Report Book

DEPARTMENT OF MINES
SOUTH AUSTRALIA

OPEN FILE

1:250 000 GEOLOGICAL SERIES

EXPLANATORY NOTES FROME

SOUTH AUSTRALIA

SHEET SH54-10 INTERNATIONAL INDEX

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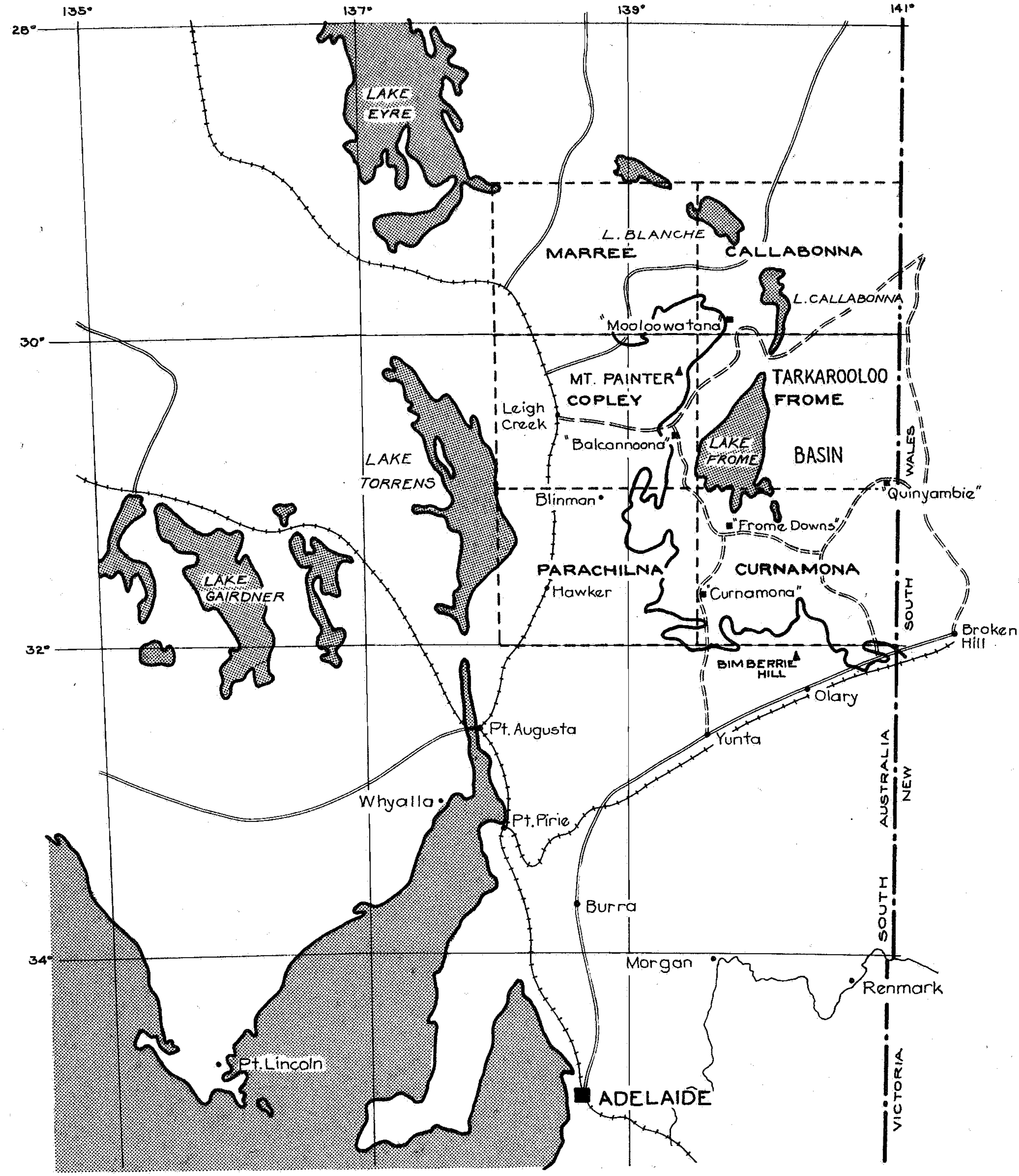
1st March, 1976

Rept.Bk.No. 76/27
G.S. No. 5704
D.M. No. 538/74

CONTENTS

PLANS



1:100,000 ENLARGEMENTS

PARALANA	*WITTAKILLA*	*AMERARKOO*
PARALANA	**COOTABARLOW**	**COONEE**
CALDINA	*PUNDALPA*	*COONEE*
	FROME	
ARKAROOLA	*ELDER*	*THURLOOKA*
FROME	**COONARBINE**	**THURLOOKA**
FROME	*COONARBINE*	*QUINYAMBIE*

1:63,360 ENLARGEMENTS

Boundary of Cainozoic Sediments (TARKAROOLOO BASIN)

FIG. 1

DEPARTMENT OF MINES – SOUTH AUSTRALIA

FROME 1:250,000
LOCALITY PLAN

COMPILED: R. Callen
DRN: A.R. CKD.

SCALE. 1:4,000,000
DATE: 21st April 1976
PLAN NUMBER: S12171

DEPARTMENT OF MINES
SOUTH AUSTRALIA

Rept.Bk.No. 76/27
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1:250 000 GEOLOGICAL SERIES
EXPLANATORY NOTES FROME
SOUTH AUSTRALIA

SHEET SH54-10 INTERNATIONAL INDEX

INTRODUCTION

The FROME 1:250 000 geological sheet (SH54-10) 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 extremities 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. The border fence is about 50 to 100 m inside New South Wales "Quinyambie" is the only permanent habitation on the sheet, being located in the southeastern corner of the sheet. "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 occasional frost in winter. Winds are dominantly from the southern quarter with a strong westerly phase during May-August and north winds in summer (Callen, 1974b). 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. Falls occur mainly in winter and summer. The central portion of the sheet east of Lake Frome receives very low rainfall. Highest and most reliable rainfall occurs at Mount Painter and in the southeastern corner of the sheet.

The vegetation is sparse. The most significant species geologically is *Eucalyptus gillii*, occurring only on the Willawortina Formation adjacent to the Flinders Ranges, particularly where calcrete or carbonates are exposed. *Callitris columellaris* occurs east of Lake Frome and on one island in the lake, tending to prefer the Eurinilla Formation as a substrate.

The nomenclature used for basins follows Wopfner (1969a). The term "Frome Embayment" therefore refers to the Mesozoic sedimentary basin. The term "Lake Frome area" refers to the region bounded by the Flinders Ranges to the west, Barrier Ranges to the east and Olary Ranges to the south. The northern limit 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 Cainozoic basin is referred to as the Tarkarooloo Basin (after L. Tarkarooloo on CURNAMONA), with the Poontana Sub-Basin (after Poontana Ck.) occupying the deeper western portion, west of Lake Frome.

Some unrecorded minor scattered outcrop may exist on the eastern part of *Paralana* and on *Wittakilla*, *Amerarkoo* and the northern part of *Pundalpa*, which were visited only briefly.

In the text 1:63 360 scale sheets are referred to thus: *Coonarbine*, and 1:250 000 scale sheets thus: FROME.

PREVIOUS WORK

1. Stratigraphy and mapping

Sturt (1849) was first to make geological observations, commenting on the remarkable parallelism of the sand ridges. He did not regard them as aeolian dunes, but as a fluviatile product. Selwyn passed through the area in 1859 (Selwyn 1860) and refers on his geological map to "recent tertiary deposits on the surface". Brown (1884) made the first true geological survey in 1883, negotiating the desert east of Lake Frome. He observed Quaternary conglomerates and clays along the Pasmore River on CURNAMONA.

The first geological map was published by Woolnough & David (1926). The next significant survey was that of Jack (1930) who published cross-sections and defined a number of groundwater basins in the Lake Frome area, describing 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 commented on the outcrop on the border fence on *Thurlooka* (just off the edge of the sheet).

Osborne (1945) was apparently first to introduce the term "Frome Embayment" into print, defining it as a synclinal basin bounded by the Flinders and Barrier Ranges. Evans (1946, Evans & Reeves 1948) located most of the ferruginous sandstone outcrops of the Tertiary and Pleistocene, which he thought were Proterozoic.

Whittle and Chebotarev (1952) studied heavy minerals from wells drilled by Enterprise Exploration Ltd. 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.

Wopfner (1970) prepared isopach and facies maps of the Cambrian.

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

These notes derive from South Australian Department of Mines report 74/25 (Callen 1974a). A basin study of the Tarkarooloo Basin was made by Callen (1975a) and stratigraphy and tectonics are discussed in Callen (1975b), and Callen & Tedford (in prep.). Earlier studies were made by Krinsley *et al.* (1968) and Firman (1970a).

2. Palaeontology

In 1882 Plant fossils of Tertiary or Cretaceous age were discovered in wells sunk along the northern edge of Lake Frome (Jones & Tate 1882, Tate & Watt 1896). Others were discovered on CURNAMONA (Tate 1886, p.55) and elsewhere (Chapman 1937). The depths suggest they were probably from Miocene sands.

Other palynological studies which include the Frome Embayment are those of Dettman (1963), Dettman & Playford (1969) on Cretaceous palynology. Harris (1970, Wopfner *et al.* 1974) studied Tertiary spores and pollen. Morgan (personal communications 1974-75, New South Wales Geological Survey) is studying Cretaceous palynology.

Recently,vertebrate fossils have been investigated by a team led by R.H. Tedford of the American Museum of Natural History, New York.

3. Geophysics and Petroleum Exploration

Reports by Wade (1915), Ward (1944) and Osborne (1945) assess the potential of the Cretaceous in the Great Artesian Basin for oil and gas. Evans (1946) was first to suggest the Cambrian beneath the embayment might have oil potential, rather than the Cretaceous.

