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CHRONOLOGY OF DENUDATION OF NORTHERN EYRE PENINSULA, SOUTH AUSTRALIA.

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Department of Geography,
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DECLARATION.

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 person except when due reference is made in the text of the thesis.

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SUMMARY.

The purpose of the investigation summarised in this thesis is to produce an explanatory account of the landforms of northern Eyre Peninsula, and in particular to identify palaeosurfaces of low relief so that the evolution of the area can be unravelled.

To this end the effects of structure on landforms are first determined and physiographic regions, which are largely though not wholly structural regions, delineated and described. Various erosional surfaces of low relief are identified within the several regions and are then systematically discussed. Three are of exhumed type, two being of Precambrian age and one of later Pleistocene date. Six erosional surfaces of epigene origin ranging in age from (?)Triassic to late Pleistocene have also been recognised. The exhumed surfaces are dated stratigraphically. Deep regoliths are associated with all but two of the other palaeosurfaces and the distinctive mineralogy of each of these duricrusts enables them to be dated by comparison with other similar surfaces carrying deep weathering profiles and of established ages in other parts of South Australia. The other two surfaces are dated by their relationship vis a vis the duricrust remnants.

Having established the denudation chronology of northern Eyre Peninsula the granite landforms of the central and western areas are then examined. Several of the minor landforms typical of the

granite residuals appear to be associated with former piedmont zones. Using such datum points phases in the emergence of the residuals have been determined, so that in the case of the lower hills various generations of whalebacks and platforms are identified. The higher inselbergs have been subdivided into horizontal zones which increase in age with elevation above the present plains. The several generations and zones have been tentatively correlated with the erosion surfaces identified in the adjacent uplands so that the development of the granite inselbergs and their minor landforms is integrated with the evolution of the region as a whole.

Finally the possible reasons for the survival of the very ancient forms and surfaces described in the thesis are briefly discussed.

CHAPTER ONE: INTRODUCTION.

> The first and most natural application of geomorphic study is to the history of the earth.
> (Kirk Bryan, 1950, p. 199).

A. PREVIOUS INVESTIGATIONS AND PURPOSE OF RESEARCH.

Much of Eyre Peninsula is to the casual observer scenically dull. Though there are plateaux and isolated ridges and ranges in the east they lack the precipitous scarps and spectacular relief displayed in such areas as the Flinders Ranges, which lie a short distance away to the northeast and east (Fig. 1.1). Moreover to the west the uplands give way to extensive rolling plains which though interrupted in places by isolated ridges and domed inselbergs nevertheless present on the whole a distinctly monotonous aspect.

No doubt this lack of obvious interest, together with the general problems associated with dating and understanding the genesis of surfaces of low relief, has delayed geomorphological investigation of the area. It is true that various individual features and areas of economic interest have been subjected to close scrutiny but there has been no close and comprehensive examination of northern Eyre Peninsula.

The first accounts of the landforms of the area were

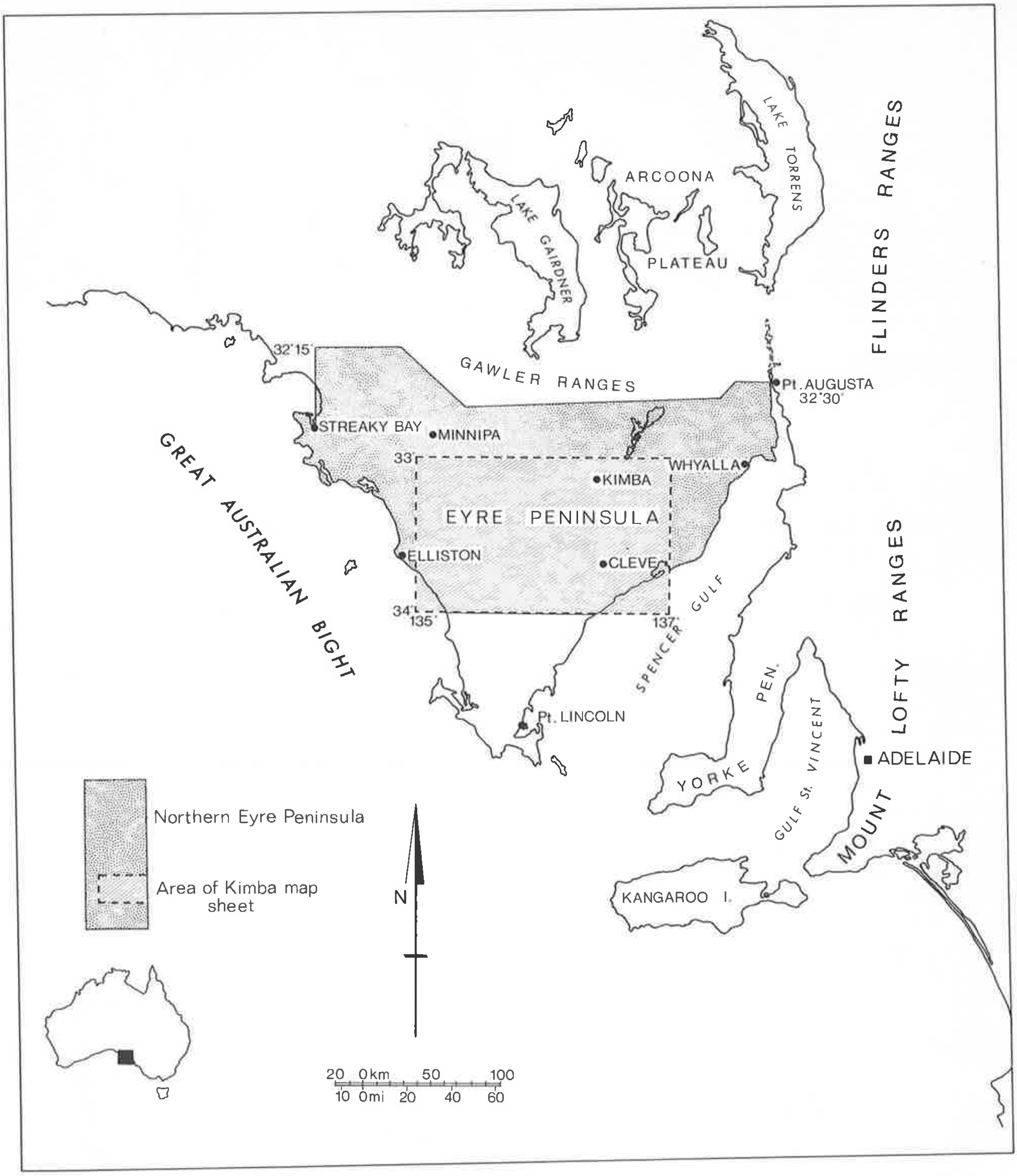

Figure 1.1.

Location map, northern Eyre Peninsula and adjacent areas.

furnished incidentally by the land explorers J. C. Darke (1844), E. J. Eyre (1845) and Stephen Hack (1857), all of whom were to chart and report on the feed and watering conditions for stock. Both Eyre and Hack returned with detailed information, the latter in particular noting granite hills in what is now the Minnipa district, but what survives of Darke's journal is a brief, incomplete account of the country unaccompanied by maps or adequate lists of bearings (Twidale, 1974).

R. Lockhart Jack (1912, 1914) was concerned chiefly with hydrological investigations in northern Eyre Peninsula but the basic geology and some aspects of the geomorphology were briefly discussed. He described the aeolianite cover of the granitic bedrock, and although he was unable to determine its age, he was impressed by the general uniformity in particle size of the sands, and the absence of coarser shell debris and concluded, correctly, that they were of aeolian origin. Despite the mask of dunes Jack contrived to draw a remarkably accurate map of the bedrock geology of northwestern Eyre Peninsula, including mention of the Corrobinnie Depression (Bourne, Twidale and Smith, 1974). However his conclusions concerning the geology of the 'Cleve Uplands' have been modified by later workers.

Over forty years elapsed before further investigations of geomorphological significance took place. R. L. Crocker (1946) was principally concerned with a study of soil type and vegetation communities but he distinguished between aeolianite limestone and siliceous sands throughout southern Australia and in particular discussed their distribution on Eyre Peninsula.

Geological studies of the Middleback Ranges and country to the east were motivated by economic considerations. K. R. Miles (1952, 1954) investigated the iron ore resources of the region, but he also described the series of meridional faults that caused the old coastal plain and associated relict linear dunes to be raised several hundreds of feet in the west relative to the east. The search for mineral resources also prompted the geological survey of central and southern Eyre Peninsula conducted by R. K. Johns (1961). The project aimed to assess the mineral potential of the area but regional mapping necessitated study of the stratigraphy and tectonics, so that Johns' report contains much more than economic geology.

The granite hills of northwestern Eyre Peninsula were mentioned by Darke, Hack and Jack and the origin of these features and various minor forms associated with them has been discussed by C. R. Twidale (1962, 1964a, 1968a, 1971, pp. 4 - 96, 1972a, 1973) and collaboratively with Elizabeth M. Corbin and J. N. Jennings (Twidale and Corbin 1963; Jennings and Twidale, 1971).

Apart from these specialised studies, northern Eyre Peninsula has attracted little attention. Yet for the geomorphologist these seemingly dreary plains and low uplands can hold great interest, for they pose several intriguing problems and offer the key to significant aspects of the geomorphological character of the area.

As L. C. King (1950, p. 101) has stated with regard to plainlands in general:

> The monotonous aspect of the great erosional plains, their seeming lack of useful data, and the difficulty of ascertaining their modes of origin and ages have for a long time discouraged their study. Yet the great plains and plateaux ... record in a relatively simple manner the geomorphological history of the continents.

So it is with northern Eyre Peninsula: the recent history of the region is, as is shown in the following pages, recorded in various aspects of the geomorphological landscape, and the primary purpose of the investigations summarised in this thesis is an attempt to unravel that story. Thus several major questions are posed in an effort to elucidate various aspects of the recent geological history of northern Eyre Peninsula:

The western and central areas of northern Eyre Peninsula consist of rolling plains in large measure developed on granitic bedrock. Of what age and origin are these plains?

In the east there are erosion surfaces of low relief developed on folded rock sequences in the Cleve Hills and on essentially flat-lying strata in the Tent Hill region. Of what age and origin are these surfaces?

The plains are surmounted by inselbergs surrounded by gently sloping plains of pediment type. Is the erosional history of the surrounding plains and uplands in any way reflected in the morphology of these granite residuals?

B. PLAN OF THESIS.

These are the major questions investigated in the field and discussed in this thesis which is the first comprehensive account of the geomorphology of northern Eyre Peninsula, a region which in toto covers an area of 17,300 square miles (44,300 km^2). Obviously the approach is historical but structural considerations are basic to the understanding of this, as of most areas, and the processes and agencies responsible for the various landform assemblages must also perforce be discussed. But the principal objective of this investigation has been to establish the sequence of events to which the present landscape owes its origin, and having established such a denudation chronology seek to distinguish and interpret the phases of emergence of the inselbergs of the study area.

Thus after this brief introductory chapter in which the problems and purpose of the thesis are stated and the area and methods of study defined and reviewed, the structure and physiography of the area under discussion are described. There follow chapters concerned with the erosional surfaces of low relief and the phased emergence of inselbergs. The geomorphological history of northern Eyre Peninsula is synthesised in a concluding chapter.

C. AREA OF STUDY.

Although the study area consists essentially of the Kimba 1:250,000 map sheet, additional field work was undertaken in areas covered by the surrounding Lincoln, Yardea, Elliston, Whyalla, Port Augusta and Streaky Bay map sheets in order to obtain evidence relevant to problems in the core area. Hence the study area came eventually to be delineated in the north by the southern margin of the Gawler Ranges, to the east by Spencer Gulf, to the west by the Great Australian Bight while the southern boundary coincides with that of the Kimba map sheet (Fig. 1.1).

D. METHOD OF STUDY.

Survey procedures were those devised by the Land Research Section, C.S.I.R.O. (Christian, 1952; Christian, Jennings and Twidale, 1957). Air photographs at a scale of 1:82,700 flown in 1966 were examined stereoscopically and landform assemblages plotted. Boundaries were transferred to air photograph mosaics and a composite map at a scale of 1:63,360 prepared. Field traverses were then planned to take in all typical assemblages as well as sites of particular interest. Boundaries based on air photograph interpretation were modified in the light of field investigation.

Because of the nature of the investigation the principal morphological units selected for mapping consist of areas of low relief. These surfaces were examined in the field in an effort to derive an age or age range for the features. Hence special attention was given to pedological and geological features, especially duricrusts, which can be used as morphostratigraphic markers, and datable faults which disrupt surfaces of low relief.

To this end maps showing the results of aeromagnetic surveys, Bouguer anomalies and conventional geological maps, scale 1:250,000, were consulted and bore logs and other drilling information were obtained from the Geological Survey of South Australia. Several topographic series of maps, at scales 1:31,680, 1:50,000 and 1:100,000, which were available for varying parts of northern Eyre Peninsula, were considered in relation to the spot heights and form lines drawn on the topographic survey maps (scale 1:250,000). The South Australian Engineering and Water Supply Department provided copies of contour maps which had been made in connection with water conservation schemes related to the inselbergs of northwestern Eyre Peninsula and this information was supplemented by special mapping of Mount Wudinna, Ucontitchie Hill, Corrobinnie Hill, Waulkinna Hill and Carappee Hill by the South Australian Department of Lands. Since most available maps had data shown in imperial units that mode is adhered to in this thesis, although metric equivalents are given where desirable.

Field mapping and other investigations were carried out during sixteen excursions totalling almost seventy days during 1972 - 1974.

Roads followed are indicated on Fig. 1.2, as is the route of an aerial reconnaissance flown in December, 1972.

E. ACKNOWLEDGEMENTS.

Acknowledgement is due to those employed within the various government and other departments who kindly assisted the writer. Particular mention is made of Mr. J. T. Hutton and Dr. A. R. Milnes of the Division of Soils, C.S.I.R.O., for their interest and willingness to conduct analyses of both silcrete and sand samples; Mr. V. Gostin of the Department of Geology, University of Adelaide, for his guidance and for making available the Sedimentology Laboratory for study of sand samples; Messrs. R. Culver and H. F. Tabalotny of the Department of Civil Engineering, University of Adelaide, for making the wind tunnel available for experiments with constructional sand forms in relation to obstructions; Prof. C. von der Borch, of the Earth Sciences Department, Flinders University, for allowing the use of facilities within his Department and the time and assistance given by Mr. A. Drummond; Mr. Farrent, Senior Engineer for South Australian Bulk Handling Co-operative Pty. Ltd., who made his files on silo construction available but unfortunately subsequent contact with building contractors failed to yield the information sought. People with properties on northern Eyre Peninsula were always helpful, and, in particular, Mr. J. Kwaterski, Senior, of "Pildappa" and Mr. and Mrs. D. R. Mullan of "Kappakoola".

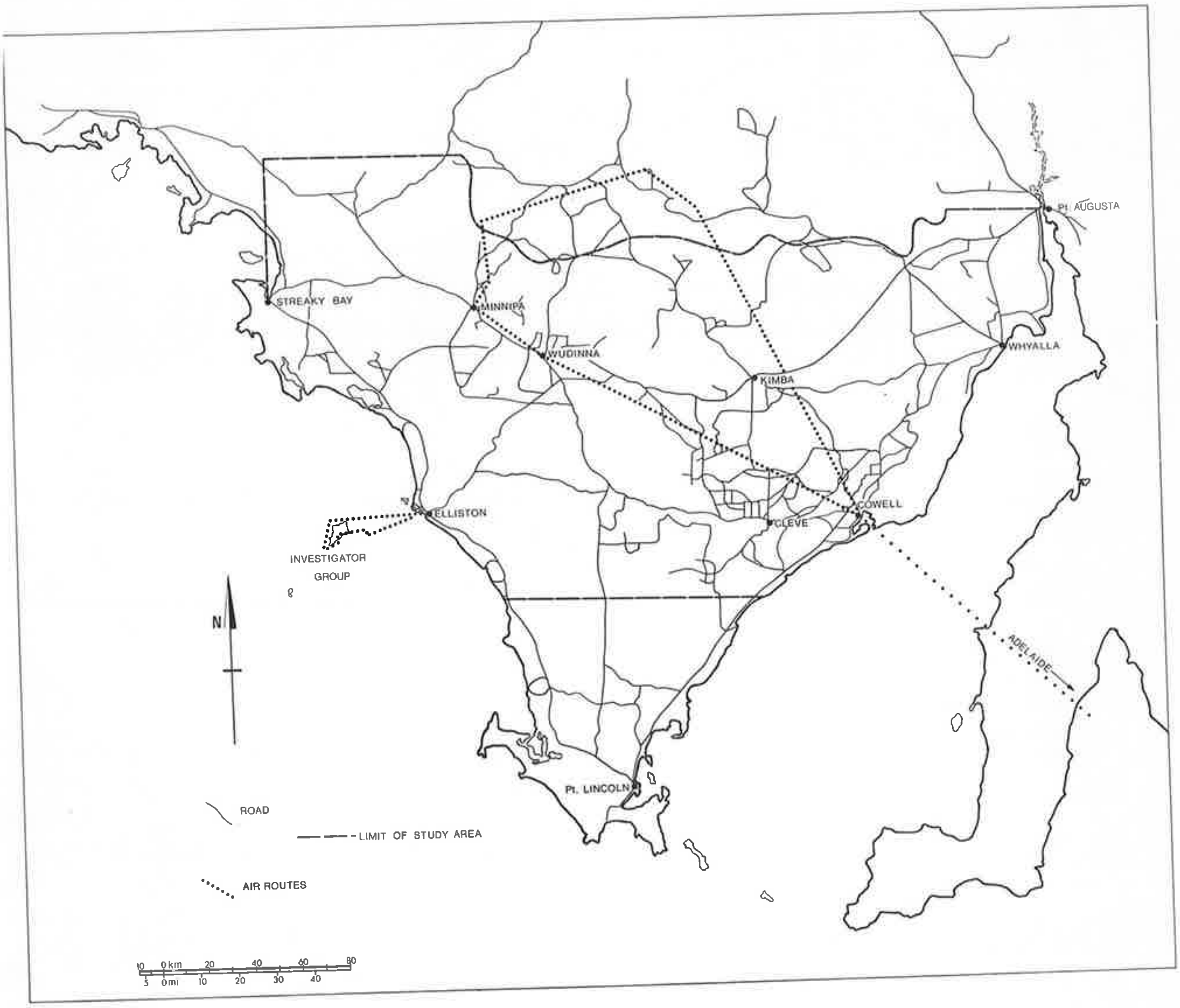

Figure 1.2.

Traverse map, showing roads and tracks travelled and along which observations were made and the route followed on aerial traverses.

CHAPTER TWO: PHYSIOGRAPHIC REGIONS.

> The influence of structure on geomorphology is profound. Not only are the great features in the morphology of the globe - mountain chains, plateaux, rift valleys, continental margins and the like - predominantly of structural origin and formed by folding, faulting, or warping, but many of the minutiae of landforms, the shape of hills or mountains and the trends and patterns of streams, are controlled by structure through the action of agents of weathering and erosion on complex rock masses.
> (E. S. Hills, 1963 p. 431).

A. GENERAL STATEMENT.

Eyre Peninsula is located at the southeastern extremity of the Gawler Block or Platform which in turn occupies the southeastern part of the Westralian Shield. This last is more properly referred to as a craton, for sedimentary rocks conceal the underlying crystalline rocks over wide areas. On Eyre Peninsula the crystalline basement crops out or lies at only shallow depths throughout the centre and west of the study area, but in the east there is a cover of Proterozoic strata which are folded in the Cleve Hills and flat-lying in the Tent Hill region (Fig. 2.1). In the west Mesozoic and Tertiary sediments occur in several small shallow basins, such as the Cummins, Lincoln, Uley-Wanilla and Polda basins and the Corrobinnie Depression.

The major relief features of northern Eyre Peninsula reflect the structure of the underlying rocks. It is therefore necessary to

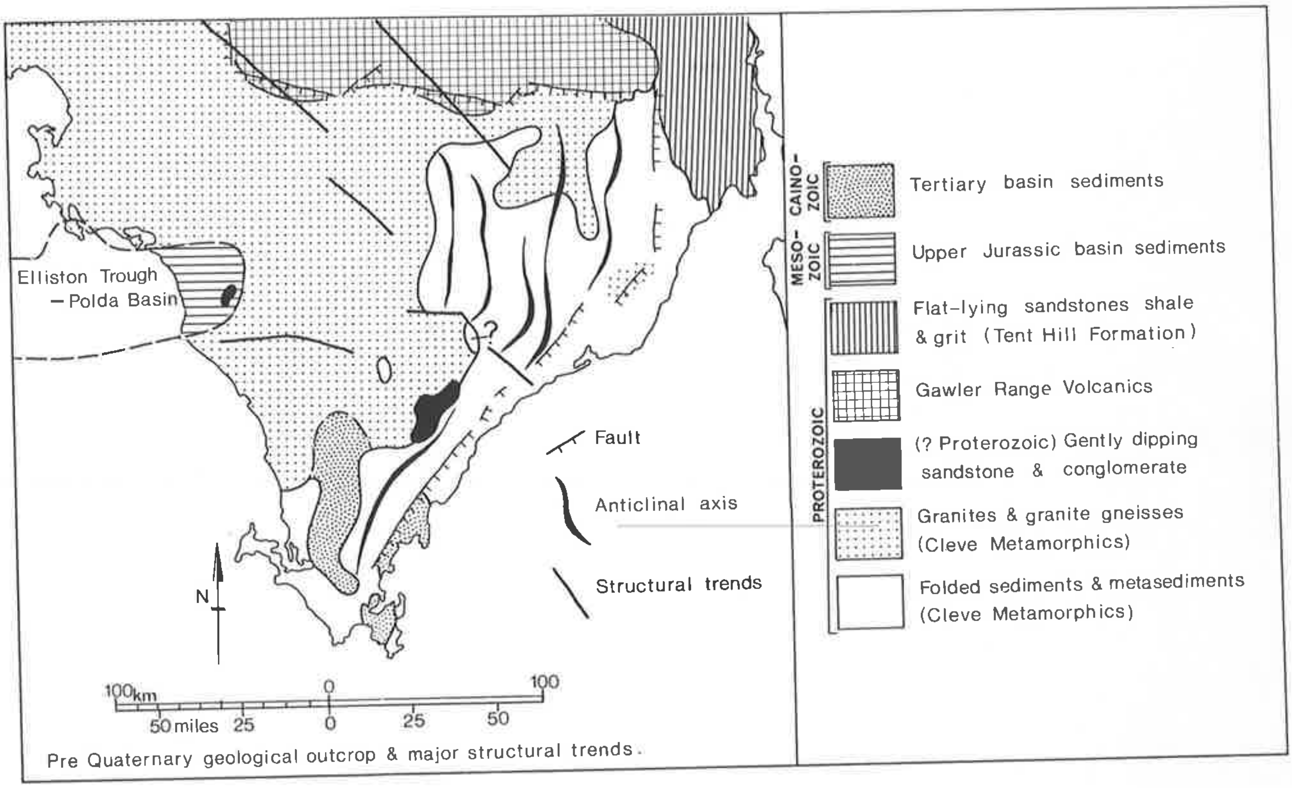

Figure 2.1.

Bedrock geology of Eyre Peninsula, excluding Quaternary deposits.

review the geological framework of the Peninsula in order to establish the basis for the explanatory account of physiographic regions which follows.

B. STRATIGRAPHY AND STRUCTURE.

The outline of Eyre Peninsula appears to be determined by faults. The fracture system which delineates the Peninsula on the southeast, the Lincoln Lineament, is reasonably well known for the faults associated with it have been traced from the southern extremity of the Peninsula to the vicinity of Port Augusta (Fig. 2.1). The faulting which has affected the early Proterozoic strata between Iron Knob and Port Augusta has not apparently influenced the disposition of the late Proterozoic Tent Hill Formation in the same area, showing that the earth movements originated in the earlier Proterozoic. However many of the faults have been reactivated in later Cainozoic times (Miles, 1952, 1954) and indeed remain active (Fig. 2.2; Sutton and White, 1968; D. J. Sutton, *pers. comm*).

The origin of the southwestern margin of the Peninsula is less certain, largely because the crucial field evidence now lies either beneath the seabed or buried beneath several score feet of aeolianite. However the west coast of the Peninsula is in broad view linear with a northwest-southeast trend, suggesting a structural origin. Moreover some earthquake epicentres have been recorded along the line of a supposed

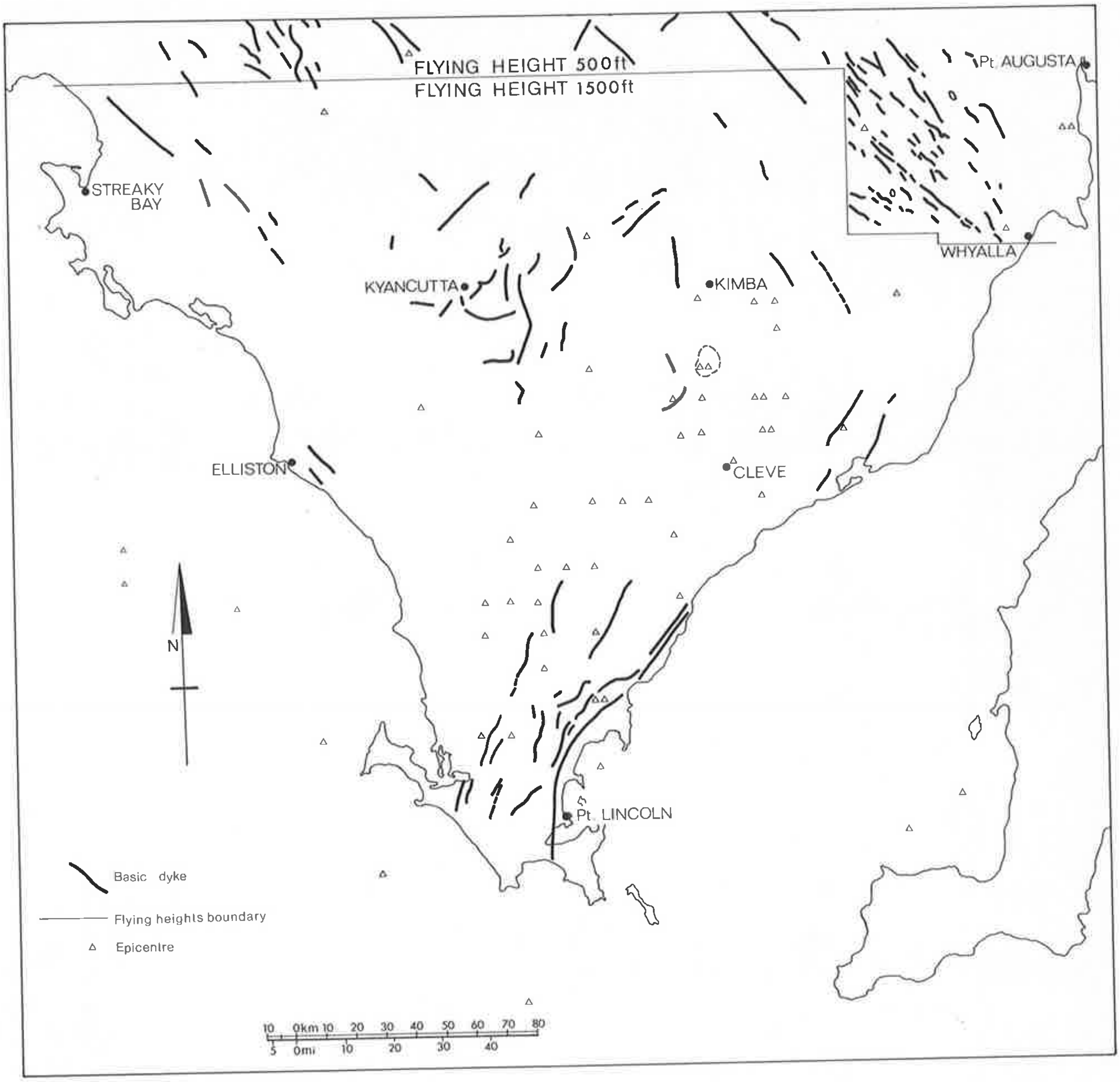

Figure 2.2.

Earthquake epicentres and basic dykes* suggested by aeromagnetic survey. (After Sutton and White, 1968, and D. J. Sutton pers. comm; and D. Boyd, 1970).

* Those aeromagnetic anomalies of the Kyancutta-Kimba-Cleve-Cowell-Port Lincoln region which trend generally N-S or NE-SW are related to banded iron formations (R. K. Johns, pers. comm.).

offshore fracture zone (Sutton and White, 1968) which can be traced to the southeast, to the west and south of Kangaroo Island, where more epicentres are recorded (Sutton and White, 1968; Twidale, 1968b, p. 54). However if the west coast is related to faulting there has been little movement since the Palaeozoic because Mesozoic and Tertiary sediments in the Elliston Trough, the off-shore continuation of the Polda Basin, noted on-shore by Harris (1964) and Rowan (1968) are not offset (Smith and Kamerling, 1969).

Several major geomorphological features within the Peninsula can also be interpreted as being related to fractures in the crust. Perhaps the most notable is the Corrobinnie Depression in the north of the Peninsula which, running virtually straight for some 125 miles from northwest to southeast, is certainly related to a fault zone and is due to its exploitation either by weathering or by rivers or both (Bourne, Twidale and Smith, 1974). Many other similar northwest-southeast trending zones of weakness have been detected by aeromagnetic surveys (Boyd, 1970). Others are expressed as linear topographic features such as the lows occupied by Agars Lake, Kappakoola Swamp, lakes Yaninee, Warramboo and Wannamana, and numerous other unnamed salinas, and the dissected but still linear bluff which delimits the Cleve Hills at their southern margin.

Superficial deposits of Pleistocene aeolianite, calcrete and dune sand mask much of Eyre Peninsula, particularly in the west and on the lowlands, but it is clear that within this structurally determined block granite occupies most of the centre and west of the Peninsula.

Contrary to the views of Whitten (1963, 1966) and Thomson (1969) Eyre Peninsula can be regarded as a large anticlinorium disrupted by regional faulting and with synclinorial structures located near both coasts, though more obviously in the east. The granitic masses which occupy the central regions are regarded as either intrusive or metamorphic products of the root zone of a Proterozoic orogen. Relicts of the former geosynclinal sediments survive in such localities as Talia Caves, Tooligie Range and more extensively in the east in the Cleve Hills, the Blue Range and the Lincoln Uplands. Gneissic granulites from the Port Lincoln area have yielded an isotopic date of 1780 ± 120 m.y. (Arriens and Lambert, cited in Compston and Arriens, 1968), indicating that the rocks are of Lower Proterozoic age.

During orogenesis this old geosynclinal trough was intruded by granitic masses notably the Charleston Granite (1590 ± 30 m.y. old according to Compston, Crawford and Bofinger, 1966), the Burkitt Granite (1550 ± 70 m.y. Compston, Crawford and Bofinger, 1966) and the granites of the Minnipa and Wudinna areas (approximately 1500 m.y. A. H. Blissett and B. P. Thomson, pers. comm.). The injection of these igneous rocks possibly indicates a middle Proterozoic orogeny (though see Gilluly, 1973).

Howsoever this may be the eroded remnants of the ancient mountains were, in late Proterozoic times, overlapped by seas and sediments associated with the late Proterozoic – early Palaeozoic Adelaide

Geosyncline. In particular sandstones of the Tent Hill Formation were deposited over the northeastern part of what is now Eyre Peninsula forming a considerable cover, which thinned westwards.

A prolonged stratigraphic hiatus followed the deposition of these still flat-lying late Proterozoic clastic sediments. No sediments of Palaeozoic age are yet recorded from the Peninsula. Even the late Carboniferous - early Permian glaciation(s) appear to have passed by the area, though it affected Yorke Peninsula, just across Spencer Gulf; in any event no rocks of certain glacigene origin survive on Eyre Peninsula. Minor occurrences of terrestrial strata of Upper Jurassic age occur in the Polda Basin (Harris, 1964; Smith and Kamerling, 1969) and in other shallow and areally limited depressions within the granitic basement. The lateritic residuals of southern Eyre Peninsula are also of probable early Mesozoic age (see later, Chapter Three). Tertiary swamp deposits are also recorded from such areas as the Cummins Basin (Shepherd, 1962a), the Polda Basin (Harris, 1964) and the eastern coastal plain of the Peninsula (Hiern, 1970).

C. PHYSIOGRAPHIC REGIONS.

A number of physiographic regions which are essentially structural regions have been recognised and delineated (Fig. 2.3). These are:

1. SPENCER UPLANDS -
   a. BLUE RANGE
   b. CLEVE HILLS
   c. NORTHEASTERN PLATEAU

2. EYRE LOWLANDS -
   a. KYANCUTTA PLAINS
      (i) Tuckey Plain
      (ii) Yaninee Plain
      (iii) Podinna Plain
      (iv) Buckleboo Plain
   b. CORROBINNIE DEPRESSION
   c. SHERINGA PLAIN
   d.. GULF PLAINS
      (i) Utera Plain
      (ii) Cowell Plain
   e. NONOWIE HILLS AND HIGH PLAINS.

Within each of these divisions there are inevitably contaminants from adjacent physiographic units.

Figure 2.3.

Physiographic regions of northern Eyre Peninsula.

