DEPARTMENT OF MINES

SOUTH AUSTRALIA

GEOLOGY OF THE FROME
1:250 000 GEOLOGICAL MAP AND ADJACENT REGIONS

by

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AUTHOR'S NOTE

DM.538/74

In accordance with the Code of Stratigraphic Nomenclature the contents and formation names of this report may not be used in any publication until first published in Callen and Tedford, 1975. "New Rock Units and Climate of the Cainozoic, Lake Frome area, South Australia"(in preparation), wherein the units are formally defined and validated.

Report No. 74/25

A D D E N D U M

Following completion of this report, additional work by Dr. R. Jensen and J. Draper of the Bureau of Mineral Resources, and Dr. J. Bowler of the Department of Biogeography and Geomorphology of the Australian National University has revealed the following relationships:

1. The sediments in Lake Frome are Holocene lacustrine clays of similar facies to the Millyera Beds ostracod-bearing clays. They are probably related to the phase of activity which cut the cliffs on the islands in Lake Frome. These sediments may be equivalent to the Coonarbine Formation.

2. The gypsum aeolianite of the islands and southeast shoreline of Lake Frome is a lunette-type deposit formed during a short interval of time, probably during deposition of the uppermost Eurinilla Formation. No major breaks could be detected in the sequence.

These alterations have not been incorporated on the map, or in the text and tables of this report. They entail the following:

1. Limits of salt remapped by B.M.R. - restricted to area north of islands.

2. Qrb Add the following:

   Homogenous black to blue green clay, semi-liquid, lacking lamination. Layers of crystalline gypsum of groundwater origin. Numerous ostracods and charophytes. Covered by Qrl over much of lake.

3. Symbol $\frac{Qrl}{Czm}$ becomes $\frac{Qrl}{Qrb}$

4. Remove Qp_2 and text beginning "Gypseolianite ....."

5. Insert new block Qp_2 between Qp_3 and Qcs. Colour and text as before, but delete "Foresets may be present" and replace with "small scale cross-bed sets arranged in thick subhorizontal sets - typical aeolian foresets absent".
   Replace word "Gypseolianite" with "Gypsum aeolianite".

6. Alter symbol $\frac{Qp_2}{Qp_4}$ to Qp_2, and $\frac{Qp_2}{\frac{Qp_4}{Czm}}$ to $\frac{Qp_2}{Czm}$ in Lake Frome and on eastern shore.

7. Delete "Gypseolianite ...." from unit Qp_4.

8. Alter symbolism on cross sections and rock relationship diagram to conform with above.

9. Alter and delete appropriate material in tables and text to conform with above.

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ABSTRACT

The Frome 1:250 000 map covers the northern part of the South Australian portion of the Frome Embayment. The embayment is essentially the eastern portion of a Mesozoic basin, developed on Palaeozoic and Precambrian rocks during Upper Jurassic time by gentle downwarping and faulting. It is an extension of the Great Artesian Basin, and contains marginal and shallow marine Cretaceous sediments, veneered by fluviatile and lacustrine (possibly estuarine) Tertiary sediments, and fluviatile, lacustrine and aeolian Quaternary sediments.

The Cainozoic sediments occupy a shallow basin, and are faulted against the Adelaide Geosyncline rocks of the Flinders Ranges to the west. To the east they thin over a broad arch, which developes into a well-defined ridge to the south. This ridge was also a positive area during Mesozoic sedimentation, and constitutes Willyama Complex metamorphic and granitic rocks and porphyritic rhyolite of unknown age.

Middle Cambrian rocks, folded into simple open structures, exist beneath the Mesozoic strata over a large area of the southern portion of the Frome Embayment.

It is thought that the area formed a stable craton during Palaeozoic time.

The climate in the Tertiary was sub-tropical to tropical in Paleocene times with high rainfall, and the surrounding terrain had high relief, the temperature dropped slightly during the Eocene. The Middle Miocene had a strongly seasonal sub-tropical climate with (initially) high rainfall and relief was low. There is also evidence for arid periods. The period from late Miocene to Lower Pleistocene is ill-defined, and it was during this time that the Flinders Ranges were rapidly uplifted. A semi-arid climate prevailed. Late Pleistocene climate was initially wet, but later became more arid, and Lake Frome probably approached its present dimensions during Plio-Pleistocene times.

The Tertiary Namba Formation and Eyre Formation contain significant uranium deposits of the geochemical cell type. Extensive deposits of swelling clays are present on the central south margin of the sheet. The major utilized resource is water, drawn from three major aquifers: the basal Cretaceous, the Tertiary sands, and conglomerates and sands of the Willawortina Formation. In general Cainozoic sediments are the present aquifer west of Lake Frome, and Mesozoic sediments to the east.

INTRODUCTION

The Frome 1:250 000 geological sheet is located between latitudes 30°S and 31°S and longitudes 139°30'E and 141°E (Fig. 1) covering most of the area between the northern Flinders Ranges and the N.S.W. border. Its southern and northern limits approximate the extremeties of Lake Frome, which occupies most of the western portion of the sheet. A southern extension of the Strzelecki Desert covers the eastern half of the area.

Main access roads are the Barrier Highway, Pt. Augusta - Leigh Creek Road, and Broken Hill - Tibooburra road. From the Barrier Highway a well-graded track branches north at Yunta, crosses the plains between the Flinders Ranges and Lake Frome, and meets an eastern branch of the Leigh Creek road from Copley near "Balcanoona". From the Tibooburra road a track branches from "Avonel" in N.S.W. to Brougham's Gate on the border, and then north along the N.S.W. side of the border fence. This track gives access to the eastern portion of the sheet. "Quinyambie" is the only permanent habitation on the sheet, being located 199 km north of Cockburn on the border fence. "Frome Downs" is immediately south of the southern edge of the sheet south of Lake Frome, and "Balcanoona", "Wertaloona" and "Moolawatana" are situated along the foothills of the Flinders Ranges to the west of the sheet on COPLEY. Part of the area is also under pastoral leases of "Wirrealpa" and "Tilcha".

The climate is dry, hot in summer, with cold winds and frost in winter. Rainfall is annually low and erratic (100-125 mm/yr), falling mostly in brief storms at 4-5 year intervals with heavy falls of 350-625 mm every 10-20 years. The central portion of the sheet east of Lake Frome is occupied by partly mobile dunes, receiving very low rainfall. Highest and most reliable rainfall occurs in the southeastern corner of the sheet and along the edge of the Flinders Ranges. Most rain falls in the summer months. Winds are dominantly from the southern quarter with a strong westerly phase during May-August and north winds in summer.

The sparse vegetation* is dominated by *Enchylena* and *Kochia* species west of the lake, with *Eucalyptus camaldulensis* in creeks, and *Acacia ligulata, A. victoriae, Dodonia sp.* and *Eremophila sp.* along creeks and on dunes. East of Lake Frome the dominant eucalypt is *E.* aff. *largiflorans* occurring with *Heterodendron oleaefolium* in areas subject to flooding. *Casuarina cristata* and *Acacia aneura* grow on dunes: elsewhere are *Acacia oswaldii, Hakea leucoptera* and in the southeast *Callitris columellaris* forms open woodland, *Nitraria schoberi* occurs around lake edges.

The twelve 1:63 360 sheets comprising FROME with access tracks and some weather statistics, are shown in Figs. 1 and 2. In the text 1:63 360 scale sheets are referred to thus: *Coonarbine*, and 1:250 000 scale sheets thus: FROME.

Geological mapping on the sheet is part of a programme to complete 1:250 000 scale mapping of the State, and to study the Cainozoic stratigraphy in the Frome Embayment, especially in relation to uranium deposition. Some minor scattered outcrop may exist on the eastern part of *Paralana* and on *Wittakilla, Amerarkoo* and the northern part of *Pundalpa* which have not been visited.

The nomenclature used for basins follows Wopfner (1969a). The term "Frome Embayment" therefore refers to the Jurassic and Cretaceous sedimentary basin. The term "Lake Frome area" refers to the region bounded by the Flinders Ranges to the west, Barrier Ranges to the north and Olary Ranges to the south. The northern limit is somewhat arbitrary, and is taken as an approximate east-west line through the southern portion of Lake Callabonna. The blanketing Cainozoic sediments are unconformable on the Cretaceous and relate to a different cycle of events. Hence the Western Tertiary basin is referred to as the Poontana Sub-Basin (after Poontana Ck.).

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*Identifications confirmed by Botanic Gardens Dept., and Woods and Forests Dept. (Adelaide).

This report discusses the regional geology of the Lake Frome area as a whole, and is intended as a basis for the Explanatory Notes for FROME.

PREVIOUS WORK

The area east of Lake Frome was occupied by aboriginal people of the Maljangapa tribe.

In 1843 Frome traversed the plains west of Lake Frome, and visited the lake itself. Later (1862) when it was shown not to be a part of Lake Torrens, Governor Sir Dominick Daly gave it the name by which it is now known.

Surveyor-general Frome was followed by Captain Charles Sturt accompanied by Browne and Flood, in November, 1844, who penetrated across the N.S.W. border in the vicinity of Lake Poverty. Later Browne and Poole reached the junction between Lakes Callabonna and Frome. Sturt (1894) commented on the remarkable parallelism of the sand ridges, but did not regard them as aeolian dunes.

Selwyn passed through the area in 1859 (Selwyn, 1860) and refers on his geological map to "recent tertiary deposits on the surface, fine red calcareous earth mixed with stones, limestone, quartz rock, sandstone, red jasper, quartz and selenite. Crystallized gypsum mostly angular".

In 1882 plant fossils were discovered in wells sunk along the northern edge of Lake Frome (Jones and Tate, 1882; Tate and Watt, 1896) and assigned a Tertiary or Cretaceous age. Others were discovered on CURNAMONA (Tate, 1886 p.55). The depths suggest they were probably Miocene, though variously prescribed an Eocene to Cretaceous age.

H.Y.L. Brown made the first geological survey in 1883. (Brown, 1884). He observed Quaternary conglomerates and clays along the Pasmore River on CURNAMONA, and negotiated the desert east of the lake from Mooleulooloo Hill on CURNAMONA to Yandama Creek on CALLABONNA. From the desert he described the red sandy plains, the poorly sorted interdune sands, and the composite structure of the dunes with an upper red sand overlying fine yellowish horizontally stratified sand. He postulated a fluviatile origin for the sediments beneath the dunes, but was not aware of the wind-blown origin of the dune-sands themselves. In the dune corridors he noted 'secondary' siliceous nodules; elsewhere he described outcrops of clays and sandstones, evidently Namba Formation or Pleistocene deposits.

The Engineer-in-Chief's Department sank water bores in the Frome Embayment during 1885-1920. Cuttings from these holes are preserved in the Department of Mines.

The first geological map was published by Woolnough and David (1926). The next significant survey was that of Jack (1930) who published cross-sections prepared from personal examination of bore cuttings. He defined a number of groundwater basins in the Lake Frome area, and described the stratigraphy, rock types and basement topography.

Kenny (1934) produced a summary of early work and geology in the West Darling district of N.S.W., including the N.S.W. portion of the Frome Embayment. He commenced on the outcrop on the border fence on *Thurlooka*.

Reports by Wade (1915) and Ward (1944) and Osborne (1945) assess the potential of the Cretaceous in the Great Artesian Basin for oil and gas. Osborne was apparently first to introduce the term "Frome Embayment" into print, defining it as a synclinal basin bounded by the Flinders and Barrier Ranges. The Zinc Corporation Ltd., Enterprise Exploration Ltd. and Frome Broken Hill Co. Ltd. began drilling in 1945, and a geophysical reconnaissance took place (Kaufman and MacPhail, 1948). Evans prepared reports and maps (1946, 1948) and carried out aerial and vehicular traverses, locating most of the ferruginous sandstone outcrops of the Tertiary and Pleistocene, which he thought were Proterozoic. He was of the first to suggest the Cambrian beneath the embayment might have some oil potential rather than the Cretaceous. A number of wells were drilled, and provide useful data on sub-surface stratigraphy.

Ker (1966) completed a hydrological survey of the embayment and prepared a structure contour map of the top of the Palaeozoic. His report contains a section by Ludbrook showing correlation with Kopperamanna bore and time stratigraphic units.

Wopfner (1966) and Freeman (1966) discussed the oil potential of the Cambrian and Ordovician, and the Department of Mines began geophysical work in 1962. Wopfner (1970) prepared isopach and facies maps of the Cambrian. Activity by the Department of Mines continued until 1969, accompanying geophysical exploration by several companies. This work is discussed in more detail in the Geophysical Section of this report.

In 1968, Santos Ltd. drilled three stratigraphic wells south of Lake Frome on CURNAMONA, and were later joined by Delhi Aust. Petroleum Ltd. In 1969 the area was farmed out to Crusader Oil N.L., who have completed an extensive siesmic survey.

Interest in the uranium potential of the Tertiary and Cretaceous sediments began with exploration by Kerr McGee Australia Ltd. (Ryan, 1969) in the vicinity of Mt. Painter. They drilled the thick section of Quaternary and Tertiary deposits, but did not penetrate the Cretaceous sediments, which they regarded as having greatest potential. They were unsuccessful in their attempts, but later companies carried out more extensive surveys, culminating in the discovery of shallow Tertiary uranium deposits in the vicinity of John Brown Wash and Four Mile Bore on *Caldina* by Exoil-Transoil and Petromin (The Beverley Prospect).

Several workers have made detailed stratigraphic and palaeontological studies. The first of these were Whittle and Chebotarev (1953) who studied heavy minerals and attempted correlation with bores to the north, but results were inconclusive. The preliminary work of Brown (1950, 1953)who recorded Cretaceous, was followed by that of Ludbrook (1962, and in Ker 1966) who refined the Cretaceous stratigraphy and recorded probable Middle Cambrian and Eocene strata.

Other studies which include the Frome Embayment are those of Dettman (1963) and Dettman and Playford (1969) on Cretaceous palynology. Harris (1970) studied Tertiary spores and pollen.

In 1972 the Department of Mines drilled three stratigraphic bores to assist in uranium exploration (Callen, 1972).

The geology and previous work of the Mt. Painter block is discussed by Coats (Coats and Blissett, 1971), and the portion of this appearing on FROME was previously published on the Mt. Painter special geological map (Coats et al., 1969).

PHYSIOGRAPHY

Physiographic regions are shown in Fig. 3.

The Flinders Ranges (region A) in the northwestern corner of the sheet rise abruptly from the Lake Frome Plains (region C) to 610 m above sea level.

On *Paralana* and *Caldina* are dissected high plains (region B) rising gently from 100 m above sea level along the eastern edge to 155 m where they abut onto the ranges. These plains were uplifted as a unit with the Flinders Ranges, formerly being a part of the Lake Frome plains. The geomorphology of this area is discussed by Twidale (1967).

The Lake Frome plains (region C) have a common fluviatile origin and geomorphic aspect. They are virtually featureless, apart from occasional creeks with eucalypts and low gravel ridges rising from ½ m above sea level at the edge of Lake Frome to 70 m near the ranges. A small area of scattered dunes is developed on *Paralana* and *Caldina* and sparse scrub clothes the area.

Lake Frome is classified as region D, and is a playa-like depression probably with some tectonic control. Islands of stabilized Pleistocene gypsum dunes occur in the southern part of the lake. Its elevation varies from 0.5 m above to 20 m below sea level. Pleistocene shoreline deposits occur sporadically along its west side. Streams, with watersheds in the Flinders Ranges, contribute fine detritus to fans along the western shore. False spits and bars also occur along this shore, and sub-recent beach deposits are present.

The extensive seif dunes of windrift type (term introduced by Melton, 1940), lying east of Lake Frome are classified as region E. These dunes are largely fixed by vegetation, but are active in the centre of the sheet. A unique undulating topography consisting of old Pleistocene gypsum dunes up to 30 m high, forms region F, and has a gypsum "karst" structure of more recent origin developed on its surface. This area lacks vegetation, and is located along the southeastern shore of Lake Frome.

STRATIGRAPHY

PRECAMBRIAN (Table I)

The stratigraphy of the Sturtian, Carpentarian and ?Lower Proterozoic is summarised in Table I. For details see Coats and Blissett (1971); the units are defined in the appendices of their report. A few small outcrops of the "Younger Granite Suite" of Coats are included in the area of brecciated Wywyana Formation outcrop, but are not distinguished on FROME. The Mt. Painter special geological sheet should be consulted for details.

The Corundum Creek Member and lower unnamed Member of the Freeling Heights Quartzite are not represented on FROME.

