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Tillites and Related Glacial Topography of South Australia

By **B. Campana***) and **R. B. Wilson****)

With 18 figures and 4 plates (I–IV)

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Résumé

Pendant les années 1951–52 les auteurs de cette publication ont levé en détail des portions de l'Australie du Sud occupées par des dépôts glaciaires d'âge pré-cambrien et permien. Ils exposent ici les résultats nouveaux d'intérêt général, en particulier l'étude du relief glaciaire fossile, et résument l'état actuel des connaissances relatives aux anciennes glaciations sud-australiennes.

Les glaciations pré-cambriennes sont représentées par des séries très complexes, essentiellement faites d'une alternance bien des fois répétée de tillites, de quartzites et de schistes argileux et qui s'étendent sur quelque 75000 km² (fig. 1–7, pl. I). Ces séries sont interstratifiées sans discordances dans le Système d'Adélaïde, d'âge pré-cambrien supérieur, et ont été déposées en continuité de sédimentation dans des grandes nappes d'eau périglaciaires. Le matériel constitutif des tillites a été transporté par des glaces flottantes, les récurrences desquelles se seraient ordinairement succédées sans importantes modifications du climat général. L'âge de ces tillites est determiné par leur relations stratigraphiques et par des mesures de radio-activité.

La première glaciation est représentée par des sédiments pouvant atteindre 1500 m d'épaisseur, et qui sont faits de tillites plus ou moins grossières en rapide alternance avec des quartzites, des schistes argileux et des lits dolomitiques.

Deux majeures périodes glaciaires pré-cambriennes ont été reconnues.

La période interglaciaire est représentée par des calcschistes ou des schistes argileux bien lités, évoquant souvent des formations à varves et pouvant avoir 6000 m d'épaisseur.

La deuxième glaciation pré-cambrienne est enregistrée par des tillites grossières et des schistes tillitiques, alternant avec des schistes argileux et des quartzites, d'une épaisseur observée de 300 m au maximum.

L'épaisseur totale des séries glaciaires et interglaciaires est de l'ordre de 8000 m et fait supposer des glaciations d'une durée tout à fait exceptionnelle, se répétant dans des conditions paléogéographiques analogues à celles des mers polaires actuelles.

La glaciation permienne sud-australienne a été étudiée dans la Fleurieu Peninsula, au Sud d'Adélaïde, où elle y est marquée par des moraines, des couches à varves et par un relief glaciaire fossile admirablement conservé (fig. 2, 8–14, 16, pl. II–IV). Les dépôts glaciaires sont comparables aux moraines de fond du piedmont alpin: argiles et sables peu ou pas consolidées, emballant des galets striés et des blocs erratiques volumineux. Ces dépôts, d'une épaisseur maximale d'une centaine de mètres, reposent en position sub-horizontale et en discordance angulaire sur des roches cambriennes ou pré-cambriennes plissées. Ils sont parfois couverts par du matériel glaciaire remanié, remplissant d'anciens bassins de surcreusement. La direction d'écoulement des glaciers permiens est donnée par les stries du plancher rocheux et par la distribution des blocs erratiques.

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L'ancienne topographie glaciaire a été étudiée sur la base d'un levé photogrammetrique à grande échelle, d'un réseau altimétrique serré et de plusieurs données de forages. Ce relief comporte des grandes vallées glaciaires exhumées, des bassins de surcreusement étendus et profonds, des niches, des verrous glaciaires et des buttes moutonnées. Les auteurs infèrent l'existence, aux temps permiens, d'une glaciation de montagne comparable aux glaciations quaternaires des Alpes.

L'évolution géo-morphologique régionale après la retraite des glaciers permiens est traitée, en relation avec la conservation des témoignages glaciaires. Les chaînes permiennes ont été arasées au cours des temps mésozoïques, mais des restes des moraines et du modelé glaciaire ont échappé à la destruction grâce à leur position au dessous du profil d'équilibre. Le rôle du surcreusement glaciaire est mis en évidence par plusieurs exemples de bassins surcreusés pouvant atteindre 1300 m de profondeur et dont certains contiennent d'importants lits de charbon.

La région occupée par les moraines permiennes est particulièrement favorable à l'étude des mouvements tectoniques d'âge tertiaire affectant l'Australie du Sud. Les auteurs montrent que les mouvements positifs debutèrent au Tertiaire inférieur, et non au Tertiaire supérieur comme il a été admis jusqu'à present.

Introduction and Previous Investigations

On behalf of the South Australian Department of Mines, the writers have carried out during 1952–53 the detailed geological mapping of the Fleurieu Peninsula, south of Adelaide, and of a large portion of the Olary region, some 250 miles northeast of the State capital.

The maps and accompanying explanatory texts will be published by the South Australian Geological Survey, as a part of the State Geological Atlas. Permission has however been granted to summarize in this article certain geological features of general interest, and particularly the most striking aspects of the South Australian Pre-Cambrian and Permian glaciations, both of which are admirably recorded in the foregoing areas by glacial deposits and by a fossil ice-carved landscape.

Specific references to previous works will be found in the main text, but particular mention must be made to the researches of the late Professor W. Howchin and of his successor to the Chair of Geology at the University of Adelaide, Professor D. Mawson. W. Howchin first recognized the great antiquity and the importance of the South Australian glaciations, and described them in numerous publications.

D. Mawson closely investigated the Pre-Cambrian glacial beds in the Flinders Ranges, recognizing their extension and stratigraphic relationship, and making invaluable comparisons with the present glaciations of Antarctica, of which he has intimate knowledge.

In the past ten years the Pre-Cambrian tillites have been studied throughout the State by geologists of the South Australian Geological Survey (Campana, Dickinson, King, Parkin, Pitman, Reyner, Sommers, Sprigg, Wilson). The same formations have been recently described in the Broken Hill area of New South Wales by H. F. King, B. P. Thomson, R. B. Leslie & A. J. R. White.

I.-GENERAL STRATIGRAPHY AND DISTRIBUTION OF THE SOUTH AUSTRALIAN TILLITES

The stratigraphic position and the general distribution of these old glacial deposits are now fairly well established. They belong to two groups of sediments which are clearly differentiated by their facies, age and lithology.

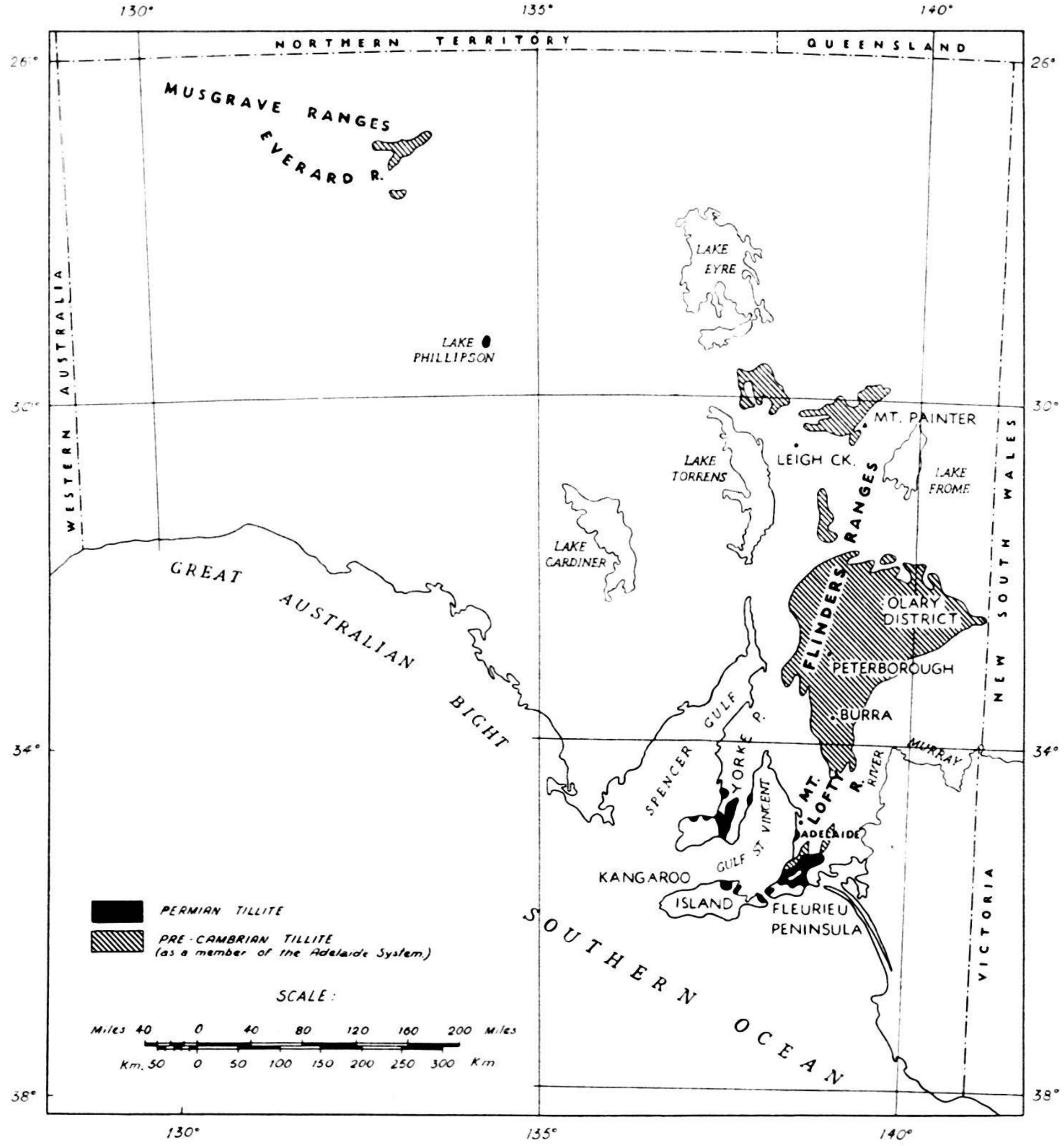


Fig. 1. Distribution of Permian and Pre-Cambrian tillites in South Australia.

(a) The oldest glacial beds, of Upper Pre-Cambrian age, are interstratified in a succession of argillaceous, sandy or calcareous-dolomitic sediments which form the Adelaide System, the thickness of which in places exceeds 40000 feet.

The Adelaide System is essentially unfossiliferous[1]). It rests with strong angular unconformity on a crystalline basement, consisting mainly of high folded and injected micaschists, migmatites, gneisses and granites, to which an Archaean age is assigned (see below), and is conformably overlain by fossiliferous beds of Lower Cambrian age, well dated by a fauna of *Archaeocyathinae*. Thus the age of the Ade-

[1]) Discoveries of alleged organic remains by T. W. E. DAVID (1936) and other scholars are now regarded as doubtful.

laide System, and consequently of the interstratified tillites, is inferred to be Late Pre-Cambrian (Proterozoic).

As shown in figure 1, the Pre-Cambrian glacial beds of South Australia are widely represented in the southern and central portions of the State. They persist from Cape Jervis in the south, to Mount Painter, in the North Flinders Ranges, over a distance of 400 miles; and they outcrop again in the Everard Range, some 1000 miles to the north-west (WILSON, 1951). These tillites form readily recognizable beds, which are in many cases reliable marker horizons for structural and stratigraphic interpretations.

(b) The younger glacial deposits, of Permian age, have on the contrary a limited extension. They outcrop at Hallett's Cove, near Adelaide, in the Fleurieu Peninsula, on Kangaroo Island and also on York Peninsula, covering a total area of some 1000 square miles (fig. 1). But they are of outstanding interest as they still retain all their original characters and are associated with fossil landscapes and rock basins of unmistakable glacial origin: it has been in fact one of the writers most intriguing work to retrace the history of such an ancient glaciation by means of the usual glaciological methods and approach.

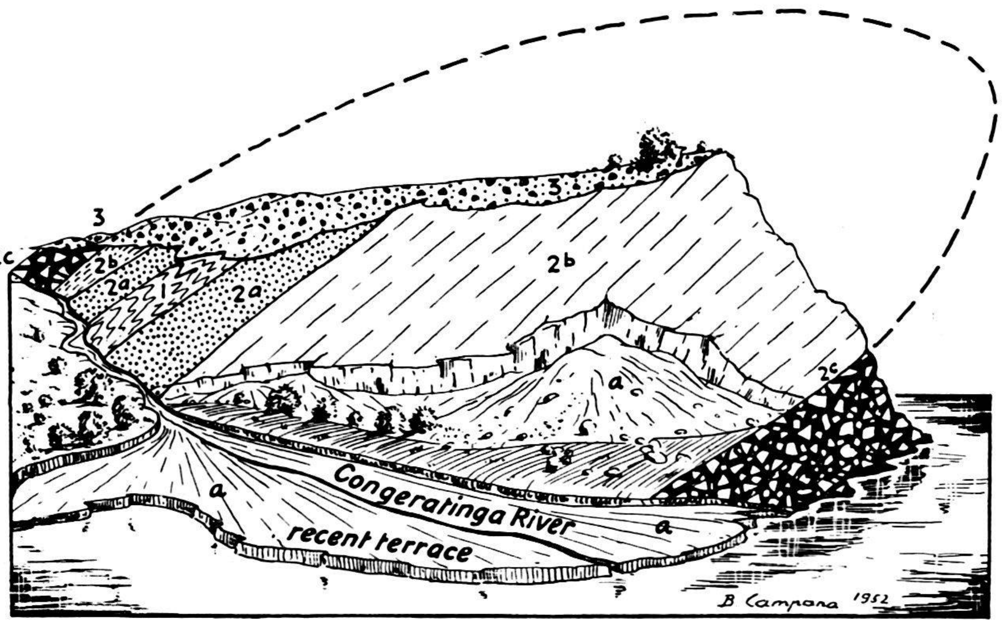


Fig. 2. Geological panorama at Congeratinga Mouth, Fleurieu Peninsula, South Australia, showing Permian moraine resting on Pre-Cambrian tillite (folded in overturned anticline).
1 Archaean micaschists; *2a* Basal conglomerate (of the Adelaide System); *2b* Slates and dolomitic beds; *2c* Pre-Cambrian tillite; *3* Permian tillite; *3a* alluvial.

