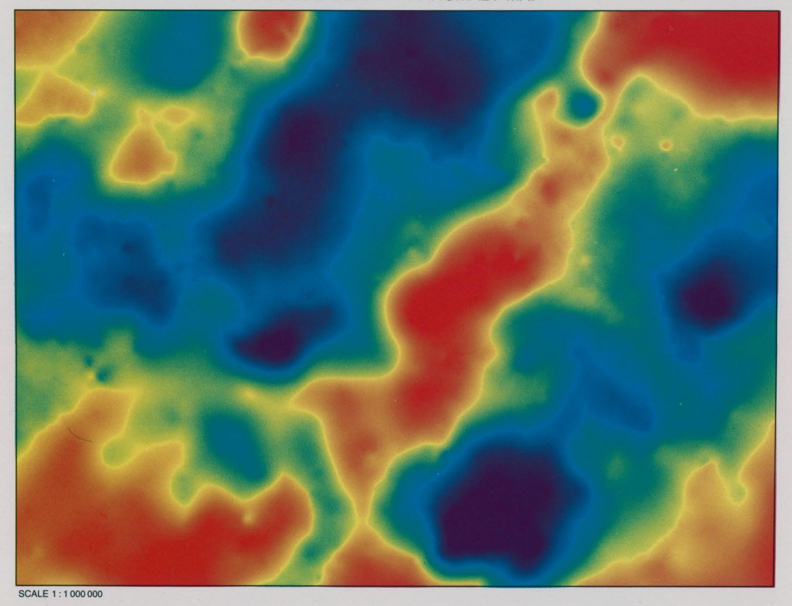
STRZELECKI

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA
DEPARTMENT OF MINES AND ENERGY ADELAIDE

AUSTRALIA 1 : 250 000

S.A. GEOLOGICAL ATLAS SERIES SHEET SH 54-2

BOUGUER GRAVITY ANOMALY MAP



SCALE 1 : 1 000 000

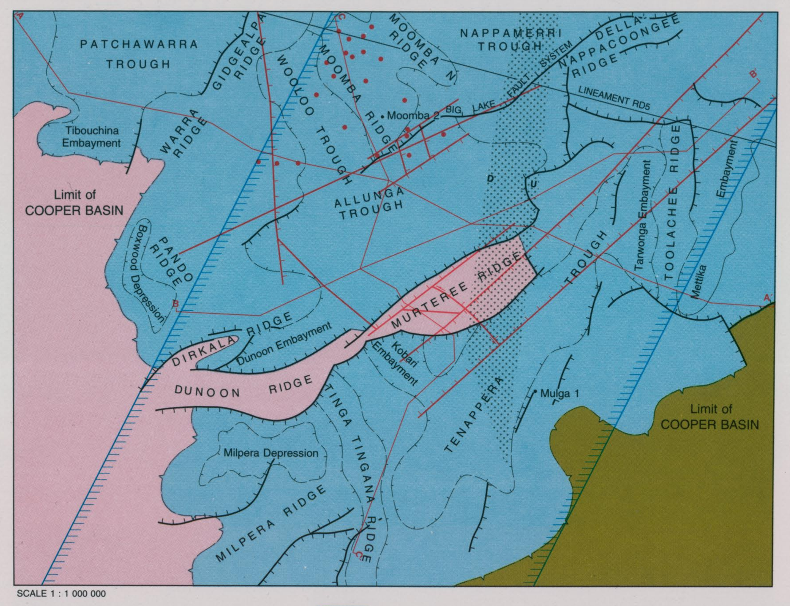
Extracted from the South Australian Gravity Database.

Grid size 500 metres. Density 2.67.

Geophysical data compiled and processed by D.N. Love and S. Biggins.

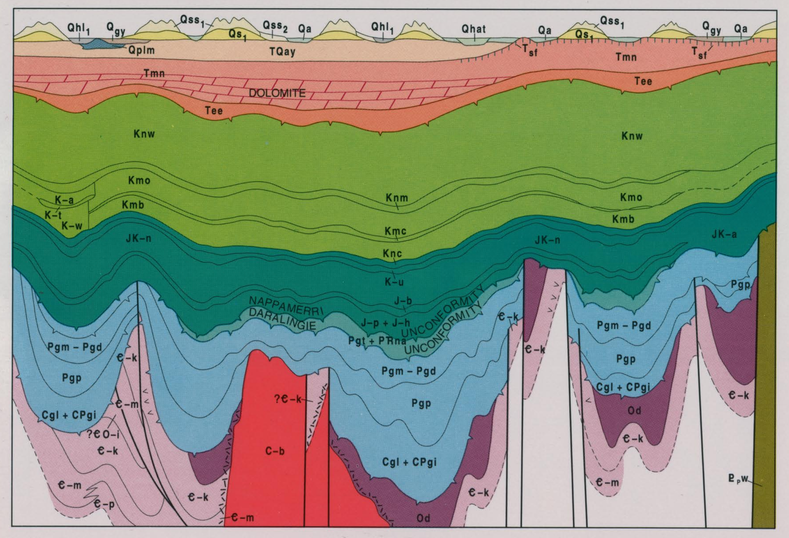
Transverse Mercator Projection.

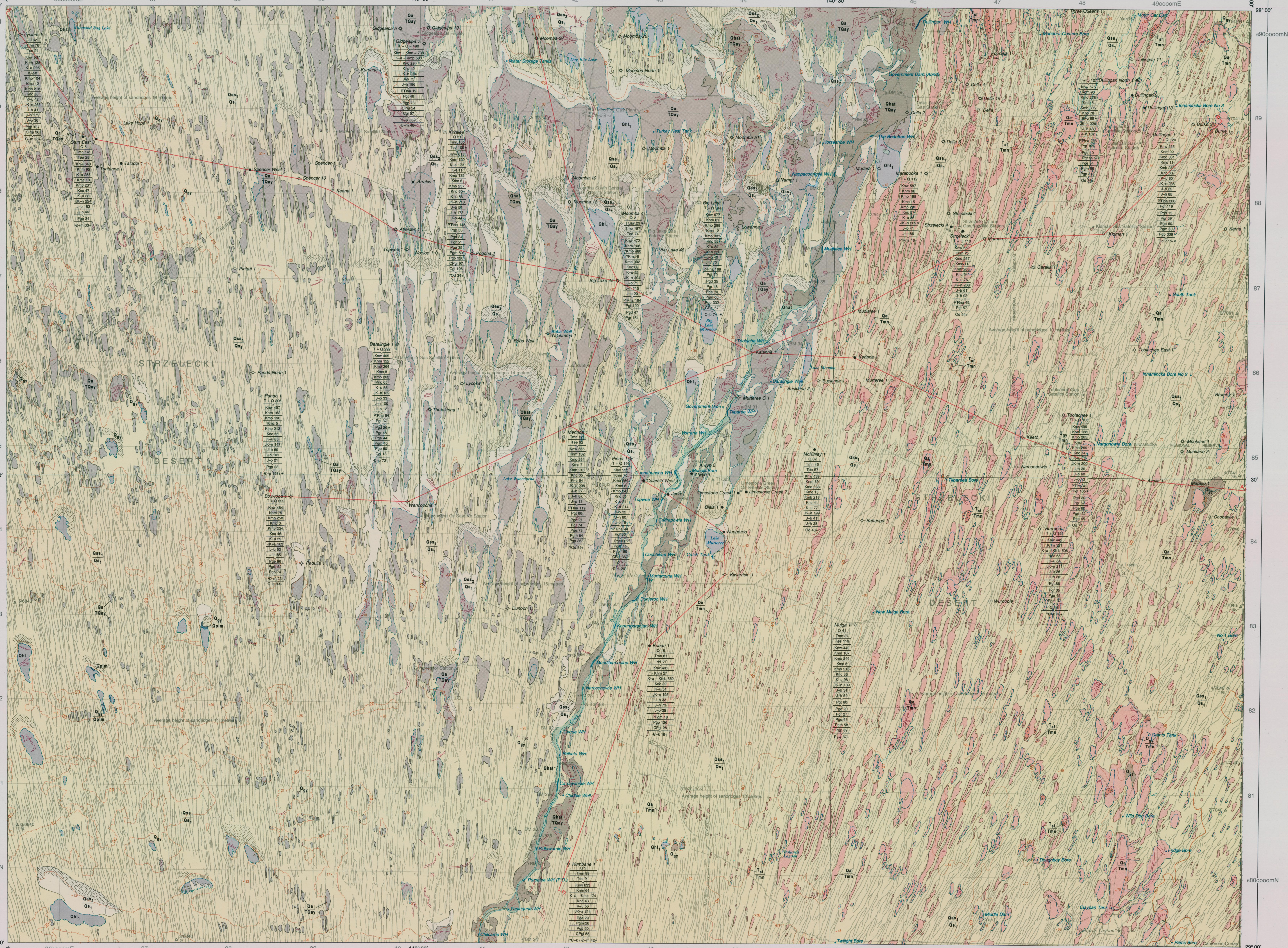
TECTONIC SKETCH



SCALE 1 : 1 000 000

ROCK RELATION DIAGRAM





FIRST EDITION 1994

REFERENCE

LAKE EYRE BASIN - CALLABONNA SUB-BASIN

Qhat — TINGANA CLAY: Grey to white clay with fine sand of quartz or clay pellets. Floodplain and channel deposits. Includes 3 000-8 000 year old alluvium and recent dunes derived therefrom associated with Strzelecki Creek. Interbedded with longitudinal dunes around floodplain margins.

Qhl_1 — Clay and halite of terminal lakes.

SIMPSON SAND:
Qss_2- Hummocky, pale yellow, very fine to medium-grained sand marginal to windward side of pans. Grades into leeside transverse dunes (lunettes). Partly local slopewash deposits from dune flanks.

Qss_1- Longitudinal single and multicrested dunes. White to pale yellow near watercourses, yellow to west of Strzelecki Creek and red-brown to orange to the east. Transverse dunes and sand ribbons west of Strzelecki Creek.

Leeside transverse dunes (area of shading).

Qs_1-(outcrops included in $Qss_{1\&2}$). As for $Qss_{1\&2}$, but generally indurated and sometimes loosely cemented by carbonate palaeosols. Often contains clay pellets and gypsum grains. Transverse dunes, moderately indurated and high in clay pellets, producing "badlands" erosional pattern. Includes COONARBINE FORMATION.

Q_{gy} — Massive gypsum crust, veins and sheets. Older high level saline groundwater deposits with clusters of disc-shaped crystals; lower level, younger, fibrous gypsum veins. Associated with celestite nodules and masses in some areas. Age ranges from 30 000 years BP to present.

Qa — Undifferentiated fluvial and lacustrine sands, red-brown to white, poorly to well sorted. Includes EURINILLA FORMATION. Overlies YANDRUWANTHA SAND or NAMBA FORMATION in interdune corridor exposures.

Meanders, channels and scroll bars of prior streams.

Qplm — MILLYERA FORMATION: Green to grey clay with sub-conchoidal fracture or soft and crumbly, interbedded fine sand and silt. Lacustrine and floodplain deposits. Usually capped by gypsite.

Qhat/TQay, Qa/TQay, TQay — YANDRUWANTHA SAND (TQay. Subsurface only): Medium to very coarse loose brown sand with rough, subangular grains, includes varying proportion of white clayey fine sandstone grains and yellow- to red-coated grains. Contains reworked Mesozoic and Tertiary sands. Fluvial sand with aeolian input.
Meanders, channels and scroll-bars of prior streams.

T_{sf} — Ferruginous mottles and cements, partially silicified, sometimes associated with alunite. On, and generally included with, NAMBA FORMATION.

Qa/Tmn — Thin Quaternary cover on NAMBA FORMATION, mainly fluvial, with scattered float of NAMBA FORMATION and silcrete.

Tmn — NAMBA FORMATION: Fine, grey to olive clay and yellow well-sorted silt to fine sand of lake, delta and fluvial deposits. Medium to coarse, cross-bedded sand, probably reworked from EYRE FORMATION in channels. Basal white lacustrine dolomitic clay and carbonate with palygorskite. Mottled with ochre in upper part, coarser facies patchily silicified and iron cemented, black and purple.

Tee — EYRE FORMATION (Subsurface only): Fine to coarse, moderately sorted quartz sand with dark green-grey grains in lower part, often with polished and subrounded grains. Fluvial sheet deposit.

(CAINOZOIC — QUATERNARY: HOLOCENE; PLEISTOCENE TO HOLOCENE; LATE PLEISTOCENE TO HOLOCENE; LATE PLEISTOCENE; LATE PLIOCENE TO MID PLEISTOCENE — TERTIARY: MIOCENE; MIOCENE-PLIOCENE; LATE PALEOCENE TO MIDDLE EOCENE)

EROMANGA BASIN (Subsurface only)

Knw — WINTON FORMATION: Dark grey carbonaceous and pyritic mudstone, cross-laminated, interbedded with pale grey, fine-grained and calcareous sandstone and coal. Limestone concretions. Fossil wood, leaves, freshwater bivalves, vertebrates. Fluvial (meandering river) and paludal.

Knm — MACKUNDA FORMATION: Pale grey-green, fine-grained, glauconitic cross-bedded sandstone. Fossiliferous claystone and siltstone interbeds. Marginal marine.

Kmo, K–a — OODNADATTA FORMATION (Kmo) and ALLARU MUDSTONE (K–a): Dark grey mudstone with limestone concretions. Fossiliferous. Interbedded with calcareous siltstone and fine-grained sandstone. Shallow marine.

K–t — TOOLEBUC FORMATION: Black algal-rich siltstone, uraniferous. Fossiliferous coquinite interbeds with *Inoceramus*, other molluscs and fish remains. Reducing marine. Restricted to northern portion of sheet area.

Kmc — COORIKIANA SANDSTONE: Grey-green to white, fine to medium-grained sandstone, bioturbated. Open marine.

Kmb, K–w — BULLDOG SHALE (Kmb) and WALLUMBILLA FORMATION (K–w): Dark grey fossiliferous mudstone with layers of calcareous concretions. Basal units of organic–rich shale with sandstone lenses. Fossil wood, molluscs, echinoids, brachiopods, foraminifera, fish remains. Shallow marine.

Knc — CADNA-OWIE FORMATION; Off-white, fine to medium-grained calcareous sandstone with interbeds of grey siltstone. Shoreline and coastal plain.

JK–a — ALGEBUCKINA SANDSTONE (JK–a): Undifferentiated alluvial and fluvial deposits, chiefly white, medium to coarse-grained, quartzose and pebbly sandstone. Replaces NAMUR FORMATION and HUTTON SANDSTONE as the interbedded, finer-grained rock units lens out towards Eromanga Basin margin.

K–u, K–um — MURTA FORMATION: Dark grey laminated siltstone, graded beds, ripple marks with interbeds of fine-grained to locally coarse-grained sandstone, ripple laminated, bioturbated. Lacustrine with basal transition to lake margin and fluvial environments (McKINLAY MEMBER K–um).

JK–n — NAMUR FORMATION: White, fine to coarse-grained sandstone, flat to cross-bedded, locally with calcareous cement. Siltstone interbeds, especially in middle part. Minor mudstone and coal stringers. Sandy lacustrine and fluvial (braided river).

J–b — BIRKHEAD FORMATION: Grey-brown siltstone with minor mudstone and sandstone. Carbonaceous, burrows, root casts, interbedded with coal as thin beds and stringers. Lacustrine, swamp, fluvial (meandering river).

J–h — HUTTON SANDSTONE: White, fine to very coarse-grained and conglomeratic sandstone, flat to cross-bedded. Common reworked clasts and minor interbeds of mudstone. Mainly fluvial, with possible aeolian and lacustrine deposition.

J–p — POOLOWANNA FORMATION: Grey-white, medium-grained sandstone, flat to cross-bedded with minor laminated siltstone. Carbonaceous stringers, common mudclasts. Overlain by dark grey carbonaceous mudstone, minor coal interbeds. Fluvial (meandering to anastomosing river).

(MESOZOIC — CRETACEOUS: LATE, EARLY — JURASSIC: LATE, MIDDLE, EARLY; MARREE SUBGROUP; NEALES RIVER GROUP)

COOPER BASIN (Subsurface only)

PRna — ARRABURY FORMATION: Grey to red-purple mudstone and siltstone, bioturbated, with minor interbedded fine to medium-grained, ripple-laminated sandstone. Section eroded in southern Cooper Basin. Fluvial floodplain and lacustrine.

Pgt — TOOLACHEE FORMATION: Interbedded sandstone, mudstone and coal. Upward-fining sands overlain by thin, upward-coarsening silt to sand. Fluvial (point bars and meandering river) and floodbasin lake.

(EARLY TRIASSIC; LATE PERMIAN; NAPPAMERRI GROUP)

Pgd — DARALINGIE FORMATION: Interbedded grey siltstone, mudstone and coal with minor sandstone. Predominantly floodbasin lacustrine with minor fluvial deposits.

Pgr — ROSENEATH SHALE: Dark grey, interbedded, carbonaceous mudstone and siltstone with minor sandstone. Laminated, variably pyritic and calcareous. Lacustrine.

Pge — EPSILON FORMATION: Off-white, fine-grained, ripple-laminated sandstone, locally thick with interlaminated siltstone, or thin with interbedded mudstone and coal. Fluvial to lower delta plain and delta front.

Pgm — MURTEREE SHALE: Dark grey, interbedded, carbonaceous mudstone and siltstone with minor sandstone. Laminated, variably pyritic and calcareous. Lacustrine.

Pgp — PATCHAWARRA FORMATION: Interbedded sandstone, mudstone and coal. Stacked channel and upward-fining deposits. Thick coal seams in lower part. Upper levels dominated by mudstone with thin interbeds of siltstone and sandstone. Fluvial (point bars, meandering river), backswamp and floodbasin.

CPgi — TIRRAWARRA SANDSTONE: Buff-white, medium to coarse-grained sandstone, massive to flat-bedded and cross-bedded. Rare mudstone and coal stringers. Stacked multistorey sand bodies. Paraglacial, fluvial (braided river).

Cgl — MERRIMELIA FORMATION: Buff-white, fine-grained sandstone, ripple-bedded, soft sediment deformation. Massive to crudely bedded conglomerate, framework supported with reworked Early Palaeozoic clasts. Poorly sorted diamictite, matrix supported, dropstones. Dark grey claystone and siltstone, flat-laminated or graded with interbeds of fine-grained sandstone. Fluvioglacial outwash, lacustrine (shallow to relatively deep water), subaerial and subaqueous tillites.

(EARLY PERMIAN; ? LATE CARBONIFEROUS; GIDGEALPA GROUP)

C–b — BIG LAKE SUITE: Coarse to very coarse grey granite. Intrusive into Warburton Basin sediments during Alice Springs Orogeny. U–Pb SHRIMP ages of 323±5 Ma and 298±4 Ma.

(EARLY TO MIDDLE CARBONIFEROUS)

WARBURTON BASIN (Subsurface only)

Od — Dark grey to black shale, laminated, pyritic, variably calcareous. Interbedded locally with cream spiculitic chert, siltstone and fine to coarse-grained, lithic sandstone. Graptolites in shale facies. Marine outer shelf and deep basin.

(ORDOVICIAN; DULLINGARI GROUP)

€O–i — INNAMINCKA FORMATION: Drab red-brown argillaceous siltstone, very finely micaceous. Interbedded with pink, fine to medium-grained, glauconitic, calcareous sandstone, claystone laminae and reworked mudclasts. Worm burrows, trilobite tracks. Nearshore marine shelf.

€–k — KALLADEINA FORMATION: Dark grey-green, laminated pyritic shale with finely interbedded chert, micritic limestone and ripple-laminated siltstone. Ribbon and nodular limestone, local slump breccia beds with shelf-derived limestone clasts, tuff and volcanic agglomerate. Trilobites, hydroids, molluscs, demosponge spicules. Marine slope and deep basin. Dolomite at base of formation, massive, pale grey-pink. Limestone in upper part of formation, massive, pale to medium grey, composed of ooid-peloid grainstone, bioclastic-oncolite packstone and cyanobacterial boundstone. Trilobites, molluscs, brachiopods, calcified cyanobacteria. Two levels of shallow marine carbonate shelf development, each overprinted by meteoric diagenesis following subaerial exposure. Alkaline within-plate basalt (Murteree A1, Jena 1, Jena 6) in middle of formation.

€–m — MOORACOOCHIE VOLCANICS:
Upper unit: Pink to pale green tuff, welded, layered, crystal, lapilli-rich varieties. Interbedded with poorly to well-bedded agglomerate, occasionally graded, scour and fill structures. Minor brown, massive mudstone and muddy sandstone interbeds. Scarce pebbles of fossiliferous limestone and chert with trilobites, hyoliths.

Lower unit: Red-purple trachyte, massive to flow banded or agglomeratic. Lavas of dacite and sodic trachyte, porphyritic.

€–p — PANDO FORMATION: Pale grey, fine to coarse-grained, bioturbated cross-bedded sandstone; glauconitic, heavy-mineral banded. Interbedded grey siltstone and buff and green-grey shale.

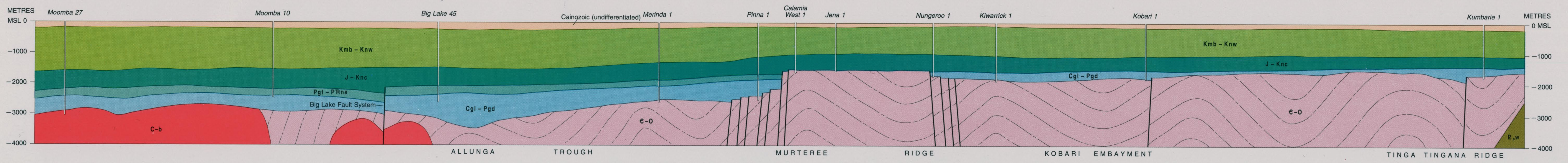
(PALAEOZOIC — CAMBRIAN)

E_pw — Quartz-muscovite phyllite (Mulga 1; Gurra 1 (Callabonna 1:250 000)) correlated with Willyama Supergroup.

(MESO-PROTEROZOIC)

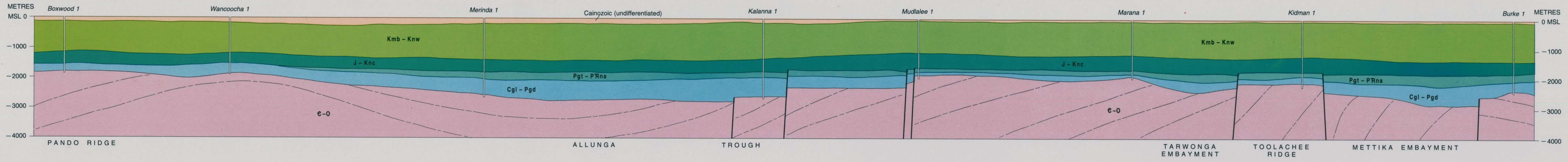
SECTION C - C′

V 2.5 / H 1



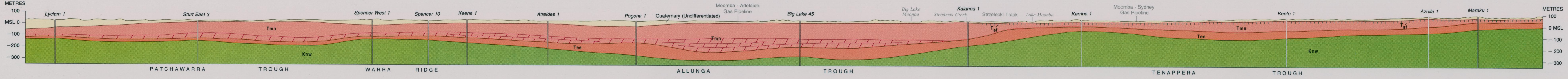
SECTION B - B′

V 2.5 / H 1

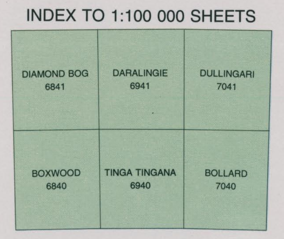


CAINOZOIC SECTION A - A′

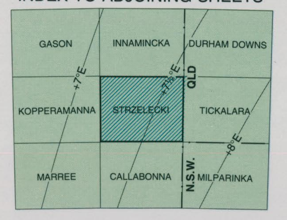
V 12.5 / H 1



INDEX TO 1:100 000 SHEETS



INDEX TO ADJOINING SHEETS



Magnetic Declination 1985
Annual Variation +2′

SCALE
1 : 250 000

KILOMETRES 5 0 5 10 15 20 25 KILOMETRES

PRINTED IN AUSTRALIA
A.J. SECKER, DIRECTOR AND GOVERNMENT PRINTER
SOUTH AUSTRALIA

Grey numbered lines indicate the 10 000 metre Australian Map Grid.

Transverse Mercator Projection.

Australian Geodetic Datum, 1966.

GEOLOGICAL BOUNDARY
OBSERVED

RELIEF FEATURES
CONTOUR (INTERVAL 20m)

Geological mapping and compilation by R.A. Callen, M.Sc., D.I. Gravestock, Ph.D. and A.J. Hill, B.App.Sc. with contributions by G.W. Krieg, B.Sc.(Hons), M.J. Sheard, B.App.Sc. and J. Hibburt, B.Sc.

A.P. Belperio, Ph.D., Chief Geologist, Regional Geology Branch.

Cartography by the Drafting Services Branch, Department of Mines and Energy.

Topography compiled from Australian Surveying and Land Information Group base maps with amendments by S.A. Department of Mines and Energy.

I.C. Dixon, Acting Chief Executive Officer, Department of Mines and Energy.

The Honourable D.S. Baker, M.P., Minister for Mines and Energy.

Published 1994.

Bibliographic Reference: Callen, R.A. and Gravestock, D.I. 1994. STRZELECKI map sheet. *South Australia. Geological Survey. Geological Atlas 1 : 250 000 Series,* sheet SH 54-2.

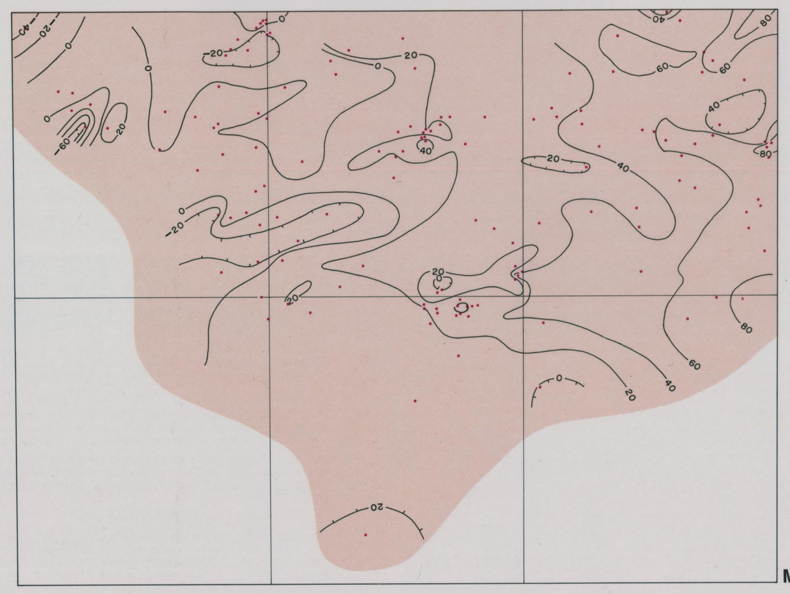
Copies of this map may be obtained from the Geological Survey of South Australia, Department of Mines and Energy, Adelaide, or the Australian Geological Survey Organisation, Canberra, A.C.T. Printed for the Geological Survey of South Australia as a contribution to the Geological Map Series of the Commonwealth.