Basement rocks beneath the embayment are known only from indirect evidence on FROME : Yalkalpo Stratigraphic Bore penetrated conglomerate (?Cretaceous) which contains boulders of porphyritic rhyolite and granite. These were presumably derived from the nearby basement high, known from CURNAMONA. Drilling of old water bores and uranium exploration drilling by Tricentrol N.L. (logged by the author) has delineated a porphyritic rhyolite body on *Eurinilla*, of pre Mesozoic age.

The Pepegoona Porphyry has been shown with tectonic contacts by Young (1973) who shows that the granitized metasediments of Coats constitute bands of "microgranite" intercolated with Terrapinna Granite. Similar bands also occur in the Wattleowie Granite. These "microgranite" bands are regarded by Young as possibly of sedimentary origin. The areas containing these bands have been distinguished by an overprint on the colours of the host rock on FROME.

Correlation between the Flinders Ranges and Barrier Ranges is provided by Thomson *et al.* (1970).

PALAEOZOIC (Table 1).

On CURNAMONA the Middle Cambrian Wirrealpa Limestone was identified (personal communication B. Daily, University of Adelaide, Department of Geology, 1971) in bores drilled by E.A. Rudd & Co., and in another report to Delhi-Santos (1968) Daily identified all the Middle Cambrian units he previously recorded in the Flinders Ranges. Thus some of the red-beds and grey limestones at the base of bores on FROME are probably Middle Cambrian. A Cambrian trilobite was found in rubbly grey limestone at the base of Yalkalpo No. 1 bore (personal communication B. Daily, 1973).

Wopfner (1966) from work at Mt. Arrowsmith, showed Ordovician strata might underlie the basin. In another paper Wopfner (1970) gave strong evidence for existence of Lower Cambrian sediments in the northwestern portion of the Frome Embayment. These probably extend onto the FROME sheet.

Permian sedimentation is not known to have occurred in the Frome Embayment, though it is possible some of the exotic clasts in the Cadna-owie Formation were reworked from a pre-existing Permian cover of glacial origin.

MESOZOIC (Table 2).

Several outcrops of Mesozoic rocks occur on the sheet along the edge of the Flinders Ranges, originally mapped by Coats (1961-1969); two northern outcrops have been identified as silicified Parabarana Sandstone (Ludbrook, 1966, p.10), and others have been referred to the Algebuckina Sandstone (Wopfner *et al.*, 1970) by Wopfner (1969b).

In the Great Artesian Basin to the north, Bulldog Shale and Oodnadatta Formation (Freytag, 1966) are differentiated, using electric log data where the Coorikiana Member is absent. This terminology has generally replaced that of the Marree Formation of Forbes (1966) (e.g. in Forbes (1973)) but is not suitable for use in areas like the Frome Embayment where the Coorikiana Member and Attraction Hill Sandstone Member are absent, and petrophysical log data unavailable. Hence Marree Formation is used in this report. Harris (Appendix II in Townsend 1971) indicates microflora cannot be used to resolve the boundary.

The Marree Formation constitutes a monotonous sequence of dull greenish grey to bluish grey finely micaceous shale and siltstone. Laminated beds, intraformational breccia and conglomerate, and pebble beds consisting largely of quartzite clasts are present. Numerous plant leaf and stem material and faunal burrows or traces are present. Bivalves, foraminifera and microflora are common. The upper part is frquently ferruginized and deeply weathered.

The Cadna-owie Formation (Wopfner, 1969b, Wopfner *et al.*, 1970) is now preferred by Forbes for use throughout the Great Artesian Basin in South Australia in lieu of Pelican Well Formation (Forbes, 1966). It has been demonstrated (Wopfner *et al.*, 1970) that the two units are equivalent. The term Cadna-owie Formation has been more widely used, and was applied informally as early as 1962. The top of the Cadna-owie Formation is gradational, and the boundary therefore difficult to place visually. In Yalkalpo No. 1 there are several readily indentifiable features in the petrophysical logs which could be used to define the top of the unit.

The Formation constitutes pebbles to large boulders forming lenses in silt, shale and sand. Sandy beds are common. Clasts are white quartzite and sandstone, reddish brown porphyry, and fine siliceous shale.

In Yalkalpo No. 1 the Cadna-owie Formation rests on a conglomerate (Unnamed Conglomerate of FROME) with a very small proportion of matrix. The matrix is grey silty shale, as for the Cretaceous, the boulders are porphyry, and various metamorphic rocks. This unit is thought to represent a phase of erosion of the nearby ridge indicated in the cross-sections (A-A' on map, and section 1, this report). This ridge is known to contain a porphyry body of similar type to the Gawler Range Volcanics (Thomson, 1966, p.216), determined from an old water bore and recent company drilling (see earlier).

The Upper Cretaceous Winton Formation has not been positively identified - Ludbrook (1959, and in Ker, 1966) shows the Cenomanian is absent from the sequence south of Tilcha Bore on CALLABONNA. Thus thin Winton beds might be expected in Muloowurtina No. 1 and Poontana Bore but not to the south of this. A brownish sandy sequence in Cootabarlow No. 1 and sandy beds at the top of Poontana No. 1 may represent the unit, but have not been distinguished as such on the bore logs or sections.

Spores and microplankton have been studied by Dettman (1963); Dettman and Playford (1969 especially pages 182-192, Tables 9.1, 9.3, 9.4), Cookson and Eisenack (1958) and Eisenack and Cookson (1960), Evans (1966). A summary of information for Cootabarlow No. 2 hole, the reference section for the *Crybelosporites stylosus* zone of Dettman, is given in Table 3.

TABLE 3

Cootabarlow No. 2 Bore - Cretaceous Microfossil Zones

Age	Zone Microfloral (Dettman & Playford)	Formation	
		Dettman & Playford	This report (From E.&W.S. cuttings)
Aptian to Upper Albian?	*Coptospora paradoxa* 177.1-320.0	TAMBO & ROMA SERIES	177.1-414.5? MARREE FORMATION
Neocomian to Upper Aptian?	*Dictyotosporites speciosus* 405.3-424.2	Lower ROMA SERIES Upper TRANSITION BEDS	414.5?-448.0 CADNA-OWIE FORMATION
Neocomian to Upper Jurassic?	*Crybelosporites stylosus* reference section 440.0-448.6 m	TRANSITION BEDS and Upper BLYTHESDALE GROUP	448.0?-487.7 Cambrian

The subdivisions of Cootabarlow No. 2 by Ludbrook are:

Tertiary	67.1-167.6 m
"Tambo" Albian	167.6-228.6 m
"Roma" Aptian	228.6-365.8 m
"Transition" Aptian-Neocomian	365.8-423.7 m
"Blythesdale" Neocomian-Upper Jurassic	423.7-448.1 m
?Middle Cambrian	448.1-492.3 m

Recently Morgan (personal communication to South Australian Dept. of Mines 1974) examined the microflora of Yalkalpo 1 and found the upper part of the Marree Formation to be missing. He also recorded a number of species characteristic of the Algebuckina Sandstone though the lithology is quite different from this unit, and resembles the Cadna-owie Formation or Pelican Well Formation.

During Upper Cretaceous time, before deposition of the Eyre Formation, deep weathering and kaolinization are reported to have occurred by some workers (Firman, 1969; Jessup and Norris, 1971). This weathered horizon is thought by others (Wopfner and Twidale, 1967) to be associated with the Tertiary duricrust developed during late Eocene to early Miocene times. No occurrences are known (to the writer) of silcrete developed directly on fresh rock, as one would expect in the course of an independent relationship between silcrete and kaolinization. In addition, no silcrete or kaolinite weathered horizons are known from the deeper parts of basins. In the Frome Embayment the kaolinitic and siliceous profiles are developed only in the margins of the basin or on basement highs. Considering the landscape in Upper Cretaceous times one would expect the kaolinitic horizon to be well developed and best preserved in the deeper parts of the basin. Thus the evidence tends to support a post Eyre Formation time for kaolinization, though this need not have occurred as a necessary part of silcrete formation. Weathering of the Cretaceous could perhaps occur through the Eyre Formation sand blanket, thus explaining the presence of kaolinized Cretaceous beneath the Eyre Formation, which is capped with silcrete.

CAINOZOIC (Tables 4, 5 and 6)

In the following text several new formal names and one informal name have been used for rock units on the eastern side of the Flinders Ranges, north of Olary block. These units are defined elsewhere (Wopfner *et al.*, 1974, Callen, 1974). Suggested equivalents are given in Table 6.

Tertiary (Table 4)

Paleocene - Eocene

Deposition during these epochs is represented by the Eyre Formation (Wopfner *et al.*, 1974, formerly Murnpeowie Formation of Forbes, 1966), recognised over a wide area of the Great Artesian Basin, and well-developed in the Lake Frome area. The supplementary sections for this area are Mines Administration bore LCIA and the Reedy Springs Section, originally the Type Section for the Murnpeowie Formation redefined to exclude a possible faulted upper portion (Callen in Wopfner *et al.*, 1974). Yalkalpo No. 1 is a third important section, representative of the eastern area. The Formation is considered to be a refinement of the original concept of "Eyrian" as expounded by Woolnough and David (1926) and David and Browne (1950), and brings together a number of formal and informal units shown to be equivalents of the Murnpeowie Formation.

In the Lake Frome area excellent stratigraphic control is provided by Harris (in Wopfner *et al.*, 1974), who has identified microflora of Paleocene and Eocene age. A disconformity occurs within the unit, a portion of the late Paleocene being absent. This disconformity has been detected in Minad LCIA and Cootabarlow No. 2 bores, and is further supported by the absence of any identifiable sediments of this age elsewhere in this area. The disconformity is also present in Lake Eyre Bore 20, which suggests it is widespread. At present the disconformity is not mappable, hence the sediments are placed in a single formation. However the Eocene is typically finer grained and of a characteristic dark brown colour with leaf remains, in contrast to the coarse sandy Paleocene deposits with black carbonaceous matter.

The lithology of the Eyre Formation is consistent over the whole FROME 1:250 000 sheet, with fine to very coarse-grained sub-mature to mature sands, moderately to poorly sorted and frequently bimodal. The sands are often pyritic and carbonaceous, becoming micaceous on approaching the Olary Ranges. Quartz grains are subrounded and original crystal faces often visible (partly as result of overgrowths). Matrix is usually dominated by kaolin, with accessory montmorillonite and illite. A characteristic pebble bed occurs at the base, with black chert (both fibrous chalcedony and microcrystalline quartz) fossil wood, red 'jasper', milky, grey and colourless quartz. The grains are characterized by high polish. Lenses of black carbonaceous clay occur, and on the western edge of *Eurinilla* (CURNAMONA) a bore drilled by Eric Rudd and Associates (EAR 5, Rudd, 1970) intersected brown carbonaceous clay beneath the basal pebble bed with a slightly older Paleocene flora than is present elsewhere.

The formation reaches its maximum thickness in the Poontana Basin, and thins over the high in the eastern part of the sheet. The base has been tentatively contoured (see tectonic sketch) using cored and uncored levelled holes logged by the author, supplemented by some water bore records interpreted from Ker (1966) and a few company bores.

The Formation does not crop out, except on the N.S.W. border on *Thurlooka*, where a patch of the basal conglomerate is present. Steeply dipping purple cross-bedded coarse sands also occur here, with micaceous matrix. These are tentatively assigned to the Eyre Formation and not to pre Mesozoic rocks as suggested in earlier reports. Lack of straining in the quartz, and retention of primary grain shapes indicates these rocks have not been subject to the metamorphic events which affected the Barrier Ranges block. However, the presence of thin quartz veins cutting across these exposures is difficult to account for : possibly the outcrop represents older rocks (Cambrian or Proterozoic) which have escaped metamorphism.

The contact with the Cretaceous is well defined : coarse polished quartz sand with chert pebbles overlie dull green grey silty shale of the Marree Formation. The upper contact can be difficult to identify, because sands may occur in the overlying Namba Formation. This is the situation in Yalkalpo No. 1 bore. In general the first sands encountered below the black clays or lower carbonate horizon of the Namba Formation are those of the Eyre Formation : they are usually coarser grained, more highly polished, with high roundness and low sphericity compared with the more poorly sorted, angular, fine Namba Formation sands.

Both the lower and upper contacts show disconformable contacts. Channelling is scarce at the lower contact (see Wopfner *et al.*, 1974) but present at the upper contact, where channel sands of the Namba Formation may cut into the Eyre Formation.

Deposition of the Eyre Formation ceased during the Upper Eocene, leaving a widespread sand blanket.

Oligocene - Lower Miocene

Following Eyre Formation deposition, stable conditions prevailed, allowing formation of a silicified duricrust or silcrete* in areas of slight elevation above the water table. Silcrete is present only along the margins

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*Silcrete (Lamplugh, 1902) - material indurated by siliceous cement(Fairbridge, 1968).

of the basin, on 'basement' highs within the basin (e.g. Yalkalpo No. 1 on the Benagerie Ridge). Along the flanks of the Barrier Ranges columnar silcrete is developed on weathered granite, and angular blocks of quartz vein material derived from the granite are to be found within the silcrete, virtually *in situ* in relation to the original vein. Silcrete is always found as a cementing agent to sediment or weathered material.

The presence of silcrete beneath the Etadunna Formation (Stirton *et al.*, 1967) at Lake Palankarinna, demonstrates a pre-Middle Miocene age for genesis of at least some of the silcretes. The number of silcrete horizons developed is unknown at present. None appear to be older than Upper Cretaceous. The significance of columnar structure in identification of a particular horizon is doubtful in view of the possible variations in maturity possible at a particular time as a result of relative position to water table, and tectonics (Wopfner and Twidale, 1967).

No sediments have been recognised from this interval. The duration of the time break may be less than indicated, since refinement of the Lower Miocene - Oligocene palynological data is required - the Namba Formation may persist down into the Upper Oligocene. New palynological zones in the Oligocene - Miocene epochs have been defined by Stover and Partridge (1973) and may clarify the situation.

The silcrete is generally accompanied by an underlying deeply kaolinized zone, which is regarded by some as part of the silcrete profile (Wopfner, 1967; Mabutt, 1965) and by others as pre-silcrete (Firman, 1969; Jessup and Norris, 1971). This is not to be confused with an earlier Jurassic kaolinization (Wopfner, 1964). The fluviatile Eyre Formation (Murnpeowie Formation) would be expected to have eroded the loose kaolinized horizon, and the kaolinization is here accepted as post Eyre Formation. In the Lake Frome area silcrete is best developed near Paralana Hot Springs and on the flanks of the Barrier Ranges, but has not been located on FROME proper.

Miocene

The Middle and ?Lower Miocene are represented by the NAMBA FORMATION (new name, Callen in prep.). The name is derived from Lake Namba (new name*) on CURNAMONA. The Formation is defined in Callen (1974). It is the time equivalent of the Etadunna Formation (Stirton *et al.*, 1967), as shown by similarity in certain characteristic fossil-vertebrates, and comparable microflora, but is treated as a new ormation partly on the basis that it was probably deposited in a separate basin. It also has significant lithologic differences, and the fauna contain new genera not found in the Lake Eyre Basin.

The Namba Formation can be divided into five units on the basis of Wooltana No. 1 (Callen, 1973), using petrophysical log data. For regional purposes an informal two-fold subdivision has been used, based on the occurrence of black tough clays, and abundance of bioturbation. The lower unit (Tmb_2) is dominated by clays rich in montmorillonite, and typified by cyclic deposition involving black clay, cross-bedded sand, finely laminated silt and thin carbonates. The upper unit (Tmb_1), which also contains carbonates, is dominated by fine laminated silt and cross-bedded fine sand with prominent bioturbation, clays are dominated by illite and are light green grey or olive. Cyclic deposition is not common in the upper unit, but where present involves carbonate and laminated silt.

The sediments reach their maximum thickness in the Poontana Basin, and appear to retain the same thickness up to the boundary fault system of the Flinders Ranges, although there is little information on the Tertiary close to the ranges, particularly west of the Poontana structure. The only bores close to the ranges are those of Ker McGee (Ryan, 1969), and a water bore sunk by Exoil N.L. for supply to the 'Beverley' uranium camp. None has suitable records for reliable subdivision. Holes drilled for Exoil and

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*Names formalized by the Geographical Names Board, South Australia, 1973.

Western Nuclear Aust. Ltd. suggest unit Tmb_1 is missing (cross-section A-A') in the high plains area (region B), Fig. 2. Studies of outcrop on *Eurinilla* (CURNAMONA) show a sharp undulating contact between units Tmb_1 and Tmb_2, though there are no signs of weathering.