The Permian tillites of South Australia rest unconformably and indiscriminately on the folded formations of Archaean, Pre-Cambrian or Cambrian age (fig. 2, pl. II–IV). They still retain a horizontal to sub-horizontal position, and are in places overlain by marine beds of Lower Tertiary to Pliocene age. The glacial strata have not yet been dated by means of fossil remains[2]), but a comparison with the fossili-

[2]) Plants remains discovered in these glacial beds on Kangaroo Island have not yet been specifically determined.

ferous tillites of New South Wales and Western Australia leave little doubt that they have also been deposited by the glaciers which covered a large portion of Australia during Permian times[3]).

II.–THE UPPER PRE-CAMBRIAN GLACIATIONS

South Australian geologists were among the first to recognize glacial deposits older than those associated with the *Glossopteris* and *Gangamopteris* flora of the Gondwana Land. H. P. WOODWARD (1884) suggested a possible glacial origin of a coarse conglomeratic bed observed by him in the Flinders Ranges.

A similar formation was discovered twelve years later by W. HOWCHIN (1901 b, 1906, 1908), who named it Sturt tillite, from the Sturt River, near Adelaide. This author demonstrated its glacial facies and its possible Pre-Cambrian or Cambrian age. Subsequent studies have shown that HOWCHIN's Sturt tillite represents in fact only one of the multiple glacial records of the Adelaide System for which a Pre-Cambrian age is now reasonably well established. It appears at present that the upper Pre-Cambrian glaciations of South Australia have been of the most complex type, their precise succession and correlations being still fairly obscure. It is, however, possible to outline a history which is in many respects quite extraordinary.

A. The Deposits: true tillites, glacio-fluvial, glacial-lacustrine and interglacial beds

The true tillite, i. e. a rock resulting from the lithification of a boulder clay, varies between two extreme lithological types. One is a slaty formation, containing small and unsorted clastic debris scattered throughout a sandy or clayish matrix which is dark to grey in colour, usually unstratified (fig. 3, 4), but showing in places a strong cleavage (fig. 7). The other is a lithified boulder clay, with erratics of any dimensions and of any degree of angularity (fig. 5, 6, 7).

Fig. 3. Upper Pre-Cambrian tillite. Olary region, South Australia.

[3]) R. W. SEGNIT (1940), however, assigned a Cretaceous age to these deposits, but this view is partly based on erroneous stratigraphic relationship (SEGNIT's "tillite" of Sellick's beach is in fact Pleistocene alluvial clay and gravel), and partly on irrelevant tectonic considerations (the fact for instance that the glacial deposits show little evidence of faulting or folding while the underlying beds are highly disturbed, is obviously meaningless for this area has been quite stable from the Early Paleozoic to the Early Tertiary times).

Both types pass gradually and more or less rapidly from one to the other. Thus, although variable in detail, these deposits are on the whole strikingly similar: the constituent material is always unsorted, unwashed and usually unstratified.

Fig. 4. Upper Pre-Cambrian tillite, showing a dolomitic matrix injected by quartz veins. Olary region, South Australia.

The erratics range from a few millimeters to ten feet or more across and represent all varieties of the underlying bedrock: granite, gneiss, micaschist, porphyries, amphibolite, quartz, quartzite, hornfels, dolomite, slate. Facetted pebbles are common, striated examples being less so. The matrix is usually argillaceous, sometimes dolomitic or sandy with angular quartz grains.

B. The sedimentary environment

That the constituent material of these formations has been transported by ice, is beyond doubt. Splendid examples of consolidated moraines, resting with angular unconformity on the Archaean basement, are observable in the Olary District of South Australia and northerly of Broken Hill, in New South Wales (CAMPANA 1954, LESLIE & WHITE, MAWSON 1912, KING & THOMSON 1953). Elsewhere, however, the Pre-Cambrian tillites of South Australia succeed the underlying beds in stratigraphic continuity and are overlain conformably by thick and well stratified fine grained sediments. Furthermore the tillites are frequently repeated at short intervals, in alternation with sandy or clayish layers, which are in many cases so perfectly and finely bedded as to suggest a varve-like lamination; and these alternating tillites, quartzites and slates may reach the extraordinary thickness of 25000 feet.

It must then be concluded that the Pre-Cambrian glacial sequences of South Australia have been generally deposited by floating ice in great periglacial water bodies, which conclusion is now accepted by all geologists closely acquainted with these formations.

The repetition of tillite beds at different stratigraphic levels is clearly due to frequent recurrences of floe ice. In the time intervals, terrigenous glacio-fluvial or glacio-lacustrine deposits were laid down, in most cases without marked changes in climatic and geographic conditions, as evidenced by the facies and thickness of the sediments. In these instances the intervals may be considered rather as episodes of a major glaciation than as true interglacial periods.

But in a large area of the central portion of South Australia a tremendous thickness of fine terrigenous or calcareous beds separates the main tillitic series, making obvious the existence of at least two major glaciations separated by a long interglacial period (pl. I).

C. The Upper and Lower glacial sequences

The existence of two distinct horizons, interstratified in the Adelaide System, was first described by R. LOCKHART JACK (1913), in a report on the Mount Grainger Goldfield, 170 miles northerly of Adelaide. Similar observations have been made since, by D. MAWSON in the Flinders Ranges (1948, 1949), by S. B. DICKINSON in the Burra area (1942), as well as by one of us in the Olary region (CAMPANA & SUMMERS, 1954).

Plate I shows the columnar sections observed from the Fleurieu Peninsula to the North Flinders Ranges, over a distance of 400 miles. The detailed correlation

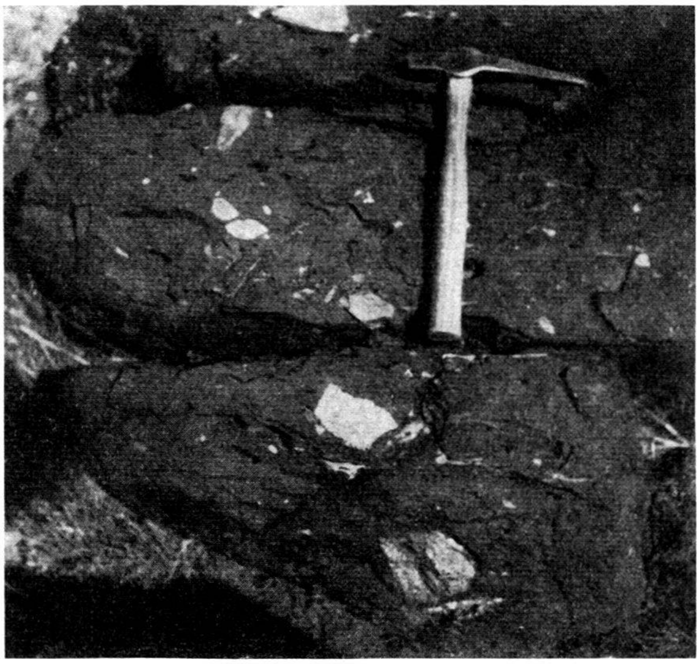


Fig. 5. Upper Pre-Cambrian tillite, showing jointing and angular quartz fragments in an argillaceous matrix.
Olary region, South Australia.

Fig. 6. Upper Pre-Cambrian tillite, showing angular blocks and pebbles in a sandy matrix. Olary region, South Australia.

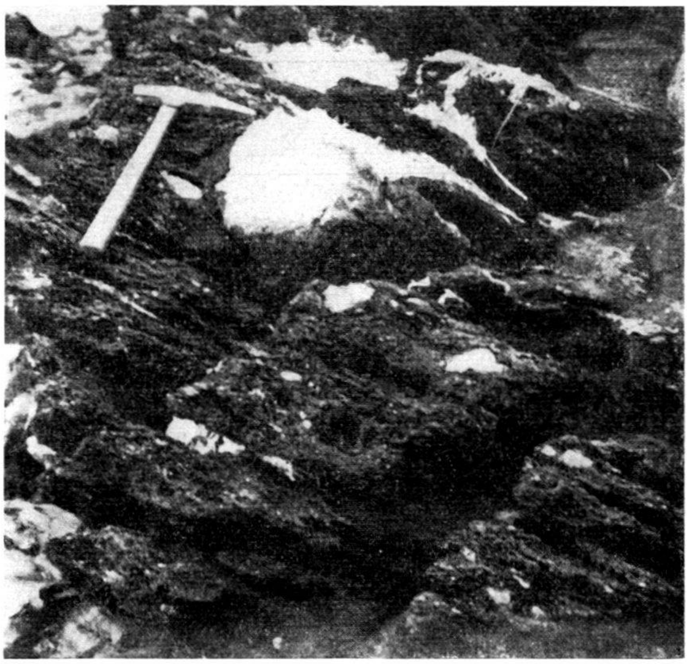


Fig. 7. Pre-Cambrian tillite, showing angular fragments in a slaty matrix with strong cleavage Detail of fig. 2.
Congeratinga Mouth, Fleurieu Peninsula, South Australia.

is still a matter of the future, but the existence of two major glacial sequences shown is now well established.

For graphic representation, the sections of pl. I have to be somewhat simplified. Their details will be found in the corresponding literature. As an example, we describe the unpublished section recently studied in the Olary region.

In this area the Adelaide System, which mainly consists of glacial and interglacial deposits, is folded into a broad syncline flanked by anticlinal cores of Archaean crystalline formations.

The succession is fairly undisturbed and from the base of the lower glacial series to the top of the upper one, is some 20000 feet in thickness. From the base to the top, the sequence is as follows:

Archaean: granite, migmatites, gneisses and injected schists, separated by a strong angular unconformity from the

Adelaide System (Pre-Cambrian):

1. Basal conglomerate and sandstone, containing well worn pebbles and heavy mineral bands. Thickness: 50 to 200 feet.

2. Slates and dolomites with sedimentary magnesite, ferruginous slates, spotted phyllites and cherts. Thickness up to 3000 feet.

3. Lower Glacial sequence, which consists of tillites with voluminous erratics, alternating with massive quartzites and slates, strongly injected in places by quartz veins (fig. 4). At least eight distinct tillite bands have been observed, each of which may be up to 100 feet thick. The erratic blocks are very numerous. Some of them reach 10 feet or more in diameter, and consist of granite, migmatites, gneisses, schists, slates, dolomite, amphibolites and quartzites. The matrix is clayish, arenaceous or dolomitic (fig. 3–6).

Occasionally, irregular patches and lenses of dolomite appear interstratified in the unsorted tillitic material. The total thickness of the Lower Glacial Group exceeds 2000 feet.

4. Interglacial Formations. These consist of a monotonous succession of blue calcareous slates, which are frequently well laminated. Some thin dolomite or sandy bands are also present. Thickness 16000 feet.

5. Upper Glacial sequence, formed by lenticular bands of tillite, passing rapidly to tillitic slates (bluish argillaceous slates with clastic fragments). Thickness variable, up to 2000 feet.

6. Quartzite and blue laminated slates, forming the core of the syncline.

A characteristic feature of the Olary glacial beds is the presence of dolomite in the lower sequence, either as continuous layers separating tillite bands, or as matrix of the tillite, and in other instances as patches or lenses wrapped by unsorted tillitic material. This dolomite is clearly derived from the magnesian beds underlying the glacial beds, presumably as a result of dissolution by glacial streams and reprecipitation in the periglacial water body during a lowering of the water temperature.

In other respects the succession shows strong general similarities with those of the Flinders Ranges, Burra, and Mount Grainger regions. Their common characters may be stated as follows:

The lower glacial sequence succeeds conformably to magnesian formations, and it is the thickest and more complex. It consists of many tillite bands, some of them being up to many hundred feet thick and alternating with or passing to sandy or slaty layers, with or without pebbles. The total thickness may reach 4000 feet or more. In the Central Flinders Ranges the lower glacial sequence consists of two series (MAWSON 1948), the equivalent of which have not yet been identified elsewhere.

The interglacial sequence overlies conformably the Lower glacial sequence and is characterised by argillaceous or marly slates, which are frequently well laminated and may reach 16000 feet in thickness. The bedding has a marked varve-like character; but the alternating dark blue and grey layers appear to be usually of a similar petrological composition. In many cases an eminently calcareous horizon (the "Brighton horizon") forms the top of the series.

The upper glacial sequence consists of tillitic layers similar to those of the lower glacial sequence, but is usually thinner.