MINES AND ENERGY
SOUTH AUSTRALIA

STRZELECKI
SHEET SH 54-2

LAKE EYRE BASIN — CALLABONNA SUB-BASIN

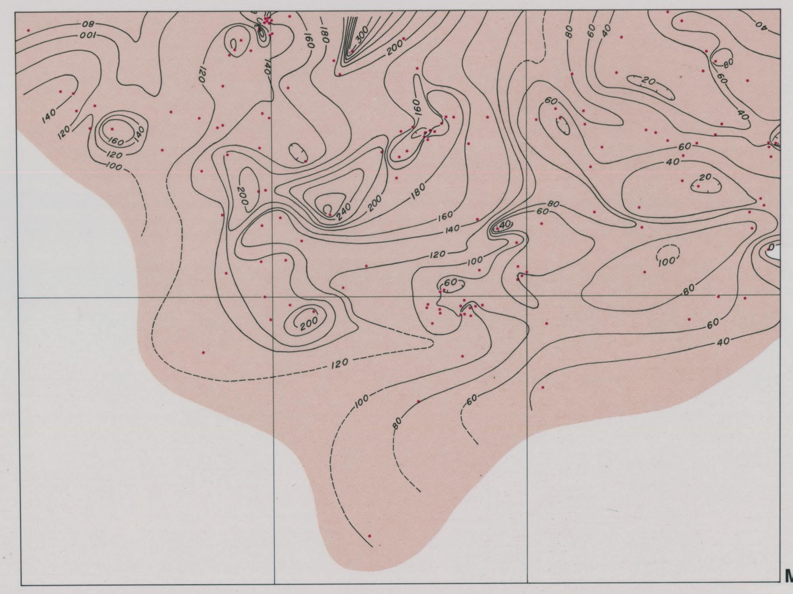
STRUCTURE CONTOUR MAPS



M1

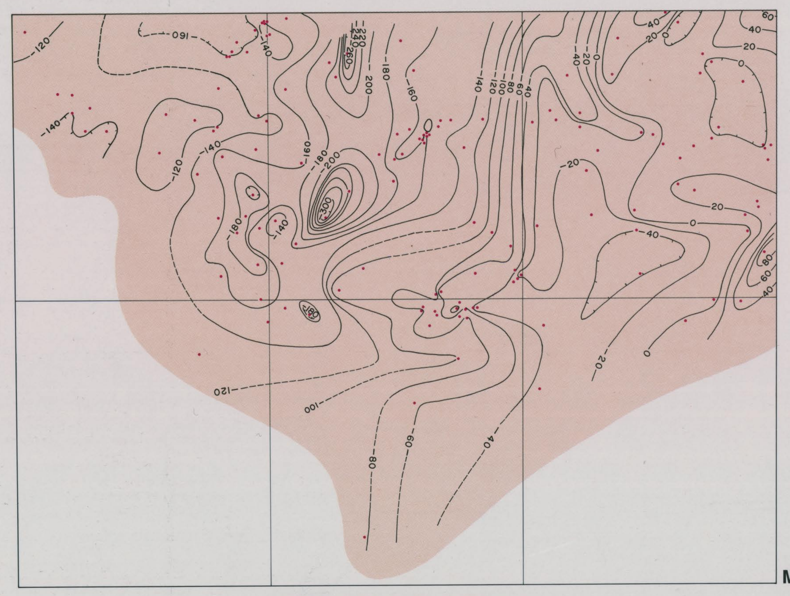
TOP OF NAMBA FORMATION (Tmn)

ISOPACH MAPS



M2

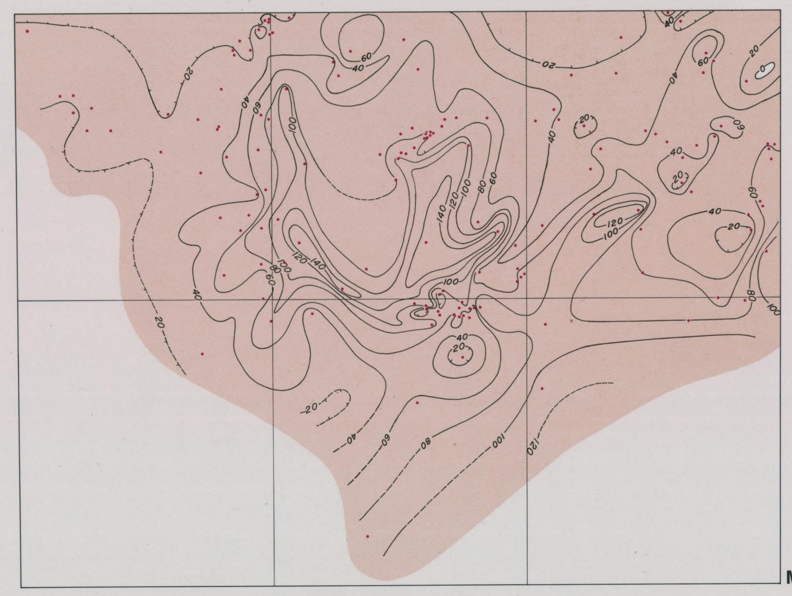
NAMBA FORMATION (Tmn)



M3

TOP OF EYRE FORMATION (Tee)

WELL DATA POINT.........

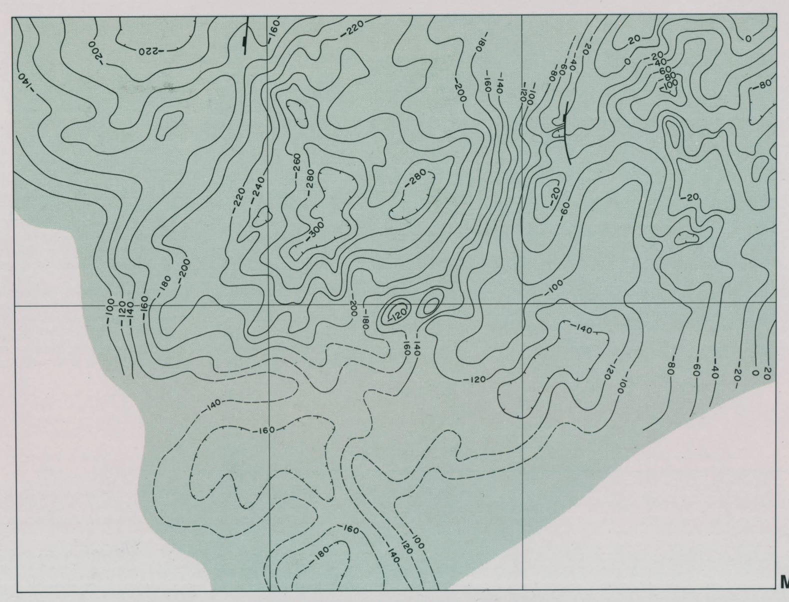


M4

EYRE FORMATION (Tee)

EROMANGA BASIN

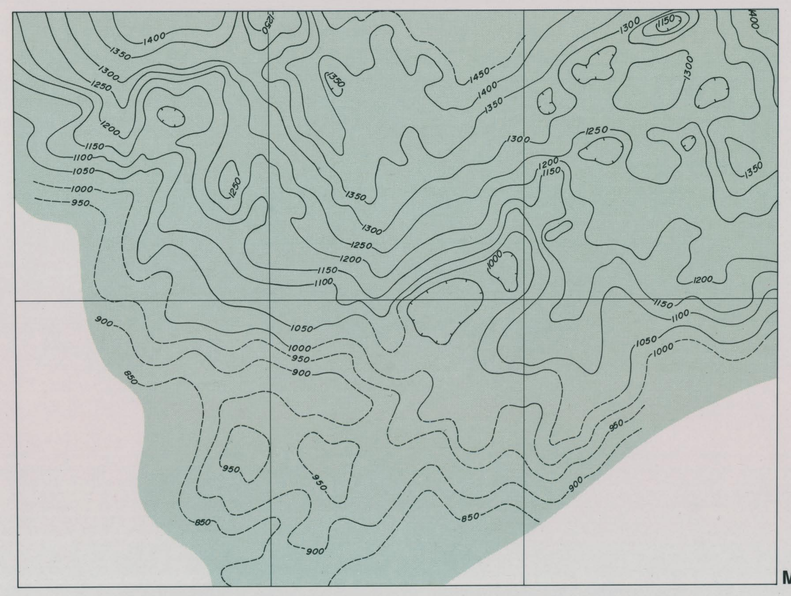
STRUCTURE CONTOUR MAPS



M5

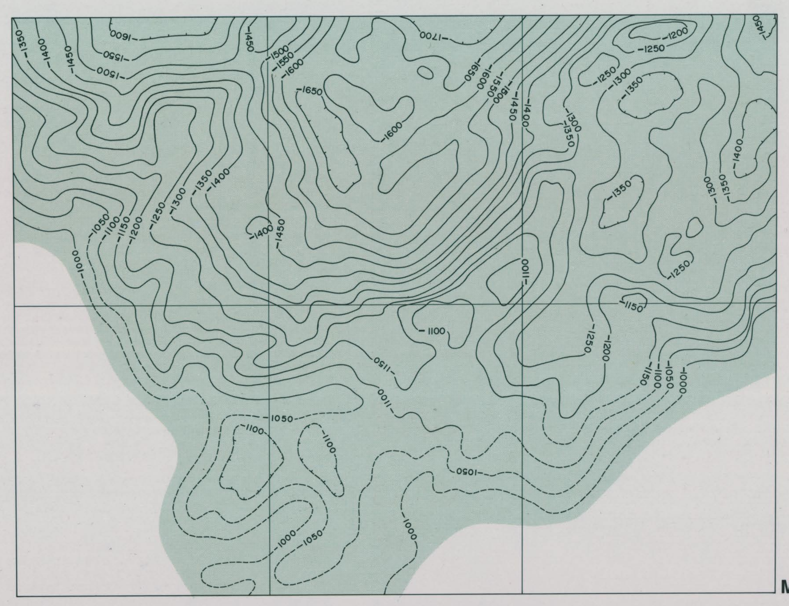
TOP OF WINTON FORMATION (Knw)

ISOPACH MAPS



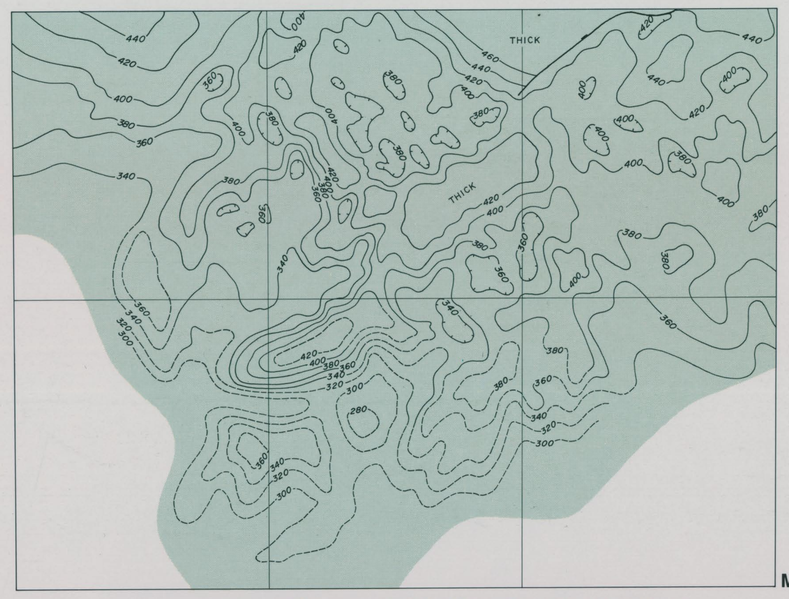
M6

WINTON FORMATION (Knw) TO TOP OF CADNA–OWIE FORMATION (Knc)



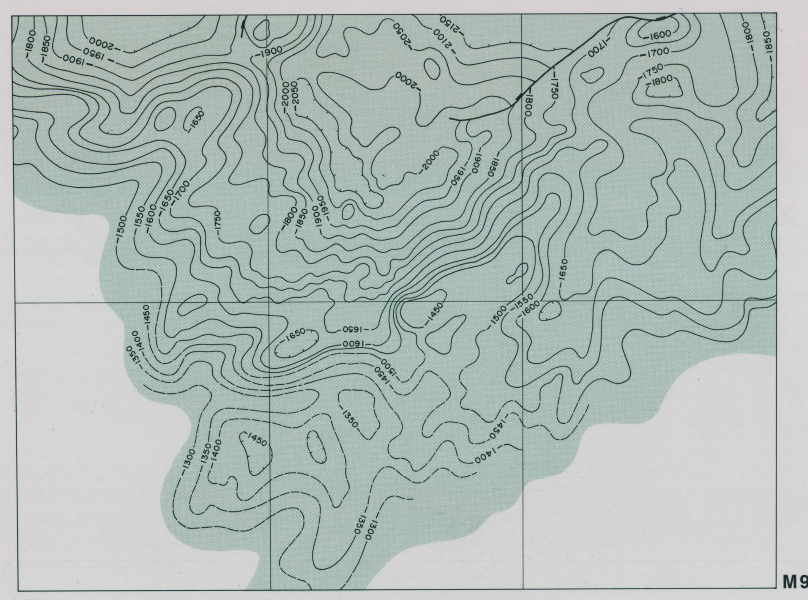
M7

TOP OF CADNA–OWIE FORMATION (Knc)



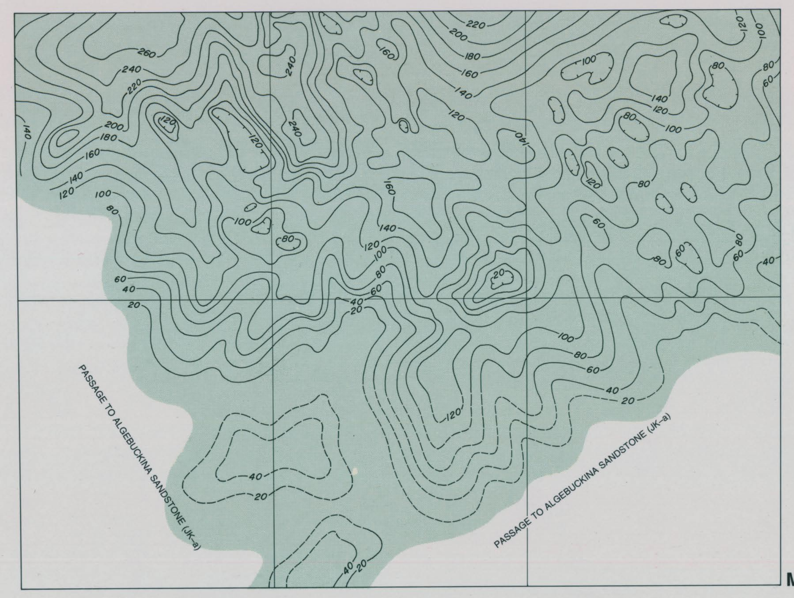
M8

CADNA–OWIE FORMATION (Knc) TO TOP OF HUTTON SANDSTONE (J–h)



M9

TOP OF HUTTON SANDSTONE (J–h)

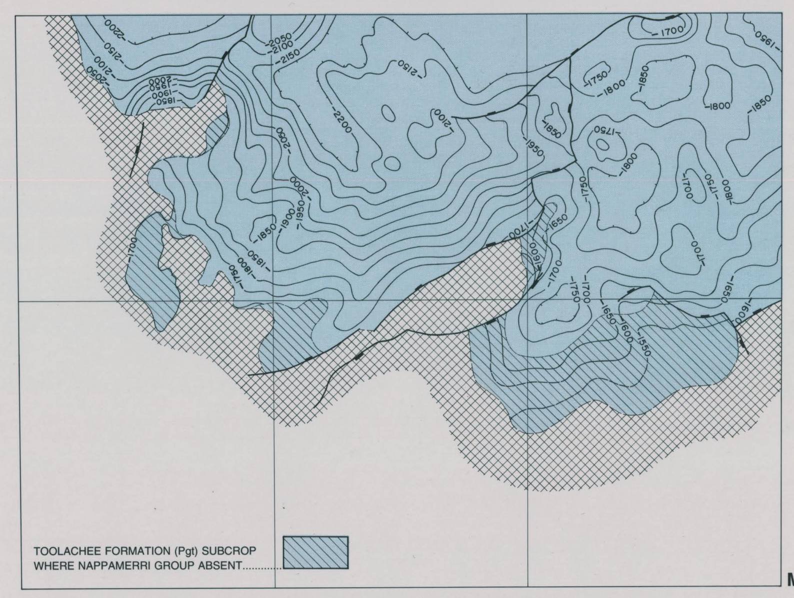


M10

HUTTON SANDSTONE (J–h) AND POOLOWANNA FORMATION (J–p)

COOPER BASIN

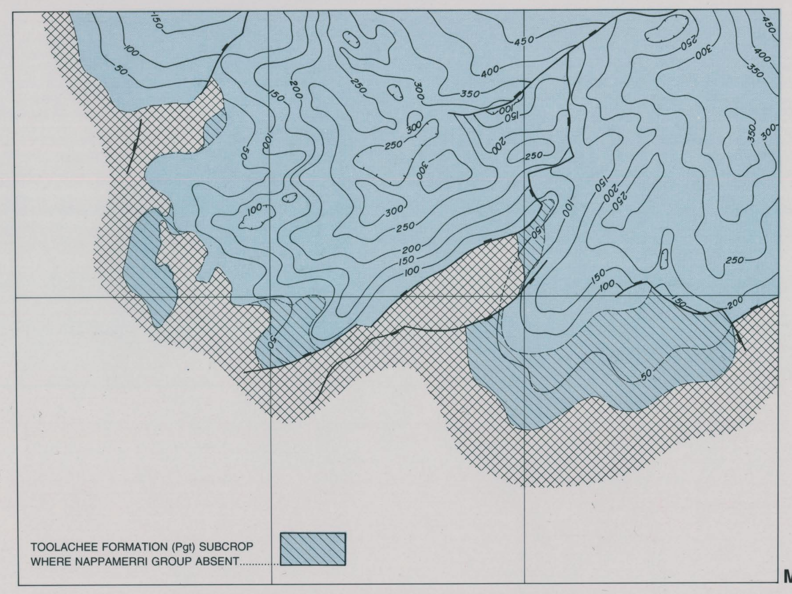
STRUCTURE CONTOUR MAPS



M11

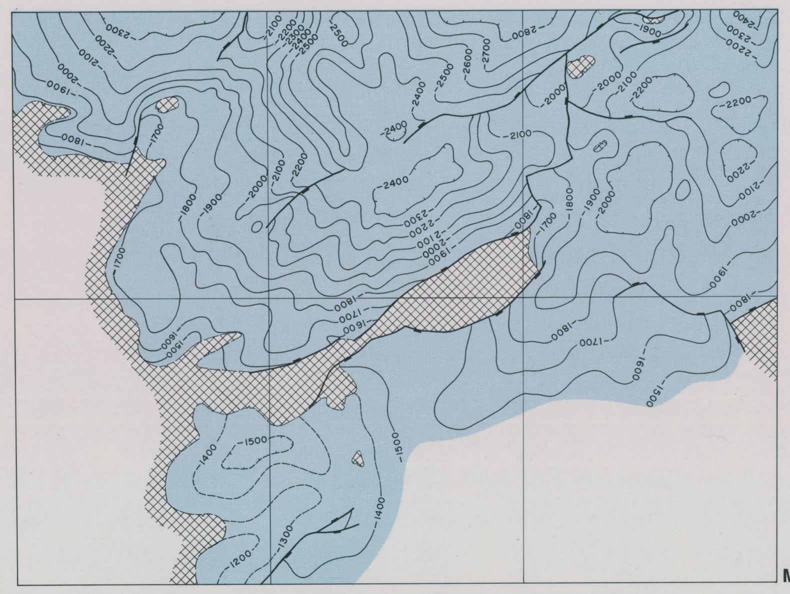
TOP OF NAPPAMERRI GROUP OR TOOLACHEE FORMATION (Pgt)

ISOPACH MAPS



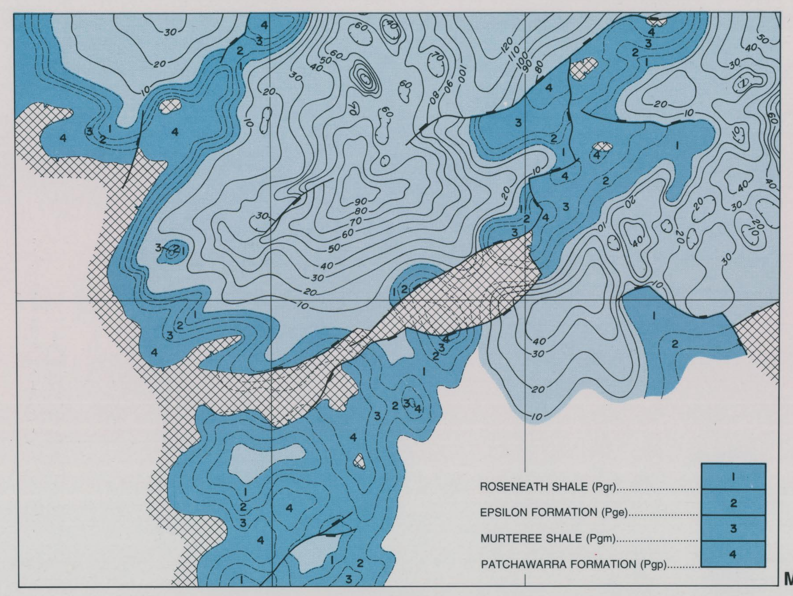
M12

NAPPAMERRI GROUP AND TOOLACHEE FORMATION (Pgt)



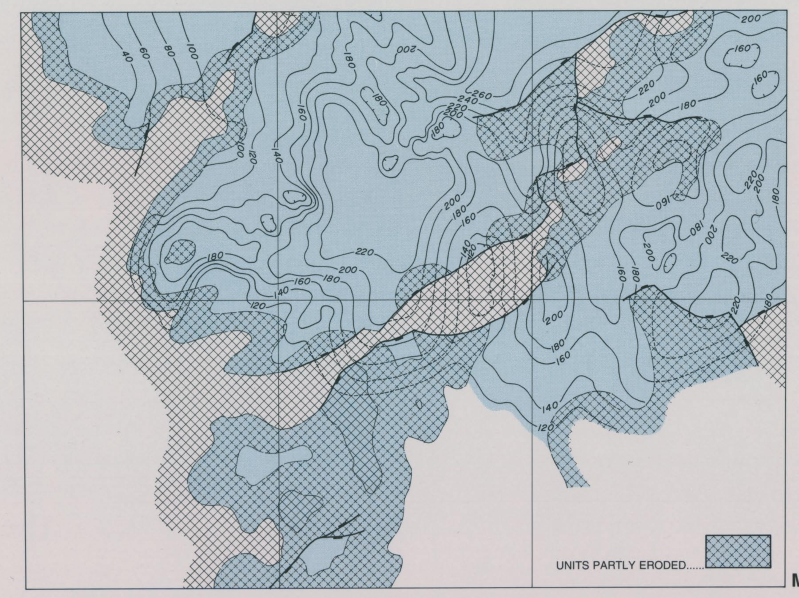
M13

TOP OF "DARALINGIE UNCONFORMITY"



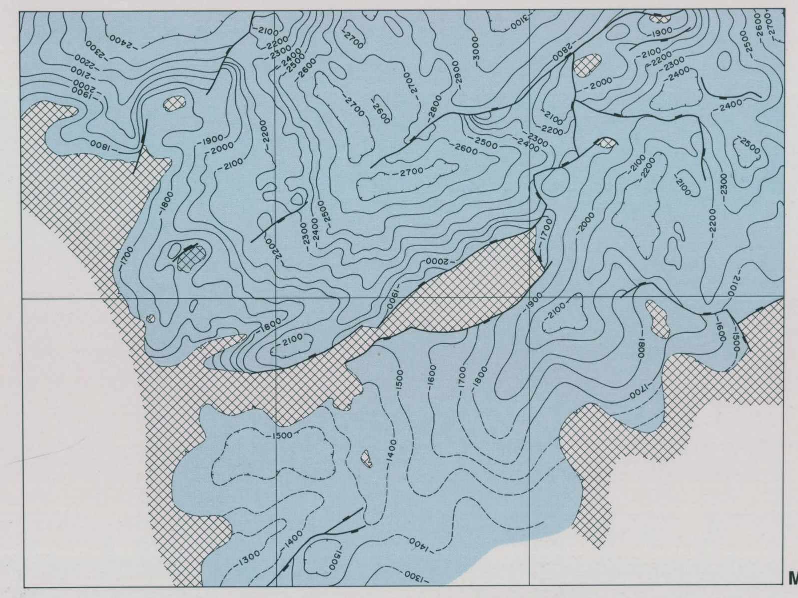
M14

DARALINGIE FORMATION (Pgd)
Showing subcrop of units at the "DARALINGIE UNCONFORMITY"



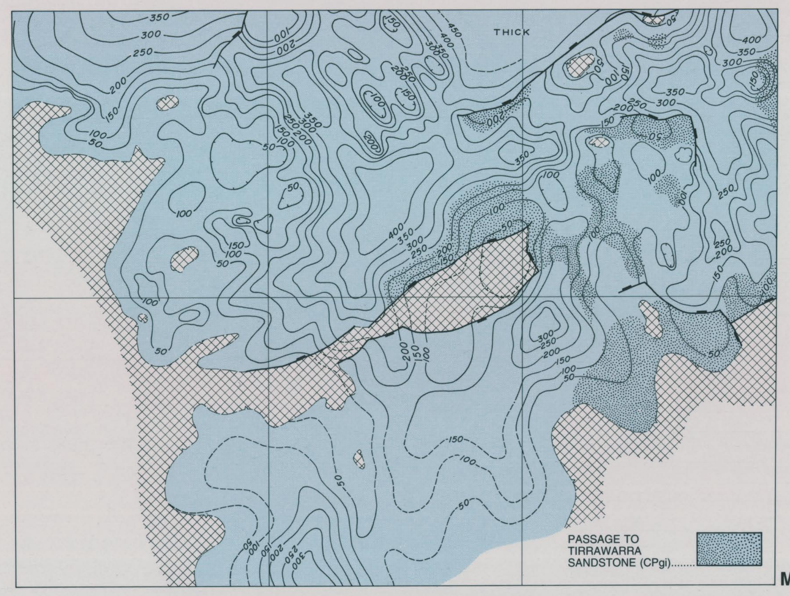
M15

ROSENEATH SHALE (Pgr), EPSILON FORMATION (Pge) AND MURTEREE SHALE (Pgm)



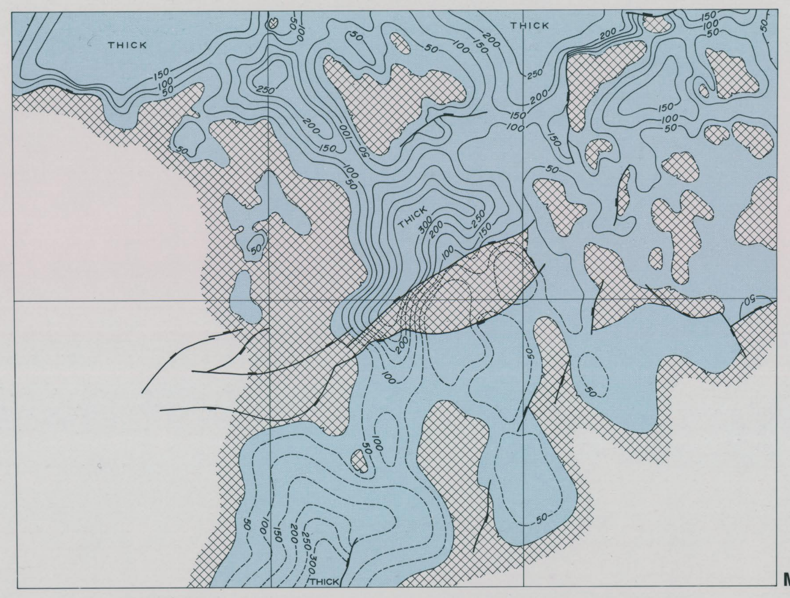
M16

TOP OF PATCHAWARRA FORMATION (Pgp)



M17

PATCHAWARRA FORMATION (Pgp)

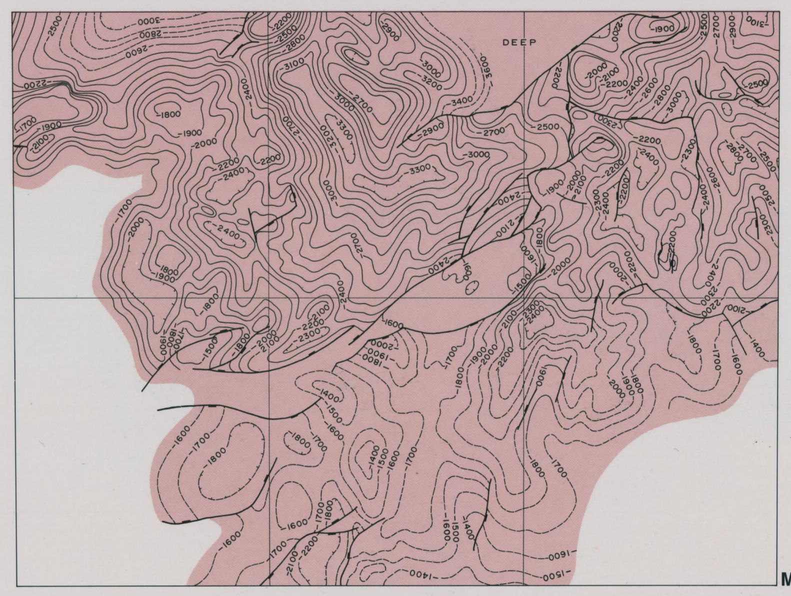


M18

TIRRAWARRA SANDSTONE (CPgi) AND MERRIMELIA FORMATION (Cgl)

WARBURTON BASIN

STRUCTURE CONTOUR MAP



M19

TOP OF PRE-PERMIAN

SUMMARY MAPS

STRUCTURE AND STRATIGRAPHY

STRZELECKI

1 : 250 000 Map Sheet

REFERENCE

STRUCTURE CONTOUR:

- VALUE IN METRES (MEAN SEA LEVEL=0) 50
- INFERRED 100
- DEPRESSION 150

ISOPACH:

- VALUE IN METRES 20
- INFERRED 40
- RESTORED IN ERODED AREA 60
- THINNING 80

FAULT, SHOWING DOWNTHROW ....