The outcrop on FROME is mainly of unit Tmb_2 black clay, or silicified sands. The main outcrop occurs on *Eurinilla* and the eastern edge of *Siccus* on CURNAMONA, where unit Tmb_1 is well developed, and the contact with Tmb_2 can be observed.

The dominant clay minerals are montmorillonite or degraded and mixed layer clays (R. Brown, 1972-74, various reports; Davey and Whitehead, 1971) with lesser amounts of kaolinite and illite. Palygorskite is frequently associated with dolomite, the dominant carbonate mineral. The sands are predominantly quartz, with occasionally a high proportion of fine muscovite, and feldspar (dominantly plagioclase); carbonaceous matter may be present. The dark clay contains iron (probably ferrous) as the pigmenting agent, though carbon may contribute to the colour in some horizons. The black clays also contain a varying proportion of fine to medium sand, usually polished and sub-rounded.

The dolomites in the sequence are extremely fine grained, and may contain irregular ooliths. Branching pores often occur, having a dark halo. Ostracods are common, and turreted gastropods and charophyte oogonia and stem moulds may occur.

An early to middle Miocene age (Balcombian, possibly Batesfordian) has been ascertained palynologically by Harris (personal communications 1972, 1973), who compares the flora with that of the Munno Para Clay Member (Lindsay and Shepherd, 1966; Lindsay, 1969) of the St. Vincent Basin. The Miocene flora was found in Cootabarlow No. 2, Wooltana No. 1, Minad LCIA, Central Pacific Minerals F22/26, Glenmore No. 1 (on BROKEN HILL, Brunker, 1967) bores of the Lake Frome area and in Lake Eyre Bore 20 in the Lake Eyre

Basin. The Lake Eyre Bore flora is similar to that of Wooltana No. 1. Correlation with foraminiferal zones of the Murray Basin has been obtained from Tricentrol Aust. Ltd. bores near Mutooroo, OLARY and Southern Victoria (Lindsay and Harris, 1973).

Wopfner (1974) has suggested his Doonbara Formation is Oligo-Miocene and overlying carbonates are equivalent to the Etadunna Formation. His evidence is based on correlation with a ferruginous horizon in Lake Eyre Bore 2, and on the lithological similarity between the Cadelga Limestone and Etadunna Formation limestones. In the first instance the "pisolite" in Lake Eyre Bore 20 is composed of goethite fragments and iron oxides cementing sand, and within this zone Harris (pers. com., 1973) has found a Miocene flora similar to that in the Namba Formation. Thus the maximum age of the ferruginization is early to middle Miocene, and assuming it is the same as Wopfner's pisolite, the Doonbara Formation is middle Miocene or younger. The only ferruginous horizon resembling the pisolite in the Lake Frome area is younger than the Namba Formation, and probably older than the Willawortina Formation. Thus, if this is the same horizon, the Doonbara Formation is Upper Miocene to Pliocene in age, unless there are two pisolite ferruginous horizons as suggested by Firman (1971) and Jessup & Norris (1969).

The carbonates of Wopfner's Cadelga Limestone certainly have a strong physical resemblage to those of the Etadunna and Namba Formations, but this is not enough evidence for correlation, without other criteria.

The contact between the Willawortina Formation (new name, Callen, 1974) and Namba Formation is unclear : it is not certain whether it is gradational or disconformable. A tongue of poorly sorted material, lithologically similar to the Willawortina Formation, is present at the top of unit Tmb_2 in Western Nuclear WC2. The upper boundary of the Namba Formation is here based on the first appearance downhole of characteristic black clays, impregnated with alunite. The alunite is widespread in the western high plains and east of Lake Frome at Lakes Starvation and Bumbarlow. Its structure and vertical distribution suggest it is related to a weathering horizon or soil profile development, thus indicating a hiatus : there is associated silicification at Lake Bumbarlow. In the "Murnpeowie" area drilling by Pechiney (Australia) Exploration Pty. Ltd. (Mannoni and Barral, 1972) has shown "puddingstone" and "grey billy" silcretes are developed at the top of the Namba Formation, and are apparently overlain by Willawortina Formation. A similar relationship is observed in Mines Administration Pty. Ltd. LB12 bore (Brunt, 1970).

The lacustrine clays of the younger Millyera Beds (new name, Callen, 1974) may be difficult to distinguish from the Namba Formation. They are finely laminated and contain abundant ostracods and lenses of sand rich in charophyte oogonia. The clays have a characteristic sub-conchoidal fracture which distinguishes them from the Miocene sequence; they often have a distinctively finely laminated charophyte limestone or gypsum bed at the top.

Upper Tertiary to Lower Quaternary Upper Miocene to Lower Pleistocene (Table 5, 6)

This interval, as elsewhere in continental sequences in South Australia, is poorly defined : there are no distinctive fossils and stratigraphic relationships are ill-defined because the sediments are frequently discontinuous.

In the Lake Frome area, the WILLAWORTINA FORMATION was deposited in the Poontana Sub-basin. It constitutes a wedge shaped deposit of conglomerates, flood plain and stream deposits, and is characteristically affected by secondary carbonate cementation resulting from groundwater action and soil profile development. A red and green mottled effect produced by variations in oxidation state of iron is also characteristic.

In petrophysical logs the base of the unit is well defined in the southern portion of the basin, but in the northern area, where secondary carbonate cementation is absent, it is less distinctive. The repetition of facies in the Namba Formation of Western Nuclear WC2 bore has already been discussed, the problem being whether the unit is conformable or not.

The relationship between the two units has been demonstrated in outcrop by Leeson (1967), and the author (Coats, 1972) on *Balcanoona*, but the outcrop is patchy. A thick sequence of conglomerate and clay of the Willawortina Formation overlies clastics of the Namba Formation and there is no evidence at this locality for an unconformity between the two units, though further detailed mapping is required. On CURNAMONA, along the southern shore of Lake Frome, the Willawortina Formation forms prominent cliffs, which give way over ¼ km to a landscape dominated by the Namba Formation. The sudden disappearance of the Willawortina Formation is possibly the result of depositional processes, (such as the bounding edge of a valley of Willawortina Formation) there being no evidence for former existence of the unit in the eastern regions unless it is represented by a distinctly different facies (the Millyera Beds?). Alternatively faulting may explain the change.

The southern margin of Lake Millyera (new name) on *Eurinilla* and the western bank of Billeroo Creek on *Coonarbine* have outcrops of clays, lithologically identical to the Willawortina Formation, interbedded in the Eurinilla Formation (new name, Callen, 1974). However, the sequence at the mouth of the Pasmore River demonstrates the Eurinilla Formation is disconformable on the Willawortina Formation, making it unlikely that the two units intertongue. Auger borings by the Bureau of Mineral Resources Geology and Geophysics (R. Jensen, personal communication, 1973)have revealed a sequence which suggest a transition from the Millyera Beds in Lake Frome to facies resembling the Willawortina Formation near the western shore, thus lending support to a disconformity between Willawortina Formation and Namba Formation (Millyera Beds are disconformable on Namba Formation).

In the area flanking the northwestern shore of Lake Frome, drilling has shown hard red-brown calcareous and green-grey clays are present (Schindlmayr, 1970). These are probably fine grained equivalents of the Willawortina Formation, and may grade into the Millyera Beds.

The formation is a possible correlative of the Avondale Clay (Firman, 1967) with which it has strong lithological similarities, and which occupies a comparable position in the landscape on the opposite side of the Flinders Ranges.

The Millyera Beds constitute laminated light green to bluish green clay with thin fine sand beds and thin charophyte stem limestone and gypsum laminae at the top. They are structureless and semi-liquid in the lower areas of Lake Frome. They contain abundant fossils (ostracods, charophytes, "Coxiella", worm burrows), but not enough is known of the distribution of these in time to make them useful for age determination or correlation. The Beds have been named after Lake Millyera on *Siccus* and *Eurinilla,* where they are best exposed.

The doubtful stratigraphic position of the unit is the reason for treating it informally. Channel deposits, believed to be the fluviatile equivalents of the lake sediments, are included in the Millyera Beds. They are correlated on the basis of the presence of charophyte-coxiella limestone laminae in both deposits, and apparent equivalence in outcrop. The channels contain brown calcareous nodules derived from the Willawortina Formation, and are therefore younger, though it is possible that these nodules formed contemporaneously with the Willawortina Formation and could therefore be reworked into channels higher in the same sequence. In Lake Callabonna, similar clays contain vertebrate remains of Pleistocene age (personal communication R.H. Tedford, 1972, American Museum of Natural History, New York) indicating the Millyera Beds may be in part equivalent to the channel deposits at or immediately below the base of the Eurinilla Formation (Qp5, Qp6). In Lake Eyre similar beds are referred to the Bopeechee Clay by Firman (1971).

There is therefore evidence that at least the upper part of the Millyera Beds are of Late Pleistocene age. If equivalence with the Willawortina Formation is correct, the unit may have a considerable range in age : this is possible where slow deposition in a playa lake is proceeding : Lake Frome is the lowest part of the basin and therefore deposition could be much more continuous than elsewhere. Even if deposition ceased for long periods, the breaks would be hard to detect unless the groundwater table fell sufficiently to allow soil development. Auger samples taken by the Bureau of Mineral Resources show no obvious breaks in sedimentation.

Limestone beds with charophytes and vertebrate bones were also found overlying Tertiary sediments near Orroroo (Howchin, 1909) and may represent an intermontane basin equivalent of the Millyera Beds.

The next unit to be discussed (Qp_7) is unnamed, because its affiliations are in doubt. It constitutes an extensive sheet of cross-bedded conglomerate and sand, developed particularly along the southern shore of Lake Frome, and the Siccus-Pasmore River system. The unit is solidly cemented with white or buff carbonate, usually crystalline. It contains boulders and pebbles from the surrounding ranges, with a local admixture of carbonate nodules derived from the Willawortina. The Willawortina Formation contains numerous similar lenses of conglomerate, also cemented, but these have different cross-bedding types and directions and are not known to contain carbonate nodules.

Quaternary (Tables 6, and large scale section D-D')

Pleistocene

The Eurinilla Formation is of proven upper Pleistocene age, containing basal channel sands with *Diprotodon, Procoptodon goliah* and *Macropus* being similar in content to that of Lake Callabonna (R.H. Tedford, personal communication, 1973). The fauna was discovered on Billeroo Creek on *Eurinilla* (CURNAMONA).

The formation consists of fine to medium clayey poorly sorted sands, of orange brown colour, impregnated with gypsum at the base, and with interbedded green clays and silty clays. The upper portion often lacks sedimentary structures, or is horizontally laminated, whereas the lower portion contains trough cross-bedding.

The unit has a strongly disconformable contact with the underlying units. East of Lake Frome it generally cuts into the Namba Formation or Millyera Beds, whereas west and south of the lake it is developed on the Willawortina Formation, or cuts into unit Qp7. Frequently the formation is underlain by a cross-bedded loose sand with pebble beds, often cemented in its coarser parts by massive white fine-grained crystalline calcite or gypsum or both. The carbonate and gypsum are related to a past groundwater table, and therefore to an ancient land surface. The deposits occur at variable topographic level in the landscape, but always beneath the Eurinilla Formation, hence they have been distinguished from the latter as a separate unit (Qp6). The best development is on CURNAMONA.

On FROME undifferentiated gravels on the Lake Frome Plains area have been included in unit Qp6. These gravels occupy ridges in the landscape, though they are older than the surrounding sands (Qp1, etc.), this reverse topography being the result of differential compaction and erosion. Some of the gravels may belong to the Qp7 channel deposits.

The distinction between Qp6 and Qp7 sediments is difficult to determine unless the full sequence is observed, as at the mouth of the Pasmore River on CURNAMONA - here Eurinilla Formation, with a thin basal conglomerate (Qp6) cuts down into unit Qp7 and Willawortina Formation. On *Balcanoona* (COPLEY) a small patch of unit Qp6 gravels and sands rests with angular unconformity on dipping Willawortina Formation.

Along the southeastern shore of Lake Frome, and on the islands in the lake itself, are extensive gypseolianite deposits. These dune sands grade through quartz sand dune deposits to the more typical lithology described above. The bedding is of unusual type for dunes, being subhorizontal. The deposits have virtually the same distribution and lithology as unit Qp2, and have therefore been mapped with this unit (Qp2/Qp4), though underlying, and separated from it by a time break.

Unit Qp5 is another unnamed sequence, developed in two widely separated areas : the southeastern shore of Lake Frome and the northern shores at the junction with Lake Callabonna. It invariably occurs at the base of the Eurinilla Formation, directly overlying clays of the Millyera Beds. Lithologically it has a fine to coarse fossiliferous sand. Fine cross-bedding and wavy horizontal bedding is typical, and abundant charophyte stem fragments and oogonia occur.

The presence of a time break between Qp5 and the Millyera Beds is uncertain. The contact with the Eurinilla Formation is apparently gradational at the northern end of Lake Frome, but disconformable with considerable erosion at the southern end, thus it is probably a facies equivalent of this unit.

Beach ridges (Qp3) are developed along the northwestern shore of Lake Frome, which become better developed on Callabonna. There is a distinct change in geographic pattern observable on the photomosaics, east and west of the deposits, which form a line parallel to present shore of Lake Frome. If the line is followed to the south, it is evident that certain gravel ridges (Qp6) coincide with it. One of these has pebbles imbricated perpendicular to its length. The deposits probably represent an old shoreline developed during Upper Pleistocene times. They are overlapped by the Coonarbine Formation sands. They have been mapped as an unnamed separate unit, because stratigraphic relationships need clarification.

The high level plains flanking the Flinders Ranges are veneered with pebbles and cobbles with a sandy matrix, sometimes cemented with soft white carbonate or gypsum. This unit may be an upland equivalent of the Eurinilla Formation.

Units Qp6 and Qp7 are possible equivalents of the Telford Gravel (Firman, 1963, 1964, 1966b, 1967, 1970a).

The Eurinilla Formation is regarded as equivalent to the Tirari Formation (Stirton *et al.*, 1961). J.B. Firman (personal communication 1973) equates the Tirari Formation with the Telford Gravel, but relationships outlined here, and investigations elsewhere in the vicinity of the Flinders Ranges suggest equivalence with the Pooraka Formation or Lake Torrens Formation is also a possibility. The Pooraka Formation has been dated by Williams (1969) and Williams and Polach (1971) as 25 000 to at least 30 000 years B.P.

Pleistocene - Recent

The age of the Coonarbine Formation (Qp1) is unknown, but may extend into the Recent. It contains aboriginal artifacts, land snails and bones of wombat and rat-kangaroo in its upper layers.

The deposits are poorly sorted sands with gravel lenses, forming a thin widespread blanket. Cross-bedding is common in the gravels, but sedimentary structures are usually restricted to diffuse horizontal layering. East of Lake Frome the fluviatile sands grade into better sorted sands of the longitudinal dunes which form the harder cores of the southern Strzelecki Desert dune system. Along the southeastern shore of Lake Frome and on the islands in the lake, occur the coarse gypsum aeolianite deposits, (Qp2) which have already been mentioned.

The Coonarbine Formation has been mapped as Pooraka Formation (Firman, 1966a) on COPLEY, but could also be a correlative of the Lake Torrens Formation of Thomson Creek Formation of Williams and Polach (1971). For this reason, and other reasons outlined at the beginning of the Cainozoic section, the name Coonarbine Formation is preferred for the unit in the Lake Frome area.

In the Callabonna area to the north Firman (1970c) has defined a unit, the Simpson Sand, which apparently includes the modern dunes and the dune system of unit Qp1.

The high level plains are veneered by a thin layer of red-brown sand with reworked cobbles, which occasionally passes into thick cobble deposits derived from weathered Willawortina Formation containing land snails similar to those of the Coonarbine Formation. The two sequences have been mapped as one and distinguished by an overprint. On COPLEY these beds were referred to the Arrowie Formation, but further work is needed before this unit is formally defined, or eliminated by naming priorities and equivalence.

The desert area east of Lake Frome, and also part of the Lake Frome plains, are veneered with red brown loose sands and longitudinal dunes (Qrs). These have been largely reworked from the Coonarbine Formation dunes, and are partly active today. They have steep north faces, and are of the windrift type (Melton, 1940). The unit dominates the eastern half of FROME.

