floor, indicate that the tread of each sub-debris bedrock slope is elevationally coincident with, and is actually touched by a yellow stratum, and each step has adjacent to it a sequence of hearth and other occupational debris (Twidale 1964). The sedimentary sequence does not appear to be of fluvial origin, e.g. the yellow stratum, clean and sandy contains no foreign material, but rather disintegrated fossiliferous country rock.

Sacred Flame Cave, a rock shelter downstream from Overland Corner, 4.6 m wide and 7.6 m deep, with a height variation from 3.7 m to 0.3 m inland, and 9.1 m above present water level displays marked joint control of its sides and entrance. The bedrock floor is masked by several metres of debris, but numerous small caverns were seen to be forming at the soil rock contact along the sides, and especially along the back wall. Smaller cavernous forms occur on the roof (cf. rock shelters p. 26) stained with smoke, and evidence of aboriginal occupation. A break of slope two thirds of the way into this rock shelter appears comparable to the steps at Fromm's Landing described by Twidale (1964). Therefore, a soil layer weathering process and solution from ground waters along a major joint appear to have caused the extension of this landform. Water level contact at the period of river impingement against the cliff may have been the initial cause of the cliff irregularity. The difference in composition of the Morgan Limestone compared with the Mannum Formation is suggested as the cause of the difference between this rock shelter and those described above (see p. 25).

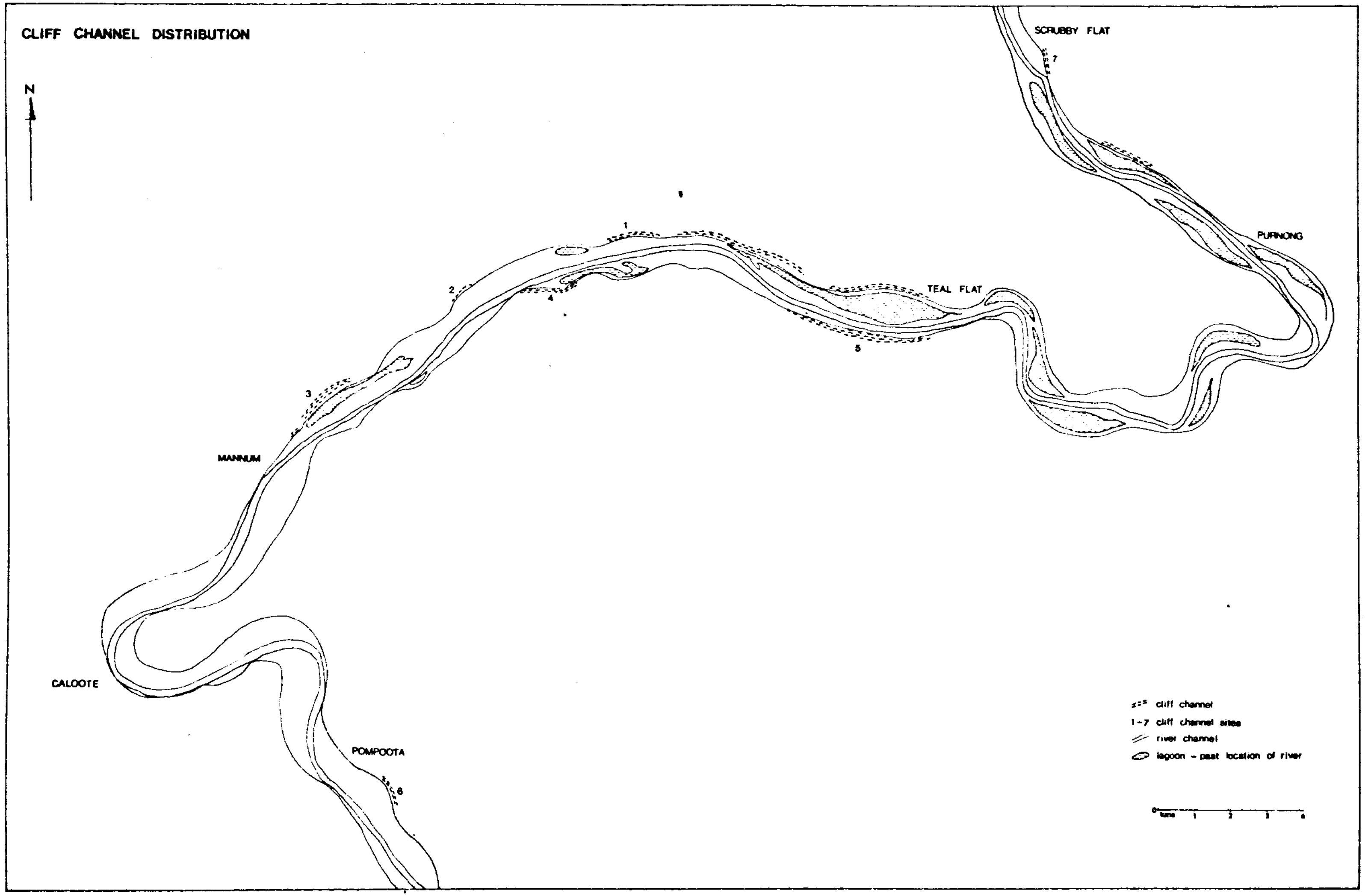
Punyelroo Cave, Swan Reach, also in Morgan Limestone displays a similar morphology to Sacred Flame Cave. It is 9.1 m wide, 12.2 m high, and 76 m above present river level. However, this rock shelter possesses a network of passages. The main passage is over 550 metres long. The pitted limestone contains no evidence of stalactite growth, because the high humidity prevents evaporation and precipitation (Parkin 1938). The sediments of the floor consist of fine argillaceous limestone, the insoluble residue from the weathering of the bedrock. There is some evidence of aboriginal occupation but anthropogenic activity has done little to contribute to its morphology. The cave entrance is occasionally reached by the larger floods. Fluvial scouring and some deposition of logs and sediment, have modified the passage nearest the river.

That rock shelters are weathering phenomena cannot be denied, but it is thought that water layer weathering should be assigned more of a role in their initial formation. Soil layer weathering occurs where there has been a stepped profile above river levels. Not all shelters possess such irregular bedrock slopes, e.g. Devon Downs. These landforms are possibly in an arrested stage of meander cave development, where collapse of the cave roof does not seem imminent, and the relatively slower weathering process of soil layer weathering compared with water layer weathering is now the dominant process concerned with rock shelter formation, or extension. (see p. 26).

(7) Cliff channels

Cliff channels are located on both valley-side slopes of the Murray valley between Walkers Flat and Pompoota (see Fig. 2.49). Their location was fixed by field work and analysis of aerial photographs. Previous acknowledgement of their existence is limited to Steel (1962), who reported that the rising water tables, associated with a recent rise in the river bed, caused massive slumping of the limestone walls bordering the valley. This slumped material, plus talus and interbedded sands silts and clays of the infilling channel system constitute the "older valley deposits" (Steel 1962). The other reference is to be found in Frahn (1971).

Fig. 2·49


CLIFF CHANNEL DISTRIBUTION
N
SCRUBBY FLAT
7
PURNONG
1
TEAL FLAT
2
4
5
3
MANNUM
CALOOTE
POMPOOTA
6
cliff channel
1 – 7 cliff channel sites
river channel
lagoon – past location of river
0
kms
1
2
3
4

In terms of geological distribution, cliff channels are confined to that part of the valley where Mannum Formation dominates the cliff segments. The distributional relationship to geomorphic units can be discussed under the following headings.

(a) Relationship to valley windings: There appears to be no apparent relationship between the actual location of the cliff channels to a particular segment of the valley winding. They are found on straight segments, on the inside, outside and downstream of valley curves, on either side of the valley, not necessarily opposite one another, and at stepped elevations above the floodplain.

(b) Relationship to the present river: They appear to be located where the river, or recent channel, now a lagoon, is impinging on, or close to the cliff wall. However, there are also cliff sections where the river bears the same relationship to the valley-side slope and cliff channels are absent.

(c) Distribution with the relationship to the valley-side slope: As is emphasized in the following description, there is an increase in depth of cliff channel features downstream. For example, downstream from Scrubby Flat they are poorly defined, and very shallow, whilst those at Pompoota have the greatest vertical expression. Variations in number of cliff channels, single to multiple, appear to be related to the width of exposure of the Mannum Formation in the cliffs. Cliff channels are less frequent on the steeper valley-side segments.

Morphological description of the cliff channels (see Fig. 2.50, 2.51, 2.52, 2.53, 2.54, 2.55, 2.56): The single distinguishing feature of the cliff channels is the cross-sectional profile (see Fig. 2.58). The channels possess the morphology of a river channel (hence the term cliff channel) and are all asymmetrical (see Fig. 2.59). They consist of a gentle headward slope, a steep slope or ridge on the floodplain margin, an inlet and outlet, and a floor of sediments (see Fig. 2.50). All channels but one slope downstream, and are parallel to the valley side, at slopes of 3° to 5°. The anomaly slopes 3½° upstream. Many are straight but others possess slight sinuosity, e.g. site (1) a deviation of 5° to the southeast, and site (2) 20° to the southwest.

The profile shows the composition of the floor deposits. This is not a soil profile because there is no horizon development. The layering present is merely a stratification produced by aeolian, or flood deposition, rather than soil water movement. The darker layer at 45 cm–50 cm, is due to the aboriginal occupance of the cliff channel, and perhaps some alluvial sedimentation during a high flood. In this case the channel represents a backwater rather than a channel with through flow of water. The presence of Box, *Eucalyptus largiflorens* along the cliff channel edge or ridge closest to the floodplain (see Fig. 2.55 at site (1)) testifies to the presence of floodwater after cliff channel formation.

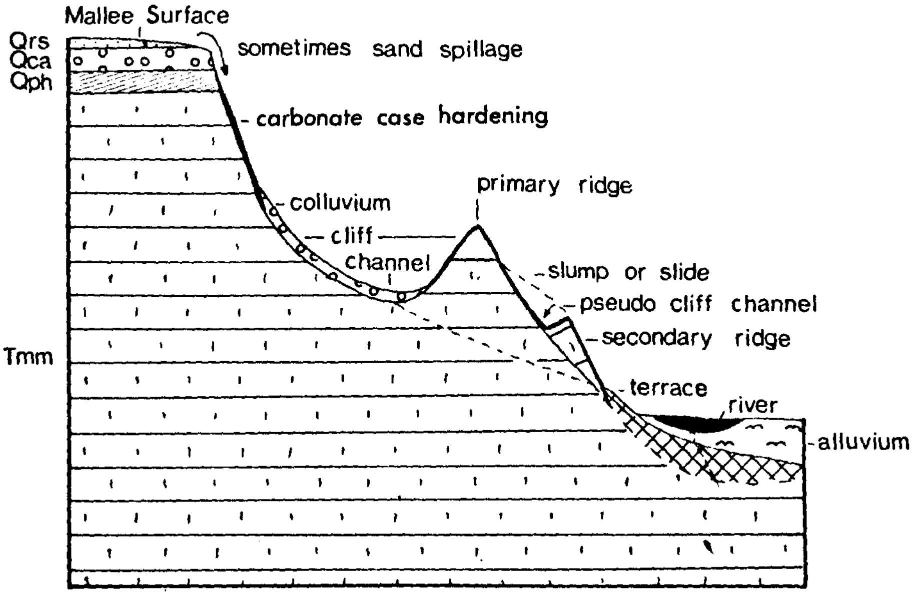


FIG. 2·50 Cliff channel components and landform association

Fig. 2.51 Cliff channel (2), looking upstream—a single form

Fig. 2.52 Cliff channel (2), looking upstream—a single form

Fig. 2.53 Cliff channel (6)—a single form.

Fig. 2.54 Cliff channel (5)—a multiple form.

1

2

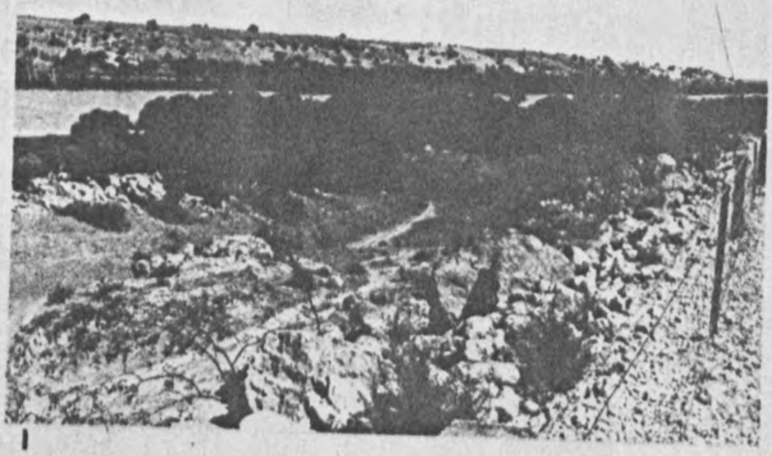
3

4

Fig. 2.55 Cliff channel (1)—a multiple form, looking downstream.

Fig. 2.56 Cliff channel (1)—looking upstream. This is the only channel to slope upstream.

Fig. 2.57 A rock shelter form developed in Mannum Limestone. This is located on one channel slope, in cliff channel site (1).



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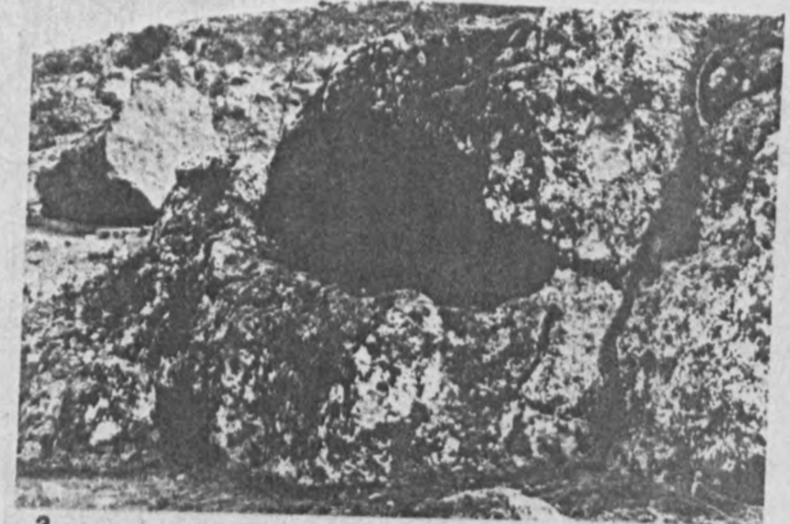
2



3

FIG. 2·58

CLIFF CHANNEL PROFILES from field measurements

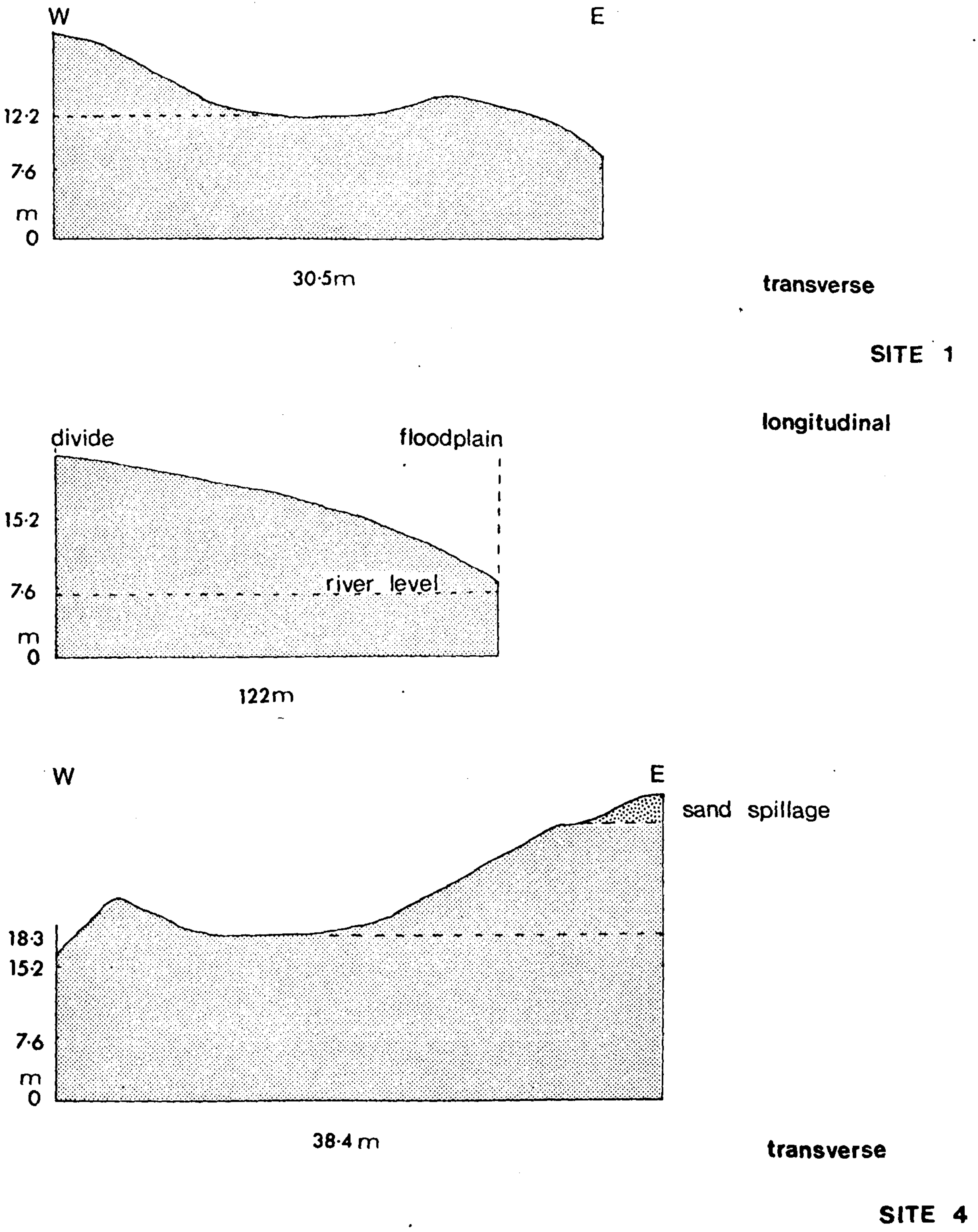
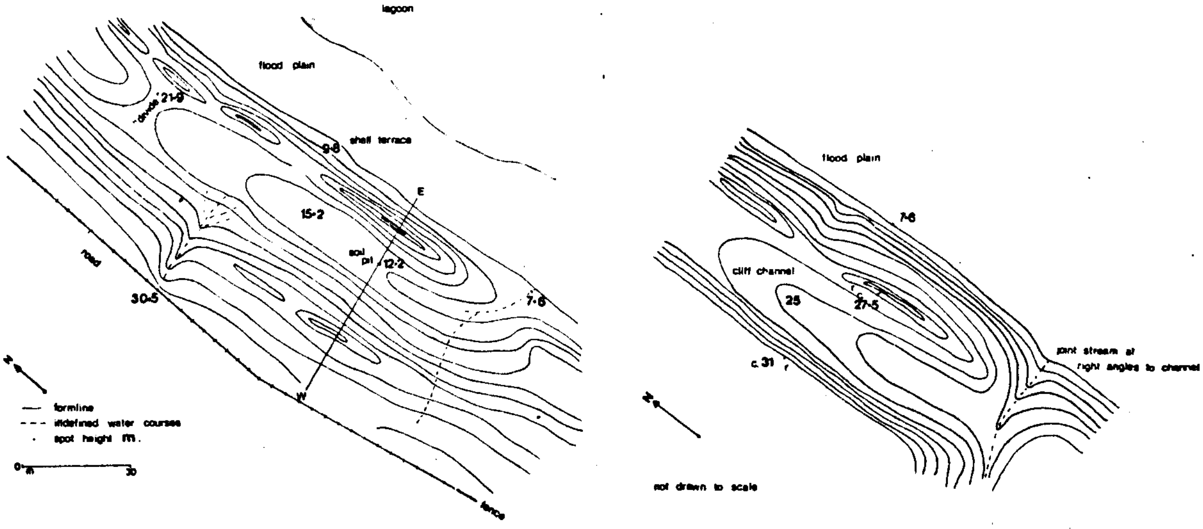


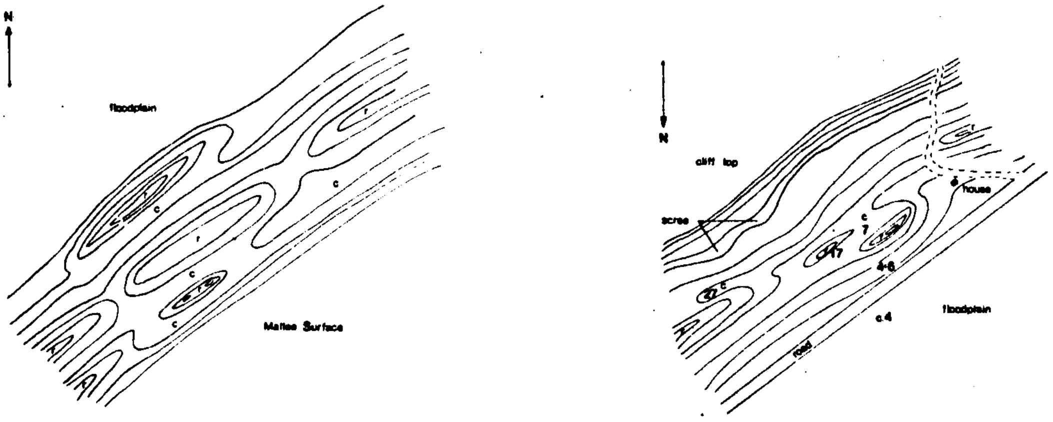
FIG. 2·59

FORM LINE SKETCHES OF CLIFF CHANNELS



SITE 1 5-14 m above flood plain

SITE 2 17·4m above floodplain



SITE 5 multiple cliff channel

SITE 6

Hypotheses relating to origin of cliff channels:

Cliff channels may result from slumping due to a rise in water table (Steel 1962). This would be at a time of increased pluviality, possibly during the Pleistocene, with expectedly a greater flow of subsurface water. A higher water table would be expected on the west of the valley-side slope with the higher intake from the Mt. Lofty Ranges, relative to the Murray Mallee. A variation in form and occurrence would be expected, but results from field work show little variation between the eastern and western valley sides. If slumping is suggested as the cause, slip-planes would have to be produced as evidence. None are found, but colluvial activity and subsequent modification may have concealed these. At site (1), (4), (5), and (6) the rock of the cliff channel edge closest to the floodplain appears to be *in situ,* so it is doubtful if slumping has occurred.

Chemical weathering or subsurface solution of the limestone may determine the cliff channel form. If water returning to the river is to dissolve the limestone along joints in the Mannum Formation, these forms would be likely to occur at right angles or normal to the main river channel (cf. Punyelroo Cave, Swan Reach) and not parallel to the valley-side slope. Also, a dominance of solutional landforms would be expected along the western side since this is the greater intake area for underground water (O'Driscoll 1960). The channels could represent the "solutional hollows," the cliff channel edges, or ridges, areas of local resistance in the limestone.

Cliff channels may represent fossil river channels. As mentioned above, the present day morphology of cliff channels is comparable to river channels and/or valleys. The cliff channels could represent former river channels, braids, subsurface braids, or diversions of an ancestral river. For braiding to have been responsible a change in the régime of the river would have been necessary, e.g. an increase in discharge, a change in grade, and/or a change in the calibre of the load.

A change in discharge could be related to the fluctuations of pluviality in the Pleistocene (Dury 1967a, Mabbutt 1971), in the source region of the Kosciusko Plateau. The localized distribution of these features lying downstream of the River Marne, the first sizeable tributary in South Australia, suggests that the increases in discharge may be related to the additional water supplied by these tributaries with increased pluviality within the Mt. Lofty Ranges.

Variations in load, related to capacity and competence of the river, can result in a change of channel form with a trend towards braiding, or numerous stream channels. This variation could result from the provenance of the tributaries, e.g. Kanmantoo schists and greywackes of metamorphic origin in contrast to the sedimentary limestones and sandstones. However, there is no supporting evidence for this in the form of water-borne deposits present in the cliff channels. On the other hand, a tafoni-like feature at site (1), well above the flood plain, may be taken as evidence for the existence of former river bedrock contact (see p. 27). It can be argued, however, that this tafoni-like feature represents an atypical form which has slumped to this position (see Fig. 2.57).

The discrepancy in size of the width of cliff channels when compared with present or recently abandoned channels within the floodplain today remains unexplained in terms of fossil river activity. Cliff channels are 30.5 m, 39.4 m and 220.7 m wide.

Meander Caves (Jennings 1970) may represent an initial form of a cliff channel. Jennings (1970) described these features formed at the base of river cliffs or bluffs in limestone as due to the undercutting processes of corrosion and corrasion (see Fig. 2.60). The cliff channels of the Murray valley could represent an extension of this landform.

The following is a suggested outline of cliff channel development (see Fig. 2.61).

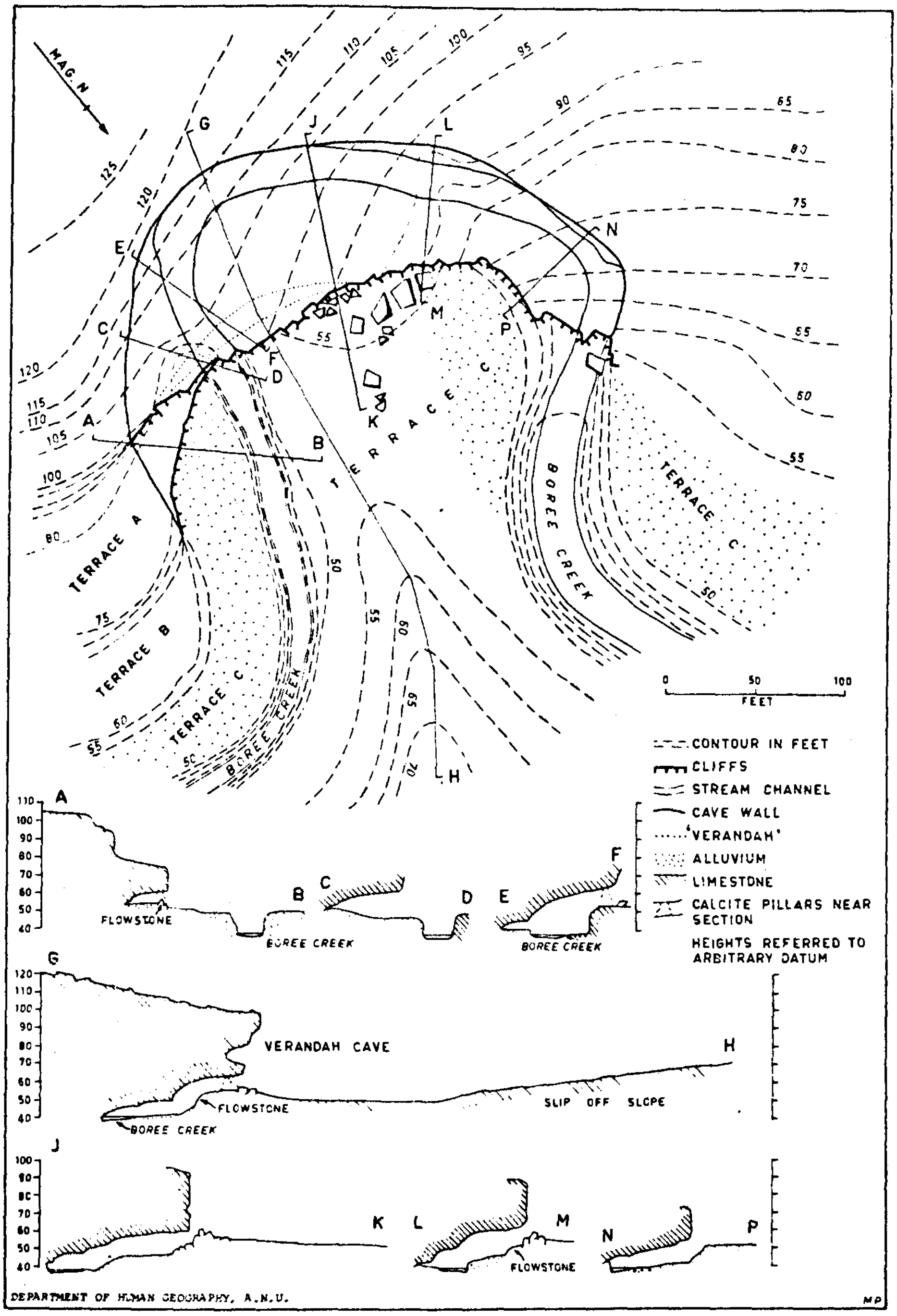
The meandering ancestral Murray River, moving in three directions, laterally, vertically, and downvalley, could have undercut the joint controlled valley-side slopes by corrosion and corrasion; corrosion by subsurface ground water flowing through highly permeable sandy Mannum Formation towards the river (see p. 3); corrasion by the hydraulic force of the water on the outside of the meander loop. The load contained in the river would contribute to the rate of attack on the slope. Thus a lateral cave may have been formed, at or near the river level. The most extensive development could occur if a joint in the bedrock intersected with a zone of oscillating water levels.

Initially the caves are probably flat floored with arching roofs produced by chemical weathering. Concurrently a verandah (Jennings 1970) could have been formed. Surface case hardening by carbonate (see p. 24) may have reinforced this unit.

Over development of the cave and lowering of local base level, river level, may lead to an undermining of the upper valley slope form and collapse of the verandah more or less vertically onto the eroded bedrock floor below, forming a primary ridge. However, the change in the river level position need not be so marked. Downvalley migration of the meander belt or a lateral shift away from the valley-side slope may produce the same effect. The number of changes of position of the river, valley-side slope contact with the river and the rate of shift could determine whether the valley-side slope will possess cliff channels of single or multiple form. The length of the individual features appears to be related to the jointing pattern, and the extent of water-layer contact with the limestone.

Fig. 2.60 Ingrown meander and meander cave, Boree Creek, near Borenore, New South Wales.

(after Jennings, 1970)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K
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M
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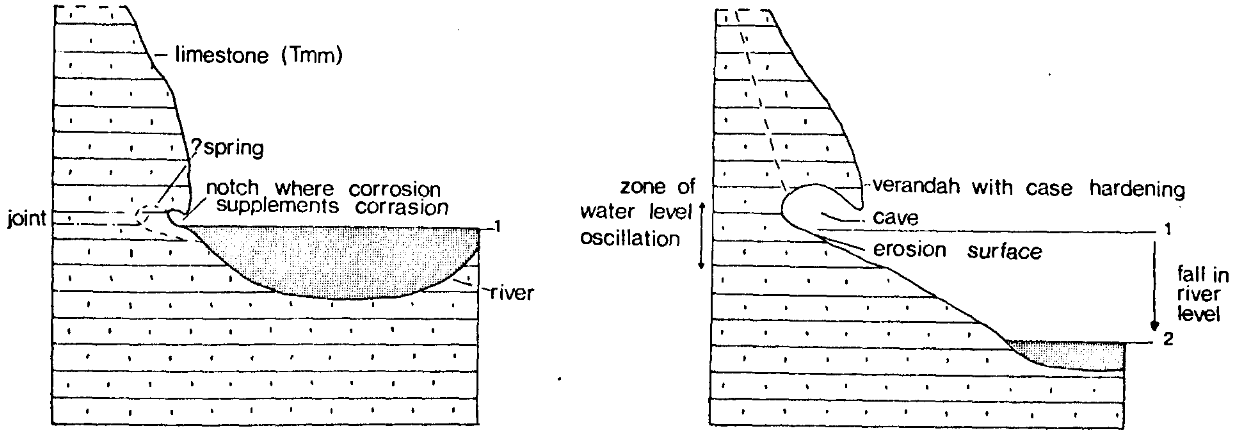
P
TERRACE A
TERRACE B
TERRACE C
BOREE CREEK
0 50 100
FEET
CONTOUR IN FEET
CLIFFS
STREAM CHANNEL
CAVE WALL
'VERANDAH'
ALLUVIUM
LIMESTONE
CALCITE PILLARS NEAR SECTION
HEIGHTS REFERRED TO ARBITRARY DATUM
FLOWSTONE
BOREE CREEK
VERANDAH CAVE
SLIP OFF SLOPE
DEPARTMENT OF HUMAN GEOGRAPHY, A.N.U.
MP

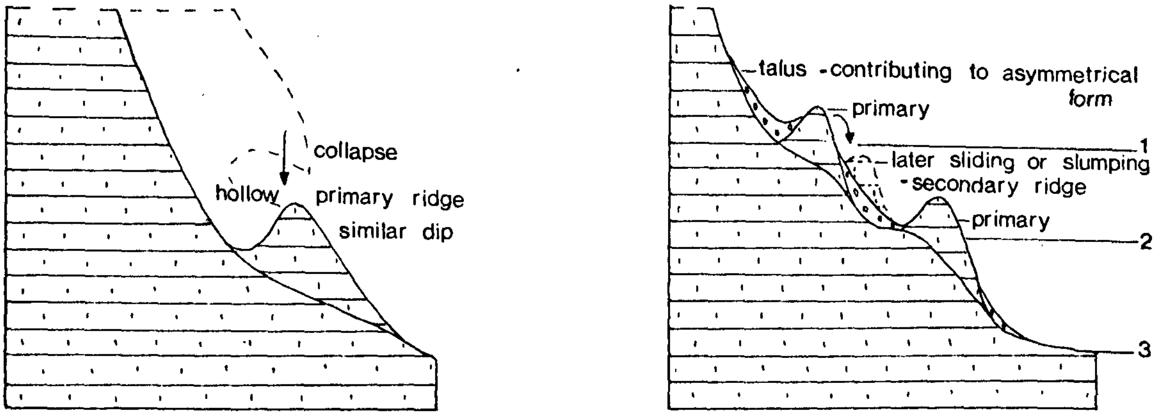
MEANDER CAVE TO CLIFF CHANNEL IN MIOCENE LIMESTONE

FIG. 2·61



I lateral percolation of water along joints may contribute to the water layer weathering

II cave development

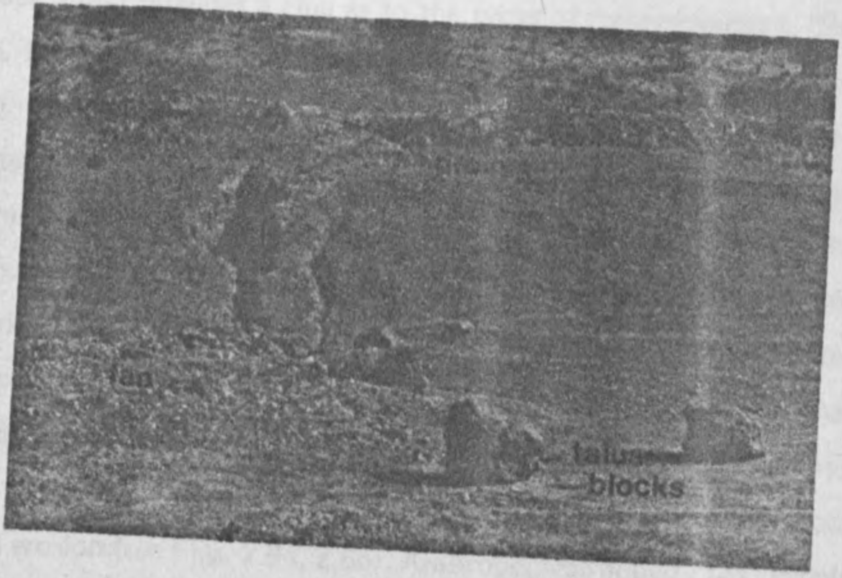


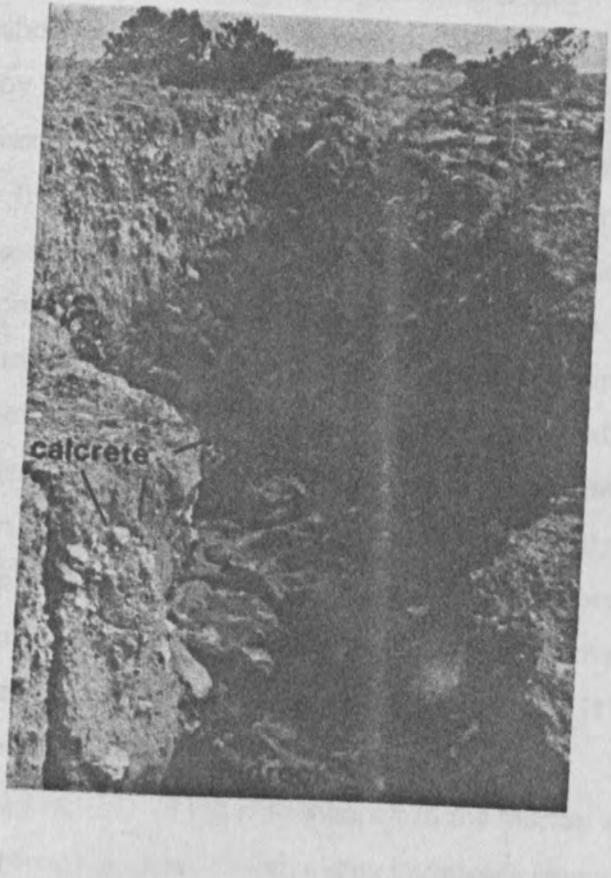
III collapsed meander cave - single cliff channel

IV multiple cliff channel

Fig. 2.62 A dissected slope of cliff channel (1). This has resulted from the construction of a drain under the road, seen at the top of the photograph. The boulders in the foreground, modifying the channel form have resulted from the construction of the road. An alluvial fan has been formed at the base of the gully.

Fig. 2.63 A close up view of the gully eroded into the channel slope. Colluvial material is exposed. Nodular calcrete forms a horizon 20 cm below the surface. Fossiliferous limestone, Mannum Formation,is seen on the floor of the gully.


fan
talus
blocks


calcrete

Once formed, much modification of this initial feature takes place. Secondary depositionary mounds may occur through a landsliding or even slumping action. The disposition of the bedrock strata provides a clue as to the types of mass-movement. Colluvial deposits are widespread. Exposure in a gully in the Mallee Surface side of the cliff channel due to the drain construction for the Mannum-Walkers Flat road shows that the cliff channel slope consists of colluvial material over limestone bedrock (see Fig. 2.62, 2.63). Unfortunately it is not possible to determine the shape of the bedrock profile. A distinct layer of relatively soft nodular calcrete lies 15.2 cm below the surface. This could be developed either *in situ* or represent colluvial material, or a combination of the two. At the end of the gully an extensive fan deposit with the expected gradation of material is built up at the base of the slope, the cliff channel floor. Other natural processes modifying cliff channels include sand spillage into the valley from the Mallee Surface, and flushing out of the fine silt material of the floor by rainwash and sheet flood erosion (see Figs. 2.64, 2.65). Anthropogenic activity has also played a role in infilling of the channel floor. For example aboriginal campsites (shell terraces or middens), exposed in soil pit form a thick sequence of sediments (see Figs. 2.65, 2.66). European man has initiated landslides by road construction (see above) and gullying, and further modified cliff channels by levelling for the erection of buildings.

The competence of the limestone, together with its special susceptibility to river attack through its solubility, registers the course of the development of an ingrown meander more patent than is commonly the case in other rocks (Jennings (1970). These "meander cave cliff channels," consisting of erosional and depositional components seem to fit the former problematical field evidence better than any of the prior hypotheses. Thus an explanation is provided for: the isolation or spatial distribution of these cliff channels around Mannum; their bedrock characteristics; the variable character of the landforms in terms of, their height above the flood plain, width and depth (dependent on length of time of formation); number, single or multiple; the obvious lack of fluvial deposits, exluding recent silts from flooding; the downvalley slope (the watershed, site (1), is a secondary ridge); the similarity of dip of the strata in the valley-side slope outcrop and the primary ridge; the tafoni site (1); and the rock shelters, e.g. at Fromm's Landing and Devon Downs (see p. 25).

It is suggested that the restricted location of the cliff channels in the Murray valley in South Australia may be related to the presence of well jointed, highly permeable Mannum Formation in the valley-side slopes, another contributing factor may be the meandering habit of the river in this winding valley, as distinct from the non-meandering habit in the rest of the fairly straight Miocene limestone valley.

However, before this meander cave hypothesis for the cliff channels can be accepted or

Fig. 2.64 Modification to the cliff channel form (4), by sand spillage.

Fig. 2.65 Aboriginal hearth stones recovered from soil pit, see Fig. 2.66, on the floor of cliff channel (1).

FIG. 2·66 THE SOIL PIT, CLIFF CHANNEL (1)

rejected a study must be made of the contact between the cliff channels and the valley side slopes. Such field work was impossible during the present research.