SPENCER UPLANDS

1. BLUE RANGE
2. CLEVE HILLS
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7. GULF PLAINS
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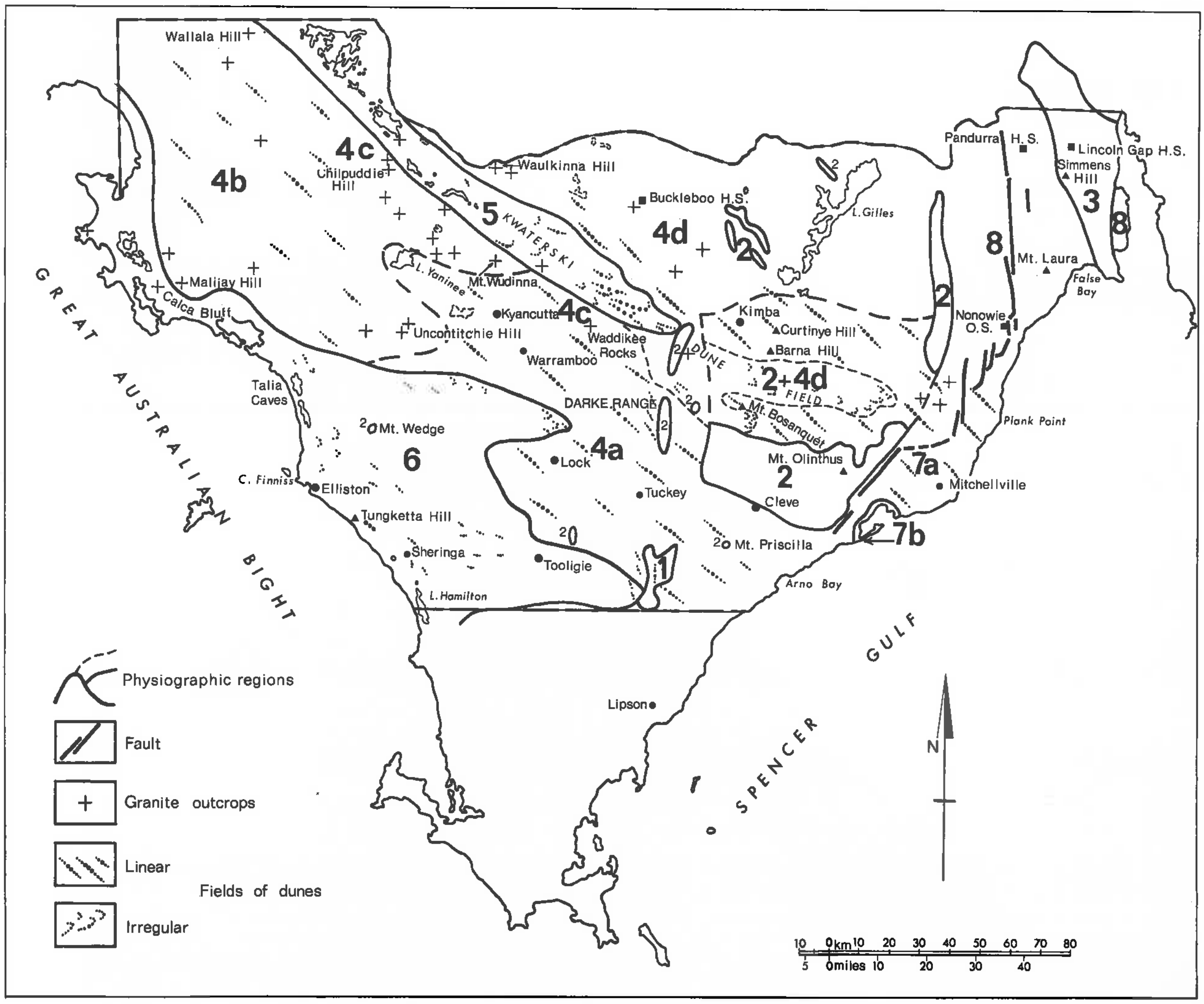

Figure 2.3.

Physiographic regions of northern Eyre Peninsula.

1. SPENCER UPLANDS.

This region basically consists of the Blue Range, Cleve Hills and the Northeastern Plateau, all developed on Proterozoic sediments and crystalline rocks, essentially flat-lying, but folded in the Cleve Hills. Several isolated peaks and ridges located north, west and south of the upland proper bear a strong morphological and genetic relationship to the main highlands but are described within the Eyre Lowlands region in which they stand (see below).

(a) BLUE RANGE.

Blue Range (Pl. 2.1) and the nearby Verran Hill are eroded in sandstones and quartzites with easterly dips of 10° - 15°, which apparently occur over a much wider area at a relatively shallow depth (Shepherd, 1958a). They have been likened to outcrops in a limited area of southwestern Cleve Hills, in Mount Wedge and on the coast at Talia (Johns, 1961; Botham, 1967). Since these lithologically similar outcrops lie on the margin of a gravity trough extending from Elliston south of Mount Wedge through the Polda Basin and across the Peninsula to a low east of Lock (Fig. 2.4), it is speculated that these sediments are of the material infilling the trough, and are overlain by younger Mesozoic and Cainozoic material (Rowan, 1968; Smith and Kamerling, 1969). These sediments are of uncertain age (B. P. Thomson, pers. comm.), although Rowan (1967) suggested Middle Proterozoic.

Plate 2.1.

Vertical air photograph of Blue Range. The lateritised summit surface is bounded by a steep westward-facing scarp but to the north and east gentle slopes lead down to the Utera Plain which is traversed by fixed longitudinal dunes. To the west of the Range stabilised dunes are irregular and reflect the disturbance of the airflow caused by the presence of the upland. (Reproduced by courtesy of the Department of Lands, South Australia).

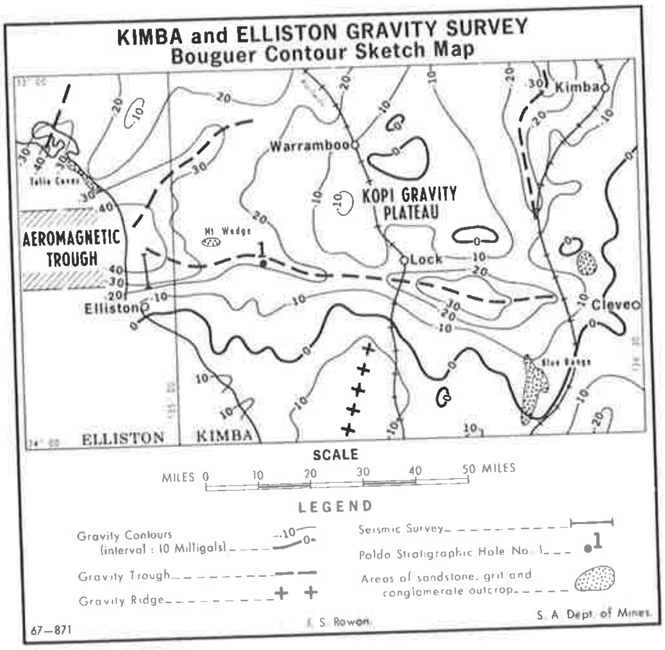

Figure 2.4.

Gravity anomalies in central Eyre Peninsula. (After Rowan, 1968, p. 4).

Blue Range has a lateritic duricrust developed on a fairly even summit surface 750 - 800 feet above present sea level. Sand covers a thin layer of pisolitic iron with mottled and pallid weathered bedrock below. The ferruginous zone is only 1 - 2 feet thick and thus compares with the laterite profiles of Kangaroo Island and southern Eyre Peninsula. From the westward facing scarp in which are developed many structural benches the surface slopes to meet the surrounding plain abruptly in the southeast, but where the weathered zone is exposed at the surface it inclines to merge with the lower level.

(b) CLEVE HILLS.

The Cleve Hills consist of an assemblage of ridge and valley forms (Pl. 2.2) associated with folded metasedimentary and sedimentary sequences, namely the Cleve Metamorphics (Fig. 2.5). These comprise the quartz-feldspar gneisses of the Flinders Group and the mica schists of the Hutchison Group which includes some granitoid rocks. These sequences are conformable, and are distinguished only by the varied intensity of metamorphism they display. ~~(Johns, 1961)~~. The strata have been folded into anticlinoria and synclinoria, the axes of which trend northeast - southwest (Thomson, 1969). The Hills are bordered on the east and south by prominent escarpments, which though dissected are essentially linear in plan and are of fault origin (Pl. 2.2; Fig. 2.5). On the west the Cleve Hills meet the Tuckey Plain in a low scarp, but to the north they merge with the Buckleboo Plain, which slopes up to the

Plate 2.2.

Vertical air photograph showing part of the Cowell fault scarp (XYZ) some eight miles northwest of Cowell. Note the ridge and valley topography and the northwest-southeast trending relict dunes traversing the plains. (Reproduced by courtesy of the Department of Lands, South Australia).

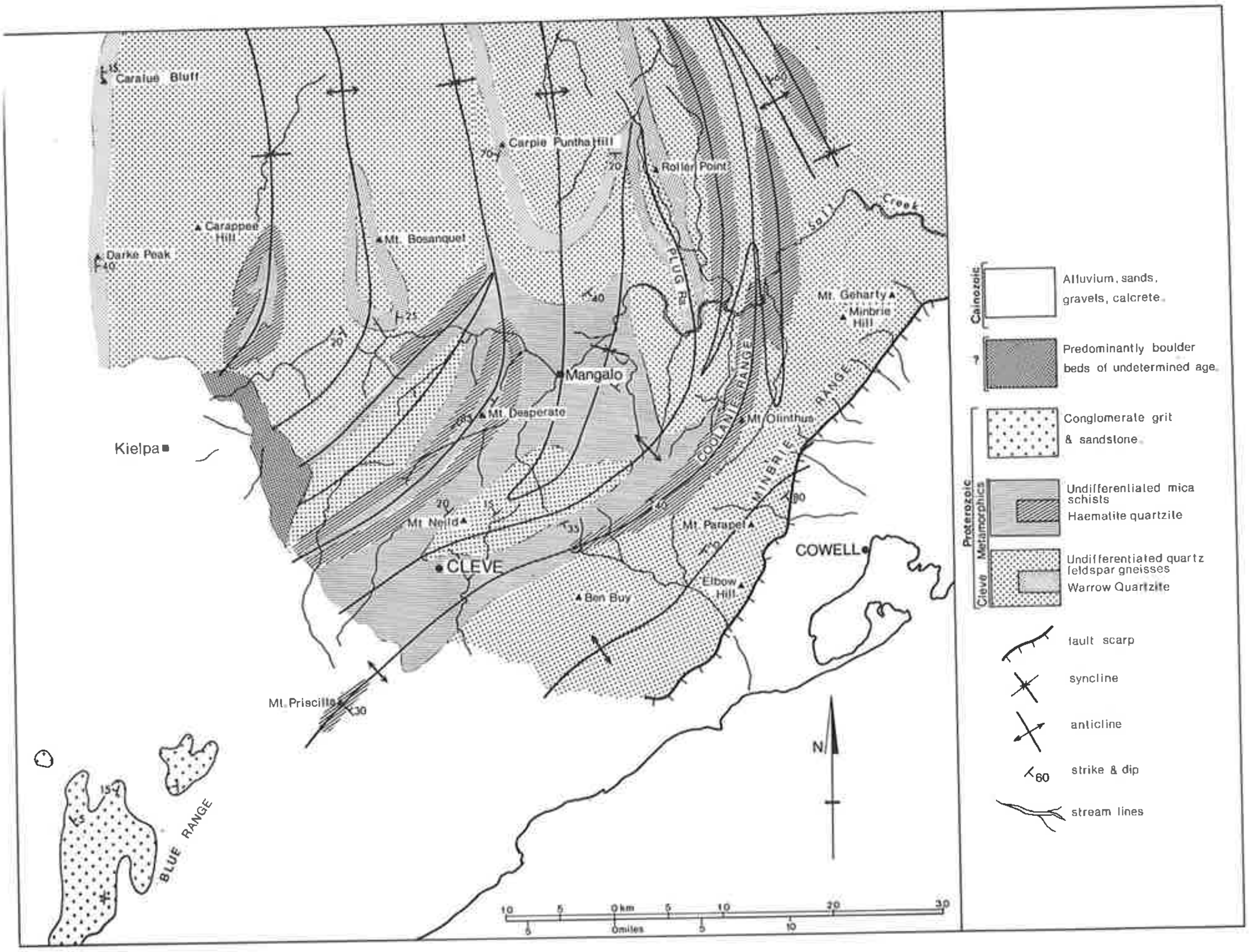

Figure 2.5.

Geology of the Cleve Hills. (After Johns, 1961).

foot of the Gawler Ranges.

Within the Cleve Hills the more resistant quartzites and schists uphold the ridges which trend more or less north-south, curving in the vicinity of Mount Geharty towards the southwest and away from Spencer Gulf. Peaks and ridge crests attain elevations of up to 1487 feet on Mount Olinthus, though Carpie Puntha Hill a northern outlier of the uplands reaches a height of 1570 feet. Relief amplitude is of the order of 300 feet and slope angles in southern Cleve Hills vary from $20^{\circ} - 35^{\circ}$. The folds extend as far north as Buckleboo; the associated quartzites giving rise to such prominent ridges and isolated peaks as Wilcherry and Botenella hills in the north, and Curtinye, Barna and Wild Dog hills in the area southeast of Kimba.

The most prominent ridges, e.g. Carpie Puntha Hill, Mount Bosanquet, Roller Point and Plug Range, are of quartzite and the homoclinal and hogback forms are eroded in the limbs of anticlines in which the strata dips at angles varying from 20° to 80°. Mount Olinthus in the Coolanie Range is cut in a tight double syncline, again in quartzite. Lower ridges such as Mount Geharty, Minbrie Hill, Mount Parapet and Elbow Hill are formed of gneissose rock. Other low areas in the relief are eroded in schists. In places more resistant strata such as dolomites and quartzites are interbedded in thick sequences of weaker schists, and for this reason Mount Neild, Benbuy, Triple Hill and Poolalalie Hill and their associated ridges stand well above the surrounding high plains. To the northwest of the main upland mass the Middleback Ranges are of haematite quartzite as are the minor ridges which stand relatively high in the relief in the western sector of Cleve Hills. At the western margin of the upland some low rounded hills are capped and protected by a mantle of gravel and boulders. The conglomerate from which these are derived has been mapped as of later Precambrian age by Botham (1967), but their unconsolidated and essentially undeformed character suggests that they are much younger.

Despite the overall ridge and valley topography prominent surfaces of low relief occur within the Cleve Hills. High above the broad floors of the structurally controlled valleys which grade into the Buckleboo Plain to the north, a prominent planate surface is eroded across steeply dipping gneisses and quartzites in the southern Cleve Hills, and some of the accordant ridge crests and peaks of more northerly regions may represent equivalents of this same surface.

The drainage of the Cleve Hills calls for some comment, for the steep-gradient scarp rivers are relatively short, and most of the region is drained by the Salt Creek system (Fig. 2.5) in its middle section. Salt Creek itself runs west-east across the structural grain and though its upper sector and tributaries are strike streams, part of Salt Creek is clearly anomalous. This transverse sector trends southeast-northwest and is aligned with the fault zone thought to underlie the Corrobinnie Depression to the northwest (Bourne, Twidale and Smith, 1974). This particular sector which is a dip stream in some stretches and anti-dip in others, extended headward and captured the strike streams to the southwest: hence the prominent elbows of capture, for instance some four miles north-northwest of Mount Geharty. But the former headwater zone like the lower reaches of the old Middleback drainage, has been inundated by the spread of dune sand from the northwest during the late Pleistocene, though subsurface waters flow to the main surface drainage channel (Hiern, 1970). The lower course has been diverted partly by sand, possibly also by uplift of the en echelon fault blocks which extend southwest-northeast between Cowell and Whyalla (Fig. 2.1): the lower Salt Creek after its junction with the old Middleback river instead of running to the sea somewhere between Mitchellville and Plank Point, has been diverted south-southwest to Pondooma and the northern shore of Franklin Harbour.

Thus the transverse sector of Salt Creek can be explained in terms of capture and diversion by dune sand and possibly also by faulting: there is no necessity to invoke superimposition, inheritance or antecedence.

(c) NORTHEASTERN PLATEAU.

The Northeastern Plateau is part of the Tent Hills region which extends from Whyalla, north of Port Augusta almost to the northern extremity of Lake Torrens (Fig. 1.1). This region of plateaux and mesas is contiguous with the extensive tableland known as the Arcoona Plateau which borders Lake Torrens on its western side.

In the study area the Plateau consists of a dissected tableland (Pl. 2.3) capped by the resistant, almost flat-lying Simmens Quartzite which overlies weaker, finely-bedded sandstones and shale of the Tent Hill Formation. The Plateau surface is in places flat or very gently undulating and only skeletal soils have developed on the weathered beds above the resistant quartzites; elsewhere however some beds persist above the quartzite and give rise to domed plateaux, so that this summit surface is of erosional origin, for it truncates various strata. Resistant members of the Tent Hill Formation, exposed in the high and precipitous scarp face, give rise to structural benches and alternations of bluff and debris slope. Gullies score the slopes and are responsible for undermining, steepening and maintaining the bluff. Detritus protects the debris slope below. Intermittent streams have cut into the Plateau from all sides, so that some parts already stand in isolation to form such mesas as Saltbush Hill and The Sisters.

2. EYRE LOWLANDS.

Essentially underlain by granitic basement the Eyre Lowlands are broadly rolling and stand some 30 - 450 feet above present sea level. They are partly erosional, partly aggradational. The Kyancutta Plains are intrinsically erosional but there are morphological variations within the region and the Buckleboo Plain stands geographically apart from the rest of the lowlands. The surface features of the Corrobinnie Depression

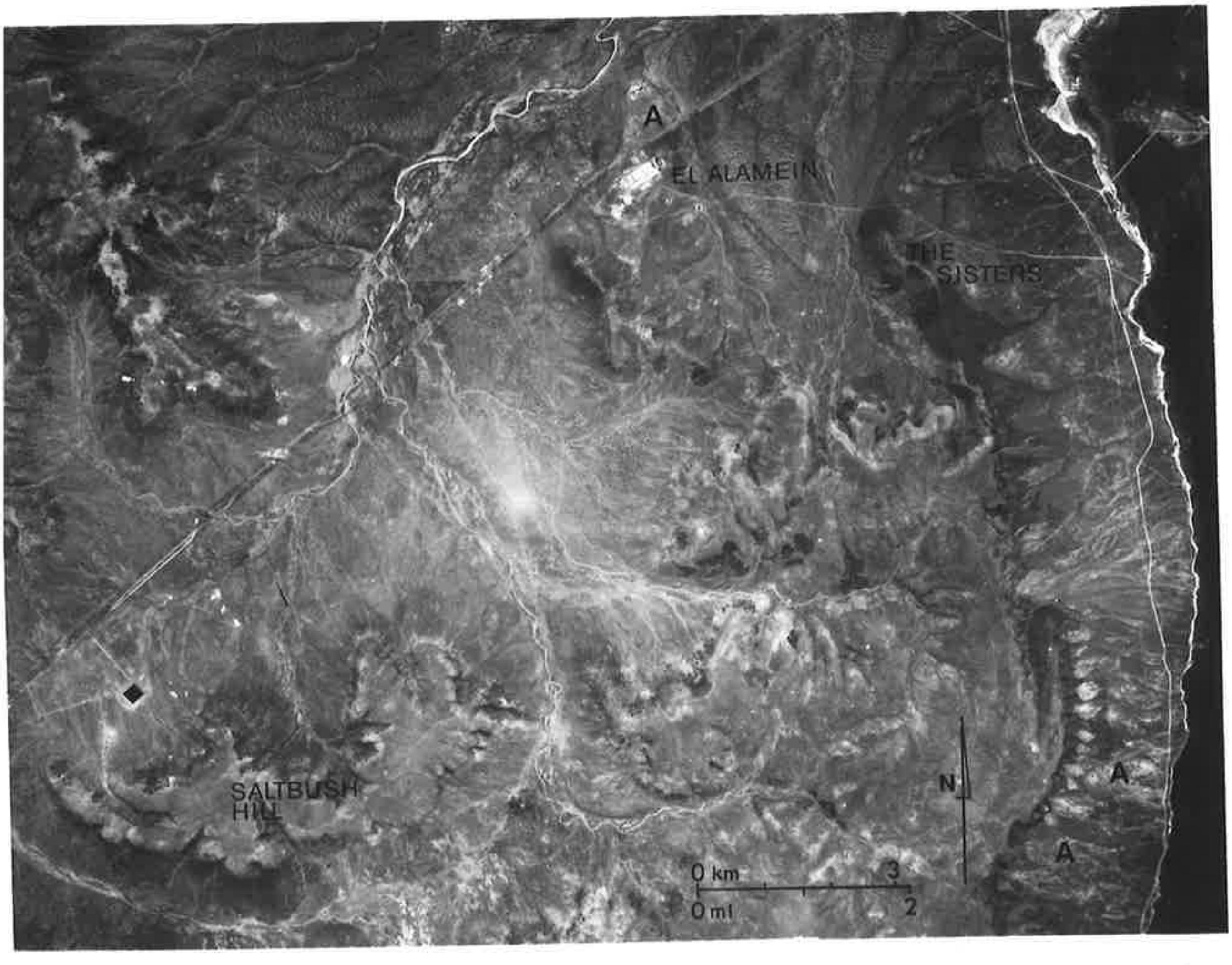

Plate 2.3a.

Vertical air photograph showing part of the dissected Northeastern Plateau. The uplands are capped by the Simmens Quartzite but siltstones and other argillaceous strata are exposed at the margins of the plateau and beneath the plains. In the scarp foot zone are preserved remnants of a higher plain on which silcrete was developed e.g. at A: the Alamein Surface. (Reproduced by courtesy of the Department of Lands, South Australia).

Plate 2.3b.

The Northeastern Plateau at Lincoln Gap, showing the sandstone capped flat-topped plateau on the left and to the right domed plateaux due to the preservation above the Simmens Quartzite of weaker though conformable sediments. A remnant of the Alamein Surface can be seen below the plateau scarp at left (A).

The Sheringa and Gulf plains on the other hand are due to deposition.

(a) KYANCUTTA PLAINS.

(i) Tuckey Plain:

The rolling Tuckey Plain is characterised by the occurrence of fields of linear, northwest-southeast trending sand dunes (Pl. 2.4). Otherwise it is similar to the Yaninee Plain and though lower than the latter is regarded as part of the same surface. Slopes average $\frac{1}{2}^{\circ}$ - 2°, and stream lines are all but absent.

The Tuckey Plain is developed largely on granitic bedrock, though southwest of Wudinna weathered schists and gneisses of unknown age occur 150 feet beneath the low lying area characterised by salt lakes and swamps between Warramboo and Kyancutta (Shepherd, 1960a). At Kyancutta weathered schists and gneisses were encountered at a depth of seventy feet below the surface (Shepherd, 1962a). Whitten (1966) identified clay outcrops at the margins of claypans in the Kopi-Kyancutta-Warramboo area as decomposed schists. But granite underlies most of the region. From the little data available it appears that there is a thicker regolith than beneath the Yaninee Plain, for the depth to fresh bedrock is reported as 150 feet between Kyancutta and Koongawa (Shepherd, 1960b), and near Lock the fresh granite is overlain by 350 feet of weathered rock and superficial deposits (Shepherd, 1962a).

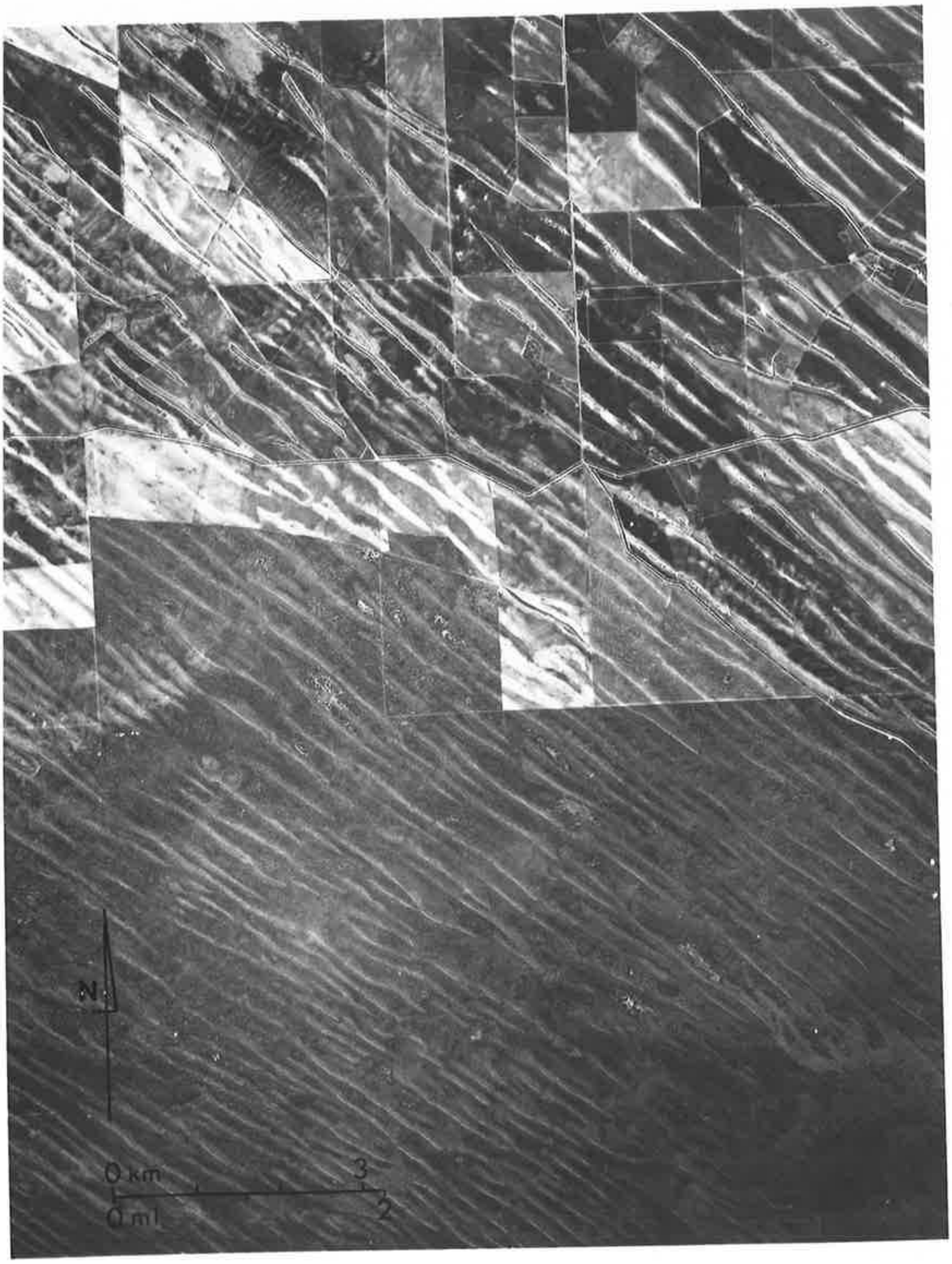

Plate 2.4a.

Northwest-southeast trending late Pleistocene longitudinal dunes of the Tuckey Plain, ten **miles** southwest of Caralue Bluff. (Reproduced by courtesy of the Department of Lands, South Australia).

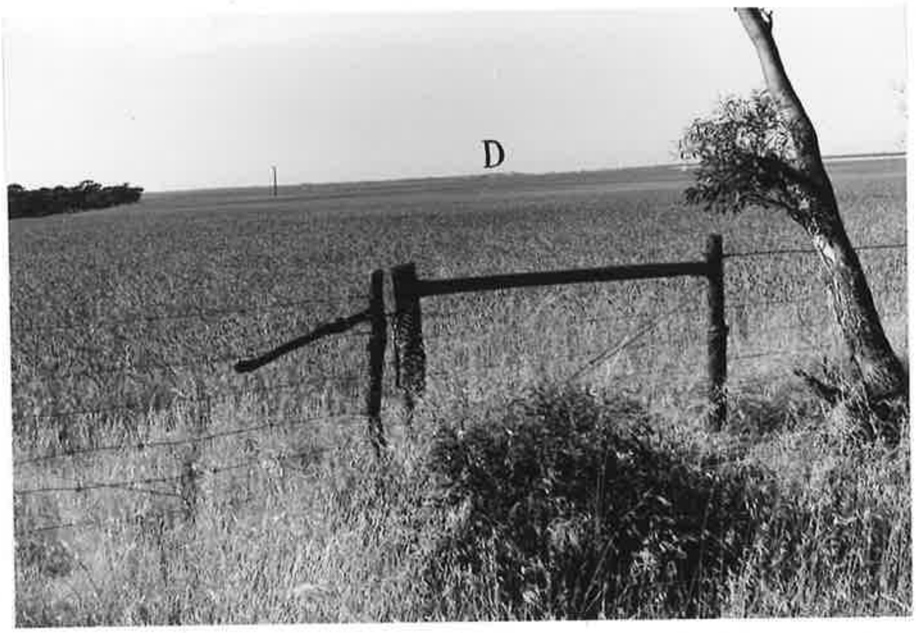

Plate 2.4b.

The Tuckey Plain in the type area showing the flat surface with low linear sand dunes (D) standing a few feet above the general level.

The dunes which trend northwest-southeast average three to four per mile and are approximately 50 - 60 feet high, 400 feet wide and continuous for as much as four miles. In the vicinity of Tuckey itself there are dune-free areas of less than four square miles which are the crests of broad rises standing some 30 feet above the adjacent surface. There is also dune-free, slightly higher ground around the township of Lock. This slopes down to the south and east, but more abruptly to the north towards the shallow depression trending northwest-southeast in which are found lakes Yaninee, Wannamana, Warramboo, Kappakoola Swamp and numerous other smaller salinas. While essentially retaining the form of longitudinal dunes, dunes within this depression display irregularities in plan. Although longitudinal dunes encroach on the northwestern margins of playas throughout the Plain this feature is best seen at Kappakoola Swamp and Agars Lake (Pl. 2.5). Lunettes are usually developed along the eastern and southern shores of playas e.g. Lake Yaninee and Kappakoola Swamp (Campbell, 1968; Smith, Twidale and Bourne, 1975); there are also man-induced oscillatory dunes bordering the Kappakoola Lunette (Smith, Twidale and Bourne, 1975).

The sand from the longitudinal dunes of the Tuckey Plain is siliceous, fine (average 2.25ø), moderately well-sorted (0.69ø), subangular to angular with a few well-rounded grains and generally frosted. The minor iron-staining and the lack of aggregates may be a result of washing. The bulk of the sands appears to have been derived from the local granitic bedrock.

Plate 2.5.

This is a low-lying part of the Yaninee Plain which is strictly speaking a part of the Tuckey Plain. However it extends over so small an area that it is unmappable. It does however illustrate the former direction of dune migration for the sand has clearly moved from northwest to southeast over the margin of Agars Lake. (Reproduced by courtesy of the Department of Lands, South Australia).

Standing above the general level of the Tuckey Plain are outliers of upland regions associated with the occurrences of Warrow Quartzite in such ridges as Darke Range and Tooligie Range, with quartzite and granite together in Caralue Bluff, and with gneissic granite in Carappee Hill. The Ridges and ranges all trend north-south and lie athwart the northwest-southeast resultant airflow responsible for the trend of the longitudinal dunes. All thus form obstacles to the wind and have disturbed the regularity of the dune pattern (Pl. 2.6).

Darke Range is an isolated homoclinal ridge eight miles long trending north-south. There are shoulders at mid-slope level at either end. Calliss Hill stands a little apart from the southern end of the range. Pediments slope east and west from the scarp foot to the Tuckey Plain. The surface of the eastern pediment slopes more gently over a longer distance and is some twenty feet higher overall than that of the western pediment. Alluvial sediments reach a maximum depth of 100 feet east of the Range, but there are less than 50 feet of sediments above a stratum of lateritic sandstone overlying weathered bedrock to the west (Shepherd, 1962b). The quartzite dipping 40° east underlying Darke Range is clearly part of the folded sequence of the Cleve Hills, as is that of Caralue Bluff to the north and Tooligie Range to the southwest with dips of 15° east and 30° west respectively.

Caralue Bluff is a meridional quartzitic ridge about four miles long, and broadening to the south. While granite occurs in outcrop northeast of the ridge, quartzitic bedrock occurs at a depth of

Plate 2.6.

The homoclinal ridge of Darke Range from the north. The field of northwest-southeast trending sand ridges run from bottom right to top left in the picture but the upland has disturbed the airflow with the result that the sand ridge pattern is deranged on its windward or western side.

120 feet immediately to the west of the upland (Shepherd, 1960c). In the north the Bluff consists of isolated flatirons separated by valleys occupied by fixed linear dunes. Ferruginous material associated with weathering on the pediment to the southwest of the Bluff is similar to that found on the Buckleboo Plain.

Tooligie Range also of quartzite trending northwest-southeast is a less prominent ridge than either Darke Range or Caralue Bluff. The low irregular outcrop some four miles long and displaying a westerly dip is surrounded by a low-angle dune-free pediment.

Carappee Hill consists of several ridges radiating from a central dome-like peak and is of granite gneiss (see Pl. 2.7; Fig. 2.6). The Hill meets the Tuckey Plain in an abrupt angle. It has intruded and lies within the syncline bordered by Caralue Bluff and Darke Range to the west and Carpie Puntha Hill and Mount Bosanquet to the east. In detail the joint pattern is similar to that of the granite inselbergs of the Yaninee Plain (see above), but in broad view there is a strong north-south lineation in the rock.

(ii) Yaninee Plain:

The Yaninee Plain is underlain by granite and gneisses. Apart from outcrops of fresh rock exposed in the numerous granite residuals the bedrock is deeply weathered. Borelog information suggests that the depth from the land surface to fresh granite varies between 20 and 150 feet according to locality (Shepherd, 1958b, 1960a, 1960b). The

Plate 2.7.