The Zinc Corporation Ltd., Enterprise Exploration Ltd. and Frome Broken Hill Co. Ltd. began drilling for oil in 1945, and a reconnaissance gravity and magnetic survey took place (Kaufman & MacPhail 1948). Seismic work began with a survey by Geoseismic (Aust.) Ltd. for Santos Ltd. (Dennison 1960). Further magnetic and gravity surveys were carried out by Geophysical Services International for Delhi Australian Petroleum Ltd. and Santos Ltd. (Harding & Geyer 1963). During 1964-65 Wongela Geophysical Pty. Ltd. conducted reconnaissance gravity surveys 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, using all available gravity and magnetic data (United Geophysical Corporation 1966). Simplified versions of their gravity and magnetic maps are shown in Figs. 4 & 5. A more accurate base level was available for their spot height survey than in earlier Department of Mines work. The Crusader survey was tied in with the Pexa-Carraweena Survey line to the north.

Wopfner (1966) and Freeman (1966) discuss the oil potential of the Cambrian and Ordovician. The South Australian Department of Mines began geophysical work in 1962, constituting refraction depth probes, seismic and an aeromagnetic survey in combination with the Bureau of Mineral Resources Geology and Geophysics. Activity by the Department of Mines continued until 1969, accompanying geophysical exploration by several companies.

In 1968, Santos Ltd. drilled three stratigraphic wells south of Lake Frome on CURNAMONA (Delhi-Santos 1968). In 1969 the area was farmed out to Crusader Oil N.L., who completed an extensive seismic survey. Aeromagnetic maps are available, and there is a report on the state magnetic map by Parker (1973). Magnetic interpretation has been done by Tucker & Brown (1973). Other interpretations have been attempted by Westhoff (1968) and Milsom (1965), both of which suffer from incorrect depth estimates.

4. Hydrogeology

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. Jack (1930) was first to assess the water potential of the area.

Ker (1966) completed a hydrological survey of the embayment and prepared a structure contour map of the top of the Palaeozoic.

5. Uranium Exploration

Uranium exploration began in 1969 by Ker McGee Pty. Ltd. (Ryan 1969), and continues to the time of writing these notes. The Department of Mines drilled three stratigraphic bores to assist this exploration (Callen 1972, 1975a, b). The following companies whose findings are on open file have undertaken exploration.

Mines Administration Pty. Ltd.:-	Jarre (1972)
Tricentrol (Aust.) Pty. Ltd.:-	Middleton (1974a, b)
Chevron Exploration Corp.:-	Morgan (1973)
Union Corp. (Aust.) Pty. Ltd.:-	Randell (1973)
Central Pacific Minerals N.L.:-	Schindlmayr (1970)
Southern Ventures Pty. Ltd.:-	Flesher (1974)
Ker McGee:-	Ryan (1969)

PHYSIOGRAPHY

Physiographic regions and topographic contours are shown in Fig. 2. Spot height data, classified with regard to reliability and origin, are available on plan 76-39, which can be purchased from the Department.

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

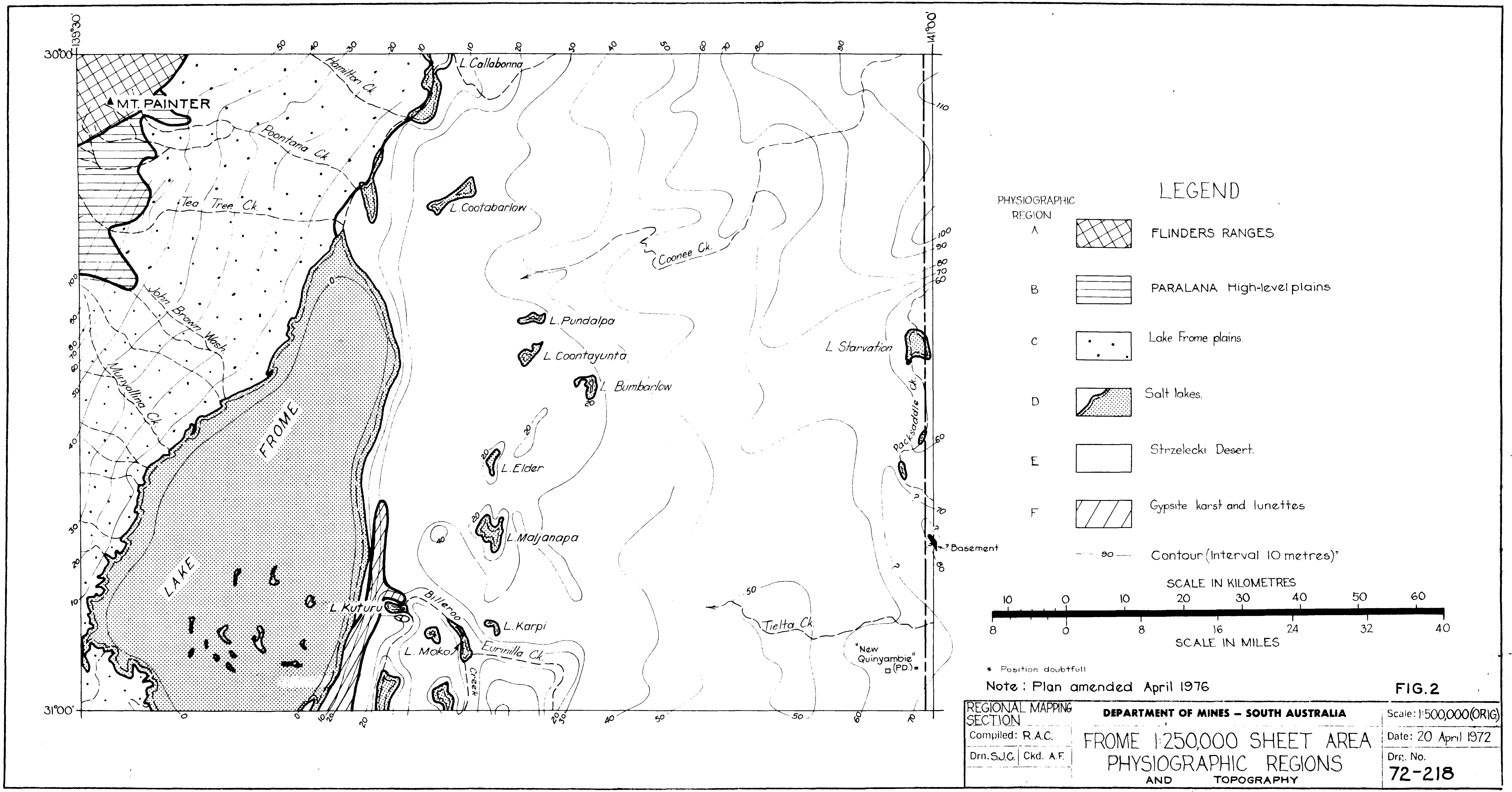


FIG. 2

1M-2.70 A1811

On *Paralana* and *Caldina* is a dissected high plain (region B - The Paralana High Plain) rising gently from 100 m above sea level along the eastern edge to 155 m where it abuts 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 is discussed by Twidale (1967).

The Lake Frome plains (region C) have a common fluviatile origin and geomorphic aspect, rising from 0.5 m above sea level at the edge of Lake Frome to 70 m near the ranges. They are virtually featureless, apart from occasional creeks with eucalypts, and low gravel ridges. A small area of scattered dunes is developed on *Paralana* and *Caldina* and sparse scrub clothes the area.

Lake Frome is region D, a playa, probably with some tectonic control. Islands of stabilised gypsum dunes, belonging to region F, occur in the southern part of the lake. Elevation of the lake bed varies from 0.5 m above to 3.0 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 Holocene beach deposits are present.

The extensive seif dunes (windrift type: term introduced by Melton 1940) lying east of Lake Frome are classified as region E. These dunes are largely fixed by vegetation.

A unique undulating topography consisting of old Pleistocene gypsum lunettes 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, and on the islands in the lake.

STRATIGRAPHY

PRECAMBRIAN (Fig. 3)

The stratigraphy of the Precambrian is summarised in Table 1 and is derived from Coats and Blissett (1971), the geology on the FROME map sheet being adapted from the Mt. Painter Special geological sheet (Coats *et al.* 1969).

A few small outcrops of the "Younger Granite Suite" included in the area of brecciated Wywyana Formation, are not differentiated on FROME. The Corundum Creek Member and lower unnamed Member of the Freeling Heights Quartzite do not occur on FROME.

The Pepegoona Porphyry has been shown with tectonic contacts by Young (1973) who indicated the granitised metasediments of Coats constitute bands of "micrognanite" intercalated with Terrapinna Granite. Similar bands also occur in the Wattleowie Granite. These "microgranite" bands (or gneiss) are regarded by Young as possibly of sedimentary origin. The areas containing them have been distinguished by an overprint on the colours of the two granite units on FROME.

Basement rocks beneath the Frome Embayment are known only from indirect evidence on FROME but have been penetrated on the adjacent CURNAMONA sheet to the south. Yalkalpo No. 1 stratigraphic bore penetrated Jurassic conglomerate at 213.2 m containing boulders of porphyritic rhyolite and granite, presumably derived from the nearby Benagerie Ridge. On *Eurinilla* an old water bore (Dud Bore), and uranium exploration drilling by Tricentrol N.L. (Middleton 1973, 1974) have delineated a porphyritic rhyolite body within the Benagerie Ridge of pre-Mesozoic age. The porphyry does not appear to be reflected by any events in the magnetic or gravity maps (Figs. 4 and 5). To the north of Yalkalpo 1 bore the South Australian Department of Mines Mudguard No. 1 bore intersected porphyritic rhyolite at 194.5 m (pers. comm. B. Youngs, 1976) confirming the presence of the Ridge, and considerably extending

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	

Unit	Symbol	Description	Stratigraphic Relationship	Fossils	Thickness (m)	Topographic Expression	comments
		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