Cliff channels by virtue of their location in the valley-side slope must post-date Pliocene sedimentation and the widespread case hardening of the surface of the limestone cliffs by carbonate (see p. 24). A late Pleistocene age with fluctuating baselevels may be important but not vital in their formation. The recent tectonism (Mills 1964), may achieve the same baselevel fluctuations necessary in their formation. However, it could be argued that cliff channels are Recent phenomena due to the fluctuating baselevels of the river associated with climatic variations. Dating of older valley fill 6020 ± 150 years B.P. (Tindale 1947) and younger valley fill 4040 ± 100 years B.P. (Firman 1971a) places an upper limit on the age of these landforms. Corrobatory evidence could also be available if the aboriginal middens were to be dated. Thus the majority of cliff channels seem to have developed from meander caves, and their age on the evidence cited above is late Recent.

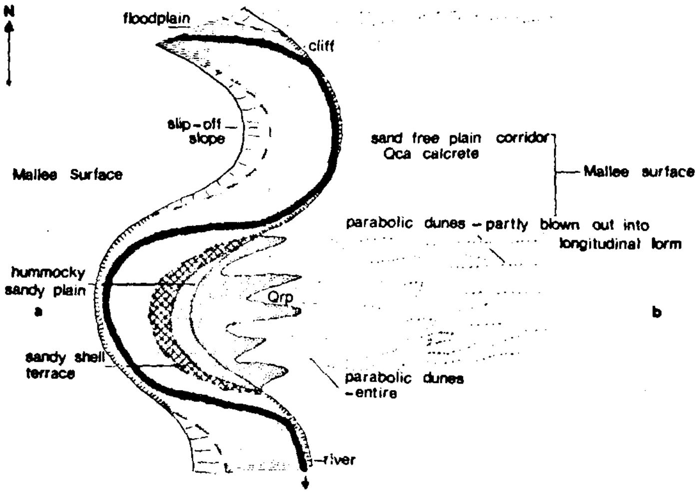
(8) Sand dune trails and cliff-top dunes

These are very common eastern valley-side slope forms between Morgan and Wellington, but they reach their greatest concentration between Morgan and Swan Reach (see Fig. 1.12). Sand dune trails represent merely a continuum of dunes in various stages of development and/or stabilization from a localized source region. Cliff-top dunes, on the other hand, have the same spatial characteristics but differ because they are detached from their sand source. To emphasize this difference the dunes bordering the Murray River in South Australia are classified by the writer as attached and detached dunes (see Fig. 2.67, 2.68).

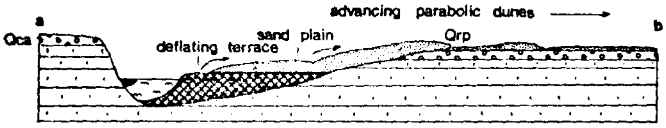
The map of sand dune orientation for the Murray Mallee and the Upper South East shows the location of the sand dune trails (see Fig. 1.12). The relationship between the river valley and these dune forms is clearly visible on this map, as well as on all topographic maps and aerial mosaics. The floodplain as a source of material for the sand dunes is of two kinds: one an older source now completely unattached to the dune field, and a younger in direct contact with mobile dunes. A vertical cliff up to 30.5 m high separates the former from the river, whilst the latter can be seen to be growing outwards from sandy pseudo terraces located on the floodplain (see p. 40). The northeast-southwest orientation of attached and detached dunes of Bunyip Sand differs from the more widespread east-west trending dune fields of Woorinen and Molineaux Sand of the Mallee and Upper South East (see Fig. 1.12). However, local blowouts of the east-west trending dunes do trend to the northeast under the present wind régime, and tend to complicate the original east-west dune orientation for example at Walkers Flat. This change in orientation can be inferred as a change in dominant wind direction, and can be used to illustrate an age difference in the dunes.

FIG. 2·67

RIVERINE – SOURCE BORDERING DUNES OF BUNYIP SAND, Qrp

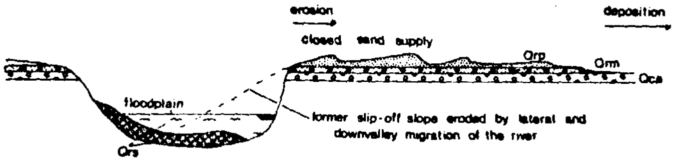


plan view showing aerial extent and spatial relationship of Mallee Surface and valley landforms

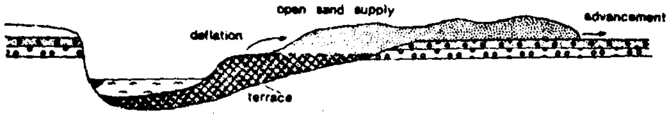


cross-section showing the relationship between dune, terrace, and river

FIG. 2·68



detached dune trail



attached dune trail

It is considered that the sand dune trails of Bunyip Sand, are quite distinct from the dunes of Molineaux Sand, varying not only in colour and composition, but in location, orientation and source of the material. Firman (1971b) considered these two units to be of the same age, but differing in mineralogy. He did not consider the possible source variation for the dunes. It is held that the parabolic and longitudinal dunes formed of Molineaux Sand are older because of their east-west orientation. They are secondary dunes, formed from the reworking of older sand accumulations of the Woorinen Formation. The Bunyip Sand, with a north-east trend to its parabolic and longitudinal dunes is younger than Molineaux Sand. River deposits are considered to be the source of the Bunyip Sand. Thus these sand dunes of Bunyip Sand are called riverine-source bordering dunes (Page 1971), and are classified as attached or detached dunes.

Detached dunes: The explanation of the location of detached on cliff-top dunes of Jennings (1967a), revolves around a problematic emplacement. The composite diagram of Jennings (1967a; Fig. 2.69), of possible explanations for coastal cliff-top dunes can equally well be applied to the Murray River situation. The high and low sea levels are analagous to high and low baselevels of erosion, or variations in discharge of the river. The isolation of the dunes could be the result of subsequent lateral and/or down-valley migration of the river. The material for the dunes, instead of resulting from coastal erosion and/or longshore drift can be seen as being derived from valley-side slope processes, the general load of the river which is deposited as point bar deposits, and older deposits such as valley fills and terraces. These have then been redistributed by deflationary processes. Borelog data from Swan Reach (Gibson 1958a), supports this suggestion (see Fig. 5.7).

Diagram (A) (see Fig. 2.69) is not applicable to the Murray River dune system. There is no evidence from the Murray Mallee of dominant easterly winds. In diagram (B) lateral migration of the river, or river meander belt, after a period of low flow, or no flow, could produce this situation. Diagram (C) seems a possible situation. High flow of the river could have removed much potential sand dune material. However it is diagram (D) which appears the most plausible explanation for the Murray River situation. River intrenchment produces the cliff form. Subsequently a period of low flow occurs in the large valley, accompanied by thick continuous deposition. A period of aeolian transport follows with an extensive trail of sand deposits blown inland from the floodplain. This sequence is then truncated by a fluvial period when a large and powerful river flows in the valley, and/or a rise in sea level results in removal of much of the riverine end of the trail. There is re-exposure of the cliff form, and isolation of the dunes on the cliff-top. The result is the formation of a detached dune system.

Attached dunes: The second type of dune is comparable to the riverine-source bordering dune described by Page (1971). These sand dunes closely border the lee side of their sediment supply (see Fig. 2.68, 2.70, 2.71). The sand dunes have a complicating effect on normal floodplain and terrace morphology according to Page (1971). However, in the valley of the Murray River, the floodplain surface is not obliterated by the dunes, since they are without exception located on the valley-side slopes. It would appear that they are a younger continuation of the detached dunes described above. Active deflation was recorded on many field trips during periods of strong south-westerly winds suggesting that they are still forming (see Figs. 2.72, 2.73, 2.74, 2.75).

The Coonambidgal Formation of very fine silts and silty clays is not a source for sand dune trail development. Luxuriant vegetation growth, especially of phragmites since the construction of the locks prevents deflation, and horizontal transfer of this material. Local overgrazing, for example at Roonka, has initiated some reworking of the flood plain sediments by wind action, but not on any significant scale. The geological sections (see Fig. 5.7) indicate that the older Monoman Formation has contributed material for this sand dune assemblage.

It is suggested that the term riverine-source bordering dunes should be applied to the dunes of Bunyip Sand, whose source is related to the fluvial depositional history of the Murray River. The dunes may in fact be a phase of an aeolian-fluvial cycle. For example, immediately downstream of Ramco Lagoon, Waikerie, sand formerly obtained from the weathering and erosion of valley-side slopes along the valley, is transported onto the Mallee Surface forming a sand dune assemblage. Given time and a sufficient source of sand these dunes will grow back into the valley as sand spillage and become a part of the sediment load once more.

4. CONCLUSION

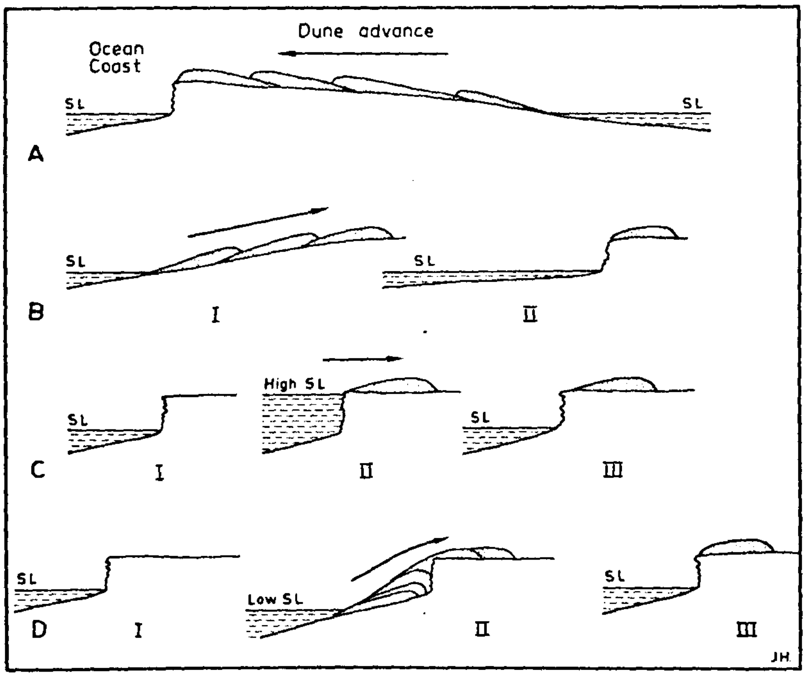
Endogenetic and exogenetic factors are the two major controlling influences on upper valley-side slope and morphology (Small 1970). Those applicable to the valley-side slopes of the Murray River in South Australia are:

(1) **Endogenetic**—rock hardness, composition, jointing, permeability, and seepage lines.

(2) **Exogenetic**—climate, vegetation, type and rate of weathering, type and rate of transport of altered and unaltered material, and the role of river incision and impingement at the foot of the slope.

The most commonly occurring slope classification is quadrizonal, with uniform to concave subunits. The slopes observed today are the result of the interaction of structure with fluvial, aeolian, and chemical weathering processes. Where the river is in direct contact with the slope, the fluvial processes override in importance all the other processes. However, where the river

Fig. 2.69 Different explanations of cliff-top dunes (after Jennings, 1970)



A: Advance from an embayment or lagoon shore onto the outer coast.

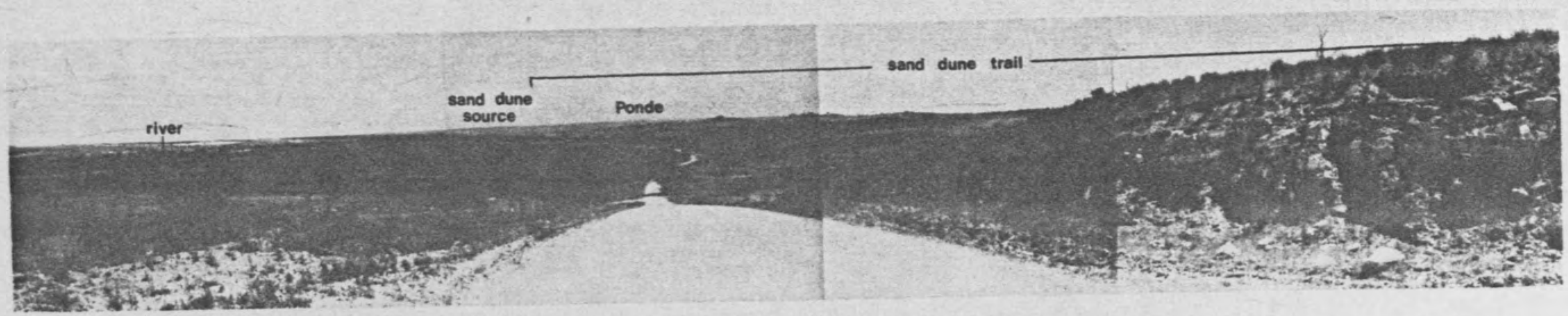
B I: Advance of dunes up gentle slope in bedrock.
B II: Coastal recession to give cliffs with dunes on top.

C I: Cliffed coast.
C II: Rise of sea-level to cliff-top and emplacement of dunes.
C III: Sea-level fall isolating cliff-top dunes.

D I: Cliffed coast.
D II: Fall of sea level exposing narrow coastal plain on which dunes accumulate and overtop cliff.
D III: Rise of sea level and coastal recession returning shore to old cliffline and isolating cliff-top dunes.

Fig. 2.70 Sand dune trail of Bunyip Sand at Ponde

Fig. 2.71 Sand dune trail Wellington East. Sandy shell pseudo terrace in the foreground is the present source for the sand dune formation.


sand dune trail
sand dune
source
Ponde
river

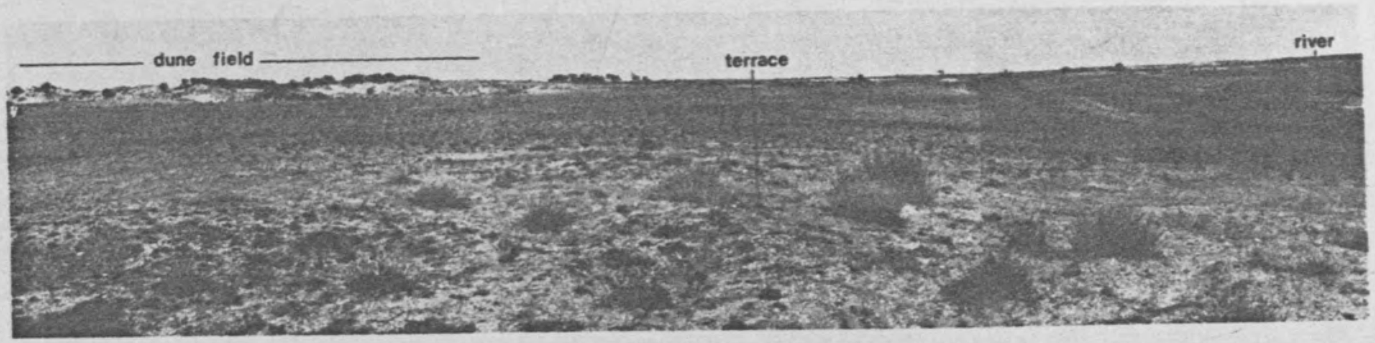
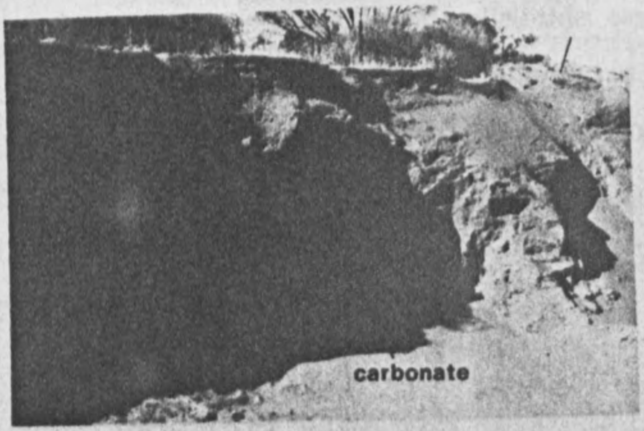

dune field
terrace
river

Fig. 2.72 Bunyip Sand, eastern valley-side slope Blanchetown.

Fig. 2.73 Recent encroachment of a sand dune of Bunyip Sand on a ruin at Wellington East. The sand from a sandy shell pseudo terrace has built up into a dune 3.7 m high since European occupation of the terrace.

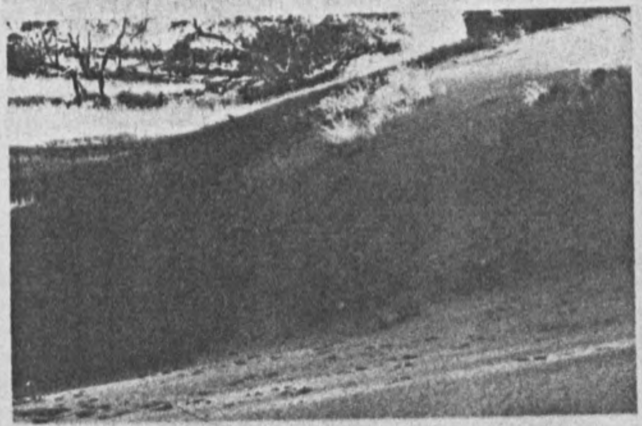
Fig. 2 74 The mobility of Bunyip Sand is illustrated at Murbko. The sand is encroaching on land cleared for agriculture.

Fig. 2.75 Sand spillage into the valley-side slope opposite Bowhill. This is Bunyip Sand which originated from a sandy shell pseudo terrace, and is being recycled into the valley to become part of the load of the river once more.



1

2



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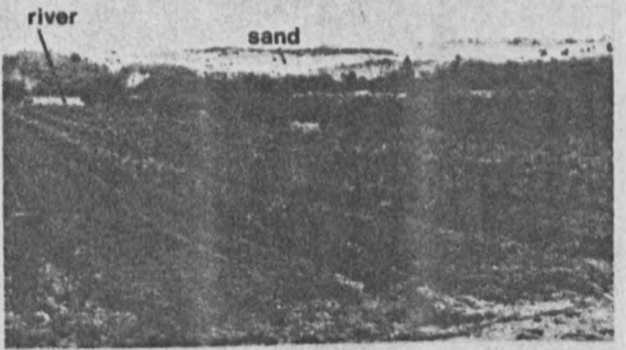


4

does not exert a direct influence on the entire slope, or on individual zones, the character of the slope is determined by those non-fluvial exogenetic, and endogenetic processes. The dominance of any one of these leads to an atypical slope profile form. Unquestionably the valley-side slopes of the Murray valley are secondary slopes. On both a macro and micro scale this study of the Murray valley illustrates the complex and multivariate character of valley-side slopes.

Thus a description of sample valley-side slopes and processes active on the slopes has been presented. These lower valley-side slopes adjacent to the floodplain and consisting of depositional material will be discussed in the next chapter. The contents of both these chapters will be used to support the hypothesis presented for the evolution of the river in Chapter V.

CHAPTER III

THE TERRACE AND FLOODPLAIN DEPOSITS

1. INTRODUCTION

It was established in Chapter 11 that the valley-side slopes of the Murray valley are secondary slopes resulting from processes which have modified the original, or primary slopes developed through the incision by the river into the Mallee Surface. Those lower valley-side slopes which do not exhibit a cliff form are also secondary slopes. Here the slopes are masked by depositional layers. These depositional layers form the content of this chapter.

(1) Definitions

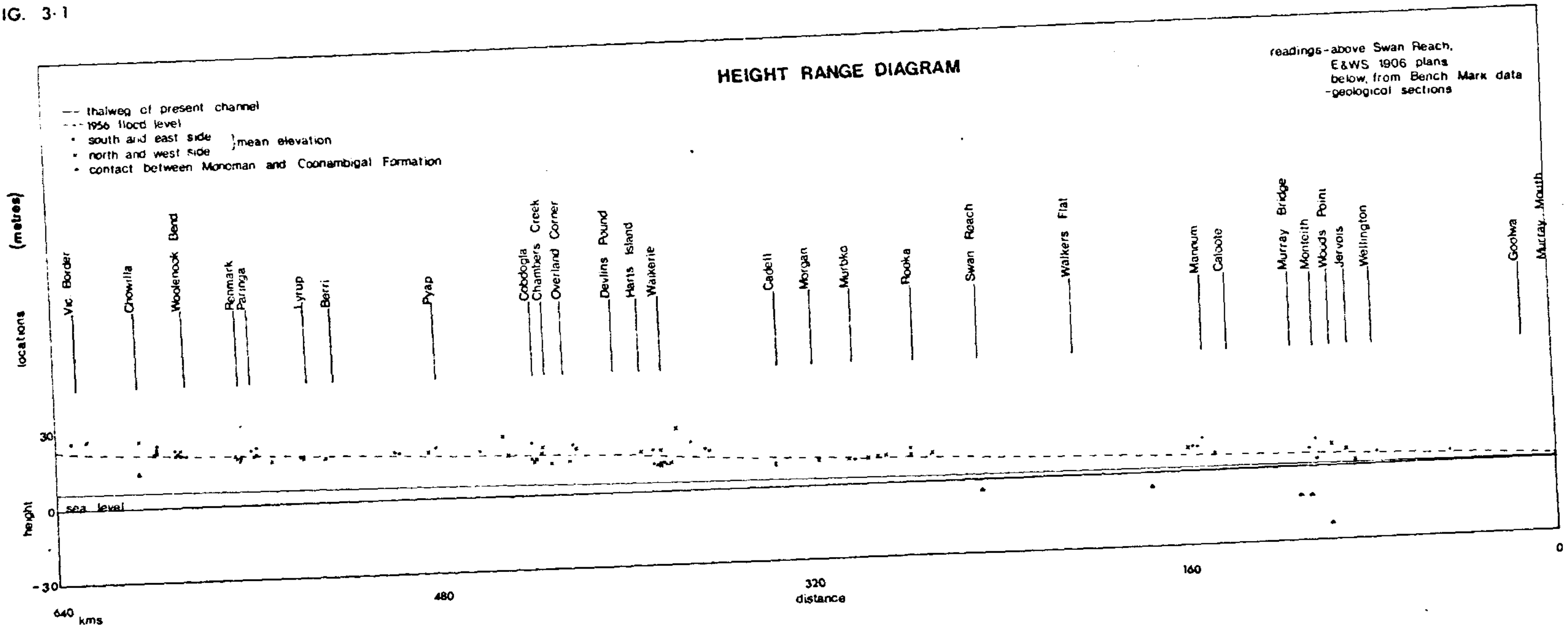
A floodplain is a fluvial depositional unit, which can be defined in both topographic and hydrologic terms. Topographically, it is a generally flat landform and lies astride the river channel. When viewed in detail its morphology is variable, ranging from narrow channels, a **dissected floodplain**, to extensive flat surfaces at or near normal flow of the river, **low undissected floodplain**, and flat to gently sloping surfaces above normal flood, but within contact of high flood, **high undissected floodplain.** Although the floodplain consists of these diverse topographic forms, it is composed of unconsolidated depositional material derived from the load of the river. Hydrologically, it is defined as a landform subject to periodic flooding by the parent stream or river.

The determination of floodplain extent is problematical. The frequency of inundation has been used to delimit the floodplain. Schmudde (1968) concluded that a flooding recurrence interval of one in ten years was most suitable for the indentification of the floodplain. The graph of stream gauging information for 1901–1968 (see Fig. 4.1) shows the maximum flows, and floods of the Murray River. It is felt that Schmudde's flooding recurrence interval is not a suitable criterion for delimitation of the floodplain of the Murray River. The antiquity of the river system compared with the limited data available, and the interference by man to the normal flow make such a statistical determination of the floodplain extent invalid. Aware of the possible inaccuracy, the 1956 floodlevel, the highest in recorded time, is taken as the level which determines whether a landform surface of fluvial origin within the Murray valley is a component of the present floodplain, or a separate geomorphic unit, such as a terace, (see Fig. 3.1)

A **terrace** is simply an abandoned floodplain, that is a floodplain which is no longer in contact with the present river rēgime, even time of flood. It is a gently sloping to planate landform produced by fluvial erosional, or fluvial depositional processes. Terraces fall into two groups classified according to the thickness of the deposition on the floodplain prior to terrace formation. A terrace possesing a very thin veneer of deposits over bedrock is referred to as an

Fig. 3.1 Height Range Diagram of selected sites within the Murray valley in South Australia. The mean elevations of depositional landforms of both sides of the channel are plotted against distance from the Murray Mouth, and the thalweg, or channel floor is compared with the 1956 flood level. The position of the landforms relative to the level of flooding indicate those landforms within the valley lying above and below possible flooding. Those above could be interpreted as terraces, those below as part of the landform assemblage of the floodplain.

FIG. 3·1


HEIGHT RANGE DIAGRAM
readings-above Swan Reach, E&WS 1906 plans
below, from Bench Mark data -geological sections
— thalweg of present channel
- - - 1956 flood level
• south and east side }mean elevation
• north and west side
• contact between Monoman and Coonambigal Formation
locations
(metres)
height
30
0
-30
sea level
Vic Border
Chowilla
Woolenook Bend
Renmark
Paringa
Lyrup
Berri
Pyap
Cobdogla
Chambers Creek
Overland Corner
Devlins Pound
Harts Island
Waikerie
Cadell
Morgan
Murbko
Rooka
Swan Reach
Walkers Flat
Mannum
Caloote
Murray Bridge
Monteith
Woods Point
Jervois
Wellington
Goolwa
Murray Mouth
640 kms
480
320
distance
160
0

erosional, destructional or strath terrace, and is produced by lateral or downvalley migration of the river. Alternatively, a terrace with a thick sequence of floodplain deposits abandoned by the river is a depositional or constructional terrace. Within the Murray valley both types of terrace can be identified.

Mapping of geomorphic units of the Murray valley reveals landforms which have the apparent morphology of terraces and are located within the valley but above the 1956 flood level contact. However, analysis of these landforms shows that their genesis is due to aeolian and anthropogenically induced processes and not to fluvial prosses which are responsible for terrace formation. For purposes of mapping these landforms are described as pseudo terraces.

(2) Method of study

The morphology of terrace and floodplain deposits within the valley was examined initially on aerial photographs. This was followed by mapping in the field on aerial photographs, and topographic maps of the Lands Department, 1:31,680 which were enlarged to the scale 1:10,000. Originally, morphological delimitation was based on positive and negative breaks of slope, but confirmation by examination of the deposits by augering or observation of available exposures was often necessary. Geological cross-sections and C.S.I.R.O. soil maps were used as additional sources of information. The data was plotted on the geomorphological maps, but modification was necessary after an analysis of flood level data of the 1956–1957 Lands Department Annual Report delimited the zone of contact of the present river régime with its floodplain landform assemblage and those depositioned landforms within the valley but above the 1956 flood level (see Fig. 3.1). Elevations of all landforms were available from the 1906 series of maps of the E.&W.S. Department, published for the proposed construction of weirs and locks on the Murray River form the Victorian Border to Swan Reach. Data downstream was collected using an aneroid barometer and the Lands Department Bench Marks.

Fig. A–H shows the distribution of terraces, pseudo terraces and floodplain of the Murray valley in South Australia. Each of these depositional geomorphic units within the valley is defined and described in terms of composition, elevation, distribution and possible genesis.

2. DISCUSSION OF SAMPLE TERRACES PSEUDO TERRACES AND FLOODPLAIN SURFACES

(1) TERRACES

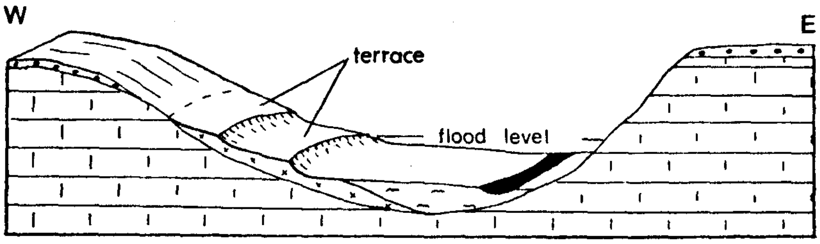
(i) *Fluvial depositional terraces*

(a) *Amphitheatre Terraces – Chowilla* (see Fig. 3.2)

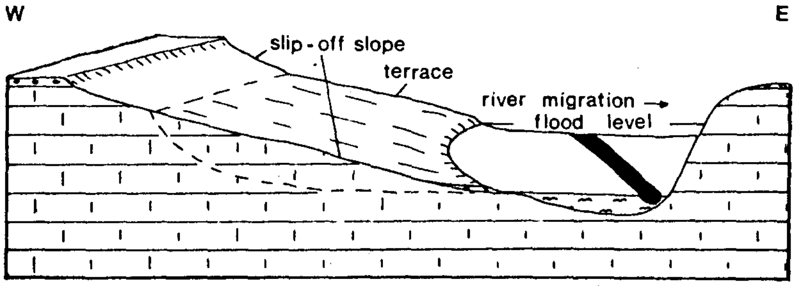
There is a concentration of extensive terraces around Chowilla, especially along the western side of the valley (see Fig. A). They are calcified to a variable extent, 1.2 m–4.0 m below a sandy surface (Johnson, Hiern and Steel 1960), and consist of fine grained sandy clay, covered

FIG. 3·2

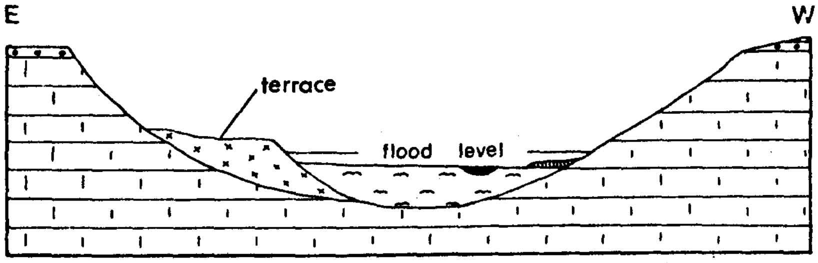
TERRACES



alluvial terrace – amphitheatre Chowilla



alluvial terrace – rock defended Woods Point



alluvial terrace – fill-top Wellington East with aeolian sands up to 14 m thick in places (Firman 1971a). From a study of the elevations of the valley floor, it would seem that the isolation, or abandonment of this former flood plain, has been achieved by the south and east migration of an incising river.

Long narrow terraces hug the valley-side slopes of the eastern bank, and the inside of the valley curves. At Murtho Homestead the river is actively undercutting and rapidly reducing the surface of a red terrace (see Fig. 3.3, 3.4). Further downstream on the south and east valley-side, isolated narrow terraces exist. It is suggested that these are also amphitheatre terraces which have fortuitously escaped erosion by lateral and/or downvalley migration of the incising river.

(b) *Rock defended terrace — Woods Point* (see Fig. 3.2)

The terrace at Woods Point, 10.4 m a.s.l., and sloping 3½° to the river, consists of red calcareous clay of alluvial origin (see Fig. 3.5, 3.7). This isolated terrace has been preserved because of the protective effect of a partially buried bedrock spur, or elongated slip-off slope (see Fig. 2.24), and is hence designated a rock defended terrace. The spur would tend to deflect the incising stream from the western part of the valley, and protect the alluvial fill immediately upstream.

(c) *Fill-top terrace — Wellington East* (see Fig. 3.2)

This well developed terrace (see Fig. I), is 4.9 m a.s.l. and 3 m above the floodplain and therefore lies above the limits of flooding. The terrace possesses a thick sequence of alluvial clays and sandy clays (see Fig. 3.6). The upper layer consists of 20 cm of grey cracking clays, overlying a thick white marl accumulation. The carbonate, containing shells (*Mollusca dennatia*) 1 cm in length consists of 7.6 cm—10.2 cm blocks overlying a 2.5 cm—5.1 cm peat accumulation. Below is a sequence of yellow-grey sandy clay. The uppermost layers of the terrace could represent lagoonal deposits formed during and immediately after the abandonment of this part of the floodplain. There is a well defined step or slope to the present floodplain below. It would be interesting to see whether this apparently unique terrace in the Murray valley has any equivalents in the valleys of the other tributaries around Lakes Albert and Alexandrina. Soil associations of this area have been mapped by de Mooy (1959).

(ii) *Fluvial erosional terraces*

(a) *Strath terraces — Jervois North* (see Fig. 3.8)

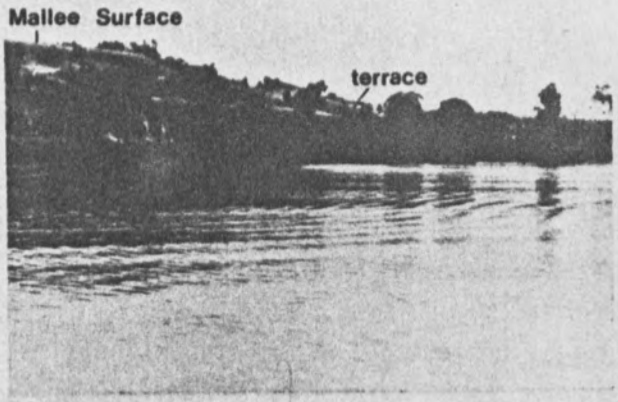
These terraces occur extensively between Woods Point and Jervois. They consist of 45.7 cm of orange quartz sand, and about 22.9 cm of darker sandy material. This may represent an incipient soil profile (see Figs. 3.9, 3.10, 3.11), developed over bedrock, which consists of Pliocene sands and clays. The terrace forms a general slope continuation, from the Mallee

Fig. 3.3 Red alluvial terraces, south of Woolenook Bend. These are narrow amphitheatre terraces.

Fig. 3.4 Red amphitheatre terrace, south of Murtho Homestead. The river terrace has been eroded into by the river swinging towards the eastern valley-side slope. A 7.6 m cliff has been cut into the terrace.

Fig. 3.5 Looking northwards along the alluvial terrace at Wood's Point. The terrace slopes about 3½° to the floodplain.

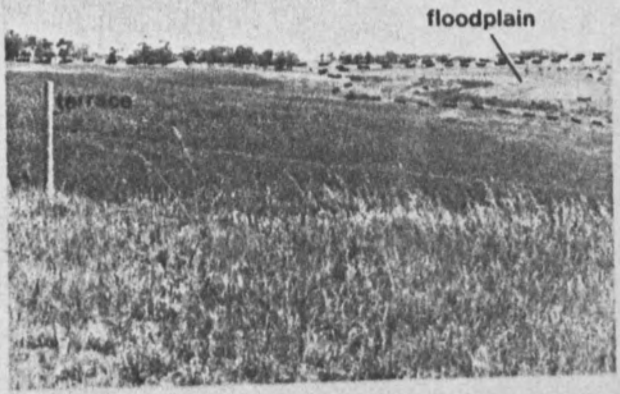
Fig. 3.6 Fill-top terrace Wellington East. The surface consists of grey silty clay, which is subject to gilgai cracking. Beneath is a thick layer of marl containing fresh water shells. Immediately below is a continuous layer of peat material lying on top of grey-grey brown clay.


Mallee Surface
terrace

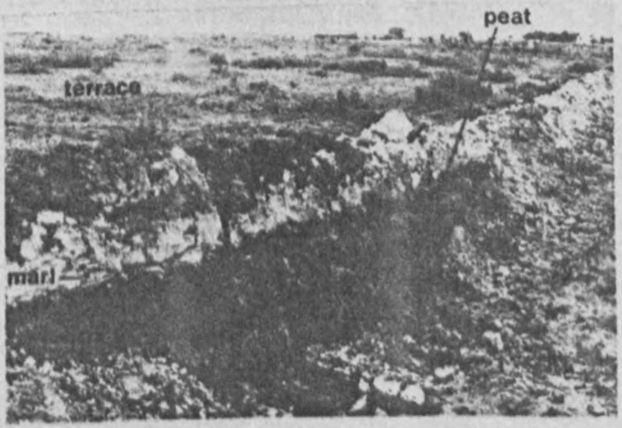
1


terrace
floodplain

2


floodplain
terrace

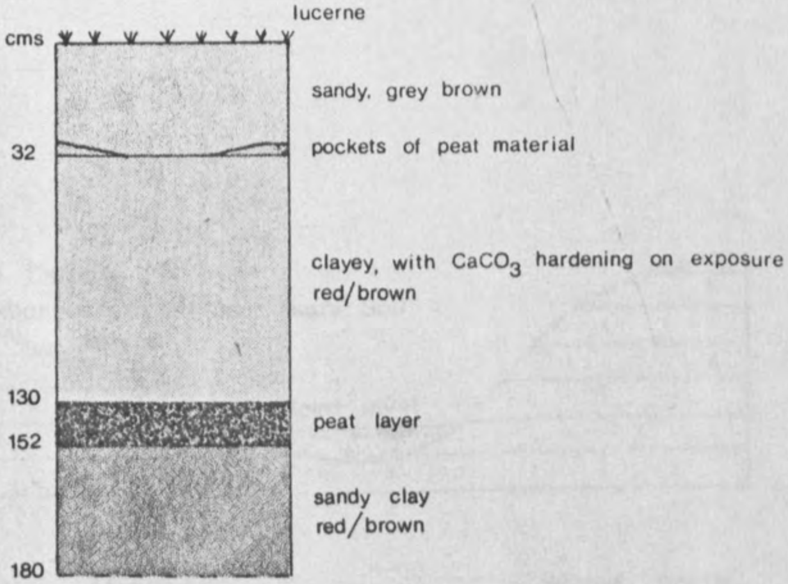
3


peat
terrace
marl

4

Fig. 3.7 Soil profile, and photograph of the red alluvial clay terrace with carbonate, at Wood's Point.

WOODS POINT



terrace soil

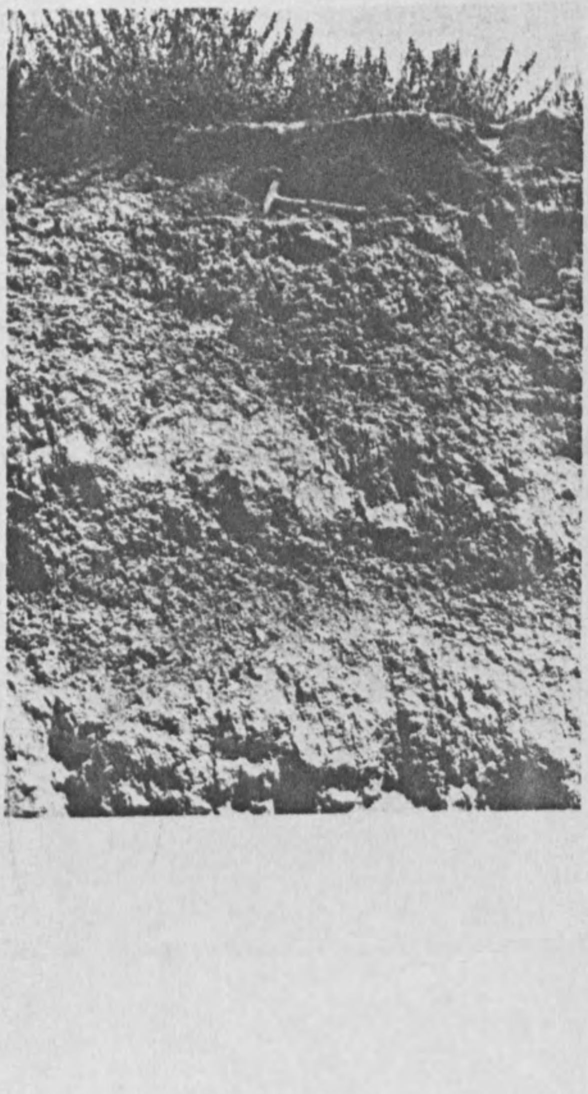
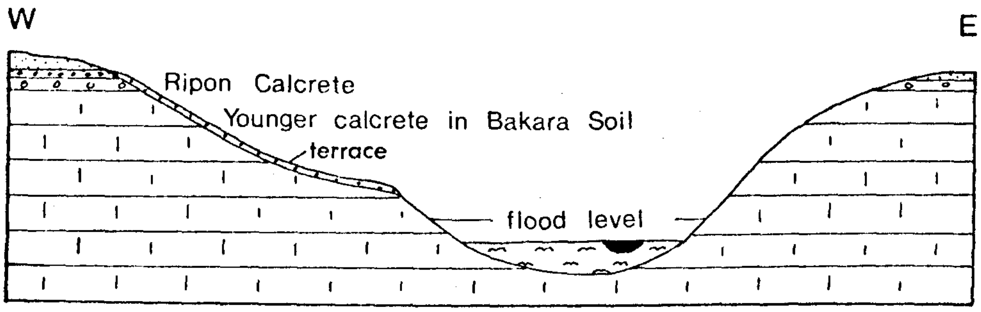
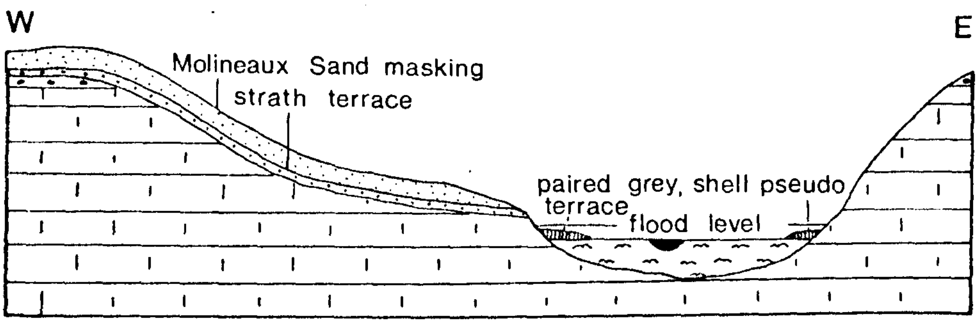


FIG. 3·8



erosional terrace – strath Jervois north

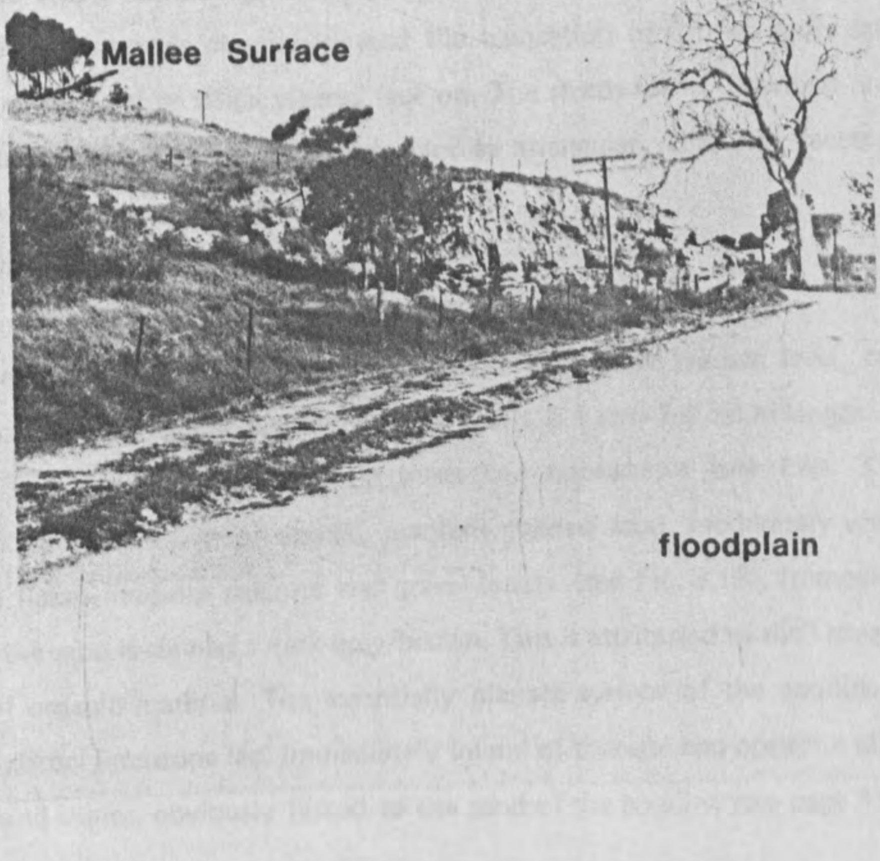


erosional terrace – buried strath Jervois south

Fig. 3.9 Strath terrace north of Jervois. A thin sandy deposit masks the bedrock surface. The soft Pliocene sandy limestone displays cavernous weathering.