Vertical air photograph of Carappee Hill, a domed inselberg eroded in Precambrian gneissic granite. Note the prominent north-south lineation displayed in the inselberg, the longitudinal dunes of the surrounding plains and the disturbance of their regular linear pattern on the western side of the upland. (Reproduced by courtesy of the Department of Lands, South Australia).

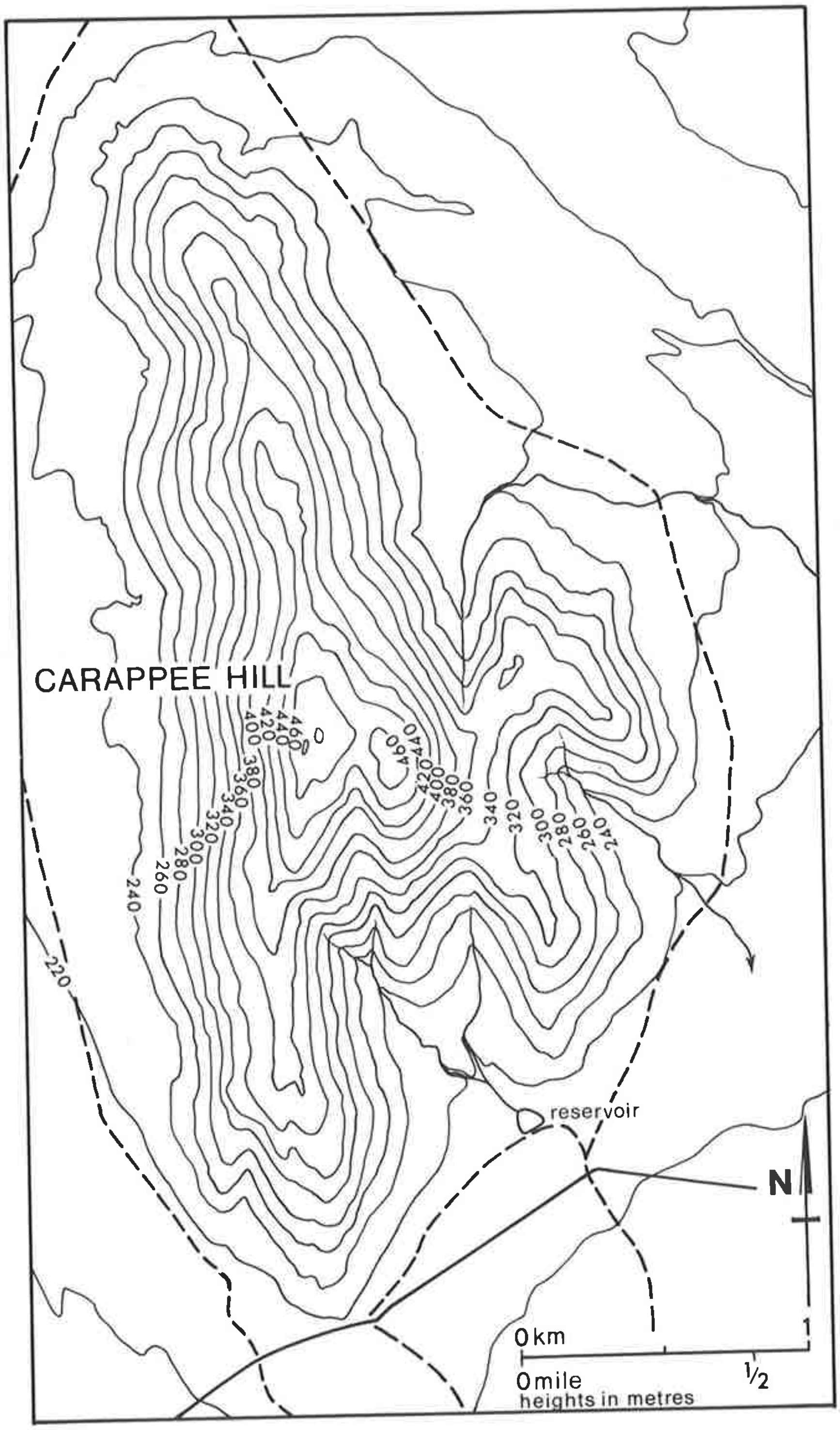

Figure 2.6.

Contour map of Carappee Hill. Note the occurrence of benches at elevations of 1390-1400 feet (425-430 m) and 1300 feet (400 m) and of several minor benches below 1200 feet. (Department of Lands. South Australia).

Plain is best described as broadly rolling (Pl. 2.8); relief amplitude is of the order of 250 feet but slopes average only 1° - 2° inclination. The ephemeral stream lines are widely spaced, and the interfluves take the form of broad convexities. The presence of some linear, northwest-southeast trending sand dunes adds to the rolling aspect of the Plain.

The lower topographic basins within the region are occupied by linear dunes and salinas such as Agars Lake and many other unnamed playas: they are properly parts of the Tuckey Plain. The highest points in the relief occur on the granite residuals which stand above the rises and higher slopes of the Yaninee Plain (Pl. 2.9). These residuals which vary greatly in size and shape are particularly well represented in the Wudinna and Minnipa districts and in County Robinson. Whatever their precise dimensions however the granite residuals display an assemblage of minor forms which include gnammas and Rillen (which are together responsible for the grooved and dimpled appearance of the outcrops) sheet structure, boulders, tafoni and flared slopes.

(iii) Podinna Plain;

The Podinna Plain ranges along the southern margin of the Corrobinnie Depression from the vicinity of Wallala Hill southeast to and beyond Poondana Rock (Fig. 2.3). It is a high plain cut across granitic bedrock and stands some thirty feet above the level of the Yaninee Plain. There are several low whalebacks and many pavements, (including the meringue-like surface (Pl. 2.10) developed on a pavement on Scrubby Peak Station), and weathered granite is preserved between these compartments

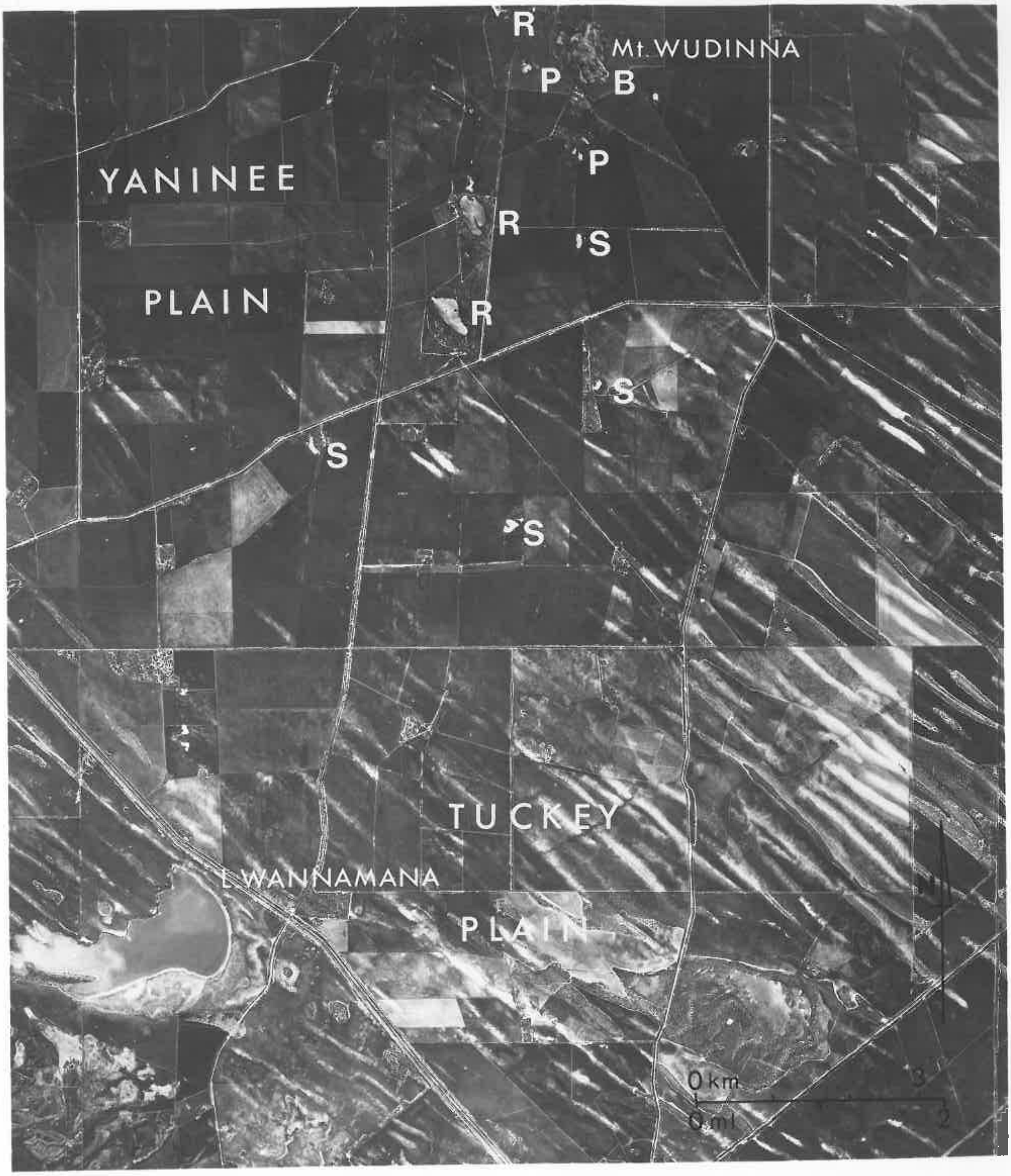

Plate 2.8a.

The contrast between the Yaninee and Tuckey plains is illustrated in this vertical air photograph of the area east of Wudinna. The Yaninee Plain is relatively free of longitudinal dunes but displays numerous granite outcrops which give rise to various features: pavements (P), swells (S), Ruware (R) and bornhardts (B). The Tuckey Plain on the other hand consists of dune fields, in the lower parts of which are playas of various shapes and sizes. The former direction of sand dune movement is clearly demonstrated by their encroachment on the northwestern margin of Lake Wannamana. (Reproduced by courtesy of the Department of Lands, South Australia).

Plate 2.8b.

The Yaninee Plain south of Minnipa. The low granite uplands on the skyline include Pordia Hill and Ucontitchie Hill.

Plate 2.9.

Ucontitchie Hill a granite bornhardt which stands on a low-angle pedimented cone above the Yaninee Plain. Note the sheet structure and the disintegrated sheet structure represented by scattered quadrangular boulders.

Plate 2.10.

The 'meringue' surface developed on a granite pavement north of Podinna Rock. The surface comprises numerous gnammas or weathering pits the margins of which have coalesced forming a knife-edged divide.

of fresh rock. There is very little relief amplitude although there are some fixed longitudinal dunes standing some 20 - 40 feet above the level of the plain. Iron encrustation occurs throughout this high plain both in outcrop and exposed in excavations, notably east of Koongawa, but it is seldom associated with deep weathering. The ferricrete is likened to that found on the Buckleboo Plain. Iron-indurated stream conglomerate occurs in the bed of one of the few streams cutting back into the Podinna Plain from the Corrobinnie Depression. On the flanks of this high plain are granite residuals, the northern and southern aspects of which are exposed depending on their location on either side of the crest, e.g. Chilpuddie Hill and Poondana Rock.

(iv) Buckleboo Plain:

The Buckleboo Plain extends from the ill-defined northern margin of the Cleve Hills northwestwards to the Gawler Ranges. It is a rolling surface with slopes of $1^{\circ} - 2^{\circ}$, and with a relief amplitude of 120 - 180 feet. The plain tongues westwards between the southern margin of the Gawler Ranges and the northern edge of the Corrobinnie Depression (Fig. 2.3). Here, and in the vicinity of Buckleboo H.S., there are numerous granite outcrops, most of them unnamed, as well as occurrences of (?) Archaean sediments, as in the conglomeratic Mount Allalone (Fig. 2.7). Within the area between Kimba and the Middleback Ranges large radius granite and gneiss domes form low, but prominent, landmarks with gnammas, flared slopes and boulder-strewn slopes above the fixed linear sand dunes traversing the Plain. Isolated ridges such as Botenella, Wilcherry and Peterlumbo hills are underlain by quartzites involved in extensions of the

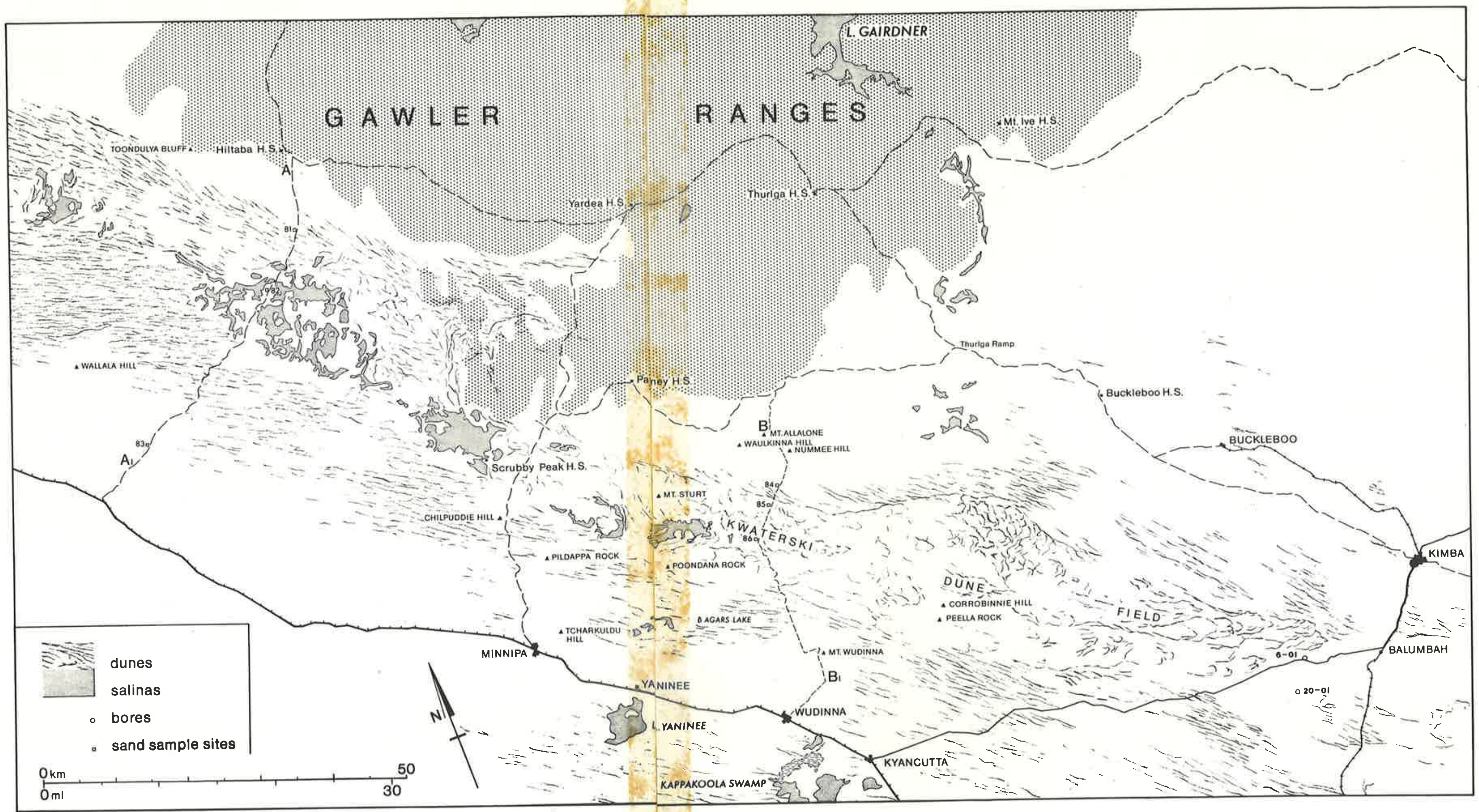

Figure 2.7.

The Corrobinnie Depression with its associated dune fields and salinas. (After Bourne, Twidale and Smith, 1974).

fold structures which underlie the Cleve Hills, and further south the Buckleboo Plain is cut across the same folded sediments and metasediments and is in reality due to the coalescence of the broad river valleys within the uplands. Residuals, such as Mount Bosanquet, Plug Range and Carpie Puntha Hill stand above the Plain.

Dune sands have blanketed these broad valley floors, in places have drifted up the slopes of the divides, and elsewhere are channelled between low outcrops. The sands are essentially of the Kwaterski Dune Field associated with the Corrobinnie Depression (see below). Riverine lunettes are developed in the lee of curves of Salt Creek and appear to have spawned linear dunes which extend eastwards from them.

Nevertheless granite underlies most of the Plain. It occurs at a depth of 17 feet just south of Buckleboo (Shepherd, 1963a), but at a depth of 80 feet northwest of Kimba (Shepherd, 1963b). Streams and valleys are widely spaced and all drainage is internal. A chain of salinas at Thurlga Ramp leads from the Gawler Ranges to the Corrobinnie Depression and similarly east of Curtinye Hill there is a line of swamps and salinas located between the Cleve Hills and Lake Gilles and associated salinas.

Ferricrete and silcrete associated with deep weathering zones occur on some rises within the Buckleboo Plain. Near Wilcherry Hill, Moseley Nobs and Cunyarie the topographic highs are capped by silcrete. Here and in the Kimba area close to the Corrobinnie Depression iron pisoliths associated with deep weathering occur at lower levels.

Impinging on the margin of Buckleboo Plain there are a few fixed linear dunes trending northwest-southeast, which are contiguous with the field of longitudinal dunes covering Tuckey Plain. Seif dunes of the same trend occur in the eastern part of the Buckleboo Plain amid a sheet of sand. Although the seif dune sands include small amounts of mica and are consistently finer, the quartz grains are sub-angular with a few larger rounded grains with frosting and iron-staining, are moderately well-sorted and so resemble the sands of the Tuckey Plain already discussed.

(b) CORROBINNIE DEPRESSION.

The Corrobinnie Depression, named after the granitic Corrobinnie Hill found within it, extends southeast from Toondulya Bluff some 125 miles to near Balumbah (Fig. 2.7). That it occupies a prominent fracture zone is indicated by its linearity, by its northwest-southeast trend which conforms with the regional tectonic pattern, and by the occurrence within it of two epicentres (D. J. Sutton, pers. comm.) indicating that movement along the supposed faults has not entirely ceased. The feature may originally have been a graben or a fault-angle depression like that which forms the Polda Basin and its seaward extension in the Elliston Trough (Smith and Kamerling, 1969). If so, this tectonic morphology has been modified by subsequent denudation as to be unrecognisable. The more immediate origin of the Corrobinnie Depression (see Bourne, Twidale and Smith, 1974) is problematic.

Though undoubtedly related to a fault zone, the difficulty is to determine what agent or agents are responsible for its exploitation. It can be suggested that run off from the Gawler Ranges in particular eroded the fracture zone, that the Depression is in reality a fault-line valley. But there is no sign of any river outlet from the Depression though it can be argued that any such feature could have been buried by aeolianite if it occurs at the western end of the Depression, or by drift sand if it formed near its southeastern extremity. On the other hand it can be pointed out that granite can in certain conditions (Ruxton, 1958) be reduced by 50% or more of its original volume consequent on hydration and hydrolysis; and that the Corrobinnie Depression, which the available evidence suggests is underlain by granitic rocks, could result from the pronounced weathering of these rocks. Or of course the Depression could have resulted from a combination of weathering and stream erosion.

The floor of the Depression stands a maximum of some 100 feet below the level of the plains on either side (Fig. 2.8). Mount Sturt, a high porphyritic upland, and Corrobinnie Hill and Peella Rock, both granitic residuals characterised by a stepped form and surrounded by broad platforms (Pl. 2.11; Fig. 2.9), stand in isolation above the general level of the Depression. The fixed parabolic dunes of the Kwaterski Dune Field occupy the Depression and extend in two fingers to the southwest

Plate 2.11.

Corrobinnie Hill is a stepped granite residual located within the Depression of the same name. Surmounted by a prominent boulder in the form of a tower the Hill is surrounded by a broad gently sloping bedrock platform which is seen in the foreground and is in detail pitted and grooved.

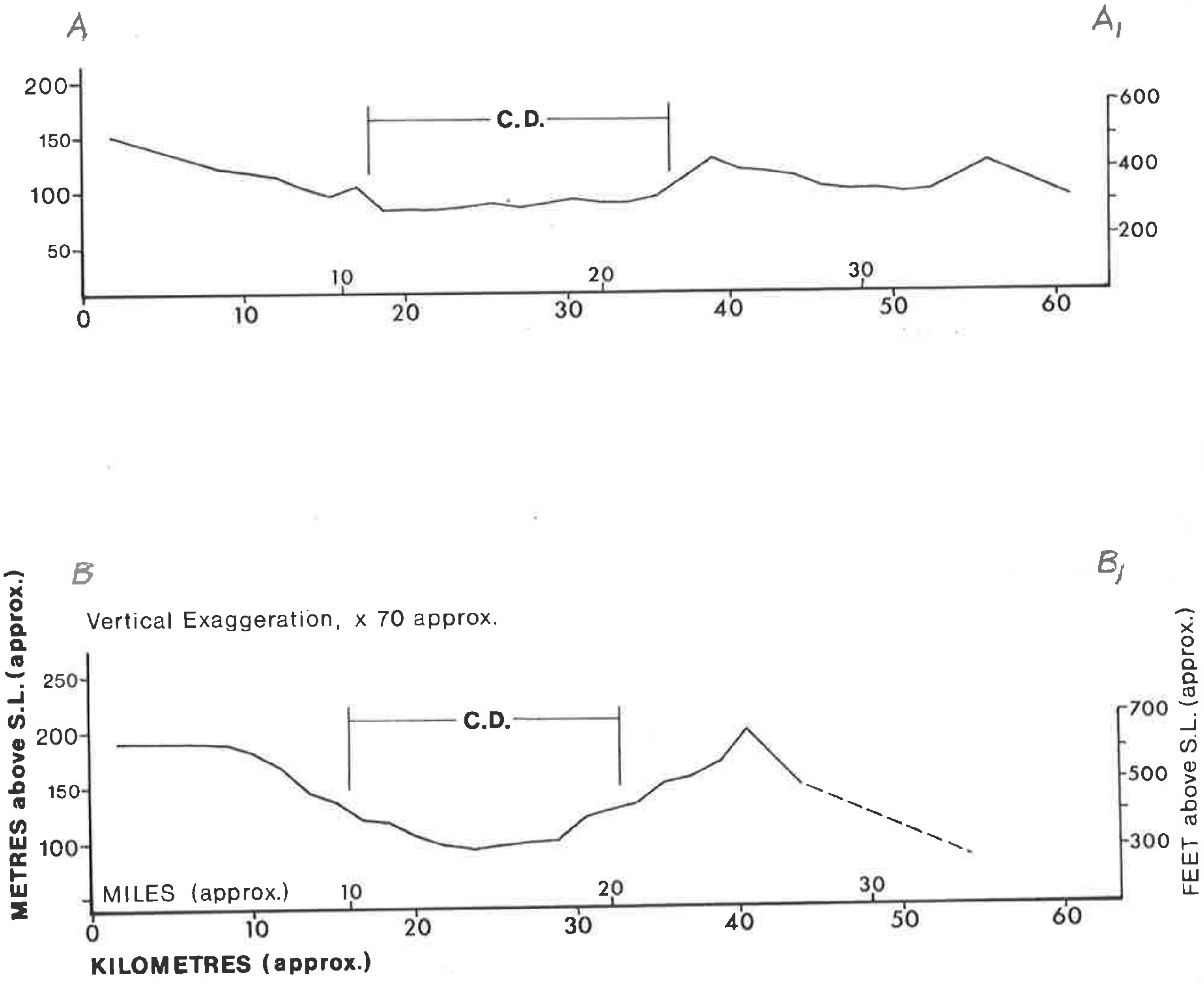

Figure 2.8.

Topographic sections across the Corrobinnie Depression between sites located on Fig. 2.7. (After Bourne, Twidale and Smith, 1974).

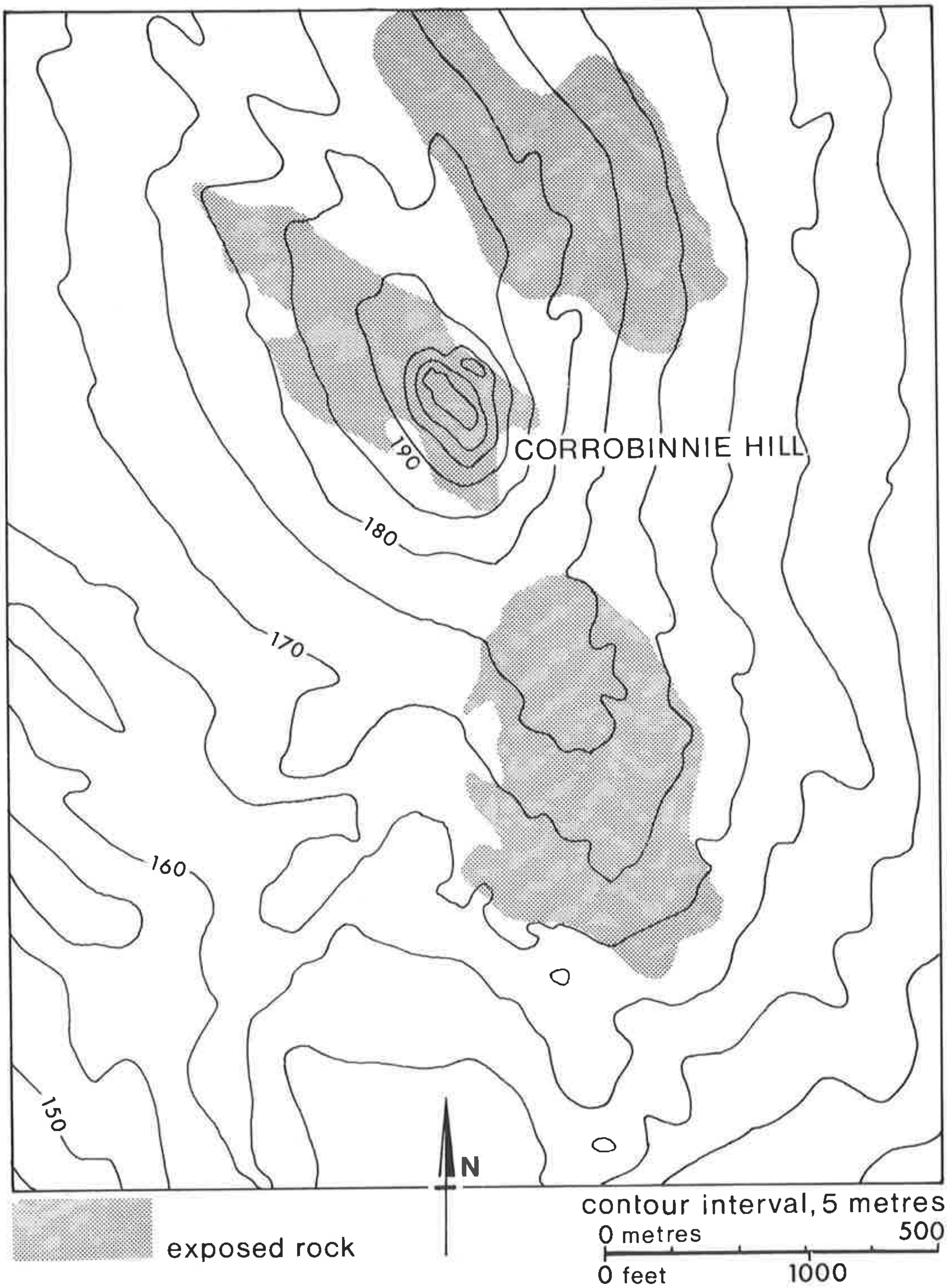

Figure 2.9.

Contour map of Corrobinnie Hill and surrounding granite platforms. (Department of Lands, South Australia).

across the northern Cleve Hills (Fig. 2.3), Their trend is generally WNW to NW but within the southeastern lobe the rather minor parabolic crests trend WNW to W, which no doubt expresses interference of the airflow by the topography.

Salinas occur in the lower parts of the Corrobinnie Depression; a few small ones are scattered throughout, but salinas found in the central and northwestern areas are the most extensive. The largest covers some one and a half square miles. All have a halite crust of varying thickness over saline muds. Islands and bordering cliffs 15 - 20 feet high of dolomitic silts and silicified dolomite stand within and border some of the salinas. These dolomitic sediments of lacustrine origin represent the depth of material presumably deflated from former more extensive lake beds. Since the sediments proved unfossiliferous dating of the erosion was not possible. Weathered gneiss has been reported from the shores of one of the salinas south of Mount Sturt (Shepherd, 1961), and outcrops of Gawler Range Volcanics occur in such residuals as Mount Sturt, whereas Corrobinnie Hill and Peella Rock are composed of granite. But dune sands, including both calcrete and occasional masses of sandstone indurated with silica and iron oxide, constitute the bulk of the outcrop.

Near Balumbah and associated with a series of long diagonal straight sand ridges are complex parabolic dunes some 50 feet high. Within these arcuate forms lie topographic depressions, smaller parabolas some 25 - 30 feet high, and areas of reticulate and irregular dunes (Pl. 2.12)

Plate 2.12.

Parabolic dunes (P) at the southeastern extremity of the Corrobinnie Depression, WNW of Balumbah. The pattern of dunes in the Kwaterski Dune Field stands in marked contrast to the regular linear pattern of dunes (L) to the north and east, and to the irregular dunes (I) to the south and southeast. (Reproduced by courtesy of the Department of Lands, South Australia).

Some of the sand ridges enclose rounded depressions. These may be deflation hollows, so that the ridges between, though morphologically comparable to true dunes may be residual features. If so the relief may be described as alveolar (Féderovitch, 1956). North of Wudinna and as far as Toondulya Bluff the alveolar dune field predominates, but the margins of the Depression are delineated by the limbs of parabolic dunes.

Circular dunes comprising concentric mounds are developed in relation to some outcrops, for instance near Scrubby Peak and in the area southeast of Corrobinnie Hill. Experiments in the wind tunnel suggest that they owe their origin to the disturbance of air flow by such obstacles as hills. The wind is deflected and eddy currents develop flowing in a direction reverse to the overall airflow. Several concentrically arranged ridges develop as shown in Pl. 2.13. Such rebounding eddies well account for the circular and concentric dunes near Scrubby Peak but, assuming a general westerly airflow at the time of formation those concentric ridges east of Corrobinnie Hill lie east, i.e. in the lee of the nearest apparent obstacle. There is no reason in theory why similar eddies should not form in the lee of obstacles though they should be less regular than those to windward; and indeed this may account for the relative malformation or irregularity of those circular dunes.

The sand of the irregular ridges is white and unconsolidated but is at present only occasionally active for it is fixed by vegetation. Red coloured sands, partly lithified, occur low in the relief within the Depression north of Wudinna and were also noted on the flanks of dunes at

Plate 2.13.

Part of the Kwaterski Dune Field showing the parabolic pattern of dunes which in places grades into concentric rings of sand ridges (A) and which gives way in the south to regular linear dunes. (Reproduced by courtesy of the Department of Lands, South Australia).

Agars Lake near Minnipa. Located close to the water table this ferruginous accumulation is probably due to the illuviation of iron salts and their precipitation in topographic lows.

Calcrete is developed within the quartz sands of the dunes. Carbonate lenses within the longitudinal dunes of the Kyancutta Plains give C14 dates in the range of 10,300 - 27,000 years B.P. (GaK 4071, GaK 4072, GaK 4639). Dates for similar precipitates within the parabolic dunes fall within that range viz. 16,000 - 22,000 years B.P. (GaK4351, GaK 4352).* As lime accumulation occurs while sand movement is still in progress in active dunes in the Simpson Desert these dates give a valid indication of the age of these relict forms, indicating that the dunes are of latest Pleistocene age.

Although less than twenty feet of sand above gneiss bedrock was logged from Bore 20-1, Hundred of Caralue, some two miles to the NNE and within the Depression (Fig. 2.7) one hundred and fifty feet of sand above weathered bedrock was recorded from Bore 6-01, Hundred of Panitya (R. G. Shepherd, Geol. Surv. S. Aust., Rept. Bk. 67/113). Unfortunately this is the only borelog evidence available but dune morphology also argues a considerable thickness of sand (Melton, 1940 and Hack, 1941). The predominantly quartz sands are fine to medium grained mostly angular to sub-angular, but some are quite well-rounded, frosted and iron-stained. The clay fraction of fines acts as a cement for quartz fragments which are the aggregates in the unwashed samples. For the most part, then, the sand is locally derived although the larger rounded grains have probably been transported along the axis of the Depression.

(c) SHERINGA PLAIN.

During the Pleistocene glacials sea level was lowered to expose the continental shelf, and sediments from the sea floor were blown inland as fields of dunes, the consolidated relicts of which extend as much as 200 feet below the present level of the eastern Bight (Shepherd, 1962c). Since the west coast of Eyre Peninsula faces the open Southern Ocean and strong onshore winds, there developed a field of calcareous dune sand, now extending some forty miles inland, which, though of variable thickness, covered most of the earlier topography save the more prominent peaks e.g. Mount Wedge. The dune sand lithified by the reprecipitation of lime forms a calcarenite of windblown origin which is commonly called aeolianite. The buried topography was cut in various rock types: conglomeratic sandstone exposed in shore platforms at Talia Caves, gneiss which is recorded in a bore at Elliston (Shepherd, 1962c) and granite which is logged at a depth of 52 feet west of Tooligie (Co. Musgrave, Hd. Peachna, Sect. 39, Bore 201). Between Streaky Bay and Port Kenny, granite boulders e.g. Murphys Haystacks and low stepped domes e.g. Calca Bluff, Malijay Hill and other outcrops such as Mount Damper near Minnipa have been exhumed from beneath the aeolianite cover (Pl. 2.14).