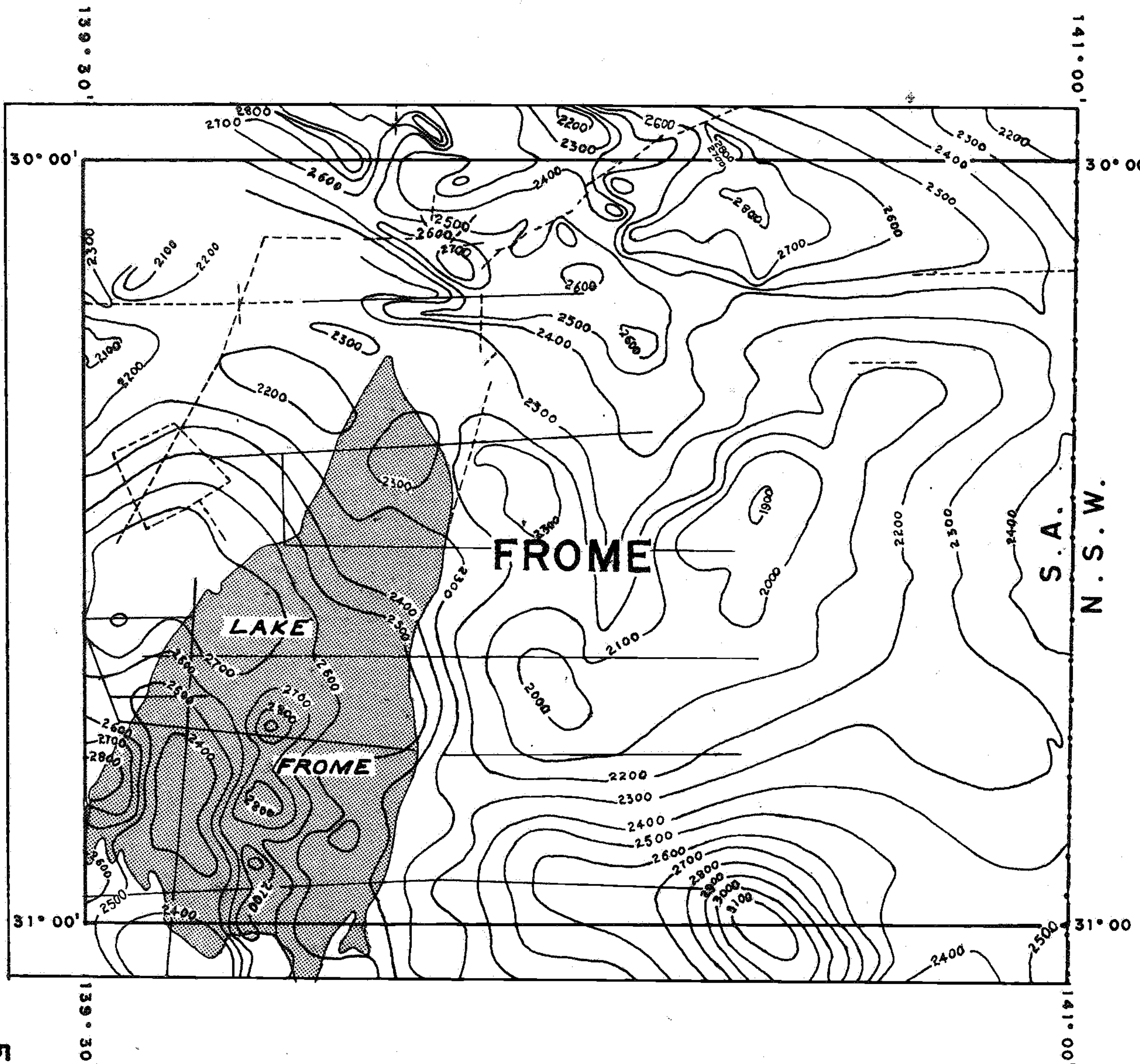
the known extent of the porphyry. The similarity between this porphyry and that of the Precambrian Gawler Range Volcanics (Blissett 1975) has been noted by Thomson (1966, p.216), the implied age being compatible with its structural relationship to the Cambrian (see Structure).

Steeply dipping (50-65° northwest) purple cross bedded coarse sandstones occur just over the border in N.S.W. at latitude 31°40' (Callen 1974b). These are tentatively assigned to pre-Mesozoic rocks, probably Adelaidean. Lack of straining in the quartz, retention of primary grain shapes and presence of unoriented mica matrix indicates these rocks have not been subject to the metamorphic events which affected the Denison and Willyama Inliers. The presence of thin quartz veins cutting across the exposures supports the idea that they are older than Tertiary, since Tertiary rocks are not affected in this way anywhere else in South Australia. The magnetic map shows a small anomaly in this region (Fig. 4), interpreted as a local basement high.

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

The magnetic basement interpretation by Parker indicates a high trending in a northerly direction, occupying the eastern half of the sheet and corresponding to the Benagerie Ridge. A low along the eastern margin of Lake Frome corresponds with the thickest Cretaceous section. Bore data suggests the depth to magnetic basement estimated in the western margin of the sheet is too low (see section B-B'). This is supported by later work of Tucker & Brown (1973) who suggest a depth of 2-6 km is more appropriate. Within Lake Frome is a small magnetic high (Fig. 4) coinciding with a gravity high, flanking the eastern side of the Poontana Structure (Figs. 4, 5). This is probably an intra-basement feature (pre-Adelaidean). Tucker's depth estimates differ in detail from those of Parker (1973), whose study was made on a much broader scale over the whole of South Australia. Tucker suggests the Palaeozoic and Adelaidean sediments were not magnetic enough to account for the anomalies found in the Lake Frome area and could better be explained by Willyama Complex crystalline basement.

TOTAL MAGNETIC INTENSITY
(CONTOUR INTERVAL — 100 GAMMAS)



Compiled from plan drawn by
CRUSADER OIL N.L. (Env. 1275 (V)
(data from Surveys by B.M.R.
& S.A. Dept. Mines)

REFERENCE
SEISMIC SURVEYS

CRUSADER OIL N.L. ...... ———
S.A. Dept. Mines .... - - - - -

Scale in Kilometres

10 0 10 20 30 40

FIG. 4

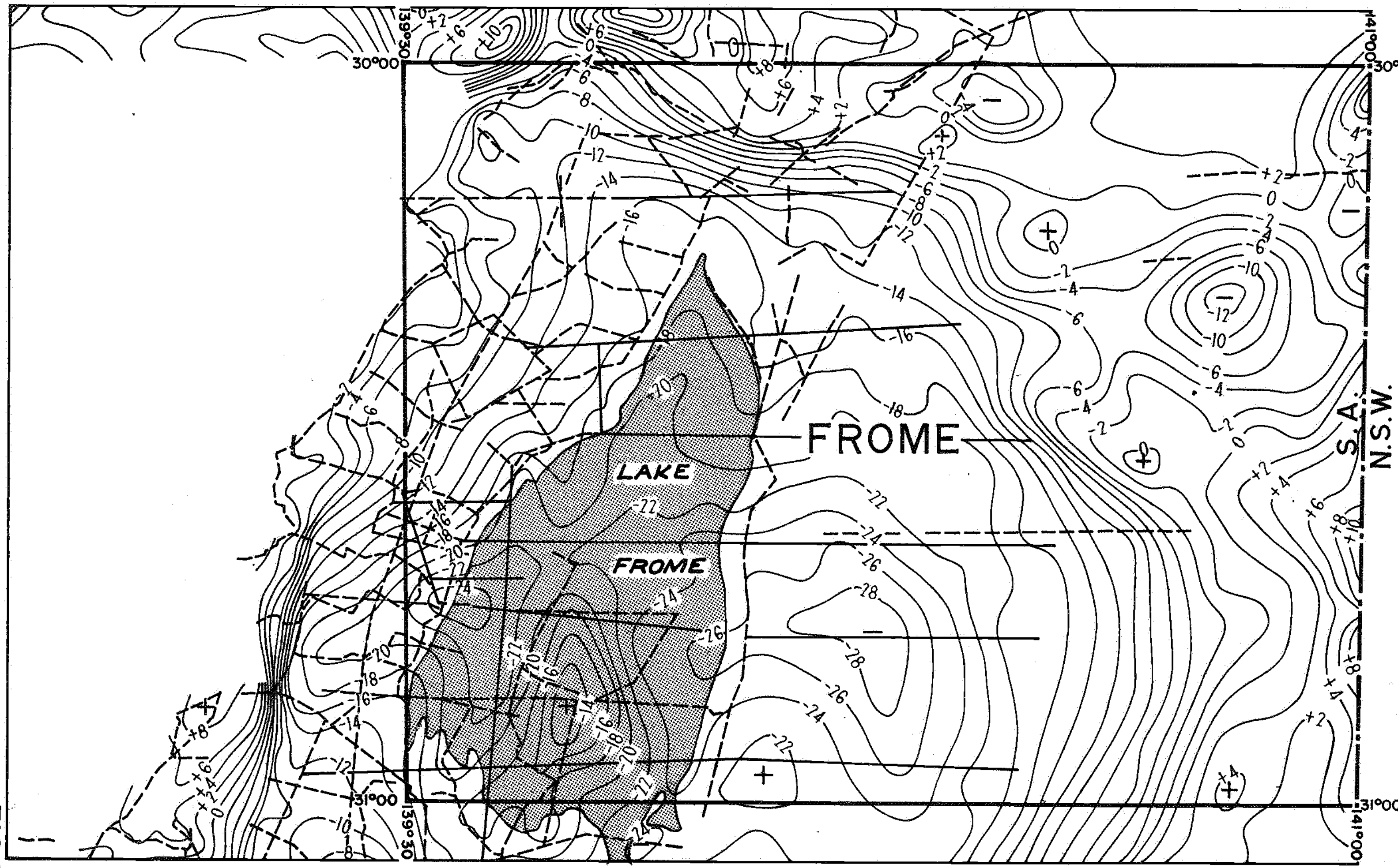
FIG. 4
S12011

R.A. CALLEN — Geologist

S.A. DEPT. of MINES

BOUGUER GRAVITY
(Contour Interval 2 Milligals)

Compiled from plan drawn by CRUSADER OIL N.L. (Env. 1275 (v)
Data from surveys by B.M.R. & S.A. DEPT. of MINES.