Fig. 3.10 Strath terrace or erosional bench between Rabila and Murray Bridge.


calcrete
sand
bedrock


Mallee Surface
floodplain

Surface to the floodplain, and usually terminates as a spur-like form, sometimes entire, sometimes truncated to produce a low cliff form of variable height on the edge of the floodplain edge. The terrace surface is about 7.6 m a.s.l., or 4.6 m–6.1 m above the present floodplain, and beyond the limits of flooding. It consists of nodular calcrete cemented together, to form a minor caprock layer, but not of the massive proportions of the Ripon Calcrete of the Mallee Surface.

These strath terraces are very much man modified, and are extensively sown with lucern, and used as sites for farm dwellings and dairy sheds.

(b) *Buried strath terraces –Jervois South* (see Fig. 3.3)

These bedrock terraces are a variant of the above, consisting essentially of the same bedrock base, but obliterated by aeolian deposition. The sand is spilling into the valley from the sand dune formations on the Mallee Surface above. The sample terrace (see Fig. 3.12) exposed because of quarrying for sand, possesses a 0.9 m thick sequence of aboriginal occupancy debris consisting of thick shell and hearth stone accumulations. It is interesting to note that here and elsewhere, the aboriginal layer of sediments is covered with sand drift, and forms a fossil or relict horizon. Only where severe deflation has occurred do the aboriginal deposits outcrop on the surface.

(c) *Triangular valley-side facets – Monteith North and South*

These are also a variant on the strath terraces, differing only in their spatial form. They occur at regular intervals downvalley and the truncation of former spurs creates triangular shaped minor cliff forms when viewed face on. The strath forms described previously have a more continuous downvalley expression. Not all triangular valley-side facets are thought to have formed in this way (see page 17).

(2) PSEUDO TERRACES

(i) *Aeolian Pseudo Terraces* (see Fig. 3.13)

(a) *Orange sandy/shell pseudo terraces – Mannum east: a coquina*

This shell bank, 9.1 m above the floodplain, 15.2 m above sea level, consists of large fragments of thin and brittle white-grey *Unio* shells, 5.1 cm–7.6 cm in length, 1.3 cm–2.5 cm in width. The shells display a partially stacked appearance (see Figs. 3.14, 1.15). The "formation" overlies 4.6 m of orange, medium grained sand, moderately uniform, but with some mica flakes, nodular calcrete and gravel lenses. (see Fig. 3.16). Immediately below the shell layer the sand is stained a dark grey/brown. This is attributed to shell breakdown, and the presence of organic material. The essentially planate surface of the coquina is strewn with angular, bryozoal limestone lag. Immediately inland of this site and opposite Mypolonga Flat is a trail of sand dunes, obviously linked to the sand of the coquina (see page 41 and Fig. 3.17).

Fig. 3.11 Strath terrace north of Jervois, showing lateral extent and the surface sloping to the floodplain.

Fig. 3.12 A buried strath terrace south of Jervois. Molineaux Sand has spilled into the valley from the western Mallee Surface. The sand is up to 1 m deep at this exposure. Aboriginal hearth stones and *Unio* shell fragments can be found in the lower layers.


terrace


terrace
floodplain
cliff

The genesis of the coquina, a regularly packed almost entire shell bank, with sand at its base, is problematical. The larger pebbles and calcrete nodules could have been brought to the site by strong undercurrents. Later quieter currents could have deposited the sand and shells (Gostin pers. comm.). The actual depositional environment is so variable, ranging from backwaters and billabongs to gentle floods, that exact conditions cannot be stated from a study of the sediments alone. The concentration of shells may be the result of aboriginal occupation. Aboriginal man could have introduced the shells into his campsite, and subsequent deflation resulted in the shell compaction. The numerous hearth stones on the surface today could have been concentrated in the same way – a type of gibber lag formation. It is conceivable that deflation of the sands could be self-limiting, with a maximum shell and lag accumulation forming a pseudo caprock effect.

(b) *Grey sandy/shell pseudo terraces – Mannum northeast*

One kilometre north and east of Mannum the much fragmented shells "outcrop," 0.6 m below a sandy layer displaying cross-bedding. A similar layer, but slightly more clayey is present beneath the shell layer. Leaching leading to a type of podsol A horizon has probably occurred (see Fig. 3.18). A kilometre further upstream, some of the *Unio* shells possess a $CaCo_3$ coating, with obvious precipitation taking palce at the moment. A fully developed coquina, that is a shell terrace cemented by $CaCO_3$, may result in time.

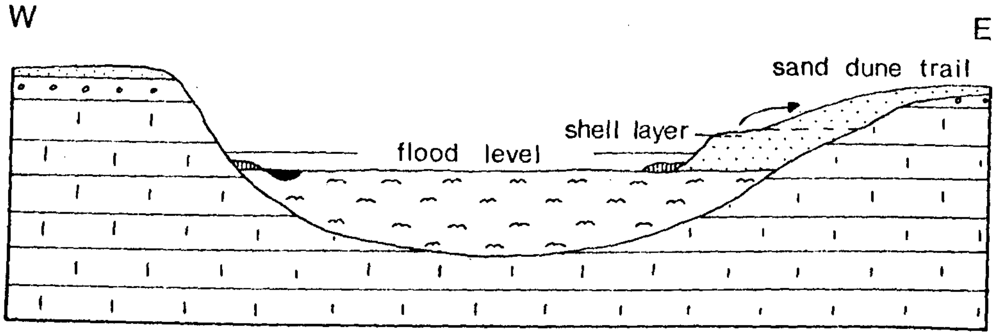
Immediately south of the granite quarry, north and east of Mannum, a road cutting exposes a shell terrace. This has a sand base, overlying a nodular calcrete surface, itself developed on sand. It is not possible to determine accurately whether the sand was deposited by fluvial or aeolian deposition. The shell deposit built subsequently produces an inversion of relief, contribution to a 0.6 m–0.9 m rise in elevation of the original landform (see Fig. 3.19).

From the field evidence around Mannum it appears that these surfaces within the valley have resulted from aeolian reworking of sands brought into the region by the river, or blown into the valley from the western Mallee Surface. Subsequently, they have been both man and wind modified. Their relationship to the river is, therefore, indirect and the landforms cannot be described as terraces *per se.*

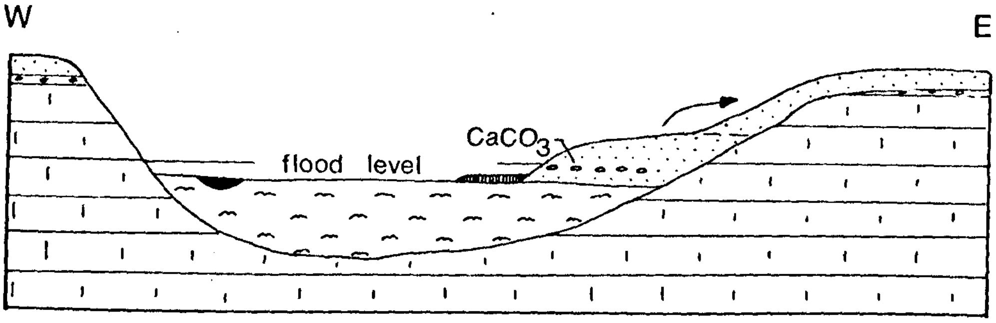
(c) *Sandy/$CaCO_3$ pseudo terraces – Mont~~h~~eith* (see Fig. 3.13)

These light orange sandy quartz landforms with no signs of river borne pebbles, but with scattered shell fragments on the surface, attain a height of 12.2 m a.s.l., and are located immediately upstream from Monteith, on the eastern side of the river. Three horizons are clearly visible, a leached upper layer 15.2 cm in depth, a darker band 1.5 m of cross-bedded brown sand, with a scattering of shells, hearth stones and charcoal fragments, and lastly a deep

FIG. 3·13



aeolian pseudo - terrace (orange, sandy, shell) Mannum east



aeolian pseudo - terrace (sandy $CaCO_3$) Monteith

Fig. 3.14 *Unio* shells, some entire, but most are fragmented. A large limestone hearth stone lies on top of a shell horizon.

Fig. 3.15 The coquina, or shell capping. The shells are interlocked in two horizons. They become more fragmented down through the sand horizons below.

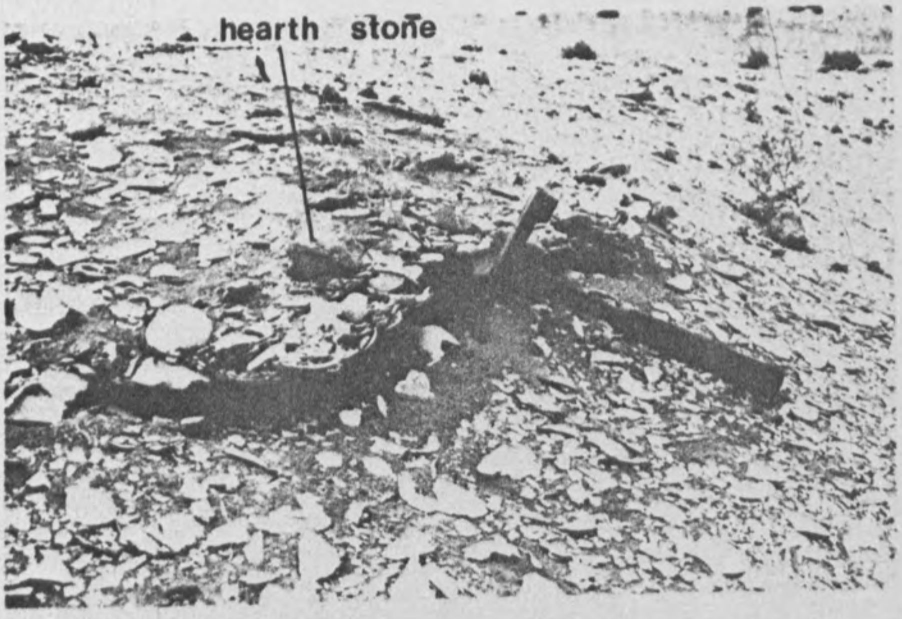

hearth stone

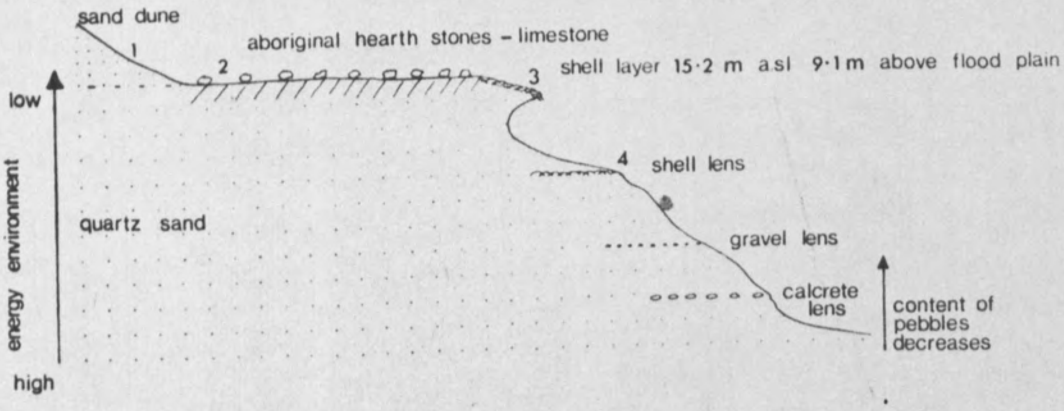
Fig. 3.16 Sandy shell pseudo terrace due east of Mannum. The landform sequence is floodplain, shell pseudo terrace, deflated shell pseudo terrace, sandy plain, and parabolic dunes. This is a sand dune trail (see p. 33)

a) section

b) photograph

a) COQUINA

Mannum east



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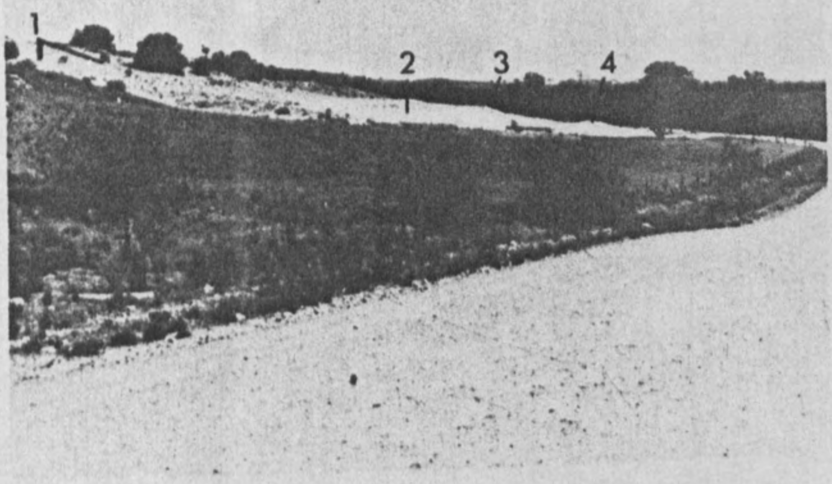


Fig. 3.17 The source of a sand dune trail, opposite Mypolonga Flat. The sandy shell pseudo terrace is being actively deflated. Cross-bedded micro yardang forms can be seen in the middle distance. The gibber-like surface consists of aboriginal hearth stones. The *Unio* shells are generally fragmented.

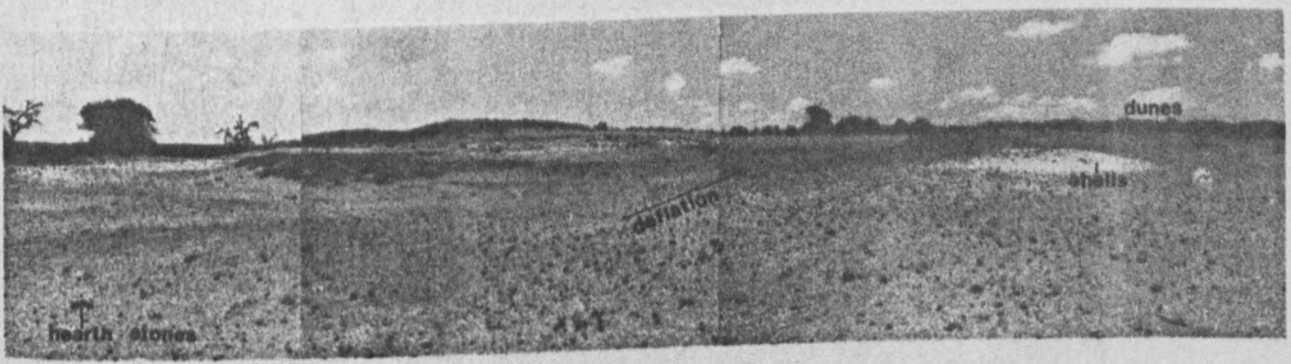
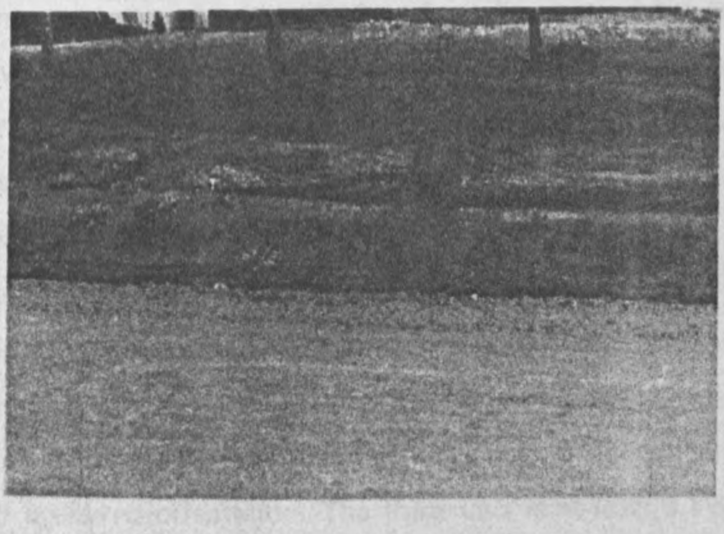
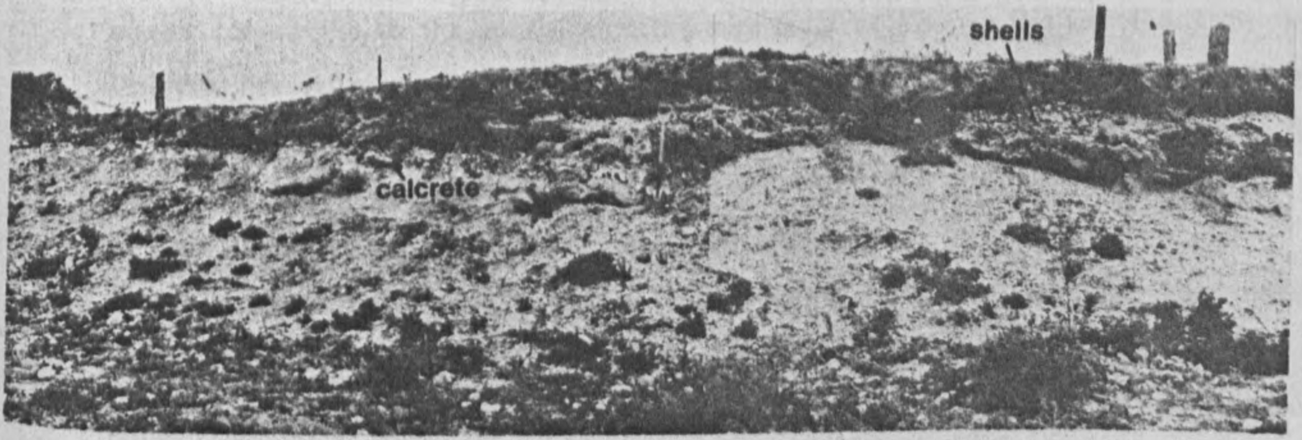

dunes
shells
deflation
hearth stones

Fig. 3.18 Grey sandy shell pseudo terrace, northeast of Mannum. A prominent layer of shells and coarse aboriginal hearth stones occurs in the centre of the cross-bedded sand deposit.

Fig. 3.19 Shell pseudo terrace, 4.8 km upstream from Mannum. The shell and aboriginal hearth stone layer has infilled a former depression in a rubbly calcrete surface, resulting in relief inversion.




shells
calcrete

sandy horizon containing a pale carbonate accumulation, outcropping about 4.6 m below the surface. The calcium carbonate is hardening on exposure to the atmosphere, into 20.3 cm rectangular blocks. This landform has the morphology and elevation of a terrace, but on closer inspection seems to be made up entirely of aeolian material (see Figs. 3.20, 21). The stratifications within the deposit are the result of aboriginal occupance and soil water movements. At the base of the formation, i.e. at the contact with the floodplain, is a grey clay, shelly alluvial terrace, about 1.5 m above the present floodplain.

(d) *Sandy pseudo terrace--Murray Bridge north: western bank*

This is yet another valley aeolian deposit possessing apparent stratification (see Fig. 3.22). The landform is composed entirely of well sorted sands in each layer. River borne pebbles are absent throughout. The upper horizon consists of pale orange sand lying unconformably on top of darker brown sands with obvious evidence of aboriginal occupation. The angular hearth stones show no preferred orientation. The third unit is at least 6.1 m deep, and consists of orange quartz sand. Complicating the site, however, is a thick stratified layer, consisting of alternate "beds" of dark brown and orange sand. The darker layers contain many charcoal fragments. At first glance this looks like a secondary slump feature, but the cross-bedded layers appear comparable to the aboriginal occupancy layer at Roonka Dig (see Fig. 3.23). The landform lies well above the present floodplain, and other terrace elevations, and appears to be solely of aeolian material. However, it differs from the dune feature at Monteith by the absence of a carbonate horizon.

(3) Cut and Fill Deposits of an Ancestral Murray River

The above descriptions are of terrace deposits within the Murray valley and related to the immediate past fluvial activity. The large Murray valley, however, possesses thick deposits in the valley floor, beneath the present floodplain. These deposits appear on the geological cross-sections (see Fig. 5.7).

Beneath the present floodplain are deposits which have been described as two formations, the Monoman Formation, and the Coonambidgal Formation (see page 43).

The lower valley fill, the Monoman Formation, is a cut and fill sequence related to ancestral fluvial activity. The upper valley fill, the Coonambidgal Formation, represents the present floodplain deposition.

The Monoman Formation of Recent age, consists of 15.2 m of coarse grained quartz sand, possibly reworked Loxton Sand, with subfossil plant material. Fossil logs, including *Eucalyptus camaldulensis* recovered at a depth of 8 m below the surface of the floodplain from around Chowilla has been dated at 4,040±100 y B.P. (Firman 1967) and 7,200±140 y. B.P. (Gill 1973).

Fig. 3.20 Sandy carbonate pseudo terrace, Monteith Flat. The carbonate has hardened on exposure to the atmosphere, and forms blocks several cms long. The slope of the surface to the floodplain can be seen.

Fig. 3.21 Layering in the sandy carbonate pseudo terrace Monteith Flat. The blocky carbonate is found at the base of the exposure. Above this is a thick brown sandy horizon containing lenses of aboriginal hearth stones. The uppermost layer consists of lighter cross-bedded sands.

Fig. 3.22 Sandy pseudo terrace 3.3 km upstream from Murray Bridge, showing marked layering in the upper deposit. There is much evidence of aboriginal occupation of the site. A possible slump feature occurs half way down the exposure.

1

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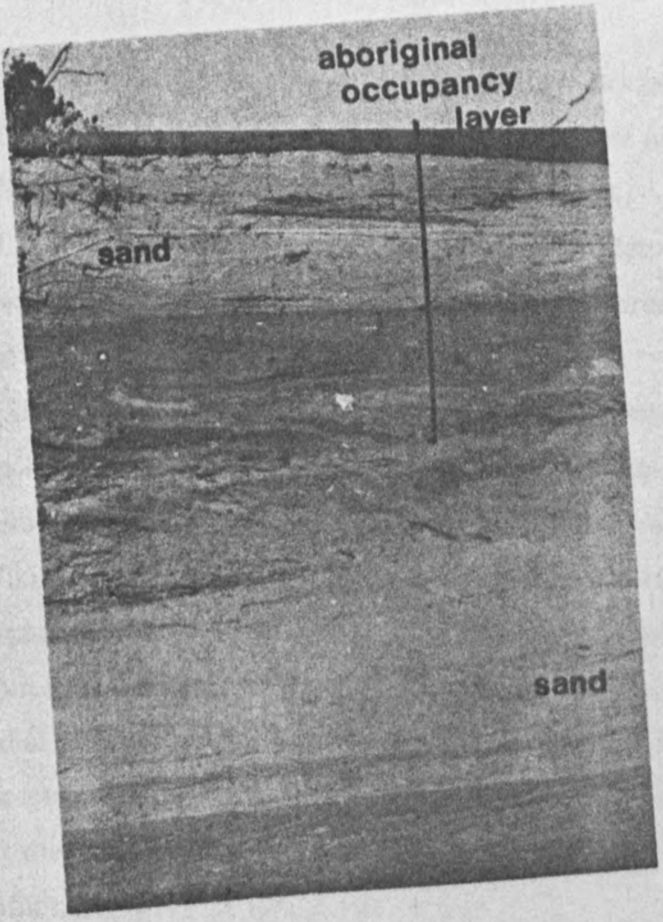

aboriginal occupancy layer
sand
sand

Fig. 3.23 Stratification in sand dune at Roonka aboriginal dig.

At Cadell a similar layer in the valley fill is shown on the cross-section of valley deposits (see Fig. 3.24). The lower valley fill consists chiefly of coarse grained sand beneath floodplain deposits of fine grained sand with clayey sand lenses.

At Swan Reach (see Fig. 5.7) detailed boring reveals the nature of the valley fill. Gibson (1958) considered the lowest valley fill to be aeolian in origin with subsequent compaction. For evidence he cited the overall compaction of the sediments, the uniformity of grain size, the angularity of the grains, and the exceptional thickness of sand with no apparent cross-bedding. However, log and smaller wood fragments indicate a possible fluvial reworking of the sediments.

Drilling at the present site of the railway bridge at Murray Bridge revealed silts, clays, and a bed of peat passing downwards into sands and gravels at the base (Johns 1961). Again there is a layer of valley fill deposits, finer sediments above coarser sands.

Gibson (1958) and Firman (1971a) have described the widespread contact between the upper and lower valley fill as an conformity, representing a time break and climatic change.

(4) Floodplain

The present floodplain sediments, the **Coonambidgal Formation**, dated as 5,110± y. B.P. (Bowler 1967), consists of at least 15.2 m of cracking clays (see Fig. 3.26), silts and sands, light grey alluvium, containing *Eucalyptus camaldulensis,* and fresh water mussels (Firman 1971a). Included in this category are the deposits of the modern river channels (see Fig. 5.7).

Planate or high undissected surfaces within this formation have been described previously as terraces, but within the limitations of the definition chosen for these landforms, these surfaces have been mapped as floodplain geomorphic units (see page 37,,and Fig. A-I).

(i) *High undissected floodplain*

The surface of the Coonambidgal Formation, to a depth of 0.3 m-1.8 m was described with the aid of soil profiles, by

(1) Baker and Potter (1968) as the "high terrace" at Lyrup and Winkie, and the "flat lower terrace" between Renmark and Loxton.

(2) Marshall and Hooper (1932) for soil types 1A and 13 from Renmark to Loxton.

(3) Marshall and King (1932) for soil type 14, 15, 16, for the Cadell Irrigation Area which they recognized as the valley of an old oxbow of the river. This landform is the extension of the present floodplain (see Fig. 3.7, 3.1 and Fig. 3.24).

(4) Holmes (1948) for "the first and second terrace" at Waikerie.

(5) Taylor and Poole (1931) for the swamps of the Lower Murray River, for "highland A, B, Soils and type 2 and 4 soils."

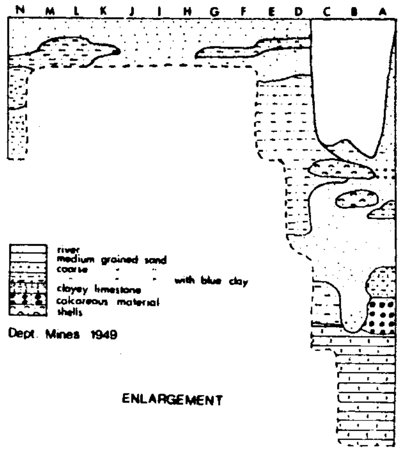
FIG. 3·24 **SECTION THROUGH CADELL - showing landform and sediments**

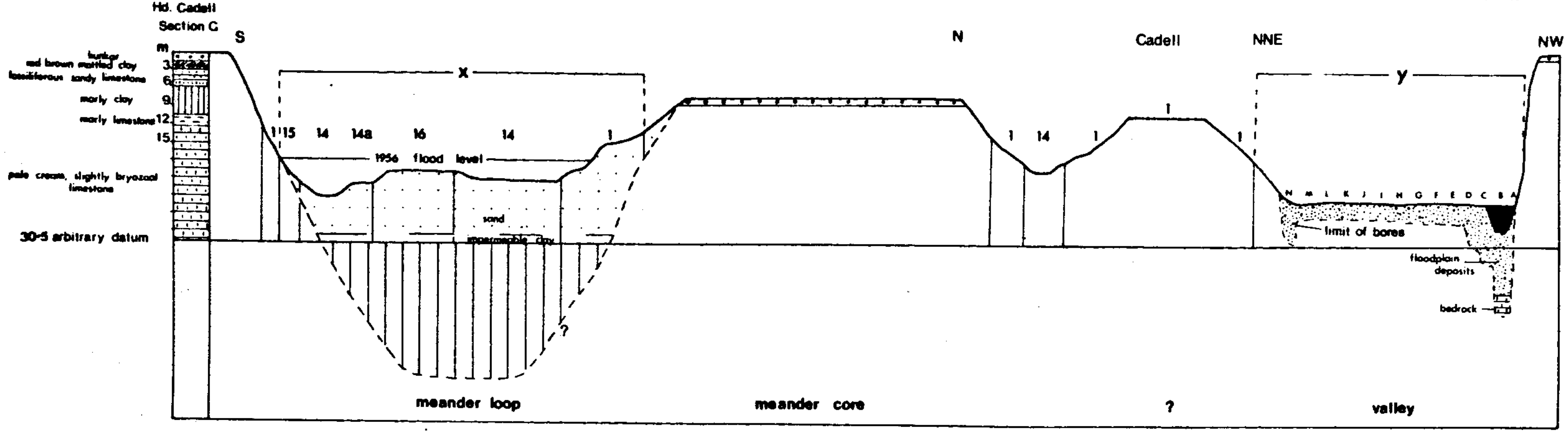
based on soil and bore log analyses

SOIL TYPES :
- 1 red, sandy, considerable depth (Orp)
- 14 light grey sand over grey clayey sand with carbonate
- 14a same, but heavier
- 15 heaviest soil, grey sand to medium grey clay
- 16 limited occurrence, red sand to light red brown clay

Marshall and King (1932)

0 m 300 600





The landforms on which the soil profiles are developed are floodplain features, since they are to be found within the present level of flooding by the Murray River (see Fig. 3.1).

From Jervois to Wellington a continuous high undissected surface was mapped, and from its distribution and composition it appears to be comparable to type 4 soil of Taylor and Poole (1931). The landform stands 3.0 m–3.3 m a.s.l., or about 0.9 m–1.5 m above the present floodplain, and is subject to inudation. The grey cracking clay contains charcoal and shell fragments, providing evidence of aboriginal occupation. This is not mentioned in Taylor and Poole's description. Further evidence of a similar form is to be found at Wellington East, but to the north of Jervois, at the base of most of the strath terraces, and at Monteith, it is usually fragmentary or its surface has been degraded by recent ploughing (see Fig. 3.2).

The formation of a soil, its nature, and composition, reflects its age and its fluvial history. For example, whether it has been swamp, levee, frequently or infrequently inundated by the river, and interfered with or modified by man, for example by drainage, irrigation, firing, and aboriginal occupance.

The oldest soil profiles of the floodplain are characterized by an aeolian addition to the A horizon, a moderate to heavy lime content in the clayey B horizon, and traces of gypsum at the base of the profile. The soils are reddish/brown to red, and have been mapped erroneously as terrace soils in the C.S.I.R.O. bulletins.

The lowest profiles, those more subject to inundation, are of grey cracking clay, with a tendacancy to gilgai formation (see geological sketch of Steel (1966) and Fig. 3.25. Variations in organic content reflect the degree of swamp formation which has taken place. Clay, with pockets of $CaCO_3$, and gypsum are present in the older, and more isolated swamp profiles.

It is concluded that the main soil types developed within the Coonambidgal Formation are a function of the site and past history of the river, rather than structure, including composition of the parent material. Man and wind have played the major roles of modification.

(ii) *Low undissected floodplain*

Between Chowilla and Overland Corner the low undissected floodplain is extensive (see Fig. A-C). Smaller, isolated surfaces exist downstream from Overland Corner (see Fig. D-I and 3.26).

(iii) *Dissected floodplain*

Generally within one or two stream widths of the river the floodplain surface is most irregular (see Fig. 3.27 and 3.28). Lenticular bar-like forms, with intervening swales, or chutes result in a micro relief of about 3 m. A scroll form is visible on the aerial mosaics, especially

Fig. 3.25 Mudcracks adjacent to the Murray River, in Coonambidgal Formation, at Wigley Reach, downstream from Overland Corner.

Fig. 3.26 A planate or undissected floodplain surface downstream from Overland Corner. A small cliff form developed in Morgan Limestone can be seen in the background.

Fig. 3.27 The dissected floodplain surface of a point bar deposit, Wigley Reach.

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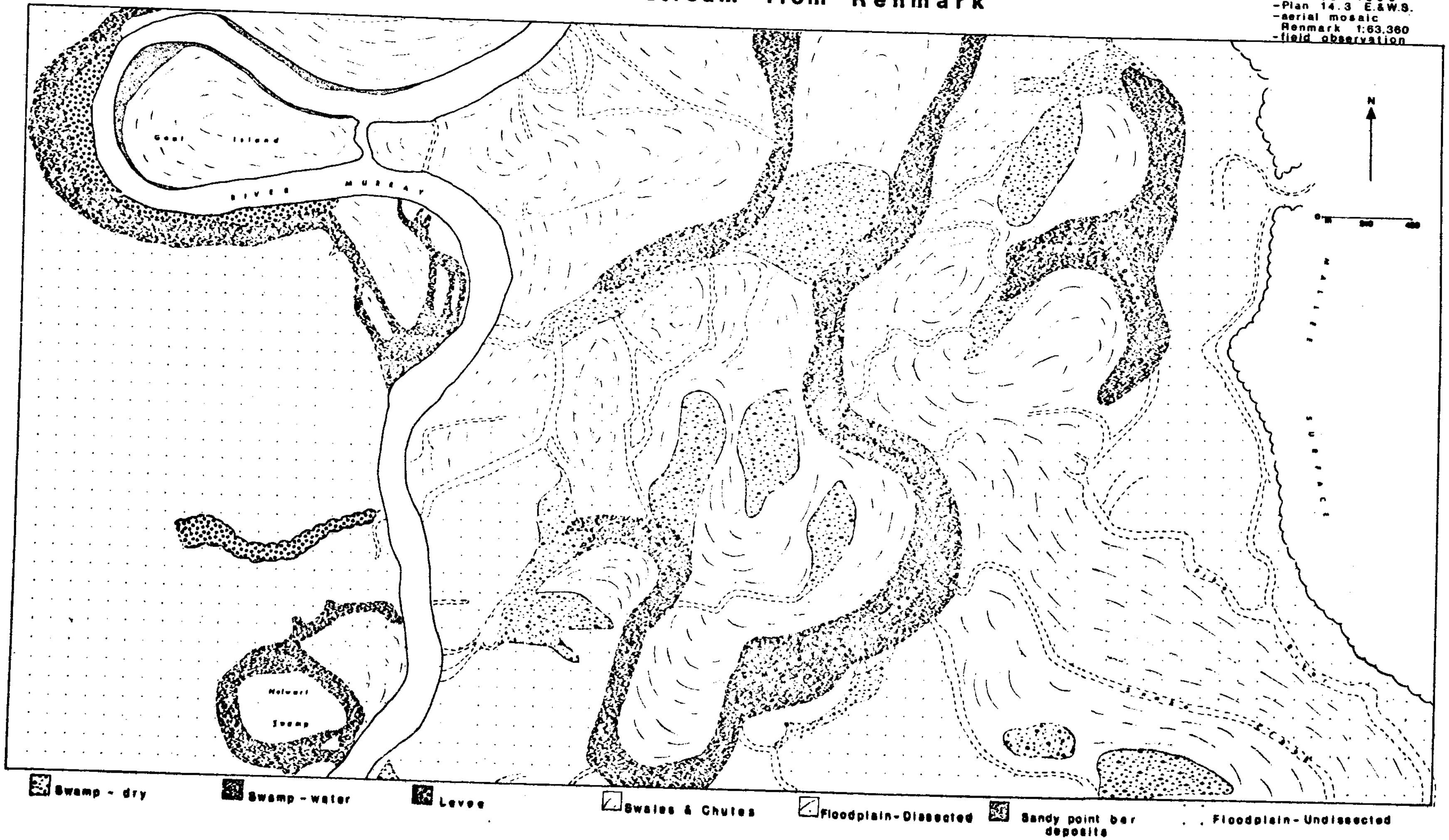
3·28 FLOODPLAIN DEPOSITS - Downstream from Renmark



Source 1908
-Plan 14.3 E.&W.S.
-aerial mosaic
Renmark 1:63,360
-field observation

upstream from Overland Corner. Levees occur where there has been a repeatedly slow addition of fine deposits over the banks, and where there has been little lateral migration of the river (see Fig. 3.29). Artificial levees, however, outnumber those formed naturally. Modification of the floodplain can result from flood activity, but occasionally there is increased gullying, for example at Roonka (see Fig. 3.30 and 3.31). Generally, surface configuration of the floodplain is smoother in those areas of the floodplain which have been isolated from contact with the river for the greatest length of time.

3. TERRACE AND FLOODPLAIN CHRONOLOGY

Relative ages for the terraces and the floodplain deposits can be based on stratigraphic survival, i.e. on the nature and degree of weathering of the materials, the relative heights of the sequence. The absolute ages can be determined by radio-carbon dating.

From the geological cross-sections at Chowilla, the terrace shown is older than the lower valley fill, Monoman Formation, and the upper valley fill, Coonambidgal Formation (see Fig. 5.7).

At Roonka the terrace predates a lower phase of the Bunyip Sand, dated at 18,900±100 years B.P. (G. Pretty pers, comm.), and Firman (1971a) suggested that the sediments on which the camp site is situated is an older valley fill, or a thin veneer of Woorinen Formation (Firman pers. comm.).

Aggradation of the valley with the lower beds of valley fill, began with the rise of the Flandrian Sea (Firman 1966). The sequence of fills from oldest to youngest is the Tartangan, 6020±150 years B.P. (Tindale 1947), the Monoman (cf. the "Upper Beds" of Hale and Tindale 1930), 4040±100 years B.P. (Firman 1967), and Coonambidgal, younger than 4040±100 years B.P. to the present (Firman 1969). The youngest formation appears to post-date the latest dune phase, Bunyip Sand (see page 9), and includes the young deposits of the lower Murray swamp lands and lakes region (Taylor and Poole 1931, and de Mooy 1958).

Unfortunately the evidence is fragmentary. Detailed radio-carbon dating needs to be carried out on all valley deposits including the terraces, pseudo terraces and the floodplain, before a picture of cut and fill for the Murray River in South Australia can be established. Particularly rewarding work could be the dating and mapping of the aboriginal camp sites, which may indicate channel and lagoon positions as a source of water and food.