Wind direction studies (Fig. 2) indicate dune building winds are parallel to the present dunes (c.f. Folk, 1971). Erosion of the southern side of the older Coonarbine Formation dunes, and the slightly indurated cores of the Qrs dunes is proceeding, with loose sand building up on the north side.

Relevant studies of Australian dunes have been made by Madigan (1936, 1946), Folk (1971), Wopfner & Twidale (1971), King (1956, 1960), Jessup & Norris (1971), Mabbut (1968), Mabutt and Sullivan (1968) and Williams and Polach (1971). A change in wind direction from dominantly westerly to dominantly southerly winds is proposed by Heath and Wopfner (1963) to explain the one-sided erosion, and the wind data presented in Fig. 2 tend to support this idea.

The unit as mapped on FROME includes residuals of older deposits exposed in interdune areas by the erosional process which led to formation of the windrift dunes.

Old beach deposits were recognised by J.M. Bowler (Dept. Biogeography and Geomorphology, Australian National University, personal communication 1973) during an examination of the islands and shores of Lake Frome. These are related to the present shoreline, but suggest a more active lake phase.

False spits and bars (terminology Reeves, 1968, Fig. 83) are well developed along the western shore, but absent on the eastern side. This is the result of wind action on waters flooding into the lake from the Flinders Ranges. The deposits are probably related to the younger beach sands, and therefore are included in unit Qrs.

Modern lake sediments are very sparse, being restricted to low fans (Qra) along the western margin at creek outlets, and to windblown sands trapped by wet sediments around the lake edge (Qrl) and on mound springs. A thin veneer of salt (Qrl) crusts the lake, and algal stems and mats are found in some areas. Conditions appear to be static over much of the lake at present, with neither erosion nor deposition.

Near the ranges are at least two series of fan deposits, younger than the Coonarbine Formation. These have been included in unit Qpl (overprinted on Qpl colour).

The stream bedload (Qra) constitutes cobbles and sand bars, reflecting a local source from the Pleistocene and Recent units, or from the Flinders Ranges. Most rocks, except vein quartz are chemically broken down by salt weathering in brine springs at the lake edge and would probably not exist more than 10 years on the lake bed without distintegrating completely.

FOSSIL SOILS AND RELATED INDURATION EFFECTS

The use of soils in stratigraphy with South Australian examples has been summarized by Firman (1970b). Stratigraphic relations on FROME are indicated on section D-D' and soil stratigraphic equivalents in Tables 4, 5, 6.

The alunite (K $Al_3(SO_4)(OH)_6$) developed in the Tertiary clays has already been mentioned and has been examined microscopically. In places the mineral grades into jarosite or kaolinite/montmorillonite mixtures. It has a distinctive nodular distribution, frequently forming vertical pipes reminiscent of soil peds with a skin of clay (cutans). Each layer generally has a sharply defined upper surface and gradational lower surface.

It has been suggested earlier that these deposits are a weathering horizon or soil profile related to an old kaolinite in association with sulphate rich solutions (from oxidizing pyrite or gypsum) (Keller *et al.*, 1967). Alunite is widely associated with weathering horizons and unconformities in South Australia and elsewhere (e.g. Millot, 1964).

The oldest recognizable soil is that of the Eocene-Oligocene columnar silcrete horizon, which has already been discussed (TSi_2). Other silcretes are present in the Murnpeowie Homestead area, north of the Flinders Ranges, although they are not known to crop out on FROME, they may possibly be found in subsurface in the north-western corner of the sheet. These silcretes constitute massive botryoidal - weathering and nodular grey orthoquartzite, identical to the older silcrete but lacking vertical structure, and a red brown and white "puddingstone" opaline - chalcedonic silcrete. The former appears to be developed in sandy beds, and the latter in clays. The massive silcrete and puddingstone silcrete are post-Miocene and pre-Eurinilla Formation.

Unit CzSi is a brown silcrete developed on channel sands of the Tertiary units. It is irregularly developed, and intimately associated with iron oxides, which coat the quartz grains of the original coarse sand. It is probably a result of subsurface groundwater type silicification. Nodules of brown silcrete, replacing carbonates, also occur in the finer Tertiary sands and are assigned to this period of silicification.

Unit Qca probably includes several horizons formed by soil processes and cementation by groundwater phenomena. The oldest part of the profile involved deposition of iron and manganese oxide crusts on sand grains, forming pipe like structures and sheets in places. This phase was intimately associated with deposition of soft to hard white carbonate, which formed irregular pipes and solid sheets in the fine sands. In places the carbonate was greenish coloured. This cement was formed as a result of groundwater movements along old Plio-Pleistocene stream channels.

A possible younger groundwater horizon is included in unit Qca. This is the white to pinkish crystalline fine grained carbonate which cements the younger Pleistocene stream channels (unit Qp6, Qp7). It has affected the cementing agents mentioned in the previous paragraph, but has a much wider distribution. It is best developed in coarse sands and conglomerates, as massive cement. In the Qp6 unit it may be developed as soft white cr mbly cement, or massive pinkish sheets. The pink colour is produced by iron oxide stain on the cemented sand grains.

The next youngest development is gypcrete (Qcs), which forms massive to nodular crystalline sheets constituting wedge shaped crystals or fibrous gypsum. This material is deposited wherever there is a suitable permeability barrier, or where the groundwater table has been static (c.f. Forbes, 1963), provided the deposits are older than basal Eurinilla Formation. Thus it frequently forms a hard capping to the basal part of this or older units, and is crudely related to old land surfaces. It is shown only in sections or areas of wide exposure on FROME.

The oldest phase of gypcrete formation is intimately associated with the younger part of the Qca carbonate, cementing unit Qp6. It appears that the two were deposited at the same groundwater surface, but that the composition of the groundwater changed with time or from place to place.

The gypsum is associated with orange and yellow ochre mottling.

Soil carbonate Qcc2 is typically a well developed horizon of soft white carbonate tubules and lumps, with minor gypsum, forming a number of layers. It occasionally develops into lumpy sheets, and hardens when weathered. The soil is widely developed, and associated with the Eurinilla Formation. A soil forming long pipes and sheets of complex structure in the Willawortina Formation is older in appearance. Orange, brown and black ochreous mottling are associated.

Numerous pinkish brown nodules and sheets developed in the Willawortina Formation are regarded as virtually contemporaneous with development of these alluvial fan deposits (c.f. Blissenbach, 1954, Denny, 1967) rather than the result of later processes.

The gypseolianite of the Eurinilla Formation has a massive gypsum crust with a blocky structure, corresponding to the Qcc2 carbonate horizon.

Unit Qcc1 is the youngest carbonate horizon and is developed on the Coonarbine Formation. It resembles Qcc2, but is more weakly developed and the carbonate cylindroids are smaller. Unit Qp2, the gypseolianite equivalent, has a massive nodular crust equivalent to this soil. Both units have a well developed blocky structure, formed by large rectangular peds which may extend into underlying formations of suitable texture.

GEOPHYSICS

Geophysical work began in 1948 for the Frome-Broken Hill Co. (Kaufman and MacPhail, 1948) with magnetic and gravity surveys. Other surveys were carried out by Geoseismic (Aust.) Ltd. - seismic reflection for Santos Ltd. (Dennison, 1950).

From 1962-69 the South Australian Department of Mines completed refraction depth probes and seismic work, and an aeromagnetic survey in combination with the Bureau of Mineral Resources Geology and Geophysics. Aeromagnetic maps are available, and there is a report on the state magnetic map by Parker (1973).

Further magnetic and gravity surveys were carried out by Geophysical Services International for Delhi Australian Petroleum Ltd. and Santos Ltd. (Harding and Geyer, 1963). During 1964-5 Wongela Geophysical Pty. Ltd. conducted reconnaissance gravity for Delhi-Santos Ltd. Further surveys were made in 1966, and three stratigraphic wells were drilled on CURNAMONA, south of Lake Frome. A farm-out agreement was made with Crusader Oil N.L. in 1970, who completed an extensive seismic survey and utilised all available gravity and magnetic data (United Geophysical Corporation, 1966). A more accurate base level was available for their spot height survey than in earlier Department of Mines work : there are differences up to 20 m in height between the two surveys. The survey was also tied in with the Pexa-Carraweena Survey line to the north.

The interpretation suffers from playback problems and velocity changes, particularly in the Cainozoic cover. This has resulted in possible oversimplification of structures, and too shallow depth estimates for the Palaeozoic-Mesozoic unconformity in the western part of FROME (see sections).

Other interpretations have been attempted by Westhoff (1968) and Milsom (1965), both of which suffer from incorrect depth estimates.

A recent interpretation of magnetic data over a wide district including the Lake Frome area was made by Tucker (Tucker and Brown, 1973) and contains useful data. Some of the data is summarised on the tectonic and structural sketch.

The magnetic basement interpretation by Parker indicates a high trending in a northerly direction, occupying the eastern half of the sheet, and a low beneath Lake Frome. Bore data suggested the depth to magnetic basement estimated in the western margin of the sheet is too low, and this is confirmed by later work by Tucker (op cit) who demonstrated the magnetic basement has a depth of 2-6 km near the ranges.

Tucker's estimates of 1-2 km in the vicinity of the Lake Frome Delhi Santos bores (Delhi Aust. Petroleum Ltd., 1968) agree with those of Parker. He suggests (Tucker, 1972) the Palaeozoic and Adelaidean sediments were not magnetic enough to account for the anomalies found in the Frome Embayment area and could better be explained by Willyama type crystalline basement. The Delhi-Santos bores intersected strata close to the base of the Middle Cambrian (1500 m), thus there is little room for development of a thick Cambrian or Proterozoic section. Granite and low grade metamorphic clasts are common in the basal Cretaceous (e.g. Yalkalpo No. 1), and no rocks resembling Proterozoic or Lower Cambrian are found, thus supporting the idea that the area is a crystalline basement block, with a cover of Cambrian, Mesozoic and Cainozoic sediments.

Gravity interpretation by United Geophysical Corp. (1966) shows a high centred beneath Lake Frome, and a broad gravity low in the southeastern portion of FROME, which is supported by Tucker's analysis (Tucker and Brown, 1973).

STRUCTURE (See Tectonic sketch)

The structural geology of the Mt. Painter Block has been described by Coats (Coats and Blissett, 1971). A precis follows.

Rocks comprising the Mt. Painter Complex form two discrete structural units, the northern Mt. Babbage Block (not represented on FROME) and the southern or Mt. Painter Block. The Mt. Painter Block has been deformed into a series of easterly, northeasterly and east-northeasterly trending folds; fold styles reflect the competence of the rocks. Folding occurred during the late Carpentarian phase of tectonism and also in the stronger Lower Palaeozoic orogeny. Adelaidean rocks were folded into a series of open easterly trending domes and basins. Strong fracture cleavage is developed in some of the tighter structures.

Faulting resulted from Lower Palaeozoic events, and took place along pre-existing lines of weakness. The Lady Buxton - Mt. Adams Fault complex is a major structure, and may involve low angle thrusting. A breccia consisting mainly of Wywyana Formation is associated. The vertical displacement of 7 300 m is similar to the Paralana Fault to the south.

Within the Frome Embayment area the broad high in the eastern half of the sheet, with a trough beneath Lake Frome, have been mentioned. The high delineated by the cross-sections is supported by geophysical evidence, and appears continuous with the well-defined structure on CURNAMONA. The structure was first recognised by Jack (1930) and is henceforth referred to as the Benagerie Ridge. Cross-sections show the Mesozoic and lower Cainozoic strata thin out over the high, and there is evidence from drilling on *Eurinilla* (CURNAMONA) that the Middle Cambrian is absent (this assumes the porphyry mentioned previously is not Cambrian).

Structure contour maps of the Mesozoic-Palaeozoic unconformity were prepared by Evans (1946), Wilson (1956) and Ker (1966) from bore data; Townsend (1968) from S.A. Mines Dept. geophysical surveys and United

Geophysics (1966) for Crusader Oil N.L. from seismic data. The Crusader interpretation is shown on the tectonic sketch.

The Tertiary Poontana basin has its axis somewhat further west than the pre-existing Cretaceous Frome Embayment basin. The sediments are faulted against Adelaide Geosyncline sediments and Mount Painter Block igneous and metamorphic rocks to the west. The bounding fault system of the Flinders Ranges constitutes high angle reverse and thrust faults. The high plain areas flanking the Range have a structural control, being uplifted by folding and faulting. Folds are broad domes of low amplitude.

In the Middle Cambrian rocks beneath the basin, seismic work for Crusader Oil N.L. indicates gentle folding with an overall westerly dip. However, this is dependent on interpretation, and further studies are now proceeding in the Department of Mines. Crusader's work indicates a major horst-like fault structure approximately corresponding to the Poontana Structure (Coats *et al.*, 1969) which dominates the area. This feature dies out in the vicinity of Wooltana No. 1 to re-appear further north. Topographic features associated with the edge of the Paralana high-plain area suggests it may persist further north, where geophysical evidence is lacking. These features are shown on the tectonic sketch. The location of the Poontana Fault or Monocline shown on an earlier map (Coats *et al.*, 1969) was based on an incorrect geophysical interpretation by W. Kendall (unpublished).

Crusader show another fault situated a short distance east of the Poontana structure, and parallel to it.

On the N.S.W. Border occur steeply dipping Tertiary rocks, intersected by quartz veins, indicating a major Cainozoic structure in the vicinity. The structure is supported by estimates of depths to the base of the Tertiary from surrounding bores (see tectonic sketch. Drilling by Chevron Exploration Corp. (Morgan, 1973) indicates no change in depth to the base of the Tertiary as one approaches the southwestern side of the outcrop, therefore a fault must be present on this side, with a throw of at least 100 metres.

Another major structure is suggested by the alignment of mound springs along the eastern side of Lake Frome. These are presumably tapping water from the Tertiary or Cretaceous aquifers. Sections drawn across the zone (see map) suggest a thickening and deepening of the Tertiary sequence west of this line, though it is uncertain how closely the two features coincide.

Folding in the Mesozoic and Cainozoic is virtually absent : slight dips were determined from drilling by uranium exploration companies and suggest block faulting with slight tilting to the west beneath the Lake Frome plains. Similar structures of Tertiary to Recent age were suggested by Horwitz (1958).

Regarding the lake itself, it is noted that the deepest end is the southern end, as at Lake Eyre (Bonython, 1955). Perhaps a slight tilting to the south, as suggested for Lake Eyre by Johns (Johns and Ludbrook, 1963) may account for this. This would explain the concentration of gypsum dunes in this region. Other geographic features, such as the zig-zag course of Eurinilla and Coonee Creeks may also have some relation to tectonics.

GEOLOGIC HISTORY

In the Mt. Painter - Mt. Adams area, deposition began at least 1600 million years ago, producing a thick sequence (6 100 m on COPLEY) of sediments known as the Radium Creek Metamorphics. Deposition began with the Yagdlin Phyllite which consits of thin alternating bands of clay (phyllite) and silt (siltstone) overlain by quartzites (Mt. Adams and Freeling Heights Quartzite) containing abundant cross-bedding and ripple marks. This suggests a change from quiet water offshore to near-shore or fluviatile environment. Intercolated in this sequence is the Pepegoona Porphyry, a porphyritic rhyolite which Coats (Coats and Blissett, 1971) regards as being extruded after deposition of the Mount Adams Quartzite and before the Brindana Schist. His conclusion is based on petrological work and observations along two contacts, which are thought to be conformable, but others

(Young, 1973) have suggested the contacts are tectonic. The petrological data supporting or negating derivation from the granites as an effusive phase is inconclusive.

The Brindana Schist underlies and partly intertongues with the Freeling Heights Quartzite, representing a more muddy period of sedimentation, in part magnesium rich.

The sequence was then intruded by the "Older Granite Suite" (Coats and Blissett, 1971 about 1600 m.y.), represented by the Wattleowie Granite and its higher level chilled phase, the Mount Neill Granite Porphyry, and by the later Terrapina Granite intrusion. This resulted in local granitization, and was accompanied by metamorphism. according to Coats.

The sequence was then folded, faulted and uplifted. After prolonged erosion the sediments of the Adelaide Geosyncline were deposited. On FROME they are represented by Wywyana Formation (Willouran) and the Fitton and Bolla-Bollana Formations (Sturtian). The Wywyana Formation marble indicates a phase of carbonate deposition, and was later involved in diapiric intrusions during early Sturtian and later times. On FROME the Wywyana Formation is seen only in a tectonic context in the unusual thrust structure near Mt. Adams. The Fitton Formation consisted of alternating boulder beds, sands and carbonates (calc-silicates) which intertongue with the bouldery greywacke of the Bolla Bollana Formation. Coats postulates a glacial origin for these sediments. Local slumping off granitic highs is another possibility. The remainder of the Proterozoic sequence is not represented.