D. The age of the glacial sequences, as deduced from Uranium-Lead ratio age determination

During 1953 one of us (B. C.) extended the regional investigations to the Plumbago–Crockers Well zone, some 40 miles north-west of Olary, where the relationship between the Pre-Cambrian glacial series and the older basement are particularly clear. One reaches in this area the edge of the water sheet in which, as a rule, the South Australian Pre-Cambrian tillites have been deposited. Therefore the glacial sequences begin in places with a very coarse and consolidated land moraine, which rests with violent angular unconformity on the crystalline bedrocks. This moraine contains large erratics, representing all rock types of the old glacier floor: schists, gneisses, quartzites, amphibolites, calc-silicate formations, as well as abundant boulders of granite, granodiorite, aplite and pegmatites. These older rocks are well exposed along or near the unconformity, and their stratigraphic relationships are manifest: schists, gneisses and calc-silicate beds form the bulk of a succession, very probably of Archaean age, which has been intensely intruded by pegmatites, aplites and granite.

Detail geological and radiometric investigations have revealed the presence in this area of numerous uranium deposits, which are no doubt genetically related to the granitic rocks. Attempt has therefore been made to determine the age of the granite by the uranium-lead ratio method. The age determinations have been carried out by Dr. J. L. KULP, of the Columbia University, on behalf of the South Australian Department of Mines and by arrangement with the U. S. Atomic Energy Commission. They gave 580 ± 30 million years as the "best age" of the granite.

The tillite, which rests on the crystalline complex and contains granite boulders but has not been affected by the granitic intrusion, is therefore younger. As the glacial beds are overlain in the Adelaide region by a thick series culminating with fossiliferous Lower to Middle Cambrian formations, it is concluded that their age is Upper Pre-Cambrian. The tillite deposition would have taken place between 600 and 500 million years ago.

E. Paleogeography and facies

It may be inferred, from the distribution and the facies of the Adelaide System formations, that a huge crustal depression extended at the Upper Pre-Cambrian time from the South Australian coasts to the heart of the continent. The facies shows that this depression was covered by rather shallow water bodies – lakes, ponds, lagoons, interior seas, where a prolonged and intense sedimentation accumulated some 45000 feet of deposits. Because of such a tremendous thickness, Australian geologists have named this zone of accumulation "Adelaide Geosyncline". The sediments are mostly of a terrigenous nature – argillaceous slates, arkoses and sandstones –, alternating with or succeeding deposits of glacial or brackish facies: tillites, varved formations, magnesian beds, etc. The Adelaide System series have thus rather a paralic than a geosynclinal facies, as defined by TERCIER (1939) and PETTIJOHN (1949) differing from the usual paralic series by an exceptional development of subaqueous tillites. The great thickness of sediments suggests a vigorous subsidence and an intermittent rejuvenation of the surrounding relief, which was repeatedly covered by thick ice-caps. Invading and covering the periglacial water bodies with floe-ice up to many hundred miles from the coast, these ice-sheets were in every respect comparable with the present glaciers of the Antarctica. Indeed the Upper Pre-Cambrian times were dominated in South Australia by polar climates, the persistence of which appear to be without equal in the geological history.

III. – THE PERMIAN GLACIATION

The records of the Permian ice age in South Australia have a limited extension, but they form one of the most clear examples of ancient glaciation. Looking down to the Inman Valley from the elevated spurs of the Fleurieu Peninsula, the view embraces a wide depression having a U-shaped and well gouged cross profile; a rolling, undulating bottom; gentle lower slopes plastered by morainic material and meeting the steep rocky spurs with a strong break of declivity. It is a fossil glacial landscape of Permian age, quite similar to the ice-carved alpine piedmonts.

The evidences of an ancient glaciation in this region were originally recognized by A. R. C. SELWYN (1859) and have subsequently been described by W. HOWCHIN (1895–1901, 1906, 1910, 1926) and T. W. E. DAVID (1897, 1932, 1950). The writers' investigations confirm HOWCHIN's and DAVID's views on the nature of these deposits; but it has also been possible, on the base of new topographical and geological data, to carry out an accurate analysis of the glacial relief and to retrace the history of the preservation of these deposits in the course of Mesozoic, Tertiary and Quaternary times.

A. The Deposits

1. – *Sand and Boulder Clay*

The bulk of the Permian glacial deposits consists of sand and boulder clay, quite similar to the Quaternary morainic drift of the northern hemisphere. These occur beneath thin veneers of residual, bleached, loamy soils and consists of moderate thickness of reddish, brown or yellowish sand and clay, with occasional pebbles and boulders (fig. 8). Frequently this oxidised layer is underlain by bluish to grey compact clay, containing thin indurated sandy layers, which give to the strata a crude irregular bedding.

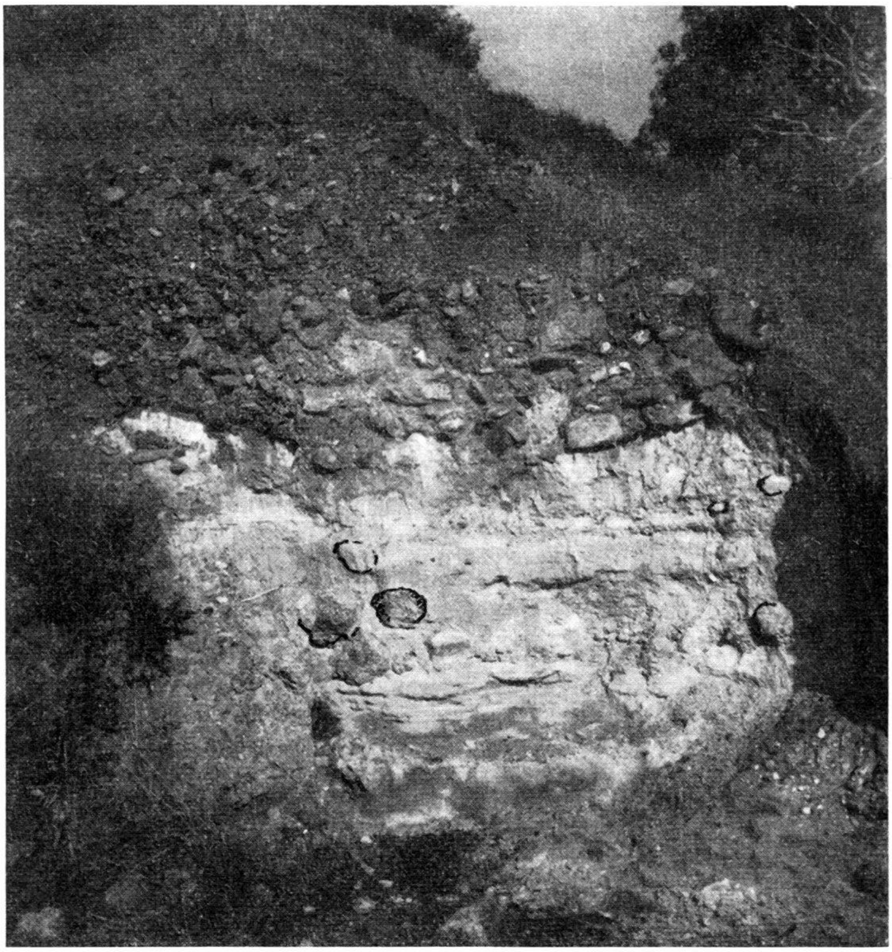


Fig. 8. Permian tillite, overlain by recent alluvial gravel.
1 mile north of Normanville, South Australia.

Large erratic blocks are found at intervals, dumped without any arrangement in clay or sand; but as a rule these contain only faceted or striated pebbles. Towards the bottom, near the outcropping basement rocks or resting on them, the coarse materials become more abundant and the erratics may reach 6 feet or more in diameter (fig. 9, 10).

The thickness of the glacial beds is variable, from a few feet to 200 feet or more. One bore passed through 1000 feet of drift before reaching the basement rock; but these thicknesses are partly the result of the outwash of material by melt-water and include also post-glacial drift.

The glacial layers still occupy a horizontal to sub-horizontal position, and as a whole, they correspond to ground moraines. Except for the abundance of boulders and pebbles near the bottom, there is no general well-marked order of succession. The sediments are seldom lithified, and this only when iron oxides,

Fig. 9. Permian tillite (t) overlying Cambro-Ordovician formations (C). Cape Jervis, South Australia.

Fig. 10. Erratics of Victor Harbour Granite, washed from the Permian tillite. Cape Jervis, South Australia

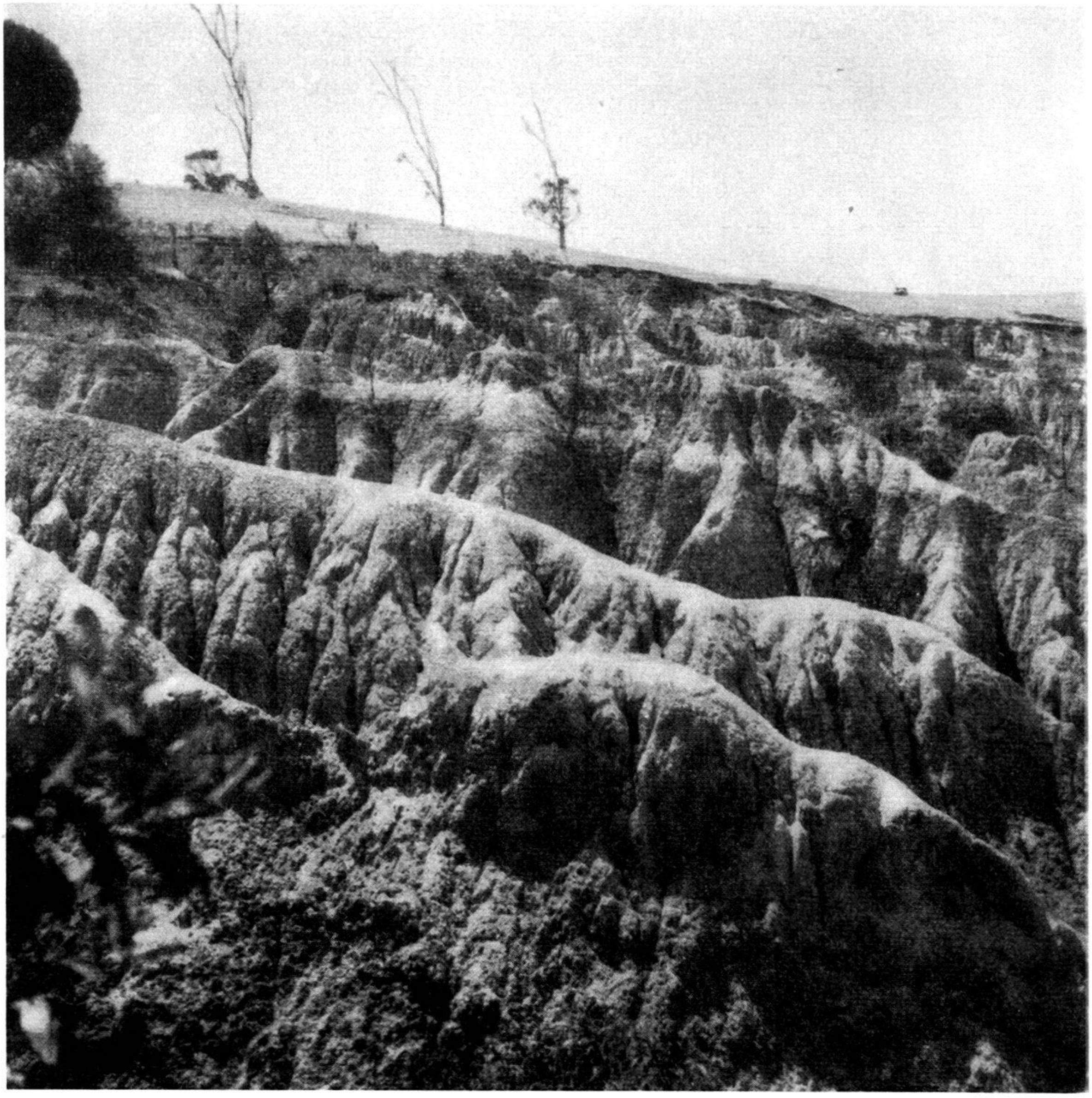


Fig. 11. Erosion gully in the Permian tillite.
Yankalilla, South Australia.

impregnating the sandy layers, have formed a coarse, easily crumbled grit. The sandy material is coarse, unsorted and frequently arkosic. While the clayey layers are compact and impervious when fresh, they readily pass into mud flow when exposed to the air in the rainy season. Assisted by wholesale deforestation, erosion has cut deep furrows in this old morainic material, quickly transforming them into gullies, creeks, and ravines (fig. 11). In less than 100 years the most fertile pastures have been extensively damaged in this manner.