4. CONCLUSION

The occurrence and frequency of landform surfaces within the Murray valley is so varied and fragmentary that extrapolation and correlation of the landforms such as terraces, pseudo terraces and undissected floodplain, in terms of age and genesis is not possible. However, it is

FIG. 3·29

FIELD SKETCH OF LEVEE, WEST BANK OF KATARAPKO CREEK, BERRI.

showing vertical accretion of sediments

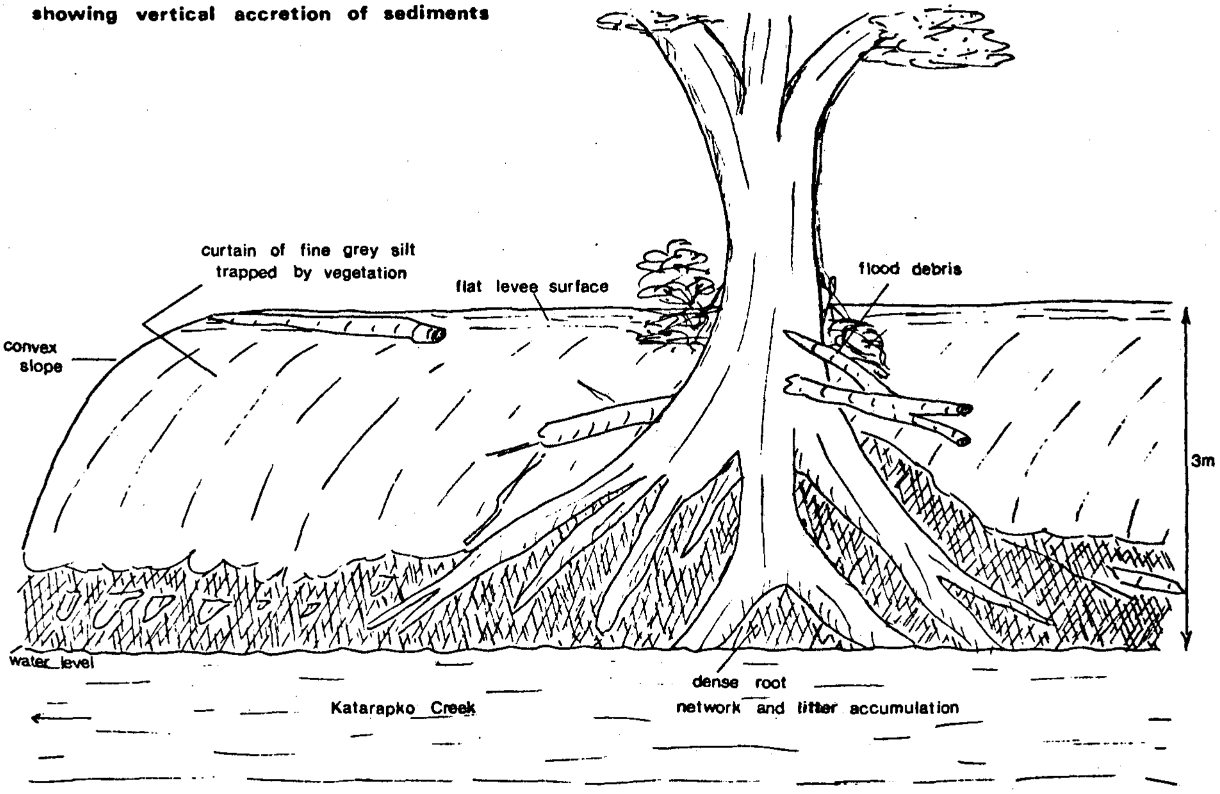
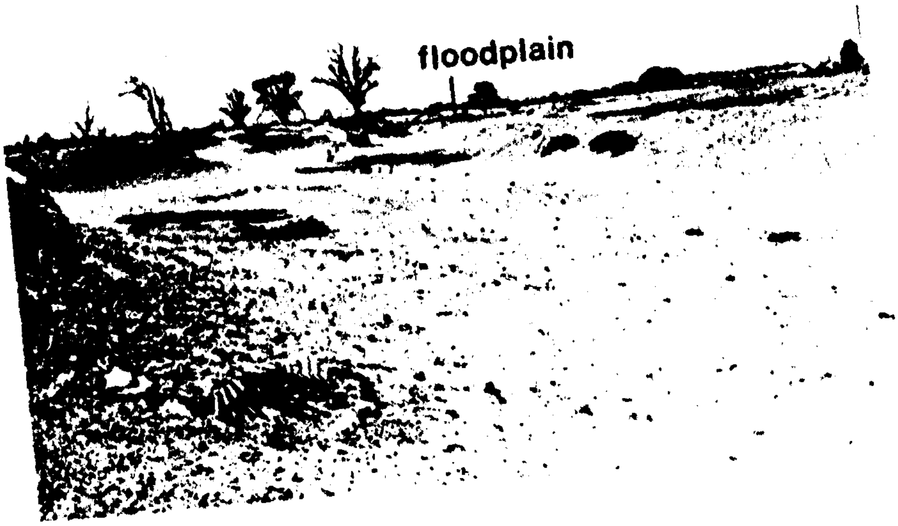
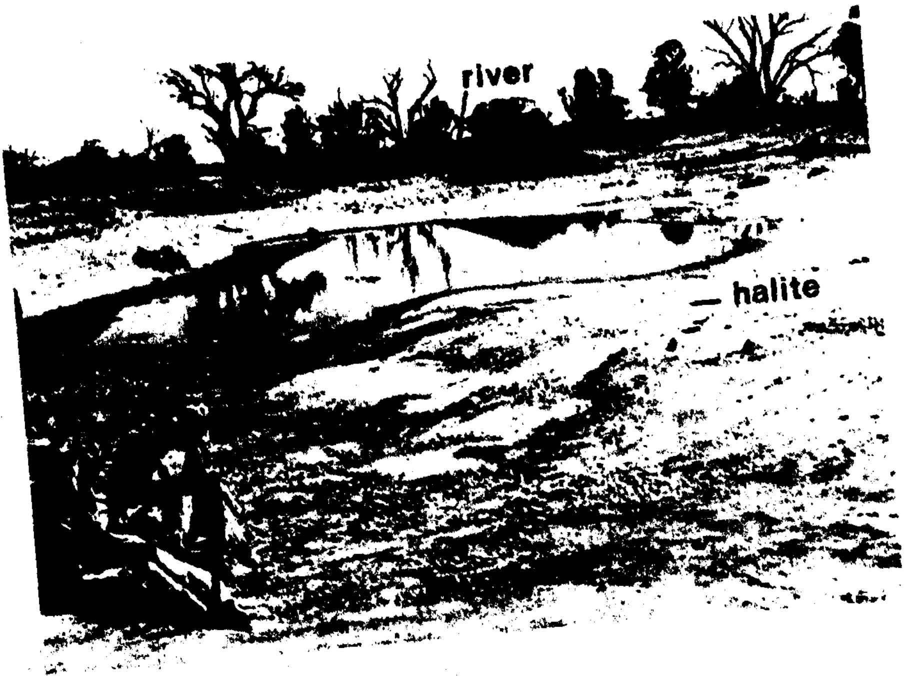


Fig. 3.30 Floodplain surface at Roonka, which has become dissected through the 1956 flood activity. Two main distributaries were formed. The soil represents a capping to the floodplain surface and the landform assemblage, mesa-butte-sugar loaf is found on a micro-scale. The floor of the gully is characterized by salt encrustations. This view is taken looking away from the river.

Fig. 3.31 Looking towards the river along a gully, which has resulted from the flooding of 1956 at Roonka.


floodplain


river
halite

suggested that the terraces of the Murray River are unpaired throughout the entire length of the river in South Australia (see Fig. 3.1). The general genetic interpretation for the formation of the terraces of the Murray valley is that these landforms appear to result from the progressive downvalley migration of the river, which occurred because of regional baselevel fluctuations during the Pleistocene. However, local tectonism may have played a minor role in initiating local baselevel control, as could have outcrops of crystalline basement rocks in the mid-lower course of the river, around Mannum.

It would seem that intrenched river systems of some antiquity, with lateral and downvalley sweeping of intrenched meanders along narrow gorges (see page 72), and little evidence of discharge variations (see page 56) militate against widespread and clear genetic interpretation of terrace formation.

The present research, however, revealed geomorphic misindentification of terraces, which were found to be part of the floodplain landform assemblage. Both erosional and depositional alluvial terraces were identified, and distinguished from various aeolian deposits and present floodplain surfaces.

CHAPTER IV

RIVER CHANNEL MORPHOLOGY

1. INTRODUCTION AND GENERAL DISCUSSION

The morphology or shape of a river channel is constantly undergoing change. Genesis is implicit in the term river channel morphology since there is interaction between channel forming processes and channel pattern. The change is of varying degree and permanence. Month to month fluctuations in flow, naturally and artificially controlled, flood occurrences, and change through geological time and associated climatic change, all produce a particular channel pattern for a given point in time.

The present channel form of the Murray River in South Australia can be considered as the result of the interaction of at least eight variables, which determine channel form (see Table 4.1). These are mutually interacting and adjusting to accomodate discharge and load by erosion, deposition, and variation in bed form (see page 48). Therefore, the cross-section morphology, longitudinal profile, and map plan of a river is adjusted to the environmental controls of load and discharge. Tinkler (1970) devised a scheme for the treatment of river channel morphology. He divided the river system into two parts; the physical shape of the channel, i.e. the boundary between the solid state, rock or alluvium, and the liquid phase, i.e. the stream itself with its distinctive discharge, velocity flows etc. These two interacting variables are responsible for channel form. The hydrograph for the Murray River for annual discharges (1901–1968) shows the total flow per annum, and the periods of high and low flow (see Fig. 4.1). The physical boundary for the river channel as displayed in the geological cross-sections is more or less uniform; the Coonambidgal Formation consists of light grey fluviatile clays, sands and silts, the Monoman Formation of coarser sands, and locally basal bedrock contact, for example, Lower Palaeozoic Kanmantoo Formation at Teal Flat and Murray Bridge Granite at the Swanport Bridge crossing, and Pliocene limestone at Kingston-on-Murray. Lateral bedrock contact varies between Pliocene Parilla Sand, Loxton Sands and Miocene limestones. The last mentioned is reflected most noticeably in the plan view of the channel. There is a marked narrowing in the channel width where the river impinges against the limestone cliffs, compared with an unrestricted passage of the channel across the alluvial floodplain sediments of the valley cut in unconsolidated sands. Variations in channel width are compensated for by an increase in channel depth (see Fig. 4.3).

2. PATTERN DESCRIPTION AND CLASSIFICATION

(1) River channel dimensions

Detailed measurements were taken from the Lands Department maps 1:31,680 of radii of curvature (r.c.), of the present river channel, oxbow lakes, and cutoffs. Simultaneously these

TABLE 4.1

THE INTERACTIONS OF THE VARIABLES WHICH DETERMINE CHANNEL FORM TODAY AND IN THE PAST

(after Dury 1954)

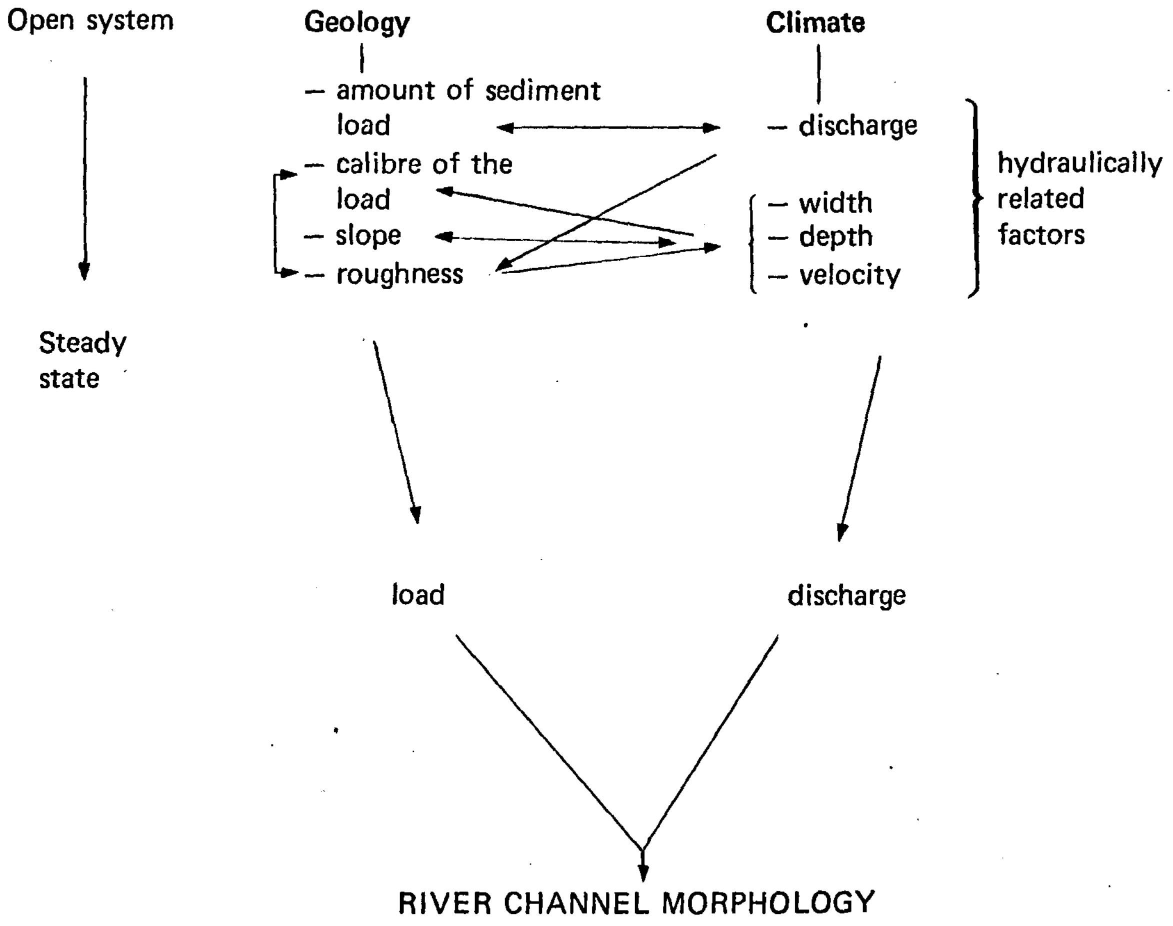
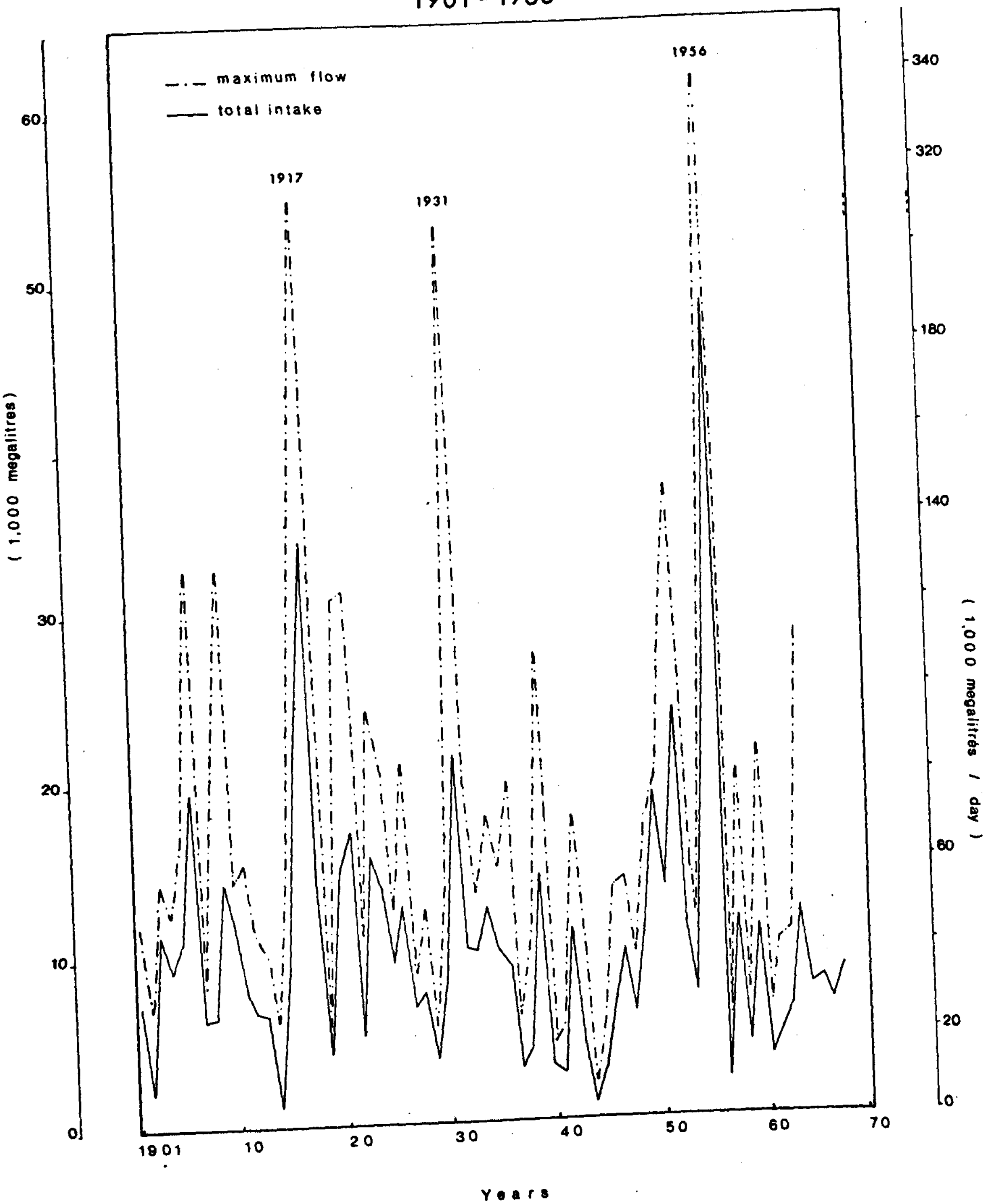


FIG. 4·1

HYDROGRAPH OF THE RIVER MURRAY S.A.
1901 - 1968



source : 1901 – 1964
E&WS Dept.
1965–1968
Weiss (1971)

were compared with the radii of curvature of the valley windings (R.C.) (see page 67). The results were plotted on the "pseudo-spectral" analysis graph which shows the frequency of a given radius of curvature (see Fig. 5.4). From the graph there appears to be two maximum radii (r.c.) of the values 2–5, and 8–10, from the Victorian Border to Blanchetown. However, from Swan Reach to Mannum the river channel radii are much greater than elsewhere and appear to surpass the valley windings. This may be explicable in terms of the nearness to the river mouth. It must be acknowledged, however, that this technique for the analysis of the change in habit of the river channel is very subjective and may suffer from the limitation of a small sample. There is an apparent uniformity in the radii of curvature of the oxbows present on the floodplain. They are about three times less than the radii of curvature of the valley windings (R.C.), and expectedly fall within the range of the most commonly occurring radii of curvature of the present channel (r.c.). Only two cutoffs are present within the entire mapped area of the Murray River in South Australia, and consequently insufficient data is available to draw any conclusions from the dimensions of these.

Generally, the variations in the radii of curvature appear to be due to variations in volume/discharge (R.C.:r.c., and the increase recorded in the lower course of the present river), and in the width of the floodplain, and the nature of the bedrock in which the valley is formed. In the confines of the narrow Miocene limestone gorge the free meandering habit is usually inhibited, whilst in the wider valley of the Loxton/Parilla Sands meandering finds its greatest expression.

(2) Profile description of the river channel (bed profile characteristics)

(i) *Introduction*

Meandering and angular reaches of the Murray River in South Australia have been recognized by the writer. The change in channel direction of a meandering reach developed in wide valleys can be expressed as a sine-generated curve (see Appendix B). However, an angular reach possesses abrupt changes in channel direction as the river impinges against limestone cliffs of narrow valleys. This type of river channel displays no conformity to a sine-generated curve. Meandering and angular reaches are readily discernible on maps and aerial mosaics. The difference in channel pattern has also been determined statistically and diagrammatically (see Appendix B). To illustrate other distinguishing characteristics of these two channel patterns an analysis was made of bed profile form.

The bed profile, essentially a wave phenomenon (cf. meandering), consists of three components, the pool, the point bar, and the riffle. The pools have a low topographic expression, produced by eversion. They generally contain relatively fine bed material, and are

POOL AND RIFFLE SEQUENCE OF A MEANDERING REACH
downstream from Renmark

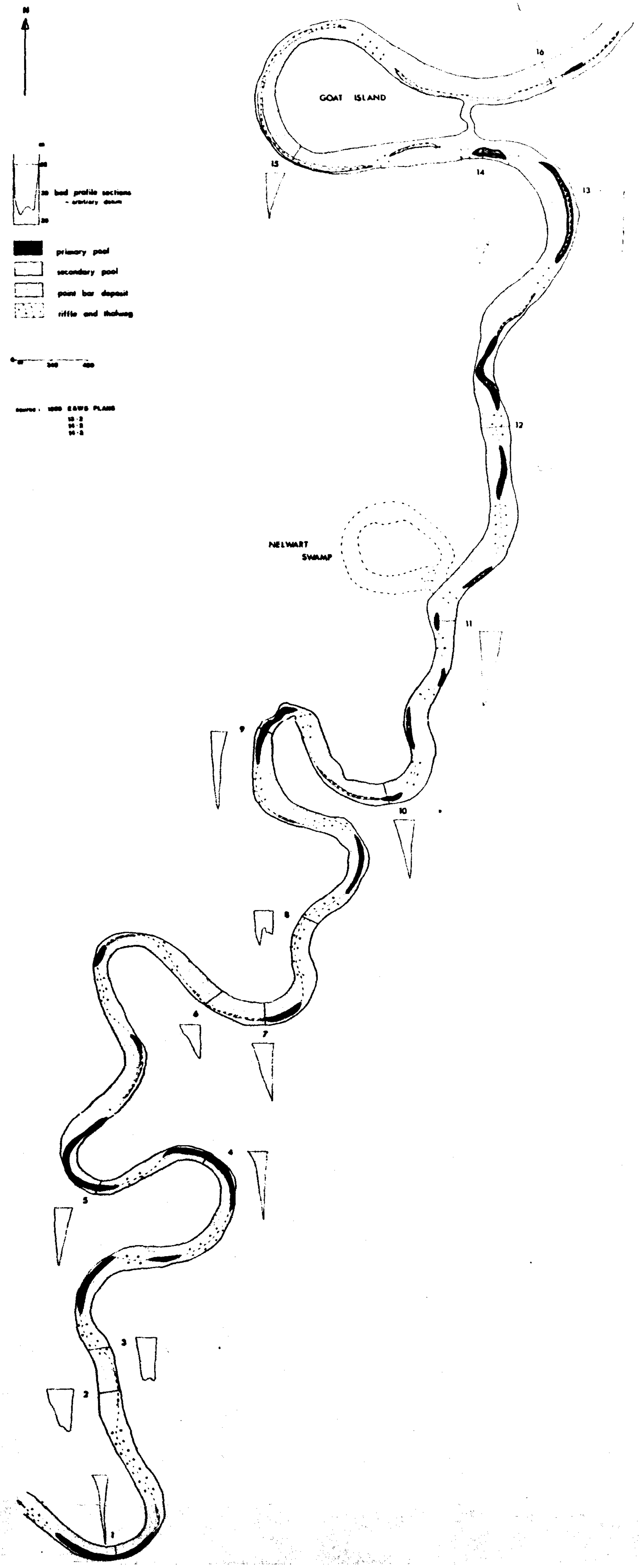


FIG. 4·3

POOL AND RIFFLE SEQUENCE OF AN "ANGULAR" MEANDERING REACH from Cadell upstream

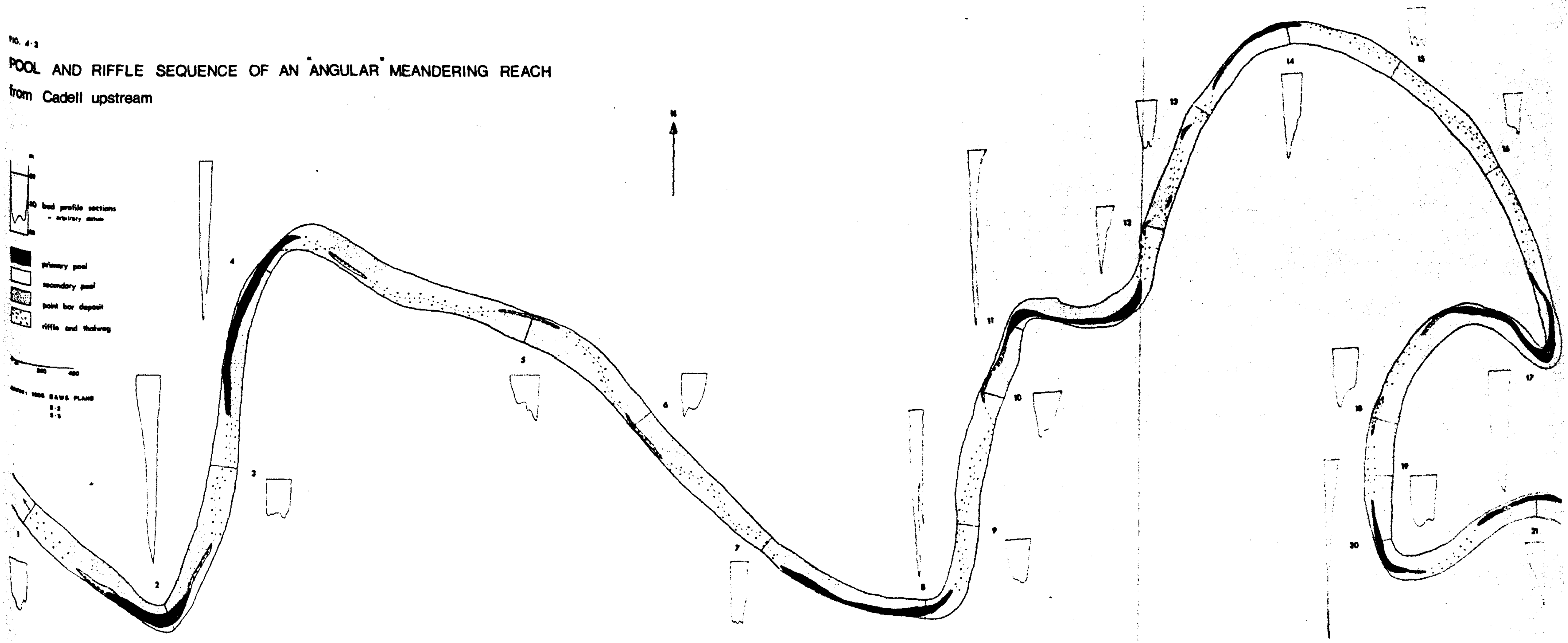
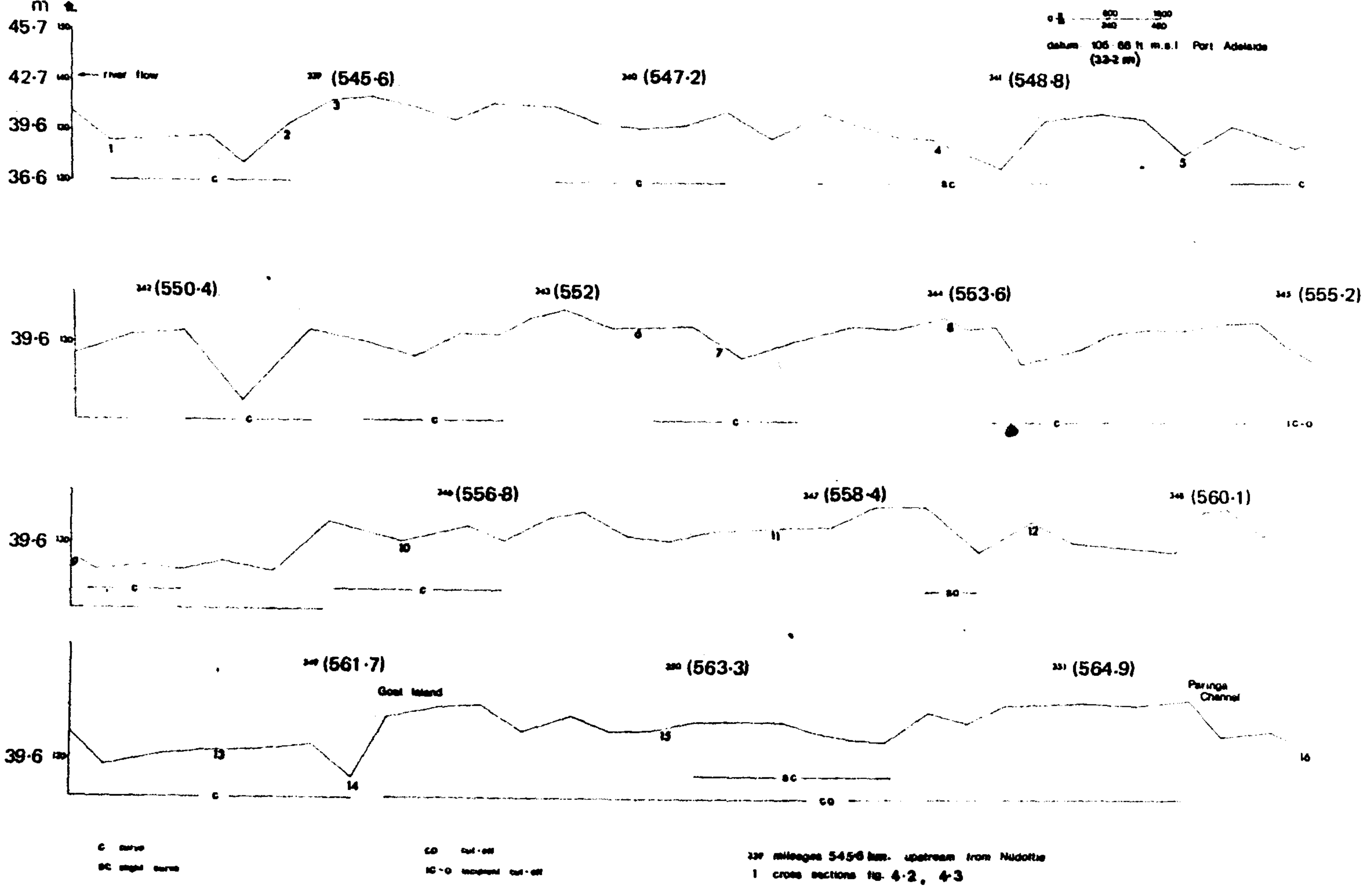


FIG. 4·4

THALWEG OF A MEANDERING REACH downstream from Renmark



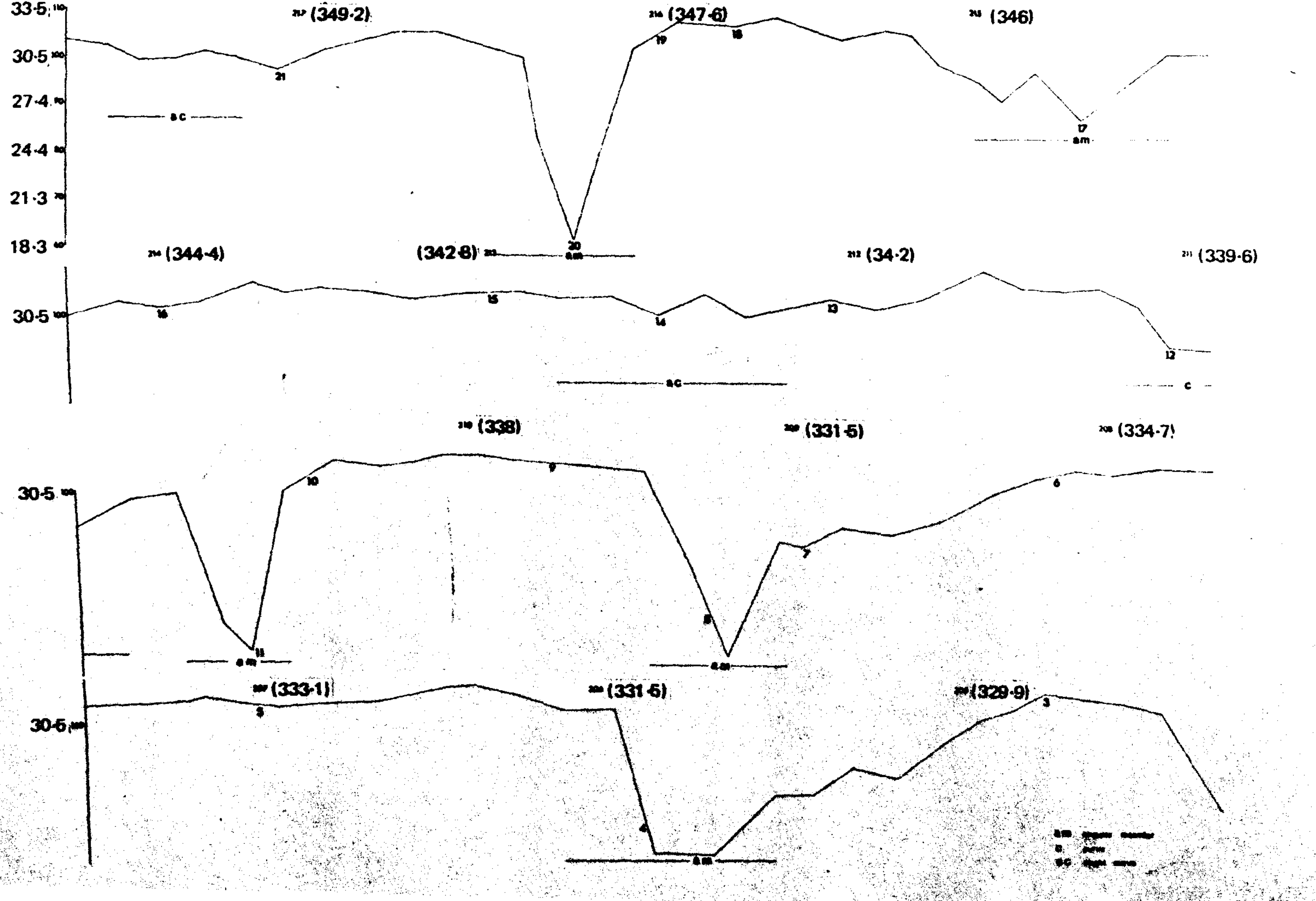
source: 1906 E&WS plans

0 ft 800 1600
240 480

datum 106·66 ft m.s.l Port Adelaide
(33·2 m)

FIG. 4·5

THALWEG OF AN "ANGULAR" MEANDERING CHANNEL upstream from Cadell



associated with a point bar deposit (Keller 1971). Correspondingly a point bar consists of a deposit of relatively coarse bed material on the concave side of the thalweg, the line of maximum channel flow, located at the deepest point in the bed profile, and adjacent to a pool in a meandering channel. Together the point bar and pool produce an asymmetrical cross-profile. The point bar lies within the confines of the channel, i.e. within the area described by bankfull conditions. A point bar deposit on the other hand, is an "abandoned point bar," resulting from the lateral migration of the river channel. Secondary pools and their associated point bars develop when new pools form as a response to channel length increase (Keller 1969). There are of recent development, or may represent potential sites for pool formation.

A riffle, a topographic high, is a lobate accumulation of relatively coarse bed material. The inflection point of the thalweg is located on this feature, approximately half way between successive pools. The cross profile is generally symmetrical (Keller 1971).

Keller suggested that these bed profile forms in straight or meandering channels are distinct units. However, plotting of the plans of their occurrence is subject to arbitrary datims and much subjectivity. As Figs. 4.2 and 4.3 show, not all pools are accompanied by point bars, and all the features tend to grade into one another. The distribution of each form can be plotted only relatively accurately using both depth and cross-sectional profiles, and even then transitional zones are common. Keller chose to include flow characteristics for substantiating proof of the exact location of pools and riffles. For example, pools at low flow have relatively slow, smooth deep water, point bars are exposed, and riffles are characterized by relatively fast, shallow water. The artificial maintenance of water level by lock construction made these particular criteria unavailable during field work along the Murray River.

Plans for the distribution, spacing and dimensions of the pool and riffle sequences were drawn for the two sections of the river, one illustrating angular reaches, the other meandering. Data was obtained from the E.&W.S. 1906 plans.

(ii) *Pool and riffle sequences*

(A) *Meandering reach,* plan 13.2, 14.2 (see Figs. 4.2, 4.4)

(a) Pools - Primary pools of mean length of 365.8 m, are located slightly downstream of the outside of channel curves without exception, as well as at the outlet of the Paringa channel, which forms Goat Island cutoff. The regular spacing between the primary pools is 975 m. The intermediate space is occupied by a point bar associated with a secondary pool, averaging 488 m. The pattern is slightly more complicated where there is recent cutoff development. The widths of both the primary and secondary pools are constant throughout, except for the anomaly of the "plunge pool" at the downstream end of the Paringa Channel. From the plan it can be seen that the cutoff occurred at the location of two primary pools, which have since suffered recent infilling. The relative antiquity of the Nelwart Swamp is reflected in the subsequent pool-riffle sequence developed due to the local change in channel length. The ratio 1:7.1 was recorded for symmetrical to asymmetrical cross profiles of pools in meandering reaches.

(b) Riffles – These are short, 198 m, and less dominant than the pool and point bar assemblage. They occur at regularly spaced intervals between the pools, chiefly at the inflection point of the major meanders, or in sections straightened because of cutoff development. The ratio 1:1.5 was recorded for the symmetrical to asymmetrical cross profiles.

(c) Thalweg – This wanders from bank to bank, following the meandering channel, but at an increased amplitude in the straighter segments. Normal behaviour is shown in the cutoff, isolating Goat Island. Greater isolation can be seen for Nelwart Swamp, with the presence of the thalweg occupying a central position in the channel.

(B) *Angular reach,* plan 3.2, 3.3 (see Figs. 4.3 4.4)

(a) Pool – The primary pools, average lengths of 488 m, are located at the channel bends, or immediately downstream from them. The only location where there is any degree of complexity occurs where a pool lies downstream of a curve, but immediately becomes part of a very tight angular bend with cliff impingement (see Fig. 4.3). The secondary pools of variable length, between 61 m–304.8 m have a variety of locations, occasionally up and downstream of an angular bend, and sometimes absent altogether. They also occur between primary pools, where the spacing exceeds the average length of the primary pools (i.e. 152 m–183 m). The width of the primary pool varies from long and uniform, to the widest development on the tight curves at the true central position in the pool where eversion is greatest and there is maximum angular change in direction of the river channel.

The secondary pools are uniform in shape. The ratio 1:5.5 was recorded from symmetrical to asymmetrical cross profiles. There is an apparent gradation of symmetry to asymmetry for the pools with distance downstream. The shortest pools are always symmetrical.

(b) Riffles – These are located between the primary and/or secondary pools, where the thalweg changes channel position from one bank to the other. The ratio 1:1.3 was recorded for symmetrical to asymmetrical cross profiles.

(c) Thalweg – There is some bank alternation present along the long straight reaches between the angular bends. The thalweg always occurs on the outside of the pools.

In conclusion, there is a marked variation in the spacing of pools between angular and meandering reaches. Pools are generally more asymmetrical with respect to meandering reaches. Riffles vary from symmetrical to asymmetrical for both types of channel pattern. The ratio of riffle to pool for angular reaches is 1:1.18, and for meandering 1:1.24, giving a mean for the Murray River channel of 1:1.26. According to Langbein and Leopold (1966) the mean spacing for pools and riffles in a river system should be 1:1.6. The thalweg conforms more readily to the meander channel pattern. Without exception secondary pools and point bars are all asymmetrical. Therefore, a detailed study of bed profile form shows a difference between the two channel patterns, and illustrates that the angular pattern is more unstable, and perhaps a precursor to the meandering pattern. There is, however, at present controversy over the development of the meandering channel pattern from a straight reach. Keller (1971), and Tinkler (1971) are in disagreement over the stability of the location of pools and riffles as the channel pattern changes. Keller suggested that riffles are converted into point bars, and are associated with pools as meandering occurs. Tinkler maintained that their location is invariant with respect to a new channel form.

The number of pools is a function of channel length rather than channel pattern, and as channel length increases due to the lateral migration of the meanders, new pools may be added to keep the spacing constant (Keller 1969). The length of the channel is kept relatively constant in the confines of the valley from Overland Corner to Wellington, whereas upstream from Overland Corner the channel is free to wander across more or less homogeneous alluvium, and a greater frequency of pools results. Also, the greater amplitude of the thalweg in the straight reaches seems to support the hypothesis that there is an increase in the number of pools with decreasing distance between them. This is associated with a change in channel form from angular to meandering.