REFERENCE
SEISMIC SURVEYS

Crusader Oil N.L. .... ———
S.A. Dept. of Mines .... - - - -

SCALE IN KILOMETRES

10 0 10 20 30 40 50

R. A. Callen — Geologist

FIG.5
S 12010

S.A. Dept. of Mines

FIG.5

PALAEOZOIC (Fig. 3)

On CURNAMONA Middle Cambrian rocks, including the Wirrealpa limestone, were identified in bores drilled by E.A. Rudd & Co. (personal communication B. Daily, University of Adelaide 1971), and by Delhi-Santos (1968 - Lake Frome 1, 2 and 3 stratigraphic bores). Daily identified 610 m of red beds and carbonates of the Middle Cambrian sequence in the Delhi Santos bores, representing almost the complete sequence he had earlier defined in the Flinders Ranges (Daily *op cit.*). Thus some of the red-beds and grey limestone at the base of bores on FROME are probably Middle Cambrian. A Lower Cambrian trilobite (personal communication B. Daily, 1975) was found in nodular mottled grey limestone, probably Parara Limestone, at the base of Yalkalpo 1 bore. Yalkalpo No. 2 bore a few kilometres east (in progress at the time of writing), has intersected a thick sequence of green and red brown shale of probable Middle Cambrian age (pers. comm. B. Youngs 1976).

The Delhi-Santos Lake Frome 1, 2 and 3 bores, intersected 780 m of strata, penetrating almost to the base of the Middle Cambrian. However, Tucker's depth estimates give 1400 m to magnetic basement here, hence there is room for only 500-600 m thickness of Lower Cambrian and Adelaidean cover on the crystalline basement. Both Tucker's and Parker's depth estimates agree in this area.

The Crusader seismic interpretation suffers from playback problems and velocity changes in the Cainozoic cover. This has resulted in possible oversimplification of structures, and too shallow depth estimates for the unconformity in the western part of FROME (see section B-B'). Note that two-way time rather than depth has been contoured on the structural sketch.

Gravity interpretation by United Geophysical Corp. (1966) shows a high centred beneath Lake Frome, and a broad low in the southeastern portion of FROME. This is supported by Tucker's analysis (Tucker & Brown 1973). The thickest Cretaceous sequence is beneath Lake Frome and cannot contribute to the gravity low, therefore there must be some other older low density sediments suggesting a thicker Palaeozoic sequence. The work of Wopfner (1966) at Mt. Arrowsmith, showed Ordovician strata might underlie the basin. He also (1970) suggested Lower Cambrian sediments might exist under the northwestern portion of the Frome Embayment (Arrowie Basin). These may extend onto the FROME sheet.

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

MESOZOIC (Fig. 6)

Usage of the term 'Frome Embayment' was discussed in the Introduction and Previous Work sections. The term was first published almost simultaneously by three authors - Ker (1966), Wopfner (1966) and Freeman (1966).

The oldest Mesozoic unit on the sheet is the unnamed conglomerate in Yalkalpo 1 bore, resting on the Lower Cambrian ?Parara Limestone. This has a very small proportion of grey silty shale matrix, identical to the overlying Cadna-owie Formation equivalent. The clasts are porphyry and various metamorphic rocks. This unit probably represents a phase of erosion of the Benagerie Ridge (see Section A-A'on map).

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 top of the Cadna-owie Formation equivalent in the Frome Embayment is gradational with the Marree Formation, and the boundary therefore difficult to place visually. However, in Yalkalpo 1 bore it can be identified using the petrophysical logs. The Cadna-owie Formation on FROME constitutes pebbles to large boulders, COMPILED: R.A.Callen

DRN:

CKD:

DEPARTMENT OF MINES—SOUTH AUSTRALIA

LAKE FROME AREA

MESOZOIC

SCALE: (Chart)

DATE: 5TH APRIL 1976

PLAN NUMBER: S12170

TABLE 2 LAKE FROME AREA - MESOZOIC ROCK UNITS

	ROCK UNIT	SYMBOL	LITHOLOGY	FOSSILS	THICKNESS (METRES)	COMMENTS
CRETACEOUS	MARREE FORMATION (OODNADATTA FORMATION AND BULLDOG SHALE equivalent)	Klm	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.
CRETACEOUS ? JURASSIC	?CADNA-OWIE FORMATION equivalent (Pelican well Formation) ↓	Klc	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 Basal part Jurassic and therefore Algebuckina Sandstone equivalent, but facies resembles Cadna-owie F.
JURASSIC	UNNAMED CONGLOMERATE	Kll	Marine boulder bed of granitic rock types, rhyolite porphyry and grey slate. Low percentage grey slate matrix.		2·4 min.	Probably Jurassic, derived from Benagerie Ridge. Porphyry locally derived.

FIG.6

forming lenses in a matrix of silt, shale and sand. Sandy beds are common, especially near the base. Clasts include white quartzite and sandstone, reddish brown porphyry, and fine siliceous shale.

The nomenclature for the Great Artesian Basin to the north differentiates the Bulldog Shale and Oodnadatta Formation, two lithologically similar units separated by a distinctive greenish sand, the Coorikiana Member. In the absence of this Member the boundary can be differentiated using electric log data. This terminology has generally superseded that of the Marree Formation (Forbes 1966), for example 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. Microflora can be used only in a broad sense to resolve the boundary (Harris, Appendix II *in* Townsend 1971) which is probably time transgressive.

The Marree Formation constitutes a monotonous sequence of dull greenish grey to bluish grey finely micaceous shale and siltstone, laminated beds, intraformational breccia and minor polymictic conglomerate. Numerous plant leaf and stem material and faunal burrows or traces are present. Bivalves, foraminifera and microflora are common. No weathering horizon has been detected on the Cretaceous in subsurface.

The Cretaceous Winton Formation has not been positively identified on FROME; Ludbrook (in Ker 1966) shows the Cenomanian is absent from the sequence south of Tilcha Bore on CALLABONNA. However, thin Winton Formation may occur in the extreme north of the sheet area (Muloowurtina and Poontana bores). A brownish sandy sequence in Cootabarlow 1 bore and sandy beds at the top of Poontana bore 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 & Playford (1969, especially pages 182-192, tables 9.1, 9.3, 9.4), Cookson & Eisenack (1958) and Eisenach & Cookson (1960), Evans (1966). Cootabarlow 2 bore is the reference section for the *Crybelosporites stylosus* zone of Dettman.

Recently Morgan (personal communication R. Morgan, New South Wales Geological Survey, 1974) examined the microflora of Yalkalpo 1 bore and found the upper part of the Marree Formation (Bulldog Shale equivalent) to be missing. He recorded a number of species characteristic of the Algebuckina Sandstone in the sequence shown as Cadna-owie Formation equivalent on the FROME map. However the lithology resembling the Cadna-owie Formation or Pelican Well Formation, is quite different. Thus the basal conglomerate and the lower part of the Cadna-owie Formation equivalent are Jurassic, not Cretaceous as shown on the FROME legend.

CAINOZOIC (Figs. 7, 8 and 9)

Several new names 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 & Tedford *in prep.*). Suggested equivalents are given in Table 6.

TERTIARY (Fig. 7) (for detailed stratigraphic relationships and soils see Section D-D' on FROME map).

The new name TARKAROOLOO BASIN is given to the Cainozoic sediments deposited in the Lake Frome area. These form a thinner, though more extensive cover to the Frome Embayment Mesozoic sequence. The sediments resulted from a different series of tectonic events than the Mesozoic rocks. They are dominantly continental in character. The northern limits of the basin are at present undefined. The term 'basin' has been used, but in reality it is a complex of interconnected shallow basins. Two of these have been named *viz.* the Poontana Sub-basin west of Lake Frome, and the Wirrealpa Sub-basin north-west of Reaphook Hill in the vicinity of 'Wirrealpa' on COPLEY. In addition there are considerable differences in the tectonic history of 'Paleogene' rocks compared with the remainder of Cainozoic time ('Neogene').

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. 2.5-7YR3-8/1-8, 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. (0-150m)	Forms basic landscape of uplifted "high plain" flanking Flinders Ranges, where it supports growth of <u>Eucalyptus gillii</u>. 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, NO-N9, 10YR2-7/1-2, rarely 5B5-7/1, 5-10R3-3.5/3-4, 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 ooliths 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, <u>Potamopyrgus s.l.</u>, Aves, Cetacea, Dipnoi, Teleosti, Chelonia, Crocodilia, Monotremata, Marsupialia Plant spores - <u>Nothofagus</u>, <u>Dacrydium</u>, <u>Podocarpus</u>, <u>Eucalyptus</u>, GRAMINEAE, RESTIONACEAE, CUPANIEAE, <u>Pediastrum</u>	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. <u>Podocarpus</u> <u>Dacrydium</u> <u>Nothofagus</u> PROTEACEAE CASUARINACEAE GRAMINEAE RESTIONACEAE CUPANIEAE MALVACEAE SANTALACEAE MYRTACEAE HALORAGIS	Thin widespread blankets (10-75m)	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

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

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. Supplementary reference sections for the Eyre Formation in the Tarkarooloo Basin are Mines Administration LC1A bore on *Paralana* (FROME) and the Reedy Springs section on MARREE (Fig. 1, Callen & Tedford *in prep.*). The Reedy Springs section was originally the type section for the Murnpeowie Formation and has been redefined to exclude the probably faulted flat lying upper portion (see Callen in Wopfner *et al.* 1974). Yalkalpo No. 1 bore is a third important section, representative of the sequence on the Benagerie Ridge.

The lithology of the Eyre Formation is consistent over the whole FROME 1:250 000 sheet, with fine to very coarse-grained (medium dominating) 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. Matrix is usually dominated by kaolinite, with accessory montmorillonite and illite. A characteristic pebble bed occurs at the base, with black chert (both fibrous chalcedony and micro-crystalline quartz), fossil wood, red 'jasper', milky, grey, yellow and colourless quartz. The grains are characterised by high polish. Lenses of black carbonaceous silt occur.

The Eyre Formation reaches its maximum thickness in the Poontana Sub-Basin, thinning 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.

In the Lake Frome area there is excellent biostratigraphic control (Harris *in* Wopfner *et al.* 1974), discussed in detail for the Mooloowatana-Reedy Springs area by Callen (1975b, Fig. 15). A disconformity may occur within the unit, a portion of the late Paleocene being absent. At present the disconformity is not mappable, and there is an element of doubt as to its validity, hence the sediments are placed in a single formation. 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 formation does not crop out, except on the N.S.W. Border on *Thurlooka*, where a patch of the basal conglomerate is present.