GEOLOGICAL SUBCROP BOUNDARY ....

UNCONFORMITY ....

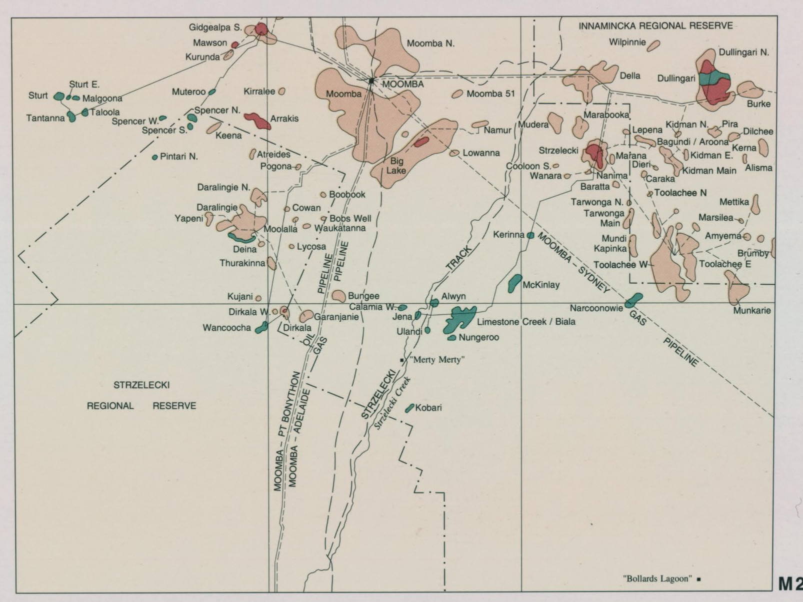
GEOLOGICAL UNIT ABSENT DUE TO EROSION OR NON–DEPOSITION ....

Tertiary Structure Contours and Isopachs compiled from well data by R.A. Callen, M.Sc.

Pre–Tertiary Structure Contours and Isopachs compiled by D.I. Gravestock, Ph.D.

SCALE
1 : 1 000 000
0 — 50
KILOMETRES

OIL AND GAS FIELDS — JANUARY 1992



M20

Proven and probable field:

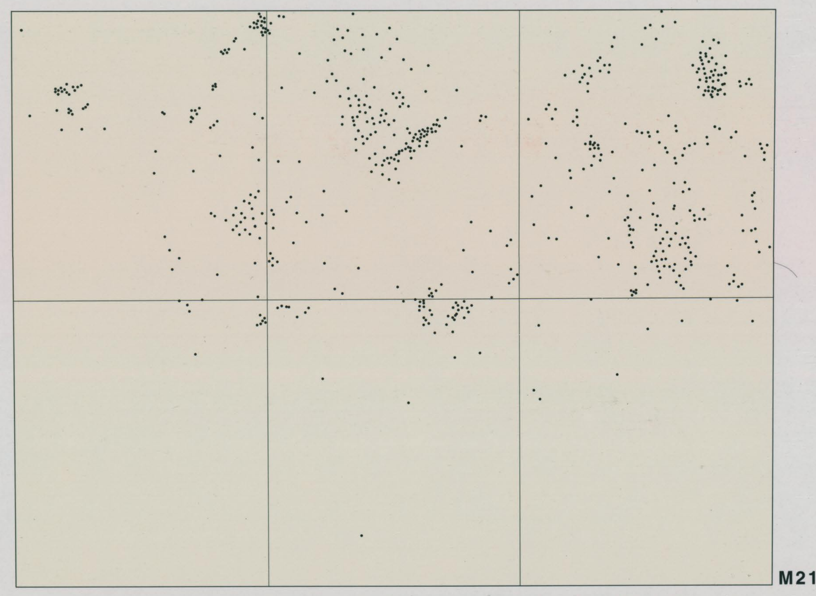
- Oil ....
- Gas ....
- Oil and gas ....

Oil pipeline ....

Gas pipeline ....

Boundary of Regional Reserve ....

Main track ....



M21

PETROLEUM EXPLORATION AND PRODUCTION WELLS — AUGUST 1992

STRZELECKI

SOUTH AUSTRALIA

Explanatory Notes

1:250 000 Geological Series — Sheet SH/54-2

Geological Survey of South Australia

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1:250 000 Geological Series — Explanatory Notes

STRZELECKI

SOUTH AUSTRALIA

SHEET SH54-2 International Index

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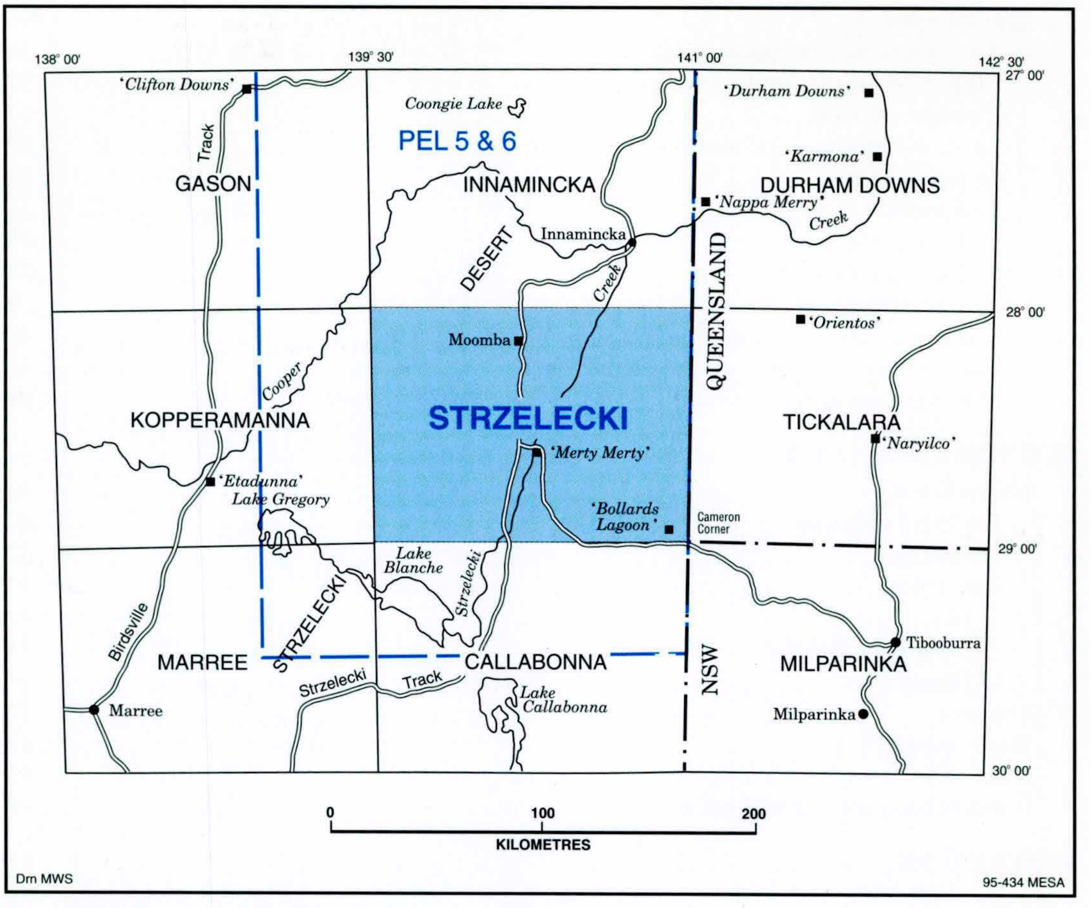


Fig. 1 Regional locality and physiographic map.

Explanatory Notes for the STRZELECKI 1:250 000 Geological Map

D.I. Gravestock, R.A. Callen,
E.M. Alexander and A.J. Hill

INTRODUCTION

The STRZELECKI map area lies adjacent to the New South Wales border, in the centre of the Strzelecki Desert, covering some of the main hydrocarbon production areas in South Australia around Moomba (Fig. 1). Most of these oil and gas fields are located in the northern half of the map area. Liquids and gas pipelines transport products to Adelaide and Port Bonython in South Australia, and Sydney in New South Wales.

Pastoral properties in the map area are 'Bollards Lagoon', 'Merty Merty' and 'Lake Hope'. The northeastern corner is covered by the Innamincka Regional Reserve and the central part by the Strzelecki Regional Reserve.

The natural history of the region is described in Tyler *et al.* (1990).

While there are a number of important Aboriginal sites in the desert, the surviving Aboriginal inhabitants and their descendants (Hercus, 1990) now live in Birdsville and Broken Hill.

The region is very flat and covered by longitudinal, northerly trending sand dunes (Wasson *et al.*, 1988) with sparse shrub and grass cover which is dense in low lying areas. The Strzelecki Creek, and areas subject to flooding, are fringed by Coolabahs (*Eucalyptus microtheca*). Corkbark (*Hakea eyreana*), *Bauhinia* sp. and other tree and shrub species typical of the central and northern Australian deserts (cf. Simpson Desert, Lange and Fatchen 1990) become prominent in northeastern STRZELECKI. Access is via the Moomba road, using the Strzelecki Track, which begins at Lyndhurst (Fig. 1). Access within the oil fields area is good because public roads, station tracks, and other access roads to installations are maintained to high standard by licensees. Use of seismic lines after surveys have been completed is prohibited to facilitate plant regeneration, and most of the roads are private. Permission from Santos Ltd is required for travel within the oil field areas, except on designated public roads.

Cooper Creek flows into Coongie Lakes during most years as a result of monsoon rains in the Queensland headwaters. Extreme southerly migrations of the monsoon occur every 9-10 years and produce widespread local floods which activate Strzelecki Creek. Flooding has produced a complex interaction between dunes, playas, pans and watercourses along the southern margin of Cooper Creek fan on INNAMINCKA, extending to the Moomba area on STRZELECKI (Callen and Bradford, 1992). The floodouts coalesce to the south to form Strzelecki Creek, which is constrained to the west by dunes and hence does not flow down the westerly gradient defined by the topographic contours (see map and Fig. 2). Instead, Strzelecki Creek follows the western margin of significantly higher land (150-200 m AHD) with Tertiary outcrop along the State border to the east, and flows south to Lake Blanche on CALLABONNA, where an extensive low-angle fan-delta has been built.

The area has an average rainfall of 100-155 mm, which falls mainly in the summer months in the northern part of the area (Allan, 1990). Temperatures are in the high 30's in summer and 20's in winter. Cold winds and frosts are common in winter.

Geological investigations began with the work of R.L. Jack (e.g. the results of his investigations into underground water supplies in the region were published in 1930). The early work of R.C. Sprigg, H. Wopfner and others of Geosurveys and Delhi Petroleum inspired interest in the possibility of hydrocarbons which eventually led to the discovery of the Permian gas fields at Gidgealpa in 1963 and Moomba in 1968. Interest in the Mesozoic was rekindled by the discovery of natural gas in Namur 1 in 1976 and oil in Strzelecki 3 in 1978.

Surface mapping took place in 1973 by I.J. Townsend, and in 1986 by J. Morton. In these early surveys, Namba Formation outcrop was misidentified as Eyre Formation or Winton Formation, and silicification as late Eocene to Oligocene (Wopfner, 1978) rather than Oligocene-Miocene (Wopfner, 1974). A large group of geologists, geophysicists, and consultants has worked on the subsurface geology of the area for the licensees and operators Delhi Petroleum Pty Ltd and Santos Ltd.

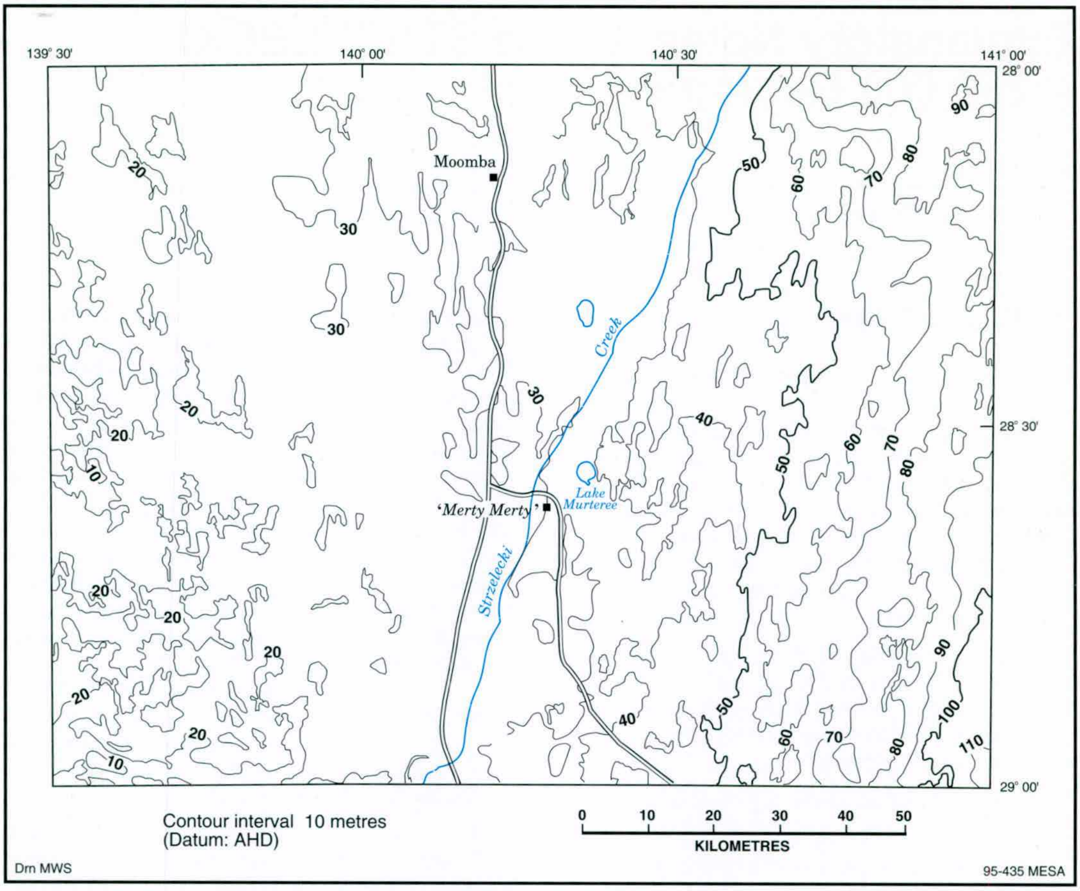


Fig. 2 Topographic map, STRZELECKI.

Photointerpretation was made on 1:87 500 scale colour photography (svy 2 548, 2 547, 2 552) following five weeks of ground surveys, carried out by R.A. Callen with assistance from G.W. Krieg and M.J. Sheard (Regional Geology Branch, MESA). Drillholes through the Cainozoic were logged by R.A. Callen. Pre-Cainozoic subsurface geology description throughout this text is largely the work of D.I. Gravestock, E.M. Alexander and A.J. Hill (Petroleum Division, MESA); the basement geology section was based on the work of J. Hibburt and D.I. Gravestock. The oil field history was written by A.J. Hill. Latitudes and longitudes of wells are given in Clarke coordinates.

Data used in compiling the STRZELECKI 1:250 000 geological map were derived from the PEPS-SA database, which is maintained by the Petroleum Division of MESA.

Throughout this text, references to figures printed on the reverse of the STRZELECKI map are prefixed 'M'.

STRATIGRAPHY AND TECTONICS

EARLY PALAEOZOIC — EASTERN WARBURTON BASIN

D.I. Gravestock

Deeply buried Cambrian-Ordovician sedimentary rocks and volcanics constitute the Warburton Basin in northern South Australia (Wopfner, 1972; Gatehouse, 1983, 1986). The rocks are folded and faulted but essentially unmetamorphosed except in the vicinity of Carboniferous granitic intrusives. Silurian-Devonian rocks, if present, were not part of the Warburton Basin depositional regime and have not been found to date on STRZELECKI. Depth to the top of the Warburton Basin ranges from 1 300 m to greater than 3 600 m (see map, Fig. M19) and cumulative drilled thickness exceeds 3 000 m (a complete stratigraphic section is not likely to be drilled).

A brief description of the Cambrian in the Gidgealpa area was provided by Wopfner (1969) who was the first to point out similarities with the sequence in western New South Wales and the likelihood of former connections with the Amadeus and Georgina Basins. Rock stratigraphic units were described by Gatehouse (1983), who later provided the first unified account of the basement geology of the region (Gatehouse, 1986). Detailed mapping of carbonate sediments was carried out in the Gidgealpa area by Roberts *et al.* (1990), and aspects of the geology of the Daralingie area, where Permian gas was found in commercial quantities, were investigated by Taylor *et al.* (1991).

Pando Formation (new name)

The type section of the Pando Formation is in Pando 1 (latitude 28°24'56"S, longitude 139°48'20"E), from which the name is derived. It occurs over the logged interval from 1 736 to 1 933 m. The base of the Pando Formation has not been penetrated in the type section, but in Daralingie 1 it is underlain by steeply dipping orthoquartzite of possible Proterozoic age. The top of the formation is defined by a rapid increase in gamma-ray response in the type section.

The Pando Formation is characterised by pale grey-green sandstone with minor interbedded siltstone and shale, but shale is the dominant lithology in some drillholes, for example in Pando North 1 and Boxwood 1. Penetrative burrows resembling *Chondrites* occur in the sandstone which is fine to coarse grained with common detrital zircon and glauconite or 'glauconitic illite' (Taylor *et al.*, 1991); these features distinguish it from other sandstones. The sandstone is silica-cemented but moderately porous. Interbedded siltstone is grey-buff and occasionally pyritic. The shale is olive green-grey with disseminated glauconite and interbeds of ripple-laminated fine-grained sandstone disrupted by soft-sediment deformation. Sandstone intersections typically have a variable, high gamma-ray response (60-260 API units) attributed to abundant zircon (Taylor *et al.*, 1991) whereas shale and siltstone lithologies have a uniform gamma-ray response of 140 to 160 API units (Fig. 3).

The upper contact of Pando Formation intertongues with the lower part of the Mooracoochie Volcanics. Thus, in Boxwood 1, shale of the Pando Formation is overlain by sandstone then tuff of the Mooracoochie Volcanics but, in Gidgealpa 5 (core 27), sandstone of the Pando Formation forms thin (0.2 m) interbeds in lava flows of the Mooracoochie Volcanics. The Pando Formation is the oldest unit of the Warburton Basin and is presumed to be Early Cambrian on the basis of the penetrative burrows.

The formation occurs in a number of drillholes on western STRZELECKI, notably in the Daralingie area. The thickest intersection (246 m) is in Moolalla 1 which has previously been correlated tentatively with the Ordovician Dullingari Group (Taylor *et al.*, 1991). The most easterly bioturbated sandstone attributed to the Pando Formation occurs in Moomba 3. In Daralingie 2, steeply dipping to overturned Pando Formation is

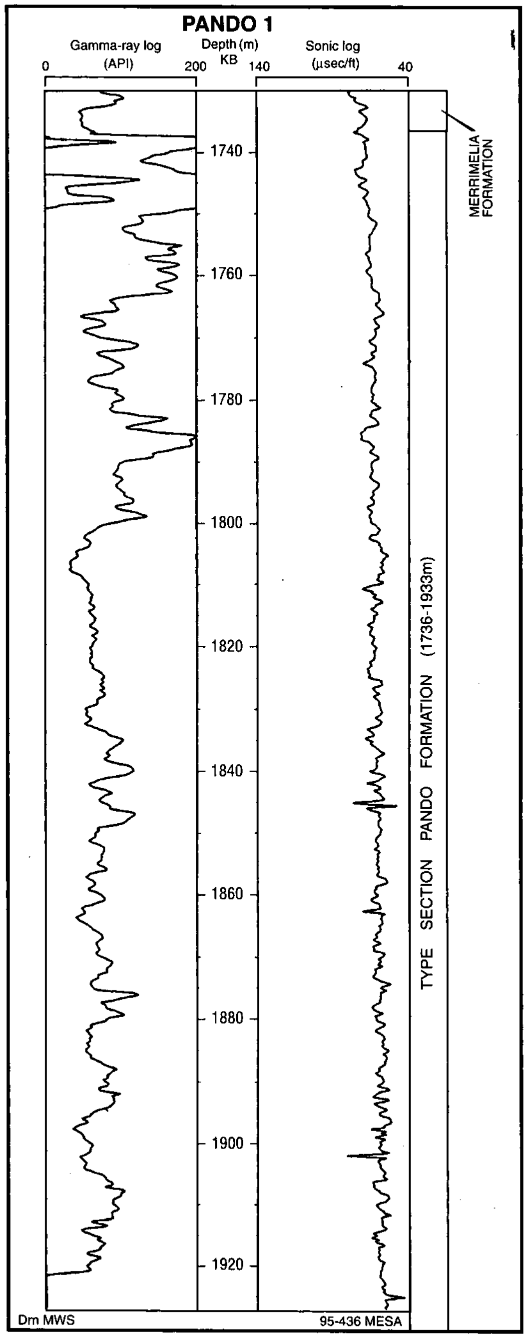


Fig. 3 Composite log of the Pando Formation type section.

overlain disconformably by fine-grained muddy sandstone and dark grey shale of the Dullingari Group, implying a long period of exposure prior to onlap in the Ordovician.

A moderate energy shallow marine shelf environment is indicated for the sandstone, while a more sheltered or possibly deeper marine setting is suggested for siltstone and shale of the Pando Formation.

Mooracoochie Volcanics

The Mooracoochie Volcanics (Gatehouse, 1983) comprise a lower unit of acid volcanics, mainly porphyritic trachyte, dacite and rhyolite, and an upper unit chiefly of tuff, ignimbrite and agglomerate (Gatehouse, 1986). The lower unit is represented in the Gidgealpa area whereas to the south and southwest (Spencer, Sturt, Taloola, Tantanna drillholes) only the upper unit has been penetrated. The upper unit is composed of lapilli and crystal tuff ignimbrite and agglomerate. Agglomerate in Gidgealpa 7 (core 17) displays scour and fill structures, and is interbedded with wavy and ripple-laminated muddy sandstone with occasional reverse-graded grit bands. In Gidgealpa 1 on INNAMINCKA, an agglomerate contains scarce pebbles of limestone and chert with hyolithid and trilobite fossils of Cambrian age (Daily *in* Harrison and Higginbotham, 1963).

The Mooracoochie Volcanics are interbedded with sediments deposited in a shallow marine setting but lapilli tuff and poorly sorted to chaotic agglomerate beds may be subaerial in origin. Proximity to a volcanic vent or feeder in Gidgealpa 2 has been suggested by Fander (*in* Harrison and Higginbotham, 1964). Gatehouse (1986) considered the volcanics to have formed in an island arc setting. Alternatively, the volcanic eruptions may mark early stages of continental rifting, the rift axis following the Wooloo Trough which was possibly a side-branch of a large-scale feature (Boucher, 1991).

Kalladeina Formation

The Kalladeina Formation comprises carbonates, shale, minor sandstone and volcanics, with trilobite faunas providing the basis for age determination (Gatehouse 1983, 1986; Sun *et al.*, 1994). Two carbonate shelf complexes are present, each of which can be mapped seismically in the Patchawarra Trough (Roberts *et al.*, 1990). The lower shelf carbonate appears to be restricted to western STRZELECKI where it comprises the basal Kalladeina Formation. Thickness varies from 30 to 110 m. The unit was originally bioclastic and ooid-pelloid limestone but now occurs as recrystallised vuggy and fractured dolomite. Scarce volcanic pebbles suggest reworking of the underlying unit.

Transgressive deposits in the succeeding lower to middle Kalladeina Formation comprise grey, variably fossiliferous, micromicaceous shale, bioturbated and ripple-laminated siltstone, and flat to wavy laminated limestone of Middle to Late Cambrian age.

Altered vesicular basalt in Murteree A1 on the Murteree Ridge was tentatively included in the Mooracoochie Volcanics by Gatehouse (1986) but he noted their geochemical difference from acid lithotypes. Trace element analyses of cuttings from nearby Jena 1 and 6 show the basalt to be an alkaline intraplate type (Boucher, 1991; Fig. 4).

Basaltic sand in Gidgealpa 1 (cores 20, 21), and in lenses and pods in black shale in Kalanna 1, are possibly reworked equivalents. Vesicular agglomerate in Gidgealpa 1 (core 18) and in Kobari 1 (cuttings) has a distinctive appearance; vesicles are rimmed with chalcedony and filled with prehnite.

Trilobites in Gidgealpa 1 (core 17) indicate a Late Cambrian (Mindyallan) age (Gatehouse, 1986) and place this volcanic suite within the Kalladeina Formation, not the older Mooracoochie Volcanics. Kobari 1, south of the Murteree Ridge, is located over a magnetically anomalous trend which may mark the southern continuation of a Cambrian rift (Boucher, 1991).

Late Cambrian shallow marine limestone is represented in Gidgealpa 7 by 235 m of massive, fossiliferous oncoid-pelloid packstone interbedded with calcimicrobial ('algal') wackestone. Recrystallisation and solution-collapse breccia fabrics indicate subaerial exposure and a second phase of karst development (Roberts *et al.*, 1990).