Mount Wedge which has probably never been entirely buried by aeolianite, lying as it does near the eastern limit of the Sheringa

Plate 2.14a.

The northern margin of Malijay Hill displays flared slopes, stepped relief and boulders typical of many other granite residuals. However calcrete developed on aeolianite occurs beneath the surrounding plains and there is also calcrete formed on granite sand on the crest of the Hill (see Pl.2.14b). It is surmised that the Hill is of pre late Pleistocene age and that it has been recently exhumed from beneath a calcareous cover.

Plate 2.14b.

Detail of the crest of Malijay Hill showing the calcrete capping (C) and the pitted granite platform in the foreground. The location of this platform is indicated (P) on Plate 2.14a.

Plain, is underlain by sandstones and quartzites similar to those of Blue Range and dipping $5^{\circ} - 10^{\circ}$ west (Pl. 2.15). The outcrop trends WNW to ESE and the fairly flat summit surface at the eastern end has an area of one and a half square miles. This surface cuts across the strata but slopes gently to the west over some three miles. Steep scarps at the eastern end meet a pediment surface some 200 feet higher than, but sloping down to, the Sheringa Plain.

Thin deposits of aeolianite persist on the flanks of high ridges and thicknesses up to 100 feet fill old river valleys (Johns, 1958). The consolidated remnant of a dune which parallels the coast from near Sheringa Lagoon to Cape Finniss with a major break at Waterloo Bay, stands 100 - 250 feet above present sea level and extends to an unknown depth below (Gibson, 1958). Just north of Lake Hamilton, Tungketta Hill and some ridges to the east and northeast are 200 feet above the general level of the Plain. In the coastal section of the study area the aeolianite attains thicknesses of 400 feet and has been reported to be more than 600 feet thick on Thistle Island near Port Lincoln (Johns, 1959). With the continued accession of sand coastal inlets were isolated and, in addition, water draining the land was impounded to form lakes like lakes Hamilton, Tungketta and Hamp and Middle and South lakes.

Marine erosion has since cut spectacular cliffs and shore platforms in the aeolianite. The profile of the old dunes is seen to be foreshortened by wave attack and subsequent collapse at the

Plate 2.15.

Mount Wedge is an isolated cuesta underlain by Precambrian sandstone and fringed by pediments which merge with the rolling Sheringa Plain.

base of the cliffs. Notch, plinth, spike and stack have been formed. Shore platforms are generally intertidal, although contemporary platforms at levels above high tide have been noted at several sites.

The ancient dune fields consist of a series of lobes which are related to the configuration of ancient lower shore lines, in that the dune field extended from embayments or beaches (Fig. 2.3). Some parabolic dune crests may be distinguished and these are best delineated at the inland margin of the aeolianite cover, and within the great spread of the aeolianite there are areas of linear and irregular dune crests (Fig. 2.10), but generally the old dunes have lost their sharpness and the sediplain is one of rounded hill and dale with a relief amplitude of 30 - 40 feet (Pl. 2.16).

The area lacks surface drainage. Short streams flow intermittently at the coast and to a few collapse dolines. Some of the sinkholes have a smooth rounded form and are so perfectly aligned that they have been mistaken for meteorite craters (Wilson, 1947). Other solutional features present are typical of a weakly developed karst landscape and are best displayed at the coast.

Plate 2.16.

The rolling Sheringa Plain as it terminates against the precipitous cliffs bordering the Great Australian Bight south of Sheringa. Note the stony rises with calcrete which is developed on the aeolianite exposed in the coastal cliffs and the depressions with a superficial layer of silts overlying the calcrete.

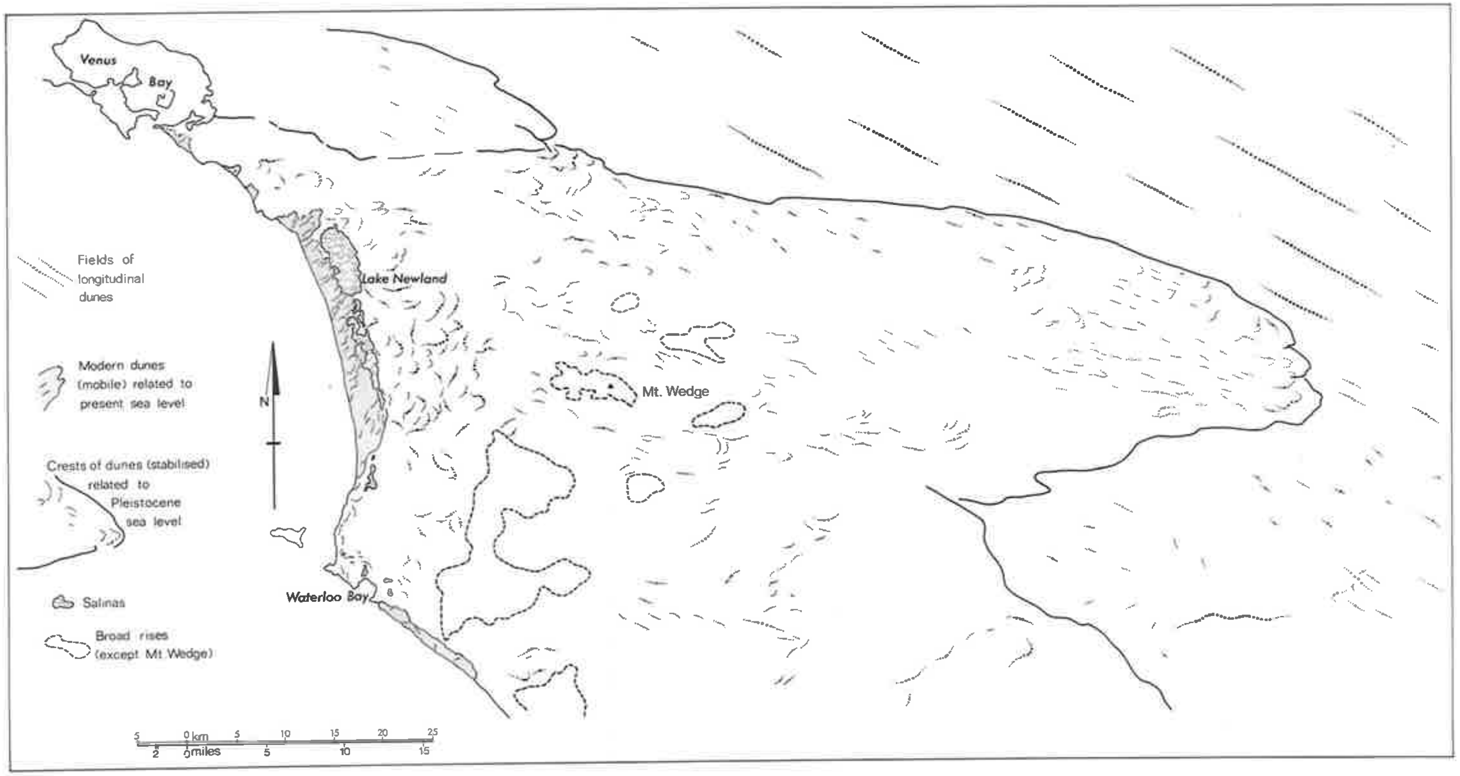

Figure 2.10.

Pattern of aeolianite dunes on part of the Sheringa Plain. (Drawn from air photographs).

(d) GULF PLAINS.

(i) Utera Plain.

The greater part of the coastal plain within the study area is termed the Utera Plain. It extends from Arno Bay to Whyalla along the western shores of Spencer Gulf, is bounded to the east by the Gulf and the Cowell Plain, and is delimited on its western margin by the fault scarps which step up the plain to the Nonowie Hills and High Plains. The faults which delineate the eastern edge of the Cleve Hills from the Utera Plain are traceable to south of Lipson Cove.

The land gradually rises from the shore to a fairly flat alluvial coastal plain, some 50 - 100 feet above present sea level. Old alluvial fan and riverine deposits are exposed in cliff sections and creek banks. Modern alluvial fans occur along the foot of the Cleve Hills and at the base of some minor fault scarps. Precambrian bedrock is exposed in creek beds beneath the shallow riverine deposits covering the Utera Plain. There are alluvial fans in the piedmont zone bordering the Cleve Hills, and the Plain is traversed by northwest-southeast trending sand dunes which stand some forty feet above the plain and average five to six per mile in a direction normal to their trend.

Most of the eastward flowing streams dissipate on the Utera Plain before reaching either the coast or the north-south depression possibly related to faulting which apparently links Salt Creek, the trunk stream within the Cleve Hills, (see earlier), and the tidal creek associated with Franklin Harbour.

(ii) Cowell Plain.

The coastal plain associated with present sea level, the Cowell Plain, is limited to the immediate shoreline save where it penetrates inland about tidal creeks related to Franklin Harbour and False Bay and also where it occurs about lakes and salinas located in topographic lows e.g. Corrobinnie Depression and the Myall Creek drainage system.

At the coast there is a succession of wide open bays, backed by sandy beaches and separated by headlands underlain by gneiss. Intertidal shore platforms are generally cut in Precambrian metamorphic rocks, but cliffs are of sandstones, grit and gravels and stand less than forty feet above present sea level. A number of disconnected saline lagoons and samphire swamps stand behind low coastal foredunes. A sand spit built out northeastwards from its southern headland protects shallow Franklin Harbour, which is fringed by coastal samphire swamps and mangroves. From Franklin Harbour to Whyalla low water mark is well off-shore and mangroves stand on the seaward side of coastal foredunes. Submerged longitudinal dunes were seen from the air within Franklin Harbour and offshore immediately to the north at Lucky Bay (Pl. 2.17).

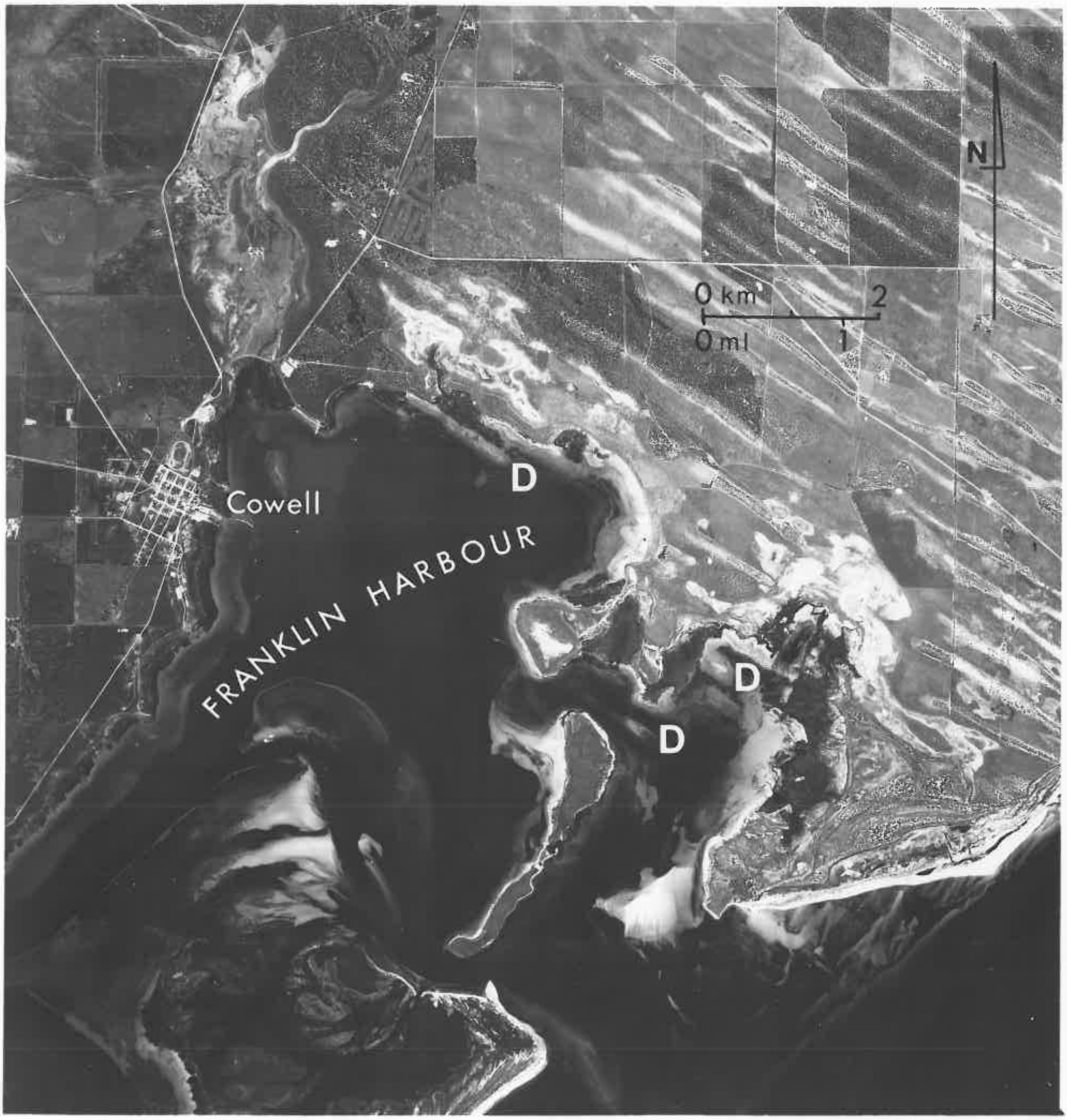

Plate 2.17.

Vertical air photograph of Franklin Harbour and environs. Submerged longitudinal dunes (D) are contiguous with the subaerial field of fixed longitudinal dunes. (Reproduced by courtesy of the Department of Lands, South Australia).

(e) NONOWIE HILLS AND HIGH PLAINS.

Meridional faults have stepped up the Utera Plain from the vicinity of Pondooma northwards beyond Whyalla to form the Nonowie Hills and High Plains (Fig. 2.3).

East of the point where Salt Creek emerges from the Cleve Hills proper and south of the Middleback Ranges and Moonabie H.S. there is a high undulating plain with granite residuals cut in the Charleston granite intrusion and bounded by fault lines to the south and east. The granite bedrock surface is quite irregular but generally lies at shallow depths (Shepherd, 1959). Broad swells and pavements, many of them strewn with boulders, are common. They display many of the usual minor features found on granite outcrops, such as flared slopes, sheeting joints, gnammas, tafoni and Rillen and in addition provide evidence of movement along the sheeting joints (Twidale, 1973). Fixed longitudinal dunes stand in the lower parts of the relief and where the airflow was channelled by granite outcrops as at the fault scarps.

West of Whyalla north-south trending faults have caused a series of minor 'dirt' scarps to reach a maximum elevation of 450 feet (Miles, 1952, 1954; Johns, 1961). Low north-south ridges of Precambrian bedrock stand above this rolling high plain which slopes up to the foot of the Middleback Ranges. Standing some 15 - 20 feet above the eastern pediment of the Ranges are remnants of high pediment surfaces variously duricrusted with ferricrete and silcrete.

Lag-covered plains surround remnants of the Northeastern Plateau and slope very gently away from an abrupt junction towards drainage centres. Silcrete occurs in the scarp foot zone on either side of the present Myall Creek drainage system and is preserved on scattered remnants distant from the upland. Low asymmetric ridges developed on resistant members of the Pandurra and Moonabie formations and on gabbroic intrusions of Proterozoic age protrude as much as 150 feet above the plain. The Proterozoic sedimentary sequences were deposited unconformably upon one another at the margin of the Adelaide Geosyncline, the shoreline of which oscillated in time, so that strata was differentially tilted, and has since been affected by faulting.

Perhaps the rolling surface, some 130 feet above sea level, which lies between the Cleve Hills, Blue Range and the Lincoln Uplands, should be included within the Nonowie Hills and High Plains. South of the main ridges of Cleve Hills low rises stand above the plain which slopes south to a dune-covered area in which stands Mount Priscilla, an isolated hill of ~~haematite~~ quartzite, patently involved in the fold structure of the uplands. Minor fault scarps association with the Lincoln Lineament bound this area to the east.

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* Results of radiocarbon assay on samples of calcrete from dunes of northern Eyre Peninsula conducted by the Gakushuin University, Tokyo, Japan.

Code No.	Age B.P. (years before 1950).
GaK 4071	10,310 ± 190
GaK 4072	16,690 ± 440
GaK 4639	26,940 ± 1200
GaK 4351	15,780 ± 350
GaK 4352	22,040 ± 760

CHAPTER THREE

EROSIONAL SURFACES OF LOW RELIEF.

> ... the great plains and plateaux ... record in a relatively simple manner the geomorphological history of the continents.
>
> (L. C. King, 1950, p. 101).

A. GENERAL STATEMENT.

As has been made clear there are in each of the physiographic regions just described areas of low relief of varying extent located either at or close to present baselevel or high in the relief. The latter have been dissected and there are only remnants, but they are sufficiently extensive and widespread to suggest that they were formerly parts of contiguous surfaces. Their development, uplift and destruction in a broad way reflects the geomorphological history of the region under discussion, but their precise significance depends on the interpretation placed upon them. Several types of erosion surfaces of low relief have been recognised in theory and it is therefore necessary to discuss these before attempting to establish the denudation chronology of northern Eyre Peninsula.

B. PENEPLAIN AND PEDIPLAIN.

Surfaces of low relief are widely distributed over the continents but there is as yet no general agreement as to their origin. Marine planation was favoured until late in the last century (see e.g. Ramsay, 1846), and although marine agencies are responsible for modern and for relict planate surfaces of limited extent (see for instance Barrell, 1920; Olmsted and Little, 1946; Wooldridge and Linton, 1955) and for some retouching of the land surfaces (Baulig, 1952), both theoretical considerations and field evidence strongly suggest that subaerial processes are responsible for regional planation.

W. M. Davis (1899), basing his ideas on the field studies of such workers as Dutton (1882) and Powell (1895), conceived that surfaces of low relief are the result of long-continued subaerial denudation of the continents. He considered landscape development in humid temperate conditions and assumed that after rapid uplift of the region and stream incision into the raised block, the land surface evolved through a series of predictable stages. This sequential development he called the cycle of erosion, since the end product was closely similar to the theoretical initial form. The penultimate stage of this geomorphic cycle he called the peneplain, a gently undulating or rolling surface of low relief which results from stream incision and planation plus the downwasting of interfluves. Though depositional plains occur in the valleys the peneplain was conceived as being essentially of erosional origin.

The peneplain concept remained virtually unchallenged for many decades despite the inability of its proponents to cite modern examples of the forms, though many - and perhaps too many - relict remnants were identified, often on dubious grounds. It is true that modifications were suggested. For instance, Crickmay (1933), placed greater emphasis on the power of the lateral stream planation than did Davis, and suggested that some extensive surfaces of low relief are due to the coalescence of broad flat-floored river valleys; i.e. flood plains. Such surfaces he called panplains. Again, and more recently, Trendall (1962) has suggested that surfaces of low relief can develop in humid tropical conditions, not through surface stream activity, but through subsurface solution and flushing (see also Ruxton, 1958) which results in volume decrease and lowering of the surface: an apparent peneplain. Nevertheless until very recently, and particularly in the U.S.A., in Western Europe and in Britain, the cyclic and peneplain concepts were accepted as a valid basis of geomorphological interpretation.

The only real challenges both derived from the work of W. Penck (1924, 1953). One was developed by L. C. King (1953) into the pediplain concept. Pediments were first formally recognised in the American Southwest (McGee 1897) and have been described, mainly for the arid and semi-arid tropics, by many others since. A pediment is a planate bedrock surface of gentle inclination ($\frac{1}{2}^{\circ}$ - 7°) which is smooth and little dissected. Pediments carry a veneer of debris and meet any residual remnants which stand above them in a sharp break of slope, the piedmont angle. The merging of numerous pediments produces a pediplain, the dominantly concave profiles of which stand in marked contrast to the concavo-convex profiles of the peneplain. Moreover, King (1949) and his supporters are adamant that the pediplain is the result of stream incision and scarp recession - the scarp retreat and pedimentation so widely cited in the literature. In passing it may be noted that the idea of parallel scarp retreat did not originate with either Penck or King, but is implicit in the writings of Osmond Fisher (1866, 1872), as well as Lehmann (1933) and Wood (1940).

Howsoever this may be - and doubts as to whether pediments invariably arise from scarp recession have been voiced in the literature (see Twidale, 1972b) - a sharp genetic distinction has been drawn between the erosional peneplain and pediplain concepts, though both are cyclic in character, and as will be shown later, their morphological differences are not as great as is sometimes averred.

To overcome the problems posed by an inability to differentiate between backwearing and downwearing in the field, even where residual remnants stand above the plain surface, and to avoid other problems which at present appear incapable of solution both Hills (1955a) and Öpik (1961) have proposed that an erosional surface of low relief due to running water be called an 'old-land', implying merely a surface which is the result of long-continued subaerial erosion.

Some display prominent convexities and are descriptively, therefore, peneplains. Others exhibit either concave or rectilinear profiles normal to the mountain front with very little relief parallel to the latter, and therefore are termed pediments. Moreover, although the residual remnants which stand above the plains have been labelled according to whether the latter is considered a peneplain or a pediplain, and also according to the present climatic settings, this is not always justified by the field evidence. For instance, inselbergs occur in all known major climatic settings (Wilhelmy, 1958), even in the subarctic (Schrepfer, 1933). Residuals such as Mount Sonder merge gradually with the surrounding plains in arid central Australia. Thus inselbergs can be surrounded by peneplains, and monadnocks by surfaces which, apart from the lack of a piedmont angle, are of pediment type.

C. STEADY STATE DEVELOPMENT.

The second of Penck's ideas to challenge the peneplain concept concerns the interaction of exogenetic and endogenetic forces, for with this concept of <u>gleichformige Entwicklung</u> (uniform development) he implied that a landform assemblage can attain a steady-state with internal and external forces in equilibrium. In a sense this concept was anticipated by Davis (1922) with his 'old-from-birth' peneplain, but it was developed by Penck, and the notion has been recently elaborated by Hack (1960) and particularly by Kennedy (1962). The latter deduced that the peneplain-type surface could develop at any elevation in the relief according to the relative rates of activity of crustal uplift, stream incision and mass wasting of interfluves. The steady state condition visualised by Hack (1960) could conceivably be attained in areas of active and rapid crustal uplift, but it seems unlikely to offer a general explanation of surfaces of low relief, first because of the apparent disparity of relative rates of uplift and erosion (Schumm, 1963), and second because the field evidence in many areas favours cyclic development (see e.g. Bretz, 1962). Kennedy's 'perched' peneplain however offers a possible explanation for high level surfaces of low relief in such areas as the Mount Lofty Ranges. The hypothesis is susceptible to testing however, for both the volume and character of the basin sediments derived from the nearby land mass should in theory reflect the conditions of erosion there. Thus if a land mass is consistently rising the basin sediments should include coarse clastics throughout the sequence, whereas if the land surface suffered lowering only finer debris should be contributed late in the cycle. And as Kennedy pointed out the volume should vary according to the interplay of uplift and erosion and weathering.

Unfortunately these tests require a detailed knowledge of the stratigraphy of the derived sedimentary sequences as well as of the topography, and both are at present lacking in Spencer Gulf and Eyre Peninsula, though work is in hand which should appreciably improve the situation during the next few years.

D. OTHER TYPES OF LAND SURFACE.

Two other types of surface of low relief have been distinguished. One results from a particular mode of origin, one a particular history, though both can involve either peneplain, pediplain or old-land.

An etchplain (Wayland, 1934) is a surface of low relief resulting from the removal by erosion of the former regolith and the exposure of the weathering front (Mabbutt, 1961a) at the land surface. Such etchplains are increasingly recognised as significant elements of the present landscape (see e.g. Mabbutt, 1961b, 1965).

An exhumed land surface on the other hand is one which has been buried and then re-exposed. Again such surfaces have been widely identified as forming integral and important elements of the modern land surface (Woodard, 1955; Twidale, 1956; Carter and Öpik, 1961; Cowie, 1961; Ambrose, 1964).

All the surfaces of low relief mentioned so far owe their origin to degradation or erosion. There are in addition extensive surfaces of low relief which are due to aggradation. Such plains of deposition may be of marine origin, that is former sea floors which have been uplifted and remain essentially undissected, forming a sedi-plain, (see e.g. Jennings, 1963), or they may be caused by riverine deposition forming plains which in broad view are of extraordinary flatness, though in detail relicts of levee and slough and shoal are discernible; or by aeolian deposition, in which case a dune relief may be preserved.

E. DATING OF PALAEOSURFACES.

The date accorded a land surface of low relief related to present baselevel depends in large measure upon the interpretation placed on its origin. If a surface is considered to be in dynamic equilibrium then the whole of the surface must be viewed as of recent date. Similarly if a surface is interpreted as the end product of a geomorphic cycle, and the cycle is of Davisian type, with lowering dominant, the whole of the surface must again be considered essentially modern. On the other hand a pediplain is essentially a diachronous surface, with that zone near the receding scarp of recent age, but that near the coast or other regional baselevel dating from the time of initiation of the cycle.

So far as palaeosurfaces are concerned they may be considered to have two ages. The first is the absolute age or age range, that is a geological age. The other is a cyclic age, dating from the time of initiation of the cycle (and surface) and in many cases continuing at present even though the cycle has been interrupted. Thus though the surface related to a cycle may be suffering dissection at lower levels, and is being replaced by a younger surface there, it may still be extending in the interior and uplands.

The absolute dating of surfaces and cycles poses difficulties. In certain circumstances it is possible to make deductions concerning the age of surfaces and cycles, but in others the problem defies resolution.

There should be a discernible relationship between basin sediments and their source area: the erosional areas from which they have been derived. That is, it should be possible to link the stratigraphic sequence and the erosional surfaces. This has proved possible in a general way in some areas (see e.g. Twidale, 1966; Wopfner and Twidale, 1967; Twidale, Shepherd and Thomson, 1970). But there are many possible complications and the basin sediments cannot always be linked to events in the adjacent land areas.

In the case of exhumed surfaces it is a simple matter to obtain a general age for the cycle or surface in question, for it can be no older than the youngest rocks truncated by the surface, and no younger than the oldest rocks which can be seen unconformably to overlie it.

Some surfaces carry a characteristic regolith which is datable, though there are dangers in extrapolation. Laterite, for instance, has been widely used as a stratigraphic marker both in southern Africa and Australia. But though locally dated with some precision these ages cannot be applied generally. Laterite is essentially a zonal soil. It is surely unreasonable to correlate a lateritised surface in South Australia with one in north Queensland for example, and to date one on the basis of a real or alleged established age of the other.

Again silcrete is widely developed in central Australia and extends into southern Australia (Stephens, 1964, 1971; Alley, 1973). Its age has been determined as early-mid Tertiary (Eocene to late Oligocene or Miocene in the Lake Eyre Basin - see Wopfner, 1960; Wopfner and Twidale, 1967; Wopfner, Callen and Harris, 1974), and dating of silcrete with a quartzose matrix is everywhere consistent with this, though opaline silcrete, which occurs west of Lake Eyre (Wopfner and Twidale, 1967) is demonstrably younger, and possibly of Pleistocene age.

Calcrete also has been used as a stratigraphic marker in Mexico (Arellano, 1953), and more recently in South Australia (Firman, 1967a, 1967b, 1969), but as it appears to have a great age range, its use in this context is fraught with difficulties. Similarly, gibber has been used as a time-marker in South Australia, e.g. the Telford Gravel of Upper Pleistocene age (Firman, 1967a, 1967b, 1969), but it is not and should not be regarded as an index horizon or surface.

Other surfaces can be dated through their relationship with tectonic events, such as faulting and volcanicity, the age of which is known. For instance in the Mount Lofty Ranges faulting, which is dated as late Cretaceous because earliest Tertiary sediments and a full Cainozoic marine sequence lie in the fault angle depressions, argues strongly for a pre Tertiary age for the lateritised summit surface (Glaessner, 1953; Glaessner and Wade, 1958, p. 117; Campana, 1958, p. 21). Across Backstairs Passage in Kangaroo Island the laterite associated with the plateau there is apparently much older, being of post early Permian but pre Middle Jurassic age (Daily, Twidale and Milnes, 1974). Adjacent to Lake Torrens the summit surface of the Arcoona Plateau is dated as Cretaceous, for its formation was disrupted by early Tertiary faulting, dated from carbonaceous sediments laid down at the base of the Cainozoic lacustrine sequence (Johns, 1968; Twidale, Shepherd and Thomson, 1970).

Finally extrapolation as a method of dating surfaces of erosion should only be applied when no other method is possible. Error increases with increasing distance between the two regions compared. Such comparisons may indicate some sequence of events, may even point to a likely date, but they should remain in the doubtful category.

F. REGIONAL OCCURRENCES OF SURFACES OF LOW RELIEF IN NORTHERN EYRE PENINSULA.

Several erosional surfaces of low relief found in northern Eyre Peninsula stand at various elevations at and above present baselevel (Twidale, Bourne and Smith, 1975a). Names have been given these surfaces with due consideration of the localities in which they are best developed. The location of each of these surfaces is indicated on Fig. 3.1 and in Table I their character, type and age or age range are given.

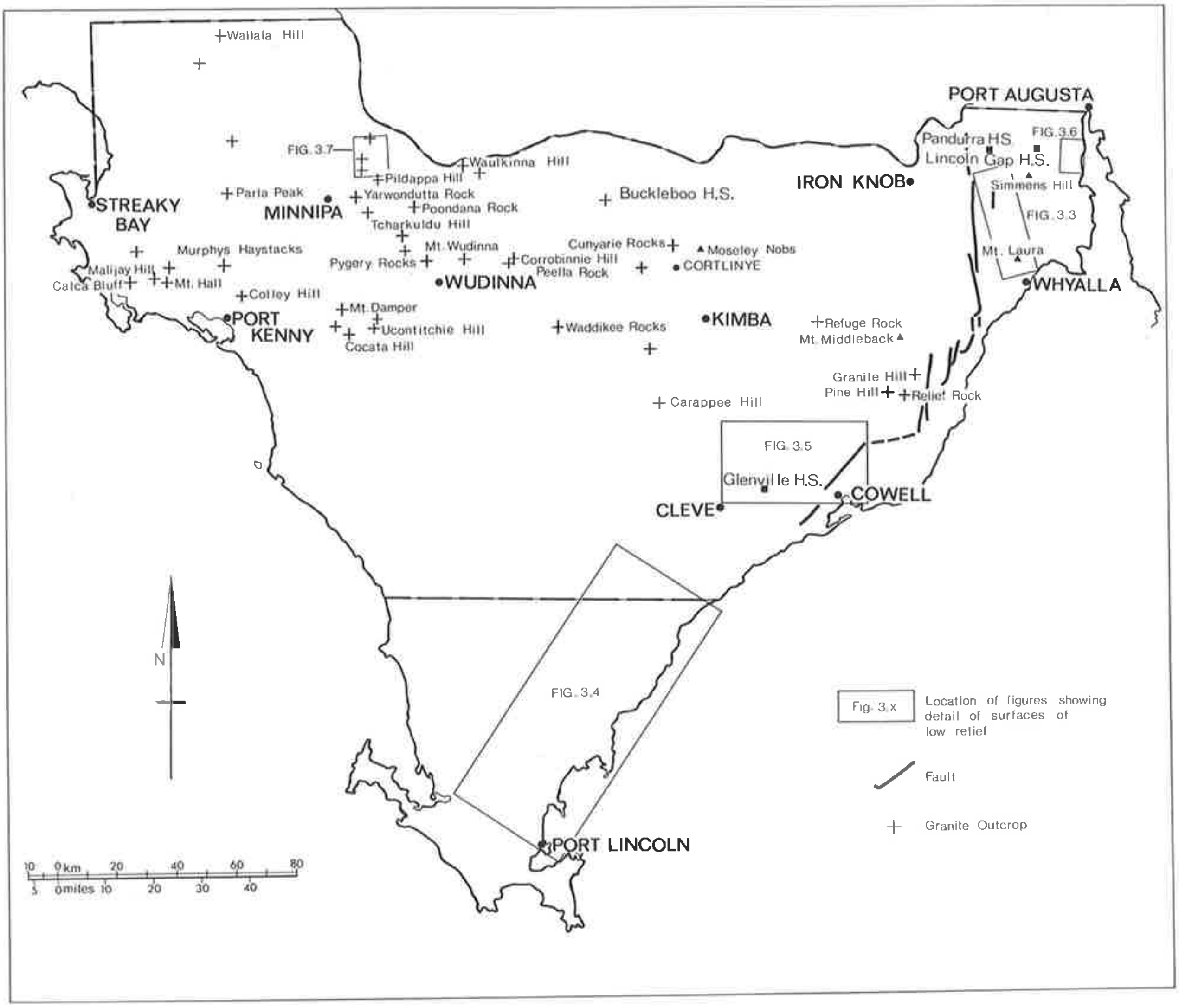


Figure 3.1.

Distribution of granitic residuals and location of key sites for erosion surfaces of low relief on northern Eyre Peninsula: Figures 3.3. - 3.7. inclusive.

TABLE I

PALAEOSURFACES OF NORTHERN EYRE PENINSULA.