The area beneath Lake Frome was probably a stable cratonic block during deposition of the Adelaidean. This is suggested by the orientation of basement trends (Thomson, 1974) around the margins of the Lake Frome area, and by geophysical evidence which indicates a thin Proterozoic cover, relatively undeformed (Tucker and brown, 1973). The Lower Cambrian and Proterozoic rocks are either absent or thin over much of the basin, excluding the margins along the eastern edge of the Flinders Ranges, where increased basement depths permit the presence of some Palaeozoic trough in the northwestern marginal area.

During Middle Cambrian times a thick sequence of redbeds were deposited, directly related to those of the Adelaide Geosyncline (B. Daily in Delhi Santos, 1968; Leeson, 1967). Deposition began with a marine transgression which resulted in deposition of the Wirrealpa Limestone. This was followed by continental fluviatile and deltaic facies of the Lake Frome Group (Daily, 1956), which must occur at least under the southwestern portion of the sheet (Delhi Santos, 1968, United Geophysical Corp. 1966; Callen, 1973). The rocks of this sequence are undifferentiated on FROME. The presence of Cambrian fossils was mentioned earlier (p.9), and Mt. Arrowsmith has a Middle Cambrian to Lower Ordovician section (Wopfner, 1966), suggesting the Middle Cambrian may be widespread.

During Middle Cambrian to Ordovician time, folding and local low grade metamorphism of the Adelaide Geosyncline occurred, followed by uplift and erosion. The folding appears to have affected the Lake Frome area to a minor degree compared with the Adelaide Geosyncline.

No Triassic or Permian sediments have been identified from the basin.

During Early Jurassic times epeirogenic movements initiated Formation of the Great Artesian Basin, of which the Frome Embayment is a part. The Embayment formed a lobe of sediments extending across the northern end of the Flinders Ranges to the west and open to the main basin to the north. It owes its present aspect partly to Late Tertiary and Quaternary tectonics. When deposition began, the surrounding ranges were low. Crystalline basement areas were exposed in the Mount Painter area and along the Benagerie Ridge, and contributed to the sandy and silty Cadna-owie Formation and Parabarana Sandstone.

Some of the exotic blocks found in the Cadna-owie Formation may have been derived from pre-existing Permian clastics. The Algebuckina Sandstone (Wopfner *et al.*, 1970, p.912-13, Wopfner, 1969b, Fig. 75) has been recorded on the western margin of the Frome Embayment, but has not yet been identified in subsurface on FROME, and seems to be absent in bores in the eastern half of FROME.

Wopfner (1969b) regards the Parabarana Sandstone as representing the beginning of the Lower Cretaceous marine transgression which followed terrestrial Jurassic conditions. The Cadna-owie Formation is thought to represent a nearshore facies (Fig. 72, Wopfner, 1969b), and hence inter-tongues with the lower part of the Marree Formation at its margins. Pebble lenses identical to those in the Cadna-owie Formation are present in thin lenses throughout the Marree Formation, and the contact between the two is gradational.

In marginal areas of the Frome Embayment the Marree Formation over-laps the Cadna-owie Formation. Thus the gradual degradation of the source area with time has contributed to the change from Cadna-owie to Marree Formations.

Pelecypods, foraminifera, microflora and carbonized plant fragments are common in the Cretaceous strata.

During Late Cretaceous time stable conditions and non deposition prevailed until the Early Paleocene, when renewed uplift initiated a new phase of sedimentation, particularly in the Barrier and Olary Ranges and on the Benagerie Ridge.

A widespread sand blanket of fluviatile origin was deposited over much of the Great Artesian Basin (Eyre Formation, Wopfner *et al.*, 1974). It represents braided and meandering stream conditions (Callen, 1973) with the former dominating during Paleocene times. Fine grained sediments form a small proportion of the volume of the deposits, and no fine equivalents are known at present, suggesting the basin had an outlet to the sea, and constant reworking and high rainfall flushed out the fines. High rainfall humid conditions are indicated by the floral content, and presence of carbonaceous deposits indicates a reducing environment. Fragments of soft fossil wood are common, and disintegrate to produce an aqueous suspension when disturbed by drilling, and subject to atmospheric exposure.

Mica content increases toward the Olary block, indicating it was a source for some of the sediments, and the Mt. Arrowsmith area is cited as a source for the north (Wopfner, *et al.*, 1974). Kaolinite is the dominant clay mineral, and is thought to be derived from Cretaceous strata, which are rich in kaolinite, or weathered crystalline basement. Pebbles of fossil wood, chert and ?porphyry are present, and originated from the Mesozoic strata, uplifted on the surrounding ranges.

The uppermost Paleocene is not represented in the Lake Frome or Lake Eyre basins, (Harris in Wopfner *et al.*, 1974), indicating a widespread hiatus. The Eocene sediments are finer, brown, carbonaceous silt, representing swampy conditions and dominantly meandering streams.

Widespread stable conditions then prevailed during the Oligocene, which was largely a period of non-deposition (e.g. McGowran *et al.*, 1971).

A massive, usually columnar, silcrete crust was formed in areas slightly above the water table, and was best developed in porous sediments or soils. Silica for this material was largely released by corrosion of quartz and possibly from weathering of, or during the formation of, kaoinite. This could have taken place in situ or the silica rich solutions may have travelled some distance to their point of deposition. Massive silcrete of this type is rare on FROME, but occurs along the margins of the Flinders and Barrier Ranges in areas which have been uplifted by later tectonic activities. Similar silcretes are widely developed in central Australia (Mabutt, 1965, 1967).

It should be noted that many similar silcretes may occur in the section, associated with other unconformities.

During Early Miocene (Balcombian-Batesfordian) the Poontana trough began forming west of Lake Frome, and was the site for deposition of very finely laminated fissile clays in a probable fresh-water lake environment. These clays contain a rich non-marine fauna, and a flora including *Nothofagus, DACRYDIUM, Podocarpus, Eucalyptus, GRAMINEAE, RESTIONACEAE, Casuarina* and the algae *Pediastrum* (Harris, W.K., personal communication, 1974). This flora was found in Wooltana No. 1 and Minad LCIA bores, but the clayey facies is restricted to Wooltana No. 1 and some of the Central Pacific Minerals bores (Schindlmayr, 1970).

The climate and environment of deposition of the Miocene is described in detail in Callen (1974).

The fissility of the clays (White, 1961) and presence of *Pediastrum* are indicative of a fresh water environment, and the plant species suggest high rainfall and probably warm conditions, particularly in the presence of *Nothofagus* and *Podocarpus* which are restricted to high rainfall areas at present. Warm conditions are also suggested from foraminiferal evidence in equivalent marine strata of the Murray Basin.

An extensive unsuccessful search for marine influence, in the form of foraminifera,was made by Lindsay (personal communications, 1972-4). There is therefore no evidence for marine influence, though shelly fauna known to be tolerant of a wide range of salinity conditions are present.

Higher in the Miocene sequence, vertebrates are recorded, including *TELEOSTI, DIPNOI, CHELONIA, CROCODILIA, LACERTILIA, AVES* (waders, ducks, flamingoes and gulls), *DASYURIDAE, PHALANGERIDAE, PHACOLARCTIDAE, ?PERAMILIDAE, CETACEA* (porpoise), *DIPROTODONTIDAE* and other new forms (Tedford, R.H., 1971-1973 personal communications, American Museum of National History, New York).

These animals occur in flood-plain or shallow lake and channel deposits, intercolated with dolomitic marl and dolomite. They suggest a large body of permanent water with forested shores. These results are in agreement with the high rainfall suggested from floral evidence, and are supported by the presence of degraded clays, which require strong leaching in the source rocks.

The abundant montmorillonite requires a different explanation, particularly in view of its association with dolomite-palygorskite horizons. Montmorillonite requires the subdued leaching found in semi-arid or arid soils, or swamps (Berner, 1971). Its present distribution is confined to high latitudes especially in areas of volcanic activity (Biscaye, 1965, Rateev, 1969).

Dolomite and palygorskite* are intimately associated, and detailed petrological relationships support the neoformation of palygorskite in a Mg^{++} rich environment as suggested by Millot (1964) and McLean *et al.* (1972).

The palygorskite-dolomite association can form in playa-lake type environments by precipitation (McLean *et al.*, 1972, Bentor *et al.*, 1963) or can be deposited as a detrital component in hypersaline type environments where it is eroded from soils (Meester, 1971, Singer *et al.*, 1972). Alternatively palygorskite can form in fresh water, marine or hypersaline environments where the adjacent land has very low relief and is being subject to tropical lateritic weathering with dense vegetational cover (Millot, 1964). The vertebrate fauna is associated with carbonate, and palygorskite-dolomite beds occur a few metres above, therefore an arid environment seems unlikely.

However a subtropical warm climate produces difficulties : plagioclase feldspars frequently form a significant proportion of the fine silts and sands, sometimes being more abundant than potash feldspar. Secondly,

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* Di-Tri Octahedral chain lattice silicate type clay : $(Mg, Al)_2 Si_4O_{10}(OH).4H_2O)$

halite associated with the palygorskite (Brown, R., Amdel Repts. 1971-73) and minor sedimentary structures of the type described by White (1961) suggest a saline environment. The presence of plagioclase can be ascribed to derivation from sources within or very close to the basin, with deposition into an environment favourable for preservation, or by derivation from volcanic ash. Vulcanicity was prevalent in southeastern South Australia and eastern Australia in Oligo-Miocene times (Sutherland *et al.*, 1973), suggesting this is a possibility, but no definite evidence of volcanics in the form of devitrified glass shards and related features have yet been found. The saline waters could be explained by assuming an estuarine environment or sufficient evaporation. The evaporative environment could be met if the basin were shallow and enclosed. Abundant evidence for a shallow basin with intermittent exposure of the lake sediments to weathering is available.

It is thus conceivable that the sediments were deposited in a monsoonal or semi-tropical climate, though arid conditions may have intervened, particularly during unit Tm times. Whatever the details, high temperature is strongly suggested, in agreement with palaeotemperature measurements (Gill, 1968; Devereux, 1968; Jenkins, 1968), for Australia and New Zealand, which were high (18-22^{o}C) at this time. During this period Australia is purported to have been closer to Antarctica (Wellman *et al.*, 1969) and the cooling of Antarctica was under way (Hayes and Frakes *et al.*, 1973). This can only be explained if drift away from Antarctica was rapid, and the subtropical climatic zone of the earth was greatly expanded, with polar and temperate zones reduced. Recently Wopfner (1974) suggested a similar situation based on evidence from the Doonbara Formation and Cadelga Limestone, though as pointed out earlier, his estimate of the age of these units is tenuous.

Throughout Miocene time the high area in the eastern portion of the sheet continued its positive movement, resulting in a thin sedimentary section when compared with the Poontana basin.

Following deposition of the Namba Formation, a marked change in conditions occurred as a result of uplift of the Flinders Ranges in Upper Tertiary to Pliocene times. The lakes were swamped with detritus, and extensive alluvial fans formed under semiarid conditions. Static parts of the fans (e.g. Blissenbach, 1954) were subject to pedogenesis, permitting build up of thick complex soil horizons. Meandering streams dominated the lower part of the fan environment, whereas thick sheets of clayey boulder deposits (probably fanglomerates) built up near the ranges. These deposits were accommodated in the Poontana Basin in the region of the present Lake Frome plains. Uplift during Miocene times was first suggested by Howchin (1913) for this area*.

Equivalence of units east of Lake Frome is uncertain. There is evidence for uplift and weathering, producing alunite and silcrete, before the Willawortina Formation was deposited.

The Millyera Beds include unlaminated sloppy clay and fine sand with charophyte (*CHARALES*) oogonia in Lake Frome, and more indurated laminated beds at a higher level flanking the lake. These beds contain ostracods, gastropods and charophytes, and have a thin laminated limestone consisting of charophyte stem moulds at the top. The latter grades into ripple marked gypsum in some areas, and is indicative of deposition in a shallow lake.

Onshore, east of Lake Frome, are ferruginized and calcified channel sands with interbedded charophyte stem limestones and basal conglomerates. Worm burrows and silicified coniferous (personal communication W.K. Harris, 1973) tree trunks (some with roots and branches) are common. These beds are possible fluviatile equivalents of the Millyera Formation, representing river channels which cut down into the Namba Formation, and flooded out in some areas into shallow ephemeral lakes with charophytes. The conifers grew on the old landsurface of the Namba Formation which later became ferruginized and silicified (CzSi) along channel banks.

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* A similar situation is recorded by Binks (1972) for the Ediacra area.

In the Siccus River region, extensive conglomerates (Qpr) represent the ancient river system, which was roughly coincident with the present-day channel, though it diverges east in its upper reaches.

Thus rainfall was higher than at present, though evaporation was also high. The basin was closed by uplift of the Olary Ranges, and folding occurred flanking the Flinders Ranges, and on the border on *Thurlooka*. The period of deposition ranges from Upper Miocene to Lower Pleistocene.

Conglomerates with local and basement derived pebbles followed deposition of the Millyera Beds and Willawortina Formation. They were deposited in meandering stream channels, which cut deeply into the earlier landscape, and re-eroded the old stream channels (e.g. Lake Tarkarooloo, new name, on CURNAMONA) formed during deposition of the Millyera Beds. They are solidly cemented by soft white or crystalline calcite, during a phase of carbonate deposition related to an old land surface.

The Eurinilla Formation records an initially fluviatile environment, later developing extensive aeolian deposits, including dunes and loess and possibly the lower phase of gypsum lunettes (c.f. Bowler, 1970). The streams coincided closely with present drainage, the sediment deposited in the linear lakes on *Eurinilla* was again eroded, and Lake Frome decreased to something approaching its present size. Deltas built out into the lake, and the western shoreline migrated to the east. Large marsupials existed in the vicinity. This unit therefore records the onset of aridity, and the development of the modern Lake Frome. The large size of the marsupials may indicate low temperature.

Beach deposits along the western shores of Lake Frome and Lake Callabonna probably represent a static lake level during Eurinilla Formation times. Unit Qp5 is closely associated with these deposits - shelly sands identical to those at the Poontana Creek - Lake Frome junction occur in patches on the beach ridges. The position shown for the beach ridges on the

FROME legend is its highest possible position in the stratigraphic column. A feature of unit Qp5 deposits is the presence of foraminifera (J.M. Lindsay, personal communication, 1973). A similar assemblage at Lake Eyre has been suggested by Ludbrook (1965) to survive in salt lakes as a result of introduction by gulls.

The Eurinilla Formation filled depressions in the landscape, and was followed by development of a calcareous paleosol. Later a new phase of deposition set in, represented by the Coonarbine Formation. Streams with floodplains deposited a blanket of sediments, eroded much of the Eurinilla Formation, and developed an extensive system of seif dunes. The distribution of sediments is closely related to the present landscape, with fans and floodplains west of Lake Frome, and seif dunes with rare streams to the east. Aboriginals hunted a fauna similar to that now living and camped at water holes during the last stages of deposition. The water holes are now absent, suggesting aridity in more recent times.

Gypsum lunettes again formed in, and adjacent to Lake Frome, indicating westerly wind directions similar to those of the earlier phase. A carbonate soil horizon formed, following cessation of deposition.

During Late Pleistocene times the Flinders Ranges and flanking high plains continued to be uplifted, whilst the Olary and Barrier Ranges were static.

A Recent lake phase resulted in wave cutting of cliffs around Lake Frome, followed by beach deposition, and later development of false spits and bars. Deposition then almost ceased, and is proceeding at a very slow rate at present. There is no evidence for erosion. Fans along the west shore are active, though deposition is slow. The Coonarbine Formation dunes are being eroded on the south side, with production of mobile red brown modern sand crests having steep north faces. The heavy rains of 1972 (2500 mm) resulted in 2 mm of clay silt being added to the plains adjacent to Poontana Creek near the ranges.

ECONOMIC GEOLOGY

Metallic Minerals

The metallic minerals of the Mount Painter Province are discussed by Blissett (Coats and Blissett, 1971).