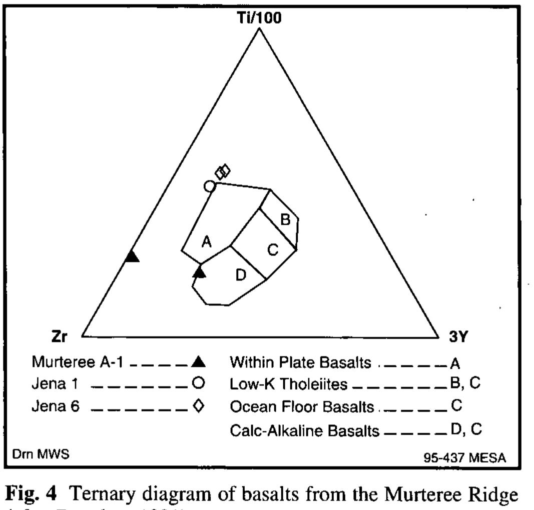


Fig. 4 Ternary diagram of basalts from the Murteree Ridge (after Boucher, 1991).

The upper Kalladeina Formation in Gidgealpa 7 comprises laminated black shale and nodular micritic limestone rich in brachiopods. A Late Cambrian (Idamean) age is indicated (Daily *in* Delhi International Oil Corp. and Santos Ltd, 1965).

The basal shelf limestone was deposited in a shallow sea representing a phase of widespread marine transgression also recorded in the Daly, Amadeus and Georgina Basins. Equivalent units in South Australia are the Wirrealpa Limestone (Arrowie Basin) and Ramsay and Stansbury Limestones (Stansbury Basin). Subsequent sea level fall is recorded by meteoric diagenesis and karst development prior to onlap of Middle Cambrian sediments (Roberts *et al.*, 1990).

Renewal of mafic volcanic activity attests to further rifting in the Late Cambrian which provided sufficient submarine topography for the contemporaneous development of shallow shelf, slope and deeper basinal marine environments. The carbonate shelf is most widely recorded in drillholes on INNAMINCKA, but it has also been intersected in Gidgealpa drillholes on western STRZELECKI. Limestone in cuttings in Thurakinna 4 marks the most southerly known extent of the shelf. Slope facies are found in Gidgealpa 1 where shelf-derived blocks (mainly oolite) and volcaniclastic detritus have been reworked with ribbon limestone clasts in slump deposits.

On INNAMINCKA, the carbonate shelf passes conformably into siliciclastics of the Innamincka Formation. In the Gidgealpa area, however, the shelf was covered by deeper marine sediments and a passage to the Innamincka Formation has not been recorded. Disconformity between the Pando Formation and Ordovician Dullingari Group in the Daralingie area is interpreted to represent exposure of the uplifted rift shoulder where Mooracoochie Volcanics and Kalladeina Formation were either eroded or not deposited.

Innamincka Formation

The Innamincka Formation has not been drilled on STRZELECKI but may occur on the downfaulted western flank of the Gidgealpa Ridge (see Rock Relation Diagram).

Dullingari Group

The Dullingari Group was defined as those rocks of known or presumed Ordovician age in the Warburton Basin (Gatehouse 1983, 1986). No separate formations have been defined but two major lithotypes, sandstone and black pyritic shale, occur on STRZELECKI. Sandstone in the Daralingie area is now referred to the Pando Formation.

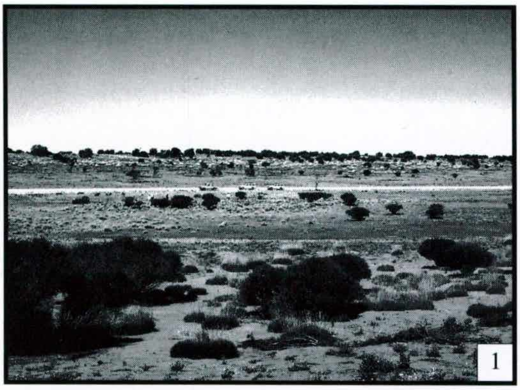
At its type section in Dullingari 1, the Dullingari Group comprises two units separated by conglomerate 0.2 m thick. The lower unit is drab-grey, moderately dipping siltstone with minor interbeds of very micaceous, arkosic, calcite-cemented sandstone. Petrographically similar sandstone occurs in Nappacoongee 1, Gidgealpa 5 (core 23) and Tinga Tingana 1 (core 9, on northern CALLABONNA), and in redbeds of the lower Innamincka Formation in Innamincka 1 (cores 26-35).

The conglomerate (only one small sample remains) comprises well-rounded pebbles in a sandy matrix. The matrix is carbonate-cemented, poorly sorted feldspathic sandstone with accessory muscovite and heavy minerals. The pebbles are composed of trilobite floatstone, carbonaceous pyritic siltstone and trachytic basalt, all evidently reworked from the Kalladeina Formation.

Thin interbeds and lenses in dark grey siltstone and shale above the conglomerate in Dullingari 1 comprise poorly sorted, lithic, micaceous, feldspathic sandstone with a sericitic muddy matrix and patchy carbonate cement. Monocrystalline volcanic quartz and composite metamorphic quartz occur in equal proportion. This lithology also occurs in Narcoonowie 1, Kidman 1, Toolachee 2 and Della 4. Where diagnostic sandstone interbeds are absent, it is impossible to differentiate between lower and upper Dullingari Group and upper Kalladeina Formation. Black, pyritic shale is currently regarded as a Dullingari Group lithotype (Gatehouse, 1983, 1986) and occurs widely on eastern STRZELECKI. Interbedded spiculitic chert is found in Brumby 1 and large sponge spicules are also present in carbonaceous siltstone in Munkarie 1, both presently regarded as Dullingari Group facies.

Uniserial graptolites in the lower unit, and diplograptids in the upper unit in Dullingari 1, indicate Early and Middle-Late Ordovician ages, respectively (Öpik and Jones *in* Harrison and Greer, 1963).

Webby (1978) considered the Dullingari Group to have been deposited on a northern continuation of the Gnalta Shelf which he named the Warburton Shelf. The graptolitic shales characterised a 'deeper water' phase or an adjacent trough subsequently named the Tilparee Trough by Gatehouse (1986). The Warburton Shelf is regarded here as the region south of the Arunta Block on CORDILLO and INNAMINCKA where the thick, shallow marine to deltaic Innamincka Formation was deposited (Zang, 1993). Deep marine black shale, siltstone and minor fine-grained



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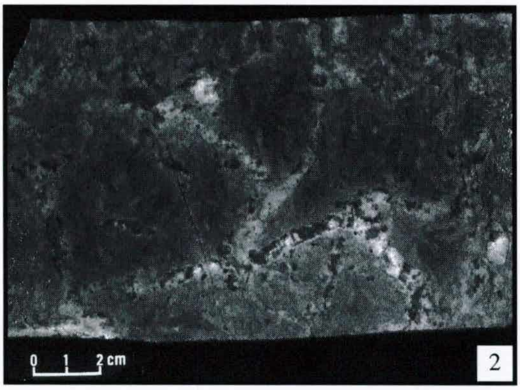

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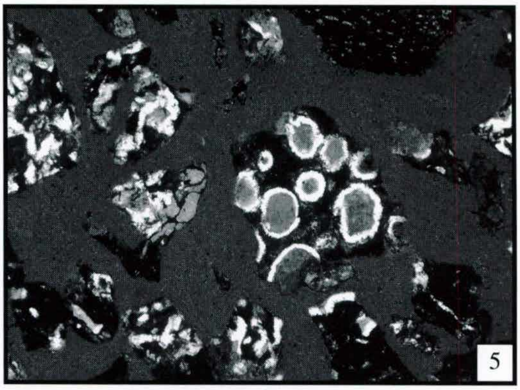

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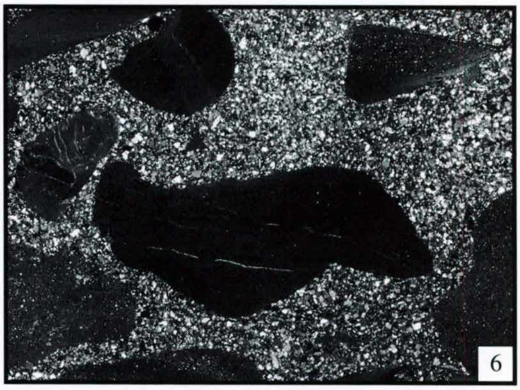

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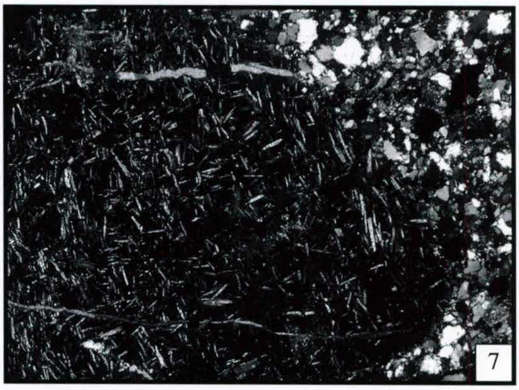

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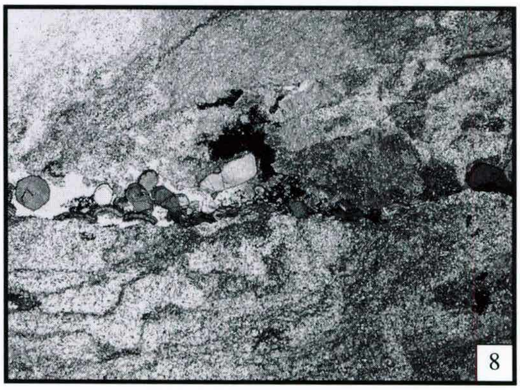

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sandstone were deposited in the Tilparee Trough on STRZELECKI between the Warburton Shelf to the north and the Gnalta Shelf to the southeast. Deeper water shales spread onto the shelves in transgressive phases of the Larapintine Sea (Webby, 1978) and, conversely, shelf sands prograded seaward from the shelves during regressions.

Early Palaeozoic tectonism

The tectonic history of the eastern Warburton Basin is at a preliminary interpretive stage owing to sparse core coverage, poor seismic data in steeply dipping regions, and structural overprint ascribed here to middle Palaeozoic orogenesis (see below). Structural relationships in cored drillholes are of three major types:

- thrust faulting within the Cambrian section, for example in Gidgealpa 1 and Daer 1 on INNAMINCKA (Roberts *et al.*, 1990)
- angular discordance between Cambrian and overlying Ordovician cores as in Gidgealpa 5 (core 23, dip 10-15°; core 24, dip 30-35°)
- structural concordance but disconformity between steeply dipping Cambrian and Ordovician rocks as in Daralingie 2 core 8 (overturned) and Tinga Tingana 1 cores 9 and 10 (dip 80-90°).

Deformation has been attributed to Late Ordovician tectonism either during the Benambran Orogeny (Gatehouse, 1986) or as a late extension of the Delamerian Orogeny (Roberts *et al.*, 1990)

1. Typical flat landscape with dune topography on STRZELECKI. Photo 42569.
2. Bioturbated, glauconitic sandstone in the Pando Formation (Pando 1, core 5, 1 771.8 m KB). Top is to right. Photo 42571.
3. Photomicrograph of skeletal quartz in crystal tuff of the Mooracoochie Volcanics (Taloola 1, core 1, 1 921.8 m KB; thin section 6841RS103). Width of view is 7.1 mm. Photo 42572.
4. Vuggy and fractured dolomite in the basal Kalladeina Formation (Gidgealpa 5, core 25, 2 474 m KB). Width of core is 110 mm. Photo 42573.
5. Photomicrograph of vesicular basalt in the Kalladeina Formation (Kobari 1, cuttings, 1 937.4-1 940.4 m; thin section 5940RS10). Width of view is 2.2 mm. Photo 42574.
6. Photomicrograph of sandstone-matrix-supported conglomerate in the Dullingari Group (Dullingari 1, core 29, 2 988 m KB; thin section 7041RS365). Width of view is 23 mm. Photo 42575.
7. Photomicrograph of basalt pebble in conglomerate of the Dullingari Group (Dullingari 1, core 29, 2 988 m KB; thin section 7041RS365). Width of view is 5.1 mm. Photo 42576.
8. Photomicrograph of spiculitic chert lamina in fine-grained sandstone of the Dullingari Group (Brumby 1, core 4, 2 349.7 m KB; thin section 7041RS413). Width of view is 11.6 mm. Photo 42577.

following rifting and back arc basin development. The alkaline basalts in Jena 1, Jena 6 and Murteree A1, however, suggest Middle to Late Cambrian intraplate rifting down the axis of the Wooloo Trough, across the Murteree Ridge (a Triassic structure) and perhaps connecting with the Wonominta Block in western New South Wales (Boucher, 1991). The Wonominta Block has been subdivided into four fault-bounded 'terranes', each of distinctive aeromagnetic character (Leitch *et al.*, 1987). The basalts are younger but geochemically very similar to Neoproterozoic and Early Cambrian volcanics in the Mount Wright terrane which are also within-plate basalts (Zhou and Whitford, 1994). Middle and upper units of the adjacent Wertago and Kayrunnera terranes are also of presumed Cambrian age, and all three are covered by a markedly diachronous overlap sequence with an intervening unconformity spanning Middle and an increasing proportion of Late Cambrian time (Wang *et al.*, 1989).

The Wertago and Kayrunnera terranes were folded and intruded before Late Cambrian onlap (Webby, 1978; Wang *et al.*, 1989). A break in deposition resulting from the so-called Mootwingee Movement is evident on INNAMINCKA where shelf carbonate of the upper Kalladeina Formation disconformably overlies the Mooracoochie Volcanics (Roberts *et al.*, 1990; Gravestock and Gatehouse, in prep.; Fig. 5). In offshelf areas such as Kalladeina 1 on GASON, however, deposition appears to have been continuous in a basinal setting (Sun *et al.*, 1994). In neither case is there evidence of deformation of the Early Cambrian section. Angular discordance in Gidgealpa 5 may point to Late Cambrian fault block rotation on the margin of the former rift or may be due to later faulting. The structural orientation of Permian-Tertiary cover rocks on eastern STRZELECKI is noticeably meridional whereas northwest to northeast trends predominate on western and central STRZELECKI. A hinge zone has been recognised at the boundary between these two regions which is presumed to mark a major contrast in basement character (see Tectonic Sketch) but it is premature to assume that the zone represents a terrane boundary. The conglomerate within the Dullingari Group in Dullingari 1 may result from sea level fall at the end of the Early Ordovician, but the cause has yet to be determined as tectonic. It may represent debris transported off the Warburton Shelf from exposed areas of Kalladeina Formation, in which case two depositional sequences may be recorded (X. Sun, National Centre for Petroleum Geology and Geophysics, pers. comm., 1992). Webby (1978) regarded the conglomerate as evidence of Middle Ordovician uplift and erosion he named the 'Dullingari Movement'.

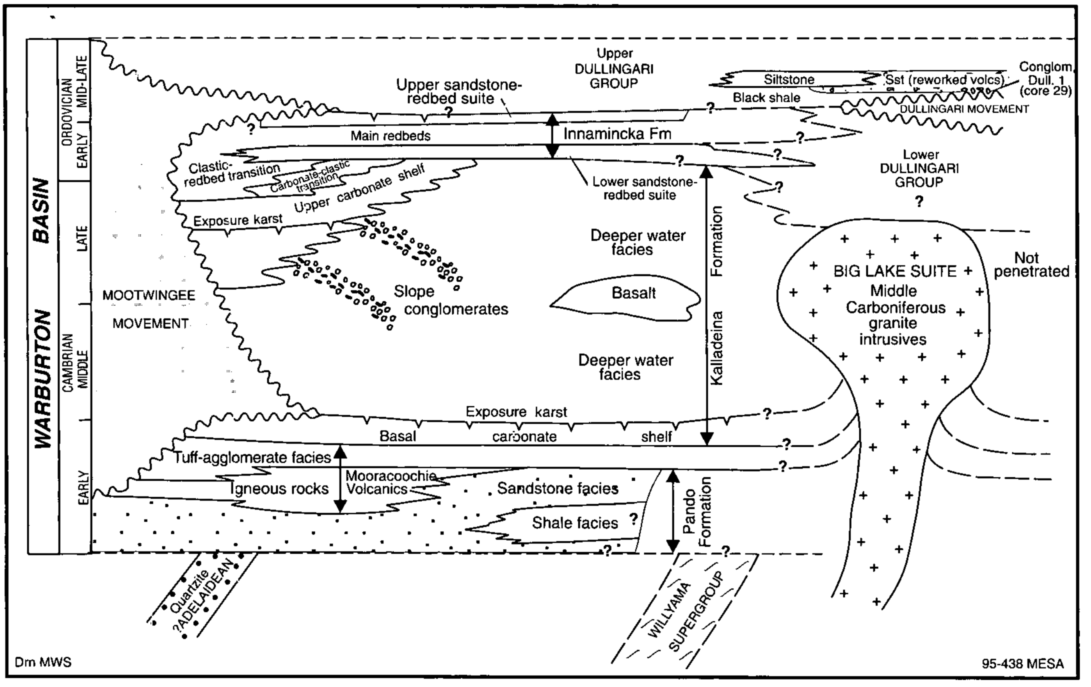

Fig. 5 Rock relation diagram of the eastern Warburton Basin.

MIDDLE PALAEOZOIC INTRUSION AND TECTONISM — BIG LAKE SUITE

Silurian to Middle Carboniferous strata have not been found on STRZELECKI but a number of granite plutons intruded Warburton Basin sedimentary rocks in the middle Palaeozoic. The plutons, collectively named the Big Lake Suite (Gatehouse *et al.*, in prep.), are coarse-grained, hydrothermally altered granites consisting of quartz, orthoclase, microcline or plagioclase, and sericite or chloritised biotite. Early-Middle Carboniferous radiometric ages (310±17, 342±28 Ma) were obtained from two samples by U-Pb dating of zircons. The zircons are uranium rich and inheritance from Proterozoic crustal sources is implied (Gatehouse *et al.*, in prep.).

Granite has been drilled mainly in the Moomba and Big Lake gas fields, and is commonly overlain unconformably by Permian sediments (see Tectonic Sketch). However, steeply dipping ?Kalladeina Formation has been contact metamorphosed in Moomba 2 and subvertical ?Pando Formation is underlain by granite in Moomba South 1 (Fig. 6). Although contacts between the Big Lake Suite and country rocks have not been cored, evidence from these wells suggests intrusion into relatively cool Cambrian sedimentary rocks.

Wopfner (1969) noted that Rb-Sr ages determined for the Mooracoochie Volcanics had been reset during the Late Devonian, and Gatehouse *et al.* (in prep.) have documented several occurrences of post-Delamerian, possibly Carboniferous, magmatism and metasomatism to the south in the Mount Painter Inlier.

This Late Devonian to Middle Carboniferous magmatism and associated thermal activity is suggested by Gravestock (in prep.) to have accompanied the main phase of deformation in the eastern Warburton Basin. The arcuate ridge-trough configuration characteristic of the overlying Cooper and Eromanga Basins is interpreted to result from northwest-directed thrusting associated with the Alice Springs Orogeny rather than the Delamerian or Benambran Orogenies. The younger (i.e. Alice Springs) age of deformation is preferred. Exposure of deep-seated Carboniferous plutons to erosion prior to Early Permian deposition would have required a considerable degree of uplift.

LATE PALAEOZOIC TO EARLY MESOZOIC — COOPER BASIN

D.I. Gravestock

The Cooper Basin has a subsurface extent of 127 000 km^2, approximately one-third of which is in northeastern South Australia with the major part in southwestern Queensland. Although originally known as the Cooper's Creek Basin

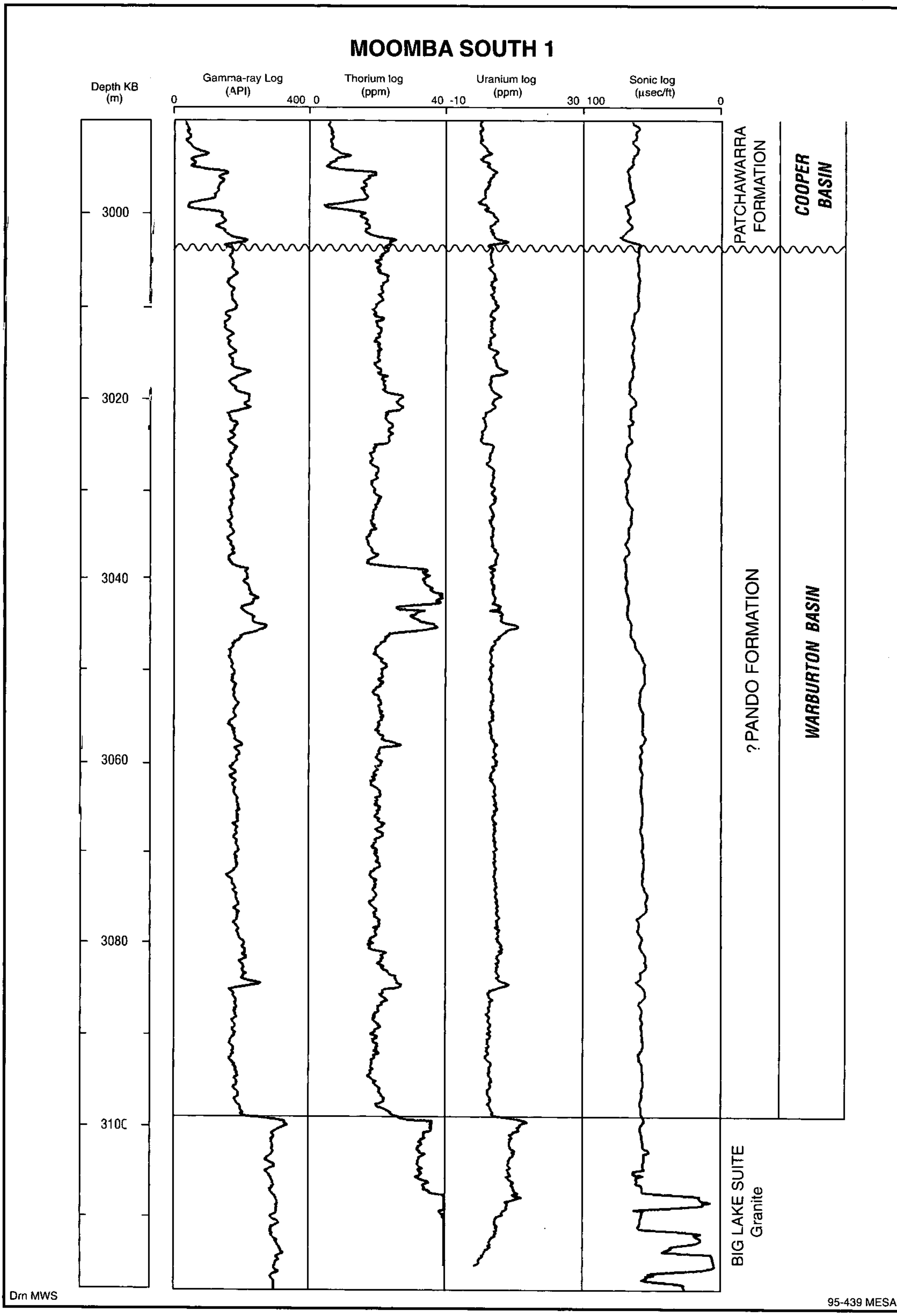

Fig. 6 Composite log of the Pando Formation overlying granite, Moomba South 1.

(Canaple and Smith, 1965) the shortened form of the name was in common usage by 1968 (see Kapel, 1972). On STRZELECKI, which is close to the basin's eroded southern margin, depths to the top of the Cooper Basin range from 1 200 to 3 600 m (see map, Fig. M11).

Sediments in the southern Cooper Basin were deposited in two unconformity bounded sequences in a predominantly non-marine setting, with fossil pollen and spores providing the biostratigraphic framework. Refinement of palynostratigraphy, principally by Price *et al.* (1985) following the early work of Evans (1967) and Paten (1969), has resulted in the stratigraphic scheme shown on Figure 7.

Regional studies (Kapel, 1966; Battersby, 1976; Thornton, 1979; Heath, 1989) traced the development of geological concepts in pace with petroleum exploration. Stratigraphic nomenclature was established for the Permian at an early stage by Kapel (1966, 1972), Martin (1967) and Gatehouse (1972), with refinements by Morton and Gatehouse (1985). Late Permian and Triassic stratigraphy (Papalia 1969; Youngs and Boothby, 1982, 1985; Channon and Wood, 1989; Powis, 1989) is now more firmly established.

Formations of the Gidgealpa Group (Kapel, 1972) constitute the lower depositional sequence in the Cooper Basin. Elevation of the Gidgealpa Formation (or the equivalent 'Permo-Carboniferous' of Kapel, 1966) to group status excluded the underlying Merrimelia Formation (Martin, 1967) as did subsequent definition of the Gidgealpa Group (Gatehouse, 1972). Following the recommendation of Williams and Wild (1984), the Merrimelia Formation is included here. The Gidgealpa Group is redefined as the succession of formations in the Cooper Basin which unconformably overlies Middle Carboniferous and older sedimentary, igneous and metamorphic rocks, and is conformably overlain by the Late Permian-Triassic Nappamerri Group or disconformably by younger sedimentary rocks.

The base of the Merrimelia Formation, where present, constitutes the base of the Gidgealpa Group. The top of the Toolachee Formation, where present, constitutes the top of the Gidgealpa Group. The second depositional sequence begins at the base of the Toolachee Formation and extends to the top of the Nappamerri Group.

Merrimelia Formation

The Merrimelia Formation (Martin, 1967) is composed of conglomerate, sandstone, siltstone and shale, with coarser lithotypes predominating on STRZELECKI. Conglomerate is massive to crudely bedded, and framework supported with well-rounded pebbles and cobbles. Reworked Mooracoochie Volcanics dominate the clast assemblage together with common quartzite and rare granite. Reworked glauconite is common in basal layers where the Merrimelia Formation overlies the Pando Formation. Sandstone units are fine to medium grained, massive, flat and planar cross-bedded. Siltstone forms a subordinate component as thin, pale, grey-brown beds and laminae which are pyritic, carbonaceous and rarely coally. Shale forms pale to dark grey, flat-laminated rhythmite, a minor facies on STRZELECKI.

Sparse spore and pollen assemblages suggest a Late Carboniferous to Early Permian age for the Merrimelia Formation (Fig. 8). The unit is very unevenly distributed; it is absent from western STRZELECKI and rarely exceeds 50 m in thickness elsewhere. In the Wooloo and Allunga Troughs, and between the Milpera and Tinga Tingana Ridges, however, the combined thickness of Merrimelia Formation and Tirrawarra Sandstone locally exceeds 300 m (see map, Fig. M18). Wedges and sheets of coarse sandstone and conglomerate formed proximal glaciofluvial outwash fans along the flanks of this north-south corridor and on the southern margin of the Patchawarra Trough (Malgoona and Lake Hope wells). The region of exposed Warburton Basin volcanics and quartzitic sandstones on western STRZELECKI is interpreted as a glaciated highland bordered by north to northeast draining outwash fans which were probably restricted to within a few kilometres of the range front. These abutted a broad outwash plain crossed by braided rivers.

Glaciolacustrine sediments are common on INNAMINCKA but rare on STRZELECKI. Williams and Wild (1984) described one example of glaciolacustrine rhythmite from the upper Merrimelia Formation in Lake Hope 1. Conglomeratic mudstone (diamictite) in Dullingari 1 may represent a subaqueous melt-out till. Both occurrences are the most southerly examples of subaqueous sediments which are presumed to have been widespread in the Nappamerri and Patchawarra Troughs on INNAMINCKA.

Tirrawarra Sandstone

The Tirrawarra Sandstone (Kapel, 1972; Gatehouse, 1972) is composed of white to pale brown medium-grained to pebbly sandstone with locally common interbeds of conglomerate and scarce interbeds of carbonaceous siltstone, shale and coal. Sandstone is massive, flat or planar cross-bedded with a siliceous or kaolinitic matrix. Matrix-supported conglomerate forms the upper Tirrawarra Sandstone in certain Big Lake wells.