(3) The role of jointing in the determination of channel location

The degree of lineation is used as the criterion for classification of the channel of the Murray River. Firstly it is necessary to demonstrate (using Schick's method (1965)) the influence of structure, chiefly jointing and lineation on the landform development in general, and the channel in particular.

The importance of lineation (fracture pattern, for example joints, faults, strike of the beds, and foliation) on aspects of the geomorphology of the Murray valley and Mallee, has been described previously by Hills (1956), O'Driscoll (1960) and Firman (1970).

An elementary statistical analysis of the orientation of four geomorphic features of the landscape was carried out to determine whether there was any similarity in their orientation. The four features were the valley orientation, the straight reaches of the river, the sinkhole distribution, and the morphology of Punyelroo Cave.

The pattern of valley orientation was determined by ploting the mid-point of the valley, measuring the orientation to the north direction, and recording the bearing (see discourse on the measure of lineative factors page 53). The sinkholes were plotted on a map of 1:250,000, derived from Lands Department topographic maps 1:31,680. The alignment was obtained by the best visual fit of a grid pattern of trend lines. During the process of scale conversion many local alignments were discovered. For the orientation of Punyelroo Cave, the centre or mid-point of each cave segment was plotted, and measured against the north direction, and the bearings recorded of each cave and off-shoot. It is suggested that this data represents the most accurate and absolute record of the jointing pattern as expressed by solutional weathering of the Morgan Limestone.

The visual comparison of the patterns on the roses (see Fig. 4.6 and 4.7) shows that there is an apparent correlation between the jointing pattern of the Miocene limestone and

the valley between Overland Corner and Teal Flat,

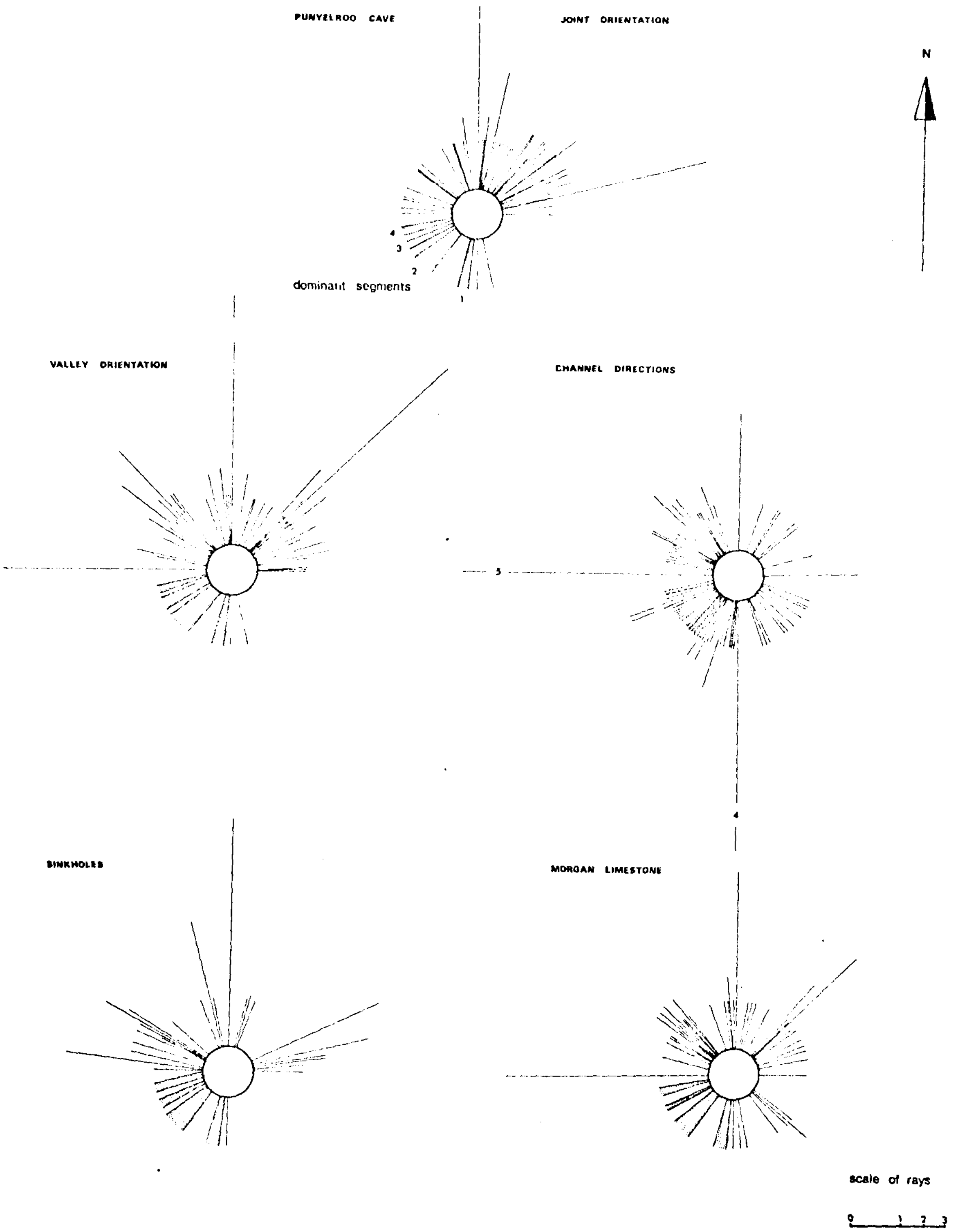
the sinkhole distribution, and with particular relevance to this chapter, the river channel.

Jointing can determine channel location both directly and indirectly. Direct structural determination of the ancestral Murray River's channel position results from the presence of faults, monoclines, crystalline intrusions, and jointing. The lineament pattern is discussed in the subsequent chapter.

Jointing appears to play a role in channel location today, since there are marked changes in channel direction in the Murray River downstream from Overland Corner. The river channel pattern is described as an "angular meandering" pattern. Cole (1930) described such a pattern as secondary meandering. He suggested the river channel possesses a clear, intimate relationship with the structure (bedrock) on which they are developed. This definition is not applicable to this part of the Murray River since there is little basal contact of the river with the bedrock. The geological sections show considerable thicknesses of alluvial fill between the present channel and the valley floor, for example, 7.6 m at Overland Corner, 12.2 m at Cadell, 7.9 m–14.6 m at Blanchetown, 35.1 m at Murray Bridge, 40.1 m at Swanport, 45.7 m–50.3 m at Monteith, and 65.5 m at the River Glen Irrigation Flats.

ORIENTATION ROSES OF SELECTED GEOMORPHIC UNITS

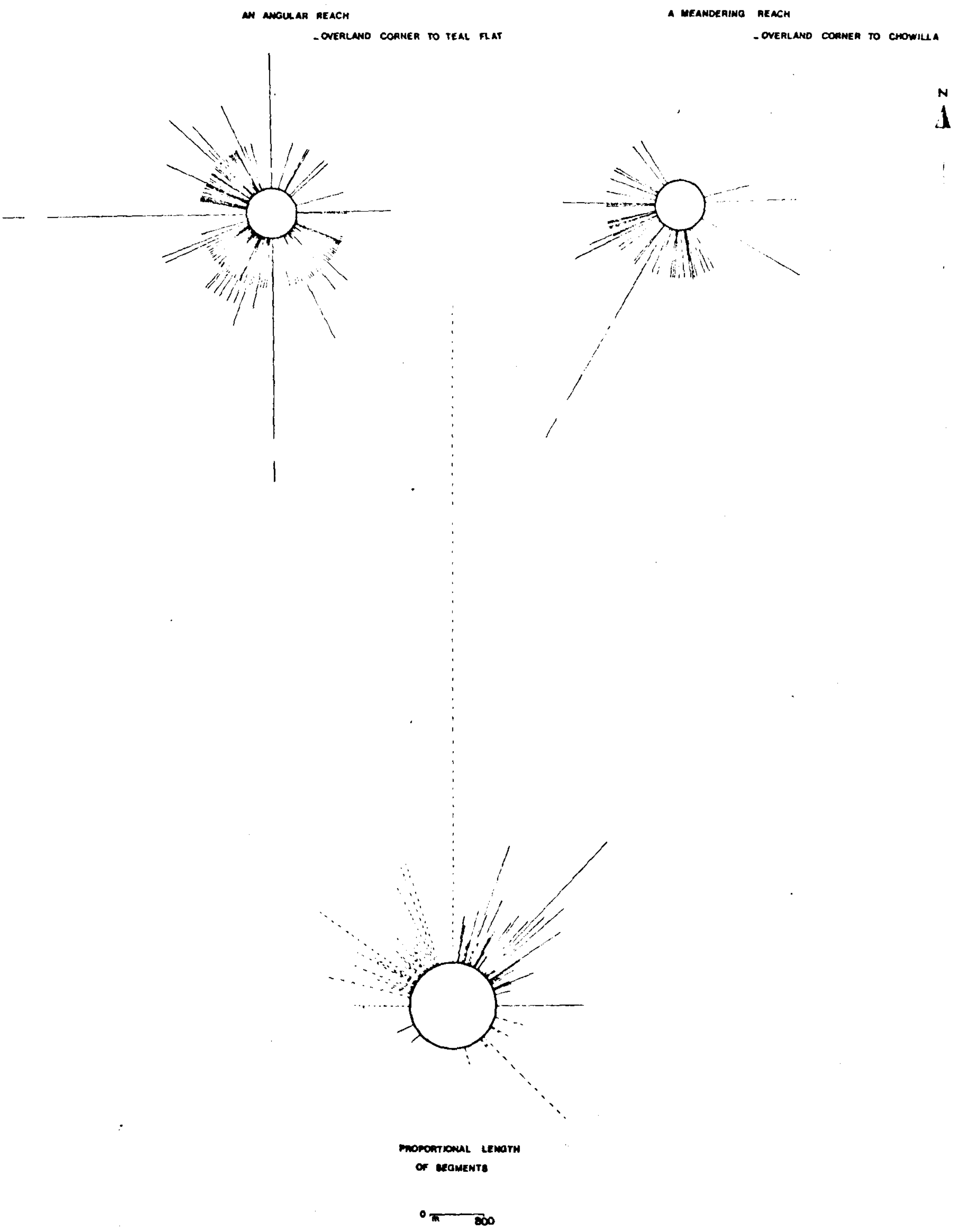
FIG. 4·6



showing conformity of Punyelroo Cave Morgan Limestone to other units

FIG. 4·7

CHANNEL DIRECTION ROSES



AN ANGULAR REACH
– OVERLAND CORNER TO TEAL FLAT

A MEANDERING REACH
– OVERLAND CORNER TO CHOWILLA

PROPORTIONAL LENGTH
OF SEGMENTS

It is suggested that during the evolution of the Murray River through the process of river intrenchment, portions of the primary loops were modified by the nature of the rock structure into which the river was downcutting. Today, because of a phase of cut and fill there is little if any basal control of channel location. However, it is suggested that there may be a local imcompetence translated into the alluvial fill immediately above the joints in the bedrock floor. Fig. 5.7 illustrates how the deepest excavation of the valley into the bedrock floor appears to lie immediately below the site of the present river channel. Perhaps continued weathering of these joints with the subsequent subsurface flushing of the weathered products results in an incoherency, mentioned above, and produces a line of weakness, a "pseudo-joint" effect in the alluvium inviting water flow in these locations.

On available evidence lateral joint control rather than basal joint control on river channel location appears to have played the more dominant role in channel location. The relatively long straight sided cliffs in the Miocene limestones represent joint planes. According to Cole (1930) joints are notable lines of weakness to erosional processes acting on the rock mass. However, joint planes exposed in the cliffs of the Murray River have been reinforced by case-hardening, and it could be argued that the cliff form is a relatively stable resistant feature. The maintenance of the angular change in channel direction in the river channel pattern from Overland Corner downstream, may be attributable to the presence of jointing, a lateral jointing effect, or it may represent simply a function of misfitness, in a river migrating downstream (see chapter V).

(4) Measure of lineative factors for the location of the Murray River

Lineative influences control the course of the present stream channel between Overland Corner and Teal Flat, according to O'Driscoll (1960). Local stream direction roses have been constructed to show the dominant stream directions as a possible index of jointing controls. For contrast a rose for a meandering reach upstream from Overland Corner, with a wide scattering of directions is included (see Fig. 4.6). However, it must be remembered that the present Murray River is flowing through alluvium from 6 m-37 m deep (see Fig. 5.7). It is suggested that an ancestral channel direction may have been governed by jointing in the Tertiary bedrock, but the present channel may be only indirectly controlled by jointing.

Included in Appendix A is a description of the technique of Schick (1965) for estimating the degree of lineation of river channels. This method is applied to reaches of the Murray River to test the degree of channel change present. A meandering, and an "angular" meandering reach were selected and compared with the normal model of Schick (see appendix). Differences between meandering and angular reaches are also illustrated.

Results from this study of the Murray River (see Fig. 4.8 and 4.9) show that the angular reach of the Murray River is highly significantly different to Schick's "normal" model for changes in mean downvalley direction of the stream.

The meandering reach of the Murray River shows an even greater highly significant difference from the normal model.

The total positive deviation from the normal is 21.3% for the angular reaches; 35.1% for the meandering reaches. The latter figure is higher than for Young's flume channel, but below that 50% index suggested by Schick.

Furthermore, the degree of change in channel direction between the angular reaches and the meandering reach is highly significantly different ($\nu = 5$, $P(x^2 > 72.17) < .01$). This shows a marked change in the fluvial habit of the Murray River upstream and downstream from Overland Corner.

The composite graph (see Fig. 4.9) of the distribution of local stream directions in relation to a normal distribution tends to show a shift in peaks and lows, for example,

the normal curve is peaked about 10–50°;

the meandering reach (an almost wave-like form), about 40° and 0°;

the angular reach, with two peaks, at 0°, and between 30–50°, and

the deeply intrenched Shenandoah (Schick), one peak only, 70–90°.

Therefore, there appears to be a bimodal effect in rivers compared to a unimodal effect in a normal curve. The peaks shift to the right, and there is a higher variation in channel direction change with a greater degree of intrenchment. Therefore, both the meandering and angular river channels are bimodal. It is suggested that the Murray River may represent a reversal of form from a formerly similar Shenandoah type of ultimately a meander pattern. Schick's model illustrating lineation in river channels shows both types of channel pattern selected for the Murray River possess strong lineation.

In agreement with Schick's findings, the two modes for meandering and angular courses are 70–90° apart, and are asymmetric with respect to the cardinal drainage direction, (CC), i.e. the negative (left hand) deviations are higher in frequency, and higher in numerical value (higher degree of angular change from the cardinal direction) than the positive (right hand) deviations.

This statistical technique sheds some light on the evolution of the Murray River. From the results obtained it is suggested that lineation was developed prior to the present river. An ancestral channel location may have been governed by jointing in the Tertiary bedrock. Today, the dynamics of stream flow on more or less uniformly homogeneous substratum, alluvium,

FIG. 4·8

FREQUENCY ANALYSIS OF CHANNEL DEVIATION FROM THE MEAN DOWNSTREAM DIRECTION

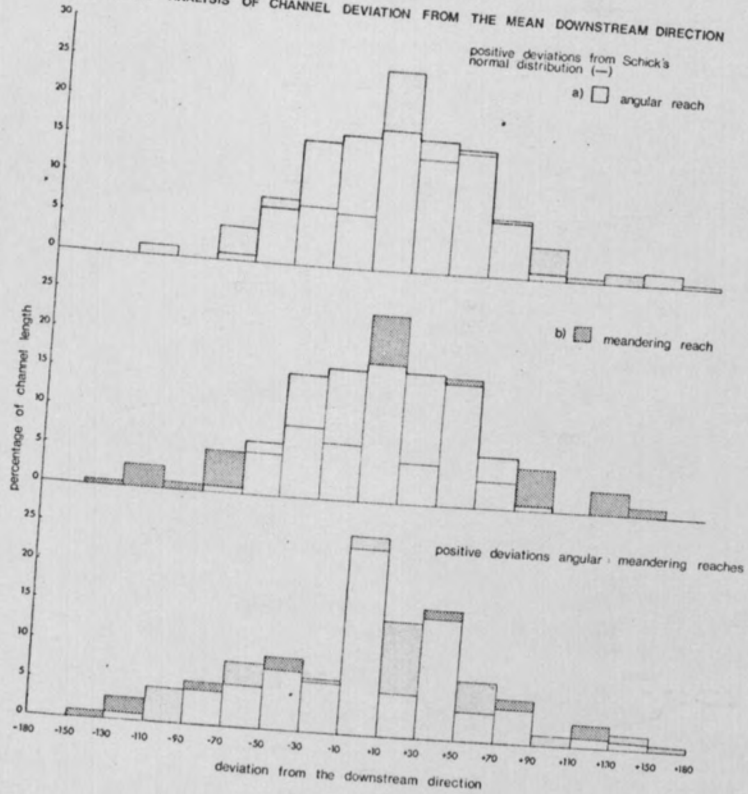
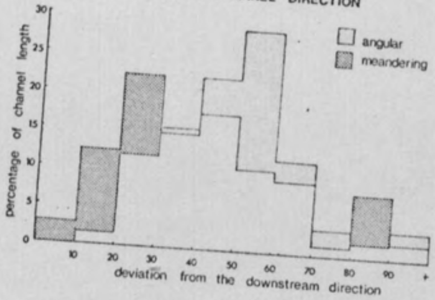


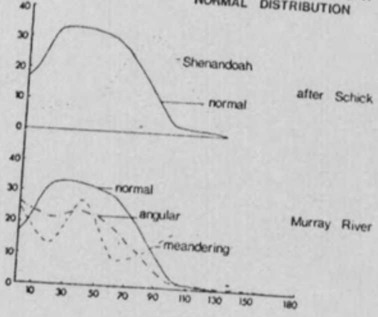
FIG. 4·9 a)

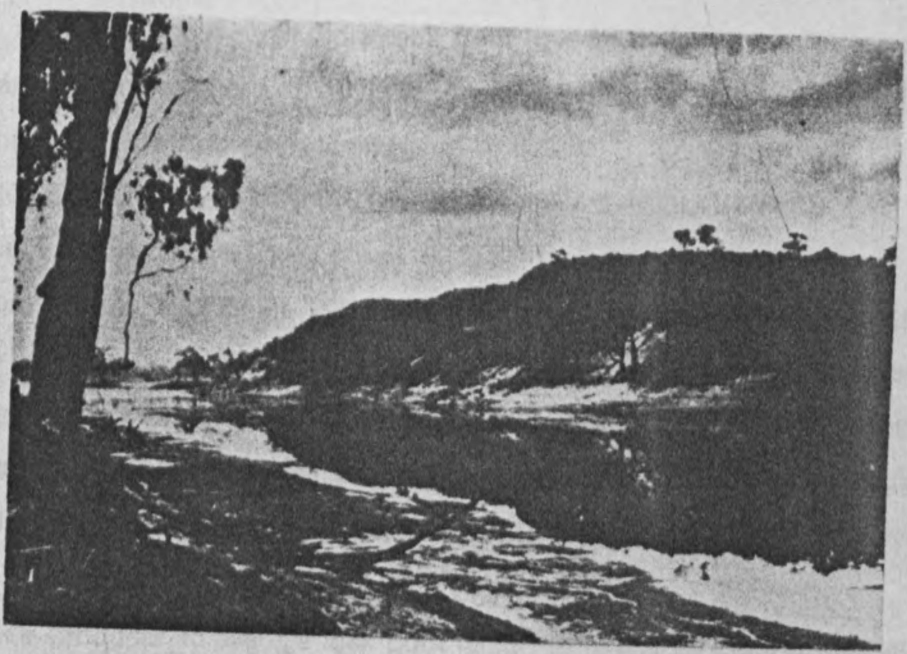
ANGULAR CHANGE IN CHANNEL DIRECTION



b)

LOCAL STREAM DIRECTIONS IN RELATION TO A NORMAL DISTRIBUTION





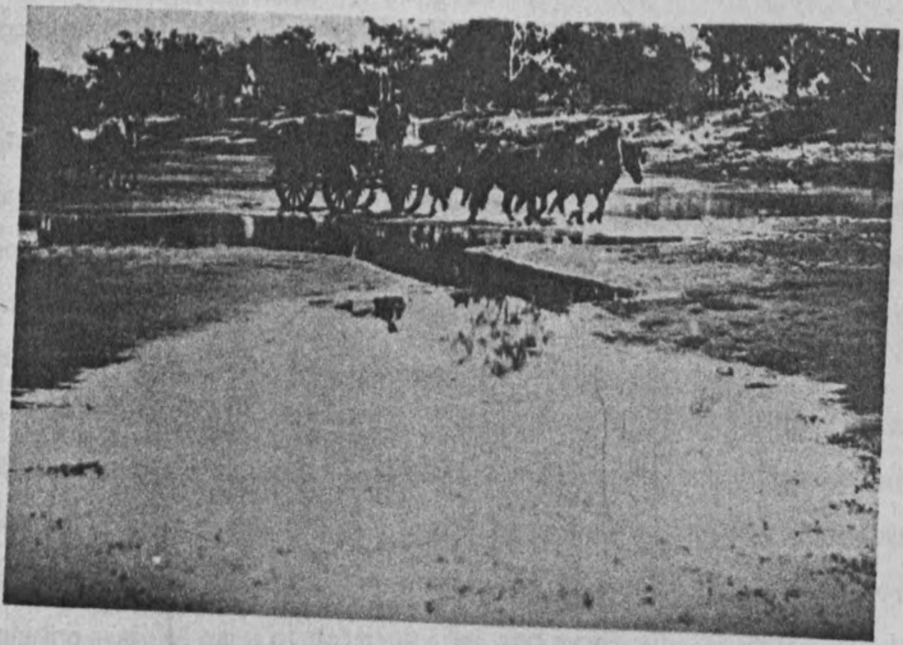


Fig. 4.10 (a) Loxton, 1914 the river during a period of low flow.

(b) Loxton, 1914. The channel bed contains a series of shallow pools.

6 m–37 m deep (see Fig. 5.7) will eventually control the location of the river channel. The present river possessing lineation may be merely in a period of adjustment to a former direct jointing control developed during a phase of earlier incision.

From this analysis of channel pattern data it seems that there are two basic types of stream channels, a more sinuous type upstream from Overland Corner, and a more angular type downstream. From Walkers Flat to Lake Alexandrina, the river, though still confined in a gorge, approaches a more sinuous form again.

3. CHANGES IN RIVER CHANNEL MORPHOLOGY THROUGH TIME

(1) Minor changes in the liquid phase

Between 1922 and 1930 six locks and weirs were constructed between Blanchetown and the Victorian Border. In addition the construction of five barrages was completed by 1940 in the vicinity of the Murray Mouth to prevent the ingress of salt water from the ocean, and to maintain a higher level in the river and freshness of water in the lakes for irrigation practices. As a result there have been minor changes in the liquid phase of the river system in South Australia.

Each weir produces an average lock pool length of nearly 64 km, for reserve storages to be drawn upon in drought years (Eaton 1945). The effect of such artificial modifications to the river system has been to reduce the frequency and extent of seasonal flood and low flow (see Fig. 4.10), and to locally alter the channel width. There has been an enormous spread of reed growth (*Phragmites australis*) along the relatively stable water margin, and the lock pools with their deep cool still waters alien to native aquatic flora and fauna, have resulted in a reduction in the natural regeneration of gum and local bank alteration (Nat. Con. Soc. 1970). The reeds have managed to trap fine sediment, with the result that the channel is narrowing appreciably as the banks grow inwards. The lock pools also act as settling basins but complementary pool enlargement is occurring immediately downstream of the locks where there is considerable plunge pool effect scouring out the bed profile, for example at lock 5, to a depth of 10.7 m compared to 6 m immediately upstream.

Strom (1962) has reported the effect of the growth of Willows (*Salix babylonica*) along the Murray River. These were planted along the river bank in earlier years for quite valid reasons, for example to provide shade, ornament, and the prevention of scour. However, they were not kept under proper control, and tall, top heavy trees resulted. Collapse of these into the channel led to a tearing away of parts of the bank area, and eventually resulted in local trapping of silt, and channel bank modification. As bank binders, this vegetation on the concave bank has considerably stabilized the channel form.

Conversely, after initial settlement in the Murray valley much overgrazing, ringbarking, and introduction of grazing animals, for example sheep, rabbits and goats at Roonka, has destroyed much of the natural vegetation along the river banks and contributed to channel bank instability, increased local runoff and encouraged channel alteration. A similar effect has been achieved along the river banks and lake sides by the wash from power boats, especially near towns and popular camping areas (Bonython 1971).

Future man-induced modifications to channel morphology were enumerated in the River Murray Commission's proposals in the Gutteridge, Haskins, and Davey Report. Some of the proposals suggested with a view to eleviating the salinity problems included:

(1) the damming of Chowilla Creek, cutting off the effluent creeks, anabranches, from the Murray River flowing into the creek, and pumping groundwater to the nearby evaporation basin, Lake Coombool.

(2) the damming of Salt Creek at Lock 5, and the pumping of water to Dishers Creek Basin for evaporation.

(3) the isolation of Goat Island "billabong," cutoff, from the Murray River, to use it as an evaporation pan to handle the saline inflow.

(4) the sealing off of Hart Lagoon, Ramco Lagoon Waikerie, where a mound of saline groundwater exists.

Up to 1416 hectares of billabongs, lagoons, and river flats in total were suggested to progressively supplement the present evaporation basins. The effect of increased discharge, draining, and evaporite formation would undoubtedly produce minor, if not major changes in channel morphology.

(2) Major changes in the liquid phase

(a) *Flood activity*

A flood has been defined in various terms but based on differing degrees of discharge. However, overbank flow is implicit in all definitions. Since water level is controlled in South Australia, the level at which overbank flow occurs will be purely arbitrary. Locally, natural and artificial levees would raise the stage at which damage would occur. Therefore in agreement with other fluvial geomorphologists, the emphasis will be placed on the flood damage level, i.e. as is used by the U.S. Weather Bureau, referring to the water surface elevation where overflow begins to cause damage (Wolman and Leopold 1970). Local record and historical documentation are used to delimit the floods of the Murray River, of 1870, 1889, 1890, 1891, 1893, 1894, 1906, 1909, 1917, 1931, and 1956 (see chart in Tolley, 1956).

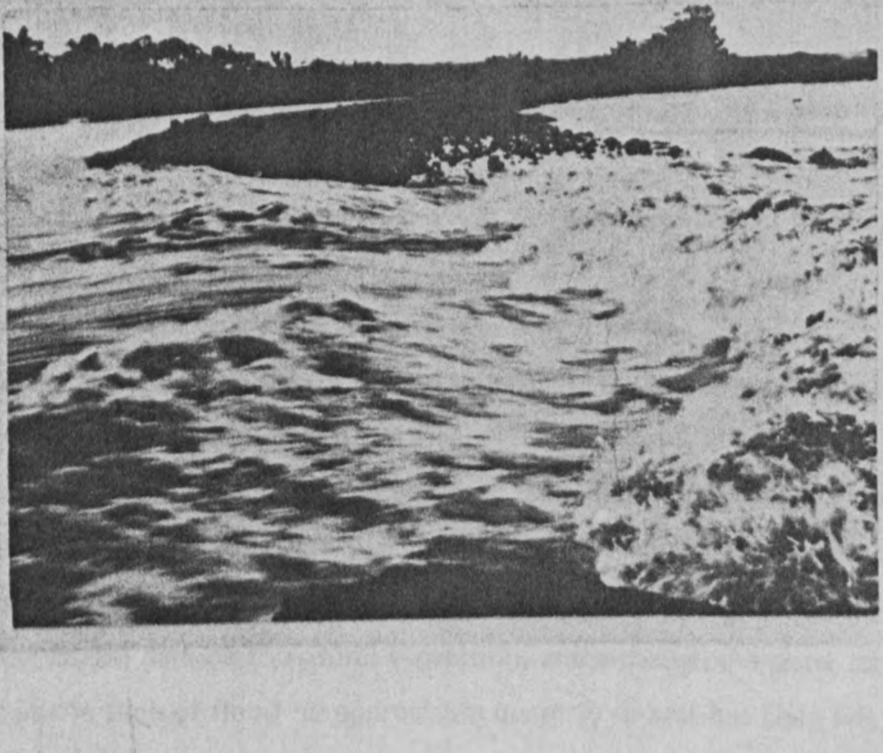
Since the 1956 flood superseded those before, attention will be concentrated on its causes and more importantly on its effects. Photographic coverage of the 1931 flood is available, but the water's effects on the floodplain surface have since been obliterated (see Fig. 4.11). The other readily available evidence of this and former floods is to be found in the line of Box

Fig. 4.11 (a) Baseby's Swamp, 1931.

The initial breach in the levee.

(b) The breach a few hours later.


river
swamp
levee



(*Eucalyptus largiflorens*), which germinate almost exclusively in receding flood waters, and isolated logs of the Karadoc tree at Swan Reach stranded by flood waters (Blainey 1964).

Kempe in a feature article in the Advertiser, 13/9/56 on "Factors which Led to Record Flood," suggested that the 1956 flood was a result of the combination of exceptionally heavy rains throughout almost the entire catchment area resulting in a high soil moisture content, and so reducing the water percolation rate on thousands, perhaps more than a million square kilometres of surface soils; the effect of melting snows in the Kosciusko catchment area; and the degree and incidence of spring rains producing flooding simultaneously in all tributaries. Normally the peak in the River Darling is earlier than in the Murray River.

In the historical documentation best summarized in the Department of Lands Annual Report 1956–57, stress is laid on the impact of flooding on cultural features. However, there is some mention of the effect on the flood plain itself, both constructive and destructive. The evidence is as follows:

(1) Chaffey, Ral Ral division – a few hectares were affected by seepage.

(2) Lyrup – seepage through rabbit burrows, the Advertiser, 28/8/56.

(3) Waikerie-Ramco divisions – seepages and a flood produced lake area in the vicinity of sections of 90/100, 106/108, in the Holder division.

(4) Mypolonga – failure of the main levee bank on the 5th August, 1956 at R.L. 35.5 m, with the subsequent inundation of the reclaimed area.

(5) Cowirra – the levee failed 31st July, R.L. 36 m after bad slipping (slumping).

(6) Neeta and Mypolonga – a breach occurred through high ground of sandy polygonum land.

(7) Wall Flat – the levee failed 13th August, 1956, 36.2 m, by a blowing through solid ground on a polygonum sandy section.

(8) Pompoota – the initial breach through the levee was 3 m in width, which became 30.5 m in half an hour.

(9) Monteith – very heavy slipping of the banks for weeks.

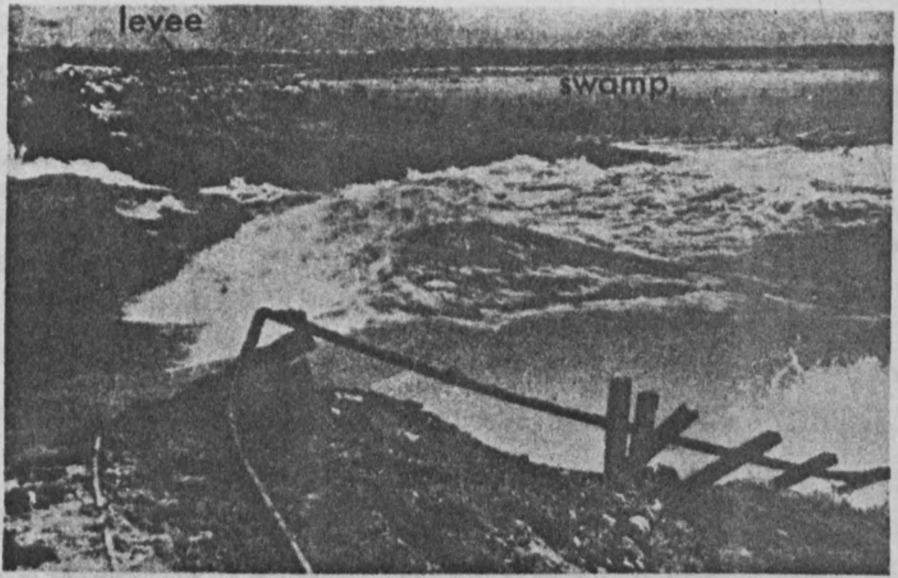
(10) Jervois – the main break in the levee occurred during a heavy storm at midnight on 1st September, 1956 (see Fig. 4.12).

The report also stressed that from recent soil tests the flooded soils have suffered no permanent damage, in fact in some places flooding has helped to reclaim previous salty patches. Furthermore, the seepages reported to have occurred behind the levee banks do not appear to have caused damage to natural vegetation, and although the water tables were more highly saline at the time of flood no appreciable quantity of salt has been left behind in the soil as the water table receded.

Fig. 4.12 Levee gap at Jervois.

"two pictures of huge rapidly widening levee gap, at Jervois. A roaring wall of water, about 3.7 m deep swept over the pasture land. A change of wind to the south caused the breach, with a banking of the rising waters resulting in terrific pressure on the levee."

The Chronicle 6/9/56.


levee
swamp

The most notable results of the 1956 flood activity on the floodplain observed during field work, were gullying and salt encrustration at Roonka (see Figs. 3.27, 28), and silt curtains on levees at Katarapko Creek, Berri district (see Fig. 3.29).

The increase in discharge alone associated with the flooding was not responsible for the major damage during the 1956 flood. The combination of storms as well as high water presented the most critical conditions, as can be seen in the reports in the Advertiser, 10/8/56:

> . . . whipped up by 50 m.p.h. (80.5 kph) winds Lake Alexandrina and Albert became raging seas yesterday as white capped breakers 6′ (1.8 m) high pounded the shores, smashed down levees, cutting main roads, and flooding lakeside homes . . . Barmera had a serious emergency yesterday, when waves sweeping for 9 miles (14.5 km) across Lake Bonney were seriously eroding the town's northern bank.

With respect to channel morphology, flood activity can result in local channel modification, in breaching or building, and in cutoff and oxbow lake formation. However, from a close study of the 1906, pre-weir construction, and aerial photography analysis, little overall change in channel morphology in recorded time was seen to occur.

(b)*Changes in the position of the Murray Mouth, especially in historical time*

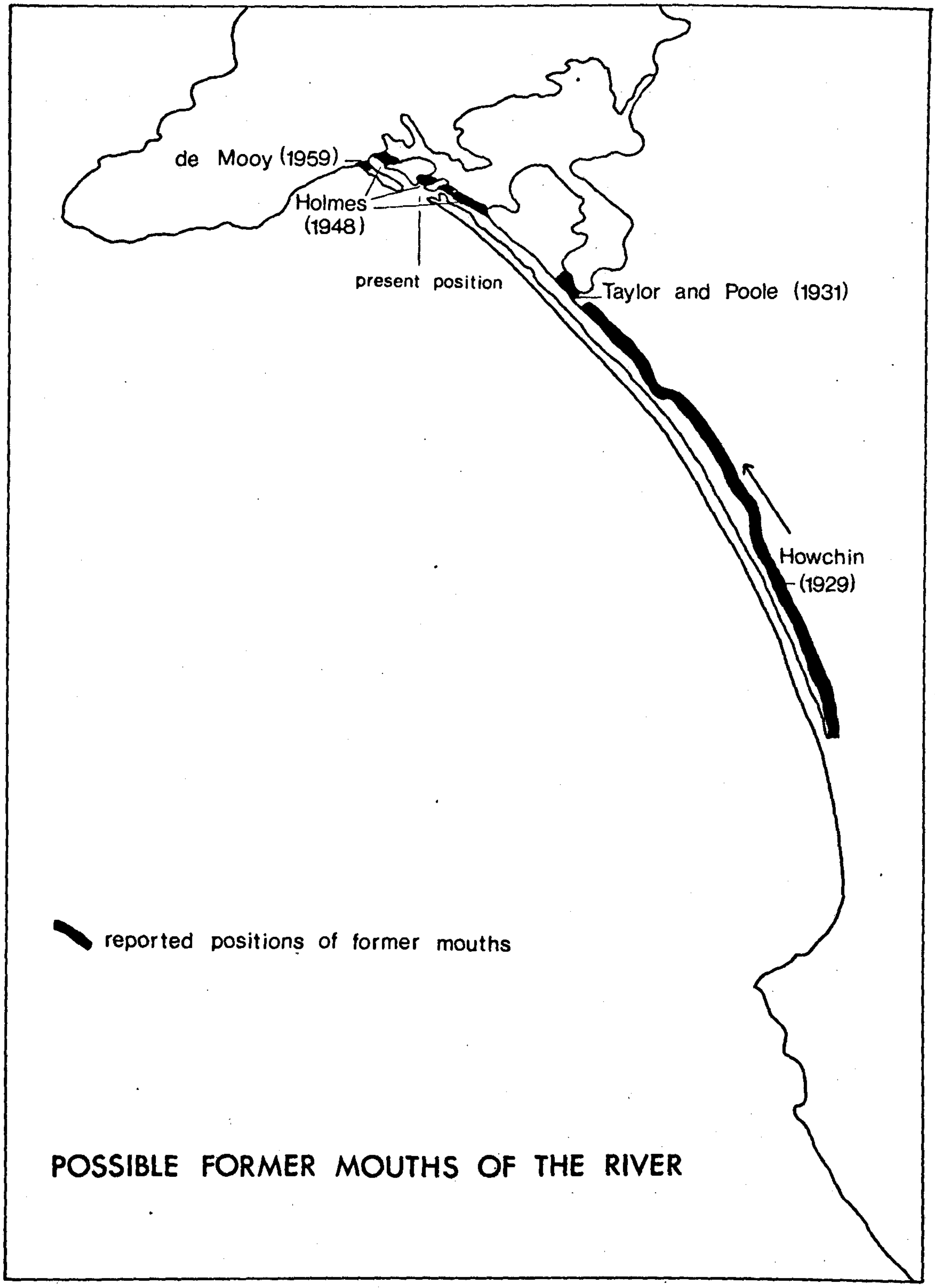
The position of all river mouths is known to fluctuate. A study of the changes in the Murray River mouth may reveal variations in discharge, and coastal processes. However, before discussing the relatively minor fluctuations in historical time, it is necessary to describe past positions over geological time (see Fig. 4.13), since these might explain the present and future positions.

(i) *Former positions of the mouth*

Howchin (1929) suggested that it was not improbable that the river at one time had its mouth situated more to the south in the direction of the base of the Coorong. He considered that the growth of the encroaching sandridge, resulting from the action of the prevailing southwest and southeast winds gradually drove the outlet northwards.

Taylor and Poole (1931) maintained that the Murray at some stage flowed through Lake Albert to join the Coorong. The evidence they used was derived from soil survey reports and the location of silted up river channels.

Holmes (1948) proposed that the Murray River was multi-mouthed, the water escaping simultaneously out to sea through a series of well defined channels (those which now have barrages constructed across them). All except the most northerly (Goolwa), became partially blocked as a result of the combination of earth movements i.e. uplift of the coast in Pleistocene times, and ocean current activity. In turn, the northern channel was also blocked and the river was forced to flow southwards.



POSSIBLE FORMER MOUTHS OF THE RIVER

FIG. 4·13

de Mooy (1959) described the former outlet of the river located near Goolwa, just to the north of the road to Goolwa Beach. Here, he claimed there was good evidence, such as a marked narrowing in the coastal dunes and their relatively low altitude compared with the dunes south along Sir Richard Peninsula, and north to Port Elliot. Soil surveys again indicate a channel-like pattern of alluvial deposition (connected with the Goolwa channel) immediately landward of this area.

(ii) *Physiography of the mouth today* (see Figs. 4.14, 15, 16)

The mouth is non-deltaic, because of the settling basins of Lake Alexandrina and Albert. Occasionally staining out to sea has been reported, but the material mainly consists of sand blown from Sir Richard Peninsula into the channel, and then transported through the mouth. However, arrangements have been made to resume some 4.99 hectares) of Sir Richard Peninsula with a view to preventing such sand drift. Extensive areas which have hitherto been sandhills subject to drift have been planted with Marram grass (*Ammophila arenaria*) pyp grass (*Ehrharta villosa*), and bushy shrubs. It is also intended to keep stock off the reserve (Eaton 1945).

There is a bar across the mouth at the shore line position. It has been seen to advance out to sea. Various records have been kept of the depth of water across the bar, one of the most interesting being in the "Log Book of the Murray Mouth Signal Station," a record of happenings at the station from June 5th to June 30th, 1881, compiled by James McRobert (in Finnis 1953). The bar is submerged except in times of drought, with the average depth of water being 2.4 m–3.0 m.

Two spits lie either side of the mouth, Sir Richard Peninsula to the north and Younghusband Peninsula to the south. Dunes developed on the former attain a height of 11.3 m–25 m, on the latter 42.7 m–49.4 m.

According to Fraser (1969), interference with the natural outflow of the Murray River resulted in a build up of a sandy shoal, with tidal currents depositing sand in a "delta-like" formation. Pale sandy cloud-like features beyond the surf zone characterize the mouth and Younghusband Peninsula (see page 61).