The contact with the Cretaceous is well defined: coarse polished quartz sand with chert pebbles overlies 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 (new name Callen & Tedford *in prep.*, Callen 1975a *in press*). This is the situation in Yalkalpo 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 (by virtue of higher mud content) angular, fine Namba Formation sands.

Both the lower and upper contacts show regional disconformable relationships. 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 - Early Miocene

During Upper Cretaceous time, before depositon of the Eyre Formation, deep weathering and kaolinization are reported to have occurred by some workers (Firman 1969, Jessup & Norris 1971). This weathered zone is thought by others (Wopfner & Twidale 1967) to be associated with the Tertiary duricrust (Tsi) developed during late Eocene to early Miocene times. The problem is discussed in Callen (1975b) who is in broad agreement with Wopfner & Twidale, though regarding the age of much "grey billy" silcrete originally delegated to the one Oligocene silcrete (CZsi), as medial Miocene e.g. at Reedy Springs on *Mooloowatana*. In the Frome Embayment the kaolinitic and siliceous profiles are developed only in the margins of the basin or on basement highs.

Stable conditions are thought to have prevailed, allowing formation of a siliceous duricrust or silcrete horizon (Tsi) in areas of slight elevation above the water table. Silcrete is present only along the margins of the basin, or on 'basement' highs within the basin (e.g. Yalkalpo 1 bore on the Benagerie Ridge). This is illustrated on the rock relation diagram on the map. In the Lake Frome area grey-billy silcrete of the type geomorphologically associated with the Eyre Formation 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 medial Miocene is represented by the Namba Formation (Callen & Tedford *in prep.*, see Callen 1975b). The name is derived from Lake Namba (new name*) on CURNAMONA.

The type section is in Yalkalpo 1 bore on *Quinyambie*, and an important supplementary section is located at Wooltana 1 bore on *Arkaroola*. The outcrop supplementary section is on the western central shore of Lake Tarkarooloo (CURNAMONA). The unit is the time equivalent of the Etadunna Formation (Stirton *et al.* 1961), as shown by similarity in certain characteristic fossil-vertebrates, and comparable microflora. However, it has significant lithologic differences (more arenaceous), and the vertebrate fauna contain new genera not found in the Lake Eyre Basin.

The Namba Formation can be divided into several units in Wooltana 1 bore (see Callen & Tedford *in prep.*), using geophysical and litholog data.

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*Names formalised by the Geographical Names Board, South Australia, 1973. Detailed list in Callen (1974b).

For regional purposes an informal two-fold subdivision is used, based on the occurrence of dark grey tough clays with a characteristic irregular shiny fracture pattern in the lower unit (Tmb_2). This unit is dominated by clays rich in smectite, and typified by rather poorly defined cyclic deposition involving black clay, cross-bedded sand, finely laminated silt and thin carbonates. The upper unit (Tmb_1), also containing carbonates, is dominated by fine laminated silt and cross-bedded fine sand with prominent bioturbation, muds are dominated by illite and are light green grey or olive. The numbering for the two members (Tmb_1, Tmb_2) has been reversed in Callen & Tedford (*in prep.*) so as to coincide with the time sequence.

The carbonates (dolomite) alternate regularly with clays, and are rich in palygorskite at the start of each major carbonate horizon. Clay mineralogy was determined by Brown (see complete list in Callen 1975b, Appendix 2) and discussed in Callen & Tedford (*in prep.*) and Callen (1975b).

The sediments reach their maximum thickness (see Table 4) in the Poontana Basin, and appear to retain the same thickness up to the Paralana fault system of the Flinders Ranges. There is little information on the Tertiary close to the ranges, particularly west of the Poontana structure. The only bores close to the range are those of Ker McGee (Ryan 1969), and a water bore sunk by Exoil N.L. for supply to the 'Beverley' uranium camp. Neither has suitable records for reliable subdivision. Holes drilled for Exoil and Western Nuclear Aust. Ltd. suggest unit Tmb_1 is missing (cross-section A-A') in the Paralana High Plains area (region B, Fig. 2).

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

A medial Miocene age (?Balcombian) has been ascertained palynologically by Harris (personal communications 1972, 1973), who compares the flora with that of the Munno Para Clay Member (Lindsay & Shepherd 1966, Lindsay 1969) of the St. Vincent Basin. The Miocene flora was found in Cootabarlow 2, Wooltana 1, LC1A, F22/26, and Glenmore 1 (on BROKEN HILL, Brunker 1967) bores, and in Lake Eyre 20 bore in the Lake Eyre Basin. The Lake Eyre bore flora is very similar to that of Wooltana 1 bore. Correlation with foraminiferal zones of the Murray Basin and South Victoria has been obtained from a Tricentrol Aust. Ltd. bore near Mutooroo, OLARY (Lindsay & Harris 1973).

An alunite horizon, developed on unit Tmb_2 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 & Barral 1972) has shown "Puddingstone"* and "grey billy" silcretes (CZsi) are developed on top of the Namba Formation, and overlain by rocks resembling the Willawortina Formation. A similar relationship is observed in Mines Administration Pty. Ltd. L812 bore (Brunt 1972). A disconformity therefore exists between the units Tmb_1 and Tmb_2, best developed in the margins of the basin, and absent in the Poontana Sub-Basin.

There is a ferruginous horizon physically resembling the early Miocene Doonbara Formation of Wopfner (1974) in the Lake Frome area, but it is younger than the Namba Formation and therefore late Miocene. This is mapped with unit CZsi on the map. Two ferruginous "laterite" horizons have been suggested by Firman (1971) and Jessup & Norris (1971) for the northern part of the state, which may explain this discrepancy.

Late Tertiary to Early Quaternary (Late Miocene to Early Pleistocene) (Figs. 8, 9).

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*Chalcedonic red and white mottled silcrete, *not* conglomeratic or nodular in the sense of having a friable matrix.

In the Lake Frome area, the WILLAWORTINA FORMATION (Callen & Tedford *in prep.*) was deposited in the Poontana Sub-Basin. Its type section is WC2 bore on the Paralana High Plains with an outcrop supplementary section, south of "Wertaloona" on *Balcanoona* (COPLEY). Another supplementary section is Wooltana 1 bore. It constitutes a wedge shaped deposit, thickest near the Flinders Ranges, of poorly sorted conglomerates, flood plain and stream deposits. Characteristically it is affected by secondary carbonate cementation resulting from groundwater action, and partly contemporaneous soil profile development. A red and green mottled effect produced by variations in oxidation state of iron is also ubiquitous.

The Willawortina Formation (new name, Callen & Tedford *in prep.*) intertongues with unit Tmb_1 of the Namba Formation.

The base of the unit is well defined by petrophysical logs in the southern portion of the basin, but in the northern area, where secondary carbonate cementation is absent, it is less distinctive. The relationship with the Tertiary sequence has been demonstrated in outcrop by Leeson (1967), and Callen (see Coats 1973) on *Balcanoona* (COPLEY). Here, 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.

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 grade into the Namba Formation unit Tmb_1.

The Willawortina Formation is a possible correlative of the Avondale Clay (Firman 1967), with which it has strong lithological similarities.

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 MILLYERA FORMATION (new name, Callen & Tedford *in prep.*) is equivalent to the Millyera Beds (Qp_6) *plus* unit Qp5 of the FROME map (Callen 1974b), its stratigraphic status having been resolved since drawing up the map. It constitutes laminated light green to bluish green clay with thin fine sand beds and thin charophyte stem limestone and gypsum laminae. They contain abundant ostracods, charophytes, "coxiella", and worm burrows. The Formation was named after Lake Millyera on *Siccus* and *Eurinilla* (CURNAMONA) where it is best exposed.

The lacustrine clays of the Millyera Formation may be difficult to distinguish from the Namba Formation when affected by pedogenesis. When fresh they are finely laminated and contain abundant ostracods, and lenses of sand rich in charophyte oogonia. The clays have a characteristic sub-conchoidal fracture, distinguishing them from the Miocene sequence, and often have a distinctively finely laminated charophyte limestone or gypsum bed at the top. cf Avondale Clay.

Some fluviatile channel deposits, intertonguing in outcrop with the charophyte limestone are equated with the Millyera Formation. These channels contain brown calcareous nodules derived from the Willawortina Formation, and are therefore younger than this unit, but are poorly developed on FROME.

Unit 'Qp5' is a facies of the Millyera Formation developed in two widely separated areas: the southeastern shore of Lake Millyera and the northern shores at the junction of Lake Frome with Lake Callabonna. It invariably occurs directly overlying the green clays of the type Millyera Formation section. Lithologically it is fine to coarse fossiliferous sand. Fine cross-bedding and wavy horizontal bedding is typical, and abundant charophyte stem fragments and oogonia occur. Bright reddish orange gypsum-impregnated silt lenses, closely resembling the Eurinilla Formation, are present.

In Lake Callabonna, clays similar to those of the Millyera Formation type section contain vertebrate remains of Pleistocene or Pliocene age - these are the *Diprotodon*-bearing beds of Tedford (1973). There is therefore evidence that at least the upper part of the Millyera Formation is of Pleistocene age.

The next youngest unit is the unnamed conglomerate (Qp_7), constituting extensive sheets of planar cross-bedded conglomerate and sand, developed particularly along the southern shore of Lake Frome and the Siccus-Pasmore River systems. The unit is solidly cemented with white or buff carbonate, usually crystalline. It contains boulders and pebbles from the Olary and southern Flinders Ranges, with a local admixture of carbonate nodules derived from the Willawortina Formation. The Willawortina Formation contains numerous similar lenses of conglomerate, also cemented, which may be difficult to distinguish from unit Qp_7 in isolated outcrops. The unnamed conglomerate is thought to be equivalent to the Millyera Formation, by comparison with a similar sequence in Lake Tarkarooloo on CURNAMONA, known to intertongue with the Millyera Formation. The correlation is based on the presence of interbedded yellowish sands, and relationship with a calcrete (represented by greenish carbonate nodules).

On *Balcanoona* (COPLEY) a small patch of unit ?Qp_7 gravels and sands rests with angular unconformity on dipping Willawortina Formation. Unit Qp_7 is possibly equivalent to the Telford Gravel (Firman 1963, 1964, 1966b, 1967, 1970a).