AGE	STAGE	INTERVAL ZONES			SPORE-POLLEN INDEX FORMS	DINOFLAGELLATE ZONES
LATE CRETACEOUS					*Phyllocladidites mawsonii*	
	Cenomanian	PK7			*Crybelosporites cf. C. brenneri*	
EARLY CRETACEOUS	Albian	PK6				*Pseudoceratium ludbrookiae*
		PK5	PK5.2		*Phimopollenites pannosus*	*Canninginopsis denticulata*
			PK5.1		*Pilosisporites grandis*	*Muderongia tetracantha*
		PK4			*Coptospora paradoxa*	
	Aptian	PK3	PK3.2		*Crybelosporites striatus*	*Diconodinium davidii*
			PK3.1		*Pilosisporites parvispinosus*	*Odontochitina operculata*
	Barremian	PK2	PK2.2		*Foraminisporis asymmetricus*	
			PK2.1		*Trilobosporites purverulentus*	
	Neocomian	PK1	PK1.2		*Foraminisporis wonthaggiensis*	
			PK1.1		*Cyclosporites hughesii*	
LATE JURASSIC		PJ6	PJ6.2	PJ6.2.2	*Cicatricosisporites* spp.	
				PJ6.2.1	*Foraminisporis dailyi*	
			PJ6.1		*Ceratosporites equalis*	
MIDDLE JURASSIC	Hettangian to Callovian	PJ5			*Retitriletes watherooensis*	
		PJ4	PJ4.2		*Murospora florida*	
			PJ4.1		*Crybelosporites*	
		PJ3	PJ3.3	PJ3.3.2	*Retitriletes circolumenus*	
				PJ3.3.1	*Camarozonosporites ramosus*	
EARLY JURASSIC			PJ3.2		*Klukisporites lacunus*	
			PJ3.1		*Staplinisporites manifestus*	
		PJ2	PJ2.2	PJ2.2.2	*Callialasporites dampieri*	
				PJ2.2.1	*Foraminisporis caelatus*	
			PJ2.1		*Nevesisporites vallatus*	
		PJ1			*Podosporites tripakshii*	
LATE TRIASSIC	Carnian to Rhaetian	PT5			*Classopollis classoides*	
		PT4			*Polycingulatisporites crenulatus*	
MID TRIASSIC	Ladinian	PT3			*Craterisporites rotundus*	
	Anisian				*Aratrisporites parvispinosus*	
EARLY TRIASSIC	Scythian	PT2.2			*Aratrisporites tenuispinosus*	
		PT2.1			*Protohaploxypinus samoilovichii*	
		PT1			*Lunatisporites pellucidus*	
LATE PERMIAN	Tatarian	PP6			*Triplexisporites playfordii*	
	Kazanian	PP5			*Dulhuntyispora parvitholus*	
	Ufimian	PP4	PP4.3		*Dulhuntyispora dulhuntlyi*	
EARLY PERMIAN	Kungurian		PP4.2		*Didecitriletes ericianus*	
			PP4.1		*Dulhuntyispora granulata*	
		PP3	PP3.3	PP3.3.2	*Lopadiospora vermithola*	
	Artinskian			PP3.3.1	*Acanthotriletes villosus*	
			PP3.2		*Praecolpatites sinuosus*	
			PP3.1		*Phaselisporites cicatricosus*	
	Sakmarian	PP2	PP2.2		*Granulatisporites trisinus*	
	Asselian		PP2.1		*Pseudoreticulatispora pseudoreticulata*	
LATE CARBONIFEROUS	Stephanian	PP1	PP1.2		*Microbaculispora tentula*	
	Westphalian		PP1.1		*Protohaploxypinus* spp.	
	Namurian	PC4	PC4.2		*Brevitriletes 'leptoacaina'*	
			PC4.1		*Protonieisporites* spp.	
		PC3			*Grandispora maculosa*	

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Fig. 7 Permian and Mesozoic palynostratigraphic chart (after Price *et al.*, 1985; Channon and Wood, 1989).

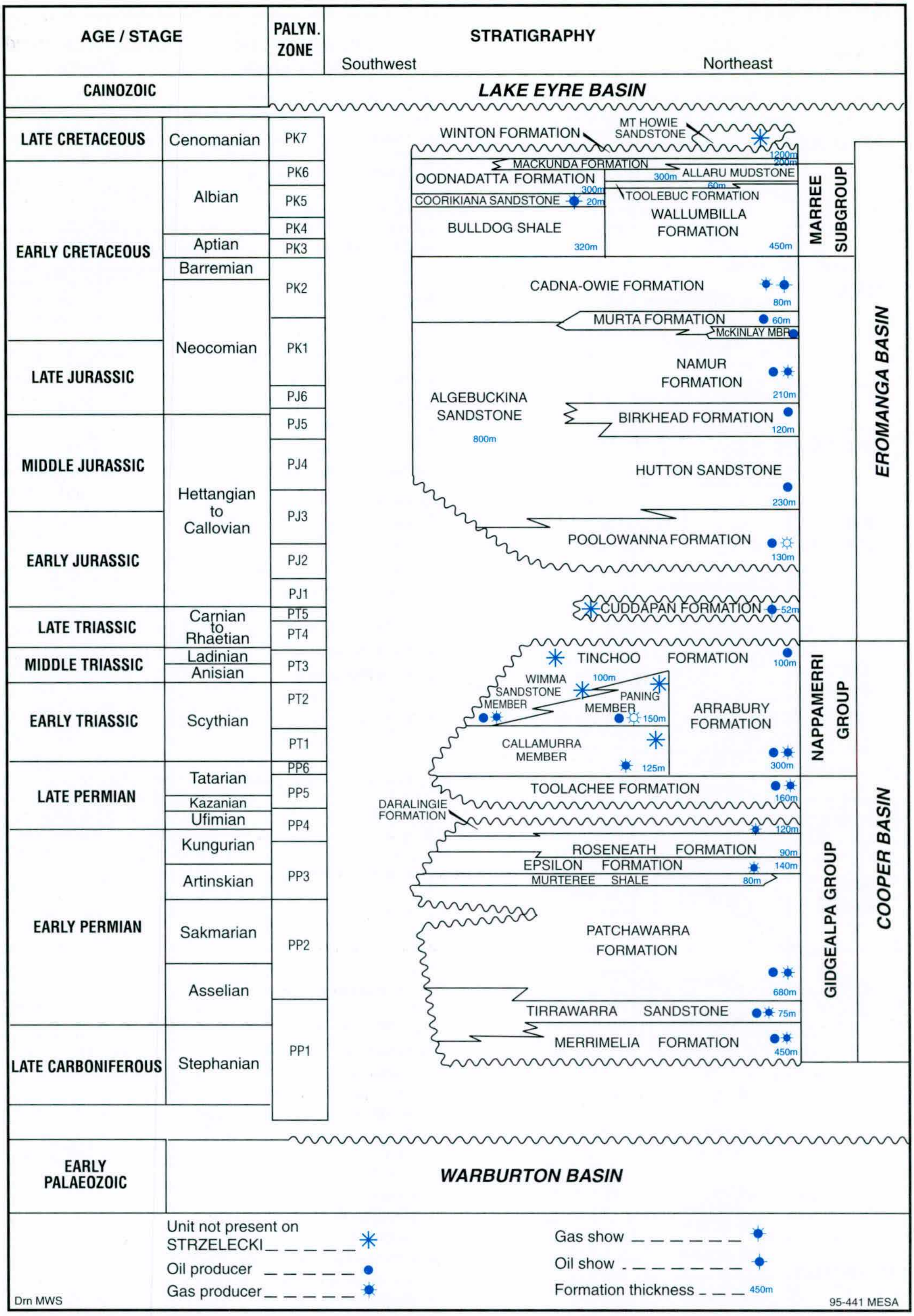
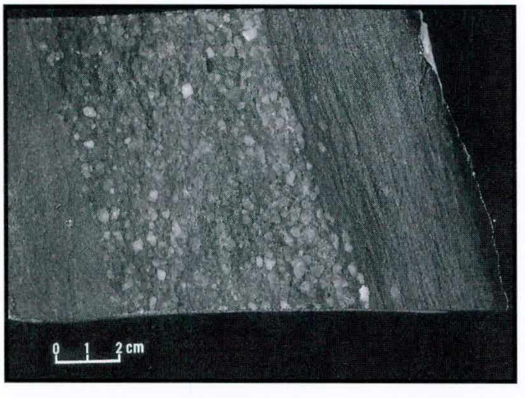


Fig. 8 Permian and Mesozoic stratigraphic column (after Price *et al.*, 1985).

The matrix is composed of deformed ductile clasts of clay, mica and quartz; a high gamma-ray response is associated with the conglomerate (Stanley and Halliday, 1984; Steveson and Gravestock, 1984), which is regarded by some workers as basal Patchawarra Formation.

Sparse spore-pollen assemblages indicate that the Tirrawarra Sandstone is predominantly Early Permian in age but may range downward into the Late Carboniferous where interbedded with the Merrimelia Formation.

Thickness distribution of the Tirrawarra Sandstone is variable. The formation is absent locally but may reach 150 m or more in the north-south corridor running through the Wooloo and Allunga Troughs. Williams (1982) and Williams and Wild (1984) described four major facies associations; the lower two intertongue with the Merrimelia Formation. Association 1 represents low-sinuosity braided outwash fan environments characterised by in-channel longitudinal gravel and stacked medial sand bars, and unconfined sheet flood gravels. Association 2 represents a more established fluvial channel pattern with bedforms typical of lower fan environments, the balance between glacial and fluvial processes evolving to a point where fluvial processes dominated. Association 3, found at the type locality on INNAMINCKA, has not been cored on STRZELECKI but is evident on wireline logs where the Tirrawarra Sandstone passes laterally into the Patchawarra Formation (Fig. 9). The association represents a mixed-load fluvial environment with occasionally preserved bar-top coals and backswamp mudrocks. Examples of Association 4 have been described from Gidgealpa 5 and 7 by Williams (1982). Typical facies are upward-fining exotic conglomerate and sandstone beds with reworked clasts of Merrimelia Formation, and rarely preserved abandoned-channel mudrocks. Matrix-supported conglomerate in Big Lake wells (deformed lithic clasts constitute the 'matrix') probably belongs in this association (cf. Steveson and Gravestock, 1984). Kaolinised feldspar and coarse-grained hydromuscovite in the upper Tirrawarra Sandstone in this region suggest a granitic provenance (Stuart *et al.*, 1990). Localised tectonic activity was the likely cause of renewed coarse clastic deposition (Williams, 1982).



Top: Braided outwash of petromictic conglomerate in the Merrimelia Formation, with acid igneous clasts reworked from the Mooracoochie Volcanics (Lake Hope 1, core 4, 2 487 m KB). Width of core is 65 mm; top is to right. Photo 42578.

Bottom: Matrix-supported conglomerate and interbedded fine-grained carbonaceous sandstone in the upper Tirrawarra Sandstone (Big Lake 27, core 6, 2 788 m KB). Width of core is 77 mm; top is to right. Photo 42579.

Patchawarra Formation

The Patchawarra Formation (Kapel, 1972) is composed of stacked upward-fining facies associations of sandstone, siltstone, mudstone and coal, with siltstone and mudstone predominating at the top of the formation. Sandstone is grey, buff or brown, fine to medium grained, and locally coarse grained and pebbly. Authigenic quartz, kaolinite and dickite are common (Schulz-Rojahn and Phillips, 1989). Siltstone and mudstone are grey-brown to dark grey, thinly bedded or laminated with common carbonaceous and argillaceous partings. Inertinite-rich coal occurs commonly as laminae, thin seams and beds sometimes reaching 16 m in thickness (Fig. 10).

Spore-pollen assemblages are Early Permian (Asselian-Kungurian) and characteristic of the cold to cool-temperate *Glossopteris* pteridosperm flora (Thomas, 1982).

The Patchawarra Formation is widespread, its preserved limits more or less enclosing the southern Cooper Basin depocentre. The top of the formation ranges from depths of 1 300 to 3 100 m, and it is up to 450 m thick. The formation is absent from some elevated structures such as the Dunoon, Murteree and Della-Nappa-

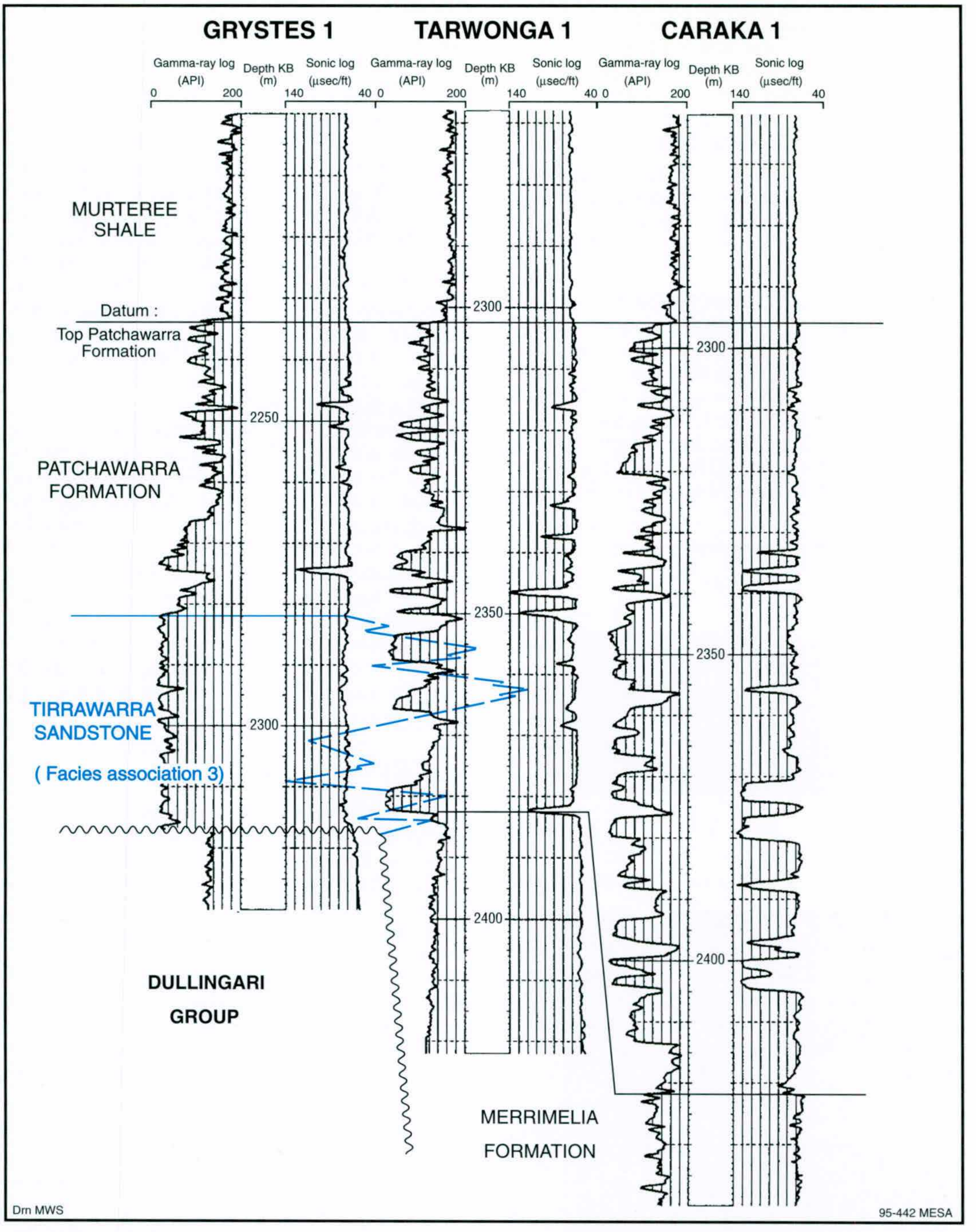


Fig. 9 Cross-section of Tirrawarra Sandstone-Patchawarra Formation transition (depth in m).

coongee Ridges due to erosion at the end of the Early Permian, and may be absent due to non-deposition on southwestern and southeastern STRZELECKI (see map, Figs M16, M17, and Tectonic Sketch). Regions where Warburton Basin rocks had been exposed were progressively onlapped (e.g. Moomba, Daralingie, Toolachee structures). Elsewhere the Patchawarra Formation either conformably overlies the Tirrawarra Sandstone or, as on eastern STRZELECKI, passes laterally into the Tirrawarra Sandstone (Thornton, 1979; see map, Fig. M17).

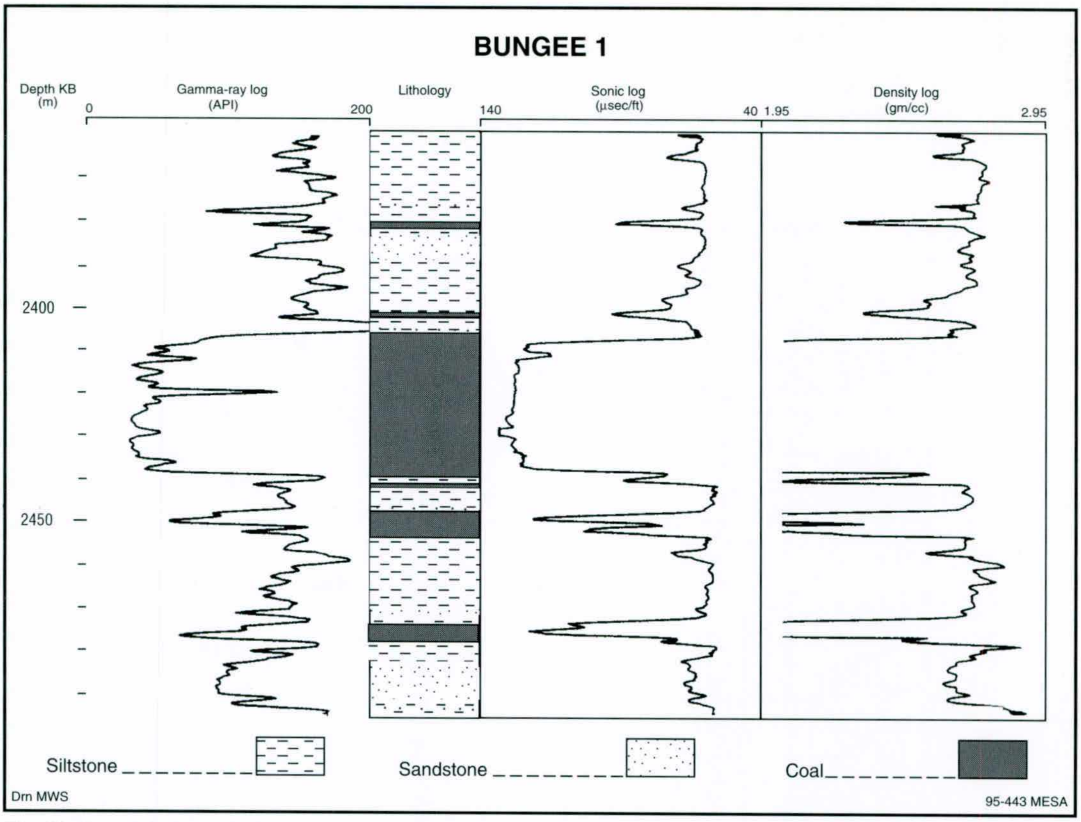


Fig. 10 Composite log of Patchawarra Formation coal, Bungee 1.

The Patchawarra Formation accumulated during waning stages of Gondwanan glaciation. Sedimentary facies and environments of deposition have been described by Battersby (1976), Stuart (1976) and Thornton (1979). Stanmore and Johnstone (1988) provided detailed interpretations of seismic facies in the Patchawarra Trough, the southern part of which is present on STRZELECKI. The formation is principally a mosaic of fluvial, swamp and flood-basin lake deposits. Sediment was transported northwards into the Patchawarra and Nappamerri Troughs by mixed-load streams with characteristic channel and point-bar deposits (Stuart, 1976; Thornton, 1979; Stanmore and Johnstone, 1988; Fig. 10). Vegetated bar top and flood-plain coals are sometimes underlain by root-disturbed, sideritic siltstone beds whereas other coals represent transported vegetation. Many swamp coals originated as thick peat accumulations, which were seasonally desiccated and covered by algal mats (Hunt and Smyth, 1986; Taylor *et al.*, 1988).

The upper Patchawarra Formation is a flood-basin lake facies characterised in the Moomba-Big Lake area by fine-grained, shallow lacustrine sediments and little or no coal. Facies include fine-grained, wave-rippled sandstone, bioturbated siltstone, and upward-coarsening sandstone deposited in crevasse splays. Sediment was supplied by deltas feeding from the south (Stuart, 1976).

Murteree Shale

The Murteree Shale (Gatehouse, 1972) conformably overlies the Patchawarra Formation and consists of black to dark grey-brown laminated, argillaceous siltstone (the term 'shale' is a misnomer) and minor fine-grained sandstone. Disseminated carbonaceous matter, fine-grained pyrite and muscovite are characteristic of the formation which has high gamma ray and density values on wireline logs (Fig. 11). Spores and pollen indicate an Early Permian age.

The Murteree Shale is widespread and relatively uniform in thickness (50±25 m). Absence of the formation from southern STRZELECKI is due partly to uplift and erosion but depositional thinning is evident in a westerly direction across the southern Patchawarra Trough. In addition, thinning and increased sand content in the Pando to Tinga Tingana Ridge area suggests proximity to a shoreline on southwestern STRZELECKI.

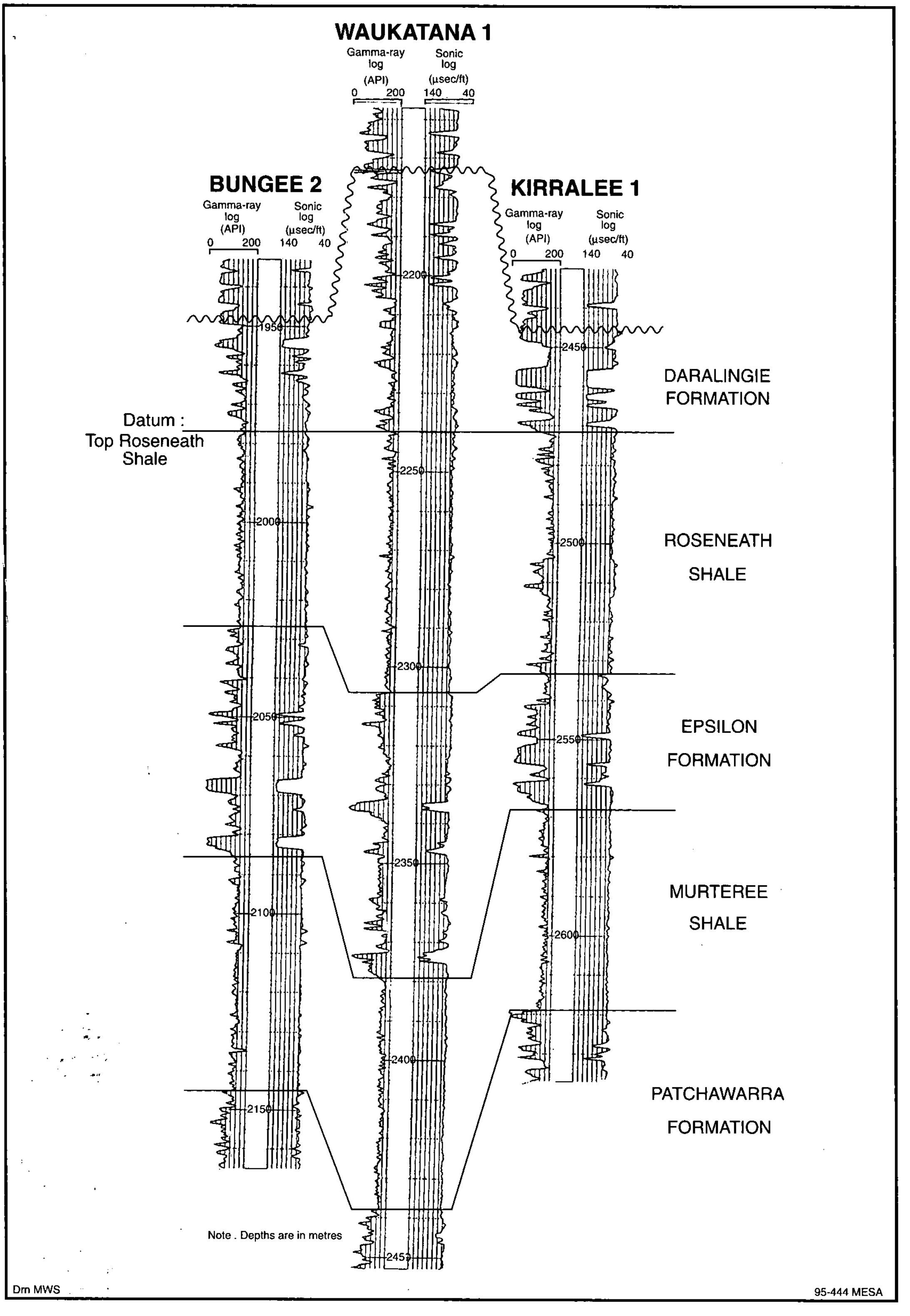


Fig. 11 Cross-section of Patchawarra Formation to Daralingie Formation in Bungee 2, Waukatana 1 and Kirralee 1 (depth in m).

Sedimentary structures in the sandier, proximal cores include ripple lamination and contorted bedding with frequent scour surfaces. Rare pebbles, such as in Wancoocha 1, may have been transported by mass flow processes or conceivably by seasonal ice floes. Convolute laminations, slumps, micro-faults and reactivation surfaces of sporadic occurrence in otherwise uniformly laminated mudstone were suggested by Gravestock and Morton (1984) to have originated through seismic activity.

There is a question as to whether the Murteree Shale was deposited in a large freshwater lake or restricted sea of low salinity. Stuart (1976) and Thornton (1979) argued for both alternatives but favoured an open basin with eventual access to the sea south of the Galilee Basin in Queensland. A freshwater environment is the preferred interpretation, since:

- microfloral assemblages are often rich but no marine microplankton (acritarchs) have been found in any palynological preparations (N. Marshall and G. Wood, Santos Ltd, pers. comm., 1992); acritarchs are usually present even in stressed proglacial marine systems
- no invertebrate fossils (e.g. foraminifera, molluscs) have been found and trace fossils are rare
- glauconite pellets reported by Stuart (1976) may have been reworked from exposed Pando Formation in source areas on southwestern STRZELECKI.

Characteristic parallel lamination, abundant dispersed organic matter (DOM), silt-sized pyrite and rare trace fossils all suggest a freshwater lake with restricted circulation and episodically anoxic bottom conditions. The extent and minor thickness variations of the Murteree Shale suggest a hinterland with low topographic relief. The lake inundated the flood-basin environment of the uppermost Patchawarra Formation. .

Epsilon Formation

The Epsilon Formation (Gatehouse, 1972) conformably overlies Murteree Shale and comprises sandstone, siltstone, mudstone and coal in varying proportions. Fairburn (1992) recognised three major depositional sequences; basal and top units characterised by upward-coarsening sandstone, and a middle unit dominated by coal but locally with well-developed sandstone. Stuart (1976) and Fairburn (1992) attributed the lowermost and uppermost units to regression of the lacustrine system which deposited the Murteree and Roseneath Shales.

Sandstone in the Epsilon Formation is thinly bedded, fine to medium-grained (rarely pebbly) quartz arenite. Sandstone is texturally and mineralogically mature with authigenic quartz, kaolinite and carbonate in the matrix (Taylor *et al.*, 1991). Siltstone and mudstone are dark grey-brown, carbonaceous and slightly pyritic. Coal forms extensive but generally thin seams which rarely exceed 2-3 m and are commonly less than 0.3 m thick.