2.–*Varved Formations*

A clear outcrop of varved sediments has been recently exposed by an excavation along the road joining Torrens Vale to Mt. Hayfield (fig. 12). One observes

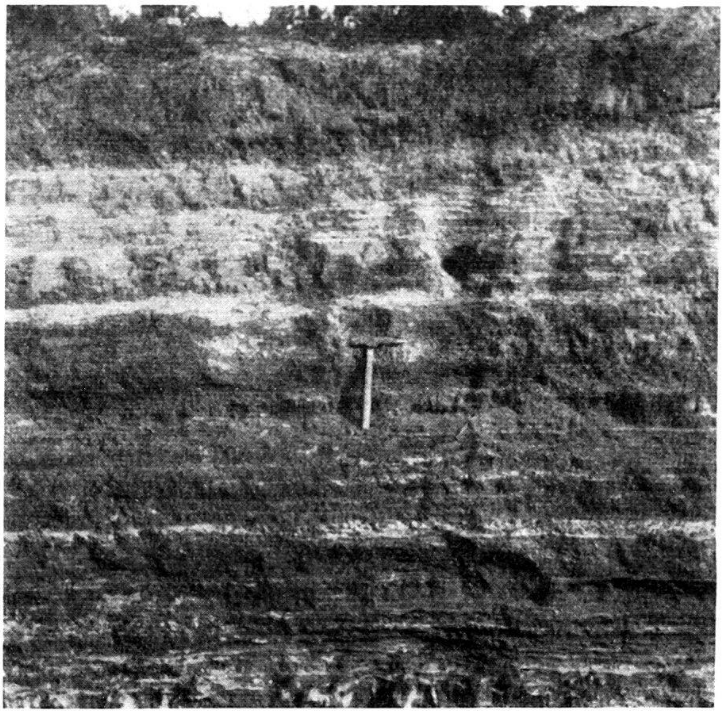


Fig. 12. Varved beds.
Torrens Vale, Fleurieu Peninsula, South Australia.

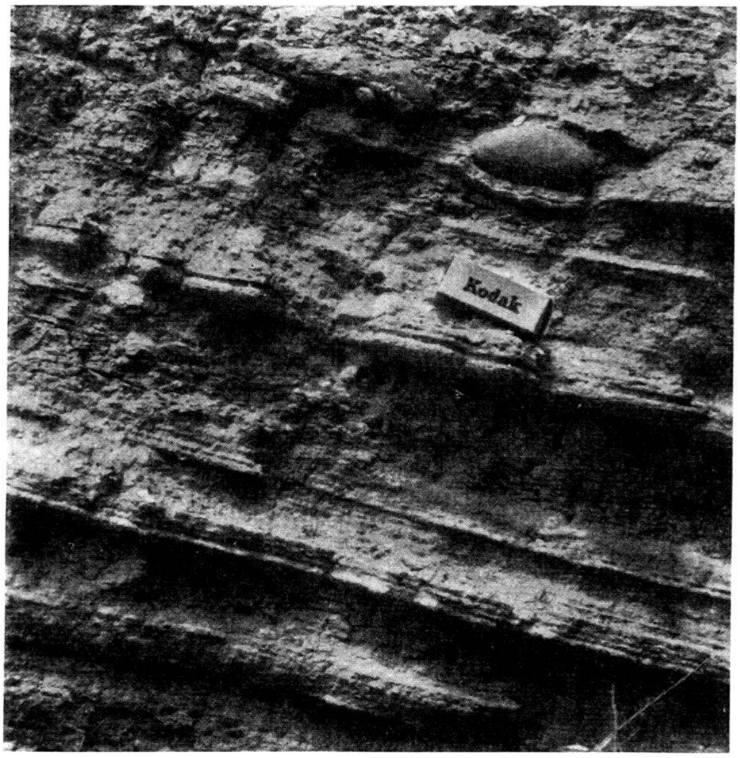


Fig. 13. ? Varved formations, interbedded in unsorted Permian tillite.
Cape Jervis, South Australia.

there, resting horizontally on the bedrock, an alternation of clayish and sandy layers, each of which has a thickness of a few millimetres. The total visible thickness of these layers is about twelve feet and they seem to lie stratigraphically above the sand and boulder clay. They would represent a glacio-lacustrine deposit formed during the recession of the glaciers. In places they are minutely contorted as a result of slumping or of frictional ice drag.

Presumed varved beds are also interstratified in unsorted tillite along the Cape Jervis cliff (fig. 13).

3.–*Pebbles and Erratics*

As already pointed out, coarse rock fragments are particularly abundant at the contact of the glacial drift with bedrock. When isolated by erosion from their soft matrix, pebbles and boulders of any size are strewn on morainic soils or on the older rocky floor, many of them being up to 6 feet across (fig. 10).

The pebbles are usually well worn, polished and faceted, and almost invariably composed of hard quartzitic rock. This is due to the selective action of a prolonged and deep weathering, which destroyed the less resistant fragments. Only the biggest of the granite boulders are still preserved, the source of which is the porphyritic granite outcropping near Victor Harbour, at the mouth of the Inman Valley (pl. II, IV). This shows that the glaciers adavanced from east-south-east to west-northwest, a fact also substantiated by many fine pavement striations.

B. The Glacial Relief

1.–*Glacial Valleys and Basins*

Plates II–IV illustrate major topographic features carved in the Fleurieu Peninsula by the Permian glaciers. As a starting-point to their study we shall consider the region of Victor Harbour, where as said most of the Permian granite erratics had their origin. This picturesque town is laid-out in the centre of an amphitheatre, occupied by alluvial deposits or flooded by the sea in its lower portions, from which emerge granitic islets, sand-covered hillocks and rounded spurs. In this amphitheatre the Inman and the Hindmarsh rivers almost join at their mouths.

(a) The Inman Valley traverses Fleurieu Peninsula from near Normanville, on the Gulf of St. Vincent, to Victor Harbour on Encounter Bay. Its main water course, the Inman River, has cut its banks in the glacial drift, exposing inliers of the glacier floor, upon which fine examples of glacial striae may be observed. One of these, Selwyn's Rock, is classical (Coleman 1926). In the Inman Valley the bedrock hillocks may reach a height of 300 feet above the valley-bottom. They are separated by depressions which have been overdeepened in the bed-rock and subsequently filled with glacial or alluvial drift to river level. In this valley, the importance of the overdeepening is unknown, as no bore records are available. But the records of Back Valley, a tributary of the Inman Valley are in this respect illuminating.

(b) The Back Valley, which joins the Inman Valley near Victor Harbour, is about 8 miles in length and 4 miles in width. Its profile is of a very open U-shape, and glacial drift covers the slopes up to 800 feet above sea level. The Valley corresponds to an old glacial basin, at present filled with sand, clay, and boulder-clay, the existence of which would not have been suspected but for three prospecting bores drilled in 1929. The bores were sunk at the very bottom of the valley, at intervals of one and a half miles along the river course. Two of them, at 200–300 feet above sea level, reached the bedrock at depths of about 700 feet below sea level, after having intersected glacial or fluvio-glacial deposits, probably reworked at shallower level[4]). The third, further downstream, intersected the unconsolidated drift up to 570 feet without reaching the rocky floor.

The formations passed through by the deepest bore were as follows:

0′ – 15′	Superficial clay	212′ –214′	Consolidated sand
15′ – 70′	clay	214′ –235′	Sand with some clay
70′ – 71′	Consolidated sand	235′ –255′	Solid clay-shale
71′ –110′	Clay and sand	255′ –306′	Clay and sand
110′ –110′6″	Consolidated sand	306′ –306′9″	Consolidated sand
110′6″–130′	Clay and sand	306′9″–500′	Clay and mainly sand
130′ –130′9″	Consolidated sand	500′ –696′	Consolidated sand
130′9″–150′	Clay and sand	696′ –964′	Sand with boulders
150′ –150′6″	Consolidated sand	964′ –975′	Bedrock (Blue slate)
150′6″–212′	Clay and sand		

The other two bores were drilled in quite similar formations, the biggest and most abundant boulders being always located in the lower layers of the glacial drift immediately above bedrock. It may be assumed that the lower beds represent the true Permian ground moraines, the upper ones being post-glacial deposits, possibly reworked in part.

Downstream along the Back Valley creek, bedrock appears about 7 miles East of the bore-sites at 70 feet above sea level not far from the junction with the Inman River. As the bores have penetrated the bedrock at about 700 feet below sea level, the present depth of the basin is thus 770 feet. In order to assess its original depth, we must however refer to the Pre-Miocene peneplain (fig. 16) which, although not dating back to Permian time, gives the minimum value: the difference of level between this surface and the bedrock struck by the bores is 1700–1800 feet. The original basin depth, i. e. the glacial over-deepening, is therefore of the same order of magnitude[5]) (pl. III, IV).

(c) The Hindmarsh Basin (and Myponga Basin) differ from Back Valley only in the respect that the Permian deposits are overlain by fossiliferous marine formations of Lower Miocene age, characterized by Polyzoal limestone (fig. 16, pl. II–IV). These formations outcrop at the edge of both basins, some 3 miles southwest of Myponga and near the Hindmarsh Falls. Their thickness has been ascertained by bores, two of which reached the Pre-Cambrian basin bottom.

[4]) By comparison with the New South Wales and Western Australian Permian successions, which contain workable coal seams, it was supposed that these beds could also be coal bearing. The search was unsuccessful.

[5]) Glacial overdeepening is defined in this paper as the depth of erosion of the old glacial floor below the Pre-Miocene base level, which approximately corresponds with the Pre-Miocene peneplain. This, in turn, may be considered to coincide with the Permian base level, as no tectonic movements of Mesozoic age are recorded in the area concerned.

In 1952 a bore was sunk for water search on the banks of the Hindmarsh River, at 791 feet above sea level. This reached the basement rock at a depth of 300 feet, i. e. 491 feet above sea level. As this basement outcrops at the "Falls", three miles downstream, at 672 feet above sea level, the apparent glacial overdeepening is 181 feet at least. The original over-deepening, as related to the Pre-Miocene peneplain, is of the order of 800–900 feet (fig. 16, pl. III, IV).

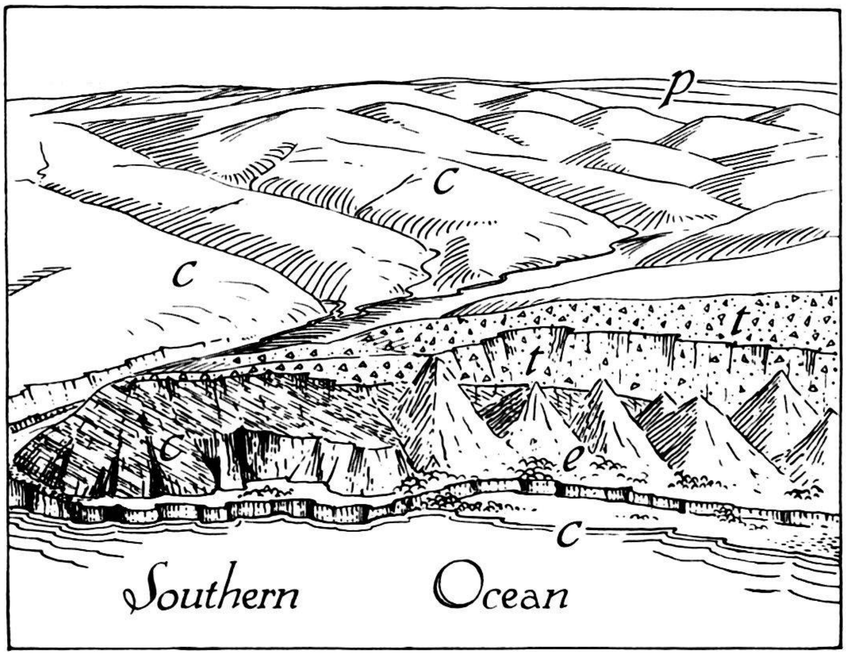


Fig. 14. Aerial view of Cape Jervis – Backstair Passage (South Australia) showing the uplifted Pre-Miocene peneplain (*p*) in the background and Permian glacial depression in the foreground, with remnant of moraine (*t*) resting on Cambro-Ordovician formations (*c*). *e* = talus.

The cross profile of the basin is asymetric, the northern slope being steeper than the southern one. Both join the old erosion surface at the same heights above sea level, i. e. 1360–1370 feet, evidencing that the Tertiary marine formations filling the valley bottom have been deposited in a glacial basin after uplift of the plateau. This fact is of importance for a correct interpretation of the Tertiary tectonic movements in South Australia, and its structural implications will be discussed below.

(d) The Myponga Plain is the north-western extension of the Hindmarsh Valley, from which it is separated by a low ridge of Archaean micaschists. The plain has an average elevation of 700 feet above sea level and occupies an elliptical area of about 20 square miles. It is bounded by ridges of Pre-Cambrian rocks, partly covered by reworked Permian moraines. The small river which drains the plain has cut only clay and sandy layers of recent alluvial origin, but the underlying beds have been penetrated by numerous bores, the deepest of which started at 759 feet above sea level and pierced the following succession:

Recent to Pleistocene: alternating clayish and sandy layers from the surface to 276 feet.

Miocene[6]), consisting of Polyzoal limestone and sandy beds: from 276 to 661 feet.

Permian morainic drift, formed mainly by sandy beds with occasional pebbles and subangular fragments of quartz, quartzites, granite, micaschists and limestone: from 661 to 1079 feet.

Pre-Cambrian bedrock, consisting of phyllite and quartzite: from 1079 to 1086 feet in depth.

Thus, the bore pierced 276 feet of Quarternary alluvial deposits, 385 feet of marine Miocene, 418 feet of Permian moraines and finally penetrated the Pre-Cambrian bedrock, at 370 feet below sea level.