SURFACE	AGE or AGE RANGE	CHARACTER	EXTENT and LOCATION
Moonabie	Proterozoic	Not known but exhumed	Very minor: Nonowie Hills and High Plains.
Pandurra	Proterozoic	Not known but exhumed	Very minor: Nonowie Hills and High Plains.
Lincoln)	Early Mesozoic (?Triassic)	Subaerial laterite duricrust	Minor: Blue Range.
Glenville)		Etch surface related to laterite regolith	Minor: southern Cleve Hills.
Simmens	Late Mesozoic (Cretaceous)	Subaerial	Moderate: Northeastern Plateau.
Alamein	Early Tertiary	Subaerial, silcrete duricrust	Minor: Nonowie Hills and High Plains, Buckleboo Plain.
Koongawa	Late Tertiary	Subaerial, ferricrete duricrust	Minor: Nonowie Hills and High Plains, Buckleboo Plain, Podinna Plain.
Malijay)	Pleistocene	Exhumed granite relief	Minor: Sheringa Plain.
Wudinna)		Subaerial, calcrete duricrust	Extensive: central and north-western Eyre Peninsula and east coast Eyre Peninsula.
Cowell	Recent	Coastal, erosional and depositional plain	Very minor: east coast Eyre Peninsula.

1. PRECAMBRIAN PALAEOSURFACES.

Within the Nonowie Hills and High Plains is the oldest surface recognised as forming part of the present landscape. It is of middle Proterozoic (Carpentarian) age. It takes the form of fragments of an exhumed unconformity displayed on the 40° dip slopes of hogbacks and homoclinal ridges of gabbro and quartzite a few miles east of Iron Knob. The overlying unconformable sedimentary sequence has been eroded, re-exposing the former surface of low relief. Disrupted now by low north-south trending fault scarps, the surface is seen in unconformity (Fig. 3.2) at New Water Tank Hill, in Whyalla (Miles, 1954) and also at Mount Laura (Pl. 3.1) where the folded and weathered and planed sediments are overlain by gently dipping sandstones, with a basal conglomerate, of the (?) Sturtian Pandurra Formation.

However these relicts of the Moonabie Surface together total only a few square miles, and the oldest palaeosurface of any significance is the Pandurra Surface which occurs on the gentle (5° - 10°) dip slopes of an essentially continuous cuesta which has been recognised in the vicinity of Pandurra H.S. and extends southwards as far as Whyalla (Pl. 3.2; Fig. 3.3). This ridge which stands some 250 feet above the undulating and rolling plains to either side is underlain by the sandstone of the Pandurra Formation. In many places the dip slope carries a mantle of rounded gravel and pebbles derived from the basal grits and conglomerate of the Tent Hill Formation (Whyalla Sandstone) of Marinoan age, which unconformably overlies the Pandurra Formation, and the erosion

Plate 3.1.

The unconformity (M) between the gently dipping Pandurra Formation and the steeply dipping Moonabie Formation below can be seen here at Mount Laura four miles north-west of Whyalla.

Plate 3.2.

Mount Laura seen from the north. The capping of gently dipping Pandurra Formation is clearly visible as is the exhumed Pandurra Surface (P) eroded in strata of the same name.

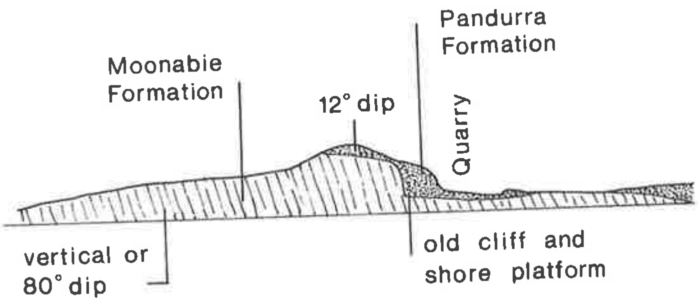


Figure 3.2.

Section through New Water Tank Hill, Whyalla. (After Miles, 1954, p. 28).

The old sea-cliff is some 20-25 feet high and the length of the section is approximately 200 feet.

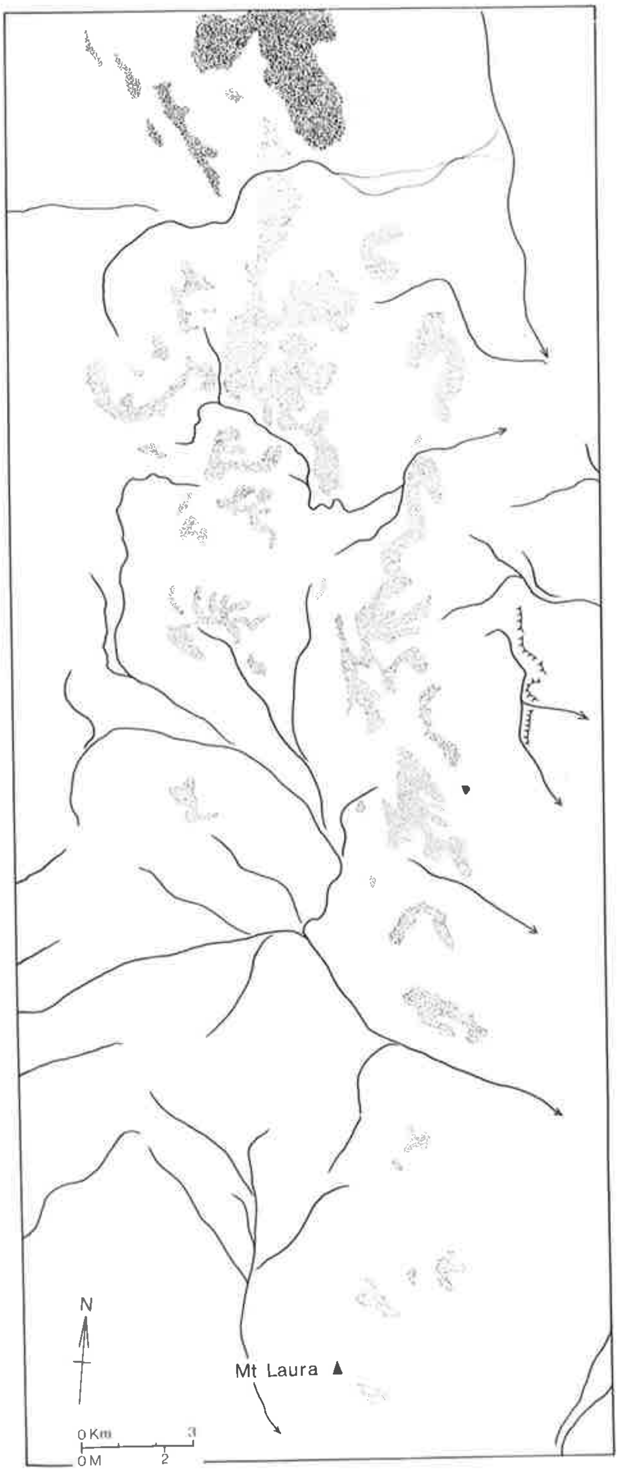


Figure 3.3.

The Pandurra Surface (light stipple) between Whyalla and Pandurra H.S. Dark stipple indicates remnants of the Alamein Surface. (Drawn from air photographs).

of which has caused the re-exposure of the old surface.

The origin of the Pandurra Surface, as of the Moonabie, remains obscure. There must have been some trimming and modification during the transgression evidenced by the marine sequences which overlie the unconformities, and by subsequent tectonic activity, but neither the morphology nor the extent of the limited exposures indicate whether the surfaces are fundamentally of marine or of epigene origin.

The only evidence relevant to the argument is that where it is seen in unconformity on New Water Tank Hill (Fig. 3.2) the Moonabie Surface lies at a higher elevation than what appears to be an associated shore platform. This suggests that the Moonabie was eroded by streams grading to the then sealevel represented by the platform.

No sign of any Palaeozoic land surface has been recognised in the area under discussion. Nor is there any evidence that Permian glaciers extended over it for, though there are glacigene rocks of Permian age across Spencer Gulf in Yorke Peninsula, none has been recognised on Eyre Peninsula. Possibly any evidence of these events was obliterated during the baselevelling and deep weathering which took place during the Mesozoic. The evidence for Mesozoic surfaces of low relief is considered in a regional context, for two types of Mesozoic palaeosurface have been recognised each located in separate and distinct parts of the Peninsula.

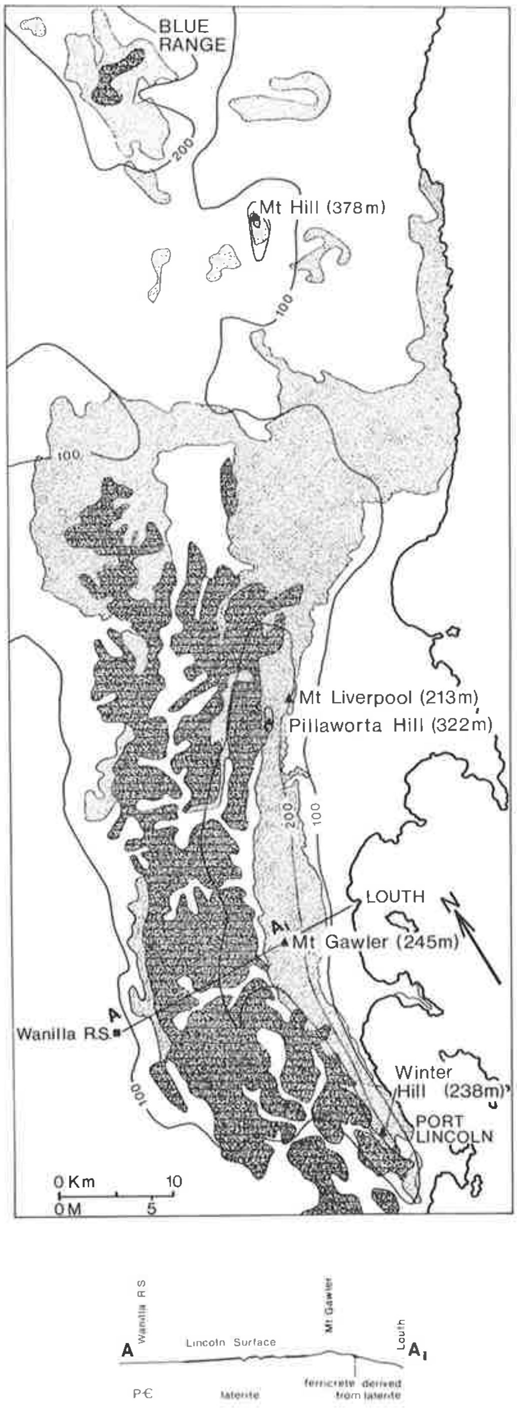


Figure 3.4.

Distribution of the laterite. Lincoln Surface (dark stipple) developed on Precambrian sediments and metasediments (light stipple indicates outcrop) in southern Eyre Peninsula A - A_1 section across upland. (Adapted from Geol. Surv. S. Aust, 4 mile map sheet, Lincoln).

2. MESOZOIC LAND SURFACES.

Bordering Spencer Gulf on its western side Spencer Uplands include landforms developed on horizontal and folded strata as well as on crystalline rocks. The linearity of their eastern scarps is undoubtedly related to tectonic movement responsible for the foundering of the Gulf and continuing to the present day. Plateau, mesa and butte assemblages are dominant in the northeast of Eyre Peninsula and the ridge and valley topography of the Cleve Hills and Lincoln Uplands reflects the fold structures in Precambrian metasediments. The duricrusted summit surface of the Lincoln Uplands and Blue Range is undergoing dissection. The Lincoln Uplands (Johns, 1961) is, strictly speaking, outside of the study area as defined but its inclusion in this discussion is necessary in order to arrive at a likely date for the lateritic and associated surfaces in Blue Range and southern Cleve Hills.

The Lincoln Uplands in places approach and exceed heights of 1050 feet. Located at elevations of between 700 feet and 760 feet, particularly on the western side of the upland backbone there are high plains protected by a duricrust of laterite (the Yallunda Ferricrete of Firman, 1967a, 1967b, 1969). The laterite extends as far north as Blue Range where it stands at an elevation of about 830 - 845 feet (Fig. 3.4). The laterite consists of a sandy A-horizon, a thin (three feet maximum) zone of mainly pisolitic iron oxide accumulation underlain by mottled and pallid zones in which however the structures of the original bedrock survive in many places.

The laterite of southern Eyre Peninsula is lithologically similar to that described from Kangaroo Island (Northcote, 1946; Daily, Twidale and Milnes, 1974) and the Mount Lofty Ranges (Fenner, 1931, pp. 43 - 46; Sprigg, 1946), and is located in topographically similar situations (see Fig. 1.1). In all probability the lateritised land surface in all three areas mentioned was originally a contiguous surface which has been disrupted by faulting. In southern Eyre Peninsula it is called the Lincoln Surface.

If modern analogies are relevant the laterite of the Lincoln Surface formed as a weathering profile under subaerial conditions and in a humid tropical climate, i.e. equatorial or monsoonal rain forest. Even if laterite is not considered a zonal soil of the tropics its development is dependent on suitable lithology and rapid leaching (Paton and Williams, 1972). Whatever the climate the laterite did not necessarily form close to regional baselevel. There can be little doubt, for instance, that were the deep red earth soils of the uplands of northern Queensland dessicated they would form a laterite, yet they are located at an elevation of 2500 - 3000 feet above sea level (C. R. Twidale, *pers. comm.*).

The age of the high level laterite in South Australia has given rise to much debate and varied opinions. Estimates of its age range between Cretaceous and Pliocene; and some writers have argued that there are two phases of lateritisation evidenced in the present land surface. Pre Tertiary or earliest Tertiary planation and lateritisation have been suggested by Hossfeld (1926), Glaessner (1953), Glaessner and Wade (1958,

p. 117), Campana (1958, p. 21) and Sprigg (1961). A Pliocene age has been claimed for the laterite tacitly by Fenner (1930, 1931, pp. 43 - 46), and explicitly by Sprigg (1946), Northcote (1946), Johns (1961, p. 26) and Major and Vitols (1973). The latter as well as Sprigg, Campana and King (1953), believe that the lateritisation on Kangaroo Island may have extended into the early Pleistocene. Horwitz (1960) and Thomson and Horwitz (1961) claimed evidence for two laterites in the southern Mount Lofty Ranges, one of Cretaceous age and the other late Pliocene or Pleistocene, the latter age deriving from evidence on northern Yorke Peninsula (Horwitz and Daily, 1958, p. 57; Crawford, 1965, pp. 39 - 41).

The only direct evidence for the age of the main or summit surface laterite occurs on Kangaroo Island (Daily, Twidale and Milnes, 1974). There the laterite plateau has been dislocated along the Snelling-Cygnet fault zone. On the downthrown northern block the duricrust has been eroded, especially where it developed on Permian glacigene rocks west of Kingscote. In the same area basalts were extruded over the truncated laterite profile (mottled and pallid zones) and at a level below that of the laterite surface on the same side of the fault zone. Thus the basalts clearly postdate the laterite. The volcanic rocks have been dated as Middle Jurassic using K/Ar ratios (Wellman, 1971). Thus the lateritisation must have occurred between that time and the Permian.

Palaeoclimatic considerations suggest that the only period suitable for laterite development during that time was the Triassic which is well known for its humid tropical conditions in southern Australia.

For these reasons the laterite capped remnants of the Mount Lofty Ranges, Kangaroo Island and southern Eyre Peninsula, in particular of Blue Range and the Lincoln Uplands, are thought to be of early Mesozoic age. And indeed the presence of Upper Jurassic lignitic clays in the Polda Basin and Elliston Trough (Harris, 1964; Smith and Kamerling, 1969) suggests that gentle erosion of lowlands continued at least until that time.

There are no remnants of laterite at higher levels on Eyre Peninsula north of Blue Range. There are pedogenic accumulations of iron oxide lacking mottled and pallid zones and located at topographic levels below relicts of the silcrete duricrust in the Buckleboo Plain. As the silcrete (see below) is assigned to the middle Tertiary the iron concentrations must be younger and they are correlated with similar ferricretes of northern Yorke Peninsula and southern Mount Lofty Ranges which are also located at low elevations.

At the southern margin of the Cleve Hills however, north of Glenville H.S. and at an elevation of approximately 1200 feet there is a prominent summit surface cut across folded Archaean sediments and metamorphic rocks (Pl. 3.3; Fig. 3.5). In several places in this locality mottled weathered bedrock is exposed at the surface and at one site, on a low rise standing a few feet above the general level of the high plain, there are fragments of a poorly developed pisolitic iron. The evidence is scant but in view of its elevation and its proximity to

Plate 3.3

This montage taken from the top of the south-facing escarpment of the Cleve Hills just north of Glenville H.S. shows the planate surface of the same name eroded across contorted older Precambrian sedimentary and metamorphic rocks. A few blocks impregnated with iron oxides occur on the Surface suggesting correlation with the lateritic Lincoln Surface preserved on Blue Range a few miles to the south.

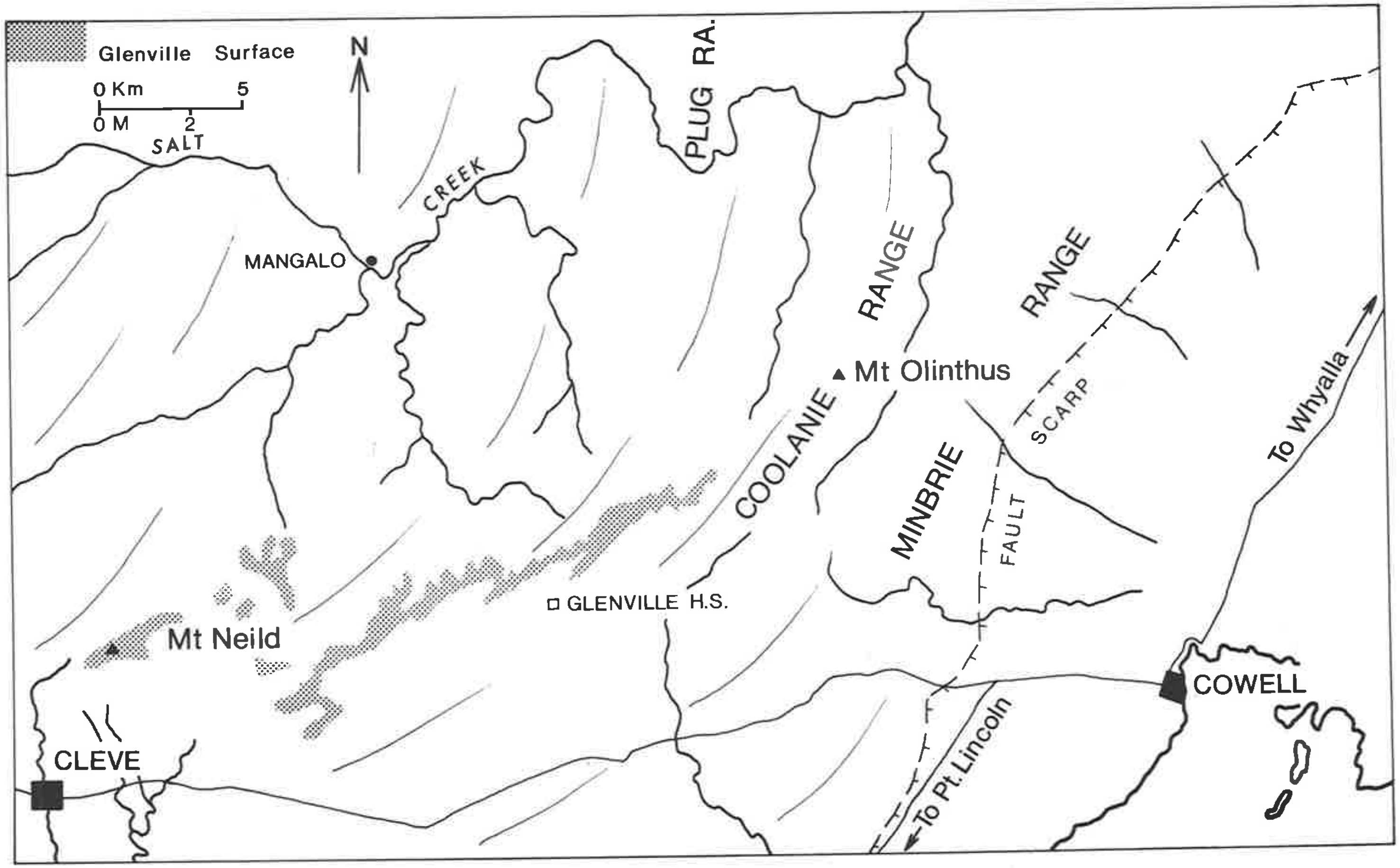


Figure 3.5.

The Glenville Surface in the southern Cleve Hills. (Drawn from air photographs).

established true laterite (on Blue Range) this surface is interpreted as an etch plain equivalent of the laterite surface, the Glenville Surface. The Surface occupies only a narrow strip at the southern extremity of the Cleve Hills. It is being destroyed by vigorous steep-gradient streams heading back into the upland from the south, and by low-gradient streams of the Salt Creek system from the north.

The laterite developed there was probably thin and near the northern limit of formation, but whatever regolith was there has been eroded, exposing the weathering front as the planate surface now located high in the relief, and with its probable equivalents extending to the north along ridge crests. The prominences e.g. Mount Neild and Mount Olinthus which stand above the general level of this high plain have zones of iron accumulation on their flanks which may represent the scarp foot zone where the laterite surface lapped against the peaks which rose above it. The iron capping of Prominent Hill and High Bluff may represent a local accumulation in a drainage centre on the Glenville Surface. The weathering front was formed as a result of early Mesozoic (?Triassic) weathering but its exposure occurred at some later, as yet undetermined, date, after lowering of baselevel and stream incision.

Faulting has affected the Spencer Uplands, but the Lincoln Uplands and the Cleve Hills blocks may well have moved independently. Topography within the two areas may have differed at the time of the laterite development and has differed since, for although the laterite duricrust of the Lincoln Uplands and Blue Range is dissected nothing but a litter of fragments of pisolitic iron remains of the profile in the Cleve Hills. Be that as it may it is not possible to use faulting to date surfaces in either area, because the movements are not dated with precision. The Pliocene age of the faulting in the Whyalla area suggested by Miles (1952) has been questioned (Lindsay, 1970), but no other study has been undertaken to date movements along the Lincoln Lineament. Upward movement may equally have occurred recurrently, for tectonism continues within the region (Sutton and White, 1968; D. J. Sutton, pers. comm.).

Correlation with sediments in the Spencer Gulf is also impossible at this time for the stratigraphy is not yet known. However the pebble beds in the southwest sector of the Cleve Hills (Fig. 2.5) though unfossiliferous, offer possible answers. They have been grouped with the sandstones and quartzites of Blue Range and Mount Wedge, and are considered to be of possible Precambrian age (Botham, 1967), but on inspection were seen to comprise at least two contrasted members. Although there are sandstones obviously involved in the folded sequence, with dips varying 10° - 80°, there are unconsolidated pebble beds with weathered matrices. Where the loose material has been removed the pebbles, sub-angular to sub-rounded, cap low rises and slopes. They appear to be slope lag derived from, and therefore younger than, the Cleve Metamorphics.

All that can be stated for the Cleve Hills fault block is that after laterite development in the early Mesozoic, possibly at a high level, baselevel was lowered, there was dissection by streams and the weathered zone was etched to expose the Glenville Surface.

A second palaeosurface of Mesozoic age is preserved on the Northeastern Plateau in the Whyalla - Lincoln Gap area and its northerly extension to the Arcoona Plateau which lies along the western shores of Lake Torrens. The Simmens Surface survives as the upper levels of plateaux and domed plateaux which, though they in some degree reflect the near horizontal bedding of the local members of the Tent Hill Formation, nevertheless in detail can be shown to truncate the strata and thus to be of erosional origin (Pl. 3.4; Fig. 3.6). The Surface is flat or gently undulating with skeletal soils developed on shallow weathered beds, above the resistant quartzite member. It is an 'old-land'.

Evidence of the age of the Simmens Surface, which lacks any regolith of significance, is indirect. There are three possibilities. It could be an equivalent of the Lincoln Surface which has not developed a laterite profile for climatic reasons (less humid) or because the bed-rock is largely siliceous. Or it could be a northerly extension of the etch plain equivalent of the Lincoln Surface. Certainly the plateaux are of similar elevation to that of the Lincoln and Glenville surfaces. Or it could be a temporally distinct surface. The sedimentary history of the Torrens Sunkland to the north of the study region points to the

Plate 3.4.

The Simmens Surface (S) is preserved on the Northeastern Plateau (see also Pl. 2.3b) seen here near Lincoln Gap. The Alamein Surface which carries a discontinuous mantle of silcrete survives in low cuestas (A) in the scarp foot zone.

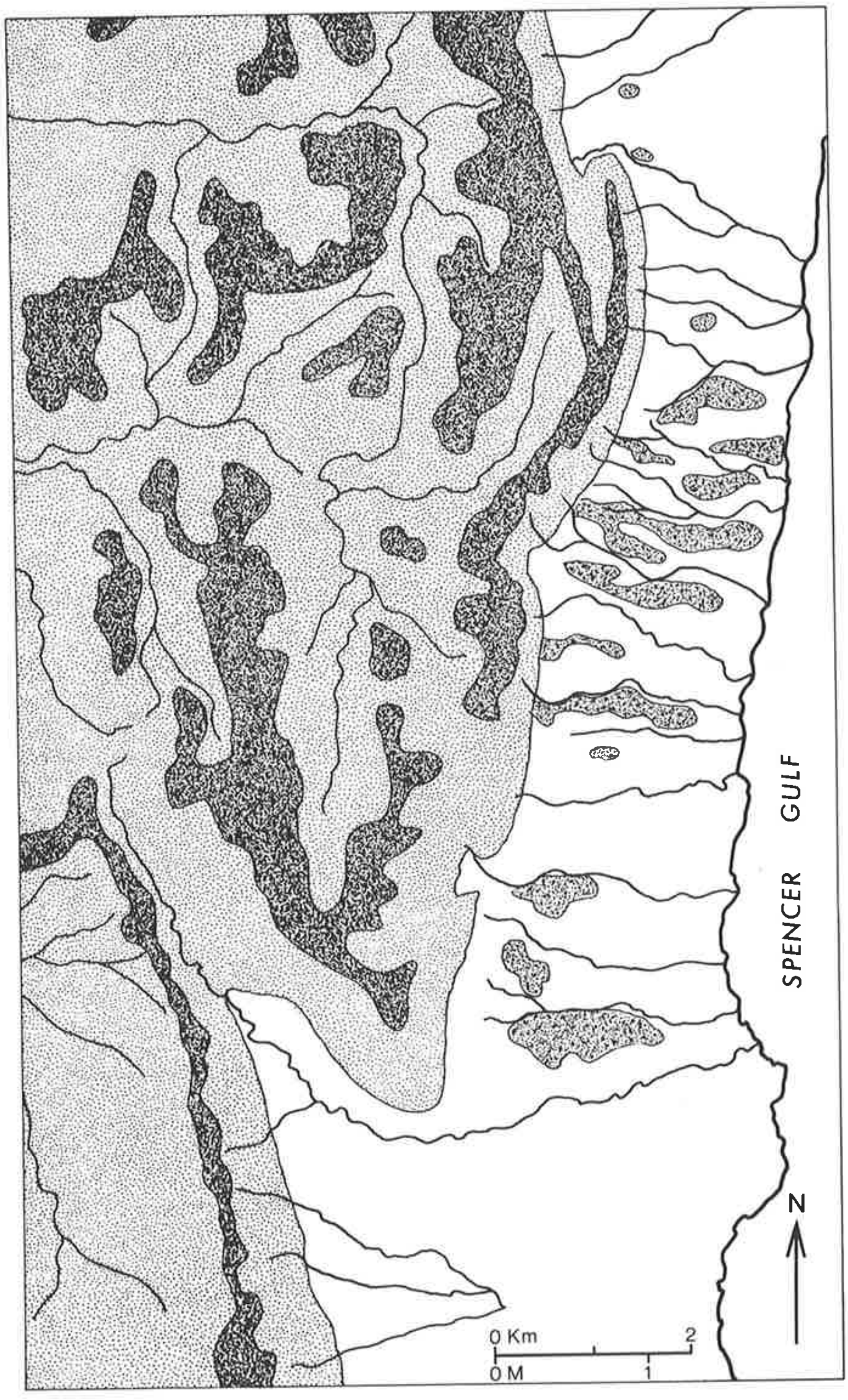


Figure 3.6.

The Simmens and Alamein surfaces (dark and medium stipple respectively) in part of the Northeastern Plateau, adjacent to Spencer Gulf. Light stipple indicates hillslopes. (Drawn from air photographs).

latter alternative. The Sunkland developed as a topographic low as a result of faulting in the late Cretaceous or earliest Tertiary for there are Eocene sediments at the base of the Cainozoic sequence recording the beginning of lacustrine deposition on the subsiding fault block (Johns, 1968). This argues that the surface dislocated by faulting is of Cretaceous age and in the region immediately adjacent to the southern extremity of Lake Torrens, in the Beda Valley, the only land surface of low relief older than the mid Tertiary silcreted Beda Surface is the Arcoona Surface which forms plateaux and domed plateaux standing some 180 - 200 feet above present baselevel (Twidale, Shepherd and Thomson, 1970) and which can be traced southwards and seen to be the direct equivalent of the Simmens Surface. Thus though the other possibilities cannot wholly be discounted the evidence points to the Simmens Surface being of Cretaceous age. Presumably it extended in some measure at the expense of the older Lincoln Surface, that is as an etch plain, though as described above there is reason to suggest that laterite development did not extend much further north than Blue Range.

3. TERTIARY LAND SURFACES.

The faults which delineate the present Spencer and St. Vincent gulfs were reactivated late in the Cretaceous and during the early Cainozoic. The Gulfs as we know them were initiated then. This is borne out by the complete Tertiary marine section present beneath the bed of the Gulf St. Vincent and exposed in coastal cliffs in fault angle depressions located on the eastern side of the Gulf (Glaessner, 1953; Glaessner and Wade, 1958; Sprigg, 1961). Recurrence of regional faulting is also suggested by the marked erosion of the Gawler Range Volcanics, blocks and fragments of which were carried by high energy streams into the vicinity of the present Lake Eyre (Wopfner, 1969, pp. 152 and 156), suggesting upfaulting of the Volcanics block at the southern margin and its tilting to the north. Little is known of the thickness and nature of the stratigraphy of the sediments of Cainozoic age beneath Spencer Gulf, but Pliocene marine deposits occur at Whyalla (Miles, 1952; Lindsay, 1970) so that whatever the details the Gulf was an arm of the sea by the later Cainozoic. This reactivation of faults caused the disruption of the surfaces of low relief developed during the Mesozoic, the rejuvenation of streams and renewed dissection resulting in the destruction of parts of the former land surface and the formation of new areas of low relief.

The earliest Tertiary surface of which remnants survive in the present landscape of northern Eyre Peninsula is that protected by a silcrete duricrust. During the early Tertiary extensive areas of central Australia were baselevelled. On this surface of low relief silcrete developed as a pedogenic accumulation, and despite subsequent folding (see Wopfner, 1960; Wopfner and Twidale, 1967) and strong dissection, remnants of this duricrust are widespread in these regions. Similar occurrences developed and survive in more southerly parts of South Australia, for instance the Mid North (Alley, 1973) and the Flinders Ranges (Campana, Coats, Horwitz and Thatcher, 1961; Twidale, 1966). It extends into the southern part of the Arcoona Plateau in the Beda Valley (Twidale, Shepherd and Thomson, 1970; Hutton, Twidale, Milnes and Rosser, 1972) and into the Lincoln Gap area where it forms discontinuous cappings on dissected pediment remnants. To the south and west silcrete occurs high in the relief of the Buckleboo Plain and in the Nonowie Hills and High Plains, though in both the areas mentioned the silcrete surface forms only a minor element of the landscape (Fig. 3.1).

Dissection of the higher palaeosurfaces and formation of broad valley floors, now the Alamein Surface, was accompanied by development of silcrete in the scarp foot zones of the Northeastern Plateau and of the low relict ridges of the Pandurra Surface, and in drainage depressions, which now appear in the Nonowie Hills and High Plains as low silcrete-capped remnants.

The Buckleboo Plain is a rolling surface above which stand low granite hills and quartzitic ridges. With a relief amplitude of 120 - 180 feet the Plain is eroded in granite and metasediments and weathered to moderate depths. Silcrete is developed on the higher points of the topography for instance near Mosely Nobs and Cortlinye, and is regarded as an equivalent of the Alamein Surface described above.

Although silcrete is preserved in arid conditions the available evidence suggests that it formed under humid tropical climates (Dorman, 1966; Ludbrook, 1969, p. 173; Brown, Campbell and Crook, 1968, pp. 305 - 308). Its origin is not clear though several hypotheses have been suggested (see e.g. Bassett, 1954; Öpik, 1954; Stephens, 1964, 1971; Hutton, Twidale, Milnes and Rosser, 1972). One of the most vexing problems is to define precisely what is meant by the term silcrete for rocks which are acceptable as silcrete in hand specimen are on close examination in the laboratory seen to display important chemical and mineralogical differences.

The silcrete preserved in southern South Australia has a matrix which is predominantly of crystalline silica in the form of quartz; it thus differs from limited occurrences in the area west of Lake Eyre of opaline silcrete which are of Pleistocene age (Wopfner and Twidale, 1967), and which are not represented in northern Eyre Peninsula. The quartzitic silcrete appears on all the evidence to be of early mid Tertiary age, with late Oligocene to Miocene as perhaps the best age in detail. There is much evidence which points to this conclusion and no evidence to the contrary.