The economic value of the area, with respect to mineral resources, lies in its potential for sedimentary uranium. Considerable uranium has been proved by Petromin N.L. and Western Nuclear Aust. Ltd. at the Beverley Prospect in the Paralana area. Some has also been located on CURNAMONA. The uranium is of the roll-front (Gruner, 1956) or blanket type, occurring in a sedimentary environment which is common to many of the North American deposits (Gabelman, 1971; Finch, 1967; Parker, 1969). The clayey fine sands of the Namba Formation and coarser sandy facies of the Eyre Formation are the prospective horizons (Callen, 1973).

Potentiality for V, Cu and other minerals associated with U should be explored. Thick (up to 1 m) beds of pyrite-marcasite cemented sands are present in the Eyre Formation on CURNAMONA.

There is also potential for heavy mineral deposits - the Eurinilla Formation at one locality on the western shore of Lake Frome contains rutile, and heavy minerals containing 70% zircon and 2.8% rutile were found in surface deposits at Lake Cootabarlow (Stillwell, 1949). The sands of the Eyre Formation, particularly on CURNAMONA, contain up to 5% rutile in some of the company bores.

Manganese "Wad" occurs rarely as massive layers in the Miocene sands, and is related to past groundwater movements of probable Plio-Pleistocene age. Some outcrop of this material has been prospected along Tielta Creek.

Non-metallics

Several workers have studied the hydrogeology, the most recent being Ker (1966). Underground water resources are good over most of the sheet,since the Lower Cretaceous Great Artesian Basin sediments are present. West of

Lake Frome water of variable quality is obtained from several sources. (1) The Eurinilla and Coonarbine Formation gravels, (2) the sands of the Willawortina Formation in the northern areas, where it is uncemented, (3) Tertiary sands which provide good quality sub-artesian water. East of Lake Frome, aquifer (3) provides good supplies (W. Brown, 1950, who misidentified the aquifer as Cretaceous). The fourth, major, aquifer is the Cretaceous Cadna-owie Formation or Algebuckina Formation (Interstate Conference on Artesian Water 1929). The Cretaceous aquifer has not been utilized in the western region. Various springs situated along the western shore of Lake Frome, and the mound springs within the lake, are too salty for stock.

Flow from the eastern artesian bores is uncontrolled and local graziers state that a reduction of 25-50% has occurred in the last 30-40 years.

Swelling clays of the palygorskite and degraded ?montmorillonite type occur in outcrops around many of the small lakes. Palygorskite is associated with dolomite. Kaolinite is common in association with Eyre Formation sands, particularly near granitic source areas.

Extensive gypsum deposits are present, usually mixed with clay and sand of the Eurinilla Formation and also deposited beneath the Lake Frome surface. Salt crust is very thin, and has not altered appreciably in thickness over the last four years, in spite of large inflows of waters.

Alunite occurs over a wide area, but is often impure, mixed with montmorillonite and kaolinite or jarosite. Outcrop occurs at Lakes Bumbarlow and Starvation; elsewhere it occurs in bores.

The Eyre Formation contains large fragments of coalified wood (e.g. Yalkalpo No. 1) and methane gas has been detected from many bores on the east side of the lake.

Testing for phosphate (Russ, 1966) was unsuccessful, and recent tests on Tertiary material gave very low results (consistent with a non-marine environment).

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NAMING OF FEATURES IN LAKE FROME AREA

No. on map	New Names	Derivation	Lat.	Long.	Map Sheet
1.	Arboola Claypan (Dry claypan, fills intermittently	From Arboola Bore 2 mls. on 52° ENE.	From 30°31'55" To 30°33'08"	140°20'00" 140°18'53"	FROME 1:250 000 Elder 1: 63 360
2.	Lake Yellnif (Dry salt pan, fills intermitt- ently).	From Yelniff Dam 10 mls. on 100° to SE.	Betw. and Betw.30°35'42" and 30°36'38"	140°16'31" 140°17'16"	"
3.	Lake Maljanapa (Dry salt pan, fills intermitt- ently).	After Aboriginal tribe which once inhabited the area (Tindale 1940).	Betw. and 30°42'05" 30°45'32"	140°11'30" 140°11'30"	"
4.	Lake Culberta (Dry salt pan, fills intermitt- ently).	From Culberta Bore, 8 mls. on 42° to NE.	Betw. and between 30°46'42" 30°48'20"	140°21'15" 140°22'00"	" Coonarbine 1: 63 360 sheet
5.	Lake Karpi (Dry salt pan, fills at very rare intervals).	Local aboriginal name for egg (Curr, 1886).	Betw. and between 30°51'50" 30°53'30"	140°12'32" 140°14'30"	"
6.	Lake Moko; clay pan at junction of Eurinilla and Billeroo Creeks. Generally some water.	Local aboriginal name for fly (Curr, 1886).	30°53'30" 30°56'01"	140°10'14" 140°11'06"	"
7.	Lake Kuturu; as above. Generally con- tains some water.	Local aboriginal name for swan (Curr, 1886).	30°50'08" 30°51'34"	140°01'04" 140°04'13"	"

No. on map	New Names	Derivation	Lat.	Long.	Map Sheet
8	Lake Koorka; as above. Generally dry.	Local aboriginal name for stone axe or tomohawk.	30°58'24"	140°19'55" centre of pan	Coonarbine 1: 63 360 sheet

No. on map	Names for confirmation(already used locally)	Derivation	Lat.	Long.	Map Sheet
9	Lake Sonneman on Coonee Creek.	From Mr. F. Kelly "Quinyambie" via Broken Hill.	30°07'51" centre of pan	140°42'58"	FROME 1:250 000 Amerarkoo 1: 63 360 sheet
10.	Lake Coonee on Coonee Creek.	as above after Coonee Creek.	30°17'28" centre of pan	140°39'36"	Coonee 1: 63 360
11.	Lake Kamerooka on Coonee Creek.	On old pastoral plans.	30°03'00" centre of pan	140°53'07"	Amerarkoo 1: 63 360
12.	Lake Wallace Creek.	Flowing into North side L. Starvation - continuation of this creek from NSW (ref.. Broken Hill 1:250 000 geol. map, NSW geol. survey).			Coonee 1: 63 360 map sheet.
13.	Packsaddle Creek	Flowing into South side L. Starvation - continuation of creek of same name in NSW (ref. as above).			Coonee 1: 63 360 map sheet.
14.	Floods Creek	Crosses border at ending in unnamed clay pan on Thurlooka sheet (ref. as above).	30°40'16"		Thurlooka 1: 63 360 map

No. on map	Names for confirmation (already used locally).	Derivation	Lat.	Long.	Map Sheet
15.	Tielta Creek	Continuation of Creek of same name in NSW (ref. as above), ends at Glanmanyie Bore.			Quinyambie 1: 63 360
16.	Lake Poomanyie	Wrongly shown as Lake Carnanto on recent maps, old pastoral plans indicate correct location.	Betw. 30°54'55" 30°55'58"	140°44'06"	"
17.	Lake Carnanto	Wrongly shown to north (see 16). 4 appears from old pastoral plans that is the correct position.	Betw. 30°58'00" 30°59'30"	and 140°44'00" 140°45'10"	"

No. on map	New Names	Derivation	Lat.	Long.	Map Sheet
2.	Lake Tarkarooloo (semi permanent Waterholes(briny) Runs like a creek after heavy rain).	Aboriginal for "many water holes" - a number of salt springs exist along the lake. Joins Billeroo Creek at thence southeast to thence east to an arm extends due west to	31°00'32" 31°03'38" 31°11'55" 31°02'59"	140°01'53" 140°06'14" 140°07'30" 140°01'05"	CURNAMONA 1:250 000 map sheet Eurinilla 1: 63 360
1.	Lake Millyera on Billeroo Creek. (Fills after heavy rain).	Local aboriginal for "water".	Betw. and 31°01'19" 31°04'24"	139°56'25" 140°00'19"	Eurinilla & Siccus 1: 63 360 sheets
3.	Lake Yanda (Claypan on Eurinilla Creek).	Local aboriginal name for "hill" - low rocky hills on north west side.	31°00'08" 31°01'10" At north and south ends of clay pan.	140°19'37" 140°19'11"	Eurinilla 1: 63 360

No. on map	New Names	Derivation	Lat.	Long.	Map Sheet
5.	Lake Pinpa (oval shaped lake which rarely contains water).	Characterised by extensive growth of "native pine" (<u>Callitris</u> sp.) on west side - Pinpa is local aboriginal name for this species of tree (Curr, 1886). Axis of lake Extremities lie between and	 31°07'20" 31°08'39"	140°13'06"	Eurinilla 1: 63 360
6.	Lake Namba (long narrow lake running N-S, fills after heavy rain).	Name derived from local aboriginal for "bonefish" (Tindale, 1940) - fossil lungfish and other vertebrates were found here in 1972 Extremities are	31°10'40" 31°15'18"	140°14'23" 140°13'49"	Eurinilla - Benagerie 1: 63 360 sheets
9.	Lake Jadliaura & Jadliaura Creek	After aboriginal tribe living in area.(Tindale, 1940). Lake adjoins L. Frome, and creek flows into it from south. Head of Creek Ck. outlet into Lake Western extremity of Lake Eastern extremity of Lake	 31°27'47" 31°06'52" 31°05'39" 31°07'45"	 139°51'30" 139°54'39" 139°51'13" 139°54'39"	Siccus 1: 63 360

No. on map	Names for confirmation	Derivation	Lat.	Long.	Map Sheet
4.	Lake Wauwauba (small claypan).	On old pastoral plans (S.G.O. 617/67)	31°05'41"	140°31'19"	Berber 1:63 360
7.	Lake Mongala (Claypan)	On old pastoral plans.	31°19'35"	140°20'54"	

18. on FROME	Extension of name Billeroo Creek (formerly "Salt Creek").	From Billeroo Creek of which it is the continuation, after joining with Eurinilla Creek at Lake Moko. Passes through Lakes Kuturu and Millyera before emptying into L. Frome. Adjoined by Lake Tarkarooloo.	FROME 1:250 000 Coonarbine 1:63 360 CURNAMONA 1:250 000 Eurinilla & Siccus 1:63 360

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Contribution by Reid & Morton

Green

Bonney

Dix

Lebrun

TINDALE, N.B., 1940. Trans. R. Soc. S. Aust. 64-(1).

TABLE 1. PRECAMBRIAN AND PALAEOZOIC ROCK UNITS

Unit	Symbol	Description	Stratigraphic Relationship	Fossils	Thickness (m)	Topographic Expression	comments
COVER OF CURNAMONA CRATONIC NUCLEUS							
Unnamed Cambrian sediments	?Є	Probably Lake Frome Group - reddish brown slate, siltstone, blue grey rubbly limestone (WIRREALPA LIMESTONE) may include Lower Cambrian.		Trilobite		Subsurface, southern Frome Embayment area	Fluviatile and shallow marine
Undifferentiated Cambrian and Proterozoic	Є - P	Grey limestone, white quartzite, grey slate				Subsurface Frome Embayment area	
ADELAIDE GEOSYNCLINE & MT. PAINTER INLIER							
Bolla Bollana Formation	Pyb	Massive blue green pebbly greywacke, minor siltstone and quartzite.	Intertongues with Fitton Formation.			Moderate relief	Glacigene
Fitton Formation	Pyf	Tilloid and calc-silicate metasediments quartzites, boulder beds, pebbly arkose.	Unconformably overlies Burra Group.		2000	Low relief	Glaciomarine?
UNCONFORMITY							
Unnamed Dykes		Amphibolite (metamorphosed basaltic rocks)	Intrusive				Basic intrusive
Wywyana Formation	Pcy	Actinolitic marbles, minor amphibolite, calcsilicate hornfels and siltstones.	Tectonic contacts			Valleys	Breccia Diapiric?
UNCONFORMITY							
Terrapinna Granite	pЄt	Rapakivi - like granite, minor adamellite, augen gneiss.	Intrusive			Low hills	Acid intrusives all related.
Mount Neill Granite Porphyry	pЄn	Massive red-weathering porphyritic granite or granite porphyry. Phenocrysts dominant over matrix.	Intrusive			Rounded hills	
Unnamed Granite	pЄ2	Massive white weathering dark grey microgranite.	Intrusive				
Wattleowie Granite	pЄw	Weakly gneissic white granite and adamellite	Intrusive				
Freeling Heights Quartzite (Lower Member)	pЄf	Medium to coarse sericitic feldspathic quartzite, quartzose schist, quartz pebble conglomerate at base.	'conformable' contact Brindana Schist		600	Rugged hills, some strike ridges and valleys.	Cross bedding common, rare ripple marks.
Brindana Schist	pЄr	Quartzose schist, biotite and muscovite schists, minor garnet sericite schist, epidote quartzite, hornfels, amphibolite. garnet rock.			950+	Forms small ridge	
Pepegoona Porphyry	pЄp	Recrystallized porphyritic rhyolite(?).	Contacts may be tectonic		1 300	Low foot hills	Lava flow or near surface intrusive
Mount Adams Quartzite	pЄa	Medium grained feldspathic quartzite, minor grit.	Stratigraphic relationships uncertain.		310+	Rugged hills.	
Yagdlin Phyllite	pЄg	Laminated grey-green phyllite, lenticular quartzite, (sedimentary lamination).			400		

Note: Plan amended April 1976

FIG. 3

DEPARTMENT OF MINES — SOUTH AUSTRALIA

MOUNT PAINTER BLOCK AND LAKE FROME EMBAYMENT

PRECAMBRIAN AND PALAEOZOIC

	R.A. Callen GEOLOGIST	Drn. R.A.C.	SCALE: —
		Tcd. A.F.	74-773
		Ckd.	
Director of Mines		Exd.	DATE: SEPT. 1974

TABLE 2 LAKE FROME AREA - MESOZOIC ROCK UNITS

	AGE	ROCK UNIT	SYMBOL	LITHOLOGY	FOSSILS	THICKNESS (METRES)	COMMENTS
CRETACEOUS	Aptian to Upper Albian	MARREE FORMATION (OODNADATTA FORMATION AND BULLDOG SHALE)	K1m	Monotonous sequence of dull greenish grey micaceous shale and siltstone, intraformational breccia, minor pebble beds.	Burrows, leaf impressions & carbonaceous material. Spores. Foraminafera	150-275	Often pyritic or ferruginous. Present in most deep bores, outcropping in small areas along Flinders Ranges. Sand beds may be Attraction Hill Sandstone in part. Could include some Winton Formation at top (non-marine). The Oodnadatta & Bulldog shale are lithologically indistinguishable on present evidence.
	Aptian or younger	PARABARANA SANDSTONE	K1r	Massive medium grained white sandstone with rare poorly defined cross-bedding.	Plant stem and leaf impressions.	20 max.	Not recognised in bores, small silicified outcrops adjacent to Mt. Painter Block. Porphyry pebbles
	Neocomian to Aptian	CADNA-OWIE FORMATION (Pelican well Formation)	K1c	Sandstone, micaceous, medium grained and subangular interbedded with dull greenish-grey micaceous shale and silty shale, pebble and boulder beds common, some limestones.	Leaf and stem detritus, spores.	52 max.	Identified in Cootabarlow No. 2, Coonee Ck., Arboola, Lakeside No. 1.Black Oak, and Curraworra Bores and Yalkalpo No. 1
JURRASSIC - CRETACEOUS	Upper ?Jurrasic to Neocomian	?VILLAGE WELL FORMATION		Well-sorted sandstone with subrounded to rounded grains alternating with micaceous sandstone, reddish sandstone.		55?	Curraworra Bore? (very thin). Mooloowurtina No. 2, Poontana Bores. Possibly Algebuckina Equivalent. Not differentiated from K1c on map.