The importance of glacial over-deepening in the formation of this basin is evident. Although observations at the edges of the depression are somewhat obscured by morainic material, the writers estimate that the apparent over-deepening is of the order of 700–800 feet, and originally was at least 1800 feet (fig. 16).

(e) Backstairs Passage, which separates the Fleurieu Peninsula from Kangaroo Island, has to be regarded as a Permian depression still partly submerged by the sea. Its glacial origin is clearly recorded by the fringe of moraines capping the cliff on Kangaroo Island and at Cape Jervis (fig. 9, 10, 13, 14). The Passage is 8 miles in width, with a maximum depth below sea level of 180 feet. In respect with the Pre-Miocene base level its depth is 1200 feet.

2.–*Glacial amphitheatres*

The slopes of the fossil glacial valleys of Fleurieu Peninsula show clear evidence of cirques which have to be attributed to Permian glaciers.

The largest of them may be observed along the southern slope of the Back Valley, where it has been gouged in the Cambro-Ordovician phyllites and quartzites. Its bottom, which is covered by sand and clay, joins the main valley bottom near the site where three bores mentioned above have shown important glacial over-deepening.

Other remnants are found south of Torrens Valley as well as in the Myponga Plain and Inman Valley, where they always occupy the southern slope of the glacial depressions.

3.–*Glacial Bars*

Plate IV illustrates the disposition of the glacial bars and their related basins. The most important are the following ones:

The Crozier Hill Bar, is formed of Cambro-Ordovician micaceous quartzites. It is dissected by the narrow gorge of the Inman River at a short distance from its mouth, and closes to the East the Back Valley and Inman Valley glacial basins.

The Bald Hill Bar, forms the present water divide between the Inman River drainage, directed eastwards, and the Bungala River, directed to the west. The Inman River and Bungala River basins belong to the same glacial valley.

[6]) The age of this formation is at present under review by Dr. M. F. Glaessner, of the University of Adelaide, who considers that the base is of Upper Oligocene age.

The Hindmarsh Falls Bar, closes downstream the Hindmarsh basin. It determines a steep step in the river course, before the latter reaches the sea a few miles further east.

The Bar of Edinburgh Swamp, forms the watershed which separates the Hindmarsh Valley from the Myponga basin, which manifestly belong to the same major glacial depression.

C. Evolution of the Fleurieu Peninsula after recession of Permian glaciers: Preservation of the glacial records

1. – *The Pre-Tertiary Peneplain*

There is no doubt that the Permian glaciers progressed on a land of accentuated relief, comparable to the Alpine topography during the Pleistocene glaciations. The importance of glacial overdeepening, the nature and thickness of the morainic deposits and the existence of cirques and rock bars are characteristic of mountain glaciers. But this relief has been planed down to a peneplain before the Tertiary times. How could then the Permian moraines and the glacial records escape total removal? One could suppose that these landscapes have been submerged in post-Permian times by negative movements. But the absence of marine deposits of Mesozoic above the Permian tillites, suggests that the Peninsula persisted as a stable land surface throughout the whole Mesozoic era. It is thus difficult to escape the conclusion that the Permian glacial records were part of a "negative relief", i. e. an over-deepened depression lying – up to the Tertiary era –, below the base level of the old land mass. In early Tertiary times the buried topography has been uplifted and re-exposed by tectonic movements, which we shall now describe.

2. – *The Pre-Miocene movements*[7])

The tectonic movements which impressed the present physiographic characters on South Australia and indeed on a large portion of the Australian continent, have generally been believed to be of late Tertiary to Pleistocene age: it is the "Kosciusko epoch"[8]) of Australian geologists. In particular, these movements have been considered responsible for the upheaval of the Mt. Lofty Ranges of which the Fleurieu Peninsula forms the most southerly segment. It was also generally admitted that the Tertiary marine formations, pre-dating the Kosciusko epoch and to be found now in the lower portions of the country, covered also the uplifted old surface from where they would have been removed by the present erosion cycle. However, doubts remained about the correctness of this picture, as one could hardly explain why the erosion would have completely removed many hundreds of feet of Tertiary deposits, while leaving intact large portions of the uplifted surface on which they were supposed to rest. Thus the writers paid particular attention to this question, and carried out a careful study of the stratigraphic, structural and topographic

[7]) The general uplift of the M[t] Lufty-Olary arc, of which the Fleurieu Peninsula is a part, has been recently described by one of us as result of the folding of a geosynclinal belt, comprising an Archaean, an Early Palaeocoic and a Tertiary orogenic cycle (CAMPANA, 1955). In this article it will suffice to consider the vertical effect of the Tertiary cycle.

[8]) From Mt. Kosciusko, in New South Wales, the highest mountain in Australia (7328 feet).

relationship between the Tertiary inliers of the Myponga-Hindmarsh Valleys and the remnants of the uplifted plateau which form the surrounding ridges. At about the same time Tertiary geology was studied by M. F. GLAESSNER in the adjoining Echunga area (GLAESSNER 1954), and many common problems have been profitably discussed with this author.

In addition to the existing topographic data, supplementary heights have been determined by the surveying section of the South Australian Department of Mines. Furthermore the writers have access to the new tacheometric survey which has been recently carried out by the Military Authorities.

The results of these investigations are graphically represented on plates III and IV and on figure 16. They may be summarized as follows:

(a) Both Miocene inliers of the Myponga and Hindmarsh basins outcrop at about the same altitude (720 feet and 695 feet respectively).

(b) Both outcrops are about 700 feet below the plateau remnants of the surrounding Myponga Hill (1445 feet), Mt. Cone (1362 feet) and Mt. Spring (1373 feet).

(c) The level difference between these Miocene inliers and the uplifted plateau, cannot be ascribed to tectonic movements. No differential faulting affects this zone and the regional structural setting, as well as the specific geological and topographical data, clearly show that the Pre-Tertiary plateau was uplifted before the Lower-Miocene transgressions. This conclusion presumably applies to all the Lofty Ranges, where no marine Tertiary beds have been observed. The raising of the chain would have thus started in Pre-Miocene times and continued during the Pliocene-Pleistocene as we shall mention later.

3.–*The Miocene negative movements and marine transgression*

These movements are responsible for a marine transgression which covered the coastal low land and a great portion of the Murray Plain. This transgression is recorded by epicontinental sediments of variable thickness, from less than 100 feet to about 1200 feet (MILES 1952), frequently consisting of very fossiliferous polyzoal limestones and sandy limestones, to which a Lower Miocene age has been assigned[9]).

In the area studied by the writers the Miocene rests either on Permian morainic deposits (Myponga bore) or on Cambrian beds (Sellick's Hill). At this locality the transgression surface is marked by a basal conglomerate, formed by 2–3 feet of black, manganiferous, unconsolidated sand in which well rounded pebbles are embedded. On this sand rests the polyzoal beds, sandy limestones or calcareous sandstones, the thickness of which is not directly measurable as they are partly covered by the sea.

The cycle of erosion subsequent to the pre-Miocene upheaval had re-excavated, by differential erosion, the ancient glacial depressions of Myponga and Hindmarsh River. The Miocene sea invaded these rejuvenated basins, thus forming gulfs of variable depth. It appears that the advancing sea covered first the deeper Myponga basin, the shallow Hindmarsh trough being invaded at a later time (pl. III, IV, fig. 16).

[9]) See footnote 6.

4. – *The post-Miocene positive movements*

These movements are well known in South Australia, where the most apparent effects are recorded in the southern portion of the State by block-faulting and uplifts. They have been recognized in large parts of the Australian continent and they are undoubtedly still active, as evidenced by widespread, splendid examples of recent marine terraces and raised beaches bordering the Australian coasts. In South Australia, the post-Miocene positive movements are neatly recorded at Sellick's Beach, some 25 miles south of Adelaide, where a detailed survey has been carried out by the writers (fig. 15, pl. II–IV). One observes there a major block-fault, marked topographically by the Willunga escarpment, which separates the low-

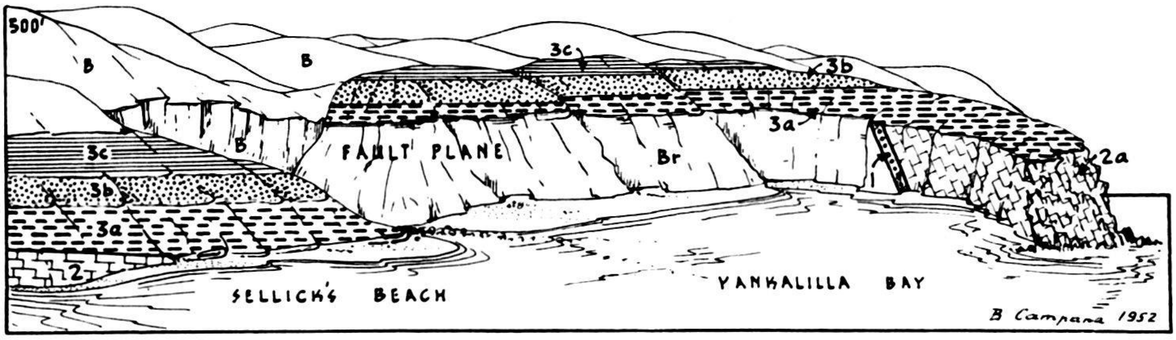


Fig. 15. Geological panorama of Sellicks Beach, South Australia, showing Post-Miocene coastal uplift.
B Cambrian and Pre-Cambrian; *Br* Brecciated Cambrian slates; *1* Miocene basal conglomerate; *2* sub-horizontal Miocene limestone; *2a* Miocene limestone, uplifted along fault plane; *3a, 3b, 3c* Pleistocene clay and gravel, also affected by faulting.

land of the Aldinga Plain to the West from the long, regular, unbroken plateau to the East. At Sellick's Beach, the fault runs into the sea, but on its western side the Miocene beds outcrop along the beach, broadly folded and capped by horizontal Pleistocene gravel and clay. To the eastern side of the fault the uplifted coast joins, with steep slopes, the Myponga Plain. The fault-plane is marked by brecciated Cambrian slate on which rest, with strong angular unconformity, the Miocene polyzoal limestones. These beds, usually flat-lying, are folded and warped up to the vertical position along the fault. At a later stage the horizontal Pleistocene gravels, which cover the Miocene as well as the Cambrian brecciated slates, have also been affected by the movement, for they are warped and displaced along the fault-line from a few feet to fifty feet. The succession of the Post-Miocene may thus be tabulated:

(a) Folding of the transgressive Miocene beds and warping of these strata along the fault plane. Uplift of the coastal block.

(b) Erosion and deposition of the Pleistocene clay and gravel.

(c) Faulting of the Pleistocene beds in recent time.

D. Extension of the Permian glaciation in Australia: other examples of glacial basins

It is beyond the scope this paper to summarize the abundant literature concerning the Australian Permo-Carboniferous glaciations. It suffices to note that the oldest glacial beds of Palaeozoic times occur in the Kuttung Series of New South Wales to which a Namurian age has been assigned (DAVID 1932, 1950, TEICHERT 1948). The Carboniferous glaciations appear to have been of a local extension, affecting only the old highlands. But the Permian glacial beds are much more widespread, and the related deposits are well dated by many species of *Glossopteris* and *Gangamopteris*. It has been inferred that the main late Palaeozoic glaciation in Australia was a Sakmarian age (TEICHERT 1948).

In some instances the glacial deposits are preserved in depressions quite similar to the glacial basins described above, and it is now suggested that they have an identical origin. The most striking examples are the Collie and Wilga coalfield of Western Australia, on the western margin of the Darling plateau, and the Lake Phillipson coal field, in the north of South Australia.

The Collie coalfield, occupies an area of about 100 square miles, at 600–700 feet above sea level. It is in the form of an elliptical depression which is filled by subhorizontal deposits of Permian age resting on, and completely surrounded by Pre-Cambrian granite. The base of the sedimentary series consists of a tillite with erratic blocks, which is overlain by alternating cross-bedded sandstones and schists, containing 24 coal seams. The series has recently been traversed by bores, one of which penetrated the granite basement at a depth of 1800 feet. A geophysical survey has shown a thickness of sediments of 4000 feet in the south-eastern portion of the basin (fig. 17).

It was previously admitted that this Permian succession has been preserved in a graben of the granitic plateau, but the supposed faults at the margins of the basins are quite controversial and they can scarcely account for the morphology of the trough as it has been revealed by CHAMBERLAIN's gravimetric survey (fig. 17).

The presence of tillites at the very bottom of the sedimentary series, the absence of underclays on the coal seams, and the high ash content of the coal, are suggestive of drift material deposited in a lake of glacial rather than of tectonic origin (FAIRBRIDGE 1951).

The Wilga coalfield, represents the southern extension of the Collie basin, from which it is separated by a bar of granite. Its sediments and geo-morphologic conditions are similar to those described above.

Lake Phillipson, is situated about 450 miles north-west of Adelaide, in a large plain formed of horizontal Cretaceous and Tertiary sediments, covering a granitic basement. In 1905 a bore for artesian water was sunk in this region, up to a depth of over 3000 feet. H. Y. L. BROWN (1905) describes as follows the intersected strata:

"Several seams of brown coal, similar to that of Leigh Creek[10]), were met with at intervals from 166 feet to 551 feet. These varied in thickness from a few inches

[10]) The Leigh Creek coal basin, some 300 miles north of Adelaide, is at present intensely worked by the South Australian Government. It consists of three depressions in Pre-Cambrian formations, filled by lacustrine Triassic sediments containing several brown coal seams. No glacial deposits have yet been described beneath the Triassic strata and it is suggested by some investigators that the basin is related to local tectonic deformations, as the Triassic coal measures would appear to be folded into the basement rocks (ELECTRICITY TRUST OF S. A. 1951). In many respects, however, the similarities of the Leigh Creek coalfield with the above described glacial basins are striking.