Upon these units is developed the soil and groundwater carbonate horizon Qca. Unit Qca probably includes two horizons, one formed by soil processes and the other by younger groundwater cementation phenomena. The oldest part of the profile involved deposition of iron and manganese oxide crusts on sand grains, forming pipe-like structures and spherical bodies or sheets. This was intimately associated with deposition of soft to hard, white to greenish, well crystallised carbonate. The material is best developed east of Lake Frome. A possible equivalent horizon on the Balcanoona High Plains (COPLEY) is not represented on FROME.

A younger groundwater carbonate horizon is included in unit Qca. This is the white to pinkish crystalline fine grained carbonate which cements

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.	No bedding, 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		RECENT?	Bench-linear		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.	RECENT? (From relationship to EURINILLA FORMATION)	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, as for Eurinilla Formation. Lime biscuits and shell columella in basal layers.	Low angle to moderately inclined very large scale cross bed sets. Complex fine scale cross-lamination.	Gypsum sand, moderate angle cross-stratification.	Charales oogonia Rare gastropods		Wedge shaped blocks (0-5m)	Cliffs along southeastern shore of Lake Frome and crests of 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?	Soil horizon		Probably the Bca horizon of a fossil soil.
UNNAMED GRAVEL	Qp_3	Cobble and pebble deposits.	Imbricated flat pebbles in some localities.			Shown in youngest possible position Probably equivalent to EURINILLA FORMATION	Linear (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_2)	Gypsum sand, coarse grained to very coarse grained, minor quartz grains. Sorting very good in individual layers. Mapped with Qp2.	Very large scale cross-stratification in very low angle sets, with individual sets have high angle fine to medium scale cross-stratification.	Gypsum sand, low angle cross-stratification.	Charales oogonia (very common), turretted gastropods near base.		Lenses (lunettes) (0-15m)	Islands in Lake Frome, hills along south eastern shore of Lake. Undulating bare hills with karst morphology. Cliff-forming.	Calcareous horizon at top, massive gypsum crust (Qcs). Mapped with unit Qp2
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 2.5-5Y4-9/4-7 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.	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 (6-7m)	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

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74-772

DATE: SEPT '74

the younger Pleistocene stream channels (unit Qp_6, Qp_7) and basal Eurinilla Formation. 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 Qp_6 unit it may be developed as soft white crumbly cement, or massive pinkish sheets. The pink colour is produced by iron oxide stain on the cemented sand grains.

QUATERNARY (Figs. 7, 8 and large scale section D-D' on map). The two horizons are usually superposed and difficult to distinguish.

Pleistocene

The EURINILLA FORMATION (Qp_4) (new name, Callen & Tedford *in prep.*) has its type section at Lake Moko on *Coonarbine* (CURNAMONA) with supplementary sections at Lakes Millyera and Koorka. It is of proven upper Pleistocene age, containing basal channel sands with *Diprotodon*, *Procoptodon goliah*, and other species being somewhat similar to the Lake Callabonna fauna (Callen & Tedford *in prep.*). The fauna was located at Billeroo Creek on *Eurinilla* (CURNAMONA), east of L. Pinpa.

The formation consists of fine to medium clayey poorly sorted sands, of orange brown colour, impregnated with gypsum at the base, and with inter-bedded 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 Formation, whereas west and south of the lake it is developed on the Willawortina Formation, or cuts into unit Qp_7. Frequently, on CURNAMONA, the formation is underlain by a cross-bedded loose sand with pebble beds, often cemented in 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 conglomerates occur at variable topographic levels in the landscape, but always beneath the Eurinilla Formation. This conglomerate is thought to be equivalent to unit Qp_7.

At the mouth of the Pasmore River on CURNAMONA, the Eurinilla Formation, with a thin basal conglomerate, cuts down into unit Qp_7 and Willawortina Formation.

The Eurinilla Formation is regarded as equivalent to the Tirari Formation (Stirton *et al.* 1961). 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 between unit Qp_7 and the Telford Gravel.

On FROME, undifferentiated gravels on the Lake Frome Plains area have been included in unit Qp_6. These gravels occupy ridges in the landscape, though they are older than the surrounding sands (Qp_1, etc.). The reverse topography results from differential compaction and erosion. Most of the gravels may belong to the Qp_7 channel deposits, or to gravels ?beneath or associated with unit Qp_4.

Along the southeastern shore of Lake Frome, and on the islands in the lake itself, are extensive gypsum lunette deposits (Qp_2). These dune sands grade into quartz sand dune deposits on-shore. The bedding is of unusual type for dunes, being subhorizontal. At present they are regarded as essentially equivalent to the Eurinilla Formation, though there is some difficulty in correlating lake shore material with that further away from the lake edge.

Ridges (Qp_3) are developed along the northwestern shore of Lake Frome, consisting of gravel deposits and rare patches of material resembling unit Qp_5. There is a distinct change in geographic pattern observable on the photomozaics, east and west of the deposits, forming a line parallel to present shore of Lake Frome. One of the gravel ridges has pebbles imbricated perpendicular to its length. The deposits, probably representing an old shoreline developed during Upper Pleistocene times, are overlapped by the

Coonarbine Formation sands. They have been mapped as an unnamed separate unit, and shown in their youngest possible position on the map (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, possibly partly equivalent to the Arrowie Formation (Coats 1972).

The next youngest development is gypcrete (Qca), 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.

The soil carbonate Qcc_2 is typically developed on the Eurinilla Formation as a well developed series of horizons of soft white carbonate tubules and lumps, with minor gypsum. It occasionally develops into lumpy sheets, and hardens when weathered. The soil is widely developed, and associated with orange, brown and black ochreous mottling. The gypseolianite of the Eurinilla Formation has a massive gypsum crust with a blocky structure, probably corresponding to the Qcc_2 horizon.

Pleistocene - Recent

The COONARBINE FORMATION (new name, Callen & Tedford *in prep.*) has its type section at the same locality as the Eurinilla Formation (Lake Moko). The deposits are poorly sorted sands with gravel lenses, forming a thin widespread blanket. Cross-bedding is present 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.

The age of the Coonarbine Formation (Qp_1) is unknown, but may extend into the Recent. It contains aboriginal artifacts, land snails and bones of wombat and rat-kangaroo in its upper most surficial layers. The Coonarbine Formation has been mapped as Pooraka Formation (Firman 1966a) on COPLEY (Coats 1973), but relationships elsewhere (Williams & Polach 1971) show the Pooraka Formation is older.

Unit Qcc_1 is the youngest carbonate horizon and is developed on the Coonarbine Formation. It resembles Qcc_2, but is more weakly developed, and the carbonate cylindroids are smaller. Associated with it is a well-developed blocky structure, formed by large rectangular peds which may extend into underlying formations of suitable texture.

The Paralana High Level plain is veneered by a thin layer of red-brown sand with reworked cobbles, occasionally merging into thick cobble deposits derived from weathered Willawortina Formation, containing land snails similar to those of the Coonarbine Formation. On COPLEY these beds were referred to the Arrowie Formation, which seems to include the underlying Eurinilla Formation. The Eurinilla Formation and this red brown sand veneer have been mapped as one and distinguished by an overprint on Qp_1 colour.

The Strzelecki Desert and 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 Eurinilla Formation, and are partly active today. They have steep north faces, and are of the windrift type. The unit dominates the eastern half of FROME.

Wind direction studies (Callen 1974b) 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.

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

Holocene beach deposits (Qrb) have been recognised (personal communication,J.M. Bowler,Dept. Biogeography and Geomorphology, Australian National University,1973). These are related to the present shoreline, but suggest a more active lake phase. Semi-liquid blue-green to brown and black clays of Holocene age have been cored and dated (Draper & Jensen *in prep.*), and pers. comm. J.M. Bowler) and are continous with the modern sediments. These sediments are distinguished from those of the Millyera Formation by their lack of lamination.

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 Qrb.

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 crust of salt occurs on the southern part of the lake (dashed line), and algal stems and mats are found in some areas. At present there is slow deposition in the lake.

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

STRUCTURE (See Tectonic sketch on map)

Mt. Painter Inlier

The structural geology of the Mt. Painter Block has been described by Coats (Coats & Blissett 1971). A précis 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 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 3000 m is similar to the Paralana Fault to the south.

Structure of basement beneath the Frome Embayment

The subsurface structure on FROME is well-documented from drillhole data and magnetics (Figs. 10, 4). The Benagerie Ridge, a N-S oriented basement high, coincides with a magnetic high, and is continuous with the well-defined structure on CURNAMONA (Jack 1930, Callen 1975 *in press*). A relief of 1500 to 4000 m in the southern part of the sheet is evident from depths to magnetic basement deduced by Parker (1973) and Tucker and Brown (1973), shown in the tectonic sketch. Cross sections show Mesozoic and lower Cainozoic strata thin out over the Benagerie high, and there is evidence from private company uranium exploration drilling on *Eurinilla* (CURNAMONA) that the Middle Cambrian is absent, assuming the porphyry mentioned previously is Precambrian.

Seismic work for Crusader Oil N.L. indicates a very gentle folding in the Middle Cambrian rocks with an overall westerly dip. Crusader's work indicates a major horst-like fault structure approximately corresponding to the Poontana Structure (Coats *et al.* 1969) dominating the western part of the sheet. This feature dies out in the vicinity of Wooltana 1 bore to reappear further north. Topographic features associated with the edge of the Paralana high-plain area suggest 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 the Mt. Painter Special was based on a geophysical interpretation which has since been superseded by more accurate surveys.

The Crusader interpretation is shown in the tectonic sketch, and on one of the sections. Crusader also show another fault situated a short distance east of the Poontana structure, and parallel to it.

Frome Embayment and Tarkarooloo Basin

Structure contour maps of the Mesozoic-Palaeozoic unconformity were prepared by Evans (1946), Wilson (1956) and Ker (1966), for Crusader Oil N.L. from seismic data. The Cretaceous Frome Embayment basin has its axis beneath the eastern portion of Lake Frome, but during the Tertiary the axis of thickest accumulation moved west to a position close to the edge of the present Flinders Ranges, resulting in the formation of the Poontana Sub-basin. This is illustrated on section A-A' on the map. It appears that the western edge of the Tarkarooloo Basin once extended well into the area now occupied by the Flinders Ranges, and has since been eroded from the uplifted Flinders Ranges.