The silcrete of northern South Australia and southwest Queensland is developed on rocks which range in age from Proterozoic to early Tertiary. Silcrete is however found in the early Tertiary Eyre Formation (Wopfner, Callen and Harris, 1974), so that silcrete development must have begun in the early Tertiary. In the Lake Eyre Basin and particularly in the Oodnadatta area the silcrete is overlain by a limonitic pisolite (Wopfner and Twidale, 1967) which also contains fragments of silcrete; it is therefore certainly younger than the duricrust. To the west of Lake Eyre the pisolite unit at the base of the Etadunna Formation is either the equivalent of this, or a reworked version of the equivalent, so that the Etadunna postdates the silcrete. As the Etadunna Formation is on the foraminiferal evidence (Ludbrook, 1965) of Miocene or younger age the silcrete clearly is early-mid Tertiary. This suggestion is in some measure corroborated by the occurrence above folded and dissected silcrete in the Curalle and Betoota areas of southwest Queensland of a ferruginous duricrust, the early Miocene Doonbara Formation (Wopfner, 1960, 1974). A Miocene or Oligocene age is at variance with the Pliocene age for silcrete urged by Stephens (1971) but the stratigraphic evidence is reasonably clear.

Thus those remnants of silcrete in northern Eyre Peninsula and called the Alamein Surface are of early-mid Tertiary age. The siliceous duricrust was dissected and evidently erosion of a surface of low relief at that time contributed sediments to several shallow basins located in western Eyre Peninsula: the Polda, Lincoln, Uley-Wanilla and Cummins basins (see Johns, 1961, p. 26; Ludbrook, 1969, p. 200).

However it was after only shallow stream incision of the silcreted surface that the second phase of iron oxide accumulation took place resulting in the ferricrete which today forms cappings in many parts of the Buckleboo Plain, the Nonowie Hills and High Plains, in the area east and south of Iron Knob, and especially the Podinna Plain in the areas north of Minnipa and between Kimba and Koongawa (Pl. 3.5; Fig. 3.7). Weathered rock is shown to be heavily iron-stained where exposed in cuttings and dams but the ferruginous zone is generally

Plate 3.5

The Koongawa Surface (K) characterised by iron indura - tions is seen here capping low rises some four miles north of Mount Bosanquet. In the foreground weathered country rock is seen in the spoil heap of a dam.

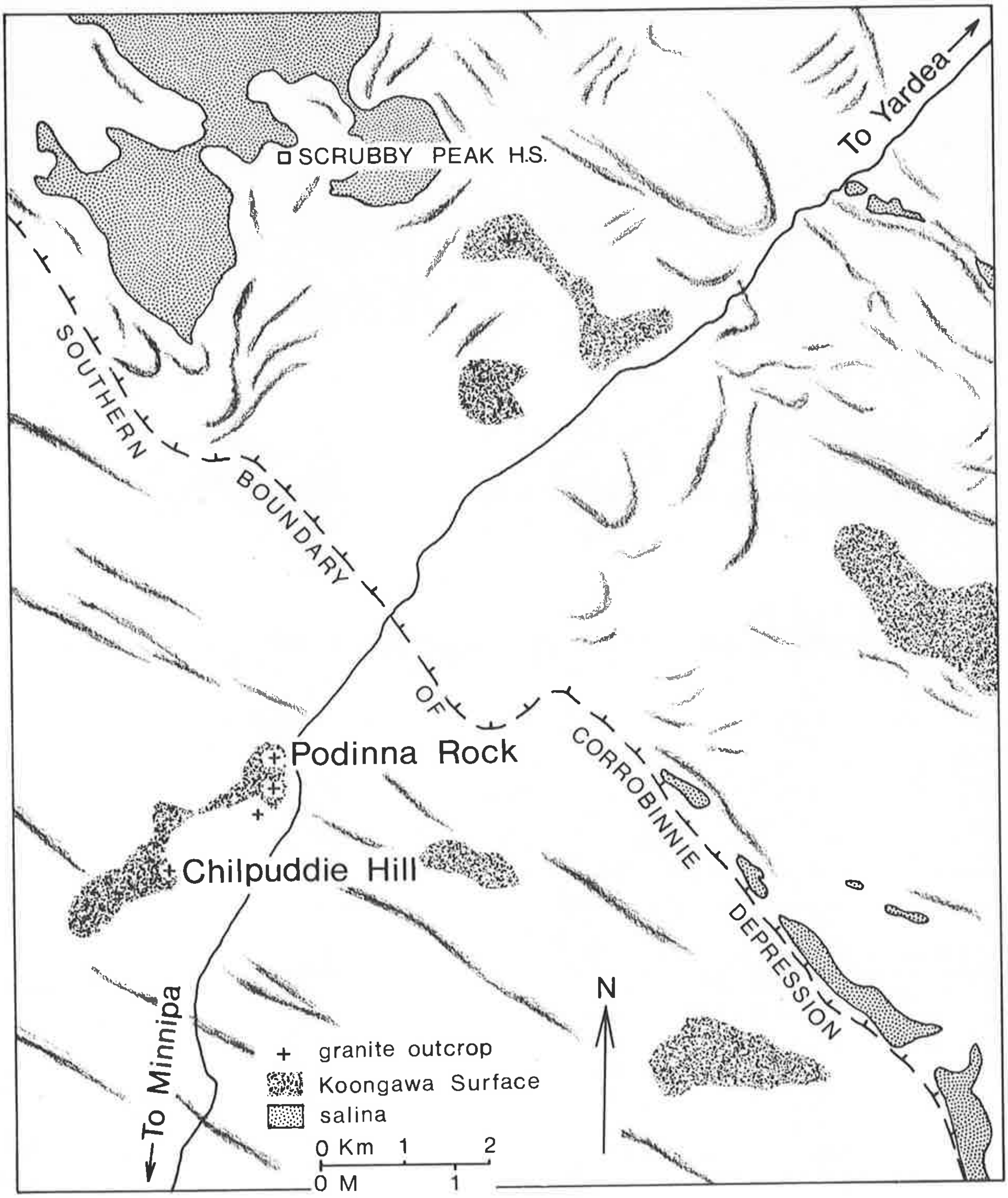


Figure 3.7.

The Koongawa Surface north of Minnipa. (Drawn from air photographs).

buried by more recent sediments, e.g. at Minnipa, east of Koongawa and within the Buckleboo Plain (Shepherd, 1963a).

Such iron accumulation affords less protection to a surface than would a fully developed laterite, but erosion is nevertheless retarded and remnants of the Koongawa Surface remain upstanding in the relief. Ferricrete caps topographic highs of the rolling surface of the Podinna Plain which is cut in deeply weathered granite though the occurrence of a few low whalebacks and numerous pavements indicate that some compartments of fresh rock survive within the altered mass. Further east in the Buckleboo Plain ferricrete occurs on a more extensive surface which is lower in the relief than the silcrete of the Alamein Surface. Again in the Nonowie Hills and High Plains east of the Middleback Ranges silcrete remnants stand higher than those capped with ferricrete.

The relative positions of these two surfaces may be viewed in a number of ways. The two duricrusts may be regarded as temporally distinct in which case the silcrete is older than the ferricrete since it is higher and the iron encrustation is developed on a surface eroded below the silcrete. But there are areas e.g. Podinna Plain, Koongawa-Kimba where ferricrete occurs with no associated silcrete. The two duricrusts seemingly represent separate events. Even if a different interpretation is placed on them and they are regarded as contemporaneous accumulations within a silcrete profile (Wopfner and Twidale, 1967) the surfaces they protect must still be of different ages with the ferruginous lower and therefore younger.

On the other hand it may be argued that the iron-indurated and silica-rich zones are genetically related (Stephens, 1964, 1971; Alley, 1973) with the silica of the silcrete derived from the strong leaching of laterite profiles. But quite apart from the fact that many laterites contain abundant free silica, the silcrete should, in terms of this suggestion, occupy lower ground than the iron-rich zone; and in fact the reverse is true in northern Eyre Peninsula. Perhaps there has been relief inversion with silcrete, which accumulated in depressions, now occupying high parts in the relief by virtue of its durability, but even if that were so the ferricrete would still be younger since it occupies slopes below the silcrete cappings.

For any of these reasons the silcrete must predate the ferricrete. Such relative dating is consistent with field evidence and stratigraphic dates obtained elsewhere (Wopfner and Twidale, 1967). If this iron encrustation on northern Eyre Peninsula is comparable with similar occurrences on northern Yorke Peninsula then the Koongawa Surface is of late Pliocene or early Pleistocene age (Horwitz and Daily, 1958, p. 57; Crawford, 1965, pp. 39 - 41). Thus it is younger than the early-mid Tertiary silcreted Alamein Surface.

4. QUATERNARY LAND SURFACES.

The late Tertiary duricrusted surfaces have suffered extensive erosion with the result that a surface of low relief of great extent has been cut at a lower topographic level. This plain, the Wudinna Surface embraces much of the Eyre Lowlands. It is a rolling surface (Pl. 3.6) eroded for the most part in weathered granite surmounted by a few inselbergs and traversed by fixed longitudinal dunes. These include lenses of lime which have been dated by C14 assay as being 10,300 - 27,000 years old (GaK 4071, GaK 4072, GaK 4639). These are superimposed on the surface cut in granite, which thus predates the later Pleistocene. The Wudinna Surface is also eroded below the late Pliocene-early Pleistocene Koongawa Surface, so that it may be regarded as of Pleistocene age.

There is virtually no stream dissection at present for the Surface is protected and stabilised by an almost continuous hardpan of calcrete which is exposed over considerable areas. Physiographic considerations were the basis for subdivision of the Eyre Lowlands (see Chapter Two), and hence of the Wudinna Surface, but the essential nature of the latter does not vary.

Though there are 'contaminants' of both earlier and more recent land surfaces the Wudinna Surface essentially comprises a morphological peneplain of Pleistocene age surmounted by inselbergs fringed by narrow pediments. There is no evidence to indicate whether the surface is due to lowering or backwearing. But in view of the zone of weathered granite over fresh rock and considering the most probable origin of inselbergs, lowering is favoured. Although a more complete discussion of the history of the inselbergs will follow (Chapter Four) suffice it

Plate 3.6.

The broadly rolling Wudinna Surface eroded in weathered granite, central Eyre Peninsula.

to say for the present that the inselbergs develop on compartments of rock which are effectively massive and impenetrable to water. Thus they are resistant to weathering and erosion. Weathered material in the more susceptible compartments is removed to expose the inselbergs.

The occurrence of innumerable broad shallow valleys shows that rivers are responsible for the erosion of the peneplain, but there are no permanent streams and few channels are in evidence even after heavy rains. But however it was formed the peneplain has now been essentially stabilised by the widespread development of a sheet of calcrete some six feet thick, which is in part buried by more recent sand and alluvium, and which acts as a protective cover for the weathered bedrock below. The gradual development of this duricrust in weathered granite from concretionary nodules to lenses to a massive hardpan stabilised the peneplain surface (Twidale, Bourne and Smith, 1975b). Lime continues to accumulate and now water filters through calcrete to deplete the weathered zone by subsurface flushing and evacuation of material as fine sand in solution to local drainage basins (Ruxton, 1958). In addition the moisture must be effecting further weathering. Presumably some subsidence of the peneplain, as a whole, has occurred (see Trendall, 1962) but without significant alteration to the original form.

The lime may have been derived from the bedrock, or it may be aeolian. The volume of lime involved suggests the latter as the dominant source. During the low sealevels of the Pleistocene, wide expanses of the former sea bed were exposed. Shell fragments were transported by the strong westerlies which were then even more prevalent in this area, and blown inland as large coastal foredunes which extended some forty miles beyond the present coast. But smaller quantities of lime were spread on the wind over much of Eyre Peninsula providing the basis of the calcrete which is now such a characteristic feature of the whole area.

Whatever its origin, stabilisation by calcrete and consequent lack of surface drainage, rather than climatic change, is cited to explain the preservation of the Wudinna Surface. In the west the Wudinna Surface, including inselbergs and clusters of boulders, is similarly preserved beneath a cover of Pleistocene aeolianite coastal dunes. Where exhumed these granitic forms are known as the Malijay Surface (Pl. 2.14). But the aeolianite cover remains intact over most of the near coastal areas, and its weathered surface gives rise to the rolling hill and vale country of the Sheringa Plain.

G. CONCLUDING STATEMENT.

Thus eight palaeosurfaces have been identified in northern Eyre Peninsula. The two oldest, the Moonabie and Pandurra are of the exhumed type. Exhumed inselbergs related to the Wudinna Surface are also found near the west coast in the Malijay Surface which occurs between Streaky Bay and Port Kenny. Apart from these however the surfaces are of sub-aerial origin and have never been buried. They are preserved either by virtue of the duricrusts developed on them or, as with the Simmens Surface, because of the inherent resistance of the quartzite which caps and buttresses it. But even taking into account the toughness of the several caprocks very slow rates of erosion are implied, as are great inequalities of erosion as between stream lines and interfluves (see Crickmay, 1959, 1971).

The erosional surfaces of low relief can in a general way be correlated with palaeosurfaces recognised in other parts of Australia and in the case of the Precambrian surfaces, they may be compared with those from other parts of the world, namely Greenland (Cowie, 1961) and northern Canada (Ambrose, 1964).

The Simmens Surface is possibly the equivalent of the exhumed pre Lower Cretaceous surface which occurs around Mount Babbage in the northern Flinders Ranges (Woodard, 1955; Twidale, 1969), or of the epigene surface described from the central and southern Flinders (Twidale, 1966, 1969). The erosion of this surface probably contributed debris to the Great Artesian Basin where there are thick sequences of Cretaceous rocks and at present the regional slope of the Simmens Surface is to the north. However sediments could equally have been carried south to the Duntroon Basin where there are more than 20,000 feet of Mesozoic sediments thought to be derived from the north (Smith and Kamerling, 1969).

The discussion of the likely ages of surfaces made clear that silcrete development was widespread throughout the Mid North (Alley, 1973) and the Flinders Ranges (Twidale, 1966, 1969) of South Australia and central Australia (Stephens, 1964, 1971; Wopfner and Twidale, 1967). Ferricrete developed during the late Tertiary and occurs within the Gulf region of South Australia, notably on northern Yorke Peninsula (Horwitz and Daily, 1958) and the southern Mount Lofty Ranges (Horwitz, 1960). While not as valuable a stratigraphic marker calcrete has developed as an effective capping in the Murray Valley and indeed throughout the State.

CHAPTER FOUR.

THE GRANITE RESIDUALS.

> I have climbed and ruminated upon too many great bornhardts ... to believe that these most powerful of landforms ... ever originated foetally within the dark body of the earth.
>
> (L. C. King, 1966, p. 98).

A. THE PROBLEM.

In the previous chapter it has been established that palaeosurfaces of low relief and of varied ages form an integral part of the present landscape of northern Eyre Peninsula. Standing above the present plains, particularly in the western region, there are numerous granite residuals which are as high as, or higher than, the palaeosurface remnants.

It is reasonable therefore to ask whether the chronology of denudation is reflected in the morphology of the granite inselbergs and other residuals. In an attempt to answer this question the origin of the granite residuals and their morphology are first described and the significance of certain minor landforms considered. These are then used to establish the occurrence of former hill-plain junctions on the residuals. Specific groups of residuals are then considered in detail in an endeavour to correlate the surfaces of low relief (described in Chapter Three) with granite landform assemblages.

B. CLASSIFICATION OF GRANITE RESIDUALS.

Major joints are responsible for delineating in plan the granite outcrops of northern Eyre Peninsula, and for determining the location and direction of clefts within the residuals. Though they display a wide variety of trends the major joints run roughly northwest-southeast, southwest-northeast, east-west and north-south: in other words they conform to major lineament directions recognised for the region (see Chapter Two, Fig. 2.2) and indeed for the whole of Australia (Hills, 1946, 1955b, 1961). The major vertical or near-vertical joints effectively subdivide the granite masses into rhomboidal, square or quadrangular blocks. Most commonly several such blocks occur in juxtaposition so that in detail the residuals have a complex but angular appearance in plan (Fig. 4.1).

Within each of these major blocks orthogonal joint sets are developed but they are usually subordinate to the curved sheeting joints (see Twidale, 1964a, 1973), the presence of which are reflected in the generally domed form of most of the residuals. And the geometry of the sheeting joints as expressed in the shape of the residual provides the basis of a convenient morphological

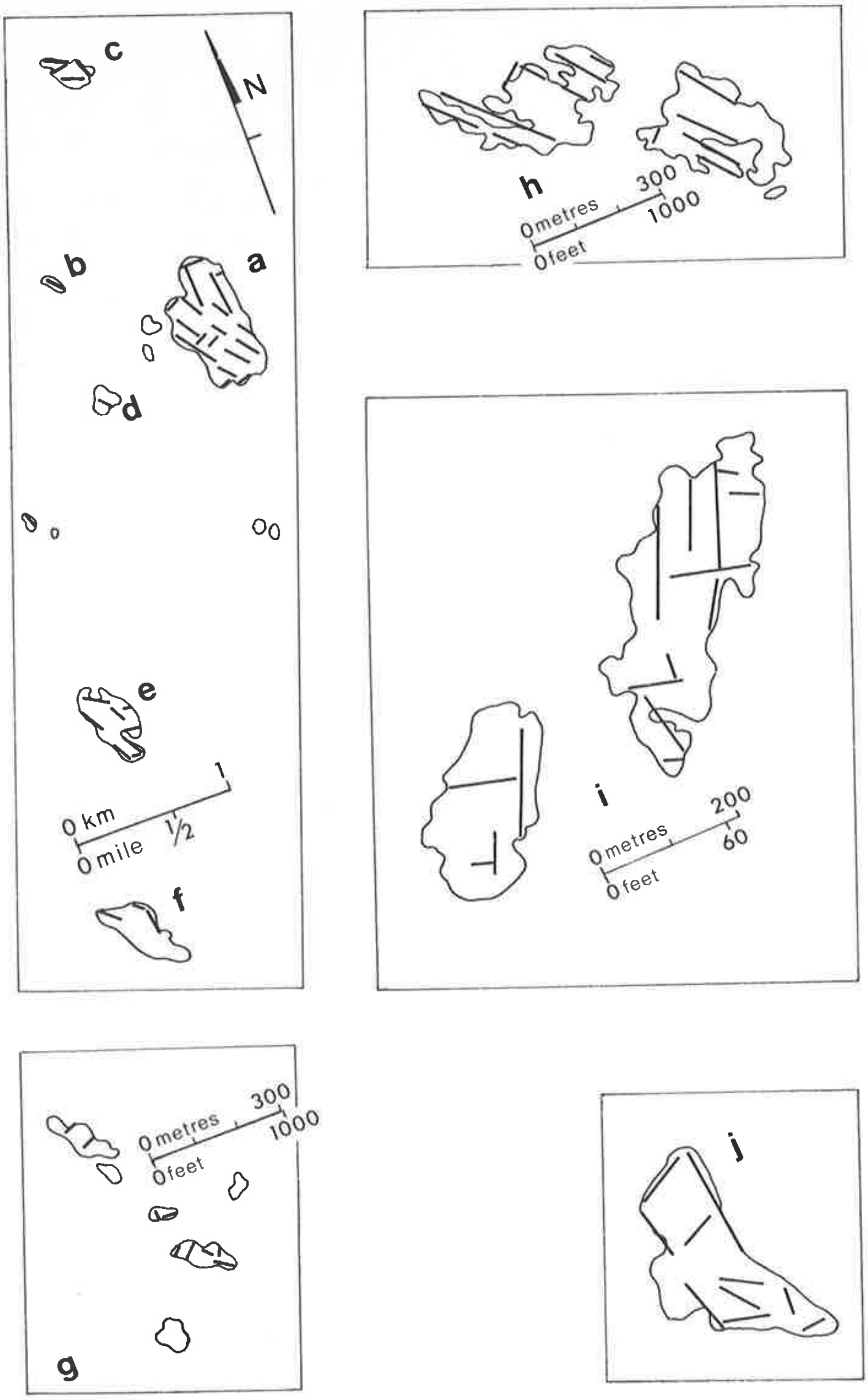
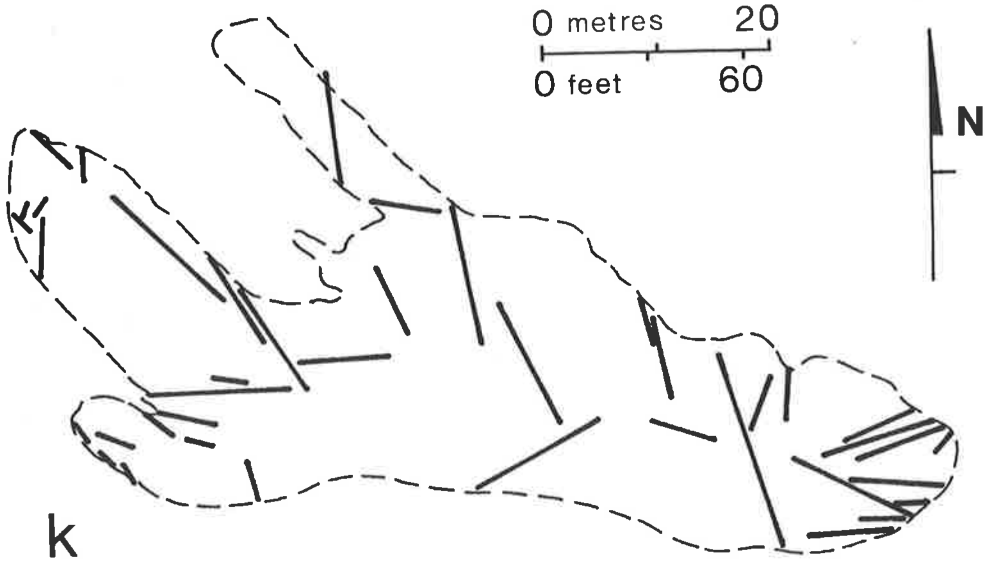


Figure 4.1a.

Plans of granite residuals on northwestern Eyre Peninsula, showing outlines and major joints. (a) Mount Wudinna (b) Dinosaur (c) Wattle Grove Rock (d) Cottage Loaf Rock (e) Little Wudinna Rock (f) Polda Rock (g) Pygery Rocks (h) Minnipa Hill (i) Yarwondutta Rocks (j) Tcharkuldu Hill (k) Pildappa Hill (l) Ucontitchie Hill.



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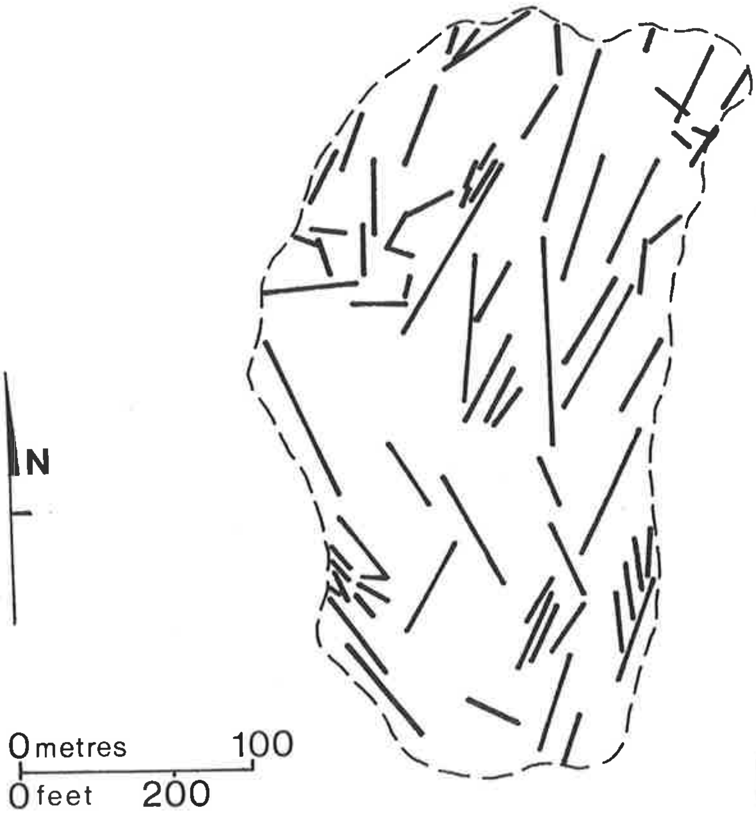

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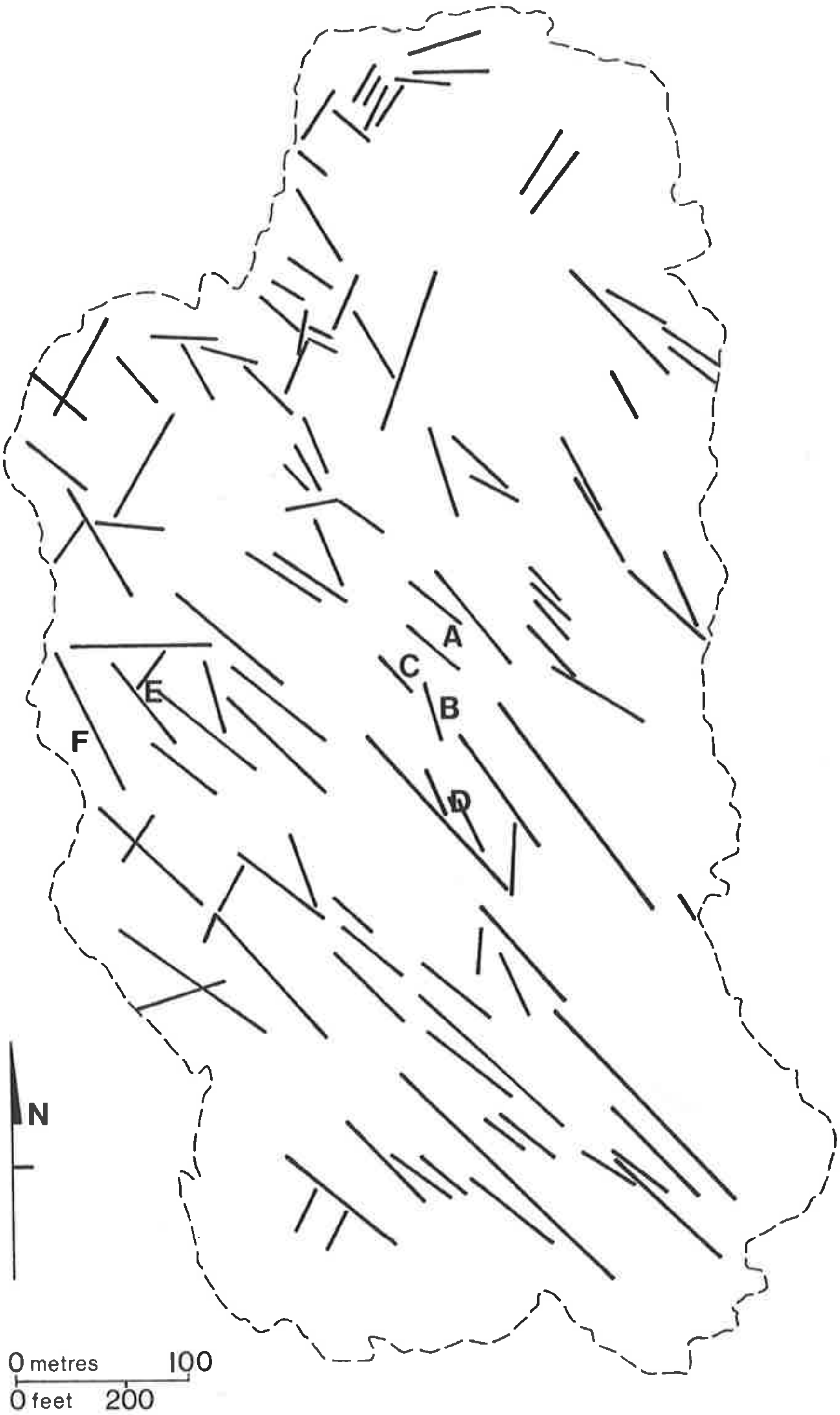
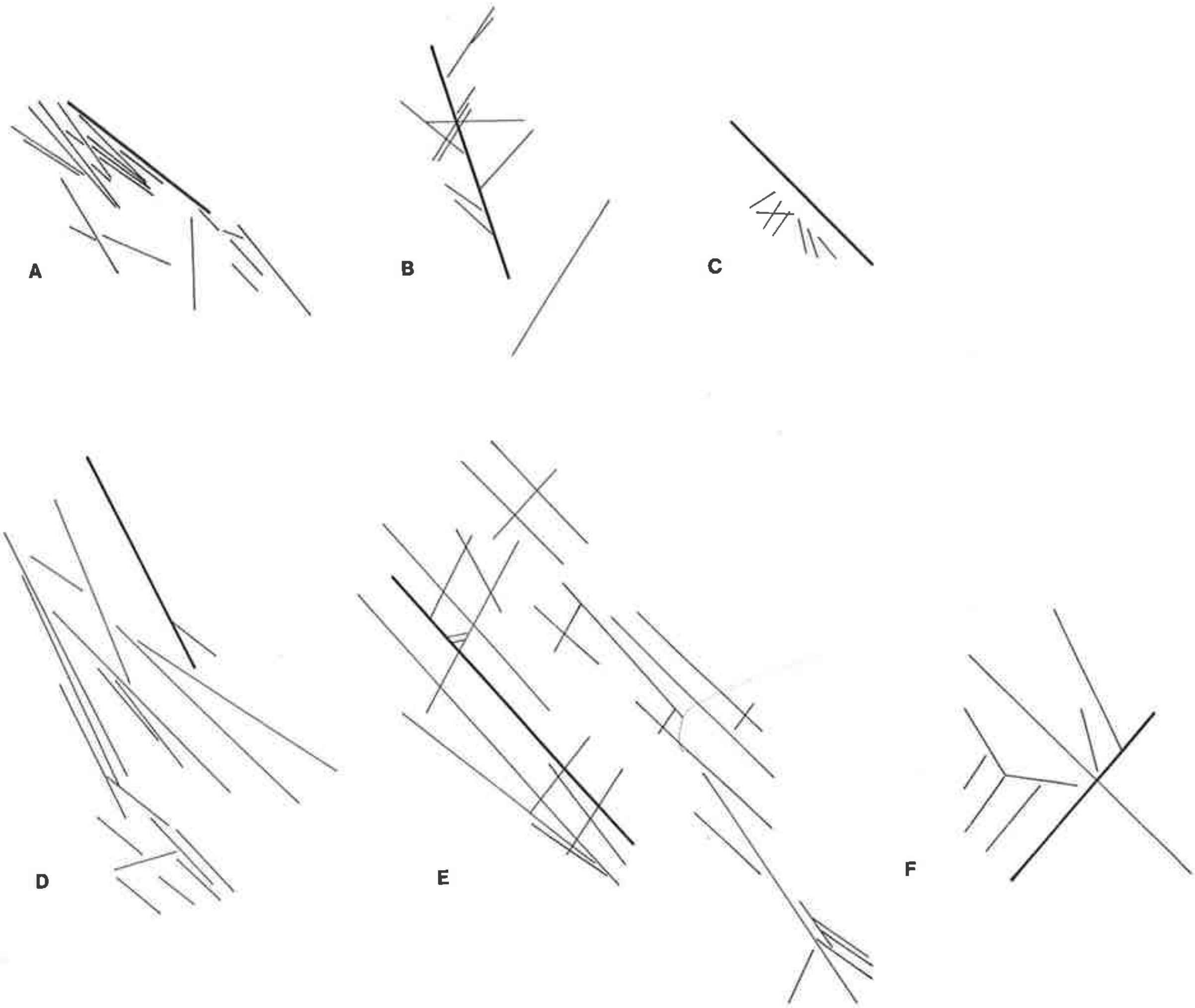


Figure 4.1b.

Mount Wudinna, showing major joints and location of sites mapped to show joint swarms in detail.



Joint swarms (A-F) in detail referred to on previous page.

classification:

<u>Pavement</u>: Low (less than 10 feet above the surrounding plains), large radius domes; plan diameter much greater than height above plain; many examples which are unnamed presumably because they do not constitute spectacular features of the landscape (Pl. 4.1).

<u>Swell</u>: Low (10 - 25 feet high), large radius domes; e.g. Pygery Rocks, Wattle Grove Rock (Pl. 4.2).

<u>Ruware or Whaleback</u>: Medium height (25 - 65 feet above plain), moderate radius; plan diameter greater than height above plain; e.g. Polda Rock, Pildappa Rock (Pl. 4.3).

<u>Bornhardt</u>: Considerable height (70 feet and more above plain), small radius dome; plan diameter same order as height; e.g. Mount Wudinna (Pl. 4.4), Ucontitchie Hill.

In addition and as is discussed below some ruwares and bornhardts have a stepped morphology, e.g. Cottage Loaf Rock (Pl. 4.5), Tcharkuldu Hill and Corrobinnie Hill.

C. THE ORIGIN OF BORNHARDTS.

1. GENERAL STATEMENT.

Much of northern Eyre Peninsula is underlain by granite at relatively shallow depths and as mentioned previously it crops out in the form of upstanding residuals surrounded by plains which are also

Plate 4.1.

Granite pavement exposed in the Koongawa Surface some fifteen miles northeast of Minnipa with the Corrobinnie Depression intervening between the pavement and Mount Sturt, built of porphyritic dacite.

Plate 4.2.

An unnamed granite swell some two miles south of Mount Wudinna which is seen in background.

Plate 4.3a.

Pildappa Hill, a granite ruware, seen from the air. Note the dimpled upper surface caused by the widespread development of gnammas and the prominent gutters or Rillen many of which are clearly joint-controlled. Overhanging flared slopes are visible at the southern margin of the rock (nearest the camera) as are drains related to a water conservation scheme.