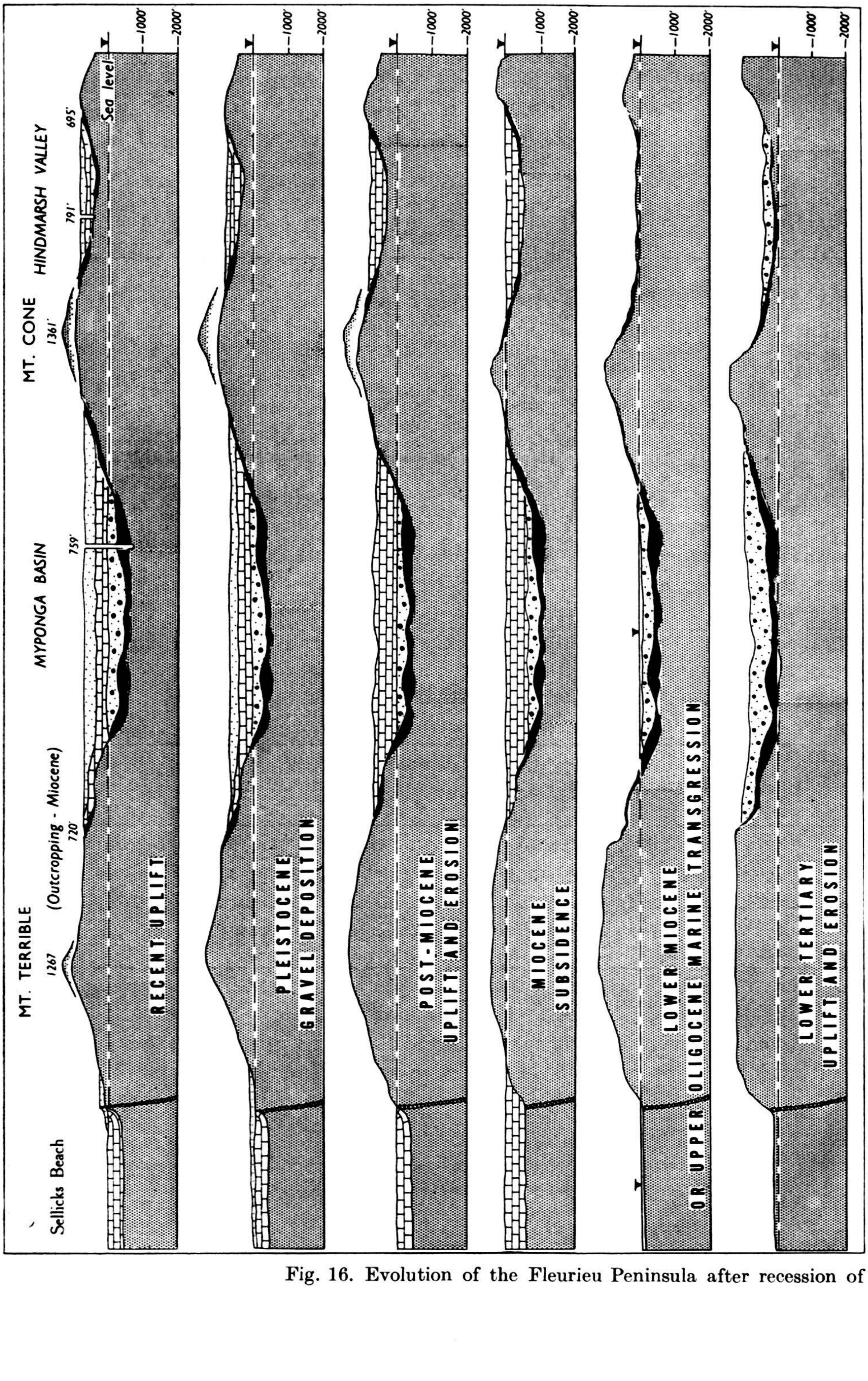
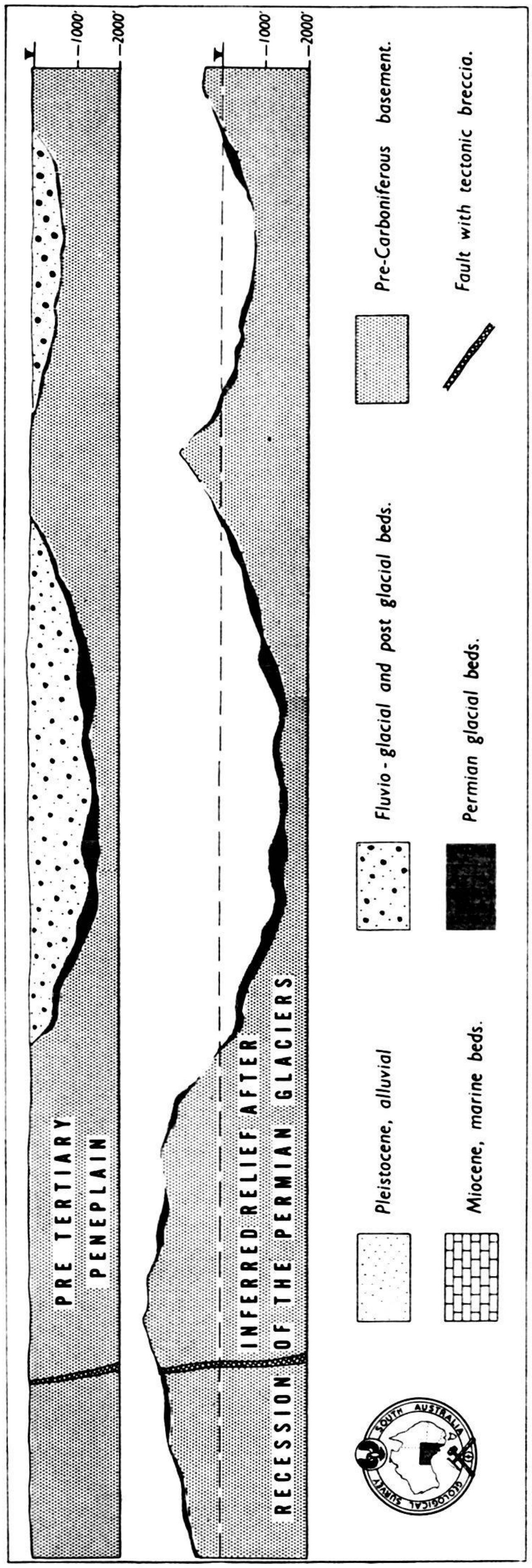


Fig. 16. Evolution of the Fleurieu Peninsula after recession of



the Permian Glaciers.

to 28 feet. From 551 feet downward the bore passed through argillaceous and micaceous shales, with thin sandstones, grit and calcareous bands at long intervals. This shale was more or less bituminous at intervals to about 2240 feet, and yielded petroleum at distillation. The stratification has been horizontal all through."

The author gives the result of the two coal analyses, showing an ash content of 18, 54 and 8.82 per cent, respectively and continues: "At depth of 3117 feet the core consists of blue argillaceous shale with fragments of siliceous grit and gravel scattered throughout it. At 3100 feet the drill passed through a fragment of granite which was embedded in the shale. The nearest granite outcrop known at present is some 26 miles westwards of the bore. The occurrence of granite suspended in this shale deposit indicates the action of ice at the time the shale was deposited."

The bore was actually sunk to the granite basement, which was penetrated at a depth of 3140 feet.

The Lake Phillipson region has not yet been studied in detail: but figure 18 (Lockhart Jack 1930) leaves little doubt that this basin is also of glacial origin.

E. The scientific and economic importance of the Australian glacial basins

It appears to the writers that the glacial basins described above throw much light on the question of the erosional power of the glaciers beneath the profile of equilibrium. The Collie, Wilga and Lake Phillipson coal basins occur in regions of high tectonic stability, made up of granite and granitized complex of the Australian continental shield, and we have seen that they cannot be ascribed to subsidence or differential faulting. Their formation appears entirely due to glacial over-deepening, which at Collie Coal Field, reaches 4000 feet, over a basin length of some 20 miles. At Lake Phillipson the rate is 3200 feet over a basin length of 70 miles.

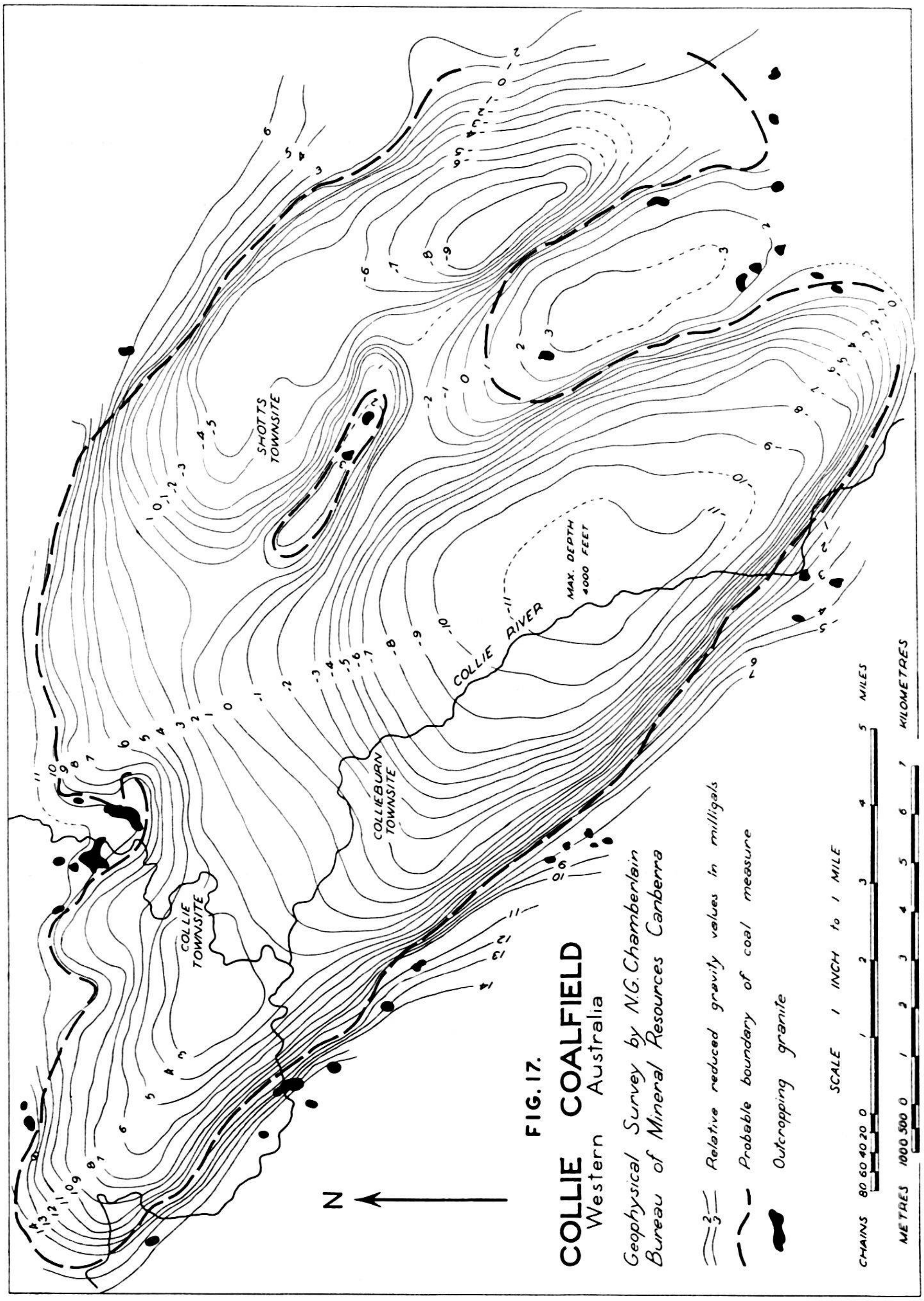


FIG. 17.
COLLIE COALFIELD
Western Australia
Geophysical Survey by N.G. Chamberlain
Bureau of Mineral Resources Canberra