The Mesozoic and Cainozoic sediments are faulted against Adelaide Geosyncline sediments and Mount Painter Inlier 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 within these form broad domes of low amplitude.

On the New South Wales border occur steeply dipping ?Adelaidean rocks, intersected by quartz veins, indicating a major structure affecting the Cainozoic in the vicinity. The structure is supported by estimates of depths to the base of the Tertiary from surrounding water bores (see tectonic sketch), but drilling by Chevron Exploration Corp. (Morgan 1973) indicates no change in depth to the base of the Tertiary on approaching the southwestern side of the outcrop. It is suggested a fault must be present here 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 derive water from the Great Artesian Basin (personal communication J.J. Draper and A.R. Jensen, Bureau of Mineral Resources, Geology and Geophysics, Canberra 1975). 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 they coincide.

The possible fault indicated at 140°33', crossing the southern border of the FROME map onto CURNAMONA, is drawn along the eastern edge of a ridge of silcreted Tertiary which has been upfaulted. The structure also corresponds to the edge of a major magnetic feature on CURNAMONA (aeromagnetic contour map available) separating a magnetic pattern typical of Willyama Inlier crystalline basement to the west, from a linear northerly oriented magnetic low to the east. Extended north, the fault must pass between Mudguard No. 1 and Yalkalpo No. 1 bores, since the Cambrian is missing in Mudguard No. 1 bore. Thus the magnetic pattern probably results from the contrast between Willyama Inlier crystalline basement along the Benagerie Ridge west of the fault, and Cambrian rocks east of the fault.

Folding in the Mesozoic and Cainozoic is virtually absent, though a westerly dip of 1-2° exists west and south of L. Frome as for the Cambrian sequence. This was determined from drilling by uranium exploration companies and applies to both the Mesozoic and Cainozoic sequence. It agrees with the dip on the Mesozoic-Palaeozoic unconformity 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 & Ludbrook 1963) may account for this. It is supported by the displacement of the centre of deposition recorded by Draper & Jensen (*in prep.*). Other geographic features, such as the zig-zag course of Eurinilla and Coonee Creeks may also have some relation to tectonics.

SEQUENCE OF EVENTS

1. In the Mt. Painter-Mt. Adams area, deposition of a thick sequence (6 100 m on COPLEY) of sediments began at least 2000 m years ago. This has since been metamorphosed to produce the Radium Creek Metamorphics. Little is known of the depositional environment of the original sediments, except that there is evidence of current action from cross bedding in the quartzites.

   Intercalated in this sequence is the Pepegoona Porphyry, a porphyritic rhyolite which Coats (Coats & 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 he thought to be conformable, though 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.

2. The sediments were intruded by the "Older Granite Suite" (about 1600 m.y., Coats & Blissett 1971), 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, accompanied by metamorphism, according to Coats (Coats & Blissett 1971).

3. The sequence was folded, faulted and uplifted.

4. After prolonged erosion, the sediments of the Adelaide Geosyncline were deposited. The Wywyana Formation marble indicates a phase of carbonate deposition, later involved in diapiric intrusions during early Sturtian and

DEPARTMENT OF MINES–SOUTH AUSTRALIA

LAKE FROME AREA – CAINOZOIC CORRELATION CHART

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DRN: A.R.

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SCALE: —

DATE: 13TH APRIL 1976

PLAN NUMBER: S12169

FIG.9

TABLE 6 LAKE FROME AREA, CORRELATION CHART – CAINOZOIC

CAINOZOIC MAP UNITS AND POSSIBLE EQUIVALENTS

TIME UNIT	AFTER CALLEN & TELFORD (in press): SYMBOL	NAME	EQUIVALENTS IN OTHER BASINS AND ADJACENT MAP SHEETS: FIRMAN 1971 FROME	COATES et. al., COPLEY 1:250,000 MAP	STIRTON et. al., 1961 LAKE EYRE
RECENT	Qra		Qra	Qra	
	Qrl		Qrl	Qrl	
	Qrs		SIMPSON SAND	Qrs	
	Qrb	Unnamed clays & sands	TINGANA CLAY CALLABONNA CLAY	ARROWIE FORMATION; Qrl	
LATE PLEISTOCENE TO RECENT	Qcc_1	Unnamed soil	LOVEDAY SOIL		
	Qp_1	COONARBINE FORMATION	POORAKA FORMATION	POORAKA FORMATION	
	Qp_2	Unnamed gypsum lunettes			
MEDIAL TO LATE PLEISTOCENE	Qcc_2	Unnamed soil	LOVEDAY SOIL		
	Qp_3	Unnamed beach deposits			
			Qcs	Qcs	
	Qp_4	EURINILLA FORMATION (Mound Spring Deposits ?)	POORAKA FORMATION + TELFORD GRAVEL	POORAKA FORMATION	KATIPIRI SAND & TIRARI FORMATION
	Qca	Unnamed calcrete	BAKARA SOIL + (RIPON CALCRETE) Includes groundwater calcrete in basal Eurinilla Formation.	Qca Includes groundwater calcrete	
	CZm + Qp_5	MILLYERA FORMATION (MILLYERA BEDS + unit Qp_5)			
	Qp_7	Unnamed Conglomerate (Equiv. MILLYERA FORMATION)	TELFORD GRAVEL	TELFORD GRAVEL	MAMPUWORDU SAND
LATE MIOCENE TO EARLY PLEISTOCENE	CZw	WILLAWORTINA FORMATION	AVONDALE CLAY ? & "Conglomerate at Lyndhurst"	BUNGUNNIA LIMESTONE Equiv., AVONDALE CLAY, "T – Q"	WIPAJIRI FORMATION
	CZsi	Ferruginous horizon & Silcrete (Relationship to Willawortina Formation, uncertain)	Ferruginous horizon	Tsi	
MEDIAL TO LATE MIOCENE	Tmb	NAMBA FORMATION	AVONDALE CLAY ?	? AVONDALE CLAY (Upper part of Tmb)	ETADUNNA FORMATION
OLIGOCENE ?	Tsi		Tsi	Tsi	
EARLY PALEOCENE TO LATE EOCENE	Tee	EYRE FORMATION	EYRE FORMATION	EYRE FORMATION	

later times. On the map area the Wywyana Formation is seen only in a tectonic context in the unusual thrust structure near Mt. Adams. The Fitton Formation and Bolla Bollana Formation are postulated by Coats (Coats & Blissett 1971) to be of glacial origin. Slumping from basement highs is another possibility. The remainder of the Proterozoic sequence is not represented on FROME.

The Lake Frome area was probably a stable cratonic block during deposition of the Adelaidean, as suggested by the orientation of basement trends around the margins of the region, and by evidence for a thin relatively undeformed Adelaidean and Cambrian cover. This block has been named the Curnamona Craton (Thomson 1975 *in press*), being a different concept than the "Paralania" of Sprigg *et al.* (1958) which is further north. The Lower Cambrian and Proterozoic rocks are either absent or thin over much of the sheet, excluding the margins along the eastern edge of the Flinders Ranges, where increased basement depths permit the presence of some Palaeozoic rocks.

Lower Cambrian marine carbonate sedimentation took place at least in the region of the Benagerie Ridge. During Middle Cambrian times a sequence of redbeds accumulated, directly related to those of the Adelaide Geosyncline. These are essentially continental fluviatile and deltaic deposits, with a marine transgression represented by the Wirrealpa Limestone.

5. During Middle Cambrian to Ordovician time, folding and low grade metamorphism of the Adelaide Geosyncline rocks occurred, followed by uplift and erosion. The folding appears to have had little affect on the Curnamona Craton basement cover. Deposition probably occurred into the early Ordovician in the northeastern portion of the basin.

6. No further deposition occurred in the map area until Early Jurassic times, when epeirogenic movements initiated formation of the Great Artesian Basin (Wopfner 1964), 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. When deposition began, the surrounding ranges were low and crystalline basement areas were exposed, in the Mount Painter area and along the Benagerie Ridge (Callen 1975b).

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 must intertongue with the lower part of the Marree Formation at basin margins.

Gradual degradation of the source area with time partly contributed to the change from Cadna-owie to Marree Formations.

7. During the Late Cretaceous stable conditions and non-deposition prevailed.

8. In the Early Paleocene, renewed uplift initiated a new phase of sedimentation, particularly adjacent to the Barrier and Olary Ranges and Benagerie Ridge. A widespread sand blanket was laid down by braided and meandering streams over much of the Great Artesian Basin (Eyre Formation). The basin had an outlet to the sea, and constant reworking and high rainfall caused fines to be flushed out. High rainfall humid conditions are indicated by the floral content: forests grew in the vicinity.

The Olary block supplied granitic detritus to the sediments, and the Mesozoic of the Mt. Arrowsmith area is proposed as a source for the northern parts (Wopfner *et al.* 1974, Callen 1975b). Pebbles of fossil wood, chert and ?porphyry originated from the Mesozoic strata, uplifted on the surrounding ranges.

The uppermost Paleocene is probably not represented in the Lake Frome or Lake Eyre basins (Harris *in* Wopfner *et al.* 1974).

The Eocene sediments are finer, brown, carbonaceous silt, representing swampy conditions and dominantly meandering streams, indicating decrease in stream (general) gradient as adjacent upland was eroded.

9. Widespread stable conditions then prevailed during the Oligocene, which was largely a period of non-deposition.

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 solution of quartz by alkaline groundwater and possibly from weathering of, or during the formation of, kaolinite from smectite. This could have occurred *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 because the sheet records the centre of the basin of deposition. However, it occurs sporadically 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), though are not necessarily of this age. It should be noted that many similar silcretes of differing age may occur, associated with other unconformities (Callen 1975b).

10. In medial Miocene times the Poontana trough began forming west of Lake Frome, and was the site for deposition of very finely laminated fissile carbonaceous clays of the lowermost Namba Formation, in a probable fresh-water lake environment. These clays contain vertebrates, and a flora indicative of permanent water and high rainfall. This flora was found in Wooltana 1 and LC1A bores, but the carbonaceous clayey facies is restricted to Wooltana 1 and some of the central Pacific Minerals Pty. Ltd. bores (Schindlmayr 1970). Warm conditions are suggested from foraminiferal evidence in equivalent marine strata of the Murray Basin.