Plate 4.3b.

Pildappa Hill seen from the north.

Plate 4.4.

Mount Wudinna is a granite bornhardt which stands 180 feet above the surrounding plains.

Plate 4.5.

The Cottage Loaf, two miles southwest of Mount Wudinna, is a small granite residual with stepped relief, each step displaying to a greater or lesser extent flared slopes.

cut in weathered bedrock. The rectangular or rhomboidal shape in plan aligned parallel to local lineament trends is undoubtedly determined by the joint pattern. But what determines which compartments of rock remain upstanding and essentially fresh while others are weathered and worn down? Several hypotheses have been advanced in explanation of this problem.

2. BATHOLITHIC INTRUSION.

Holmes and Wray (1912) suggested that inselbergs are primary structural forms which reflect individual dome-like batholithic intrusions extending from a larger plutonic mass. Although xenoliths found in the granite of the Victor Harbour and Caloote areas of Fleurieu Peninsula indicate that that granite was close to the roof of the intrusions and may indicate that they are batholithic intrusions (Twidale, 1971, p. 59) such inclusions do not occur in the granite outcrops of northern Eyre Peninsula.

3. PETROLOGICAL CONTRAST.

There is no evidence to suggest the granite of the outcrops differs mineralogically from that underlying the plains, which excludes the explanation for Stone Mountain in Georgia, U.S.A., whereby the granite of the residual is couched within schists, gneisses and granitic gneisses (Lester, 1938). Petrological differences appear to account for the The Pinnacles, southwest of Broken Hill, in western New South Wales.

4. SCARP RETREAT AND PEDIPLANATION.

L. C. King (1949) has long been concerned to account for the extensive plains of southern Africa. He suggested that from joint-controlled stream incision there was scarp retreat and pedimentation with inselbergs left as residuals on drainage divides. Almost twenty years later he firmly adheres to his contention, and as indicated in the quotation cited at the beginning of this chapter specifically denies the two-stage hypothesis (King, 1966) which many workers consider offers the best explanation of the field evidence (see below). King holds to his concept of scarp retreat and pedimentation despite lack of corroboration from field evidence or from general argument. Yet there is weathered granite in the compartments between the inselbergs both in the Valley of the Thousand Hills, in Natal, and in parts of Namaqualand, in Cape Province, South Africa (C. R. Twidale, pers. comm.). The mechanism of scarp retreat and pedimentation fails to explain why the inselbergs survive while the compartments between are weathered or eroded away.

Moreover, King's concept of scarp retreat and pedimentation for the delineation and development of inselbergs and other lower outcrops is unlikely to be applicable in areas of weathered granite such as that which underlies the present plains of northwest Eyre Peninsula. The altered rock has a high porosity and permeability, lacks cohesion and strength, and is unstable save on very gentle slopes. This is the reason that $\frac{1}{2}^{o}$ - 2^{o} slopes are typical of widespread areas of weathered granite both on northwest Eyre Peninsula and in the Wheat Belt of Western Australia, slopes which stand in strong contrast with the vertical and even overhanging cliffs formed on the fresh, cohesive rock. Of course, it may be argued that the weathering of the rock beneath the present plains is a geologically recent event and that it post-dates the plain and inselberg development rather than fundamentally determining it. But in view of the observed variations in joint spacing (which largely controls the penetration of waters and weathering) today, there is no reason to suppose that at higher levels in the granite massif there were not similar contrasts between compartments of rock. For this reason it seems inherently unlikely that scarps could have developed to any significant extent in granite and thus that scarp retreat could have occurred. It is more probable that the resistant compartments gradually emerged from the granite outcrop through lowering of the intervening masses of weathered rock.

5. METAMORPHISM.

A quite different interpretation is due to Brajnikov (1953) who envisaged inselbergs as large cores of resistant rock developed by compression during metamorphism within a mass of disintegrated granitic material. Subsequent removal of the grus exposes the cores at the surface. As erosion proceeds fresh cores are revealed, and those exposed earlier are worn away.

Although the tightness of the joints within the granite residuals indicates that they are in compression, metamorphism, as postulated by Brajnikov, is not responsible for the formation of the inselbergs of northern Eyre Peninsula. The granite mass of Eyre Peninsula is intrusive; no typical hydrothermal minerals are present. Moreover hydrothermal activity tends to rot granite rather than strengthen it (see e.g. Palmer and Nielson, 1962; Edmonds, et al, 1968).

Brajnikov's notion that variations occur in the vertical plane as they obviously do in the horizontal means that the inselberg does not necessarily persist in depth and new inselbergs await exposure, baselevel permitting, beneath the present surface. Thus whether the ruwares and pavements of the present surface are incipient inselbergs or worn down remnants of former inselbergs, can only be conjecture.

Though geologically very different in its application Brajnikov's concept is in its geomorphological effects close to the two-stage hypothesis, whereby subsurface preparation of tors and inselbergs by deep weathering is followed by erosion and exposure (Jones, 1895; Branner, 1896; Linton, 1955). It is merely that instead of suggesting that resistant compartments arise as a result of joint spacing and condition (which in turn may reflect stresses, past or present, in the crust) Brajnikov attributed them to metasomatism. In either case there is structural variation in the bedrock giving rise to differential weathering and hence erosion.

6. TWO-STAGE DEVELOPMENT.

Field investigations from many parts of the world suggest that the plains which separate the various granite inselbergs and other residual forms are underlain by deeply, and in many instances intensely, weathered granite (see Linton, 1955; Twidale, 1971, pp. 45 - 55). Certainly, and as has been described in the sections concerned with physiographic regions, the Wudinna Surface is underlain by weathered granite the thickness of which varies between 60 and 150 feet.

Moreover at both Ucontitchie Hill and Mount Wudinna core-stones set in a matrix of grus occur immediately adjacent to the massive granite of the bornhardts (Pl. 4.6). The size of the corestones is in large measure a function of the joint spacing and in the areas mentioned a maximum of the order of three feet is indicated, contrasting with the 15 - 60 feet unweathered blocks observed in the nearby residuals. Finally there is increasing evidence that many of the minor granite forms were initiated whilst the inselberg surface was still beneath the land surface and enclosed in a cover of grus. Thus in addition to flared slopes, tafoni and pavements (see below), Rillen have been and are being revealed from beneath a cover of grus and granitic soil at Pildappa Hill

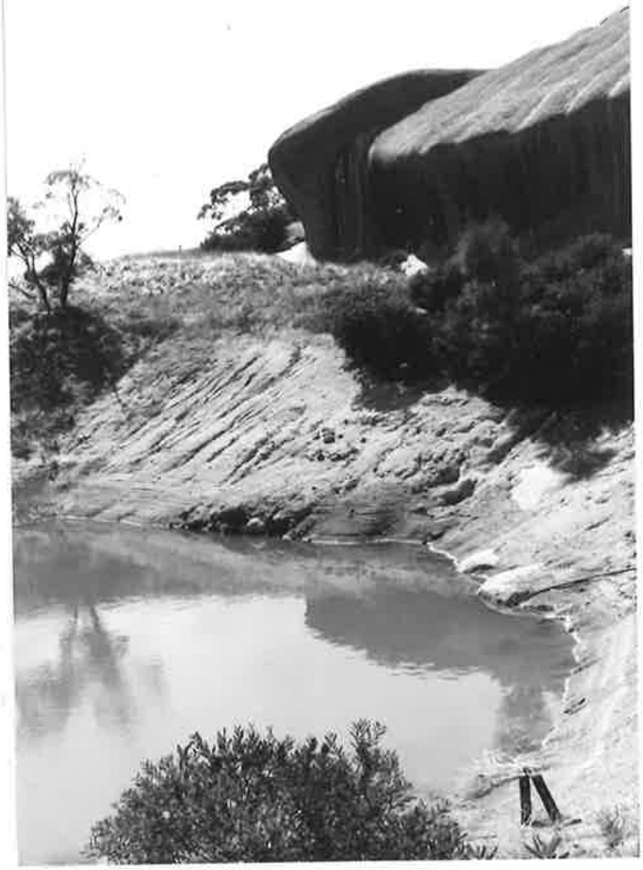


Plate 4.6.

Ucontitchie Hill is a bornhardt built of massively jointed granite. The northwestern margin of the Hill which exhibits pronounced flared slopes is seen here. However an excavation nearby shows quite clearly that closely jointed rock underlies the plains, immediately adjacent to the residual, for corestones which range in diameter from 1 - 3 feet and which reflect the spacing of the joints are exposed set in grus in the walls of the dam.

Plate 4.7.

Dumonte Rock is a low granite swell some three miles ENE of Wudinna. A shallow dam has been excavated at its western side with the result that the local baselevel has been lowered. This in turn has caused the erosion of much of the granitic soil, which formerly covered the lower margins and the lower points in the relief of the Rock, exposing both Rillen and gnammas which had formed beneath the soil surface as either linear or roughly circular depressions in the weathering front.

Seen here is the 'tidemark' which is the natural upper limit of the soil and below which is the pitted granite surface and the Rillen which clearly continued beneath the natural soil level. A patch of soil which has so far survived erosion is seen filling one of the Rillen.

and Dumonte Rock (Pl. 4.7), and gnammas are being exposed at several sites e.g. Dumonte Rock, Pygery Rocks (Pl. 4.8). If these features are indeed initiated subsurface they surely lend support to the argument that the rock surfaces on which they occur originated beneath the land surface?

This evidence forms the basis of what has been called the two-stage hypothesis of inselberg development (Fig. 4.2). Some compartments of granite are attacked by groundwater while they are in the near-surface zone. Others however are resistant and form upstanding towers of fresh rock surrounded by weathered rock or grus. When base-level is lowered and streams cut into the bedrock for some other reason it is the weathered rock which is eroded, leaving the resistant compartments as upstanding residuals or inselbergs.

This hypothesis is consistent with and indeed follows from the field evidence. It is widely supported as an explanation not for all, but certainly for many, granite residuals. However some further comment is required concerning the resistance of some compartments and the vulnerability of others. No fully satisfactory explanation has been put forward. It can be suggested that the jointing of the resistant masses is less dense and more tightly closed than in the weaker compartments. This is borne out by field observations (Pl. 4.6), but is susceptible to an alternative explanation, namely that the closer and more open joints of the plains areas are an expression of volume decrease consequent upon weathering: in other words that they are the result and not the cause of weathering.

Plate 4.8.

Gnammas being exposed as the soil level is lowered at the margin of Pygery Rocks located some five miles west of Mount Wudinna.

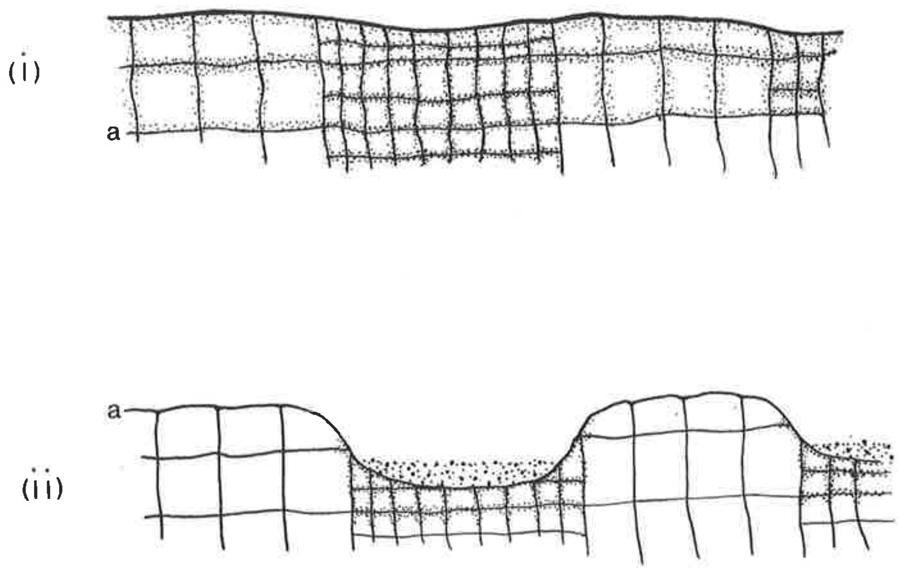


Figure 4.2.

The two stage development of inselbergs.

However if it is assumed for the sake of argument that joint spacing and condition initially determine the location of intense weathering of the granite, then it is still necessary to explain why some compartments are intrinsically massive or monolithic, while others, nearby, are subdivided by joints of the orthogonal system into innumerable comparatively small joint blocks. This problem is the key to the survival of inselbergs. In this context it is relevant to consider the nature and origin of the sheet jointing which is characteristic of many granite residuals and particularly of granite domes or bornhardts.

D. SHEET JOINTING.

Sheet structure sheeting joints or sheet jointing has been attributed to insolation, chemical weathering, off-loading, plutonic injection, metasomatic expansion, vertical uplift and lateral compression. Most of these have limited application, and although erosional off-loading is the one often cited, lateral compression is favoured for the domed inselbergs of northern Eyre Peninsula (see Twidale, 1973).

Observations and laboratory experiments demonstrated that heating and cooling of rock is most effective in the presence of moisture (Barton, 1916; Blackwelder, 1927; Griggs, 1936). Although the effects of heating and cooling in respect of shallow features cannot be discounted, the effects of the sun's rays cannot be responsible for sheet jointing at depth. The accession of moisture via joints and chemical weathering usually results in compaction (Ruxton, 1958) rather than the expansion required for fracturing the rock. Moreover the primary breakdown of the granite, e.g. around the corestones at Palmer in the eastern Mount Lofty Ranges is mechanical and not chemical. Nor is there sign of chemical alteration about the wedges of rock associated with sheet structure.

Few would disagree with Chapman (1956) that once the overburden is removed the joints, latent because of vertical pressure, are made manifest. Gilbert (1904) and his followers supposed that mere decompression after erosional offloading caused the sheeting joints to occur. The domed inselbergs of northern Eyre Peninsula are demonstrably in compression: joints are tightly closed, some no more than hairline discontinuous fractures, whereas if radial release of pressure had taken place the fractures would surely be open? Various general arguments have been presented in opposition to the offloading hypothesis (Twidale, 1973). On Eyre Peninsula an inverse relationship between sheeting joint and surface is displayed in the open-cut quarry on Yarwondutta Rock (Pl. 4.9). Joints dip at approximately 15^{o} beneath the low dome and in no way parallel the surface as expected if offloading were the cause.

With plutonic injection the roof of the crystalline mass is domed and this has been equated with the domed inselberg. Inevitably that original outline is dissected and destroyed, and anyway xenoliths are absent from the granite of Eyre Peninsula. Metasomatic expansion

Plate 4.9.

No sheet jointing or curvilinear jointing is seen to parallel the natural land surface in this quarry excavated in one of the Yarwondutta Rocks some four miles north of Minnipa.

(Jones, 1859; Brajnikov, 1953) does not apply since the granite is intrusive. Sheet structure is compared to fractures resulting from radial stretching during uplift but again the granite has not suffered vertical uplift.

Lateral compression of rock in depth may result in faulting or in stresses and strains which are obvious as sheeting joints only after the burden of material above is removed. Stresses measured in rock show those in a horizontal direction are greater than those in a vertical direction (Caw, 1956; Alexander, Worotnicki and Aubrey, 1963). The very nature of granite formation deep in the crust and the time lapse before it can be exposed at the surface make it a suitable medium for development of sheet structure consequent upon lateral compression. Field observations in northern Eyre Peninsula also favour lateral compression for the origin of the sheet structure. Wedges on Ucontitchie, Corrobinnie and Waulkinna hills demonstrate lateral dislocation. Some A-tents at any rate develop as a release of compressive stress (Jennings and Twidale, 1971) and possible imbricate structures were observed on Ucontitchie Hill (Pl. 4.10). In the quarry at Tcharkuldu Hill shattered feldspars, optically opaque, occur in an half inch zone either side of the sheeting joint exposed there. Sheeting planes on Ucontitchie Hill are almost horizontal over its broad crest but dip steeply to the eastern margin.

Thus lateral compression appears most likely responsible for sheet structure and for the preservation of the granite residuals of

Plate 4.10a.

Rock wedges displayed on the eastern side of Ucontitchie Hill.

Plate 4.10b.

A-tents on the western side of Mount Wudinna.

Plate 4.10c.

Possible imbricate structure developed in a massive sheet of granite on Ucontitchie Hill.

northern Eyre Peninsula, and in other regions where they have evidently formed in two stages.

It is not necessary to postulate large initial differences in joint spacing and condition to achieve eventually pronounced relief contrasts. Provided that there is sufficient variation to induce some relief contrasts, autocatalytic or reinforcement effects (Twidale, Bourne and Smith, 1975), and in particular the shedding of water from rises to lower areas, combined with the peculiar vulnerability of granite to moisture attack and its resistance when dry (see Bain, 1923; Wahrhaftig, 1965), can explain subsequent developments.

E. PHASED EMERGENCE OF INSELBERGS.

1. GENERAL STATEMENT.

L. C. King (1966) objects to the two-stage hypothesis on the grounds that the height above the surface of many inselbergs exceeds the depth to which subsurface weathering is known to have penetrated in the local region. Indeed in some instances their height is greater than the greatest known depths of weathering. The ideas of Büdel (1957) and Ollier (1965) imply that the depth of weathering is not critical for determining when the weathering took place. Büdel suggests that each cycle of erosion strips material to the weathering front, while Ollier believes that the amount of weathered debris removed depends on baselevel control so that beneath formerly weathered debris weathering associated with the new cycle continues. Certainly there are problems in dating a regolith so that it is not yet possible to correlate a given regolith with a given surface of low relief: the plain may be cut in an older regolith or the regolith may develop after formation of the plain.

But since bornhardts by their very nature should have preserved the imprint of multicyclic development (and this is certainly true in northwestern Eyre Peninsula) then it is possible first to explain those inselbergs which exceed known local depth of weathering by suggesting emergence as relief features in multiple phases or stages. Secondly if this supposition is correct then it may be possible both to identify such stages on higher bornhardts and to classify the granite residuals in terms of their order of development (Twidale and Bourne, 1975). In other words it may be possible to identify various generations of inselbergs, provided only that former hill-plain junctions can consistently be identified. What features can be used to recognise such zones?

2. CRITERIA.

Granite outcrops abound on northern Eyre Peninsula. Some are large radius domes or rock pavements which stand less than 10 feet above the surrounding plains. Some are rounded swells, 10 - 25 feet high. Others are whalebacks or ruwares which rise 25 - 65 feet above the plains. Their broadly domed upper surfaces are grooved by Rillen and pitted by gnammas (Twidale and Corbin, 1963). They are bounded by steepened, in many places flared, slopes. Some few are higher, and are called morros or bornhardts, though several have a distinctly stepped morphology. Many of these ruwares and bornhardts display evidence which can be interpreted as indicating exposure or growth in phases.

(a) Flared Slopes:

All the granite inselbergs of northern Eyre Peninsula display flared lower slopes (Pl. 4.11). Some of the flared slopes are overhanging. Basal flares form the perimeters of most of the inselbergs and many of the high residuals also exhibit flares well above the present plain level.

The characteristics and probable origin of these flared slopes have been discussed elsewhere (Twidale, 1962, 1967, 1968a, 1968b, pp. 347 - 350, 1971, pp. 90 - 96). Such features are best and most commonly developed on the shady aspect of granitic residuals especially on points of spurs and within some embayments. Not only is the feature displayed by most inselbergs, but it occurs on the small-scale upon boulders. The zone of flaring is not always horizontal but generally follows the present rock-soil junction either at the base of the residual or along joint clefts.

Excavations and augering in the scarp foot zone reveal that the weathering front (Mabbutt, 1961a) there is abrupt, concave downwards (Pl. 4.12) and thus morphologically comparable with the flared

Plate 4.11.

The Dinosaur a low ruware situated one mile west of Mount Wudinna displays flared and in places overhanging slopes on both its northeastern and southwestern flanks.

Plate 4.12.

The best demonstration that flared slopes are initiated by subsurface weathering at the margins of granite outcrops comes from Yarwondutta Rocks where a concavo-convex weathering front has been exposed in a reservoir excavated in 1916.

slopes displayed at the lower margins of the granite residuals (Twidale, 1962). For this reason flared slopes have been interpreted as exposed former weathering fronts. It is prepared subsurface. Water drains from the granite outcrops to a limited marginal area where it infiltrates, via open joints, beneath the surface. There the water effects weathering of the bedrock both in a downwards direction and laterally to undermine the residual (Fig. 4.3). The longer moisture is retained in the scarp foot zone the more effective it is, so the relatively protected southern and eastern aspects of inselbergs of northern Eyre Peninsula display the best flared slopes. Subsequent volume loss and compaction of the weathered material may result in an initial lowering of the plain surface in the scarp foot zone (Pl. 4.13), exposure of part of the weathering front (the upper facet of the steepened slope) and an increase in relief amplitude which in turn means an increase of runoff and further concentration of moisture for weathering and flared slope development at the inselberg margin. Such minor lowering of the plain surface only reinforces the development of steepened margins, but with stream incision and erosion that removes the weathered zone revealing the weathering front (Fig. 4.3) that period of flared slope development ceases.

If this conclusion is valid it is apparent that flared slopes imply a period of relative landscape stability when the rate of weathering far outpaced the lowering of the plain surface. The active tectonism of such areas as the Southwest of the United States and the consequent instability of the land surface may account for the comparative scarcity of flared forms there, despite the suitability of

Plate 4.13.

The scarp foot depressions or moats seen here at Wattle Grove Rock about one mile north of Mount Wudinna may be explained either in terms of preferential stream erosion or of volume decrease and surface subsidence consequent on intense weathering.

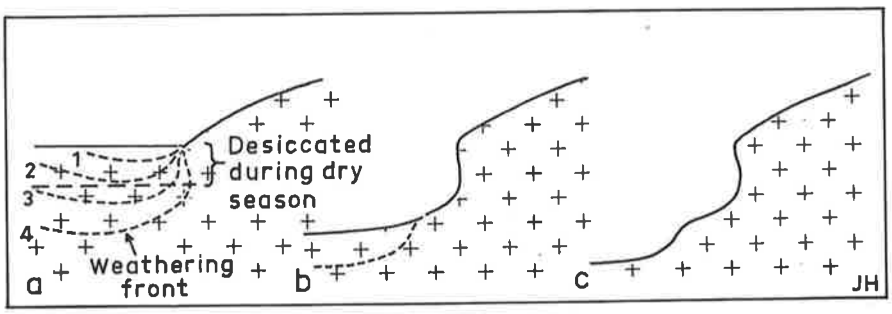


Figure 4.3.

The two stage development of flared slopes. (After Twidale, 1971, p. 93).

lithological and climatic conditions (Twidale, 1972a).

Where flared slopes occur in horizontal or near-horizontal zones above the present plain surface, they can surely be taken as representing a former zone of intense scarp-foot weathering associated with a higher hill-plain junction. The approximate level of this junction is given by the shoulder between the concave flare below and the convex slope above. Those parts of the residuals above the shoulder were domes when the flares were subsurface weathering fronts, when they were, in other words, in process of formation.

In some places the steep marginal cliffs of the inselbergs are interrupted not by flared slopes but by angular indentations (Pl. 4.14) which however appear to have the same significance as flares insofar as they are believed to represent former zones of particularly intense scarp-foot weathering. Indeed in some places flared slopes merge laterally with such angular indentations. At these sites the weathering process has not extended so far as to undermine the exposed slope above the weathering zone. However the junction between basal flat and steep backing slope has in some areas been sharpened by pool weathering (Twidale, 1968a), that is by water which has accumulated in shallow depressions which have extended laterally and thus eaten out and made angular the junction between platform and backing bluff. The development of such indentations rather than flared slopes is most likely due either to lack of moisture on limited catchments, or to the dispersal of run-off on planimetrically convex slopes and to a consequent lack of moisture in

Plate 4.14a.

This assemblage of angular indentation (I) tafoni (T) and flared slopes (F) on Mount Wudinna is located approximately 100 - 115 feet above the hill base and 65 feet below the crest.

Plate 4.14b.

Small angular indentation on a low granite swell some fifteen miles north of Minnipa. The rounded hills of the Gawler Ranges are seen in the background.

the subsurface scarp foot zone (see Twidale, 1962).

It is certainly true that flared slopes are especially well developed in some broad embayments where water is collected from the slopes above (see for instance Twidale, 1968a), though it must also be mentioned that they are well formed on the points of spurs and promontories because of the intersection of weathering fronts which have attacked the bedrock from opposed sides. Moreover the development of flares has in places been facilitated by the accumulation of moisture and debris in joint zones.

(b) Tafoni:

Tafoni or shallow caverns are associated with flared slopes in several places. Thus at Podinna Rock and Murphys Haystacks flares merge laterally with tafoni (Pl. 4.15); and similar associations have been described from Ayers Rock (Twidale, 1971, p. 95).

Most workers have argued that tafoni are formed wholly under the influence of subaerial processes (see for instance Blackwelder, 1929; Schattner, 1961; Dragovich, 1969) and it is undoubtedly true that some small shallow caverns form just above the soil level where air and moisture are in contact with the rock (Twidale, 1964b). Moreover tafoni are unquestionably enlarged subaerially. But the association of flares and tafoni surely suggests that some of the latter at least may be initiated in the subsurface, by the same weathering processes that are responsible for the formation of flares. The two forms merge one into

Plate 4.15a.

Flared slopes and tafoni in association at the margin of part of Podinna Rock some fourteen miles north of Minnipa.

Plate 4.15b.

Flared slopes and tafoni in association at Murphys Haystacks seventeen miles northwest of Port Kenny.

Plate 4.15c.

Flared slopes and tafoni in association at Murphys Haystacks seventeen miles northwest of Port Kenny.

the other too frequently for the association to be coincidental and all gradations between the two have been observed on the Peninsula and elsewhere.

Once exposed the continued development of tafoni implies that their upper limits may marginally exceed the level of the former hill-plain junction, but this is a minor consideration. The principal significance of the forms in the present context is that where tafoni occur in distinct near-horizontal bands there seems good reason to suggest that they too represent former zones of intense scarp-foot weathering and that their upper limit corresponds, albeit approximately, to the old hill-plain junction.

(c) Platforms:

Flares, angular indentations and tafoni all occur on steep slopes. These frequently give way to gently inclined rock platforms extending away from the residual hill and away from what must have been the base of the weathering front in the old scarp foot zone (Pl. 2.11; Fig. 2.9). Presumably the platforms represent the gently sloping extensions of this front, which like the flares and other steep-slope features, has been exposed as a result of baselevel lowering. These platforms are therefore interpreted as near-horizontal etch surfaces, the gentle inclination of which reflects first the gentle gradient of the plain below which it formed, and second a period of considerable standstill during which weathering took place.

Evidence of this process derives from remnants of the regolith which survive on some of the platforms. For instance at Tcharkuldu Hill a considerable area of the soil mantle, no more than three feet thick and containing small corestones (see for example Linton, 1955; Twidale, 1971, pp. 20 - 23) survives on the inner margin of the platform (Pl. 4.16). The corestones are being exposed as the granite sand and soil is washed away and the presence of isolated small rounded boulders on the platform leaves no doubt that the regolith was once more extensive: that it formerly extended over the whole of the platform.

Platforms of limited extent occur around many of the inselbergs of northern Eyre Peninsula (Pildappa, Chilpuddie and Ucontitchie hills for example). But those around Corrobinnie Hill extend more than one half mile from the residual (Pl. 2.11), and there are platforms 160 - 1600 feet wide around the nearby Peella Rock. The reason for this extraordinarily extensive development is probably related to their location in the structurally determined Corrobinnie Depression (Bourne, Twidale and Smith, 1974) which is a topographic low and which in consequence receives run off from the surrounding areas. It is in other words a wet site with the result that subsurface weathering by soil moisture has 'eaten' rapidly into the granite inselberg located there. Such consumption and planation by moisture contained in the regolith is comparable, though on a larger scale, to the mantle-controlled weathering planation invoked in other contexts by Twidale (1962) and by Mabbutt (1966).

Platforms also occur above zones of steepened and flared

Plate 4.16.

Northern extremity of Tcharkuldu Hill showing the pitted basal platform and a bouldery bluff leading up to another planate surface some 15 - 20 feet higher.

Plate 4.17.

Stepped and flared western margin of Yarwondutta Rocks. The hollow block, 6 feet high, stands on the platform which is some 12 - 15 feet above the plain level.

slopes well above the present hill-plain junction on such residuals as Yarwondutta Rocks (Pl. 4.17), Poondana Rock (Pl. 4.18), Tcharkuldu Hill Cocata Hill and Carappee Hill (Pl. 4.19). They are essentially horizontal and though some are in part an expression of sheet jointing in many places they clearly cut across these structures: they are due to degradational processes, and cannot be construed as structural features.

Each of the forms discussed above can form in contexts other than that suggested here. Flared slopes for instance can evolve in joint-controlled clefts where soil, and hence moisture, have accumulated and in such locations bear no necessary relationship to local or regional baselevels of erosion and hence to major weathering zones. Tafoni may reflect mineralogical or other weaknesses in the rock. But where the forms discussed occur in linear, vertically restricted and horizontal or near-horizontal bands they possibly reflect former zones of intense weathering at or near old hill-plain junctions. This argument is considerably strengthened where two or more of the forms occur in association, as is found on several inselbergs, examples of which are described below.

Plate 4.18.

The western side of Poondana Rock showing a lower flare leading up to a broad bench (X) on which stand boulders with flares and tafoni and which, in turn, leads up by way of a flared cliff 10 - 12 feet high to the main pitted and grooved dome (Y).

Plate 4.19a.

Stepped profile of Carappee Hill seen from the west.

Plate 4.19b.

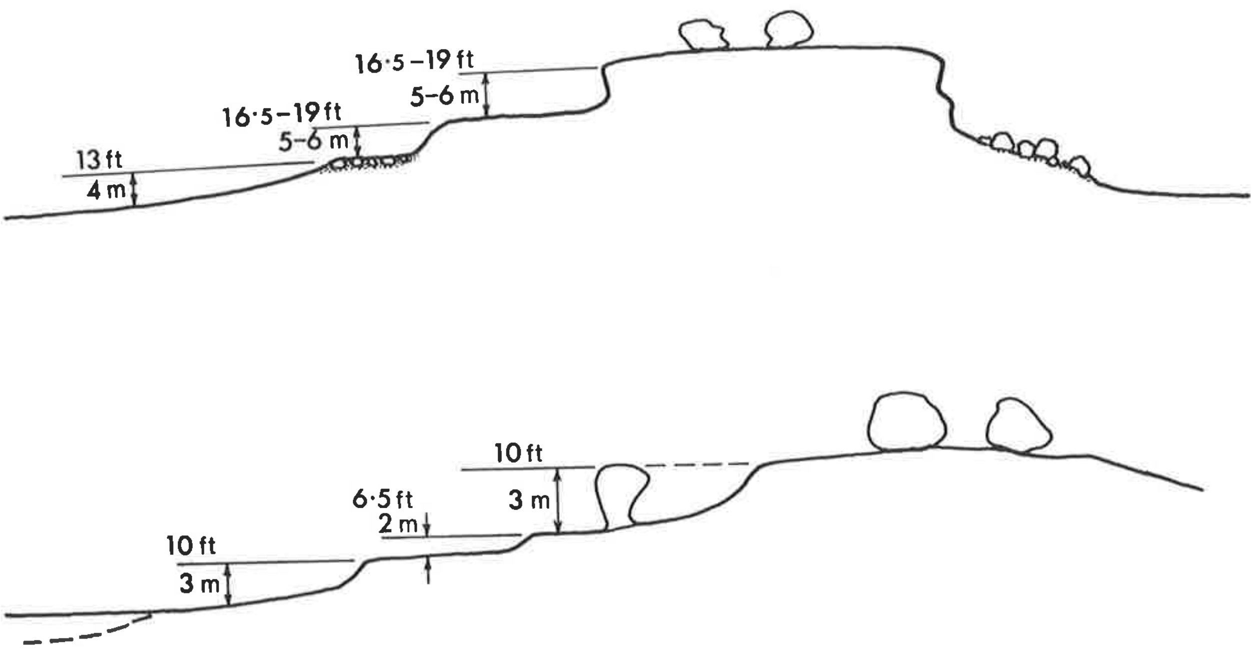
Detail of the domed peak of Carappee Hill with stepped spur radiating from it.

3. FIELD EXAMPLES.

The broad platforms around Corrobinnie Hill lead up to a complex bluff which is *in toto* some sixty feet high. For the most part this consists of flared slopes many of which are breached by tafoni. Above this bluff is a narrow platform, flat on the east and sloping on the west, which in turn leads by way of a flared and bouldery bluff to a flat platform above which protrudes a turret some twenty feet higher than the rest of the Hill (Pl. 2.11; Fig. 2.9).

Tcharkuldu Hill displays a gently sloping and pitted platform at its northern margin (Pl. 4.16) and rises by way of a low bouldery cliff, though with flares and tafoni developed in some sectors, to another bench 15 - 20 feet higher and which in turn gives way to a flared and cavernous bluff which leads up to a summit platform another twenty feet higher (Fig. 4.4a). Cocata Hill is also stepped with several minor levels distinguishable. A notable feature of this particular residual is that the boulders which stand on lower platforms are flared and reach only to the same elevation as the next highest step, suggesting that they developed their flared shape when the higher surface was in reality the local baselevel (Fig. 4.4b).

Flared boulders also occur in association with the lowest zone of flares around the base of Ucontitchie Hill, the crest of which stands some 115 feet above plain level. On this broad crest stand clusters of large boulders, some turret-shaped, and several displaying



Figures 4.4a and 4.4b.