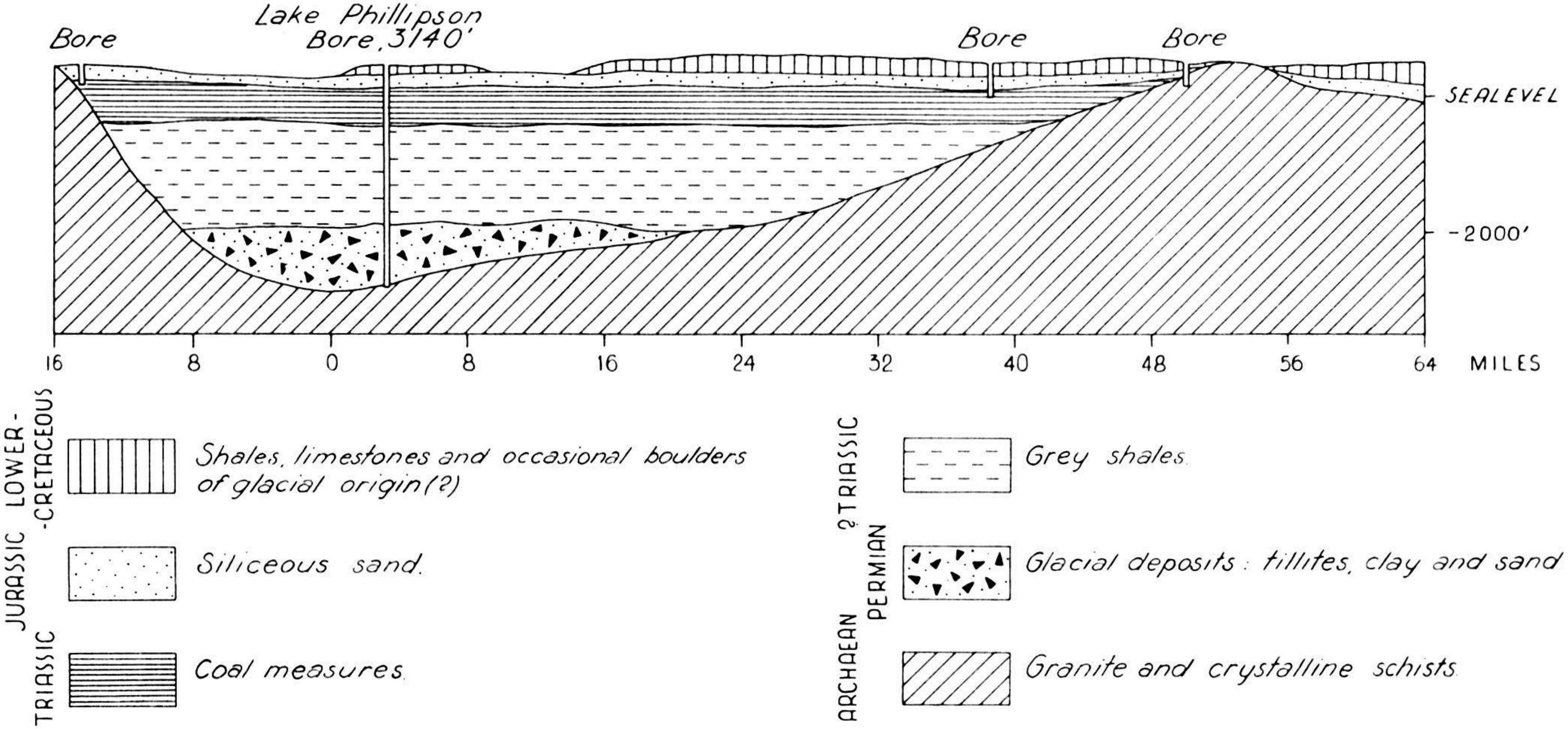


Fig. 18. Permian glacial basin of Lake Phillipson, South Australia.

In the Fleurieu Peninsula the maximum depth is of the order of 2000 feet, for a length of 10–20 miles. As a comparison, it may be noted that the Lake of Geneva, the glacial origin of which is now generally accepted, shows a depth of 1000 feet, its total length being some 70 miles. It can be concluded that the comparatively great depth of certain Alpine lakes is in no way incompatible with a glacial origin, an over-deepening of 2000 to 4000 feet over a distance of 10 to 20 miles being an established feature.

The interpretation of the origin of the above described coal fields is not, on the other hand, without economic significance. If the writers views are correct, and considering the great extension of the Permian glaciation in Australia, it is reasonable to suspect the presence of other coal bearing glacial basins, buried beneath the younger deposits which cover most of the Australian shield. It would thus appear that as a working hypothesis, the assumption of a glacial origin is more fertile and more encouraging for the prospector than an explanatory view based on accidental, isolated and fairly improbable tectonic causes.

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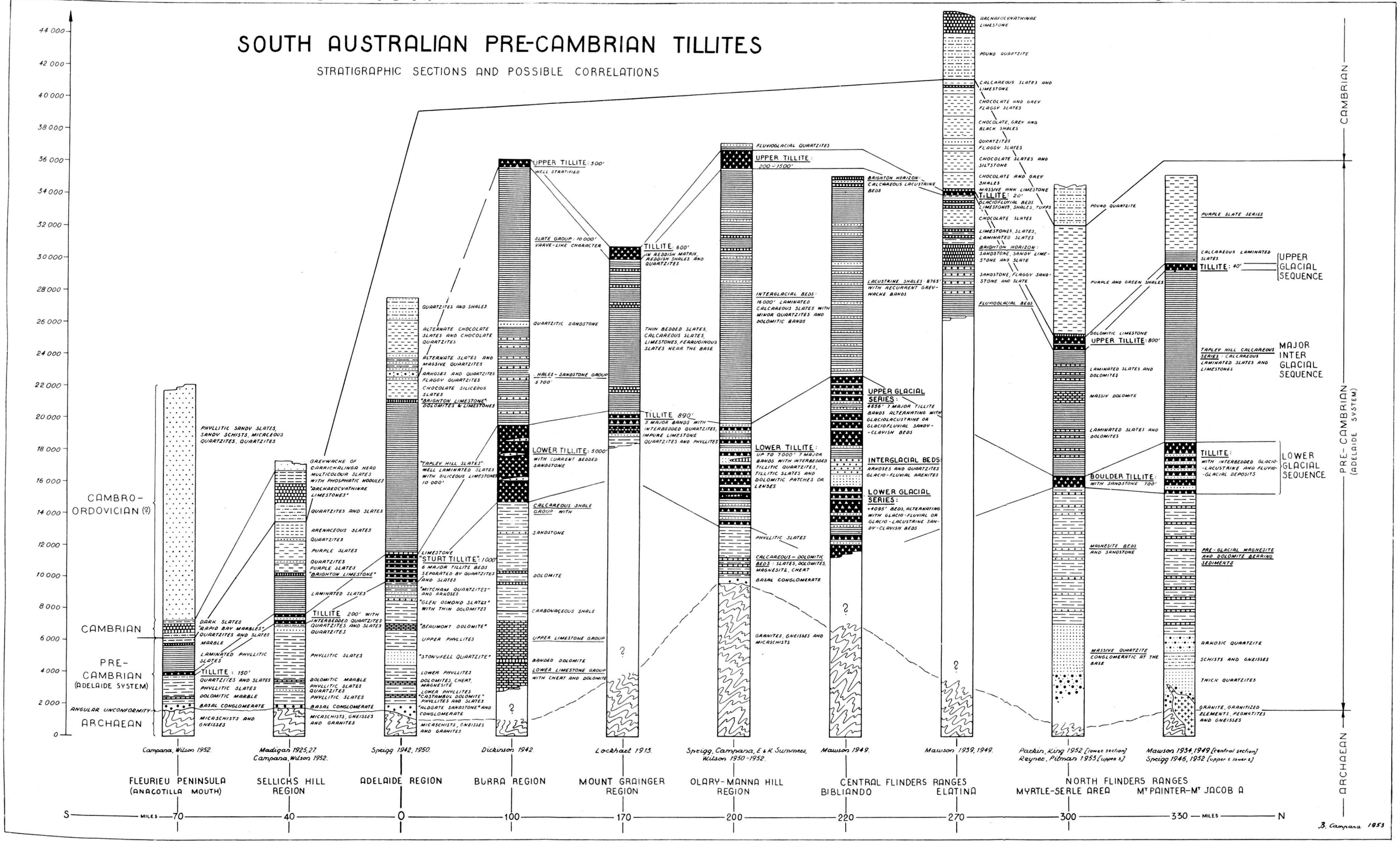
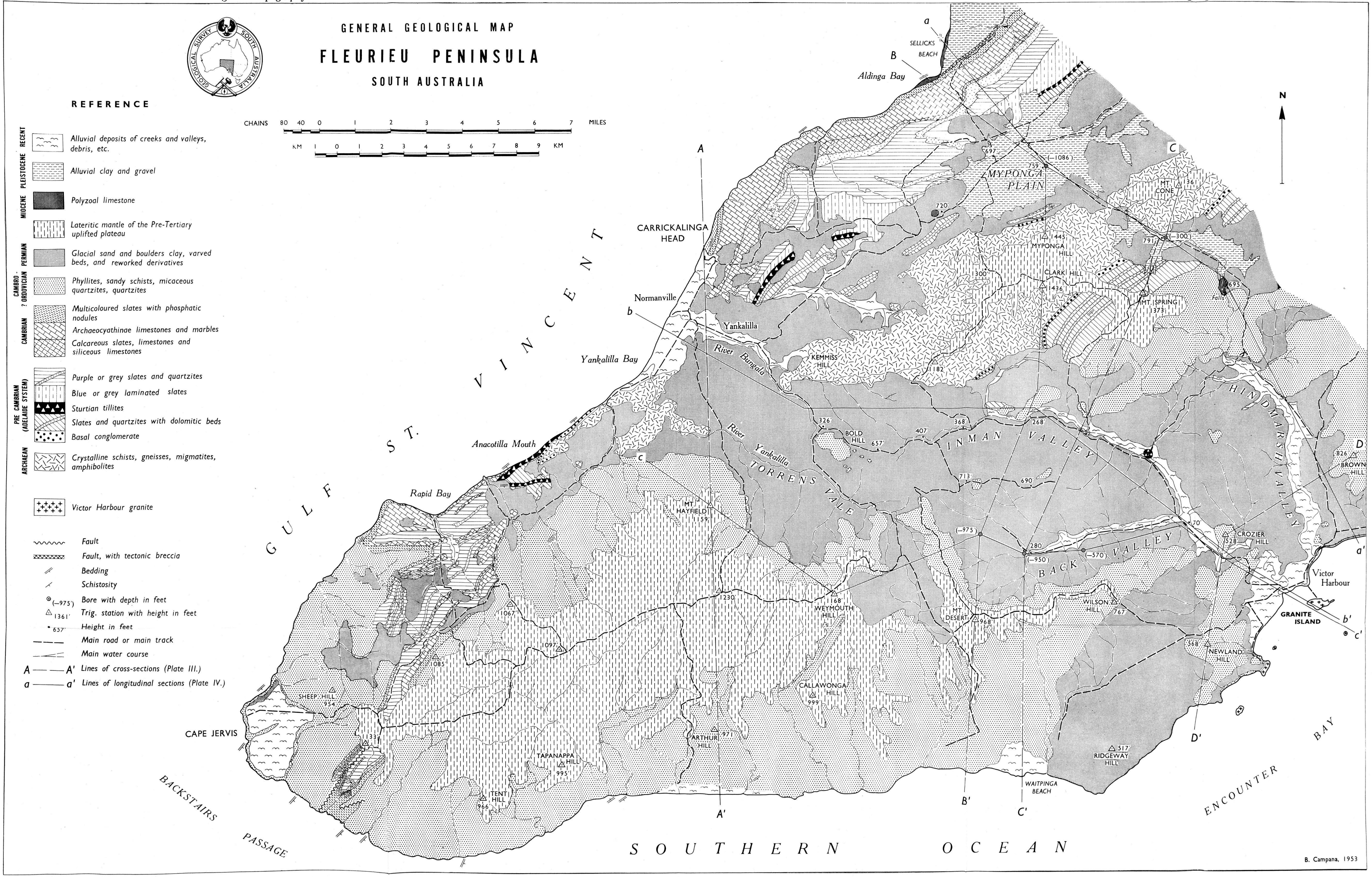
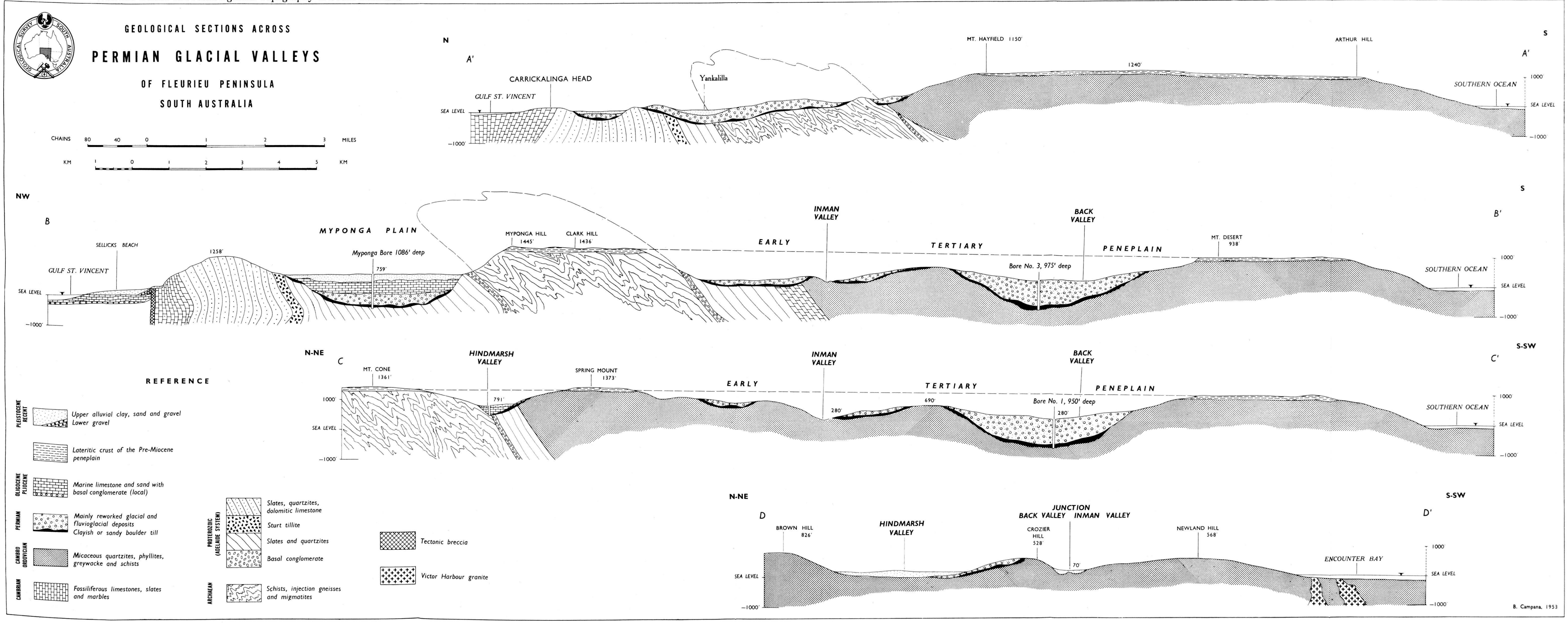
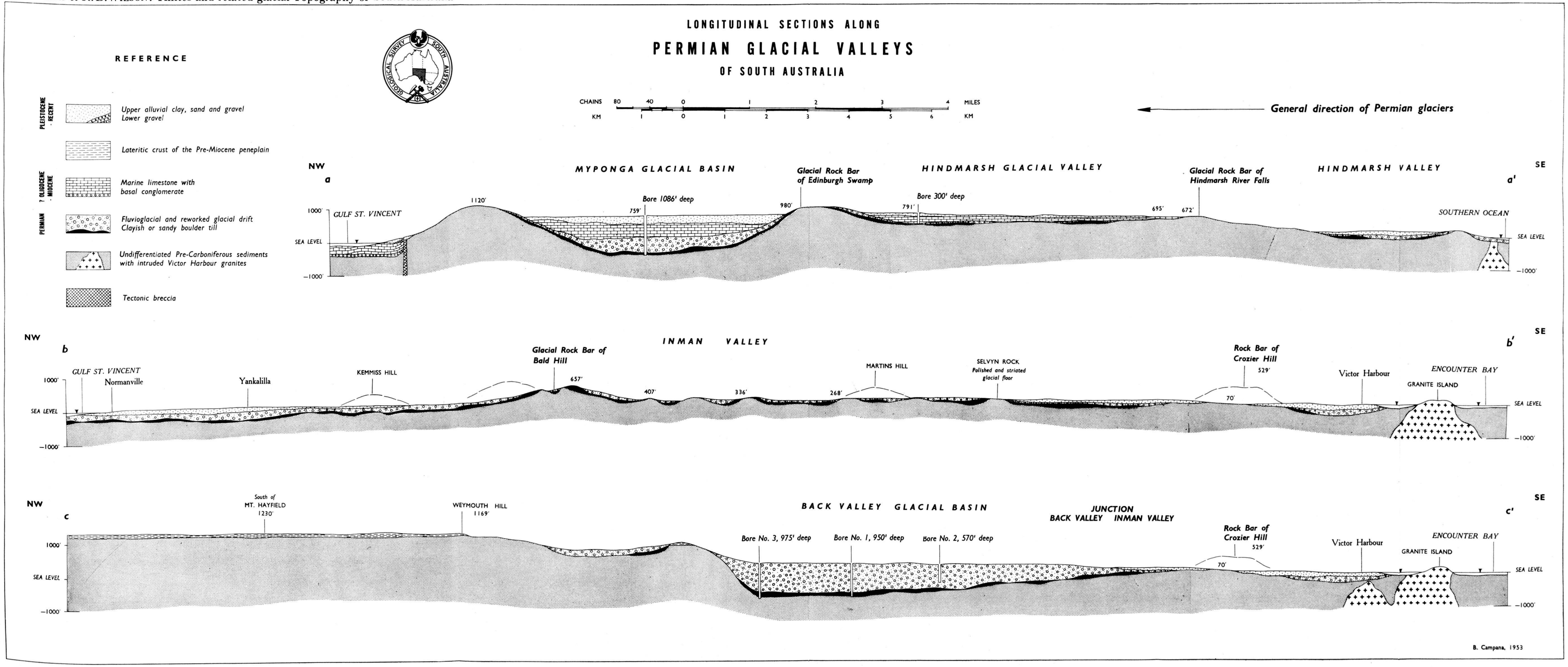