The position of the mouth in historical time is related directly to the action of longshore drift. Fortunately, fluctuations in the position in the past have been recorded by various people and comprehensively described and compiled by a Major Johnston, who was brought out from U.S.A. by the South Australian Government to make a study on the feasibility of constructing a harbour at the mouth, or a channel through to Goolwa, to serve the Murray valley. This account is tabled in the Proceedings of the Parliament and Papers of South Australia (1917).

Fig. 4.14 The mouth of the Murray River, 28/12/60, showing the physiography.

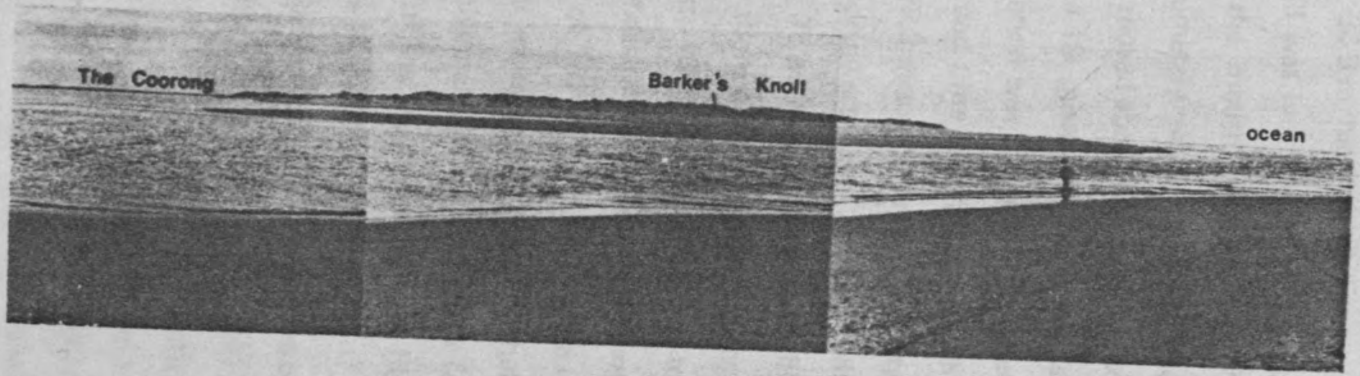
(Department of Lands).

A	Sir Richard's Peninsula
B	Barker's Knoll
C	Younghusband Peninsula
D	The Coorong
E	Hindmarsh Island
e	Holmes Creek
f	Boundary Creek
G	Boundary Creek
H	Mundoo Island
d	delta
c	channel
md	mobile dunes
fd	fossil dunes
s	shoals


N
G
E
River Murray
e
H
A
s
s
f
c
B
d
fd
C
md

Fig. 4.15 The channel, at the Murray mouth, 6/2/73. The channel is 30 m wide and 1.5 m at its deepest point. Barker's Knoll is a prominent residual sand dune at the northern end of Younghusband Peninsula.

Fig. 4.16 Panoramic view of the Murray Mouth, looking towards the ocean. The Murray River had ceased to flow 6/2/73. However, the water in the Coorong was still draining through the outlet.


The Coorong
Barker's Knoll
ocean

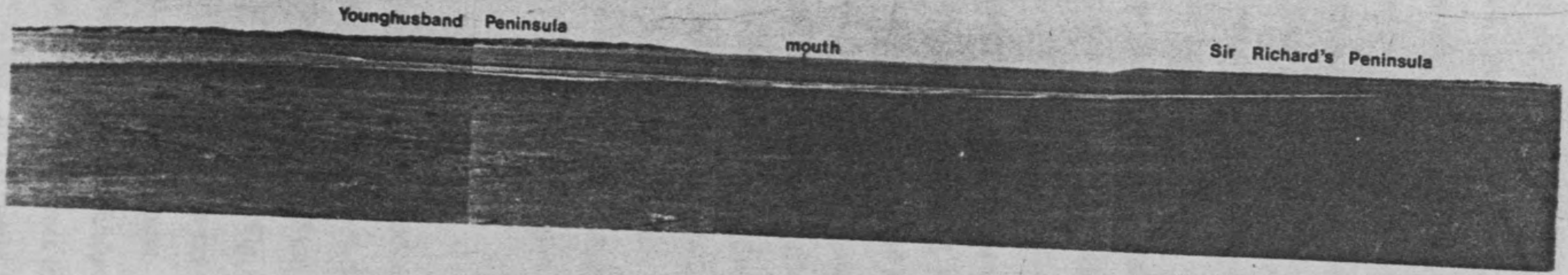

Younghusband Peninsula
mouth
Sir Richard's Peninsula

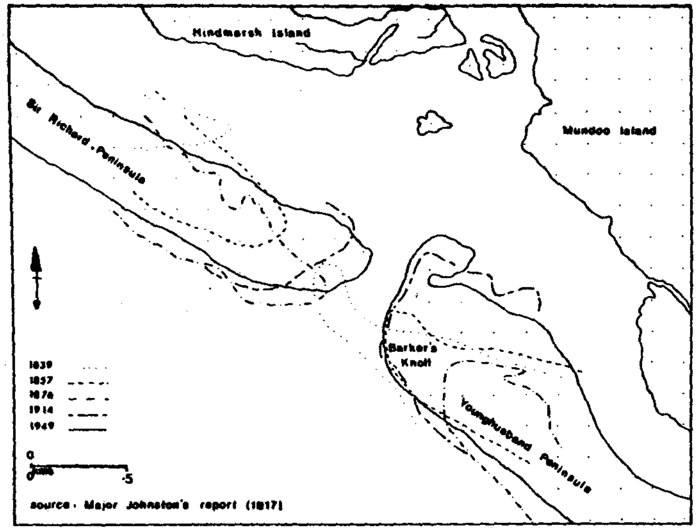
Fig. 4.17 was produced by reducing the scale of a chart drawn by Johnston and superimposing it on an aerial photograph of a scale 1:15,840 taken in 1949. A study of this comparative chart shows that between 1839–1857 the mouth moved about (488 m) to the southeast, between 1857–1876, a further (427 m) in the same direction. During this time, actually between 1857–59 the river eroded and completely removed Barker's Knoll, a sandhill about 30.5 m high, resulting in the estimated removal of 1,016,000 tonnes of sand. This sandhill was located near the northern end of Younghusband Peninsula. Between 1876 and 1914 the mouth moved about 457 m westward and the width of both spits grew to approximately twice the prior recordings. The net result of these movements was that the mouth moved about 457 m to the southeast of where it had been in 1839.

Fig.4.18 shows the fluctuations in the position of the mouth between 1919 and 1967. Information was taken from a series of aerial photographs from the Lands Department. In the unrecorded time interval between the two maps, 1914 to 1949, there was a small movement of about 18.3 m to the southeast. Between 1949 and January of 1956 the mouth moved 149 m to the northwest. From January 1956 to September, the height of the flood, the mouth moved another 75 m to the northwest, illustrating the effect of the increase of discharge on the configuration of the mouth. Between 1956 and 1960 the mouth moved 250 m to the southeast, 1960 to 1965 350.5 m to the northwest, and 1965 to 1967 (50 m) back towards the southeast. The net result of these movements since 1949 was toward the northwest by a distance of 137 m. Comparing these rates of movement with elsewhere these fluctuations seem small, for example the River Mitchell at Lakes Entrance, Gippsland, shifted 3.2 km before a cement channel was built in 1896 (Johnston 1917). For the maximum fluctuations in the position of the Murray mouth see Fig. 4.19 and for the changes in the mean position of the mouth see Fig. 4.20.

(iii) *Factors influencing the fluctuations in the Murray mouth*

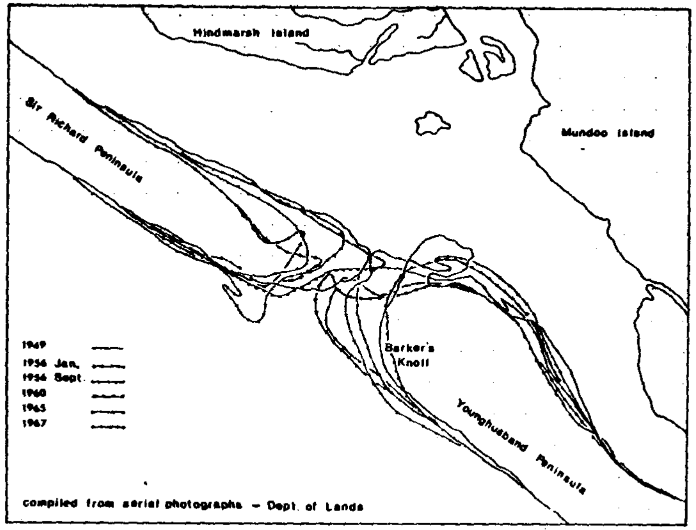
Longshore drift. Johnston (1917) carried out a detailed investigation concerned with the direction of longshore drift in relation to dredging costs for the possible harbour site. Wind directions and durations were plotted (see Fig. 4.21). Winds less than 32.2 km per hour were ignored, being considered uninfluential in the operation of longshore drift. Fig. 4.21 shows the results of his findings. Only onshore winds have been plotted: the total, the durations, and the directions for 1915. These were plotted against the line drawn normal to the shore, representing the axis of wind effect on longshore drift. The following conclusions were drawn: for the coast opposite Goolwa winds were southwest, producing a southeast longshore drift, and for the mouth, also a southeast longshore drift. However, in Lacepede Bay, north of Kingston, near the base of the Coorong, southwest winds produced a north/northwest longshore drift.

FIG. 4·17 CHANGING POSITIONS OF THE MURRAY MOUTH 1839 - 1949



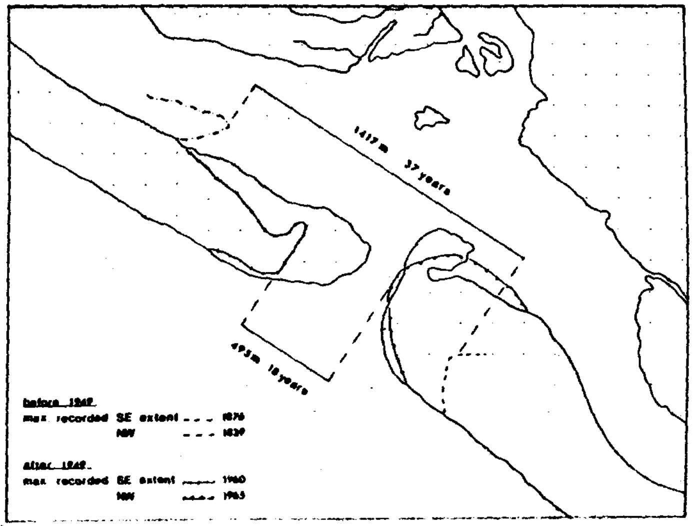
source: Major Johnston's report (1817)

4·18 1949 - 1967

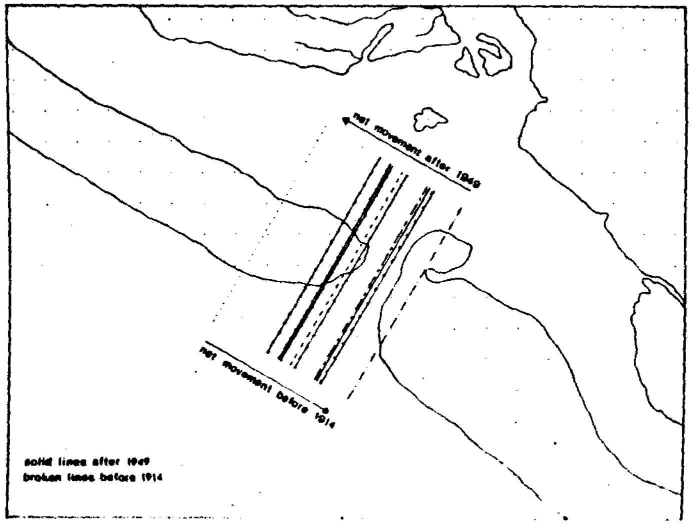


compiled from aerial photographs – Dept. of Lands

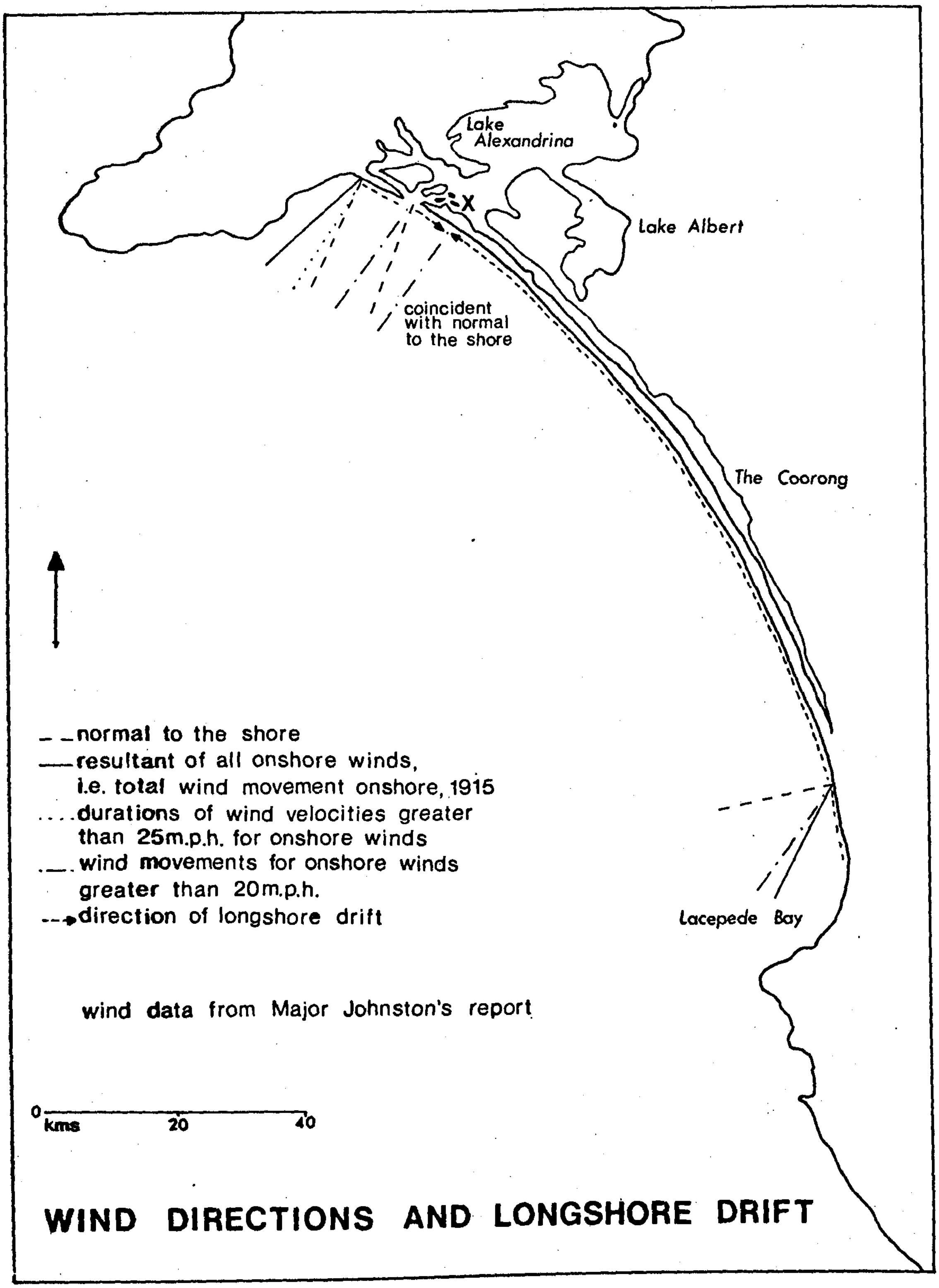
4·19 MAXIMUM FLUCTUATIONS IN THE POSITION OF THE MURRAY MOUTH < 1949 >



4·20 MEAN POSITION OF THE MURRAY MOUTH 1839 - 1967



solid lines after 1949
broken lines before 1914



WIND DIRECTIONS AND LONGSHORE DRIFT

FIG. 4·21

The wind directions are the same but their effect was a direct result of coastline configuration, or orientation.

"X" indicates the place where wind movements coincide with the neutral axis of wind effect. This lies just to the south of the mouth, and its presence is expressed in the landscape by the highest sand dunes, and the greatest width of Younghusband Peninsula. This is where the two opposing longshore drifts converge, and where one would expect to find a build up of sand reflected in a convex pattern in the fathom lines over the continental shelf. However, sufficiently detailed admiralty charts do not exist to provide such supporting evidence.

There is no evidence of the northwest trending longshore drift continuing north of the Murray Mouth. The bay between Goolwa Beach and Port Elliot is showing no signs of rapid infilling. Instead there appears to be a constant thickening of Younghusband Peninsula with its growth eastwards over the Coorong.

Sprigg (1952) suggested that in the southeast of this state longshore drift is not taking place on a large scale. He claimed that the sands of the foredunes are not being transported along the coast from Victoria to the Murray Mouth as has been claimed. Also great seaweed meadows lie in the sheltered bays and would, he argued, inhibit transfer of sand. Furthermore, Younghusband Peninsula is not a sandspit, but a submerged range, formed in the past, i.e.,not related to present day process, and the Coorong is an interdune corridor. There has been progressive downwarping northwards and the Murray Mouth lies at the lowest point. An age range for the dunes is reflected in changing orientation, observed on aerial photographs. The stable vegetated dunes of east/west orientation, and thick decalcified swales are in contrast to the mobile southwest/northeast trending dunes of today. This dune assemblage appears comparable to those developed on Newland Head (Bourman pers. comm., 1972).

Sprigg (1959) made note of an interesting phenomenon, which he called sand clouds, or more correctly suspension clouds. These appear to move northwards along most of the southeast coast. They hug the coast, but tongue out to about the 36.6 m below sea level. The material transported consists of fines from shallow waters plus increments from deeper water disturbed during storms. Perhaps these could represent the transporting agencies for much of the present sand accumulations.

Howchin (1929) a proponent of longshore drift, considered the Murray itself to have checked the northerly travel of sand, producing the unusual height and width to the sandhills of Younghusband Peninsula, immediately to the south of the mouth. However, it is felt that the sandhills themselves determine the position of the mouth.

It seems that the present mouth lies in a relatively stable zone, which may nevertheless suffer internal fluctuations. This equilibrium point represents the area where the effect of longshore drift from the southeast is counterbalanced by the effect of the northwest drift. The result of this convergence is to build up a solid barrier to penetration by the river. Here, as mentioned before, is the thickest and deepest accumulation of sand. Younghusband Peninsula could only be breached several kilometres to the south, if at all.

(iv) *Conclusions*

Fluctuations in the mouth region in historical time result from the following causes, acting singly, or in combination; strength of the wind (with winds less than 40 kph, longshore drift does not operate); increases or decreases in the source of sand for transport; increases or decreases in tidal scour; changes in discharge resulting from the effect of the construction of the barrages to regulate the flow from the river system; the effect of climatic variations, (for example drought when no actual mouth or outlet is present), and the effect of drainage schemes in the South East, which have altered the volume of water in the Coorong, and the flow through the outlet. There is, therefore, a complex of interacting variables determining channel morphology of the Murray River mouth, on a large scale, and in detail, for example hooked spits trending inwards in 1965, or outwards in January 1956, and the variable flexuring of the channel itself. Problems encountered in this study included the reliability of the original data of Johnston (1917), especially in respect to the mapping, the difficulty in distinguishing the exact position of the channel at the mouth between high and low tide on the aerial photographs, and the lack of available statistics and sand source analyses.

(3) Past channel patterns

(i) *Lagoon and cliff form*

A lagoon in this text is used to describe a body of water with free flow of water within it. It may be connected at one end only to the main river channel. A swamp represents a dried up lagoon, colonized by vegetation. Man has been responsible for some of these along the floodplain, by the construction of drainage ditches, for example, Lake Coonambidgal, to the north of Renmark.

Past channel patterns reflected in lagoon and cliff form can be used as indices of variations in channel pattern over time. Generally, angular and arcuate lagoons dominate the floodplain downstream from Overland Corner, but upstream they are without exception arcuate to sinuous in form. Structure (nature of the bedrock, and the narrow width of the valley) is suggested as the dominant control of form of past channel patterns.

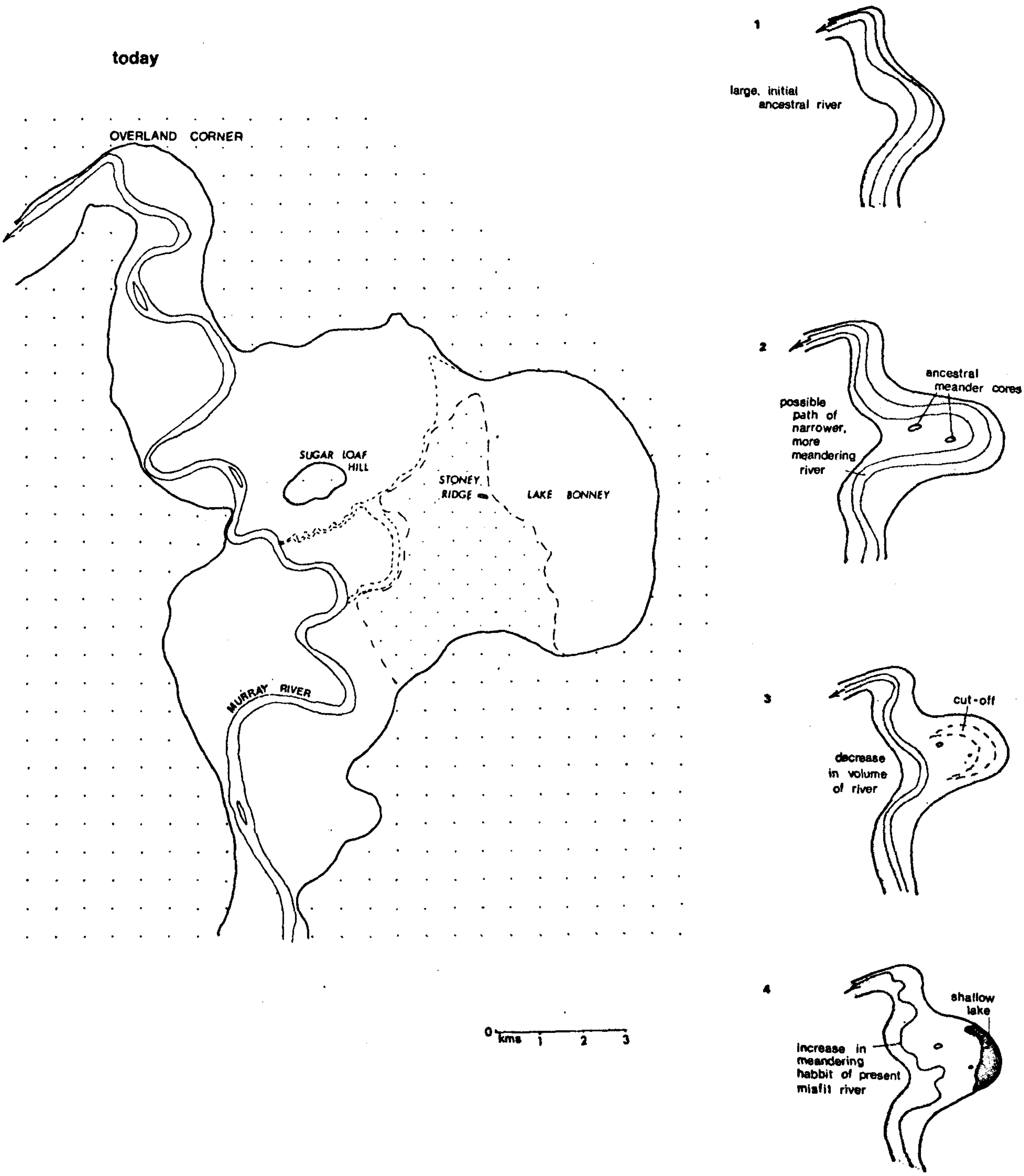
Variations in discharge between the two regions is negligible, with little evidence of past tributaries contributing to the volume of the river. A variation in age could be suggested as an explanation for the change in nature of the lagoons. Different stages of vegetation colonization could contribute to minor variations in shape, Height above river level, or isolation from the present channel could determine whether inundation from artificial damming through lock construction has been responsible for their propagation. The plans of the lagoons were, however, taken from the E.&W.S. plans of 1906, and pre-weir construction. The swamps, which became lagoons at the time of high water/flood were ignored for purpose of this exercise. Pels (1971) reported recent fluctuations in the level recorded in beach levels, and a great variation in water quality within the lagoons of the Murray River floodplain, some being highly saline, others in close proximity to the river containing fresh water. The dry lagoon beds may consist of non-saline soils, or thick layers of evaporites closely linked to the hydraulic rēgime of each lagoon (Pels 1971).

A detailed study was made of the cliff/lagoon/channel relationships with respect to the changes in channel direction over time, from Teal Flat to the Victorian Border. The number of occurrences of the relationships are as follows: angular channel to curved lagoon and cliff = 23, angular channel to angular lagoon to curved cliff = 14, curved channel to curved lagoon and cliff = 15, and angular channel and angular lagoon to curved and straight cliff form = 19. From the study of the above occurrences it can be concluded that there is a general progression of curved cliff to curved lagoon to angular meander channel today, with a possible future meander channel. It is suggested that the angular lagoons represent more recently abandoned channels than the curved lagoons in the limestone gorge section of the Murray valley. Distance of the downstream migration of the channel with the maintenance of a constant angle, vary from 0.4 km to 3.2 km, but the most commonly occurring length appears to be 0.8 km. The relative abundance of curved channels to curved lagoons and cliffs seems to suggest that the angular meander form may be adjusting/reverting to a more sinuous form, i.e. the peak of angular development of the bends has occurred, and under the existing conditions of discharge, load, slope and velocity, is in a state of adjustment of channel form.

(ii) Lake Bonney, a large lagoon, at R.L. 42.3 m, and a depth of 4.1 m, has a controlled capacity of 6,700 megalitres with a water loss of 43.2%, and a salinity of 3,300 p.p.m., in 1968 (Department of Lands). Three minor beach levels, about 9 m apart are located along the eastern shore and represent recent fluctuations in lake level. These are fringed by a lunette-like landform (see chapter I). The existence of this body of water is suggested as being due to a former channel location. Subsequently the river had a straighter course, but now is developing a tighter sinuous pattern (see Fig. 4.22). It is suggested that the original meander was

FIG. 4·22

LAKE BONNEY



today

possible development of the lagoon

developed as the result of a banking up of, or tightening of the meandering habit of the river before it entered the relatively narrow confines of the valley at Overland Corner; a similar effect to that at the entrances of large bodies of water, for example lakes and oceans.

(iii) *Lakes Alexandrina and Albert*

The evolution of these shallow but large bodies of water has been comprehensively recorded by de Mooy (1959). These large, formerly tidal lakes receive the discharge of the Murray River, Bremer, Angas, Finniss, Rivers and Currency Creek. The lakes have had a complex evolution, and it is generally agreed today that tectonism (downwarping), and the retreat of sea level, combined with the action of longshore drift, are the processes responsible for these large sedimentation basins. Minor depositional features within the lakes include the Bremer River delta and the tombolo at Pomanda Point south of Wellington. de Mooy (1959) concluded that the former extent of the lakes was due to a greater volume. His map of extensive sedimentation of the Malcolm Deposits delimited this area. The retreat of the high lake level occurred by degrees, and the gypsum precipitates indicate a brackish water environment (de Mooy 1959).

In conclusion, a study of the two major lake areas today does not throw much light on past channel morphology.

4. CONCLUSIONS

The effect of change in channel form over geological time with river intrenchment is discussed in the next chapter. From the above descriptions of change over a smaller time scale it can be concluded that the changes in the channel of the Murray River in juxaposition (meandering to angular), or in location can be attributed to variations in locally independent factors; the most dominant appear to be the structure of the materials making up the valley-side slopes, and the variations in discharge.

CHAPTER V

MISFITNESS

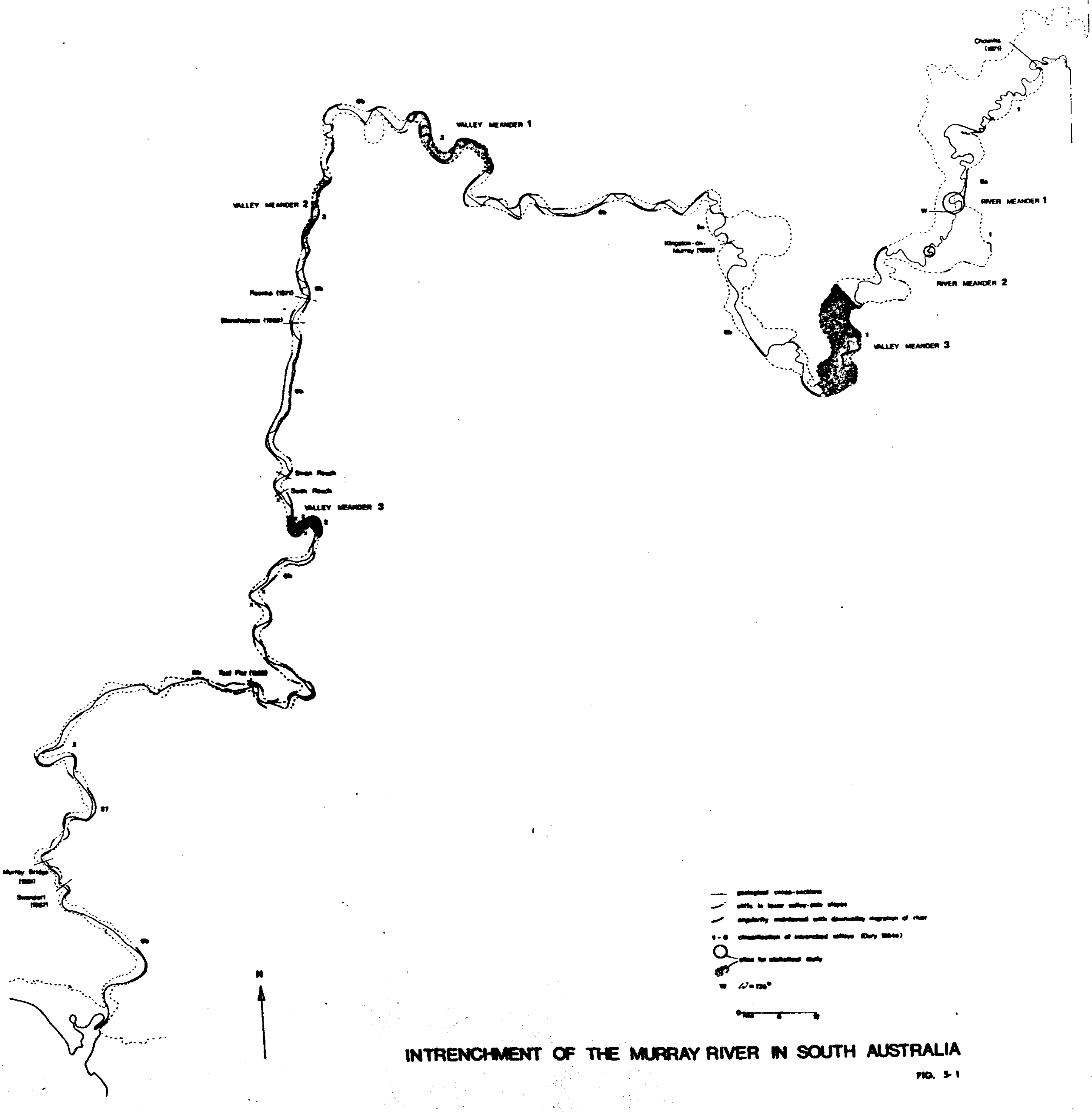
1. INTRODUCTION AND DEFINITIONS

The present Murray River in South Australia flows within the confines of steep valley walls. Ubiquitous river valleys, however, vary greatly in dimensions, relief, gradient, and slope of the valley-side walls. These are reflected in the river's cross and longitudinal profiles. Chapter II on valley-side slopes established the general type of cross profile, as well as local variants. However, the longitudinal profile of the valley floor, i.e. the bedrock profile, has not been established because of the enormous augering which would be necessary at systematic intervals both across and along the valley from the Victorian Border to the mouth. Fortunately, local transverse profiles do exist in both published and unpublished Mines Department records. Fortunately, copious measurements are available for the longitudinal profile of the present channel bed form, from the E. & W.S. 1906 plans.

An initial glance at maps or aerial mosaics of the Murray valley shows the relatively small present river flowing in a deep, and much wider valley. This is especially noticeable upstream from Overland Corner where the dimensions of the river do not seem to reflect the valley morphology (see Fig. 5.1). Similar apparent discrepancies have been recorded in both the northern and southern hemispheres, and much research in the last decade has taken place in Australia, especially New South Wales, by Dury and his students.

The term misfit was first applied by Lake and Rastall (1910), to a stream whose size and form suggest that it did not erode the valley in which it was formed. Misfit streams are of two basic types, overfit and underfit, but with many subdivisions. The most commonly recognized case, and that applicable to the Murray River, is the underfit river, i.e. one which is too small to have eroded the valley in which it flows. The condition of underfitness can persist indefinitely (Thornbury 1969). The term ancestral river will be used for the river which seemingly predated the present river and appeared to have different morphological characteristics. Pels (1971) made a distinction between prior streams and ancestral rivers (see p. 74).

Misfitness is used in this thesis to describe the apparently anomalous condition described above. In the research area, it was necessary to establish whether in fact the Murray River can be described as misfit and then to enumerate the probable causes of this misfitness. By considering all field evidence, observations, and statistical analyses the changes in channel location over geologic time were established. These may help in the understanding of the present river régime and morphology. However, it must be acknowledged that because a river is



INTRENCHMENT OF THE MURRAY RIVER IN SOUTH AUSTRALIA

FIG. 5-1

apparently too small for its valley it does not mean that given time, small streams cannot excavate large valleys by lateral erosion (Twidale 1968).

Since the geometry of the valley of the Murray River appears to stand in contrast to that of the river now flowing within it, it is necessary to substantiate the fact statistically. A direct relationship between discharge (volume), stream width (w), and radius of meanders (rc) is observed from studies of modern rivers. Present rivers have a certain width of channel and length of meander related to modern bankfull discharge. Also, there is field evidence of greater radii of curvature in the ancestral rivers, which could be indicative of higher discharges and channel width in the past. Thornbury (1969) argued that the evidence of pronounced shrinkage in meander radii gave the strongest support for an underfit condition. Former radii are indicated by the curvature in the valley walls. However, Dury (1964a) regarded the size of meanders was best expressed as wavelength compared with bedwidth. He argued that amplitude of the meander belt and radius of curvature of the meanders may be significant where measured on a floodplain, but that they may change during ingrowth, i.e. ingrowing loops commonly increase their amplitude and their radius to the limit of cutoff. Furthermore he argued that there was a practical limitation to map evidence because of lateral erosion destroying the form of the meandering valley. There is very little evidence of this along the valley-side slopes of the Murray River (see chapter II).

2. EVIDENCE OF FORMER RIVER ACTIVITY OVER GEOLOGIC TIME

(1) Statistical results

(a) *Valley windings as evidence of meandering habits of an ancestral river*

The test for river meanders and valley meanders of their approximation to sine-generated curves, helps to establish the nature of the channel habit, i.e. whether it is meandering or not, if meandering to establish the size of the ancestral river, and to prove if a selected reach of today's river channel can be classified as meandering. In a paper, on which this analysis is based, Young (1970) suggested that the results contributed to the misfitness theory of Dury (see p. 77). He demonstrated that the form in plan of a number of meandering valleys is similar to that of free meanders. The theoretical background, formula derivation and use is outlined by Langbein and Leopold (1966). The application of this technique is described in Appendix B.

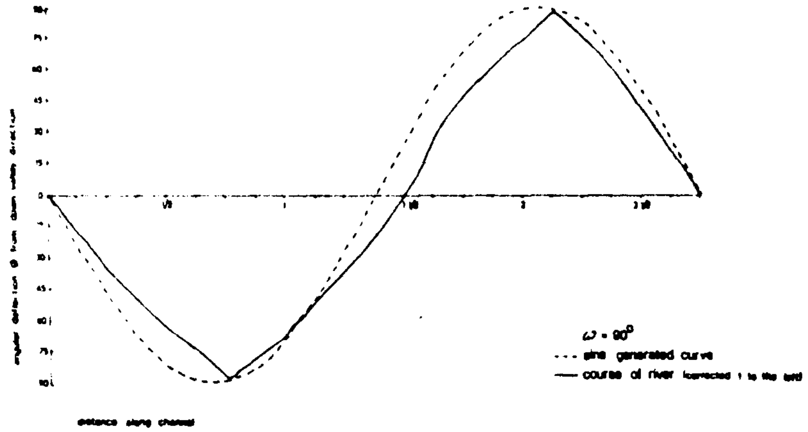
The formula $\varnothing = w \sin \frac{s}{M} 360^\circ$, is useful in illustrating whether a given reach does or does not possess a meandering habit. The reach selected to represent a freely meandering river is proved to possess channel direction changes, which are a sinusoidal function of distance. Also, the

FIG. 5 2

COMPARISON OF SINE - GENERATED CURVES AND RIVER MEANDERS

location: see figure 5·1

RIVER MEANDER 1



RIVER MEANDER 2

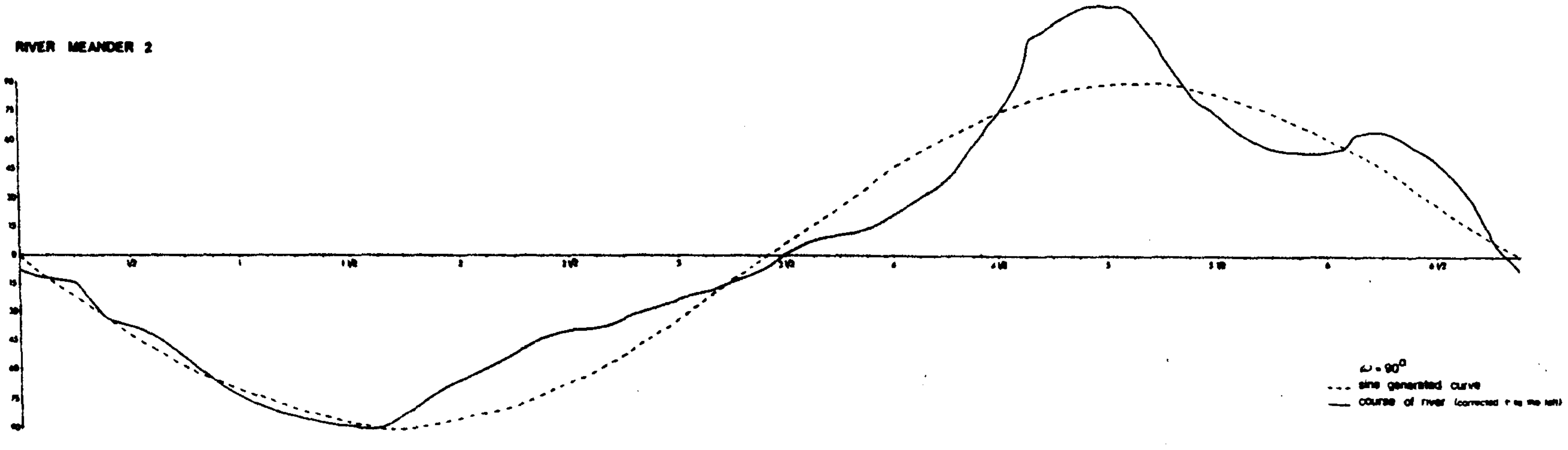
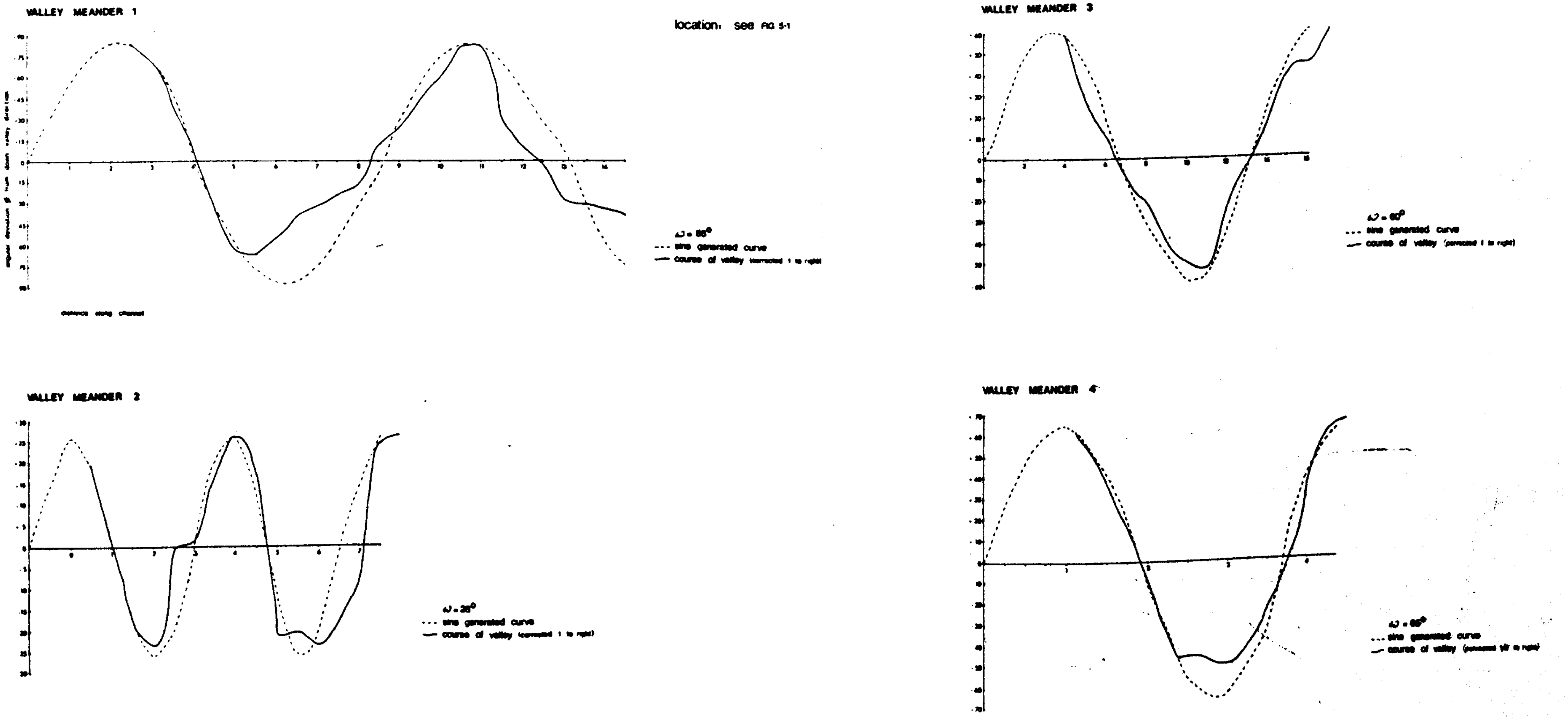


FIG. 5·3

COMPARISON OF SINE-GENERATED CURVE WITH VALLEY MEANDERS



location: see FIG 5-1

ancestral Murray River (as evidenced in the valley windings) is a meandering river both above and below Overland Corner. Three out of the four valley meanders chosen are found to be comparable to sine-generated curves within the statistical levels of correlation. Finally, distortions are shown to be present in both the valley meander pattern and the river channel (see Appendix A). It is agreed with Young (1970), that the similarity of stream and valley meanders alike to the sine-generated curve may form additional evidence in support to the climatic change hypothesis for the origin of meandering valleys (see p. 77).