Higher in the Miocene sequence, vertebrates are recorded. Their taxonomic content implies a large body of permanent water with forested shores, in agreement with the high rainfall suggested from floral evidence (Callen & Tedford *in prep.*).

Abundant smectite in the lower Namba Formation requires the restricted leaching found in swamply regions. The palygorskite-dolomite association is compatible with deposition in shallow lakes in a humid subtropical climate (Callen 1975b).

Halite is associated with the palygorskite, and minor sedimentary structures of the type described by White (1961) suggest a saline environment. The presence of saline waters in a subtropical high rainfall climate imply an estuarine environment, or high evaporation from a shallow lake with external drainage. Intermittent exposure of the lake sediments to weathering is recorded by incipient soil formation.

The presence of plagioclase, often more abundant than potash feldspars, can be ascribed to derivation from sources within or very close to the basin, where plagioclase is abundant. Arid conditions are not essential for preservation of such assemblages (see discussion in Callen 1975b).

11. A period of non depostiion was accompanied by extensive ferruginisation and silicification (CZsi) which is particularly well represented in the marginal basin areas, though represented on FROME only by scattered silicified brown sand outcrops and rare silicified shale.

12. Following deposition of the lower Namba Formation (unit Tmb_2) a marked change in conditions occurred as a result of uplift of the Flinders Ranges in Upper Tertiary to Pliocene times, and imposition of a more seasonal possibly cooler climate. Uplift during Miocene times was first suggested by Howchin (1913) for this area, and a similar situation is recorded by Binks (1972) for the Ediacara area. The lakes were swamped with detritus, and extensive alluvial fans formed. Meandering streams dominated the lower part of the fan environment whilst mud flow and streamflood deposits built up near the ranges. These sediments were accommodated by the Poontana Sub-basin.

Further out in the basin, the intertonguing upper part (Tmb_1) of the Namba Formation was deposited, with its illite-rich clay mineral suite. There is evidence for uplift, and weathering of high areas, producing alunite and silcrete, before the Willawortina Formation was deposited.

Worm burrows and silicified coniferous tree trunks (personal communication W.K. Harris 1973), some with roots and branches, are associated with the channels east of Frome. The channels are at present included in the Namba Formation.

Folding then occurred in regions flanking the Flinders Ranges, and on the border on *Thurlooka.* The basin was closed by uplift of the Olary Ranges.

13. Deposition of the Millyera Formation lacustrine sediments followed. In the Pasmore River region, extensive conglomerates (Qp_7) probably represent the ancient river system feeding this lake. The channels roughly coincided with present day rivers. Rainfall must have been higher than at present as the lake was larger, and the channel deposits extensive. Evaporation was also high.

14. Carbonate and mottled ferruginous soil developed.

15. The Eurinilla Formation records an initially fluviatile environment, later developing extensive aeolian deposits, including dunes and ?loess, and possibly the bulk of the gypsum lunettes (*c.f.* Bowler 1971). Alternatively, the lunettes may have formed during deposition of the Coonarbine Formation. The streams coincided closely with present drainage, the Millyera Formation sediment deposited in the linear lakes on *Eurinilla* (CURNAMONA) was re-eroded and Lake Frome decreased to something approaching its present size. Large marsupials existed in the vicinity. This unit records the onset of aridity, and the development of the modern Lake Frome. The Eurinilla Formation filled depressions in the landscape.

16. The Eurinilla Formation deposition was followed by development of a calcareous paleosol.

17. Later a new phase of deposition set in, represented by the Coonarbine Formation. Streams with floodplains deposited a blanket of sediments, eroded some 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. Gyspum lunettes possibly 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.

18. During Late Pleistocene times the Flinders Ranges and flanking high plains continued to be uplifted, whilst the Olary and Barrier Ranges were comparatively more static. Lacustrine sediments continued to be deposited in Lake Frome.

ECONOMIC GEOLOGY

Metallic Minerals

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

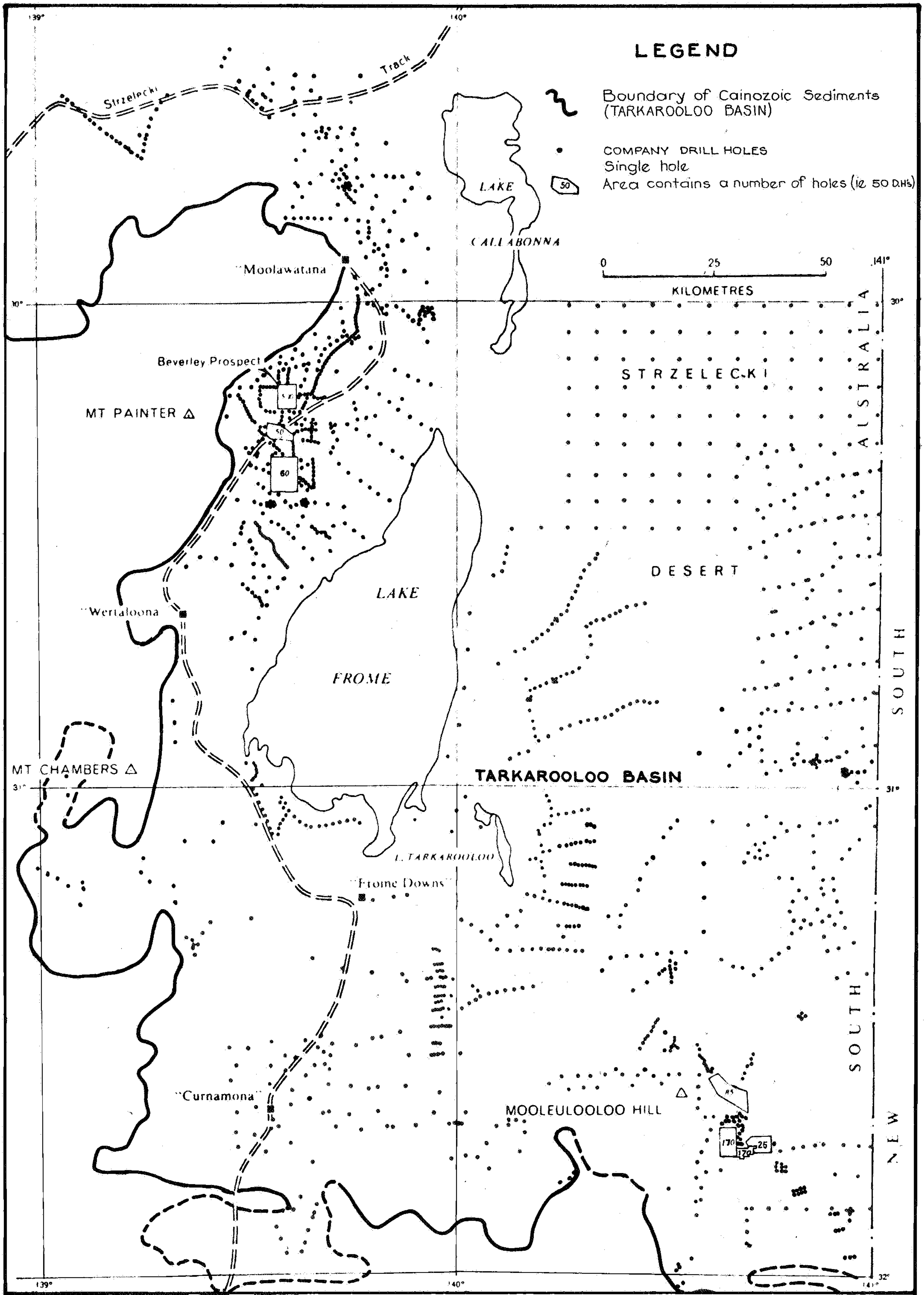
Considerable uranium has been proved by Western Nuclear Aust. Ltd. on the Petromin-Oilmin group lease at the Beverley Prospect in the Paralana area. Some has also been located on CURNAMONA. The uranium is of the roll-front or blanket type occurring in a sedimentary environment similar to many of the North American deposits (Callen 1975a, *in press*). The clayey fine sands of the lower unit of the Namba Formation and coarser sandy facies of the Eyre Formation are the prospective horizons. Drilling in the basin is shown in Fig. 10 and is discussed in Callen (1974a).

Some heavy minerals have been located - the Eurinilla Formation at one locality on the western shore of Lake Frome contains high rutile percentage 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, zircon and other minerals 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 sediments are present. West



R.A.Callen 1975

PRIVATE COMPANY DRILLING
FOR SEDIMENTARY URANIUM
TARKAROOLOO BASIN

FIG.10

S12172

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 uncemented, (3) Tertiary sands which provide good quality sub-artesian water. East of Lake Frome, aquifer (4) provides good supplies (Brown 1950, who misidentified the aquifer as Cretaceous). The major aquifer (5) is the Cadna-owie Formation or Algebuckina sandstone (Interstate Conference on Artesian Water 1929). The Cretaceous aquifer has not been used 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, though this is partly due to deteriorating bore hole conditions.

Swelling clays of the palygorskite and degraded ?montmorillonite type occur in outcrops around many of the small lakes. Palygorskite is associated with dolomite. Thick white kaolinite deposits are common in association with Eyre Formation sands, particularly near granitic source areas, and have been investigated by some companies on CURNAMONA and the Paralana High Plains.

Extensive gypsum deposits are present, usually mixed with clay and sand, in the Eurinilla Formation gypsum lunettes, and also deposited beneath the Lake Frome surface. Salt crust is very thin, and inaccessible.

Alunite occurs over a wide area, but is often impure, mixed with kaolinite, smectite or jarosite. Outcrop occurs at Lakes Bumbarlow and Starvation, elsewhere it occurs in bores. It has occasionally been used elsewhere in South Australia as a source of potassium.

The Eyre Formation contains large fragments of coalified wood (e.g. Yalkalpo 1 bore) and methane gas has been detected from many bores on the east side of the lake, but no significant fossil fuels are expected. The sources are in Cretaceous and Tertiary sediments.

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

1st March, 1976

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