SOUTH AUSTRALIAN PRE-CAMBRIAN TILLITES
STRATIGRAPHIC SECTIONS AND POSSIBLE CORRELATIONS
CAMBRO-ORDOVICIAN (?)
CAMBRIAN
PRE-CAMBRIAN (ADELAIDE SYSTEM)
ANGULAR UNCONFORMITY
ARCHAEAN
PRE-CAMBRIAN (ADELAIDE SYSTEM)
UPPER GLACIAL SEQUENCE
MAJOR INTER GLACIAL SEQUENCE
LOWER GLACIAL SEQUENCE
TILLITE: 150'
TILLITE 200' WITH INTERBEDDED QUARTZITES
"STURT TILLITE": 1000'
UPPER TILLITE: 500'
LOWER TILLITE: 5000'
TILLITE: 600'
TILLITE 890'
UPPER TILLITE: 200-1500'
LOWER TILLITE: UP TO 7000'
UPPER GLACIAL SERIES
INTERGLACIAL BEDS
LOWER GLACIAL SERIES
TILLITE: 20'
UPPER TILLITE: 800'
BOULDER TILLITE
TILLITE: 40'
TILLITE:
Campana, Wilson 1952
Madigan 1925,27 Campana, Wilson 1952
Sprigg 1942, 1950
Dickinson 1942
Lockhart 1913
Sprigg, Campana, E & K Summers, Wilson 1950-1952
Mawson 1949
Mawson 1939, 1949
Parkin, King 1952 [lower section] Reyner, Pitman 1953 [upper s.]
Mawson 1934, 1949 [central section] Sprigg 1946, 1952 [upper & lower s.]
FLEURIEU PENINSULA (ANACOTILLA MOUTH)
SELLICKS HILL REGION
ADELAIDE REGION
BURRA REGION
MOUNT GRAINGER REGION
OLARY-MANNA HILL REGION
CENTRAL FLINDERS RANGES
BIBLIANDO
ELATINA
NORTH FLINDERS RANGES
MYRTLE-SERLE AREA
Mt PAINTER-Mt JACOB A
S
MILES 70
40
0
100
170
200
220
270
300
330 MILES
N
B. Campana 1953


GENERAL GEOLOGICAL MAP
FLEURIEU PENINSULA
SOUTH AUSTRALIA
GEOLOGICAL SURVEY SOUTH AUSTRALIA
REFERENCE
RECENT
PLEISTOCENE
Alluvial deposits of creeks and valleys, debris, etc.
Alluvial clay and gravel
MIOCENE
Polyzoal limestone
Lateritic mantle of the Pre-Tertiary uplifted plateau
PERMIAN
Glacial sand and boulders clay, varved beds, and reworked derivatives
CAMBRO - ? ORDOVICIAN
Phyllites, sandy schists, micaceous quartzites, quartzites
CAMBRIAN
Multicoloured slates with phosphatic nodules
Archaeocyathinae limestones and marbles
Calcareous slates, limestones and siliceous limestones
PRE CAMBRIAN (ADELAIDE SYSTEM)
Purple or grey slates and quartzites
Blue or grey laminated slates
Sturtian tillites
Slates and quartzites with dolomitic beds
Basal conglomerate
ARCHAEAN
Crystalline schists, gneisses, migmatites, amphibolites
Victor Harbour granite
Fault
Fault, with tectonic breccia
Bedding
Schistosity
Bore with depth in feet
Trig. station with height in feet
Height in feet
Main road or main track
Main water course
A —— A' Lines of cross-sections (Plate III.)
a —— a' Lines of longitudinal sections (Plate IV.)
CHAINS 80 40 0 1 2 3 4 5 6 7 MILES
KM 1 0 1 2 3 4 5 6 7 8 9 KM
N
GULF ST. VINCENT
SOUTHERN OCEAN
ENCOUNTER BAY
BACKSTAIRS PASSAGE
SELLICKS BEACH
Aldinga Bay
MYPONGA PLAIN
CARRICKALINGA HEAD
Normanville
Yankalilla
Yankalilla Bay
River Bungala
KEMMISS HILL
MYPONGA HILL
CLARK HILL
MT CONE
MT SPRING
Falls
HINDMARSH VALLEY
INMAN VALLEY
BOLD HILL
River Yankalilla
TORRENS VALE
Anacotilla Mouth
Rapid Bay
MT HAYFIELD
BACK VALLEY
CROZIER HILL
BROWN HILL
Victor Harbour
GRANITE ISLAND
WILSON HILL
MT DESERT
WEYMOUTH HILL
NEWLAND HILL
CALLAWONGA HILL
SHEEP HILL
CAPE JERVIS
ARTHUR HILL
TAPANAPPA HILL
TENT HILL
RIDGEWAY HILL
WAITPINGA BEACH
B. Campana, 1953


GEOLOGICAL SECTIONS ACROSS
PERMIAN GLACIAL VALLEYS
OF FLEURIEU PENINSULA
SOUTH AUSTRALIA
CHAINS 80 40 0 1 2 3 MILES
KM 1 0 1 2 3 4 5 KM
N
A'
CARRICKALINGA HEAD
GULF ST. VINCENT
Yankalilla
MT. HAYFIELD 1150'
1240'
ARTHUR HILL
S
A'
SOUTHERN OCEAN
SEA LEVEL
1000'
-1000'
NW
B
SELLICKS BEACH
GULF ST. VINCENT
1258'
MYPONGA PLAIN
Myponga Bore 1086' deep
759'
MYPONGA HILL 1445'
CLARK HILL 1436'
EARLY
INMAN VALLEY
TERTIARY
BACK VALLEY
Bore No. 3, 975' deep
PENEPLAIN
MT. DESERT 938'
S
B'
SOUTHERN OCEAN
N-NE
C
MT. CONE 1361'
HINDMARSH VALLEY
791'
SPRING MOUNT 1373'
EARLY
INMAN VALLEY
280'
690'
TERTIARY
BACK VALLEY
Bore No. 1, 950' deep
280'
PENEPLAIN
S-SW
C'
SOUTHERN OCEAN
REFERENCE
PLEISTOCENE RECENT
Upper alluvial clay, sand and gravel
Lower gravel
Lateritic crust of the Pre-Miocene peneplain
OLIGOCENE PLIOCENE
Marine limestone and sand with basal conglomerate (local)
PERMIAN
Mainly reworked glacial and fluvioglacial deposits
Clayish or sandy boulder till
CAMBRO ORDOVICIAN
Micaceous quartzites, phyllites, greywacke and schists
CAMBRIAN
Fossiliferous limestones, slates and marbles
PROTEROZOIC (ADELAIDE SYSTEM)
Slates, quartzites, dolomitic limestone
Sturt tillite
Slates and quartzites
Basal conglomerate
ARCHAEAN
Schists, injection gneisses and migmatites
Tectonic breccia
Victor Harbour granite
N-NE
D
BROWN HILL 826'
HINDMARSH VALLEY
JUNCTION
BACK VALLEY INMAN VALLEY
CROZIER HILL 528'
70'
NEWLAND HILL 568'
S-SW
D'
ENCOUNTER BAY
B. Campana, 1953


LONGITUDINAL SECTIONS ALONG
PERMIAN GLACIAL VALLEYS
OF SOUTH AUSTRALIA
REFERENCE
PLEISTOCENE - RECENT
Upper alluvial clay, sand and gravel
Lower gravel
Lateritic crust of the Pre-Miocene peneplain
? OLIGOCENE - MIOCENE
Marine limestone with basal conglomerate
PERMIAN
Fluvioglacial and reworked glacial drift
Clayish or sandy boulder till
Undifferentiated Pre-Carboniferous sediments with intruded Victor Harbour granites
Tectonic breccia
General direction of Permian glaciers
MYPONGA GLACIAL BASIN
Glacial Rock Bar of Edinburgh Swamp
HINDMARSH GLACIAL VALLEY
Glacial Rock Bar of Hindmarsh River Falls
HINDMARSH VALLEY
GULF ST. VINCENT
SOUTHERN OCEAN
INMAN VALLEY
Glacial Rock Bar of Bald Hill
KEMMISS HILL
MARTINS HILL
SELVYN ROCK
Polished and striated glacial floor
Rock Bar of Crozier Hill
Victor Harbour
ENCOUNTER BAY
GRANITE ISLAND
Normanville
Yankalilla
BACK VALLEY GLACIAL BASIN
JUNCTION BACK VALLEY INMAN VALLEY
South of MT. HAYFIELD 1230'
WEYMOUTH HILL 1169'
Bore No. 3, 975' deep
Bore No. 1, 950' deep
Bore No. 2, 570' deep
B. Campana, 1953