(b) *Changes in the radii of curvature of the valley meanders (RC) and the river meanders (rc).*

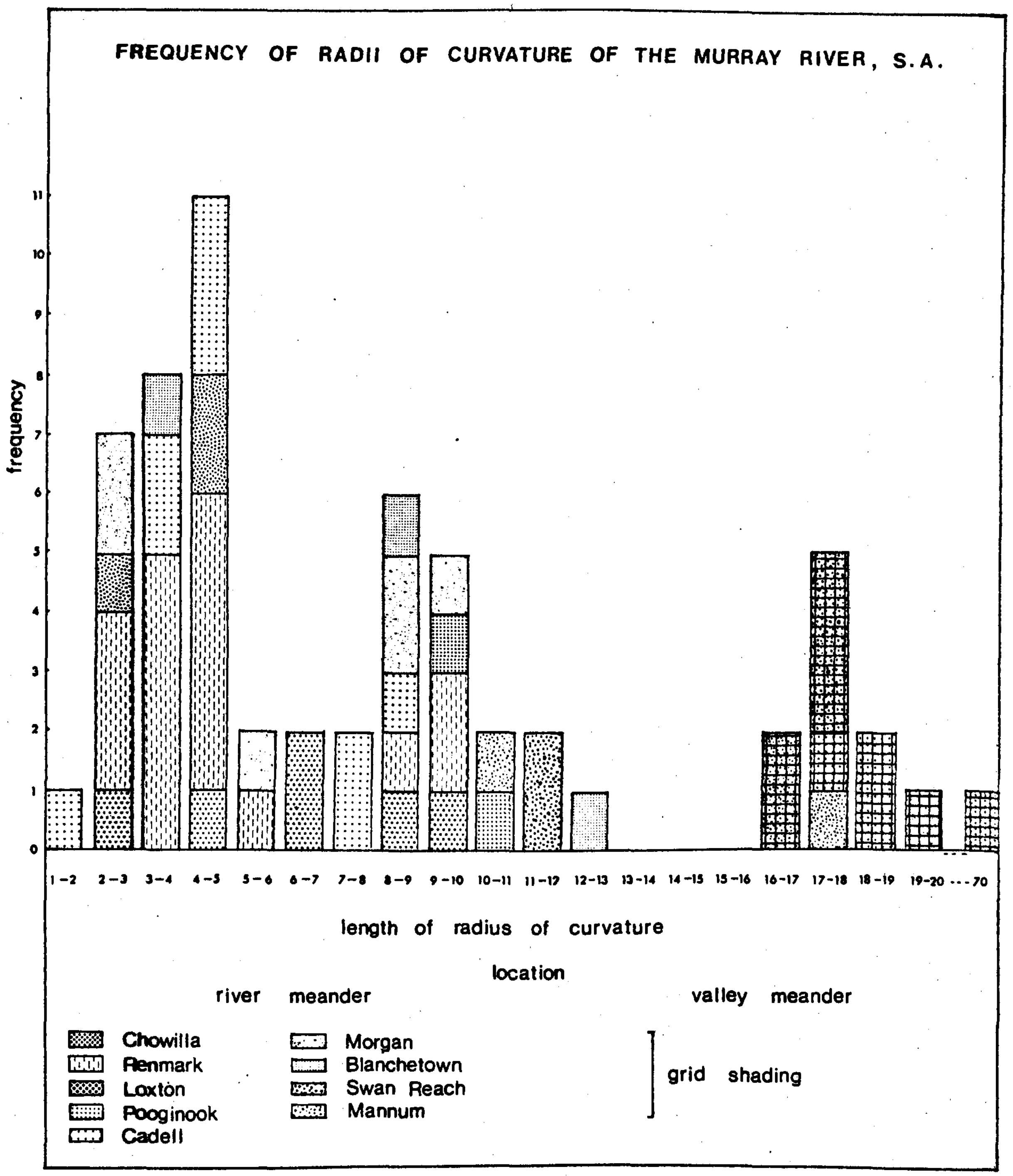
Variations in the radii of curvature are due to variations in discharge, width of the floodplain, and nature of the material through which the river is meandering. There are problems in measuring, with accuracy, the radius of curvature for both present and past channels. A certain amount of subjectivity is to be expected in the citing of the radius, and the small sample size may pose limitations on the results of the exercise. Also, it can be argued by definition that it is impossible to measure the radius of curvature of an "angular meander," i.e. the changes in channel direction downstream from Overland Corner. Similarly not all valley meanders for each segment were included in the data because of the enormous "pseudo-radius of curvature" of the ancestral channel.

The data from the Lands Department 1:31,680 topographic map is plotted on graph paper for the frequency of the radius of curvature, both for the valley windings (RC) and river channel (rc) (see Fig. 5.4). The results of the (rc) for the present channel are discussed in chapter IV. The (RC) are clustered at the opposing end of the scale, and suggest in all but one case, an appreciable shrinking of the radius of curvature. The two maximum (rc) occur for all sections of the river from the Victorian Border to Blanchetown, but from Swan Reach to Mannum the (rc) are equal, or surpass those of the valley windings. This similarity of the size of the channel direction change of the valley winding, and river channel may in turn be a function of nearness to the sea, or bedrock properties.

(c) *Changes in width between the valley windings (W), and the present river channel (w)*

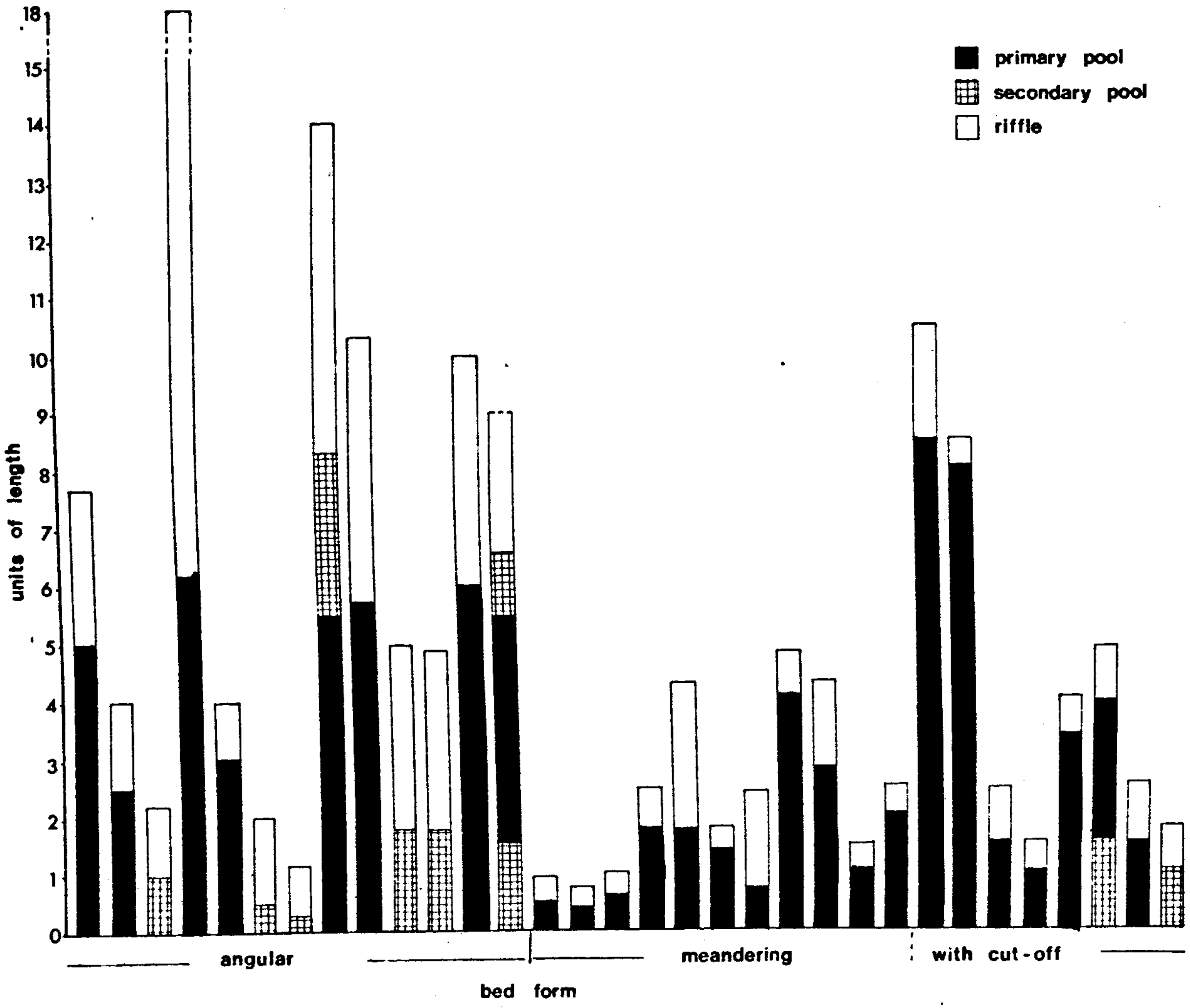
Dury (1964c), stated that the width of the channels of former streams are nine or ten times those of the present. The best position to measure (W) and (w) is at the inflection point of a meander, since either a widening of the channel occurs at the bends of the valley, or downstream from Overland Corner to Nildottie an appreciable narrowing occurs where large pools exist at major changes in channel direction (see Fig. 4.2, 3).

FIG. 5·4



FREQUENCY OF RADII OF CURVATURE OF THE MURRAY RIVER, S.A.

FIG. 5·5 THE VARIATIONS IN LENGTH OF CHANNEL BED FORM BETWEEN ANGULAR AND MEANDERING REACHES OF THE MURRAY RIVER



From calculations of width measurement it can be concluded that the valley of the Murray River from approximately Overland Corner to Murray Bridge, is comparable with the 9:1 and 10:1 ratio of Dury (1960), as an index of misfitness. Upstream from Overland Corner there is a discrepancy between the former valley (W), and the present channel. The nature of the bedrock, soft Pliocene Loxton and Parilla Sands, compared with the relatively resistant Miocene limestone is suggested as the reason for this. Therefore, Dury's basic assumption that the width of the meander valley is a function of discharge, is questioned. Resistance of the valley-side slope to lateral erosion seems to play a dominant role in the width of the incised valley.

(d) *Valley meander wavelength (L), and former channel width (W)*

Dury (1964a) and Pels (1971) compared the valley meander wavelength (L) and the estimated range of the former channel width (W) to give an approximate relationship of L/W = 13.

The results for the selected valley meanders of the Murray River are:

v.m. I	15:1
v.m. II	12.5:1
v.m. III	4.7:1
v.m. IV	3.1:1

It can be seen that when these results are compared with other examples, v.m. I and II conform to the ratio, v.m. III and IV do not (see Fig. 5.5).

(e) *Valley meander wavelength (L) and valley meander radius (Rm)*

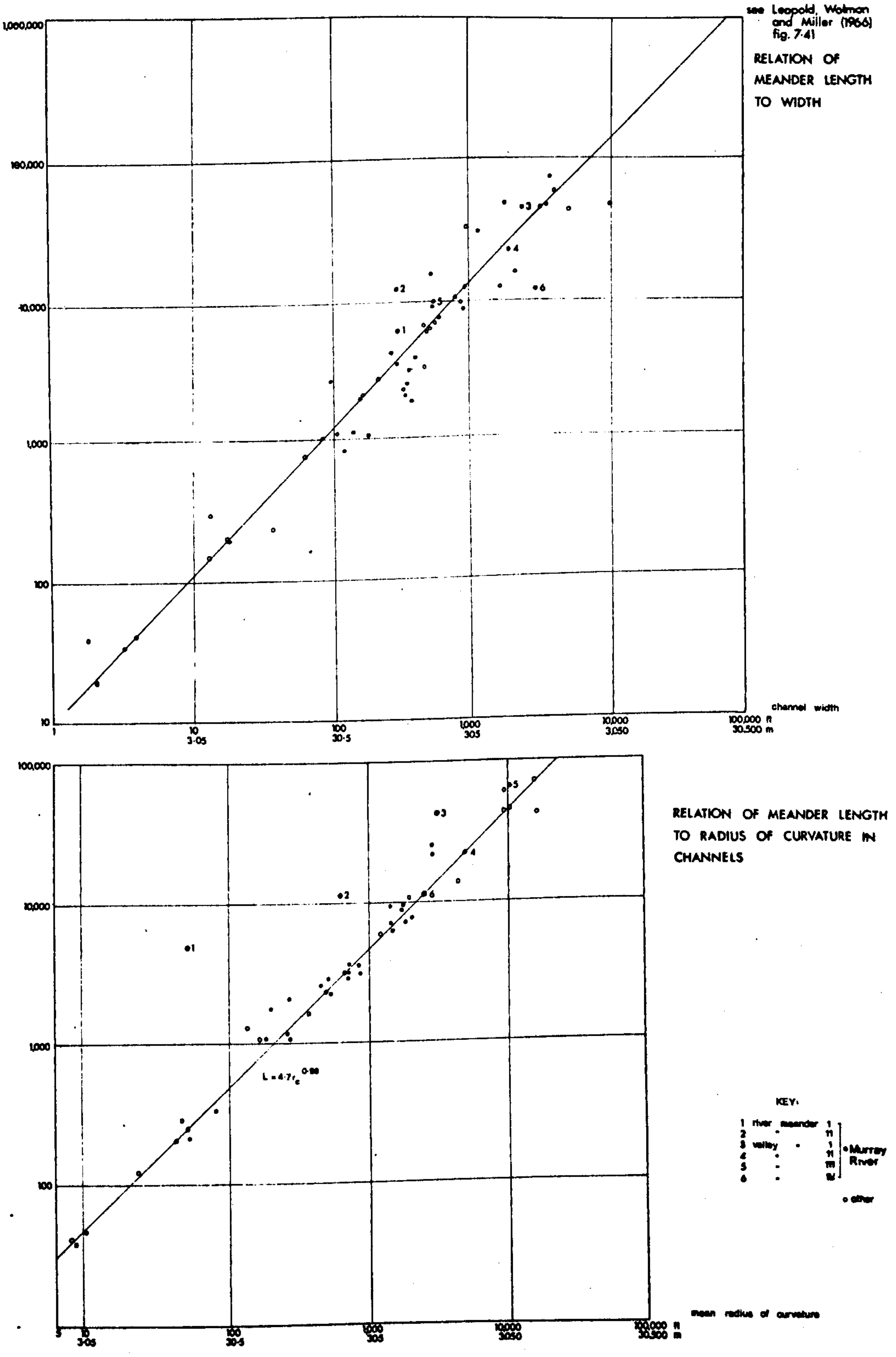
The geometric similarity of valley and stream meanders is further illustrated by the ratio of valley wavelength (L) to valley meander radius (Rm). The expected value is L/Rm = 4.5 (Dury 1964a). The corresponding relationship for free meanders is 1:4.7 rm 0.98 (Leopold and Wolman 1969).

The results for the selected valley meanders and river meanders of the Murray River are:

r.m. I	4.6:1
r.m. II	4.7:1
v.m. I	11.1:1
v.m. II	3.3:1
v.m. III	5.3:1
v.m. IV	4.5:1

A comparison with other examples shows that the meanders appear to fit in with the formula, but it is interesting to note that now the valley meanders III and IV are similar to the expected ratio but valley meanders I and II no longer conform (see Fig. 5.6).

FIG. 5·6 COMPARISON OF MISFITNESS DIMENSIONS OF THE MURRAY RIVER WITH OTHER RIVERS



see Leopold, Wolman and Miller (1966) fig. 7·41

Therefore, the results obtained from the testing of the morphology and dimensions of ancestral channels with those of the present rivers in other parts of Australia and overseas, seem to compare favourably with this statistical survey of the Murray River and valley in South Australia.

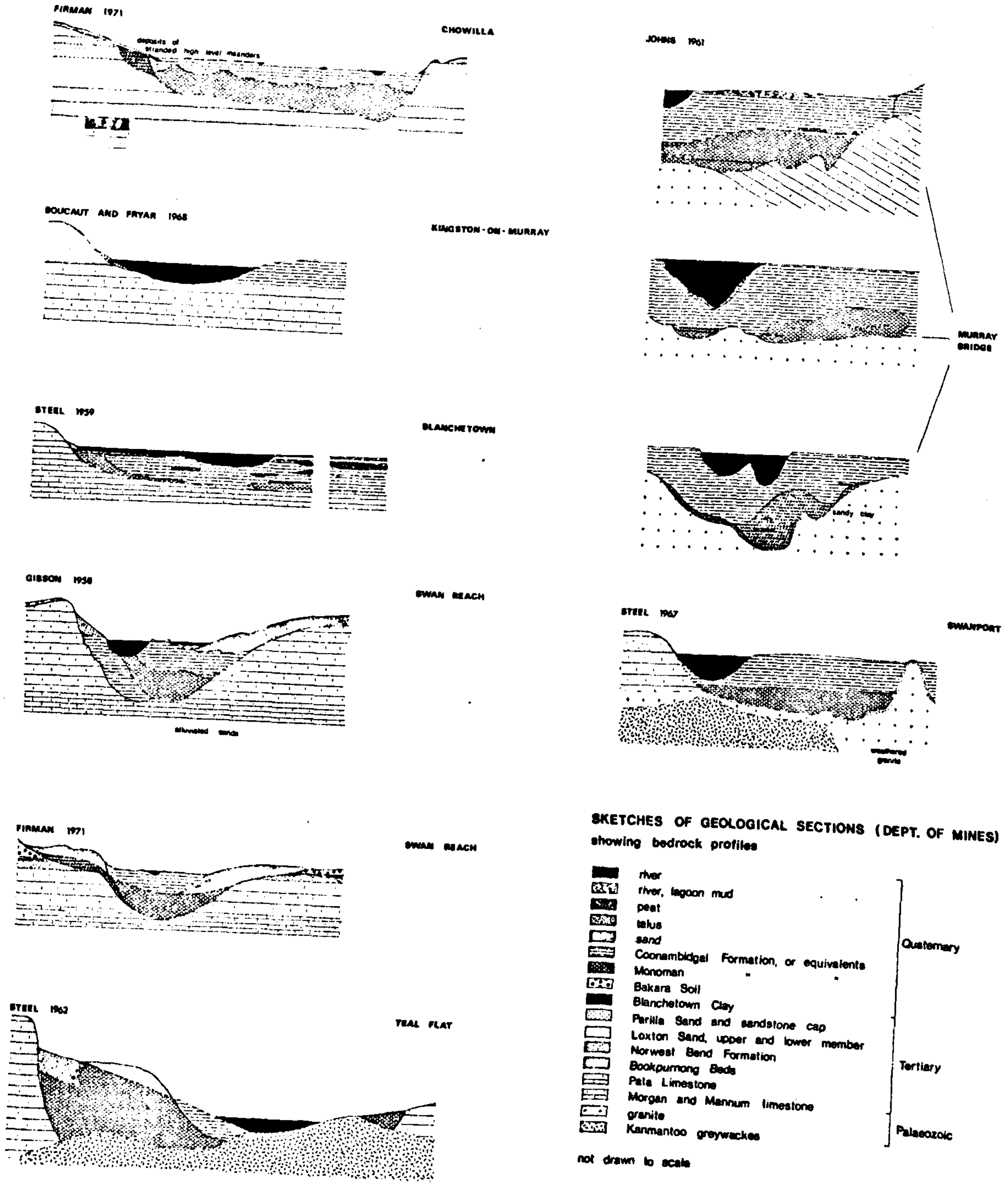
Further key evidence for establishing the former condition of the river is to be found in combining field evidence with topographic and geological mapping and cross sections. However, before local field evidence is discussed, it is necessary to describe and explain the location of the valley, This has been accounted for by geologists concerned with mapping of the area.

(2) Location of the ancestral river

It is suggested that the location of the ancestral Murray River was structurally determined. Lineaments, i.e. major trends in the basement rock, outcrops of crystalline rock, faulting and jointing of the Tertiary limestones have all played prominent roles in the channel location.

Interpretation of the geologic structure has been derived from a number of sources, for example from maps of aeromagnetic trends, and geological cross-sections constructed from borelog data. Analysis and mapping has been carried out on a broad scale firstly by Hills (1956), and then in more detail by O'Driscoll (1960) and Firman (1970). According to Firman (1970) the pattern of lineaments, although expressed mainly in brittle basin sediments and younger surficial deposits, suggested profound structures and tectonic elements in the crystalline basement.

Pronounced geophysical anomalies are present at Great Pyap Bend, and near the South Australian–Victorian Border (O'Driscoll 1960). These are reflected in both river and valley configuration. However, the most pronounced effect of the structure on the river valley location is the Morgan Fault. This is one of a group of faults in County Eyre and Sturt and appears to be part of a system of step faults down-throwing to the east and recurrently active since pre-Tertiary times, with the most active stage developed towards the end of that period (O'Driscoll 1960). Mills (1964) described the Morgan Fault as one of a family of younger meridional faults of a gravity type, for which there is evidence of a long and complex history of recurrent movement from the Late Palaeozoic to Recent time. The river valley runs almost north-south from Morgan to Blanchetown. The more sinuous course of the valley downstream from Swan Reach is attributable to the termination of the Morgan Fault and to the presence of crystalline outcrops, for example at Walkers Flat (see Fig. 2.30) and Teal Flat (see Fig. 5.7).



SKETCHES OF GEOLOGICAL SECTIONS (DEPT. OF MINES)
showing bedrock profiles

FIG. 5·7

(3) Field evidence of former river channels

The evidence of the existence of former river channels takes the form of morphological features of the valley i.e. the consistency of the radius of curvature, the smoothness of the meanders of the valley, crescentic scars cut in the valley side, abandoned loops, and the formation of slip-off slopes (Bates 1939). To these can be added the nature of the intrenched meanders, the form of the bedrock profile, the type and variation of the valley fill, the valley-side slope in detail, for example the erosion remnants, the marked breaks of slope, and the cliff form itself.

The morphology of the valley in terms of consistency and smoothness of the features can best be described statistically as above.

(a) Triangular valley-side facets (see p. 17).

(b) Marked breaks of slope (see p. 21).

(c) Disappearing cliffs (see p. 21).

(d) Valley fill (see p. 42).

Dury (1964b) suggested that the infilling of ancestral channels is ascribed to stream shrinkage, rather than to aggradation. From the detailed geological cross-sections, and unpublished reports from the Department of Mines, Sprigg (1952), Steel (1959, 1962 and 1966), and Johnson, Hiern and Steel (1960), there appear to be two phases of valley fill, which Firman (1971a) has called the Monoman and Coonambidgal Formations (for a detailed account of the sediments see p. 42). The oldest and that in contact with the basal bedrock in most examples is the Monoman, consisting of coarse gravels and sands. Some of the latter are interpreted as of aeolian origin, deposited during a phase of climatic aridity when there was no free flow of water downvalley. However, these sediments are thought to have been reworked in later pluvial conditions. Finer silty sands and clays make up the younger Coonambidgal Formation and it is suggested that the change in texture of the deposits could relfect a change in volume/discharge, velocity/gradient, and possibly source of sediments for the river. Thus this change in the type deposits could be used as supporting evidence for Dury's theory of stream shrinkage (1964b). However, the red alluvial terraces of the lower valley described in chapter III would appear to result from aggradation. Due to their proximity to the coast and their location in a regionally tectonically active area, they seem to qualify as aggradational deposits. It is suggested that the valley fills of the Murray valley in South Australia are a combination of both stream shrinkage and aggradation.

(e) *The bedrock profile*

Dury (1964b) demonstrated that valuable corroboratory evidence of former large channels exists in the shape of the bedrock profile, both in cross-section and longitudinal section. It is claimed that an asymmetrical bedrock profile of a cross-section is indicative of a former large channel, which meandered around large bends.

To date ten geological cross-sections have been drawn by the Department of Mines (see Fig. 5.7). Unfortunately, the sections were drawn at proposed dam and bridge sites. Since they occur at "inflection" points in the valley windings they are not located at the bends where the asymmetrical profiles would be expected. The sections of Gibson (1958) and Steel (1962), for Swan Reach and Teal Flat respectively, are the only sections to display some asymmetry, and it is interesting to note that these sections occur close to the bends in the valley windings. Unfortunately, the absence of data for longitudinal profile construction of the valley makes support of Dury's assumption unjustified.

Information of local significance to the question of ancestral river activity is contained in the report on the new river crossing at Swanport, 4 km downstream of Murray Bridge (Morris 1971). Drilling has exposed cavities up to 5.8 m deep encountered in otherwise fresh bedrock of very strong granite, and located in the Murray River very close to the right bank.

It appears that these features are a weathering phenomenon, and their presence helps to explain the depth of incision by an ancestral river. Furthermore, their presence may be used as support for climatic change. The weathering of the joints may have occurred as groundwaters circulated freely during a phase when the river had ceased to flow.

Similarly, the assemblage of granite landforms around Murray Bridge and 3.2 km northeast of Mannum, may have resulted from exposure of bedrock during intrenchment of the ancestral stream. Weathering probably occurred along the jointing planes, and was followed by the removal of the weathered products with river erosion and/or mass movements on the valley-side slopes. At Mannum sheeting, tors, flares, pitting, rillen, flaking, and gnammas are all developed on the Palaeozoic granite (see Figs. 5.8, 5.9, 5.10, 5.11).

(f) *Intrenched meanders*

A study of the nature of the intrenchment of the Murray River in South Australia may reveal some of the processes which lead to the present form of the river and valley.

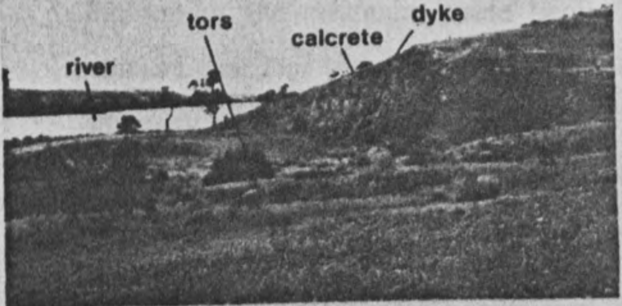
Intrenched meanders can be of two basic types. The generic definition according to Thornbury (1969), describes any meanders enclosed by rock walls as intrenched meanders. They can be subdivided genetically into two units, N + I cycle (Mahard 1942), and autogenic (Twidale 1955). N + I intrenched meanders are inherited from a plain surface, which existed

Fig. 5.8 The granite quarry northeast of Mannum.

Fig. 5.9 Northeast of Mannum. An inselberg granite form, possessing tor-like forms flared slopes, and sheeting.

Fig. 5.10 Scattered tors, northeast of Mannum.

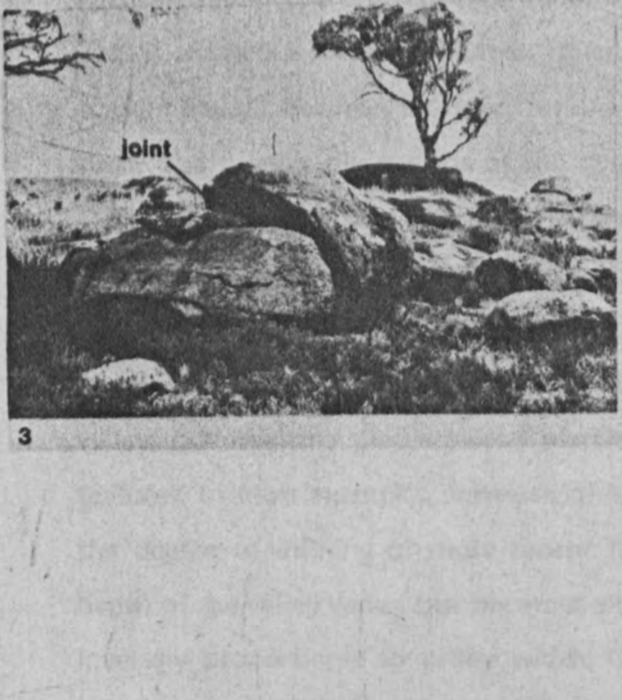
Fig. 5.11 Flares and flaking developed on granite at Swanport. The Murray River is immediately to the right of the granite outcrop.


tors
calcrete
dyke
river

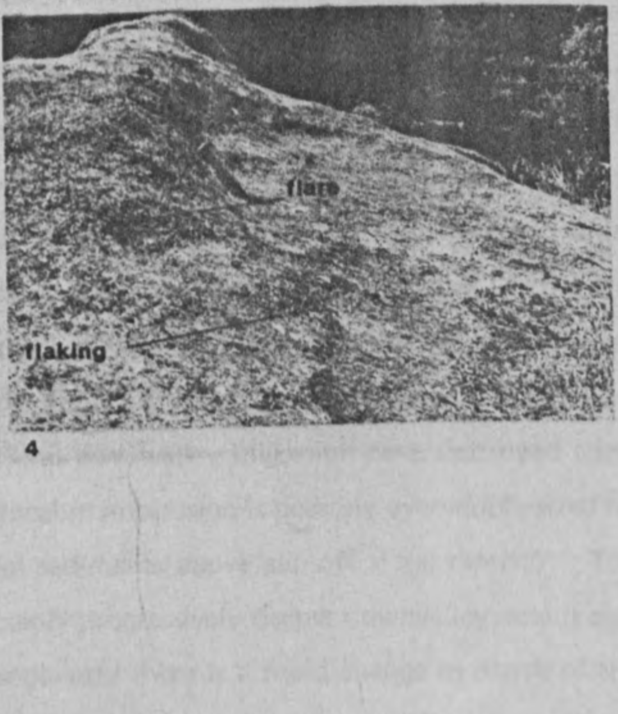
1


tors
sheeting

2


joint

3


flare
flaking

4

prior to uplift and rejuvenation. The intrenched river preserves the meandering habit, and the valley possesses a symmetrical cross-section. Rapid incision into generally resistant rocks is suggested by Mahard (1942) as the cause of N + I intrenched meanders. On the other hand, autogenic intrenched meanders with asymmetrical cross-sections are original features formed during incision, and by the enlargement of initial irregularities of a stream into serpentine bends, whilst the river is downcutting. Twidale (1955), using a similar technique to Sprigg (1945) for landsurface reconstruction, suggested that by linking the outer tips of alternate meander spurs at the upland level it is possible to establish the maximum limits from which incision of the meanders could begin. N + I intrenched meanders produce a line which is non-sinuous. This technique must be used with caution as Twidale claimed, since the degree of sinuosity of the line should be proved to be meandering. Furthermore, subsequent lateral erosion, with the lateral retreat of the valley-side walls, could have obliterated this evidence.

Description and classification of the intrenched meanders of the Murray valley in South Australia:

The entire length of the Murray valley in south Australia can be described as intrenched. In past explanations, this has been limited to only the reaches downstream from Overland Corner. This is erroneous since the Murray River and its valley, even though marked variations exist in the dimensions between the two, form a single unit in South Australia, and must be viewed as such. The relative dimensions of the two sections, upstream and downstream from Overland Corner, can best be seen on **Fig. C.** As mentioned previously (see p. 67) the variation in width is due to the differences in the major unit of rock strata of valley-side walls. Softer Loxton and Parilla Sand are more easily eroded than the more resistant limestones. In both segments valley windings occur with the comparable slip-off slopes developed on the adjacent side of the valley, but in many places lateral planation and downvalley migration have destroyed these features. In most examples, however, this truncated impression is possibly over-emphasized by the degree of infilling of more recent fluvial sediments above slip-off slope remnants. The depth of the valley varies, but becomes expectedly progressively deeper downvalley, and is also inversely proportional to valley width. Consequently there is a rapid change in depth of the valley downvalley from Overland Corner. Structural benches (see chapter II) give variety of form to both the slip-off slopes and valley meander bluffs. Plotting of the line of reconstruction of the spur tips was impossible because of the degree of post-incision lateral erosion, and downvalley migration, and as recent subaerial weathering and erosion have tended to obliterate the evidence. Field evidence in Chapter III and the geological sections (see Fig. 5.7) seem to indicate that the valley windings of the present river are autogenic, i.e.

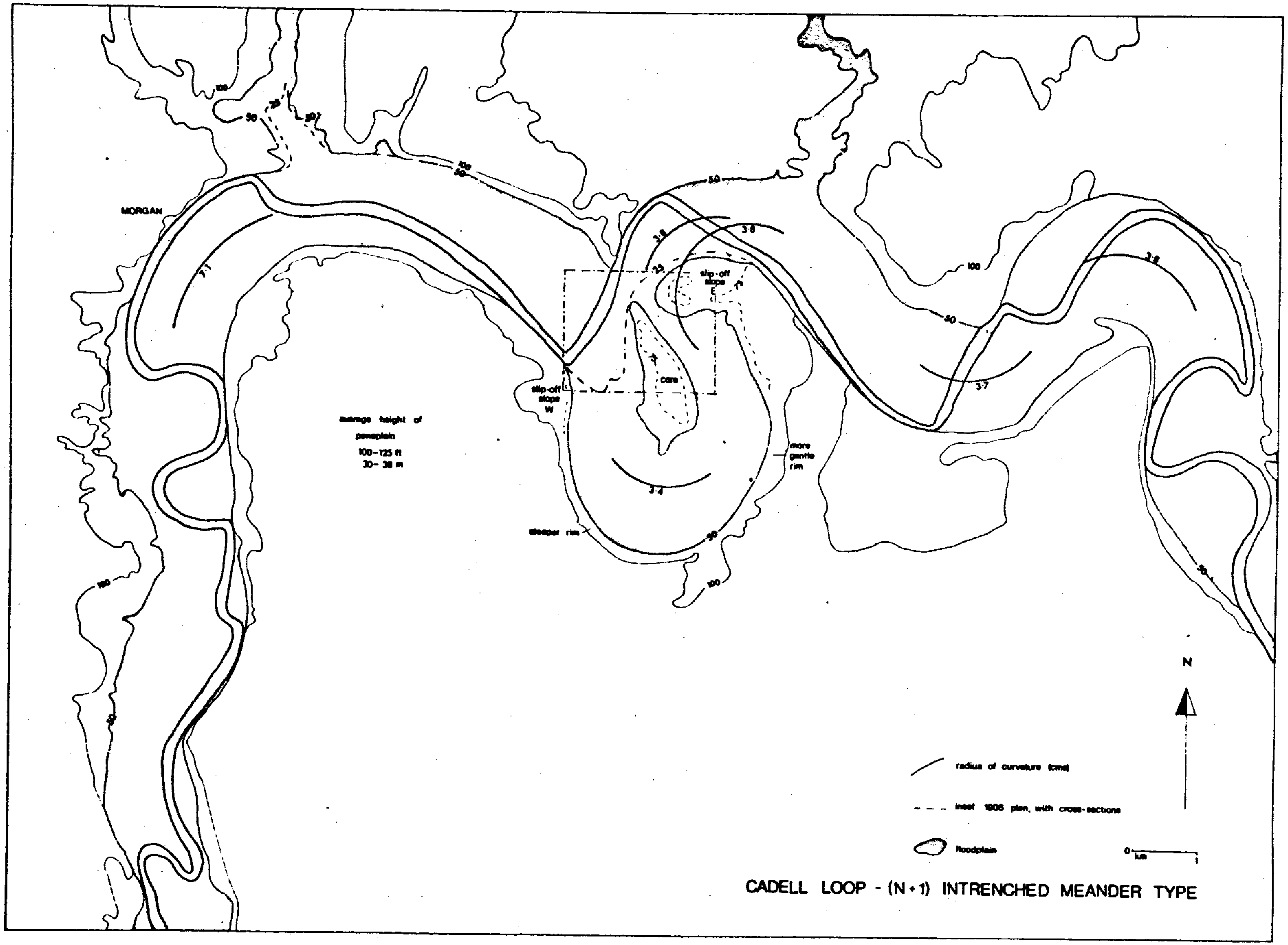
formed though lateral corrasion during incision. However, as downcutting proceeds structural modification of the stream course can evolve into lithologically and joint controlled stream channels (see p. 53).

Abandoned intrenched meanders:

No high level meander cut-offs, only crescentic scars, are present in the valley-side slopes of the Murray valley in South Australia. However, at Cadell a distinct abandoned meander loop is clearly visible on aerial mosaics, topographic maps, and the Lands Department Survey Diagrams. Nevertheless, this landform cannot readily be described as a perched intrenched meander. The cross and longitudinal profiles drawn from E. & W.S. 1906 Plans show the local asymmetry of this feature. It is asymmetrical with respect to the valley-side slope and the sides of the meander core, or pembina (Crickmay 1960). The north facing slope is steeper than the south facing slope. Of special interest to the problem of the classification of this landform into an N + I or autogenic intrenched meander, are the slip-off slopes located at "S" (see Fig. 5.13a). The eastern slip-off slope is more developed than the western, attributable to the westerly direction of downvalley migration of the intrenching river (cf. Twidale 1955). Therefore development of the meander loop occurred during intrenchment.

The floor of the present floodplain is undulating, but unfortunately basal bedrock data is unavailable, and the shape of the valley floor has to be interpolated. From the foregoing evidence, especially the development of the slip-off slopes (see Figs. 5.12, 5.13), the Cadell intrenched meander appears to be an autogenic feature. However, the lack of borelog data in this region makes it difficult to say with certainty whether the present valley to the north of the town is of the same depth as that to the south, but from analysis of the radii of curvature of the river upstream it would appear that the ancestral river first meandered in a southward loop, and then cut through the meander neck to occupy the present valley position. This, too, is indicative of the autogenic nature of the intrenching river. It is difficult to comprehend the initial ancestral river in a stage of cut-off development excavating simultaneously two gorge-like valleys of comparable size.

Twidale (1964) suggested a classification of autogenic intrenched meanders into youthful, mature, and full maturity. The first stage is characterized by a steep "V" shaped asymmetrical valley with much vertical and lateral erosion. Subsequently there is a downvalley sweeping of the meanders which result in a trimming off of the spurs. Finally, the stream meanders in a flat valley bottom, and the intrenched meanders, i.e. those enclosed by bedrock no longer exist. The meanders upstream from Loxton can be classified as being in a stage of late-maturity, those downstream varying from mature to "early" late mature.