Diagrammatic sections through (a) Tcharkuldu Hill and (b) Cocata Hill.

well-developed basal tafoni. Some few are modestly flared (Pl. 4.20). The eastern side of Ucontitchie is notable for its massively developed multiple flaring (Pl. 4.21; Fig. 4.4c) the upper two of which are of a height comparable to the steps described from other inselbergs and which are interpreted as representing distinct standstills in the lowering of the plain surface. The shoulder of the basal flare stands up to 15 feet above the narrow platform which is in places exposed around the base of the residual.

One of the clearest examples in which flared slopes, tafoni, indentations and platforms occur in association is found on Mount Wudinna. In broad view this residual is domed, but in detail there are flares around much of the base, indicating a lowering of the plain, in comparatively recent times, of the order 20 - 25 feet. Other flares occur at several sites on the inselberg, some for instance within joint clefts, but there is a distinct concentration of flares, minor tafoni, benches and angular indentations with associated low cliffs some 100 - 115 feet (the elevation varies from place to place around the slopes of the Mount) above the present base of the residual, that is about half way up the hill (Pl. 4.14). An angular break of slope with a low swell above and extensive tafoni development below the summit flat occurs 50 feet higher and only 15 feet below the highest point of the Mount (Pl. 4.22).

On Waulkinna Hill (see Fig. 2.7) which is composed of granite there are remnants of a prominent rock bench 850 - 880 feet above

Plate 4.20a.

Ucontitchie Hill from the east showing domed outline sheet structure and boulder-strewn upper surface.

Plate 4.20b.

Boulders on the crest of Ucontitchie Hill showing flared forms suggestive of prolonged weathering at this level.

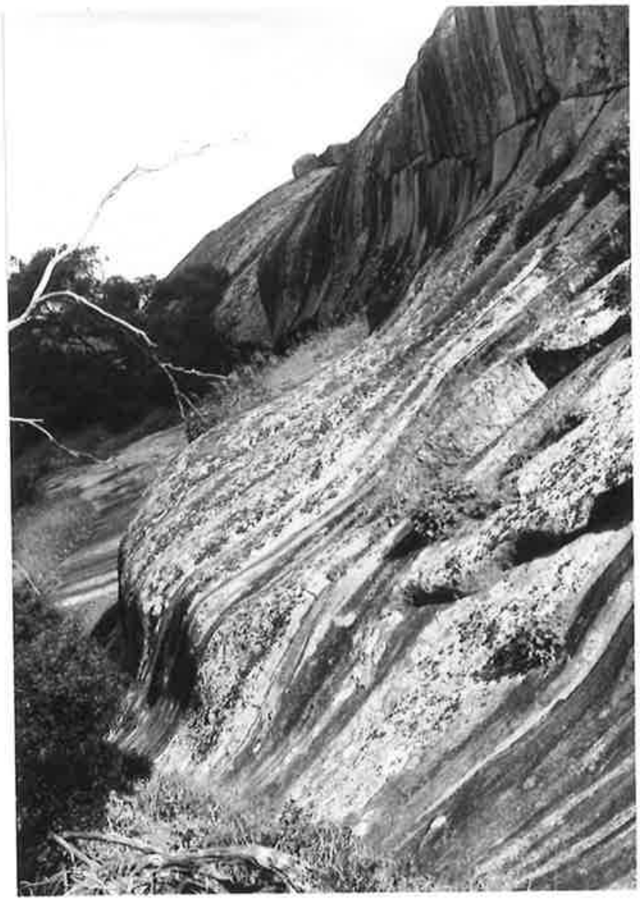


Plate 4.21.

Pronounced multiple flares on the eastern side of Ucontitchie Hill.

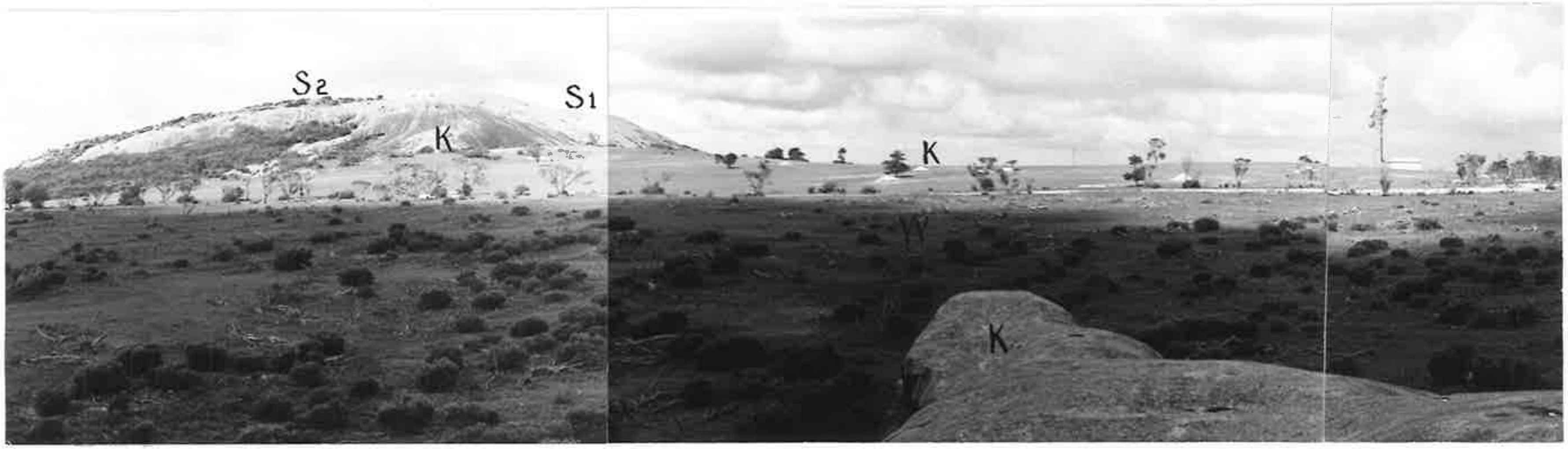


Plate 4.22

Mount Wudinna seen from the east from the top of the Dinosaur (seen in foreground). Two distinct steps are discernible on Mount Wudinna (S1, S2). In addition there is a scarp foot depression eroded below the level of the Koongawa Surface (K) and equivalent to the Wudinna Surface (W) seen in the foreground.

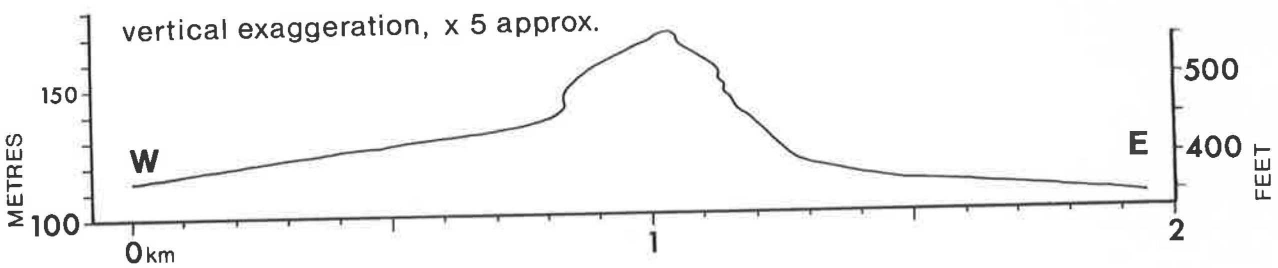


Figure 4.4c.

Section through Ucontitchie Hill.

sealevel and about 300 feet above the surrounding pediments.

Carappee Hill (Pls. 2.7 and 4.19; Fig. 2.6) is a complex upland of gneissic granite which in plan consists of a number of massive joint blocks. In profile several distinct steps can be identified. The prominent summit dome over 1600 feet (485 m) above sealevel gives way to a distinct and extensive, virtually horizontal, shoulder some 1600 feet long which, located at an elevation of between 1390 - 1400 feet, stands well above plain level. Below this at 1300 feet is another bench 1600 feet long and at still lower levels as many as four other shoulders, each with associated bouldery bluffs, flares and indentations, can be located. Those at 1190 - 1210 feet and 1050 feet are especially well developed. Also frequently present is a bench 35 - 50 feet above plain level with a basal 10 - 15 feet flared slope with bench above.

The existence of similar zones of flared slopes, benches and boulders with tafoni was noted on the inselbergs in the area between Streaky Bay and Port Kenny. Two levels occur on Mount Hall at approximately 40 feet and again some 40 feet above that, but the lower zone only is represented elsewhere at Colley Hill, Malijay Hill, Calca Bluff and Murphys Haystacks.

4. CORRELATION AND DATING.

(a) General Remarks:

In this section the relative ages of the inselbergs and parts of inselbergs are considered. There follows a brief account of the palaeosurfaces recognised on Eyre Peninsula and a discussion of their possible correlations with inselberg morphology.

(b) Relative Dating:

Many swells and all the whalebacks and bornhardts of northern Eyre Peninsula display flared lower slopes. The height as well as the precise morphology and frequency of these forms varies, not only from place to place around the perimeter of the residuals, but from outcrop to outcrop. But it would not be unreasonable to suggest that the crucial upper shoulder delimiting the flare from the more gentle convexity of the whaleback proper stands on average some 12 feet, though in places as much as 25 feet, above the present plain level. Thus a comparatively recent lowering of the plain surface of this order is indicated. It is responsible for the exposure of the flares, associated tafoni and the rock platforms.

Many, though not all, of the higher inselbergs display at least one high level step or zone of former weathering, but they do not all exhibit the same number. The flanks of Tcharkuldu and Cocata hills display two steps as well as basal flares (Figs. 4.4a and b). On Mount Wudinna there is above the present piedmont zone one pronounced band of features indicative of a former hill-plain junction, some 100 - 115 feet (variable) above the present plains, and, 50 feet higher, a summit flat. On the summit of Ucontitchie Hill, 115 feet above the plains, there is evidence of a former prolonged phase of weathering in the shape of flared boulders. Waulkinna Hill has bench remnants 300 feet above the plains and on Carappee Hill the high bench located about 420 feet above the surrounding plains is strongly developed.

Although it is possible to assign relative ages to the steps on any one inselberg or in any given district on the basis that the higher benches are older than those at lower levels on the same residual, there is no direct evidence as to the geological or to the absolute ages of the features. However reasonable inferences can be derived from the correlation of benches and associated forms with palaeosurface remnants in the same areas.

(c) Correlations:

The variation in elevation displayed by present zones of flares and tafoni and associated platforms suggests that it would be imprudent to use height as a basis of correlation. The possibility of local erosion and exposure of flares precludes the indiscriminate use of a countback system of correlating either from one area to another or from granite residuals to palaeosurface sequences. However a few inselbergs occur in close proximity to palaeosurface remnants and here it is possible to make reasonable correlations between the granite forms and the old surfaces of low relief, and thus suggest a chronology for the exposure of the inselbergs.

The granite-gneiss inselberg of Carappee Hill is of particular interest for it is located close to the Cleve Hills and is set amidst outliers of that upland. It offers a better opportunity for closer correlation between former hill-plain junctions preserved on the inselberg and remnants of palaeosurfaces preserved in adjacent uplands than does any other bornhardt on the Peninsula. The inselberg stands over 1600 feet above sealevel and displays a wide rock bench on several of the spurs which radiate from the central bornhardt (Fig. 2.6). The benches at elevations of 1390 - 1400 feet and 1300 feet extend about 1600 feet along the spur crest and, like the platforms at the base of Corrobinnie Hill and Peella Rock, indubitably reflect prolonged periods of mantle-controlled planation. Their great length is consistent with development in relation either to the earlier Mesozoic lateritic weathering evidenced in the Blue Range and Port Lincoln areas to the south or with the later Mesozoic planation which resulted in the formation of the surface of low relief preserved in the Arcoona Plateau and in the Flinders Ranges to the northeast of Eyre Peninsula.

Even allowing that the benches are devoid of any regolith and are therefore etch surfaces their elevation is consistent with a Mesozoic age, for they are located at heights similar to those attained by remnants of the Mesozoic palaeosurface in the nearby Cleve Hills (Fig. 4.5a). Both in the south, near Cleve, and in the latitude of Carappee Hill, the etch plain related to the Mesozoic surface eroded across folded sediments stands at about 1300 feet above sealevel which is comparable to the 1300 - 1400 feet range of the main shoulders on Carappee.

In northwestern Eyre Peninsula, in the Wudinna and Minnipa areas the field relationships of flared slopes and associated features on the one hand, and remnants of the late Pliocene-early Pleistocene Koongawa Surface on the other, permit the dating of residuals or parts of residuals in that area. Two low domes or swells are crucial in this respect; Chilpuddie Hill, north of Minnipa and Waddikee Rocks, east of Wudinna. The ferruginous Koongawa Surface abuts against the northern and northwestern flanks of Chilpuddie (Fig. 4.5b), and here the granite gives rise to pavements and low swells with little or no exposure of flares. But Chilpuddie is located where the Wudinna Surface is encroaching on the Koongawa and on its southeastern side the weathered granite has been removed exposing flared slopes and leaving the associated low dome some 10 - 15 feet above the present hill-plain junction. A similar situation obtains at Waddikee Rocks which is a granitic gneiss residual. Here remnants of the Koongawa Surface lap against the northern slopes of the low dome but to the south where the Wudinna Surface is developing there are modest flares. Thus it can be suggested that the whalebacks and low domes or swells of the Wudinna and Minnipa districts were mere platforms during the late Pliocene and early Pleistocene as suggested

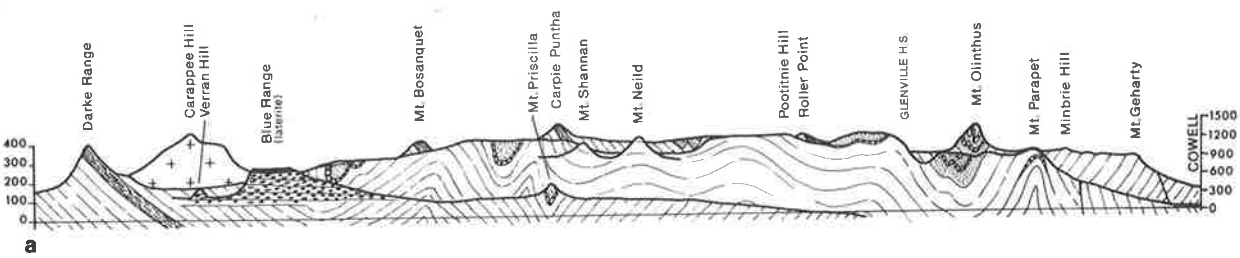


Figure 4.5a.

Projected profile showing relationship of Carappee Hill, the Cleve Hills and Blue Range.

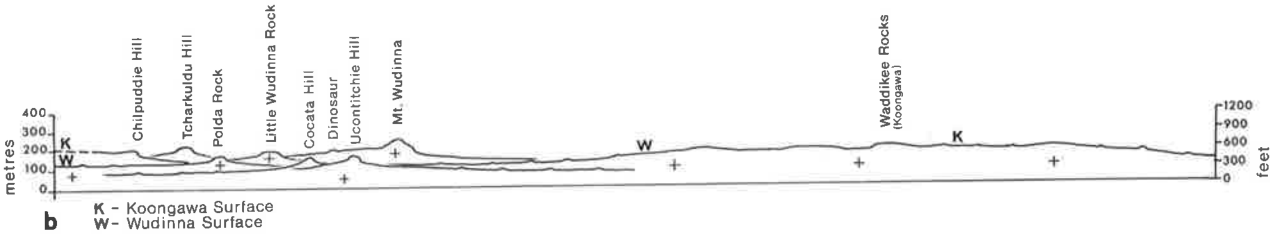


Figure 4.5b.

Projected profile of part of northern Eyre Peninsula showing granite residuals in relation to major surfaces eroded also in granitic rocks.

earlier (Twidale, 1962), and that it is the development of the Wudinna Surface which has caused their relative elevation and the exposure of the marginal flared slopes. This group includes Pildappa Hill, Podinna, Chilpuddie and Spencers rocks near Minnipa, and the Dinosaur, Wattle Grove and Pygery rocks near Minnipa. Also of this age are the lower steepened slopes and flares of such higher inselbergs as Mount Wudinna, Ucontitchie Hill and Tcharkuldu Hill (Pl. 4.22; Fig. 4.7).

Corrobinnie Hill and Peella Rock appear to be analogous in their general development insofar as their present morphology evolved during the later Cainozoic. The broad basal platform of Corrobinnie Hill (Fig. 2.9) is lapped by sands which have been moulded into the parabolic dunes of the Kwaterski Dune Field and in which has accumulated calcrete of late Pleistocene age (Bourne, Twidale and Smith, 1974). This suggests that the platform and associated flares and bluffs predate the late Pleistocene. And although the residuals are located in a topographic depression which has likely been moist throughout the later Tertiary the great breadth of the platforms associated with them argues a long period of standstill, consistent with the deep weathering associated with the Koongawa Surface. Thus the summit platform of Corrobinnie must be older and may be related either to the early-mid Tertiary Alamein Surface and associated silcrete development, or to a Mesozoic weathering profile, in which case the early Tertiary weathering may be represented by the narrow intermediate step on the flanks of the residual.

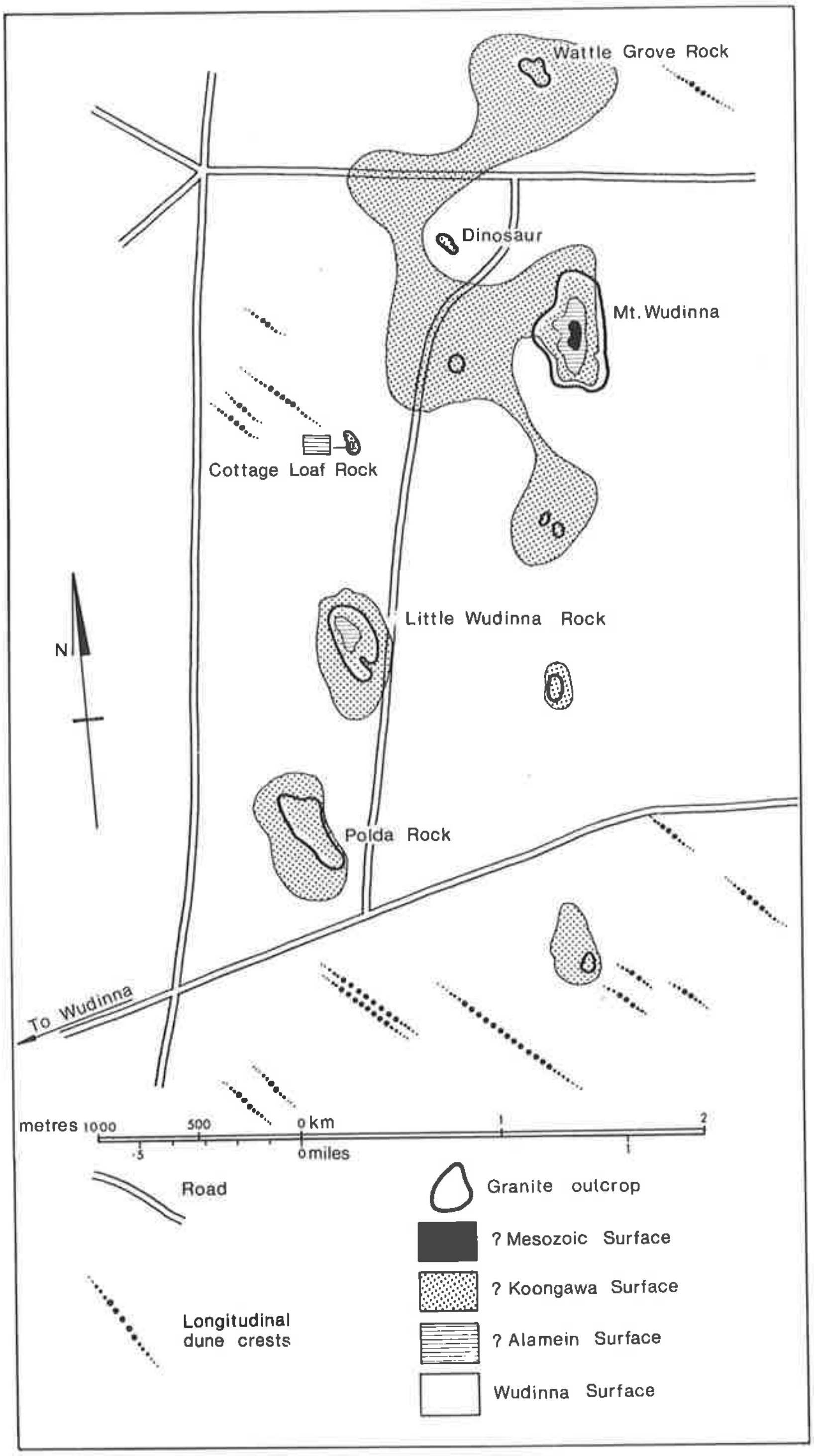


Figure 4.6a.

Map of Mount Wudinna area showing the suggested ages of plain surfaces and granite residuals and of various elevational zones of the higher inselbergs.

Figure 4.6b.

Section through Mount Wudinna and the nearby Dinosaur showing suggested evolution in relation to phases of surface lowering.

Apart from the relicts on Carappee Hill and the widespread younger low level features, however, the dating of former hill-plain junctions as represented by associations of flares, tafoni and platforms must be tentative. Thus the 100 - 115 feet level on Mount Wudinna can be construed as related to the early Tertiary Alamein Surface, with the summit surface of Mesozoic age. And the suggested 100 feet summit level of Ucontitchie can be interpreted as of either Tertiary or Mesozoic age, depending on whether the multiple flares of the eastern margin are regarded as reflecting local or regional erosion.

One of the possible reasons for these elevational contrasts is the varied susceptibility of rocks to planation consequent upon contrasted structural settings. For example, apart from its being a large mass of granite-gneiss, Carappee Hill is buttressed by virtue of its being surrounded by outcrops of resistant quartzite. The residuals of central and northwestern Eyre Peninsula, on the other hand, are surrounded by well-jointed granite which affords no such protection.

F. CONCLUDING STATEMENT.

Thus in summary it can be stated that the high bench remnants on Carappee Hill are almost certainly of great antiquity. They can be firmly correlated with palaeosurfaces in the nearby Cleve Hills and are of Mesozoic age. The former hill-plain junctions preserved on such lower residuals as Mount Wudinna and Ucontitchie Hill may be of similar antiquity but there is no clear evidence on this point. The numerous low domes, whalebacks and other granite residuals of central and northwestern Eyre Peninsula are of late Pliocene age. The massive compartments to which they are related were completely disintegrated during the early-mid Tertiary phase of intense weathering which is responsible also for the development of silcrete. Only the most massive compartments, such as those on which Mount Wudinna and Ucontitchie Hill are preserved survived this alteration; the rest of the granite mass was converted to grus, and the upper surfaces of such present low residuals as the Dinosaur, Pildappa Hill, etc. may be regarded as old weathering fronts, dating from that time (Fig. 4.6). They were exposed as etch surfaces, as pavements, low domes and whalebacks during late Tertiary times and were part of the Koongawa Surface. Scarp foot weathering caused the incipient development of the flares which were exposed during the extension of the Pleistocene Wudinna Surface.

It is evident that if the hypothesis outlined above has any validity, many of the granite residuals of northern Eyre Peninsula are of great antiquity: it is argued here that the upper zones of some of the higher bornhardts are of early Cainozoic or even Mesozoic age. But it is not implied that all residuals, once formed, are permanent features of the landscape and necessarily survive *ad infinitum*. It has been suggested that the basic reason for the formation and survival of the inselberg masses is that they are compartments of compression. This argues that there are lateral variations in stress conditions in the rock; and general theory suggests that there are similar variations in the vertical distribution of stresses within the rock. Hence the resistant compartments need not be continuous vertical columns (Fig. 4.7), but rather compartments systematically scattered through the rock mass. If this were so, then some erstwhile inselbergs may be expected to suffer undermining and erosion during the lowering of the land surface, eventually to be destroyed. Others would emerge from depth as the land surface is lowered (Fig. 4.7). Thus any discussion as to whether the pavements and swells of northern Eyre Peninsula are worn-down bornhardts or the recently exposed tops of inselbergs is fruitless for they could be of either origin, and without deep drilling there is no evidence on the point.

Whether or not the geological ages assigned to the various granitic and other residuals of northern Eyre Peninsula are correct, there can surely be little doubt of the relative dating of various inselbergs and parts of inselbergs. The zones of flares, tafoni, indentations and platforms surely represent former hill-plain junctions, and the lower they are on a residual or in a landscape, the younger they are. And since some occur high in the present relief, at similar elevations to nearby remnants of very ancient, probably Mesozoic, land surfaces, those remnants which stand above the old hill-plain zones must be inselbergs of great geological antiquity.

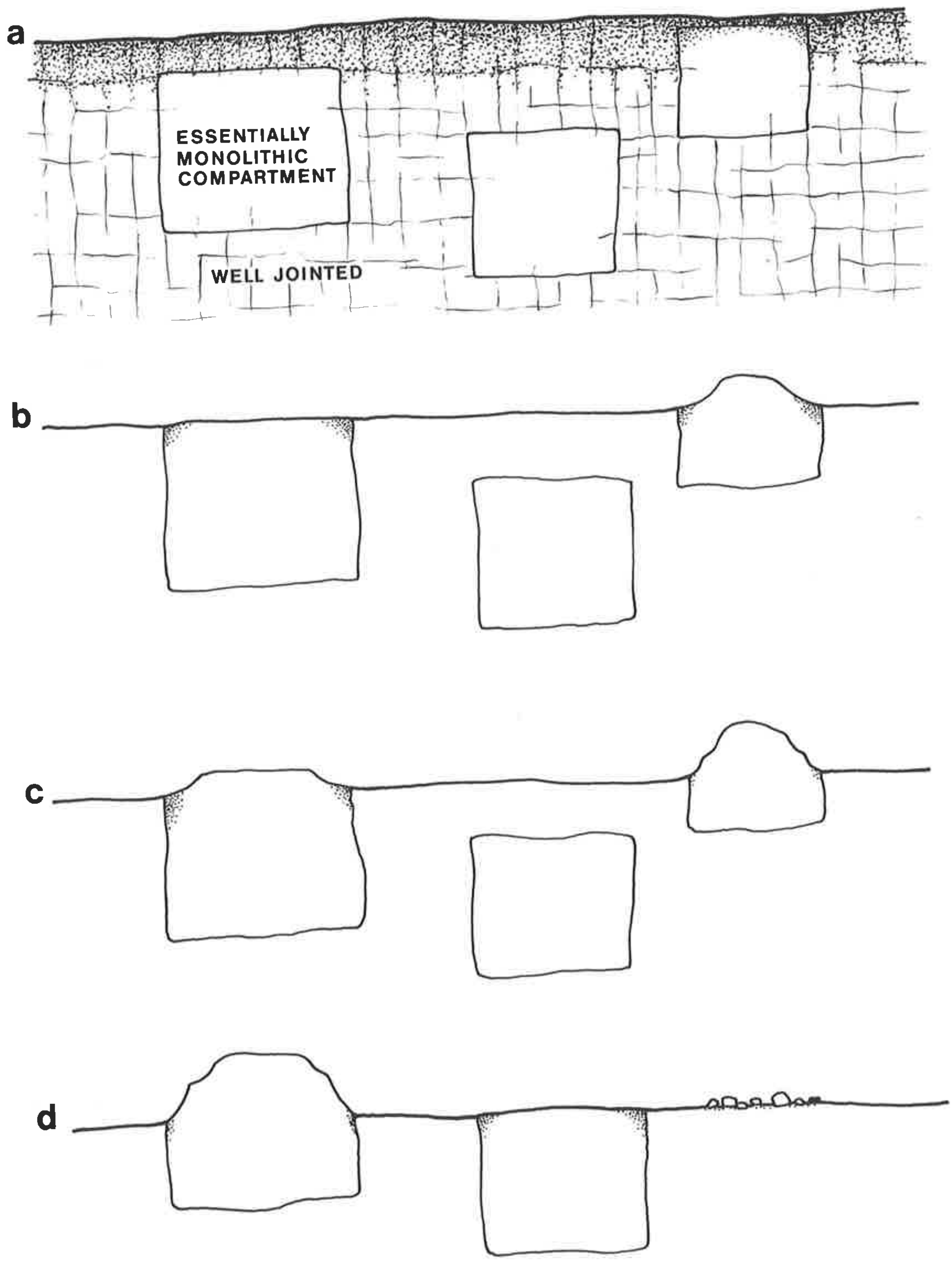


Figure 4.7.

The phased emergence of inselbergs.

CHAPTER FIVE: CONCLUSION.

> Little of the earth's topography is older than Tertiary, and most of it is no older than Pleistocene.
> (Thornbury, 1954, p. 26).

Though the extensive rolling plains which occupy such a large part of northern Eyre Peninsula, as well as the many valleys of the eastern upland regions, are of relatively recent origin, there are nevertheless many facets of the landscape which are of great antiquity. Together they comprise a significant proportion of the landscape in the eastern half of northern Eyre Peninsula, and though of minor areal extent those ancient relicts of the western districts are of great interest. Inevitably the question of their survival arises, for in terms of the constant if slow change taught by geomorphological orthodoxy the persistence of landscape elements over periods conceivably as long as 200 m.y. requires explanation. It is to be emphasised that neither the Mesozoic and Tertiary palaeosurfaces discussed in Chapter Three nor the inselbergs, the origin of which is argued in Chapter Four, have been preserved by burial with the single exception of the inselbergs designated the Malijay Surface.

The survival of these features is the subject of an investigation now in progress, and it is inappropriate and premature to consider the problem at length here. Suffice it to say that it is not possible to explain their survival wholly in terms of lithological protection. The resistance of the duricrusts of the Lincoln, Alamein, Koongawa and Wudinna surfaces, and the inherent toughness of the Simmens Quartzite have contributed in no small measure to the persistence of remnants of the surfaces on which they formed, but scarcely accounts for their survival over such long periods of time. No matter how tough a rock may be, all are to some degree vulnerable to weathering, however slow, and there has been ample time during which weathering processes have been at work.

Appeal may be made to retardation of erosion by climatic conditions, but the significance of climatic conditions is difficult to evaluate. Although Eyre Peninsula was arid at times during the Pleistocene, from the earlier part of the Tertiary it seems likely that humid tropical or subtropical conditions prevailed (Dorman, 1966; Brown, Campbell and Crook, 1968, pp. 306 - 307; Ludbrook, 1969, p. 173). But which climate induces the most rapid erosion? Arid lowlands are subject to only slow erosion, whereas some evidence points to humid tropical regions, and particularly those with a dry season, being regions of comparatively rapid denudation (Corbel, 1959). And commonsense apparently supports this view, for the prevalent high temperatures and heavy rainfalls of such areas would seem to be conducive to rapid weathering and erosion. However other factors are introduced, and it is possible to argue for example that the lack of flood conditions in rivers, the vegetational cover and deep regolith in equilibrium with its environment are stabilising factors mitigating against rapid erosion.

Autocatalytic or reinforcement effects also contribute to the persistence of the forms (see Twidale, 1966; Twidale, Bourne and Smith, 1975b). The gist of this concept, as it applies in geomorphology is that once developed a landform contributes to its own persistence or even augmentation. Thus it may be argued that because they bear resistant caprocks the erosion surface remnants that have survived would tend to become topographic highs. They would tend to shed water to the surrounding areas (initially less resistant because of the non-development of the duricrust, or the formation of a less massive duricrust or perhaps for reasons of drainage or lithology), which would therefore be weathered and eroded at even greater rates. Similarly the structurally determined compartments of more resistant granite that form the present residuals need only have been slightly more resistant than the adjacent compartments initially in order to develop a higher relief. Once this happened water would again be shed to the adjacent lower ground which would therefore be weathered much more rapidly than the intrinsically resistant compartments. The significance of this contrast between granite residuals subject to moisture attack and that which remains essentially dry was fully appreciated by Bain (1923) and used in explanation of stepped topography in the Sierra Nevada of California by Wahrhaftig (1965).

A further and as yet qualitatively untested suggestion which may go some way to explain the durability of some parts of the land surface compared to others is due to Crickmay (1968). He argues with considerable conviction that the concept of universal denudation propounded by W. M. Davis and many others is incorrect, and that erosion is unequal on the earth's surface. Crickmay develops what he calls his Law of Unequal Activity and cites many field examples in support of his contention. In a sense this is a special case of the autocatalytic effect outlined above for what is implied is that erosion along and near stream lines is intense, but that the interfluves remain but little affected by degradational forces.

Finally it may be pointed out that the evolution of landforms on northern Eyre Peninsula, and as described in this thesis, is contrary in one important respect from that which might be anticipated from the application of conventional theory whether it be the orthodoxy of W. M. Davis or of L. C. King. For what is clearly implied in all that has gone before is that northern Eyre Peninsula has not been repeatedly baselevelled, nor has there been a progressive decrease in relief amplitude in time. On the contrary it has been urged that relief amplitude has actually increased with the passing of time as the hill crests and high plains protected by duricrusts and buttressed by resistant strata remain but little affected by weathering and erosion, while the valley floors are repeatedly weathered and eroded deeper (cf. Twidale, 1966 with respect to the Flinders Ranges). Similarly several of the larger granite bornhardts far from being repeatedly baselevelled appear to have grown in amplitude through the Mesozoic and Cainozoic.

Thus this seemingly dull and uninteresting area of northern Eyre Peninsula has on investigation revealed many features of antiquity and interest, and stimulated the development of concepts contrary to those embodied in geomorphological convention.

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