The Epsilon Formation is Early Permian, diachronous, being younger to the west and southwest (Gatehouse, 1972; Thornton, 1979), and similar in extent and thickness to the Murteree Shale. Locally, it is poorly developed (e.g. Grystes 1).

Stuart (1976), Taylor *et al.* (1991) and Fairburn (1992) provided a comprehensive account of depositional environments from core and wireline log studies. They interpreted the lower and upper Epsilon Formation as stillstand accumulations of lacustrine shoreface sands. The upper unit is particularly thick in the Big Lake area possibly because of a balance between slow subsidence and gradual regression. Fluvio-deltaic influence is expressed in the upper unit as key distributary mouth bars in which Taylor *et al.* (1991) discovered 'glauconitic illite'. The precursor glauconite, like that described by Stuart (1976), is considered here to have been transported in streams eroding Pando Formation exposures in the southwest.

The middle Epsilon Formation was deposited by fluvial-dominated deltas. Meandering fluvial channels deposited sand in the Toolachee, Kidman and Burke areas (Fairburn, 1992) and also transported fine-grained clastics to the Big Lake and Moomba delta complex from the west, southwest and ?south (Taylor *et al.*, 1991). Mud and peat accumulated in flood-plain and interdistributary swamps.

Roseneath Shale

The Roseneath Shale (Gatehouse, 1972) comprises light to dark brown-grey or olive-grey argillaceous siltstone, mudstone and minor sandstone. Siltstone is laminated or mottled, rich in dispersed organic matter, micromicaceous and slightly pyritic. Like the Murteree Shale, the formation is characterised by elevated gamma-ray and density log values. Sandstone is light brown, fine grained and rarely forms beds more than 1-2 m thick (Fig. 11). Spiked excursions on density logs may be due to pyrite or siderite concentrations.

The Roseneath Shale is Early Permian and diachronous, younging southwest (Gatehouse, 1972; Thornton, 1979). The formation is similar in extent and thickness to the Murteree Shale but is thicker (up to 90 m) in the Mettika Embayment.

The combined thickness of Roseneath Shale, Epsilon Formation and Murteree Shale (see map, Fig M15) exceeds 220 m in all major troughs. An exception is the Patchawarra Trough where thinning is evidently due to reduced sedimentation. Depositional thinning also occurs on southern and western STRZELECKI, over the Murteree Ridge and north-south across the Tenappera Trough. In contrast, thicknesses are greater on the Toolachee Ridge, and would have been greater but for subsequent erosion on the Della-Nappacoongee Ridge.

The Roseneath Shale was deposited in a similar lacustrine setting to the Murteree Shale. Slump folds and common reactivation surfaces in the lower part of the formation (e.g. Big Lake 47) suggest high initial rates of deposition on a mildly unstable slope.

Daralingie Formation

The Daralingie Formation (Gatehouse, 1972; Morton and Gatehouse, 1985) is the uppermost formation of the lower depositional sequence. It comprises interbedded siltstone, mudstone, coal and minor sandstone. Siltstone varies from light grey to black, grading to mudstone and coal. Sandstone is light grey-brown, very fine to fine grained (rarely medium or coarse) with a white, kaolinitic matrix and occasional carbonaceous material.

Pollen and spores indicate an Early Permian age for the formation, which is overlain disconformably by the Late Permian Toolachee Formation.

Uplift at the end of the Early Permian (see below) resulted in progressive erosion of the Daralingie Formation and underlying units from the crests and flanks of structural ridges and from the southwest Cooper Basin margin. The thickest remaining intersections range from 30-40 m in the Tenappera and southern Patchawarra Troughs, to 90-120 m in the southern Nappamerri and Allunga Troughs (see map, Fig. M14).

Stuart (1976) and Battersby (1976) interpreted a return to fluvial flood-plain and deltaic sedimentation similar to that prevailing for the Epsilon Formation.

Toolachee Formation

The Toolachee Formation (Kapel, 1972) disconformably overlies the Daralingie Formation and constitutes the top unit of the Gidgealpa Group. It is composed of interbedded sandstone, mudstone and coal often in upward-fining sequences. Sandstone is buff-white, fine to coarse grained and locally pebbly to conglomeratic. Exotic clasts of reworked early Palaeozoic rocks occur in basal conglomerate beds which unconformably overlie the Warburton Basin on structural ridges. More commonly the conglomerates are quartzose channel lags or bank-collapse features with carbonised plant fragments and mud clasts sometimes composed of micritic siderite. Authigenic quartz, kaolinite and patchy carbonate comprise the sandstone matrix (Schulz-Rojahn and Phillips, 1989). Fine-grained sandstone is thinly bedded or laminated with muddy or carbonaceous partings. Mudstone is dark grey to grey-brown, massive to laminated, often root mottled and sideritic where capped by coal. Coal seams rarely exceed 3 m in thickness.

The Toolachee Formation is Late Permian in age from palynological evidence. It disconformably overlies the Daralingie Formation and unconformably overlies older rocks. The Toolachee Formation is overlain conformably by the Arrabury Formation (Powis, 1989) or, where the latter is eroded, unconformably by Eromanga Basin sediments. Maximum thickness of the Toolachee Formation is 152 m in the Toolachee-Munkarie area; elsewhere the formation has an average thickness of 60 m. An isopach of the combined Toolachee and Arrabury Formations is shown on the map (Fig. M12).

Environments of deposition of the Toolachee Formation have been studied intensively in the Moomba, Big Lake and Della gas fields (Battersby, 1976; Stuart, 1976; Thornton, 1979; Williams, 1984; Gravestock and Morton, 1984; Stuart *et al.*, 1988; Fairburn, 1989). Two major facies associations (Fig. 12) were recognised by Williams (1984).

Facies Association 1 (Toolachee Unit C of other workers) characterises the lower Toolachee Formation which consists mainly of upward-fining, sandstone-dominated facies transitions deposited by mixed-load meandering streams. Scour-based channels, point bar, punctuated bar, chute and ephemeral flood-basin lake sediments are represented. Streams are interpreted to have flowed from southwest to northeast in the Moomba-Big Lake area (Stuart *et al.*, 1988) and from south to north in the Della area (Gravestock and Morton, 1984).

Facies Association 2 of the upper Toolachee Formation (Toolachee Unit B) is dominated by frequently interbedded, thin, upward-coarsening facies transitions deposited in extensive, perennial flood-basin lakes. Williams (1984) also recognised a third facies association in the Gidgealpa area comprising coarse-grained, bedload-dominant fluvial channels. He attributed this to Late Permian tectonism and/or base level lowering; other occurrences are likely to be found.

Nappamerri Group

The Nappamerri Group (Papalia, 1969; Powis, 1989), representing a different palaeo-environmental regime from that of the previous succession, comprises the Arrabury and Tinchoo Formations, with only the Arrabury Formation preserved on STRZELECKI. The Arrabury Formation is a redbed suite composed of interbedded siltstone and sandstone. Siltstone is variegated grey, green, red and brown, micromicaceous and rarely carbonaceous. Sandstone is very fine to medium grained, white to pale brown, variably dolomitic and calcareous. The formation is characterised by high, 'ragged' gamma-ray and density-log character with thin 'blocky' sandstone interbeds (Fig. 13).

The Arrabury Formation contains a sparse, usually oxidised pollen assemblage indicative of a Late Permian to Early Triassic age (Youngs and Boothby, 1985; Channon and Wood, 1989; Powis, 1989). The Arrabury Formation conformably overlies the Toolachee Formation on STRZELECKI, the top of the latter marked by the uppermost coal used for seismic mapping purposes.On wireline logs and in cores, the base of the Arrabury Formation is marked by the first appearance of redbeds (Gatehouse, 1972). Subsequent erosion has confined the Arrabury Formation mainly to a region north of the Dunoon and Murteree Ridges with a lobe extending south into the Tenappera Trough (see map, Fig. M12, Tectonic Sketch) but the depositional area is likely to have been much more extensive (Battersby, 1976). The Arrabury Formation is overlain disconformably by Eromanga Basin sediments.

Youngs and Boothby (1985) interpreted a fluvio-lacustrine environment for the Arrabury Formation (their Unit 1) and, with Papalia (1969) and Powis (1989), noted that the onset of continental redbed deposition coincided with widespread aridity and global lowering of sea level at the end of the Palaeozoic.

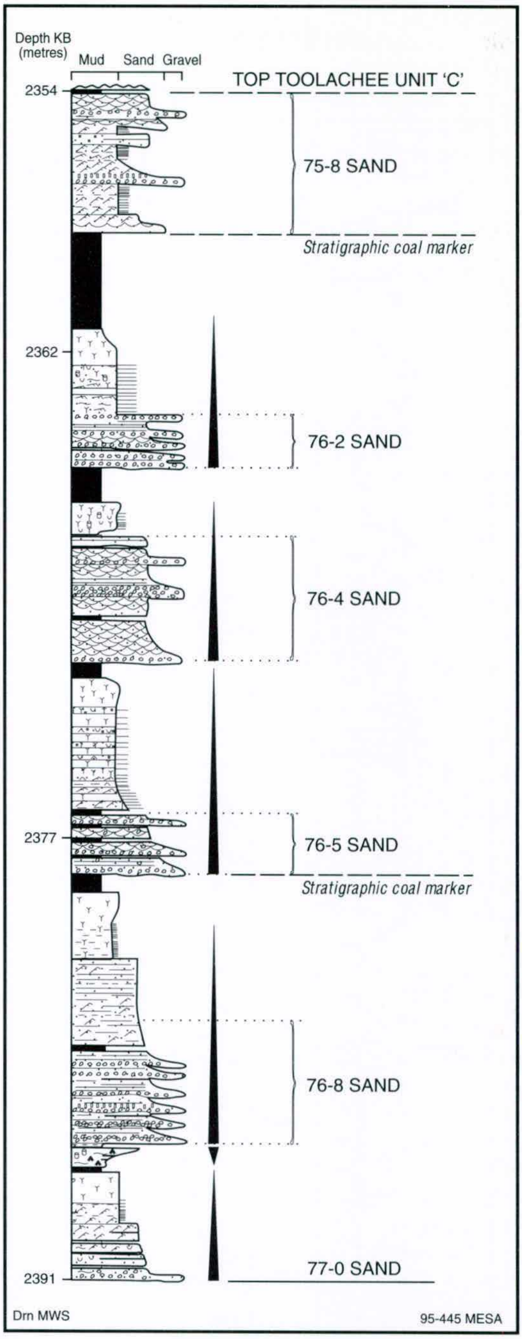
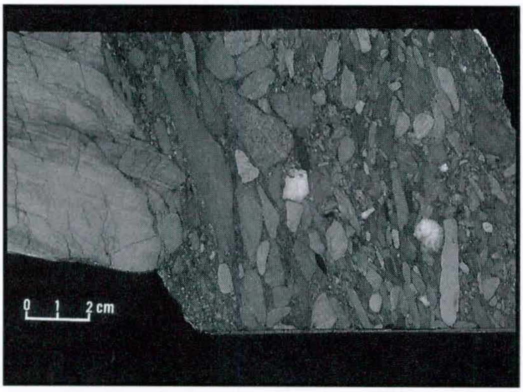


Fig. 12 Facies log showing upward-fining sequences in the Toolachee Formation Unit 'C', Moomba 10 (after Fairburn, 1989; note on sand nomenclature: the 75-8 sand was intersected at a log depth of approximately 2 310 m in the Moomba Field index well.)



Basal conglomerate of the Toolachee Formation resting unconformably on steeply dipping Dullingari Group (Della 5A, core 3, 1 952.9 m KB). Top is to right. Photo 42580.

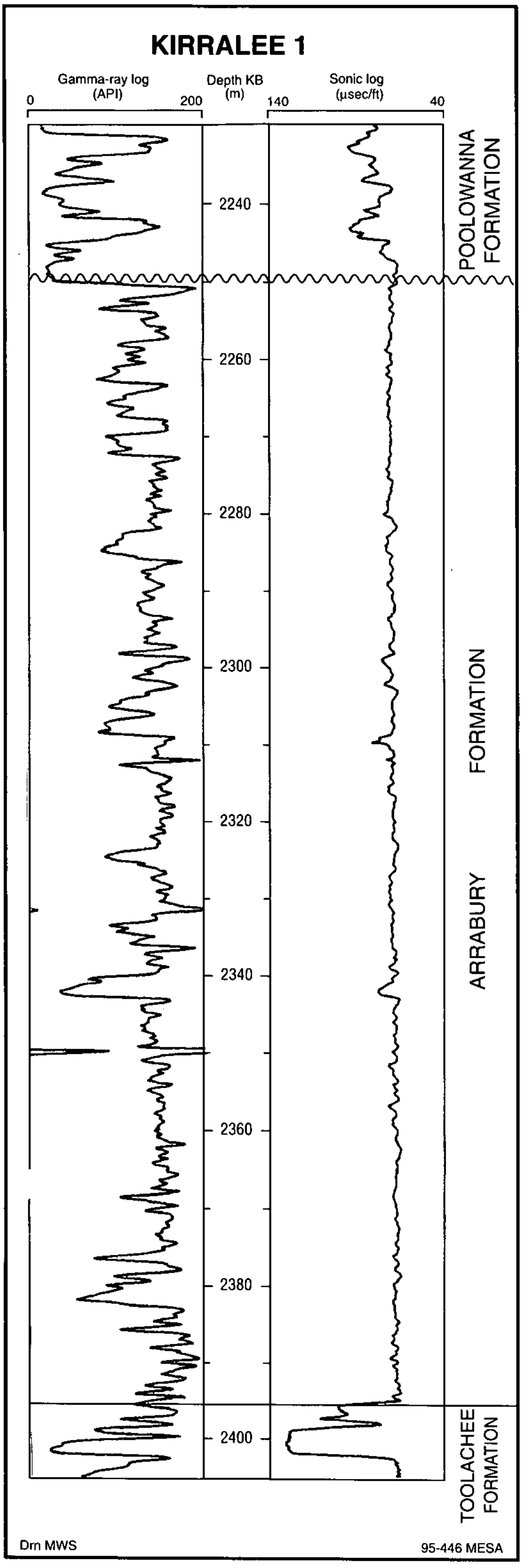


Fig. 13 Composite log of the Nappamerri Group, Kirralee 1.

EARLY PERMIAN AND LATE TRIASSIC TECTONISM

D.I. Gravestock

Sprigg (1961) first drew attention to the significance of buried, mostly 'bald-headed' anticlines 'at the base of the Permian and Triassic' in the Cooper Basin. Fault reactivation within the Permian succession was documented by Greer (1965), Kapel (1966, 1972) and Stuart (1976) who recognised that relatively few faults displacing Early Permian strata propagated into the Late Permian, and Battersby (1976) showed further that some faults were inactive near the end of Patchawarra Formation deposition.

Three major phases of fault reactivation are recognised — one within the Patchawarra Formation which can locally be resolved into two separate episodes, a second phase at the end of the Early Permian culminating in marked uplift and erosion of structural ridges and erosion at the basin margin, and a third phase in the Late Triassic which ended Cooper Basin sedimentation. These phases are outlined below.

Patchawarra Formation tectonism

A break in the palynofloral record during Early Permian (Sakmarian) time provides evidence for local disconformity in the southern Cooper Basin (G. Wood, Santos Ltd, pers. comm., 1991). Partial erosion of lower levels, and evidence of stream rejuvenation in middle levels of the Patchawarra Formation, are attributed by Stanmore and Johnstone (1988) to minor structural movements within the Cooper Basin and to mild tectonism beyond the basin to the southwest. Palynologically controlled facies mapping led Apak *et al.* (1993) to recognise two phases of uplift which controlled fluvial depositional patterns and locally caused structural inversion (e.g. between Moomba and Big Lake gas fields).

These mild tectonic episodes occurred in the Cooper Basin when deposition further west in the Arckaringa and Pedirka Basins was drawing to a close; the youngest sediments in the latter basins are Sakmarian in age (Gilby and Foster, 1988). It is doubtful that all three basins were intermittently connected prior to the end of the Sakmarian since their initial deposits appear to have been confined to structural and topographical depressions.

Daralingie Unconformity

A palynological hiatus between the Early and Late Permian (Fig. 7) is known as the Daralingie Unconformity (e.g. Heath, 1989). Renewed tectonic activity along pre-Permian fault trends (Battersby, 1976; Stuart, 1976; Stanmore and

Johnstone, 1988) caused uplift, widespread erosion and transport of previously deposited sediments. Warburton Basin rocks were exposed locally, contributing exotic clasts to basal conglomerates of the Toolachee Formation. Reverse fault movements are apparent at several localities (Stuart, 1976; Gravestock and Morton, 1984).

Peneplanation (Heath, 1989) is unlikely and uplifts were not strictly aligned with the more prominent subsurface ridge trends. Subcrop geology at the Daralingie Unconformity surface (see map, Fig. M14) is interpreted to stem from fault reactivation along two interfering tectonic trends:

- North to north-northwesterly trends sub-parallel to the interpreted orientation of an Early Cambrian rift splay (Boucher, 1991). These trends may represent a continuation of the Koonenberry Fracture Zone which extends northwesterly from the Wonominta Block in New South Wales.
- Arcuate northeasterly trends associated with reactivation of thrust faults originating from the late Devonian to Early Carboniferous Alice Springs Orogeny.

Fault reactivation on north-northwesterly trends is revealed by thickness variations of the Daralingie Formation in the Moomba and Toolachee regions and by the *en echelon* arrangement of anticlines from the Tinga Tingana Ridge to the Della structure (Fig. M14). Lower Permian formations have been increasingly eroded towards anticlinal crests, with local exposure of Warburton Basin rocks in crestal locations (e.g. Della, Strzelecki, Spencer West).

Fault reactivation on the arcuate trends is evident from alignment of the Warra, Gidgealpa, Della-Nappacoongee and Milpera Ridges (see map, Tectonic Sketch). Oblique interference between the two trends is interpreted from the 'S'-shaped zone of faults between the eastern Murteree and Della-Nappacoongee Ridges.

On STRZELECKI, the Toolachee Formation disconformably overlies the Daralingie Formation in structural troughs. However, close to the Cooper Basin margin, a mild angular unconformity is evident between the Toolachee Formation and underlying formations of the Gidgealpa Group attesting to severity of uplift in this region.

Nappamerri Group tectonism

Cooper Basin deposition was terminated by tectonic activity during the late Early and Middle Triassic (Channon and Wood, 1989). Consequent northeasterly tilting of the Cooper Basin (Kuang, 1985) resulted in erosion of the Nappamerri Group from southern and southwestern STRZELECKI (Fig. M12). Uplift of the Murteree, Dunoon and Warra Ridges along the arcuate northeast trends modified the underlying Early Permian structural fabric. There is no evidence on STRZELECKI for Triassic fault reactivation of north to north-northwesterly trends except in the eastern Murteree Ridge-Della area.

MESOZOIC — EROMANGA BASIN

E.M. Alexander

The Eromanga Basin is an intracratonic sag basin extending over 1.7 million km^2 of central Australia. Approximately 360 000 km^2 lie in northern South Australia. The Eromanga Basin is part of the hydrogeological Great Artesian Basin (Habermehl, 1986), one of the world's largest artesian water systems.

On STRZELECKI, the Eromanga Basin occurs entirely in the subsurface and lies unconformably on the Cooper Basin. It is unconformably overlain by Lake Eyre Basin sediments. Depths to the top of the Eromanga Basin range from 50 to 300 m on STRZELECKI, and the sedimentary succession comprises three depositional sequences:

- lower non-marine sequence (Poolowanna to Murta Formations)
- marine sequence (Cadna-owie to Mackunda Formations)
- upper non-marine sequence (Winton Formation).

Refinement of palynostratigraphy by Price *et al.* (1985) has produced the stratigraphic scheme shown on Figure 7. Eromanga Basin stratigraphy was initially developed from studies of outcrop on the basin margins in South Australia and Queensland. Outcrop nomenclature has been extended into the subsurface and combined with nomenclature developed from over 1 000 petroleum exploration wells in northeastern South Australia, producing the stratigraphic framework depicted on Figure 8.

Poolowanna Formation

The Poolowanna Formation (Moore, 1986) disconformably overlies Cooper Basin units on STRZELECKI, and consists of sandstone with minor laminated siltstone, interbedded with carbonaceous mudstone and minor coal seams. Sandstone is grey-white and cross-bedded, fine to medium grained, and locally granule rich and conglomeratic. Conglomerates consist of bank collapse carbonised plant fragments and mudstone intraclasts with, rarely, channel lags of quartzitic and exotic clasts. Authigenic quartz and kaolinite comprise the sandstone matrix. Siltstone is dark grey to light grey-brown, carbonaceous, massive to laminated, and often interbedded with fine-grained sandstone. Mudstone is dark to light grey, carbonaceous, massive to laminated, and often root mottled and sideritic. Carbonised plant fossils are preserved on bedding surfaces. Coal seams rarely exceed 1 m, are typically less than 0.3 m, and are laterally discontinuous.

The Poolowanna Formation is Early Jurassic in age from palynological evidence (Fig. 8), and intertongues with, and is conformably overlain by, the Hutton Sandstone (Fig. 11). Distribution of the Poolowanna Formation is controlled by facies changes into the Hutton Sandstone (Fig. 14) and by palaeotopographical features on the Nappamerri Unconformity surface. The Poolowanna Formation was deposited in a meandering to anastomosing fluvial environment.

Hutton Sandstone

Hutton Sandstone was defined by Reeves (1947) from outcrop in the Roma area of Queensland and the name was applied by Kapel (1966) to sandstones of Early-Middle Jurassic age in the subsurface Eromanga Basin. The upper Hutton Sandstone is composed of white, fine to very coarse-grained quartzose sandstone with minor conglomerate and siltstone interbeds. The sandstone is flat to planar cross-bedded, with common upward-fining foresets. Thin carbonaceous and silty partings cover cross-sets and foresets. Channel lag conglomerates consist of quartz pebbles, carbonaceous mudstone intraclasts, rare lithic clasts and carbonised plant fragments. Mudstone is brown, laminated and carbonaceous.

Direct observation of Hutton Sandstone facies on STRZELECKI is limited to the top 50 m where most cores are cut. The rest of the unit is known only from wireline logs and cuttings. Wiltshire (1982, 1989) interpreted lake shoal, bar and beach facies, with distributary channel and fluvial facies in the lower Hutton Sandstone. Sand was supplied by aeolian transport into the depocentre. The upper Hutton Sandstone is usually interpreted as an entirely braided fluvial facies (e.g. Watts, 1987). Duricrusts of calcrete and silcrete in the upper Hutton Sandstone are interpreted on STRZELECKI (Gravestock *et al.*, 1983).

The Hutton Sandstone is Early-Middle Jurassic in age from palynological evidence (Price *et al.*, 1985). It conformably overlies and intertongues with the Poolowanna Formation and unconformably overlies older units (Fig. 8).

Hutton Sandstone is overlain conformably by Birkhead Formation (Fig. 14). The maximum thickness of the Hutton Sandstone-Poolowanna Formation is 260 m in the Jack Lake area (see map, Fig. M10). On southern STRZELECKI, Hutton Sandstone passes into Algebuckina Sandstone (see map, Fig. M10).

Birkhead Formation

The Birkhead Formation was defined by Exon (1966) from outcrops in the Tambo area, Queensland, and consists of interbedded siltstone, mudstone and sandstone with thin coal seams. The siltstone and mudstone are dark brown to dark grey, carbonaceous and sideritic, massive slumped and laminated, and often root mottled and weakly bioturbated. Interbedded siltstone and sandstone are ripple cross-bedded and linsen bedded. Sandstone is buff, fine to medium grained, trough cross-bedded, with thin basal pebble lags and intraclast breccias (Paton, 1986). Sandstone interbeds are laterally discontinuous and flat to cross-bedded. Coal seams are typically less than 0.3 m thick and are laterally discontinuous.

The Birkhead Formation is Middle to Late Jurassic in age (Fig. 8), conformably overlies and intertongues with Hutton Sandstone (Paton, 1986) and is conformably overlain by Namur Formation. Birkhead Formation silt, mud and coal accumulated in a lacustrine and overbank setting, cut by meandering fluvial channels (Paton, 1986).

Namur Sandstone (revised name)

Following the work of Martin (1983), the Namur Sandstone Member of the Mooga Formation is herein elevated to formation status as the Namur Sandstone (note, however, that it is referred to as the Namur Formation on the STRZELECKI map). The name is derived from Delhi Namur 1 petroleum exploration well, which made the first commercial hydrocarbon discovery from the Eromanga Basin with a flow of 13.9 MMcf/d of gas from this unit (Mount, 1981). Martin's (1983) informal N1 and N2 units from Strzelecki 4 cores represent the upper Namur Sandstone — his units N3 and N4 are re-assigned herein to the McKinlay Member of the Murta Formation. The term Mooga Formation (Nugent, 1969) is discarded. The unit is distributed throughout the eastern and central Eromanga Basin with equivalents in the Surat Basin. On southern STRZELECKI and in the western Eromanga Basin, Namur Sandstone passes laterally into Algebuckina Sandstone.

Namur Sandstone is identified as the predominantly sandstone unit that overlies Birkhead Formation and intertongues with Westbourne Formation siltstone and underlies the Murta Formation. The base of the Namur Sandstone is taken as the base of the first significant quartzose sandstone above the Birkhead Formation or Westbourne Formation. Westbourne Formation and Adori Sandstone have not been recognised on STRZELECKI. Siltstone interbeds in the lower Namur Sandstone in Strzelecki 4 are re-

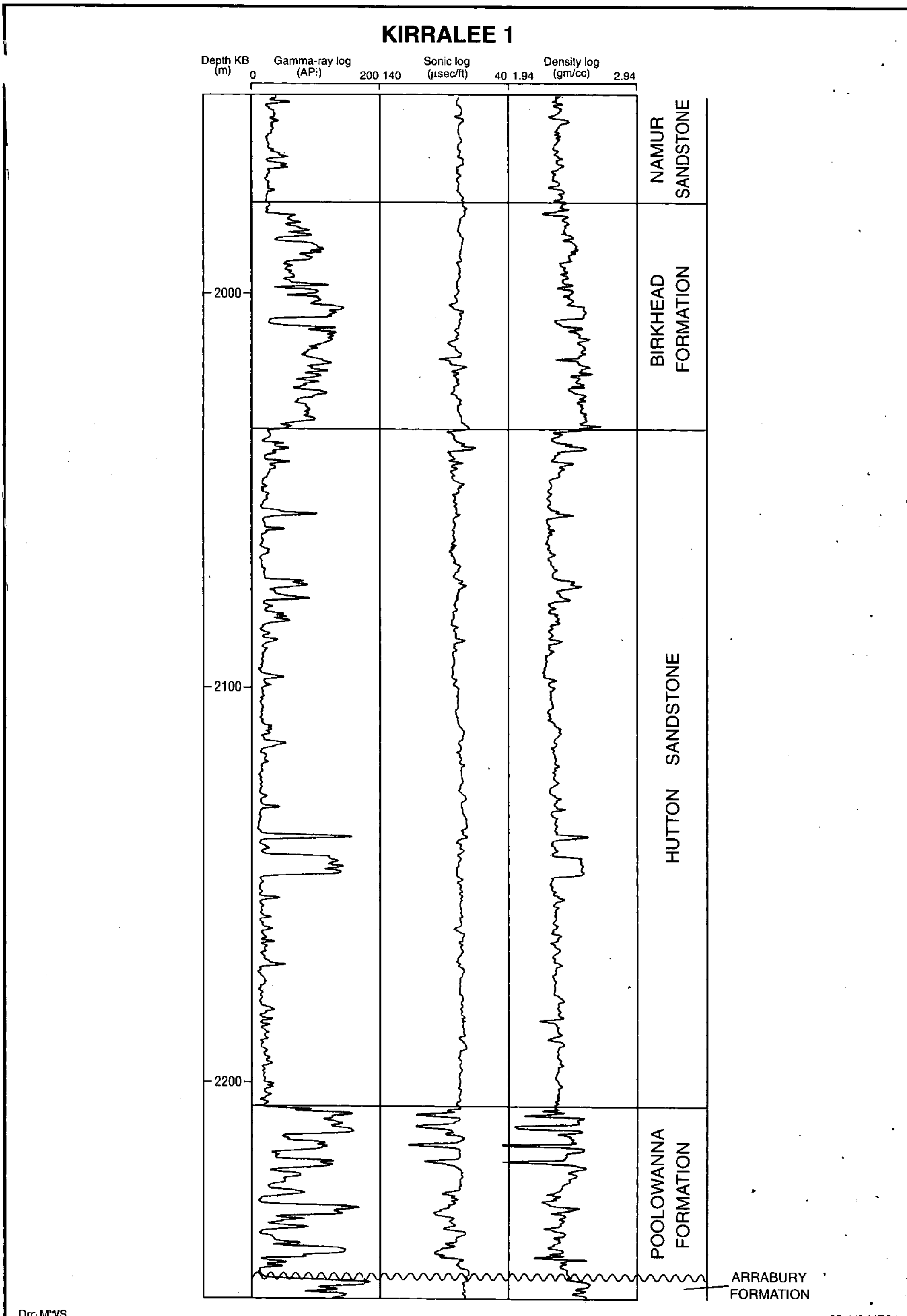


Fig. 1ε. Composite log of Poolowanna Formation to Birkhead Formation, Kirralee 1.

garded as intra-Namur siltstones rather than as Westbourne Formation. The type section is the interval 1 436.22-1 643.48 m KB in Delhi Strzelecki 4, South Australia (latitude 28°14'1.16"S, longitude 140°38'30.49"E).