DEPARTMENT OF MINES — SOUTH AUSTRALIA

LAKE FROME AREA

MESOZOIC

	R.A. Callen GEOLOGIST	Drn. R.A.C.	SCALE : -
		Tcd. A.F.	74-771 Cd
		Ckd.	
Director of Mines		Exd.	DATE : SEPT 1974

TABLE 5 LAKE FROME AREA - CAINOZOIC - TERTIARY

AGE	ROCK UNIT	SYMBOL	LITHOLOGY	SEDIMENTARY STRUCTURES	CRITERIA FOR CORRELATION	FOSSILS	GEOMETRY	GEOMORPHIC EXPRESSION	SECONDARY WEATHERING EFFECTS
Uncertain LATE MIOCENE-PLIOCENE possibly to EARLY PLEISTOCENE. From relationship to NAMBA FORMATION	WILLAWORTINA FORMATION	Czw	Extremely to very poorly sorted bouldery to pebbly silt clay or sand clay with numerous greenish carbonate nodules enveloping matrix and skeleton grains in southern areas. Lenses and sheets of pale greenish white dolomite, with scattered pebbles, bouldery dolomite near ranges. Lenses of pebbles to large boulders common near Flinders Ranges, sand beds further east. 2.5-7YR5-8/1-8, 5-7Y6-8/1-8.	Crude wavy and lenticular horizontal lamination. Well defined medium scale cross-beds. Beds 0·5 - 1 m thick. Fining upwards cycles in lower part.	Greenish clays with very poorly sorted sand to boulder content, usually matrix supported framework. Greenish silty carbonates. Red brown mottling common.	Rare vertebrates	Wedge shaped mass, thinning east, between Lake Frome and Flinders Ranges, and to south. (0-150 m)	Forms basic landscape of uplifted "high plain" flanking Flinders Ranges, where it supports growth of Eucalyptus gillii. Crops out as vertical or overhanging cliffs along creeks. Cliffs along Pasmore River and south shore of Lake Frome.	Well developed massive white hard carbonate developed in long cylindroids or horizontal sheets, pisolitic structures. Hard buff groundwater calcrete cements porous sediment. Massive crusts of gypsum rosettes. Red-green mottling, green colour increasing with depth, black patch stain on fractures.
		CZsi	Brown silcrete and iron oxide cement		Colour, petrology		Thin sheets	Capping on sands of Tmb and Tee	
Medial MIOCENE (BATESFORDIAN-BALCOMBIAN) from plant spores and pollen, to ? Late Miocene.	NAMBA FORMATION	Tmb	Alternating fine to medium poorly sorted sands, silt and clay, thin dolomite and limy dolomite beds, often oolitic. Sands generally angular, of high sphericity, but may also be polished and subrounded with low sphericity. Clays may be black (ferrous ion) and tough with characteristic irregular shiny-surfaced fractures, (unit Tmb_2) or pale green or grey. Sands and clays may be carbonaceous. Dolomites often have nodular structure, and are penetrated by branching pores lined with manganese. Rare charales limestone. 1-10Y2-9/0.25-6, N0-N9, 10YR2-7/1-2, rarely 5B5-7/1, 5-10R5-3.5/3-4, 5GY4-7/0.5-1 and 5G6/1.	Horizontal lamination common, especially in silt and very fine sand. Very small to medium scale cross-bedding common in silts and sands. Irregular oolites in carbonates, often rod shaped. Intraformational brecciation, quick flow structures common. Bioturbation common. Rare shrinkage (?subaqueous) cracks and slumps. Cyclic deposition in unit Tmb_1.	Pale grey green clays and fine silts and sands, dolomites, tough black clay with irregular fractures. Fish spines in lower beds. Vertebrates - lung fish teeth.	Ostracoda (Cypridids), Charales oogonia and stem moulds, Potamopyrgus s.l., Aves, Cetacea, Dipnoi, Teleosti, Chelonia, Crocodilia, Monotremata, Marsupialia Plant spores - Nothofagus, Dacrydium, Podocarpus, Eucalyptus, GRAMINEAE, RESTIONACEAE, CUPANIEAE, Pediastrum	Thin widespread blanket and shallow basins (20-250 m)	Sloping cliffs, often capped by dolomite, gypcrete or secondary carbonate cemented younger units, along edges of dry lakes and creeks, east and south-east of Lake Frome. Less commonly as dipping sequences upfaulted along western margin of Flinders Ranges. Mainly subsurface.	Sometimes capped by ferruginous yellow-brown orthoquartzite silcrete. (CZsi) Alunite soil-like horizons associated with uppermost black clay. Massive gypsum crust. Reddish mottling (weakly developed) Also capped by puddingstone opaline and chalcedonic silcrete.
PALEOCENE AND EOCENE from plant spores + pollen	EYRE FORMATION	Tee	Moderate to poorly sorted sands, grain size ranging from fine to small pebbles, often polished, subrounded and of low sphericity. Polish greater for larger sizes. Characteristic basal pebble beds with milky, clear or smoky quartz, grey quartzite, black chert, red jasper, agate, may be very micaceous. Brown to grey colour common from presence of carbonaceous matter. Dark brown to black carbonaceous clay, silty, soft. EOCENE beds tend to be silty and carbonaceous, PALEOCENE coarser grained. 5YR2/1, 10YR6/2, N1-N8, 4Y6/0.45, 5B8/1, 5BG-7/2.	Medium scale and small scale trough cross-stratification and planar cross-stratification. Lamination. Tool marks. Fining upwards sequences.	Polished basal pebble bed. Essentially sands, often carbonaceous, black clays are soft and silty with much carbonaceous matter.	Spores pollen, dinoflagellates, arthropods (rare), leaf, stem and fruit moulds. Plants include fragments carbonized wood. Podocarpus Dacrydium Nothofagus PROTEACEAE CASUARINACEAE GRAMINEAE RESTIONACEAE CUPANIEAE MALVACEAE SANTALACEAE MYRTACEAE HALORAGIS	Thin widespread blankets (10-75 m)	Silicified outcrop upfault-on margins of basin. Isolated outcrop on state border. Usually moderately to steeply dipping.	Often ferruginized and capped by massive microcrystalline quartz silcrete with botryoidal or columnar structure. (Tsi & CZsi) Frequently silicifies the sediment itself.

After H. Wopfner et. al. (1974), Callen & Tedford (in press)

FIG. 7

Note: Plan amended April 1976

DEPARTMENT OF MINES — SOUTH AUSTRALIA

LAKE FROME AREA – CAINOZOIC TERTIARY

Director of Mines	R. A. Callen GEOLOGIST	Drn. R.A.C. Tcd. A.F Ckd. Exd.	SCALE: — 74-769 DATE: SEPT. 1974

TABLE 4

ROCK UNIT	MAP SYMBOL	LITHOLOGY	SEDIMENTARY STRUCTURES	CRITERIA FOR CORRELATION	FOSSILS	AGE	GEOMETRY	GEOMORPHIC EXPRESSION	SOIL DEVELOPMENT
STREAM DEPOSITS	Qra	Pebbles, sand, minor clay of modern stream bed. Silt and clay of low angle fans along western shore of Lake Frome, lower part may include fans of Coonarbine Formation age.	Fine to medium scale cross-bedding, ripple marks, horizontal lamination, imbricated pebbles, etc. in streams.			Recent	Linear (stream channels) - Thin wedge (fans) (0-4m)	Bedload of streams, low-angle fans along west shore of Lake Frome.	
LAKE DEPOSITS	Qrl	Sand, silt, clay, salt. Black to green and brown	Unbedded or laminated, salt shows pressure ridges and blister structure.	Essentially continuous with Qrb clays.		Sub-Recent	Thin spread (A few cms)	Windblown sand in lake bed, salt crust, silts and clays of mound springs.	?
UNNAMED SANDS	Qrs	Fine to medium sands. Bright red brown.	Aeolian cross-bedding - very large scale.	Unconsolidated, red-brown colour. Youngest unit in landscape.	Rare - Insect carapaces, seeds. Charales oogonia.	Sub-Recent	Thin Linear (0-6m)	Modern windrift dunes of Strzelecki Desert.	?
SANDS	Qrb	Fine brown quartz sand. Blue green, brown and black structureless semi-liquid clay.	Sub horizontal bedding in sands.		Ostracods Charophytes (some reworked)	RECENT	Bench-Linear (0-4m)	Forms low benches around islands in Lake Frome and along eastern shore. False spits and bars of west shore may be equivalent.	?
DISCONFORMITY									
CALCAREOUS PALEOSOL	Qcc_1	Cylindroids and patches of soft white carbonate, sometimes oriented in horizontal and vertical tubules or cylindroids. Usually poorly developed.		Generally less well developed than Qcc_2		PLEISTOCENE -RECENT? From Radiocarbon Dating	Bench-linear	Caps benches	Probably the Bca horizon of a fossil soil
COONARBINE FORMATION	Qp_1	Sand to silty or clayey sand, poorly to moderately sorted, usually fine-grained, with subangular to subrounded grains. 2.5-10YR3-8/4-6	Weak horizontal lamination, lenses, large scale cross-bedding (rarely well-defined)	Weakly developed bedding, moderate sorting, light brown colour, absence of gypcrete and large carbonate nodules. Locally abundant land snails. Typical soil horizon at top.	Snail shells, emu shell, aboriginal artifacts. Charales oogonia (rare). Rare vertebrate Burrows.	PLEISTOCENE -RECENT?	Thin blanket (0-2m)	Flat low-lying plains, dominates landscape of planes and seif dunes. Crops out in creeks as vertical faces with columnar jointing.	Weakly developed carbonate cylindroids, weathering as hard granules. Discontinuous. Rectangular blocky structure forming columns of sediment.
COONARBINE FORMATION	Qp_2	Gypsum sand, coarse to very coarse, interbedded clay pellet layers. Lime biscuits and shell in basal layers.	Large scale cross bed sets. Complex fine scale cross-lamination.	Gypsum sand, moderate angle cross-stratification.	Charales oogonia Rare gastropods		Wedge shaped (0-5m)	Cliffs along southeastern shore of Lake Frome and islands in the lake.	Powdery gypsum crust with columnar jointing, which may persist into EURINILLA FORMATION. Qcc_1
DISCONFORMITY									
CALCAREOUS PALEOSOL	Qcc_2	Soft white carbonate cylindroids tubules blotches and lumps in several layers, weather out as hard granules or crusts.				Pleistocene! From Radiocarbon Dating	Soil horizon		Probably the Bca horizon of a fossil soil.
UNNAMED GRAVEL	Qp_3	Cobble and pebble deposits.	Imbricated flat pebbles in some localities.	Level (10-15m) same as Qp_5	Shells for Qp_5	Radiocarbon Dating & Relation to Qp_5	Linear Strandlines (0.5-2m)	Ridges parallel to western shore of Lake Frome	Weak carbonate cementation Qcc_1
GYPCRETE	Qcs	Gypsum crusts, of rosettes of disc-shaped crystals. Developed in various layers according to porosity. Includes calcareous cement in basal Eurinilla Formation.				Associated with lower part of EURINILLA FORMATION	Discontinuous tabular masses	Often forms massive cap, causing underlying strata to form in cliffs.	Groundwater origin - part same origin as younger Qca unit, with which it is associated in same horizon.
EURINILLA FORMATION	Qp_4	Clay-sand to sand, with interbeds of silt and clay in upper part, lower part sand, often with pebbles. Very poorly sorted, grains may be moderately rounded, but rough and pitted, or rounded, and frosted. Upper part 2.5-5YR4-9/4-7 Sandy lower part 7-10YR5-7.5/2-6 Clays 5Y7/1-2.	None or crude horizontal stratification well-developed horizontal lamination (2-10 cm). Sometimes developed into large scale low angle sets. Basal sands trough or planar cross-bedded on medium scale. Rarely lower part horizontal wavy laminae with load casts.	Poor sorting, fine upper part, coarse lower part. Upper part lacks bedding or more rarely has well-defined sub-horizontal cross-stratification, lower part cross-bedded. Upper part reddish-brown, lower yellowish brown. Typical soil horizons, ground water calcrete and gypcrete (in basal part).	Insect burrows and nests. Vertebrates in basal channels, including Diprotodon, Procoptodon sp. Basal layer of gastropods and lamellibranchs (Coxiella, etc) near edge L. Frome Numerous charales oogonia, especially in coarse sand.	UPPER PLEISTOCENE (Macropus)	Thin tabular widespread sand sheets, fills hollows (0-20m)	Flat low-lying plains, cropping out as low slopes around depression and watercourses. Lower part often cemented by gypcrete or calcrete, producing bench or massive cap to cliff. Frequently basal channels approximate present clay drainage.	Several well developed horizons of carbonate and gypsum cylindroids may be present at top, soft large nodules in some areas. Frequently weather out as granules or sheets on surface. Lower sand cemented with crystalline white calcrete, weakly to strongly. Also with massive or layered gypsum rosettes. Mottled in shales of red-brown and white. Qcc_2, Qcs, Qca?
FOSSILIFEROUS SAND (NOW MILLYERA FORMATION WITH UNIT CZm)	Qp_5	Pale greenish fine sands with wavy green clay laminae and coarse sand lenses. Thin basal lenses of bright orange brown sand. White sands at base of Eurinilla Formation. Cappel by chara oogonia and shell hash limestone.	Small to medium scale cross-bedding. Clasts of clay.	Foraminifera, fish bones, greenish sand.	Charales stem moulds, oogonia, fish vertebrae and spines, Coxiella. Foraminifera	PLIOCENE or PLEISTOCENE, or on boundary (from relationships to other units)	Thin discontinuous sand sheets Bench & Beach	Forms white benches near base of cliff profiles.	Affected by carbonate mottles patches in northern areas. Qcc_2, Qcc_1
CALCRETE	Qca	White to pale brown secondary carbonate cement developed in coarse grained beds, also greenish carbonate with large cylindroids and tubules of carbonate. Black manganese staining in sands of topographic lows.		May include two calcretes Black stain may be related to older bed, not younger calcrete, younger calcrete equivalent to gypcrete.		Developed on Millyera Beds and Willawortina Formation	sometimes effects Namba Formation	Bold outcrop, causes cemented units to stand out as prominent benches.	Groundwater calcrete,
UNDIFFERENTIATED CONGLOMERATE	Qp_6	Undifferentiated conglomerate, grading to coarse sand. Intertongues with greenish brown silty clay in some areas.	Planar cross-bedding, trough cross-bedding, crude lenticular bedding.	Constitutes several different units - conglomerates of Willawortina Formation, unnamed conglomerate Qp7, and conglomerate associated with Eurinilla Formation (Telford Gravel equivalent)		Conglomerate associated with EURINILLA FORMATION is PLEISTOCENE	Discontinuous linear (1-5m)	Bold outcrop capping cliffs, or as ridges projecting above Lake Frome Plains.	Massive hard or soft, white, calcrete; cements coarser layers. Qca
DISCONFORMITY									
MILLYERA BEDS (NOW MILLYERA FORMATION, WITH UNIT Qp5)	CZm	Pale green laminated clay, conchoidal fracture with thin Charales limestone (5Y9/1) laminae at top, interbedded with fine well-sorted sand (2Y7/4, 5Y7/2). Bedding absent in clay in Lake Frome. Limestone may grade to thin ripple-marked gypsum beds. Sand grains angular. Reddish to white fine sand with basal pebble beds and interbedded hard thin Charales limestone beds. Coarse loose white to greenish sands, subrounded grains. Algal limestone of mound springs Clay: 10YR5/2, 5Y5/6, 5Y8-9/1-4, Fine sand: white to 2-5Y7/2-4. Channel sand: 5-10Y6-8/2, 5-10YR5-8/4-7.	Fine horizontal lamination in clays and limestone, asymmetric small scale ripples in gypsum, oriented Charales tubules, botryoidal blister structure on gypsum. Trough cross-bedded channel sands.	Charales tubule limestone, greenish ostracod-bearing clay, fine sand with Charales oogonia.	Charales stem moulds and oogonia. Spiral gastropods (Coxiella sp.), worm burrows (spiral, along bedding planes), silicified wood (pebbles, and tree-trunks): Coniferales. Ostracods Vertebrates in mound springs.	Uncertain: LATE MIOCENE -EARLY PLEISTOCENE (From position relative to other units).	Shallow basin, discontinuous linear deposits. (5 m+)	In bed of Lake Frome and cropping out around edge; occupying old deeply eroded stream channels, now represented by linear lakes associated with Billeroo - Eurinilla Creek System. Mound spring limestone.	Massive white groundwater calcrete in sands, bright orange stain in basal coarse sands. Qca
DISCONFORMITY									
UNNAMED CONGLOMERATE	Qp_7	Massive calcareous conglomerate, calcareous sandstone. Basal cross-bedded light grey sand. Pinkish brown sand grains.	Planar cross-bedding, crude lenticular bedding.	Reworked carbonate nodules from Willawortina Formation. Interbedded yellowish brown clayey sand with greenish carbonate nodules.		Pliocene to late Pleistocene (From relationship to other units)	Discontinuous linear. (1-10 m)	Bold outcrop capping cliff tops, particularly along Siccus - Pasmore River system and southwestern shores of Lake Frome.	Massive white groundwater calcrete, often vughy and crystalline - cements coarser beds. Qca

Note: Plan amended April 1976

FIG.8

DEPARTMENT OF MINES — SOUTH AUSTRALIA

LAKE FROME AREA — CAINOZOIC QUATERNARY

	R.A. Callen GEOLOGIST	Drn. R.A.C.	SCALE: —
		Tcd. A.F.	74-772
		Chd.	
Director of Mines		Exd.	DATE: SEPT '74