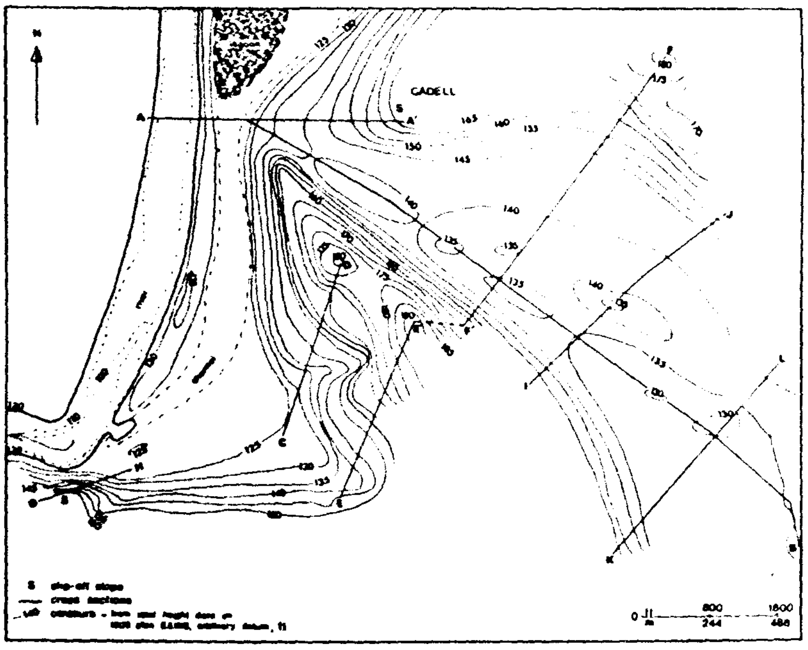


CADELL LOOP - (N+1) INTRENCHED MEANDER TYPE

FIG. 5·12

5·13 a)

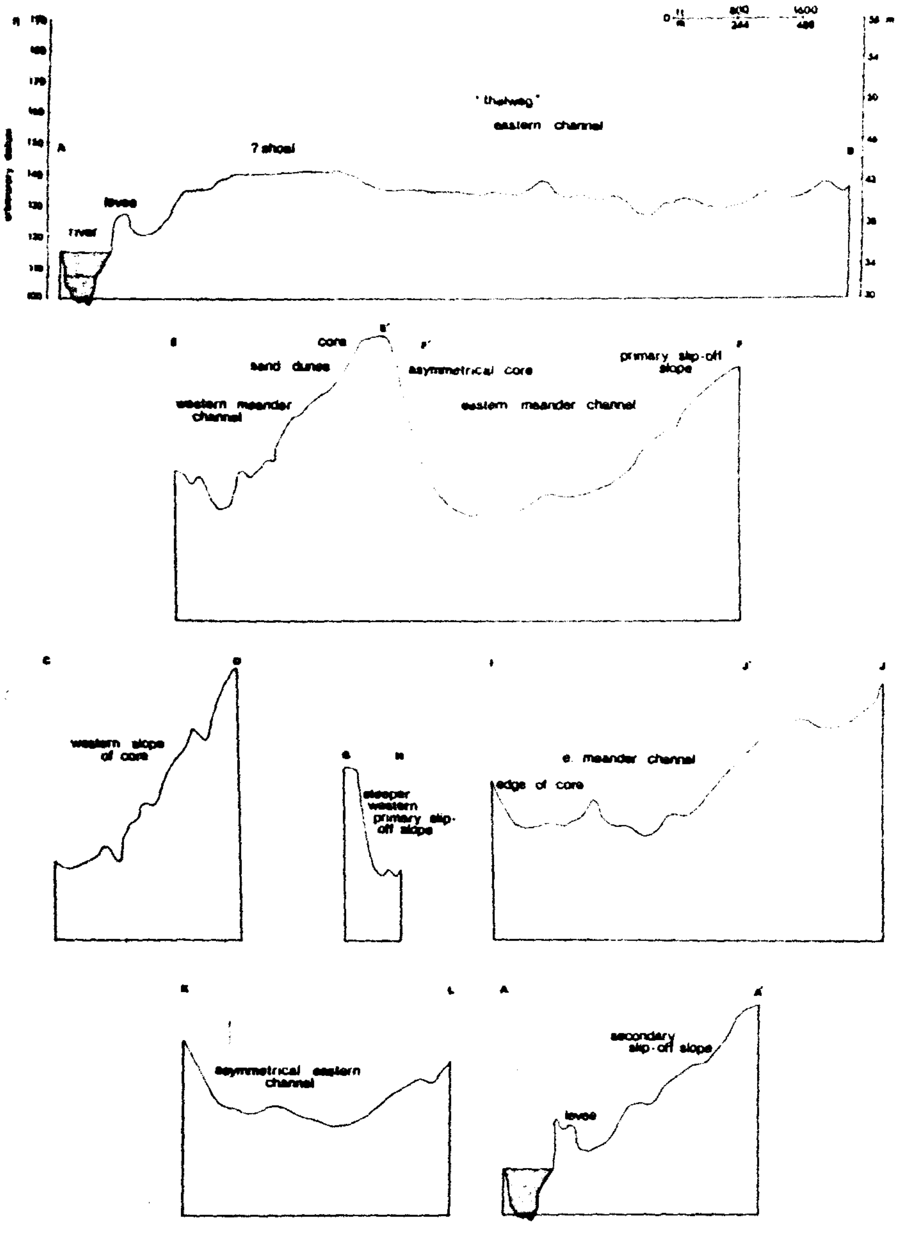
CONTOUR SKETCH NORTHERN CADELL MEANDER LOOP



5·13 b)

SECTIONS THROUGH NORTHERN CADELL MEANDER LOOP

source: 1906 E&WS plans



(4) Evidence outside of the field research area

Detailed work has been carried out in the Riverina area of western New South Wales by Butler (1950), Pels (1964, 1966), and Dury (1964d). Prior streams and ancestral rivers have been distinguished, but there is disagreement over the origin of these relict fluvial landforms. Prior stream formation is attributed to greater discharge during the Pleistocene, whilst ancestral rivers are generally thought to have been formed during an arid period. Twidale (1968) stressed the importance which tectonism may have played in the aggradation of sediments in this area. From a comparison of dates, the Coonambidgal sediments of the ancestral rivers of Pels (1971) seem comparable to the coarser sediments of the Monoman Formation of Firman (1971a), which could consist of aeolian material which has subsequently been reworked (Gibson 1958). The prior streams are older than dating possible by the radio-carbon method, i.e. older than 40,000 B.P. To the knowledge of the writer no correlations of these former sediments with those in the South Australian section of the Murray valley have been carried out. Such research would undoubtedly be invaluable in elucidating the history of the more recent phases of fluvial deposition.

3. EXPLANATIONS FOR THE ORIGIN OF THE PRESENT MURRAY RIVER

The first description of the origin of the Murray River was by Tate (1884), who emphasized the role of structure on process. He suggested a kind of massive headward erosion, a retreating waterfall effect by a stream occupying the breadth of the gorge. The retreat was said to occur from the river's "effluent" end, and simultaneously a general reduction of the bed to a uniform slope downstream from Overland Corner to Wellington resulted.

> Their united action had formed the mighty gorge. Finally the whole gorge is excavated to its present depth, and a uniform shape of the river bed being formed, erosion ceased.

Irregularities in the gorge shape were attributed to

> the original surface and the varying degree of hardness of the rocky material, rather than to the variability of the rock structure at present water level, though the latter circumstance might have operated to form the minor sinuosities of the gorge.

Twidale (1968) argued that a meander might be incised without notable lateral erosion by this waterfall retreat process, but any increase in velocity of that portion of a stream above a waterfall during incision and transformation of the vertical waterfall into an inclined rapid or a series of rapids must induce a marked lateral migration of the meanders.

Howchin (1929) described the history of the Murray River in more genetically explicit terms. He defined the river as an antecedent river, and probably the most ancient of the Australian Continent.

> The earliest phase saw the transgression of the sea, which submerged the pre-Miocene terrain to the south-west of New South Wales. The Murray, an abbreviated form, met the sea, east of what is now part of New South Wales, but the River Darling was still an independent stream. Then during the early Pleistocene, there followed a gradual rise of the land in an epeirogenic uplift as the sea retreated southwards, and the rivers followed in sympathy with the retreating coastline over a plain of marine sediments left by the sea. The low grade led to a meandering system of streams as evidenced in the dead river systems to the north and south of the present river course. Tectonic movements occured in the Miocene sediments and differential movement produced block tilting and drainage diversion. Grade was lowered, deposition occurred and a new channel had to be cut to the south. Sagging of the Lake Eyre Basin diverted the tributaries entering from the north, to drain to centre of this depression.

Howchin attributed the rejuvenation associated with the gorge development below Overland Corner to regional uplift, and not to sealevel fluctuations. His explanation introduced the aspect of tectonism in river intrenchment, but Howchin failed to explain his reasons for the drainage patterns developed initially. He called the present Murray River an antecedent stream. However, antecedent implies a well developed pattern before incision, and there was no mention made of this former stream.

Fenner (1930) began to appreciate the variations of gorge development which result from structural control, in terms of lineament development and variations in individual rock strata.

> The river in softer rocks east of Overland Corner is able to swing in an almost unrestricted way. On the north, no limiting factor, but to the south, near Loxton and Overland Corner the downcutting river met with the more resistant, gently plunging submerged Tertiary limestone, and thus was deflected northwards from Great Pyap Bend . . . The remarkable even parallelism of the sides of the gorge testifies to the general evenness of the erosive work done here. The minor tilt or warp that ran through Morgan, which was possibly reflected in the one time overlying lacustrine and fluvial beds, would be sufficient to deflect the river, and send it on that otherwise inexplicably sudden turn southward. Apart from a minor deflection at Big Bend, where barely hidden Cambrian rocks may have influenced the course of the stream, there is no important change in direction until the river meets the upwarped, or upwarping ridge that is in part indicated by the Marmon Jabok Range.

In the 1950s and 1960s geologists from the Department of Mines were in general agreement over the river's evolution. Sprigg (1952) was the first to suggest the role of eustacy and climatic change in the river intrenchment.

> The River Murray bed is now well below sealevel over most of its length in South Australia, reaching 100′ (30.5 m) at Murray Bridge . . . due to Pleistocene glacial eustacy, and downwarping . . . There is an excellent suite of sediments deposited in the valley . . . a series of aggradational sediments, all apparently related to one pronounced sealevel rise following the last glacial period . . . gravels, sands, silts and peat formations.

(See Fig. 5.7) Steel (1959) carried Sprigg's suggestion further, attributing misfitness, the first time this was used in the Murray River context, to inland warping, and probably a Late Pleistocene low sea level period. Johnson, Hiern and Steel (1960) described the ancestral river development around Chowilla in some detail.

> Evidence that an ancestral river system came into existence shortly after the geological period represented by the oyster beds of the Norwest Bend Formation. At this stage the ancestral Murray probably flowed across a plain little elevated above sealevel. The next event was the formation of a fresh water lake, to northeast of a line from the southeast of Overland Corner to Loxton. The damming of this feature was thought to be due to a differential uplift along the Murrayville Monocline (Spence 1958). The lake was breached and the present day Murray River system came into existence, through the downcutting through the land surface rising slowly relative to sealevel. It is highly possible that the Murray had several different channels cut deeper than today. Lake Bonney and Victoria are remnants of a deeper valley, not yet filled. At the end of the Pleistocene the drainage patterns, the fore-runner of the Murray valley and related valleys were excavated to a depth 70'-100' (21.3 m-30.5 m) below the present river flats.

Steel (1962, 1967) adhered to this scheme but used the formation of travertine (the Ripon Calcrete) as an index to the relative dating of the incision. He suggested that downcutting probably occurred in an arid environment. The more recent fluvial events were the result of a rise in sealevel, with subsequent infilling of the valley with both fluvial and aeolian sediments.

These past explanations, interesting and varied are, however, at best conjecture. The most recent explanations are derived from a study of field evidence.

Fryar and Rowan (1963), and Morris (1971) discussed in their accounts of the evolution of the river, the role of weathering on crystalline basement rocks in the lower valley. Mechanical weathering occurred with the opening of joints due to a redistribution of stresses after the removal of the overburden by the river, and chemical weathering resulted from the action of groundwaters within the valley.

The most recent descriptions of the river's history are to be found in Firman (1971b). Firman suggested that the formation of the Bakara Soil predated the incision by the Murray River through the calcrete sheet.

> The first incision may have been on a scarp near Murray Bridge, during a low stand of the sea, as early as the end of the middle Pleistocene . . . incision to a depth of 30' (9.1 m) in Loxton Sands at Chowilla. South of Kangaroo Island, the old course of the Murray River can be traced into the continental shelf of 350' (107 M) below modern sealevel.

According to von der Borch (1967, 1971) the Pleistocene coastline was equivalent to the 183 m submarine contour line today. He suggested that the ancestral river flowed to the edge, and the sediment spilled over the continental shelf, at the present day submarine canyon head of the Murray Group of Canyons. The abrasive sediments, for example sand delivered by the Murray River, not the bedflow of the river itself, cut the canyon.

In the above descriptions there appears to be insufficient emphasis on the evolution of the Murray River in South Australia in terms of a spatially continuous unit. Furthermore, only passing mention is made to the misfitness concept as a possible explanation of the river's evolution. Also, many of these geological interpretations appear biased towards a discussion of pre-intrenchment location of the river.

4. THE MISFIT CONCEPT

The term misfit (underfit) is useful in describing geometrical discrepancies, and the field evidence for the Murray River and its valley in South Australia. However the causes as elucidated by Dury (1954, 1958, 1964a, c) seem questionable. The underlying factor in misfitness is a reduction in discharge. Dury stressed the role played by climatic change (see Table 5.1). Davis (1913) who adhered to a river capture hypothesis for the reduction in discharge, also mentioned the possibility of climatic change. However, various other factors have been suggested by subsequent writers, for example glaciation, tectonism, overspill from pro-glacial lakes, under-flow through alluvium, floodwater erosion, and meander-belt migration.

Dury (1964c) accounting for the former discharges, described them as the sum effect of a combination of causes. Those most likely to have been responsible for misfitness of the Murray River are summarized on the Table 5.1.

The climatic findings of Dury (1964a) were a drop of temperature of 5–10%, and a mean annual runoff 5–10 times those experienced today. However, he claimed the most likely cause to have been an increase in momentary peak discharge, with an increase in single rainfall, particularly rainfall of long duration, and high frequency.

Geyl (1968) questioned the basic assumptions of Dury, for example the possibility of extrapolating present hydraulic geometry to the past, the 20–60 times increase of channel discharge, which he claimed would form a braided rather than a meandering channel pattern, and the increase in gradient, which would also produce a braided stream pattern. He criticized the lack of use of supporting evidence from existing climates, which are comparable to those he described for the past, and the climatic assumptions of Dury. Geyl himself suggested yet another cause of misfitness, i.e. tidal stream scour, but this in turn is open to criticism; Dury (1969) in reply to the above accusation justifiably attacked Geyl's theory for the lack of circumstantial evidence, citing valley meanders cut by tidal stream scour, as far inland as the 305 m contour, and the failure to acknowledge corroboratory evidence from palaeontological studies.

TABLE 5.1

THE CAUSES AND EFFECTS OF CLIMATIC CHANGE

(in reference to the Misfitness concept).

(1) reduction in air temperature
(2) increase in total precipitation
(3) change in regimen of precipitation
(4) increase in extent of frozen ground
(5) increase in size of individual rains
(6) increase in frequency of storms
(7) increase in wetness of the soil
(8) change in vegetation cover

} CAUSES

↓

PLEISTOCENE CLIMATE CHANGE

↓

	changes in precipitation and run off →	change in the character of the load
	↓	↓
EFFECTS	variations in stream flow	increase in calibre
	↓	↓
	changes in stream pattern, e.g. increase to braiding, decrease to braiding from a formerly meandering pattern	increase in slope
		↓
		to a change in channel pattern, meandering to braiding
Evidence		
	change in channel wave length change in channel width change in channel depth	presence of material of different sizes in successive valley fills

(after Dury, 1964c)

Possible supporting evidence for climatic change, if not of the proportions envisaged by Dury for the Murray valley includes, the discrepancy in size of the geometry of the valley meanders in relation to the present channel form, the weathering front phenomena in the jointing of granite at Swanport, the fossil stream patterns of the Riverina area of New South Wales, the valley fill sediments, including the size of the particles, and contained fossil matter, and the presence of the Murray Group of submarine canyons.

Three other plausible explanations for the development of intrenched meanders exist, in tectonism (Twidale 1968), flood erosion (Carlson 1965), and in downvalley migration of the meander belt (Cotton 1945). The region through which the Murray River flows, especially at its source, the Riverina, the Cadell Fault area, and the South Australian section, have been tectonically active areas. Therefore it is reasonable to assume that an increase in gradient, and a change in baselevel could be due to regional uplift, or warping. Flood erosion is directly climatically controlled, and it could well be that during former catastrophic floods the Murray valley acted as a river channel itself, in transporting the flood waters. These in turn abraded the valley floor and valley-side slopes producing in part the valley we see today.

Perhaps the valley is the result of lateral, downvalley migration of the meander belt. According to Twidale (1968) the widening of a river valley does not cease with the development of meanders, for the meander belt also migrates from side to side, undermining the bounding bluffs. This incision results in an extension of the flat floored floodplain. The valley upstream from Overland Corner can readily be interpreted in these terms, but because of the confining nature of the resistant Miocene limestones downstream from Overland Corner, there is no meander belt developed in the past or present floodplain, downstream from Overland Corner. The evidence contradicting the meander belt migration includes the chute effect between Morgan and Blanchetown, the perfect loop at Cadell, the variations in width of the valley itself, for example the lengthy slip-off slopes, the local narrowing of the channel with bedrock outcrops, at Woods Point, Swanport, Murray Bridge, Wall Flat Irrigation Area (see Soil Survey Taylor and Poole 1931), Reedy Creek, Teal Flat, Bowhill, immediately downstream from Ramco Lagoon, Waikerie, and Overland Corner. These examples are too numerous for chance bedrock irregularities. However, upstream from Overland Corner the Meander belt hypothesis could be more acceptable. The restricting effect of the bedrock unconformity at Overland Corner could cause a meander belt migration in the vicinity of Kingston-on-Murray and Gerard Mission.

5. CONCLUSIONS

It is suggested that the probable cause of intrenchment of the Murray River in South Australia is a result of a combination of climatic change, tectonism, and structure.

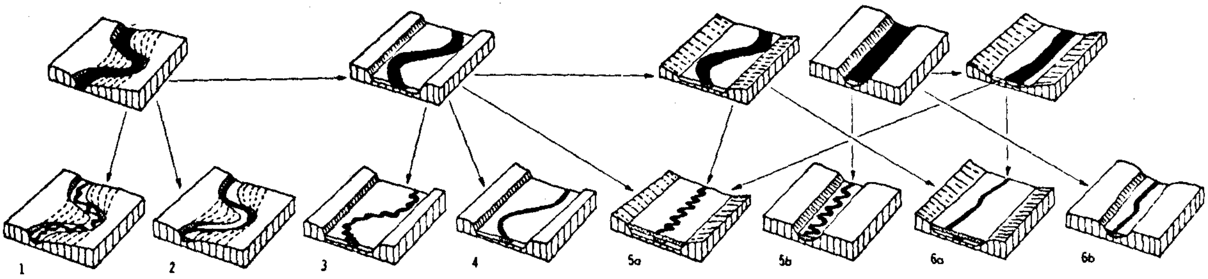
Phenomena resulting from climatic change are firstly Pleistocene glaciation in the Kosciusko region, the catchment area of the Murray River drainage system. Snow melt would contribute to an increase in volume, though not necessarily of the proportions envisaged by Dury (1964c). Also flood activity during interglacials may have played an important role of erosion. Furthermore, stream shrinkage could have resulted from later climatic amelioration. Secondly, a lowering of sea level produces an increase in gradient and extension in length of the river. The lack of sedimentary deposits, which would be expected from the valley excavation at the former mouth position is still problematical. It seems unlikely that these sediments occupy entirely the abyssal plain below the Murray Group of submarine canyons. Conversely, a high sea level produces stream shrinkage and aggradation. Terrace forms and valley fill formations may result.

Tectonism can play a role in providing periodic baselevel fluctuations, and control valley and channel location. Structure, including rock type and linaments may determine the morphology of the intrenched valley and also its location.

It seems that structure is of overriding importance in the determination of the valley of the Murray River today. The variation in the valley meanders and river channel morphology upstream and downstream from Overland Corner appears to be a function of the varying lithology, for example Miocene limestones and Pliocene sands. The river channel today is located in alluvium, but its meander wavelength varies throughout the valley as a function of the interaction of the valley-side slopes (with their local characteristic structure and slope processes, for example aspect and weathering, cliff channel and triangular facet formation), and the channel itself.

Similar conclusions were drawn by Kennedy (1972). Evidence from his recent research on the fluvial processes suggested that lithology may alter the relationship between discharge and wavelength rather substantially, and that there is a close relationship between the stream and slope processes with concomitant mutual adjustment of form. Therefore, it is suggested that these cannot be studied in isolation. The latter is in fact the thesis suggested in this research on the Murray River in South Australia.

Perhaps the most useful aspect of Dury's work on misfitness (1964c), is his scheme for the classification of intrenched meanders, and their valleys (see Fig. 5.14). He acknowledged the fact that there may be variations in the subtypes down a given valley. The valley in South Australia has been classified in this way (see Fig. 5.1). It is felt that the variations in



<table>
<tr><td rowspan="3" colspan="2"></td><th colspan="3">Pattern of valley</th></tr>
<tr><th rowspan="2">Meandering</th><th colspan="2">Nonmeandering</th></tr>
<tr><th>Trace of large free meanders preserved</th><th>Trace of large meanders not preserved or never present</th></tr>
<tr><td rowspan="4">Pattern of stream channel</td><td rowspan="2">Meandering</td><td>1. Meandering stream in meandering valley</td><td>3. Meandering stream in former meander trough; large meanders identifiable on surface</td><td rowspan="2">5. Meandering stream in (a) open valley or (b) approximately straight narrow valley</td></tr>
<tr><td colspan="2">Two series of meanders combined</td></tr>
<tr><td rowspan="2">Nonmeandering</td><td>2. Nonmeandering stream in meandering valley</td><td>4. Apparently very large meanders on floor of open trough</td><td rowspan="2">6. Nonmeandering stream in (a) open valley or (b) approximately straight narrow valley</td></tr>
<tr><td colspan="2">Only one series of meanders present</td></tr>
</table>

FIG 544 Block diagrams of underfit streams, showing character and possible origin of some combinations of stream-channel and valley patterns.

intrenchment type, 1–5a–1–6b–5a–6b–2–6b–2–6b–2–6b–2–6b is primarily a function of lithology and lineament pattern.

Table 5.2 showing the change in channel pattern through geologic time summarizes the interpretation of the evolution of the river. It is divided into the two regions, one upstream and the other downstream from Overland Corner.

TABLE 5.2

CHANGE IN CHANNEL PATTERN THROUGH GEOLOGIC TIME

GENERALIZED

(a) Chowilla to Overland Corner

Age	Type	Evidence
Future	Meandering	(1) homogenous substratum alluvium
Present	Generally meandering	(1) statistical result
		(2) cutoffs, oxbow lake pattern
		(3) valley lake morphology e.g. Littra, Limbra
Post Pliocene	Generally meandering with some partially distorted meanders	(1) map plan
		(2) lagoonal pattern
	? Meandering	(1) see valley windings —statistical evidence
		(2) slip-off slope development

TABLE 5.2

CHANGE IN CHANNEL PATTERN THROUGH GEOLOGIC TIME

(b) Overland Corner to Wellington:

Age	Type	Evidence
Future	? Meandering	(1) logical development of a river system given stability—(tectonic and climatic) through time
Present	Angular reaches and winding	(1) lineation—statistical results (2) lagoon pattern (3) maintenance of angular bend along cliffs—in a downstream direction (4) channel pattern downstream of Walkers Flat
Post Pliocene	? Meandering to to straight reaches	(1) see valley windings —statistical treatment (2) influence of Morgan Fault (3) slip-off slope development

CHAPTER VI

SUMMARY AND CONCLUSIONS

The Murray River in South Australia has a complex history through a period of intrenchment into an extensive simulant peneplain, the Mallee Surface (see Table 6.1). Structure, in the form of lineament control, especially jointing and faulting, has played a dominant role in the location of the valley, and the nature of the valley-side slopes, and the course of the present day river, which is still in a period of adjustment. However, the depositional history seems to have been in part climatically controlled.

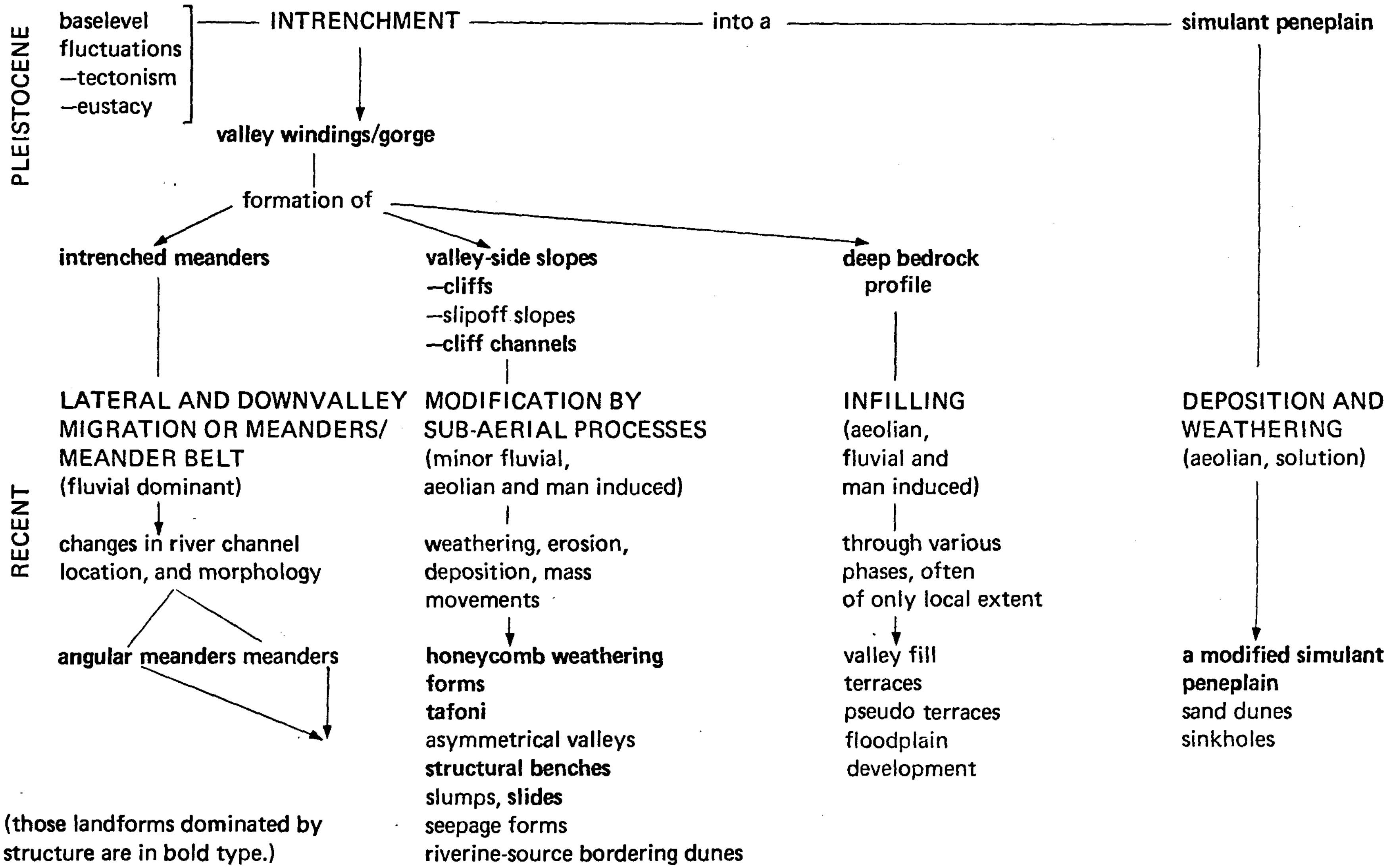
Today the geomorphic landscape reflects the intrenched history of the river, but is also subject to processes other than directly fluvial. Subaerial weathering, erosion, and depositional processes are creating, extending and modifying landforms associated with the Murray valley. Aboriginal man, and to a greater extend European man has played an ever increasing role in further modification to the geomorphic landscape, and for this reason, a map and explanation of the landform assemblage produced by the Murray River in South Australia through time is necessary as a vital record of a part of the Australian natural landscape.

The following specific conclusions were derived from mapping and analysis of the landforms associated with the Murray River in South Australia.

The Mallee Surface is an erosional surface, and not a structural or depositional surface. The use of the term uplifted simulant peneplain is introduced. However, following an analysis of the surface topographic features, which result from the single, or combined action of wind and water, the Mallee Surface is described as a modified simulant peneplain. Calcrete subunits are distinguished, and microforms explained. The sand dune study reveals a series of dunefields of differing sources and orientation.

The changes which occur in valley-side slopes down river resulting from the combined action of endogenetic and exogenetic processes is established. Macro and micro-variations in morphology are described in qualitative and quantitative terms. The most commonly occurring slope classification is quadrizonal, with concave to uniform subunits. The genesis of various slope profiles is suggested, including scalding, triangular valley-side facet formation, pediplanation, structural bench formation, aspect as a cause of valley asymmetry, organic weathering, carbonate case-hardening and honeycomb weathering, tafoni formation, seepage precipitation, sand dune trail formation, with attached and detached dunes, and cliff channel formation.

THE POSSIBLE EXPLANATION FOR THE GEOMORPHOLOGY OF THE MURRAY VALLEY IN SOUTH AUSTRALIA



(those landforms dominated by structure are in bold type.)

The definition of terraces is based on the 1956 flood level, and the former classifications are mapped as pseudo terraces and floodplain units. The role of fluvial, wind and anthropogenically induced processes is stressed. Terrace study is made difficult because of the fragmentary and much modified field evidence.

Meandering and angular channels are distinguishable statistically using Schick's technique (1964) for estimating the degree of lineation of river channels. The pool and riffle sequence of the river channel reflects the nature of the channel today, and indicates its possible future habit. Changes in channel pattern are studied in historic, and prehistoric time. Results show the dominance of structure on river channel pattern. Flood activity is responsible for change in channel form on a local scale. Fluctuations in the position of the mouth are the result of the process of longshore drift, and to a lesser degree variations in discharge.

With the application of the formula $\varnothing = w \sin \frac{s}{M} 360^\circ$, the habit of the valley can be established, and compared with the present river. Field evidence in the valley-side slopes, described in Chapter II provides additional clues to the past channel patterns. Geological evidence gives further support to the theory of the evolution of the river, which is described as a misfit river. The type of misfitness varies locally and can be classified using Dury's scheme (1964a). The misfit dimensions of the Murray River are comparable with misfit streams described elsewhere. The intrenching process results from the incising and downvalley migration of the river, and to a lesser extent lateral corrasion, resulting in some widening of the valley. The river is not inherited from a former drainage pattern. Past explanations of the river's evolution are discussed and an alternative explanation is offered. The present river is described as misfit. However, misfitness is not assigned to a great decrease in discharge. Instead climatic change, with perhaps some decrease of discharge but importantly with glacio-eustatic changes, tectonism, and structural control are considered to have played dominant roles in determining the pattern found today. The river and valley behaviour differ markedly upstream and downstream from Overland Corner, the result of differences in the bedrock materials through which the river has incised. The position of the valley, the original path of the ancestral river was governed by lineament controls in the bedrock. The present river, downstream from Overland Corner seems to be still adjusting to the relatively resistant bedrock, whilst that upstream appears to have reached a greater degree of equilibrium with the bedrock. As a result the river's dimensions are beginning to reflect that expected of a river with the discharge, bedload and gradient characteristics of the Murray River.

Far more research is waiting attention in this field area, especially in the realm of climatic change with its direct effects on past river channel morphology and behaviour. Research into the relative rates of Aboriginal and European man's modification to the natural river regimé would provide a further interesting study. However, the most important follow up research would be an account of the genesis of the Murray River drainage system as a whole.

APPENDIX A

TEST FOR THE MEASURE OF LINEATIVE INFLUENCES ON CHANNEL FORM

Schick (1965) maintains that the angular deviation of a channel from the downstream direction is amenable to frequency analysis.

> The extent of lineative control, such as jointing, as expressed in the alignment of the drainage network, can be judged only in comparison with the angularity of a channel system developed in homogeneous, non-jointed lithology. Drainage patterns indicative of lineated jointing can be identified visually only in unique cases. Deflection diagrams, characteristic of a lineated substratum are often bi-modal, in contrast to the generally uni-modal diagram of a homogeneous substream. The two modes tend to be 60–100° apart, and are systematic with respect to the cardinal drainage direction (0°). Bi-modal symmetry is shown only by stream channels with incised meanders, with the modes often more than 90° apart.

Shick's method consists of isolating the lineating factors, such as joints and fissures, and thus permitting an objective evaluation based on quantitative data.

Method of determination of local stream directions for selected reaches of the Murray River

CC = the cardinal direction of the drainage in the reach RR.

At X the local stream flow direction = x° to the left of CC.

At Y the local stream flow direction = y° to the right of CC.

Left hand deviations (X) are designated –

Right hand deviations (Y) are designated +

These deviations from the cardinal direction of drainage were measured on aerial mosaics (1:63,360) at all points where there was a change in direction, provided that the distance (length of the segments) between two consecutive points was greater than 200 m. This distance was chosen as the average width of the river on the photographs. The measurement along the Murray River for the angular reaches were from Overland Corner to Morgan ($R_1 R_1$), and Morgan to Teal Flat ($R_2 R_2$). The area was divided into these two sections, because of the 90° change in the cardinal direction of drainage, with the pivot occurring around Morgan. The meandering reach selected was between Renmark and Lyrup ($R_3 R_3$).

A distribution of deviations from the cardinal drainage was then established. Schick preferred to use a system of random numbers, to avoid the possible interference by phenomena that tend to recur at regular distance intervals, such as pools and riffles, or meanders. Bed profiles drawn from the E. & W.S. Survey Maps of 1906, showed that there was a regular distance distribution of these features, but that they were not reflected in the plan showing the change in channel direction downstream. Therefore, the total measurements were recorded.

Schick (1965) drew up a unimodal normal model from a study of streams with meander reaches flowing through non-orientated lithology. The model shows a 50% of channel length deviating from the downstream direction by 30%. This model is used as a basis of discussion for the Murray River in two ways. It is useful in comparing the selected reaches of the river with Schick's normal model, and the lineated or angular reach with the meander reach (for location of these see Fig. 5.1).

From an analysis of eight stream channels Schick concluded that (1) the patterns for streams traversing lineated substratum is often bi-modal, and (2) that the degree of lineation is indicated by the % of the channel length whose flow direction exceeds that of the normal frequency curve. Indices > 50% are linked with "highly developed" meandering, and indices < 50% are indicators of lineative influences. Schick concluded that the index serves as a direct measure of fissuring, faulting, and jointing in homogeneous lithology.

Young (1970) applied this technique to Broger's Creek, a tributary of the Shoalhaven River, New South Wales, and found a high degree of lineative influence, but he questioned the suitability of the normal model. He applied the results obtained from a flume channel developed in homogenous sand to Schick's "normal" model and a high degree of lineation (30%) resulted! Young concluded that Schick's model does not appear to apply to all cases where the index falls below the cut off value of 50%.

APPENDIX B

TECHNIQUE FOR DETERMINING WHETHER VALLEY WINDINGS DISPLAY MEANDERING HABITS

Sine-generated curves were constructed on graph paper, using the formula $\emptyset = w \sin \frac{s}{M} 360°$ (Langbein and Leopold 1966). These geomorphologists used the thesis that the meander form occupies the most probable among all possible paths. The path was defined by a random walk model based on mathematical calculations of von Schelling (1951, 1964). It will be noted that the plan view of the channel is not sinusoidal, only the channel direction changes as sinusoidal function of distance (Langbein and Leopold 1966). The meander itself is more rounded and has a relatively uniform radius of curvature in the bend portion. This can be noted in the fact that a sine curve has a quite straight segment as it crosses the X-axis.

The curve defined by $\emptyset = w \sin \frac{s}{M} 360°$ is believed to underlie the stable form of meanders. Deviations or noise are due to two principal causes (Langbein and Leopold 1966):

> Shifts from unstable to stable forms caused by random walk acts and varying flow, and
> non-homogeneities such as rock outcrops, differences in alluvium, or even trees.

In the above equation $\emptyset$ = the maximum angular deviation from the downstream direction

w = the maximum angle the path makes from the mean downvalley direction

s = the distance of any point along the meander

M = the total distance along the meander

Measurements of the angular direction of the channels with respect to the mean downstream direction were made at regular intervals, .32 cm for river meanders, for valley meanders 1 and 2, 1.2 cm, 3, 2.5 cm, and 4, .63 cm, along the centre lines of two natural meanders and four valley windings. These were plotted as angular deviations.

Firstly, two sine-generated curves for river meanders were constructed from a reach between Lyrup and Renmark (see Fig. 5.2). For both river meanders $w = 90°$. The sine-generated curve $w = 90°$ was plotted on graph paper for the river meander length.

$$1 \quad \emptyset = 90 \sin \frac{\frac{1}{8}}{2\frac{3}{4}} \times 360°$$

$$2 \quad \emptyset = 90 \sin \frac{\frac{1}{8}}{6\frac{7}{8}} \times 360°$$

and against the actual angular deviation of the valley from the mean downvalley direction.

The same procedure was repeated for the valley meanders (see Fig. 5.13), both upstream and downstream from Overland Corner.

$$\text{I} \quad \phi = 86 \sin \frac{1/2}{14} \times 360^\circ$$

$$\text{II} \quad \phi = 26 \sin \frac{1/2}{7\frac{1}{2}} \times 360^\circ$$

$$\text{III} \quad \phi = 60 \sin \frac{1}{13\frac{1}{4}} \times 360^\circ$$

$$\text{IV} \quad \phi = 65 \sin \frac{1/4}{3\frac{3}{4}} \times 360^\circ$$

The actual angular deviations of the river and valley from the mean downvalley direction are shown on the graph by the X symbol.

In the paper by Young (1970) the sine-generated curve was plotted on the valley meander sketch map. This is confusing since the plan view of the channel is not sinusoidal, only the channel direction changes as inusoidal function of distance.

Langbein and Leopold (1966) state that the maximum value of $w = 125^\circ$ on free meanders. This is the stage of incipient cutoff. Fig. 5.1 shows the case where the value of $w = 126^\circ$, and expectedly cutoff development has occurred.

Testing of the closeness of the relationship for the Murray River of sine-generated curve to actual changes in river and valley direction was carried out using the statistical technique of coefficient of correlation, i.e. to give the value of what percentage of the empirical data can be claimed to be related with the sine-generated curve, and the probability of meanders measured systematically, being like sine-generated curves. However, it must be remembered that one has not been truly related to the other, only the number or values one to the other, i.e. all pairings in a vertical direction. The actual values were not plotted on the curve. Consideration was taken only in a non-spatial plane (Griffin 1971 pers. comm.). Throughout this analysis the short-comings of the correlation coefficient method were recognised. Alternative, more complicated methods, for example the analysis of the family of curves do exist, but since all this exercise hoped to achieve was a measure of the similarity of the theoretical and empirical curve, the technique employed was considered adequate. It has not been possible to determine the significance in absolute terms.

In five out of the six examples the sequence is carried across the sine curve to find the best possible fit, i.e. to arrange the best points. the findings are as follows:

Coefficient of correlation	I	r.m. + .954	(P = .01, v = 20)
(r.m. = river meander)	II	r.m. + .248	(P = .5 – .1, v = ∞)
(v.m. = valley meander)	I	v.m. + .25	(P = .2 – .3, v = 22)
	II	v.m. + .6	(P = .02 – .05, v = 13)
	III	v.m. + .87	(P = .01, v = 12)
	IV	v.m. + .823	(P = .01, v = 13)

Or the sine-generated curve explains	91% for I	r.m.
	6% for II	r.m.
	6% for I	v.m.
	36% for II	v.m.
	75% for III	v.m.
	67% for IV	v.m.

of the sinuosity of the river course. There appears to be no correlation between the r.m. II and the sine-generated curve, $w = 90^\circ$. This non meandering habit may be due to structural influences. Similarly, v.m. I in the vicinity of the Murrayville Monocline shows no apparent meandering habit. The very close relationship of r.m. I with only 10% error of calculation is quite conceivable when consideration is taken of the variables affecting the development and propagation of meanders, for example volume (discharge), bed load, gradient, time, and error in the calculations since the aerial photo-mosaics have not been rectified. All these factors would lead to an expected error in the original data.

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