Namur Sandstone consists of white to pale grey, flat and cross-bedded, fine to coarse-grained quartzose sandstone with minor siltstone and mudstone interbeds. Channel lag conglomerates consist of lithic and quartz pebbles, carbonaceous mudstone intraclasts and carbonised plant fragments. In some wells on STRZELECKI, basal Namur sands have been strongly cemented with calcite (Schulz-Rojahn, 1993; Townsend, 1993). Lithology and sedimentary structures suggest a braided fluvial environment of deposition.

Namur Sandstone ranges from Late Jurassic to Early Cretaceous in age (Price *et al.*, 1985).

Murta Formation (revised name)

Nugent (1969) defined the Murta Member as a lacustrine facies of the Mooga Formation. It is elevated herein to Murta Formation, and the informal 'McKinlay Member' of the Mooga Formation (Mount, 1982) becomes a formal member of the Murta Formation.

The Murta Formation is the lacustrine siltstone with interbedded sandstone which overlies Namur Sandstone and is overlain by the Cadna-owie Formation. The base of the formation is taken as the base of the first thick siltstone above the Namur Sandstone (Fig. 15), and the top is placed at the first significant decrease in gamma-ray log response, or at the top of the uppermost associated carbonate layer (e.g. Dullingari 9, Ambrose *et al.*, 1986, fig. 3). The type section lies over the interval 1 469.14-1 526.13 m KB in Delhi Dullingari North 1, South Australia (latitude 28°04'35.90" S, longitude 140°51'47.51"E) as defined by Mount (1981).

The Murta Formation is characterised by dark grey, argillaceous and carbonaceous siltstone, interbedded with fine to very fine-grained sandstone, diagenetic siderite, and calcite nodules and layers. The basal dark grey siltstone often contains several relatively thick (up to 1 m) well-sorted medium-grained sandstone interbeds. The succession continues with dark grey siltstone with minor sandstone interbeds which grades upwards into the Cadna-owie Formation. Rusty brown siderite-cemented siltstone and sandstone layers occur throughout, producing distinctive spikes on sonic and density logs.

Murta Formation siltstone ranges from laminated to massive, with thin (cm scale) sharp-based interbeds of ripple-laminated sandstone.

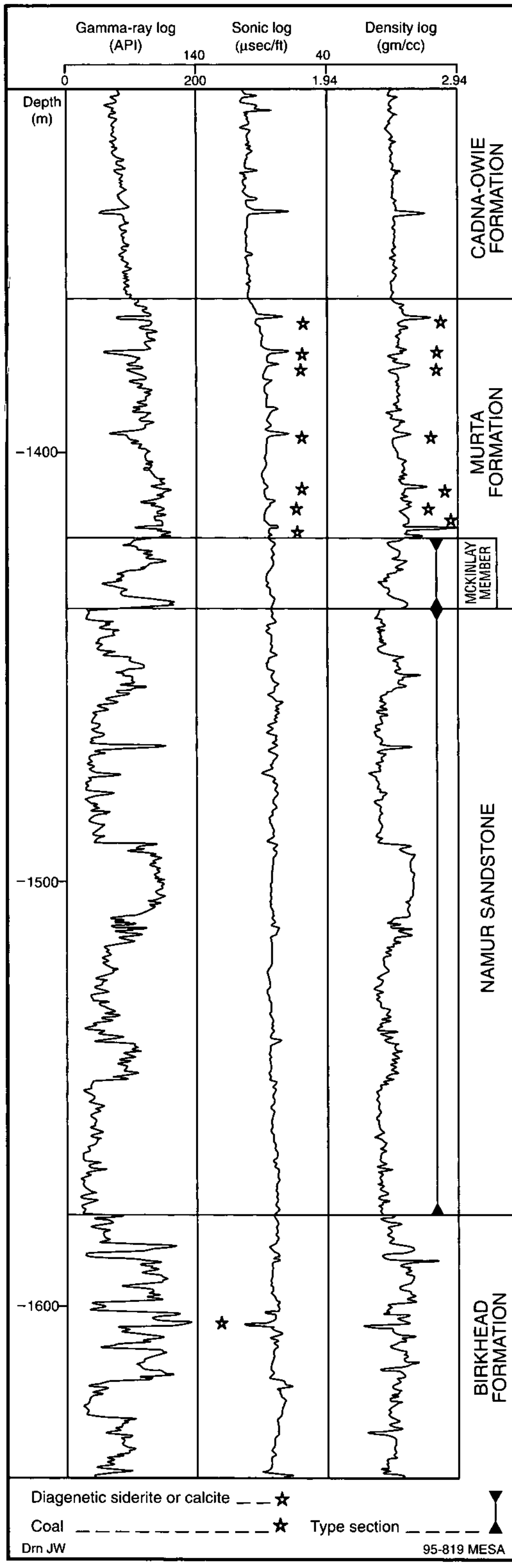


Fig. 15 Composite log of Namur Sandstone to Murta Formation, Strzelecki 4.

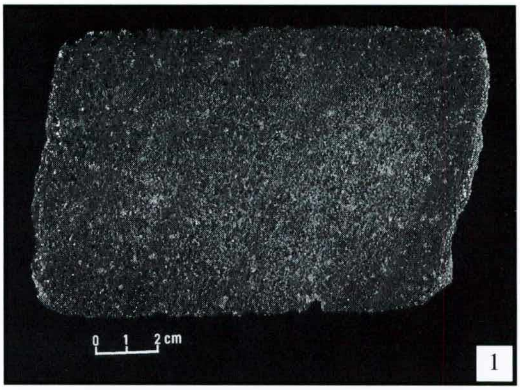
Siltstone intraclasts often occur at the base of the sandstone interbeds. The lower and middle parts of the formation have been disrupted by slumping, microfaulting and water-escape activity, suggesting rapid deposition on a slope in a lacustrine setting. There is no evidence of marine influence. Thicker lenticular fine to medium-grained sandstone interbeds are bioturbated, massive to thickly bedded, and have been interpreted as beach sands and/or offshore bars (e.g. Mount, 1982; Ambrose *et al.*, 1986).

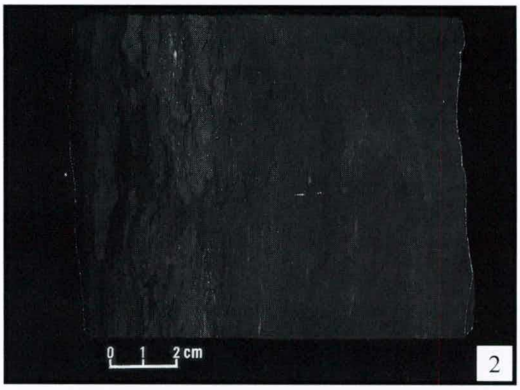
The Murta Formation is Early Cretaceous (Neocomian) in age, from spore-pollen determination (Fig. 8).

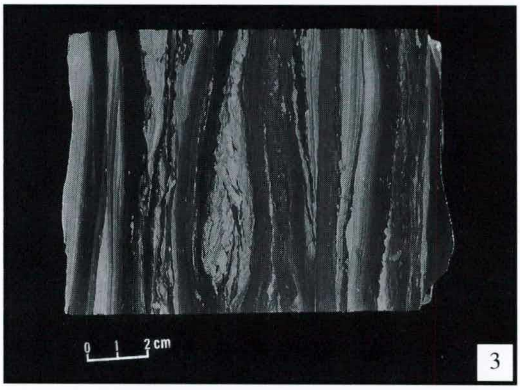
McKinlay Member (revised named)

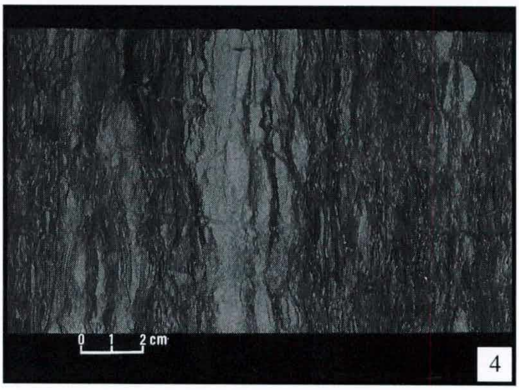
Mount (1982) first published the name 'McKinlay Member' of the Mooga Formation without definition. The unit is defined here as a basal member of the Murta Formation. McKinlay Member was named after Delhi McKinlay 1 petroleum exploration well, which recorded the first oil flow from the unit in 1981. The McKinlay Member is the interbedded siltstone and sandstone unit that overlies the top of the youngest significant clean sandstone of the Namur Sandstone, and is overlain by Murta Formation siltstone. The type section is defined as the fully cored interval 1 420.26-1 436.22 m KB in Delhi Strzelecki 4, South Australia (latitude 28°14'1.16"S, longitude 140°38'30.49"E). Martin's (1983) N3 and N4 units from Strzelecki 4, previously assigned to the Namur Sandstone, are reassigned to the McKinlay Member. Where the unit member is absent (e.g. Namur 2), Namur Sandstone is overlain sharply by mudstone of the Murta Formation.

It consists of buff very fine to medium-grained sandstone interbedded with dark grey carbonaceous and micaceous siltstone. The sandstone is flat to ripple cross-bedded, and is characteristically disrupted by intense bioturbation. Siltstone interbeds range from undisturbed well laminated to intensely bioturbated. Carbonised









1. Medium to coarse-grained, porous Hutton Sandstone showing cross-stratification and reverse graded bedding (Gidgealpa 17, core 3, 1 848.6 m KB). Width of view is 80 mm; top is to right. Photo 42464.
2. Carbonaceous siltstone with irregular thin bedding in the Birkhead Formation (Wancoocha 4, core 1, 1 564.5 m KB). Top is to right. Photo 42465.
3. Fine-grained lacustrine turbidites with microfaulting and bioturbation in the Murta Formation (Limestone Creek 3, 1 206.7 m KB). Width of view is 97 mm; top is to right. Photo 42466.
4. Heavily bioturbated micaceous and carbonaceous shoreface sandstone in the McKinley Member (Strzelecki 4, core 1, 1 423 m KB). Top is to right. Photo 42467.

plant rootlets occur in very fine sandstone and siltstone interbeds. A lacustrine shoreface environment, transitional between Namur braided fluvial and Murta lacustrine environments, is indicated by the intense bioturbation and other sedimentary structures. The McKinlay Member is Early Cretaceous (Neocomian) in age.

Algebuckina Sandstone

The Algebuckina Sandstone was formally defined from thin and incomplete exposures on the southwestern margin of the Eromanga Basin by Wopfner *et al.* (1970). Nugent (1969) assigned lateral equivalents as Hutton Sandstone, Birkhead Formation, Adori Sandstone, Westbourne Formation and Mooga Formation (now Namur Sandstone and Murta Formations). The tonguing out of shaly units marks a passage from Hutton and Namur Sandstones into Algebuckina Sandstone on southwestern and southeastern STRZELECKI (see map, Fig. M10).

The Algebuckina Sandstone consists of white, medium to coarse-grained, flat to cross-bedded, quartzose and pebbly sandstone. Moore (1986) interpreted a braided fluvial environment of deposition, however Wiltshire (1989) interpreted environments ranging from mixed aeolian and receding scarp fluvial sedimentation to a quartz sand-dominated shallow lacustrine system.

Algebuckina Sandstone disconformably overlies units of the Cooper and Warburton Basins, and Proterozoic rocks on STRZELECKI. It is conformably overlain by the Cadna-owie or Murta Formations. Algebuckina Sandstone ranges in age from Early Jurassic to Early Cretaceous (Fig. 8).

Cadna-owie Formation

The Cadna-owie Formation was originally named 'Transition Beds' by Whitehouse (1955), and the name Cadna-owie Formation was first used by Wopfner *et al.* (1970).

The unit coarsens upwards from grey siltstone to fine to medium-grained sandstone (Moore and Pitt, 1985). Sandstone interbeds are commonly calcite cemented. The basal siltstone was deposited in a lacustrine environment and the overlying sandstones were deposited in shoreline and coastal plain environments.

The Cadna-owie Formation is Early Cretaceous (Neocomian-Aptian) in age (Fig. 8) and is uniformly distributed over STRZELECKI, conformably overlying Murta Formation. Cadna-owie Formation is conformably overlain by Bulldog Shale or Wallumbilla Formation. The top of the Cadna-owie is approximated by the 'C' seismic horizon, mappable over the entire Eromanga Basin.

Figure M7 illustrates the depth-structure top of the Cadna-owie Formation, based on well information.

Marree Subgroup

Marree Formation was elevated to Marree Subgroup by Thomson (1980) and then used by Forbes (1986), and includes Bulldog Shale, Coorikiana Sandstone and Oodnadatta Formation, all of which occur in the subsurface on STRZELECKI. Where Coorikiana Sandstone is absent, as on the southern half of STRZELECKI (Fig. 16), the term Marree Subgroup is applied to the shaly sequence following the recommendation of Forbes (1986).

Bulldog Shale

Freytag (1966) defined the Bulldog Shale from outcrop on the eastern side of the Peake and Denison Ranges. On STRZELECKI, the unit consists of dark grey shale with carbonate concretions. The base of the unit consists of a distinctive organic-rich shale facies (Moore and Pitt, 1982).

The Bulldog Shale conformably overlies Cadna-owie Formation on STRZELECKI, and is conformably overlain by Coorikiana Sandstone. It passes laterally into lithologically indistinguishable Wallumbilla Formation where Coorikiana Sandstone is absent and Toolebuc Formation is present (Fig. 16). Moore and Pitt (1982) and Moore *et al.* (1986) clarified the stratigraphic relationship between Bulldog Shale-Coorikiana Sandstone and Toolebuc-Wallumbilla Formations successions.

A variety of marine vertebrate and invertebrate fossils has been described from outcrop. However, cuttings from STRZELECKI are unsuitable for recovery of intact macrofossils for age determination because of the rapid drilling rate through the Early Cretaceous sequence and cavings contamination (Gravestock, 1982). Subsurface age determinations have been based on spore-pollen and dinoflagellate assemblages, and give an Early Cretaceous (Aptian to Albian) age (Figs 7, 8). A shallow marine shelf environment of deposition has been interpreted (Moore and Pitt, 1985), in response to an early Aptian high sea level stand.

Coorikiana Sandstone

The Coorikiana Sandstone was defined as a member of the Oodnadatta Formation from outcrop on the Eromanga Basin margin (Freytag, 1966). Moore and Pitt (1982) extended the unit into the subsurface in the Eromanga Basin and elevated the unit to formation status.

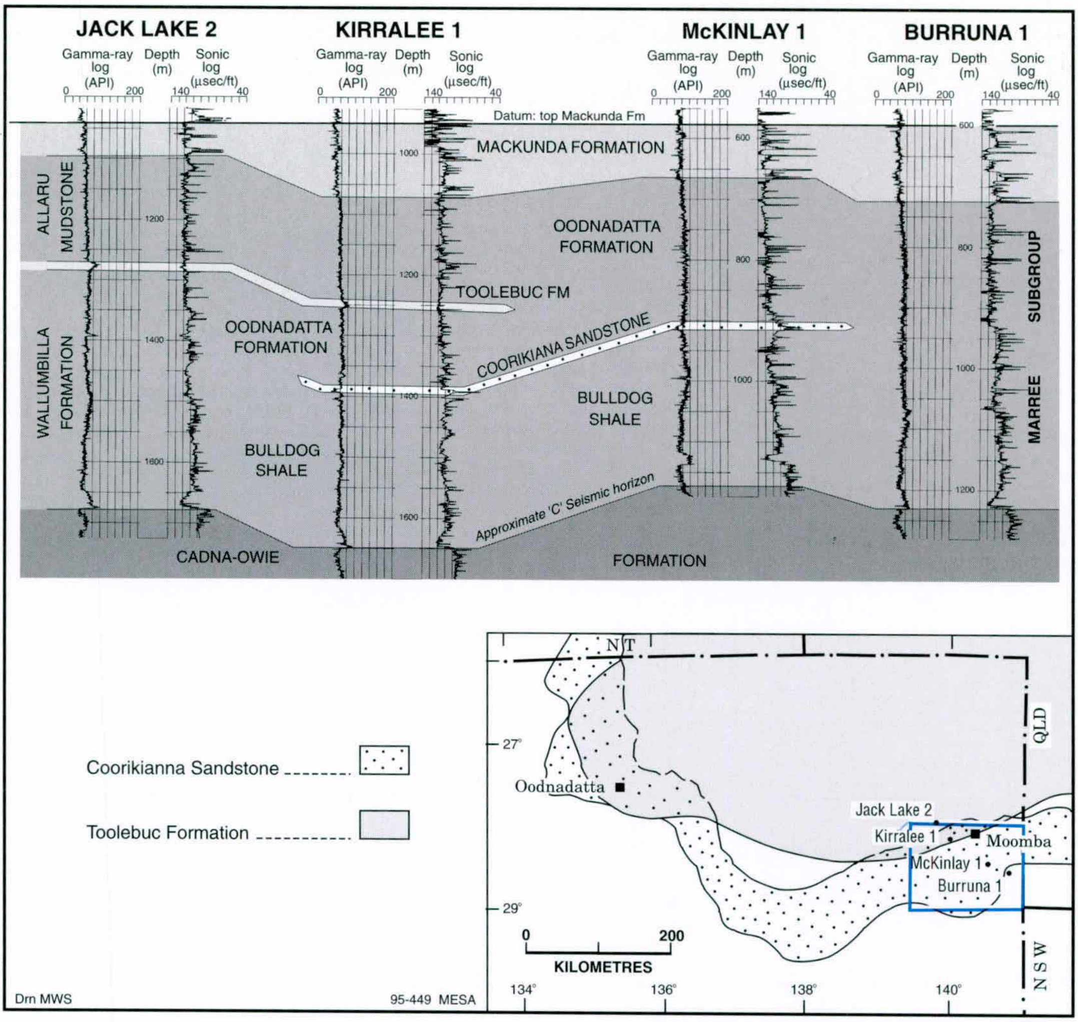


Fig. 16 Cross-section of the sequence between Cadna-owie Formation and Mackunda Formation.

Coorikiana Sandstone consists of an upward-coarsening succession of greenish white to grey, glauconitic, bioturbated, fine to very fine-grained sandstone and sandy siltstone with minor siltstone interbeds (Moore and Pitt, 1985). It conformably overlies the Bulldog Shale and is conformably overlain by the Oodnadatta Formation (Fig. 16).

Coorikiana Sandstone was deposited as an east-west orientated shoreface to open marine sand in response to a eustatic fall in sea level (Morgan, 1980). Both southern and northern limits occur on STRZELECKI (Fig. 17). The southern limit marks a passage into Marree Subgroup. Beyond the northern limit, Bulldog Shale is replaced by Wallumbilla Formation (Fig. 16).

The Coorikiana Sandstone is Early Cretaceous (Aptian) in age (Price *et al.*, 1985).

Oodnadatta Formation

Freytag (1966) and Freytag *et al.* (1967) defined the Oodnadatta Formation from outcrop on the Eromanga Basin margin on OODNADATTA. It consists of a lower unit of calcareous siltstone with calcareous concretions, overlain by dark grey mudstone and siltstone with fine-grained glauconitic and feldspathic sandstone interbeds. A low energy, shallow marine environment of deposition is interpreted (Morgan, 1980). The Oodnadatta Formation is of Early Cretaceous (Albian) age, based on spore-pollen assemblages (Figs 7, 8). Oodnadatta Formation is lithologically similar to the laterally equivalent Allaru Mudstone, and its distribution corresponds to that of the conformably underlying Coorikiana Sandstone (Fig. 16). It is in turn conformably overlain by the Mackunda Formation.

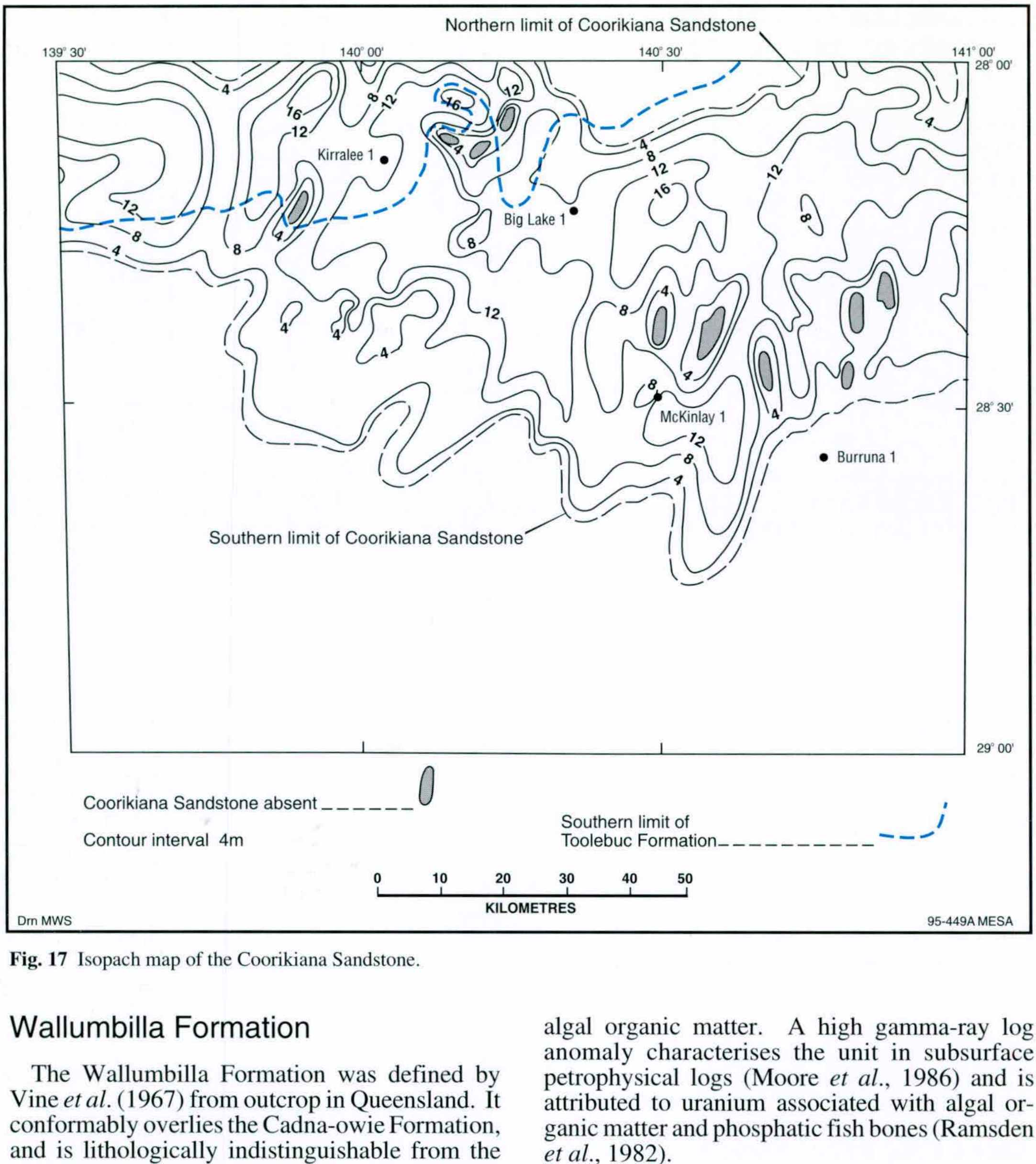


Fig. 17 Isopach map of the Coorikiana Sandstone.

Wallumbilla Formation

The Wallumbilla Formation was defined by Vine *et al.* (1967) from outcrop in Queensland. It conformably overlies the Cadna-owie Formation, and is lithologically indistinguishable from the laterally equivalent Bulldog Shale. However, its distribution is restricted by the extent of the overlying Toolebuc Formation (Moore and Pitt, 1985), and is limited to the northern part of STRZELECKI (Fig. 17). A shallow marine shelf environment of deposition is inferred. An Early Cretaceous (Aptian to Albian) age has been assigned to the formation.

Toolebuc Formation

The Toolebuc Formation was formally defined in Queensland by Senior *et al.* (1975). On STRZELECKI, the unit consists of dark grey to black calcareous siltstone and mudstone, rich in algal organic matter. A high gamma-ray log anomaly characterises the unit in subsurface petrophysical logs (Moore *et al.*, 1986) and is attributed to uranium associated with algal organic matter and phosphatic fish bones (Ramsden *et al.*, 1982).

The Toolebuc Formation conformably overlies Wallumbilla Formation and is in turn overlain by Allaru Mudstone. The formation is restricted to northern and western STRZELECKI (Fig. 16). A restricted, stratified, offshore marine environment with slow rates of deposition has been suggested for the formation (Moore *et al.*, 1986; Sherwood and Cook, 1986). Its age is Early Cretaceous (Albian).

Allaru Mudstone

Allaru Mudstone (Vine *et al.*, 1967) consists of grey mudstone with thin calcareous siltstone and very fine-grained sandstone interbeds. Allaru

Mudstone is laterally equivalent to the middle and upper parts of the Oodnadatta Formation, and the name is used only when Toolebuc Formation is present (Fig. 16). Contacts between the Allaru Mudstone and units above and below are conformable. A shallow, quiet water, marine environment has been interpreted (Moore and Pitt, 1985). It is Albian in age based on spore-pollen assemblages.

Mackunda Formation

Mackunda Formation (Vine and Day, 1965) consists of pale grey-green interbedded glauconitic, cross-bedded sandstone, siltstone, shale and calcareous shale. Sand development is erratic (Moore and Pitt, 1985). Mackunda Formation conformably overlies both Allaru Mudstone and Oodnadatta Formation, and is conformably overlain by Winton Formation. A marginal-marine to paralic environment of deposition is interpreted to be a response to a late Albian basin-wide regression (Moore and Pitt, 1985). Determinations of the spore-pollen assemblage indicate an Early Cretaceous (Albian) age (Fig. 8).