TABLE 6 LAKE FROME AREA, CORRELATION CHART - CAINOZOIC

CAINOZOIC MAP UNITS AND POSSIBLE EQUIVALENTS

TIME UNIT	CALLEN 1974 FROME: SYMBOL	CALLEN 1974 FROME: NAME		FIRMAN 1971 FROME	EQUIVALENTS IN OTHER BASINS AND ADJACENT MAP SHEETS ACCORDING TO CALLEN 1974: FIRMAN WESTERN FLINDERS RANGES, ETC.	COATS et. al., COPLEY 1:250 000 MAP	WILLIAMS AND POLACH 1971 WESTERN FLINDERS RANGES	JESSUP AND NORRIS 1971 LAKE FROME	STIRTON et.al 1961 LAKE EYRE	TEDFORD 1973 LAKE CALLABONNA (Personal communication).
RECENT	Qra			Qra		Qra	"Local alluviation and dunes"			
	Qrl			Qrl		Qrl				
	Qrs			Qrs	SIMPSON SAND	Qrs				
	Qrb			TINGANA CLAY		ARROWIE FORMATION	"EYRE" GRAVEL, THOMSON CREEK FORMATION, NACOONA PALEOSOL	"BOOKALOO ? PEDODERM", KOOTABERRA F., "MUMBALO PD."		
PLEISTOCENE TO RECENT	Qcc_1			CALLABONNA CLAY LOVEDAY SOIL	LOVEDAY SOIL		?MOTPENA PALEOSOL	PIMBA FORM.? "WONGA PEDODERM"		
	Qp_1	COONARBINE FORMATION		POORAKA FORMATION	POORAKA FORMATION	POORAKA FORMATION	?LAKE TORRENS FORMATION	KOLEROO FORMATION?		"Bird bearing Beds"
	Qp_2			-		-	-			
PLEISTOCENE	Qcc_2			BAKARA SOIL	LOVEDAY SOIL		?WILKATANA PALEOSOL			
	Qp_3	Stratigraphic position uncertain								Equivalent to Bird-bearing Beds
	Qcs			Qcs		Qcs		MYALL CREEK FORMATION		
	Qca	Possibly 2 ages of calcrete, one older than Qp-		BAKARA SOIL + RIPON CALCRETE?	BAKARA SOIL	Qca	?WILKATANA PALEOSOL			
	Qp_4	EURINILLA FORMATION		TELFORD GRAVEL	POORAKA FORMATION	POORAKA FORMATION	POORAKA FORMATION	"ILLEROO PEDODERM"	KATIPIRI SAND +	TIRARI FORMATION Equiv.
	Qp_5	?Czm							TIRARI FORMATION	
	Qp_6	Basal $?Qp_4$		TELFORD GRAVEL	TELFORD GRAVEL					"Diprotodon bearing beds"
	Czm	MILLYERA BEDS			BOPEECHEE CLAY					
	Qp-		?	TELFORD GRAVEL	TELFORD GRAVEL	"T-Q"			MAMPUWORDU SAND	
UPPER MIOCENE TO PLEISTOCENE	Czw	WILLAWORTINA FORMATION		AVONDALE CLAY	"Conglomerate at Lyndhurst" + Limestones	BUNGUNNIA LIMESTONE Equiv. + AVONDALE CLAY				
	CzSi				Ferruginous horizon and silcrete	TSi		"PUDDINGSTONE" and "PAISLEY PEDODERM"	WIPAJIRI FORMATION	
MIDDLE TO LOWER MIOCENE	Tmb	NAMBA FORMATION?		AVONDALE CLAY (Upper part of Tmb		?AVONDALE CLAY Upper part of Tmb)			ETADUNNA FORMATION	ETADUNNA F. Equiv.
OLIGOCENE	TSi			TSi	Silcrete	TSi		?NARYILCO + SILCRETE		TSi
UPPER EOCENE TO LOWER PALEOCENE	Tec	EYRE FORMATION		EYRE FORMATION		EYRE FORMATION				MURNPEOWIE FORMATION

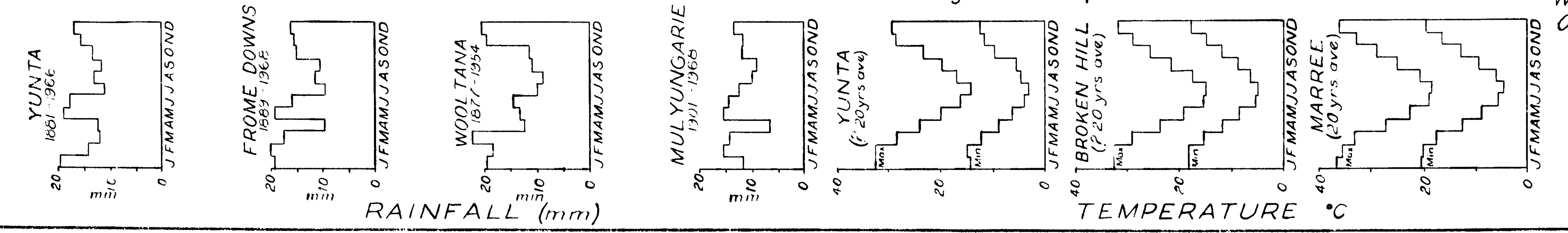
DEPARTMENT OF MINES — SOUTH AUSTRALIA

LAKE FROME AREA - CAINOZOIC CORRELATION CHART

R.A. Callen
GEOLOGIST

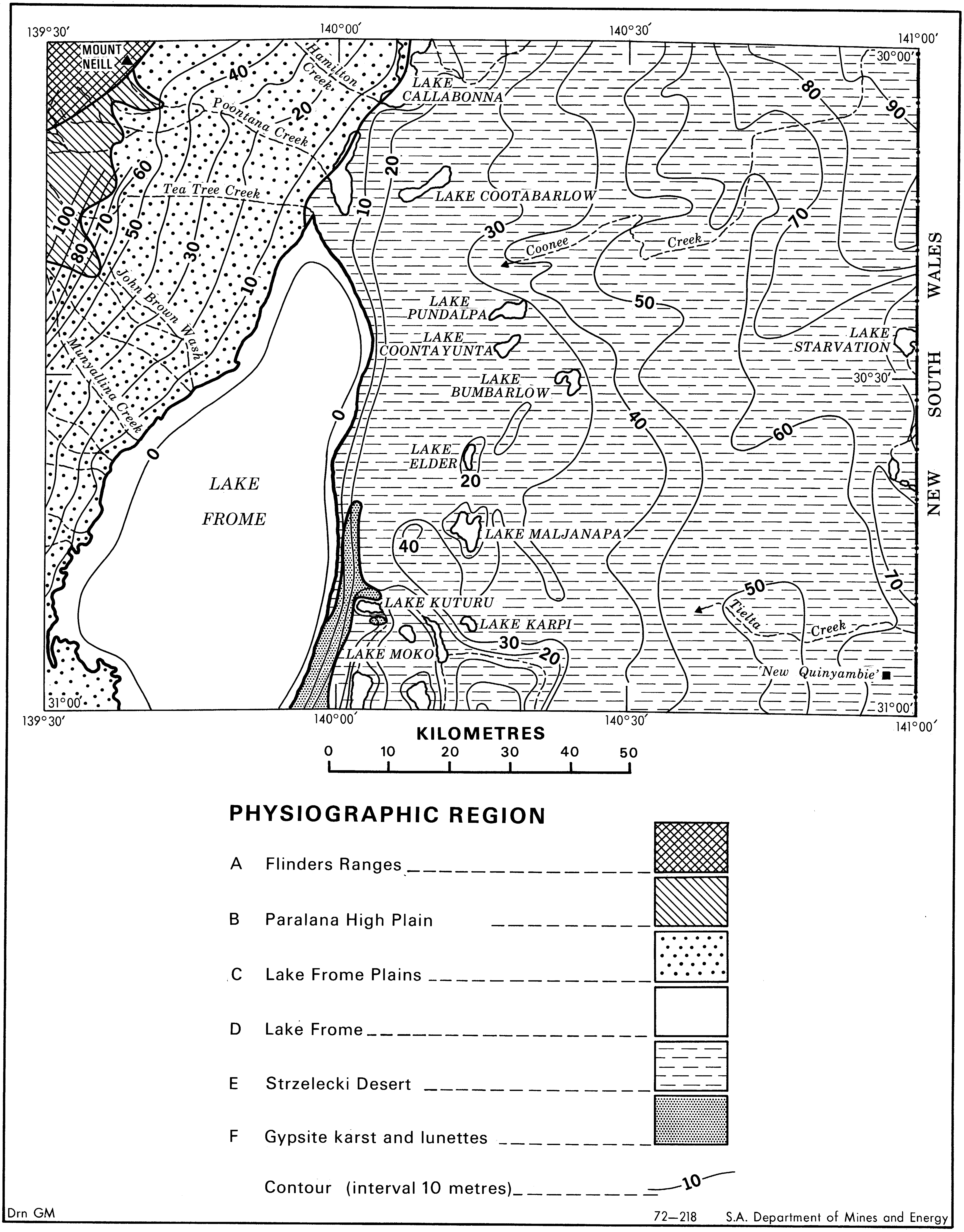
Director of Mines

Drn. R.A.C.	SCALE: —
Tcd. A.F.	74-770 Cd
Ckd.	
Exd.	DATE: SEPT. 1974

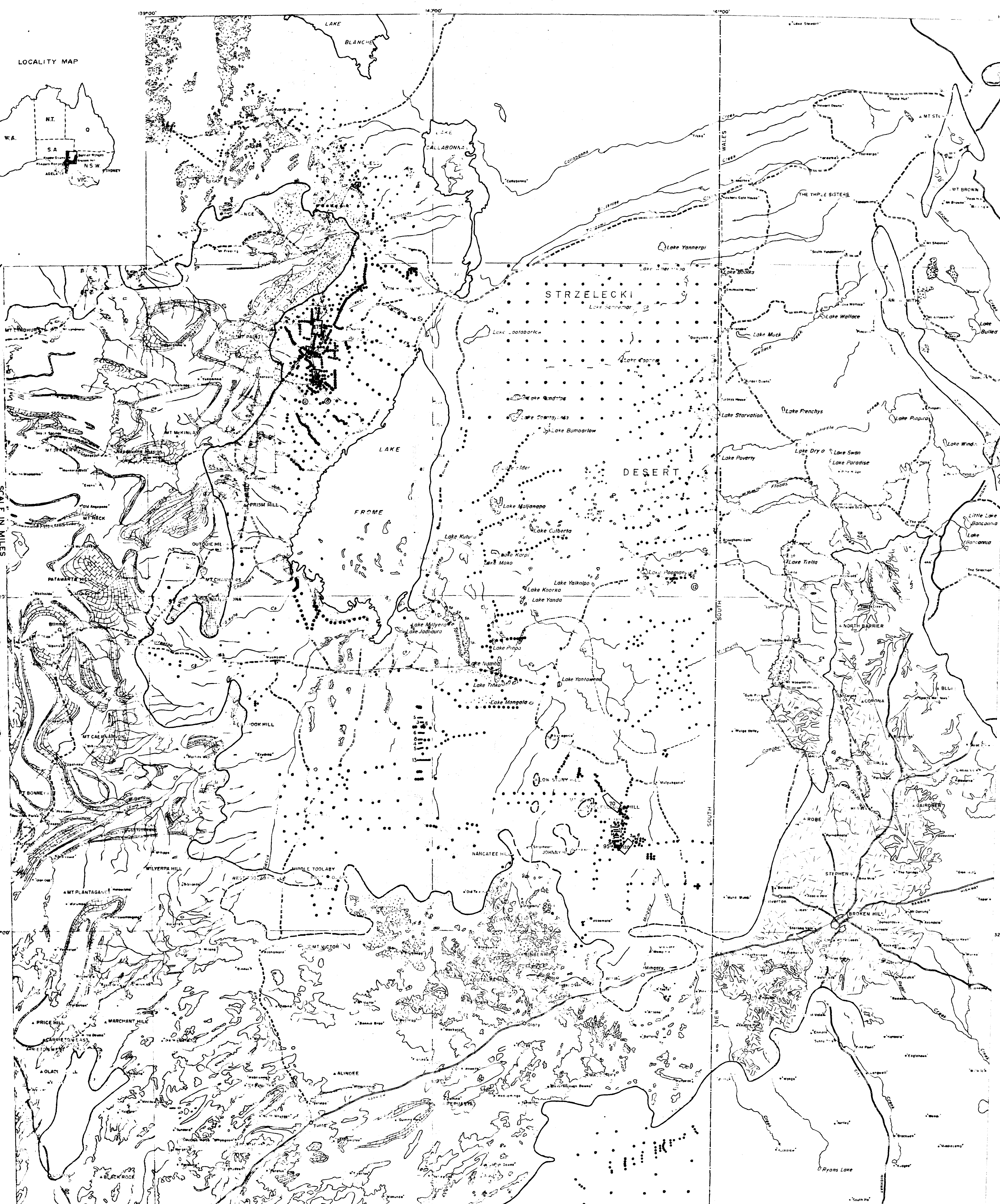


WIND VANE OBSERVATIONS: Broken Hill data originally related to 16 compass points, but redistributed among 8 cardinal points to retain essential statistical distribution (biased towards cardinal points due to observers inability to record finer subdivisions)

REGIONAL MAPPING SECTION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	Scale: AS SHOWN
Compiled: R.A.C.	FROME 1:250000 SHEET AREA	Date: 12TH MAY '72
Drn. M.A.S. Ckd. R.H.	RELEVANT CLIMATIC STATISTICS	Drg. No. 72-234 C+F



139°30′
140°00′
140°30′
141°00′
MOUNT NEILL
Hamilton Creek
LAKE CALLABONNA
Poontana Creek
Tea Tree Creek
LAKE COOTABARLOW
Coonee Creek
John Brown Wash
Munyallina Creek
LAKE PUNDALPA
LAKE COONTAYUNTA
LAKE BUMBARLOW
LAKE STARVATION
LAKE ELDER
LAKE FROME
LAKE MALJANAPA
LAKE KUTURU
LAKE KARPI
LAKE MOKO
Tielta Creek
'New Quinyambie'
NEW SOUTH WALES
30°00′
30°30′
31°00′
KILOMETRES
0 10 20 30 40 50
PHYSIOGRAPHIC REGION
A Flinders Ranges
B Paralana High Plain
C Lake Frome Plains
D Lake Frome
E Strzelecki Desert
F Gypsite karst and lunettes
Contour (interval 10 metres)
Drn GM
72—218
S.A. Department of Mines and Energy



LEGEND

BASIN AREA

CAINOZOIC
- WILLAWORTINA FORMATION[1] Outcrop
- Silcrete (massive or puddingstone type)
- NAMBA[1] & EYRE[2] FORMATIONS: Outcrop
- Present limits Tertiary sediment

MESOZOIC
- Outcrop
- Southern limit subsurface Mesozoic

1. Unit defined on FROME 1:250 000 geological atlas series.
2. See Wopfner et al. 1974, The lower tertiary Eyre Formation of the Western Great Artesian Basin, S.Aust. J.Geol. Soc. Aust. (in press).

SOURCE AREA

ADELAIDEAN
- Carbonates: Limestone; Sandy limestone; Dolomite
- Non carbonates: Mainly fine-grained clastics, minor sandstone, conglomerate

Sediments, minor low grade metamorphics in Olary area

PRECAMBRIAN (Crystalline basement)
- Granite, granitic metamorphics
- Metamorphics
- Acid volcanics

SYMBOLS

- Lakes, creeks
- Springs
- Edge of high plains
- Exploration bore
- Local concentration — in line / point / area
- Main roads
- Tracks
- Homesteads
- Trig points

SCALE 1:500 000

Bore locations and references obtained from Company reports held by S.A. Department of Mines in Open and Closed envelopes.

For Geological Base Map see drg 74-54 994-2+4

S.A. DEPARTMENT OF MINES

LAKE FROME AREA

SEDIMENTARY URANIUM

COMPANY BORE DISTRIBUTION

Regional Surveys	Compiled: R.A. Callen.	Scale 1:500 000 / Date 26-2-74
Updated 29 5 74	Drn. J.A. J.M.B. / Ckd. R.A.C.	Drg. No. 74-131 994·2+4

RESTRICTED