Winton Formation

The Winton Formation (Whitehouse, 1955) consists of dark grey, carbonaceous and pyritic mudstone interbedded with pale grey, fine-grained, calcareous sandstone and coal seams. The formation conformably overlies the Mackunda Formation. It is the uppermost Eromanga Basin unit known on STRZELECKI, and is disconformably overlain by Tertiary Eyre Formation. Erosion occurred during Tertiary uplift on STRZELECKI. Winton Formation is distinguished by its khaki colour in contrast to the black, grey and brown of the Eyre Formation. A non-marine, meandering fluvial to paludal environment of deposition is interpreted.

Structure on the Winton Formation top is depicted on map Figure M5. The formation is of Early to Late Cretaceous age, derived from spores and pollen (Fig. 8).

TERTIARY — CALLABONNA SUB-BASIN OF THE LAKE EYRE BASIN

R.A. Callen

Tertiary units are distributed across the whole of STRZELECKI and comprise part of the Lake Eyre Basin; they were formerly contiguous across the Birdsville Track Ridge with equivalent sediments in the Lake Eyre and Simpson Desert region (Tirari Sub-basin). The Callabonna Sub-basin (Drexel and Preiss, in prep.) refers to the Cainozoic Basin east of the Birdsville Track Ridge (manifested in large surface anticlines of the Gason and Kopperamanna Domes), and includes the Lake Frome area and Strzelecki Desert. It was formerly variously referred to as the Frome Embayment (modern usage restricts this to the Mesozoic basin), and Tarkarooloo Basin.

The stratigraphic nomenclature is the same as that on FROME (Callen, 1981) and CURNAMONA (Callen, 1990), and lithologies are very similar.

The boundaries between the units exhibit characteristic excursions and peaks on gamma-ray logs. When combined with cuttings, these logs provide a reasonable estimate of Cainozoic Formation tops. These isopachs and structure contours are depicted on the back of the map (Figs M1, M2, M3, M4) and on Figures 18 and 19.

The regional stratigraphy and sedimentology of the northeastern desert area of South Australia has been summarised by Callen *in* Krieg *et al.* (1990) and presented in a series of environmental block diagrams (their figs. 10, 12-15, 17).

Eyre Formation

The Eyre Formation usually consists of well-washed, mature, moderately sorted sand with subrounded grains, often carbonaceous and pyritic, with interbeds of lignite. Grainsize is mostly fine to medium. The lower part is characterised by the presence of large, dark green-grey quartzose grains, which generally distinguish the unit from the late Cainozoic Yandruwantha Sand (new name) which is white or buff, and sands in the Namba Formation.

The supplementary section for the Eyre Formation is located at Moomba 4 (Wopfner *et al.*, 1974), the type section being on the edge of Innamincka Dome about 75 km northeast of Innamincka township.

The Eyre Formation does not crop out, but is present over all of STRZELECKI. Isopachs over the northern half of the map area demonstrate a 40-100 m thick blanket, reaching 160 m in the Wooloo and Allunga Troughs (Fig. M4). Thickness distribution closely reflects the structure map of the top of the Cretaceous Winton Formation (Fig. M5). The highs which developed during the Permian and Triassic continued to dominate the distribution of sediment in the Paleocene and Eocene, the Eyre Formation being thin over the crests. The Cretaceous structures in the vicinity of the oil and gas fields are clearly reflected in the Eyre Formation isopachs, and demonstrate that drilling and logging of the Tertiary may be sufficient to delineate Cretaceous oil and gas producing features. The Eyre Formation thickens to the southeast, where a corresponding thicker Mesozoic section may be expected.

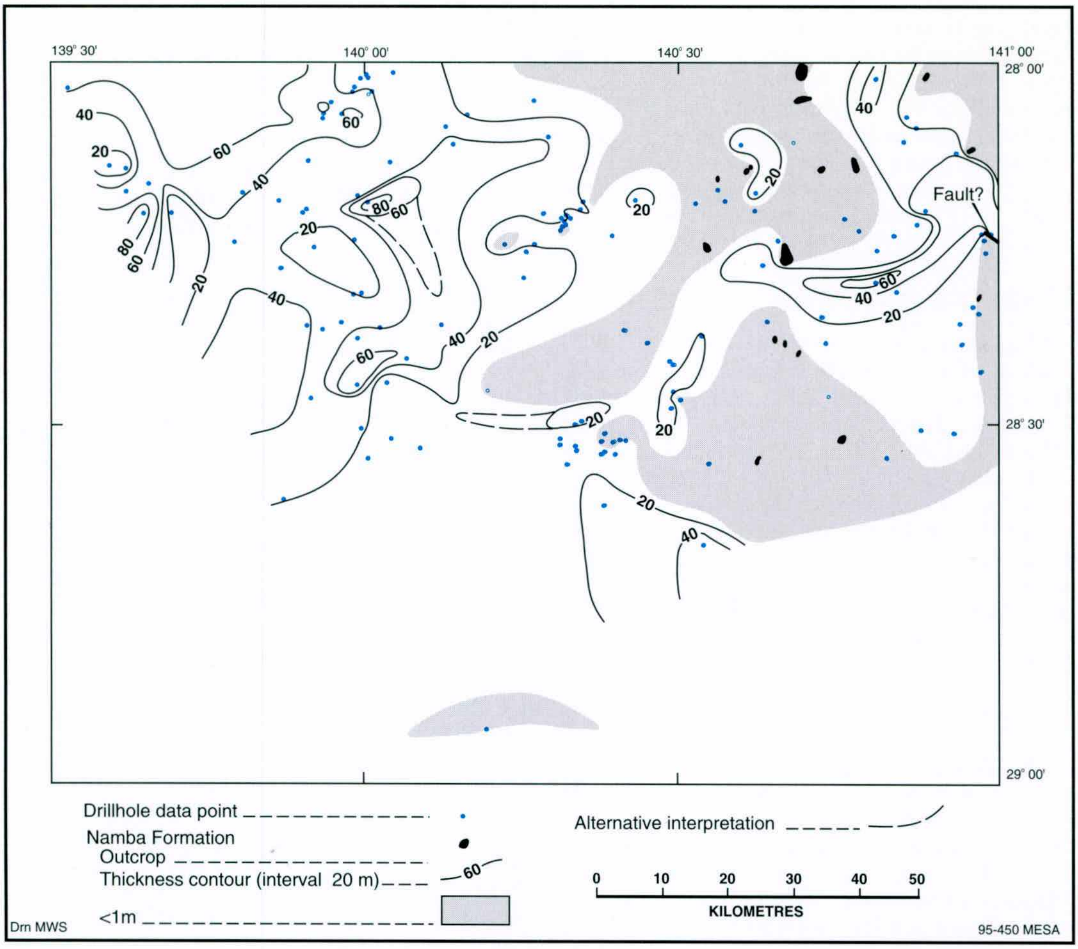


Fig. 18 Isopach map of Quaternary sediments.

Fossil wood is quite common, but the only microflora is from Moomba 4, where a broadly Tertiary age is recorded from the central lignitic unit, using species listed in Wopfner *et al.* (1974, p.29) and Townsend (1967).

In the vicinity of Three Queens well in the northeastern part of STRZELECKI, cuttings suggest that the Eyre Formation is absent, though gamma-ray logs record a unit like the Eyre Formation. It is also possible that this could be a sandy facies of the overlying Namba Formation, which would suggest the anticlinal structure shown immediately to the north of latitude 28° on INNAMINCKA is the silicified top of the Namba Formation.

The unit was deposited by broad, shallow, braided rivers of the Platte type (Miall, 1985). Fines appear to have been swept out of the region into the Tirari Sub-basin. Abundant lignite and macerated plant matter suggest extensive vegetated areas. The climate was humid and probably warm to hot (Krieg *et al.*, 1990; Greenwood *et al.*, 1990), and is likely to have been strongly seasonal.

Silcrete 1

There is little evidence for the presence of extensive silicification at this time on STRZELECKI. The Eyre Formation is silicified in rare instances, in accord with observations in Callen (1983) and Callen (*in* Krieg *et al.*, 1990) for areas marginal to the Flinders Ranges and in the Tirari Desert. The silcrete comprises a hard, tough, grey, silicified sand.

Namba Formation

The Namba Formation lies disconformably on Eyre Formation and is overlain by Yandruwantha Sand. Lithology, similar to that of the southern Callabonna Sub-basin on FROME and CURNAMONA, is grey to olive clay with iron oxide mottling and interbedded white to yellow silt to

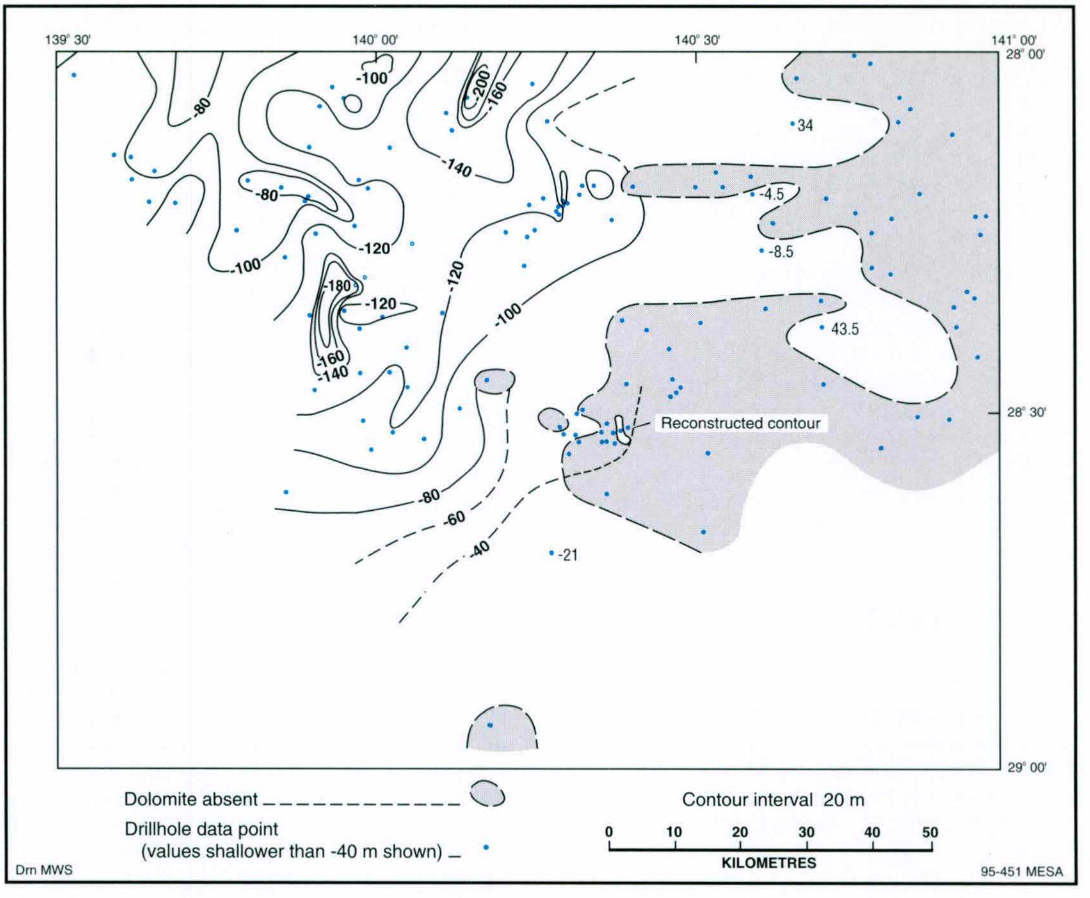


Fig. 19 Depth structure map on top dolomite of the Namba Formation.

coarse sand. Fine clayey and arenaceous clastics dominate. Some of the coarse channel sands near the top of the unit are identical in lithology to the overlying Yandruwantha Sand and the Eyre Formation. West of Strzelecki Creek, white very fine-graded dolomite, interbedded with bright-green to olive-grey palygorskite clay, is present near the base, forming 50-70% of the sediment over interbeds from 10 to 40 m thick.

The Namba Formation crops out or is extensively present as float in interdune corridors only to the east of Strzelecki Creek, and is generally recognised by grey, clayey silt and fine sand with ochre mottles and minor silicification. The top of the unit is almost planar and slopes to the west from 80 m above sea level down to 60 m below sea level in the northwestern corner of STRZELECKI. Figure 19 shows structure contours on the top of the dolomite beds at the base of the Namba Formation, demonstrating that they are largely restricted to west of the north-south hinge zone (stippled area on the Tectonic Sketch).

Little or no palaeontological information is available, the unit being identified by lithological correlation and continuity with similar sediments to the south (Callen, 1977, 1981, 1990). Martin (1990) examined palynofloras in Wooltana 1 on FROME and established a latest Oligocene age for the lower part of the unit, and Late Miocene to Pliocene age for upper beds. These observations probably also apply to STRZELECKI.

The environments were firstly alkaline lakes, followed by fluvial and swamp sedimentation. Relief was low in the hinterlands, and water flow relatively sluggish compared with that of Eyre Formation times. Martin (1990) demonstrated that there are no grasslands in the area, contrary to reports by Callen and Tedford (1976).

These sediments are correlatives of similar sequences in the Lake Eyre Basin (Wells and Callen, 1986; Freytag *et al.*, 1967; Callen and Plane, 1985).

Silcrete 2

The upper surface of the Namba Formation is patchily silicified and very ferruginised, especially east of Strzelecki Creek, to a depth of up to 10 m; alunite and gypsum form white patches in the profile. Sandy beds and channels at the top of the Namba Formation are massively silicified with quartz overgrowth cement, and also ferruginised, and can closely resemble Eyre Formation. However, pedogenic features like those in the Billa Kalina Basin and Tirari Subbasin, and on CALLABONNA (Callen, 1983; Callen *in* Wells and Callen, 1986), have not been found.

Wopfner (1974) defined Cordillo Silcrete from the Innamincka Dome on eastern INNAMINCKA. The data from STRZELECKI suggest that this material could well be mainly late Tertiary, not Oligocene-Miocene as suggested by Wopfner. Logging of Tertiary cuttings from holes on INNAMINCKA did not contradict this interpretation.

The silcrete is brittle, ferruginous, silica-cemented sand and clay, usually of a dark brown, orange or grey colour.

LATE CAINOZOIC

R.A. Callen

Borrow pits and bores, and the occasional lakeside section, demonstrate the late Cainozoic cover east of Strzelecki Creek to be very thin, often represented only by aeolian material. In contrast, west of the creek the thickness increases to over 100 m.

The isopach map shows the thickness variations of the Quaternary and late Tertiary (post-Namba Formation) sediments for the northern half of STRZELECKI (Fig. 18). In the northwest, these sediments range from 20 to 60 m thick, most of which is the Millyera Formation and Yandruwantha Sand, described below. Younger alluvial deposits are restricted to former meander belts and channels. The southern alluvial units — Eurinilla and Willawortina Formations (e.g. on FROME and CURNAMONA) — were not recognised on STRZELECKI, but can probably be equated with the Yandruwantha Sand.

Yandruwantha Sand (new name)

The Yandruwantha Sand (Callen, 1992), which has a type section in Kirralee 1 (latitude 28°08'8.04"S, longitude 140°01'58.0"E) in the central northern part of STRZELECKI, consists of orange to white, fine to gravelly quartz sand with rather irregular angular grains. It is often poorly sorted, and contains white clayey sandstone grains; the orange and white sands often alternate. The presence of pebbly lenses, white sand, and a well-washed appearance are characteristic. The unit is known only from drillhole cuttings, has a massive gypsum cap, and is usually covered by younger alluvium. The following is a description from cuttings at 10 m intervals of the type section, from base upwards:

1. 36.58-45.72 m: *Sand* (85%), well rounded, polished, medium to very coarse grained. Remainder *clay*, grey, gypseous and greasy (probably Namba Formation).
2. 27.43-36.58 m: *Sand*, coarse to very coarse grained; grains rather irregular and angular.
3. 18.29-27.43 m: *As above*, coarse grained (20-30% orange and red grains); 5-10% white grains with white clay cement.
4. 9.14-18.29 m: *As above*, but finer grained.
5. 0-9.14 m: *Sand*, fine to medium grained, orange (10-15% orange and red coated grains); grains irregular shaped, angular to subangular, very well sorted.

In an excavation for a liquid storage tank at Moomba (no longer accessible), the unit consisted of 20 m of loose, white, rather poorly sorted sand with yellow iron-stained layers and clay lenses. At the base were lenses of coarse sand, with subrounded polished grains, cemented with calcite. Beds of horizontally and finely laminated olive-grey crumbly soft clay and very fine-grained sand alternate with yellow-brown sand with medium scale cross-bedding. Transport direction, in one well-exposed 1.5 m thick bed, was consistently southeast.

The Yandruwantha Sand is probably partly Kutjitara Formation equivalent and may include equivalents of the Katipiri Sand and Tirari Formation of the Tirari Desert area (Wells and Callen, 1986; Krieg *et al.*, 1990; Callen and Benbow, in prep.).

Hard, gypsified mottled clays with lenses of orange sand representing fluvial channels and flood plains were recorded on CALLABONNA and STRZELECKI in the flats beneath the dunes (Callen, 1982; Forbes and Krieg, 1982), and most probably belong to the alluvial spreads of the Yandruwantha Sand.

Wyatt and Whitaker (1979) recorded lacustrine limestone and dolomite overlying deposits similar to the Yandruwantha Sand in southwestern Queensland.

Nanson *et al.* (1988), using uranium series and thermoluminescence (TL) dating, investigated sediments similar to the Yandruwantha Sand associated with ancestral Cooper Creek channels at Longreach in the Queensland channel country. They demonstrated the presence of alluvial sediments representing at least the last two interglacials.

Millyera Formation and equivalents

This unit consists of green clay with alternating silt and very fine sand beds. It is unconsolidated and the clay mineral consists of randomly interstratified montmorillonite-illite sheets. The extent is probably much greater than appears from the sparse outcrop, the most notable of which is at the small salt lake located 14 km southwest of Padulla 1. Its presence suggests some significant areas of lacustrine sedimentation on STRZELECKI sometime during the Pleistocene (cf. Callen, 1984). A massive gypsum crust commonly caps these deposits. No beach facies equivalent to the Coomb Spring Formation of FROME and CURNAMONA has been identified, though some of the Yandruwantha Sand may be in this category.

The Millyera Formation is disconformable on Willawortina Formation in Lake Frome and Lake Callabonna, but relationships are not seen on STRZELECKI.

Younger alluvium

Radiocarbon and TL dates obtained by Wasson (1984) and Gardner *et al.* (1987) from near Moomba, and Nanson *et al.* (1988) from the channel country of Queensland, indicate that alluvium around 40-30 ka is present.

Gardner *et al.* (1987) recorded younger alluvial sediment around 22-12 ka near Moomba, including a clay veneer likewise detected by Nanson *et al.* (1988). These sediments are presently mapped with the Yandruwantha Sand.

The Tingana Clay (Firman, 1970) is the sticky grey clay recorded along the banks of Strzelecki Creek. No suitable type section has been located, as outcrop patterns change each time Strzelecki Creek floods. This is believed to be the same unit as the laminated grey sandy clay exposed in a scour on Strzelecki Creek near Pelketa Waterhole, dated at *c*.4.3 ka (GS790, 741; Leaney, 1989) from charcoal associated with Aboriginal hearths.

Aeolian sediments — Coonarbine Formation

The Coonarbine Formation (Callen, 1981) consists of fine-grained, rather poorly sorted subangular to subrounded sand in longitudinal or transverse dunes and sand sheets. The formation is similar in occurrence to its type area on FROME but calcareous palaeosols are not so well developed and clay pellets are a more common constituent (Wasson, 1982). The distribution and type of dunes is discussed in the landform section following. Longitudinal dunes are often younger than transverse dunes, and can be seen to pass over them or to transgress over old claypans.

The unit intertongues with alluvial sediments of Strzelecki Creek (Callen, 1982). West of the creek, dunes are very active, and corridors contain low transverse and crescentic dunes. Dune traces can be seen on the beds of some claypans, and some dunes are being eroded around their edges by floods, whereas others are in the process of being buried (Krieg and Callen, 1990).

Transverse compound lunette dunes associated with lakes and pans are similar to those discussed by Lees and Cook (1991), who gave an excellent description of their derivation.

Gypsum crusts

Gypcrete and diffuse gypsum patches and nodules are common in the Quaternary and sometimes occur as a cap on the Namba Formation. Uranium series dating of these horizons (Callen and Short, in prep.) produced a variety of dates ranging from around 29 000 years BP to modern. Most were Holocene. Older dates were obtained from massive caps at the tops of profiles, younger ones are from lower in these profiles and are derived from selenite or nodules veined with younger fibrous gypsum. They confirm the mobility of gypsum, and the solution and redeposition of older gypsum to form younger material even under today's desert conditions. A 5-4 ka phase of crystallisation, associated with celestite, is recorded (Callen and Kennedy, 1993).

Landforms

STRZELECKI is dominated by two geomorphological features: the dunefield, and the Strzelecki watercourse and associated floodouts.

The dunefields

The dunes east of Strzelecki Creek are dark red, bifurcate at frequent intervals, and have swales with indurated Tertiary sediment outcrop or float, often with strong red haematite staining and ochre patches. The presence of shallow indurated rock affects the type of dunes by restricting sand supply, and hence the shape of the claypans which lie between them.

West of the creek, dunes are yellow, claypans are comparatively scarce, and transverse low dunes are a common feature; swales are sandy. A thick, pale, fluvial sand source, post-dating the Namba Formation (including Yandruwantha Sand), underlies this area. The dunes often transgress old claypans and watercourses.

The colour of iron oxides on the sand grains is derived from remobilisation of Fe ions in groundwater. The groundwater leaches this iron from the iron-rich substrate (Wasson, 1982; Callen and Farrand, 1990; Wright *et al.*, 1990), producing the red colour for the eastern dunes, where ferruginised Tertiary sediments are close to the surface. Floodouts associated with Strzelecki Creek supply clay pellets to the dunes in the northern areas, contributing to the pale colour west of the creek.

Most of the dunes are longitudinal, with tuning fork junctions pointing downwind, but there are many exceptions in the eastern dunes. Many dunes here are sinuous, and may join to form multicrested longitudinal dunes. Rarely, dunes appear to override or pass through one another. Wasson *et al.* (1988) described the dune types and spacing in more detail. West of Strzelecki Creek, broad sand ribbons and small transverse dunes are common in the swales, probably reflecting the greater sand supply in this region.

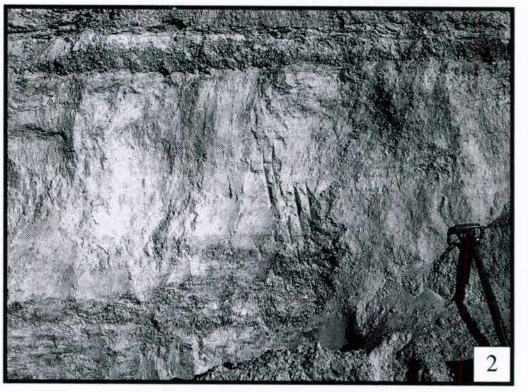
The dunes date back to before the last interglacial but the ages are variable (Callen and Nanson, 1990).

The Creek floodouts

Strzelecki Creek flows parallel to regional topographic contours, deviating slightly to the west over the Murteree Ridge, and is unrelated to the distribution of Quaternary alluvial sediments beneath the dunes, recorded by isopach mapping. Its location is controlled by two factors — the dunes, which run north-south and prevent the westerly flow of water, and the slightly higher land to the east, which has been a positive area throughout the entire geological history of the region. Strzelecki Creek was a distributary on a large, very low-angle fan of Cooper Creek which debouches from the tablelands near Innamincka (105 km northeast of Moomba). It now collects water draining off the southern half of the fan, carrying it to Lake Blanche on CALLABONNA.

Thus, Strzelecki Creek is a comparatively recent feature which has developed in conjunction with the dunes. Its course could change markedly with small changes in local topography (Callen and Bradford, 1992).

1



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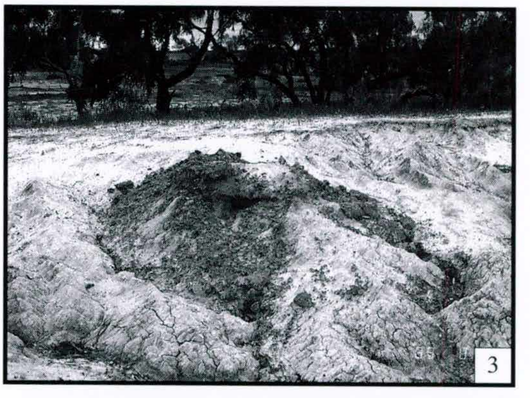

3

4

1. Massively silicified coarse sand from the Namba Formation, which was by used by Aborigines for making grindstones. Photo 42581.

2. Yandruwantha Sand, with a thin overlay of Holocene alluvium, exposed in a borrow pit. Photo 42582.

3. Tingana Clay exposed in a scour in Strzelecki Creek near Pelketa Waterhole. The unit contains charcoal, associated with Aboriginal hearths, that has been dated at *c*.4300 years BP. Photo 42583.

4. Clay-pellet rich quartz sand, forming a longitudinal dune, exposed in a borrow pit near Moomba. Photo 42584.

Meander traces in the Tingana Clay have been mapped from aerial photos and either follow Strzelecki Creek floodouts, or similar parallel watercourses to the west. These meander traces are mostly unrelated to the distribution of Quaternary sediments indicated by isopachs, which are strongly influenced by the Yandruwantha Sand. Other meander traces are developed on the cemented Tertiary sediments east of Strzelecki Creek. Most of these are Quaternary features cut into the Tertiary, but few are of Tertiary age. Distinguishing the two on aerial photographs was not possible, though they can be separated in the field from the presence of silicification and ferruginisation in the older units.

The relative age of a series of parallel meander belts west of Strzelecki Creek is unknown. They may have been active simultaneously, or they might become younger from west to east as the dunefield spread. The regional slope of the land is to the west, hence one might expect the western channels to have been active first.

A series of high transverse leeside dunes, which probably formed during the last glacial, have helped to block southerly drainage. These developed on the northern margin of a zone of active sedimentation and ponding of floodwaters on the Cooper Creek fan.

The claypans within the dunefield, particularly west of Strzelecki Creek, are often remnants of larger flood pans like those in the northern part of STRZELECKI. Subsequent dune activity has overridden these. The large pans are the result of ponding of water around the margin of the Cooper Creek fan (Callen and Bradford, 1992) as a result of longitudinal dune growth to the north. As soon as pans begin to form, transverse dunes develop on the downwind margin, thus further interfering with the free flow of water during flooding. The system is similar to the Coongie Lakes region to the north (Krieg and Callen, 1990). Those lakes which fill frequently have developed saline crusts.

The claypan patterns and alignment in South Australian dunefields have been discussed by several workers (Krieg *et al.*, 1990 and references therein). Callen and Benbow (*in* Drexel and Preiss, in prep.) have suggested that these parallel chains of pans reflect underlying late Cainozoic lacustrine beach ridges. Stevens (1991) examined the evidence for part of the Strzelecki Desert in New South Wales and suggested transverse aeolian erosion is the cause of pan alignment. This hypothesis is accepted for at least some of these features, but not where the Namba Formation subcrops between the dunes.

CAINOZOIC TECTONICS

R.A. Callen

The structure contour and isopach maps (Figs 18, M1-M4) for the Cainozoic were prepared from much more unevenly spread data than those for the Palaeozoic and Mesozoic hydrocarbon-bearing sequence. This is indicated by the drillholes, which sampled the sediments in sufficient detail for the regional geological picture to emerge from purely Cainozoic sources. This can be demonstrated from the consistency of information derived from cuttings and supplemented by gamma-ray logs, and the close correspondence with independently derived structural conclusions from the older rocks. Wopfner *et al.* (1974) also drew attention to the correspondence between Permian Cooper Basin structures and those of the Eyre Formation.

Closures around the different oil and gas fields are evident, with Limestone Creek and Big Lake showing up particularly well. This is due largely to the extra density of data here, and suggests that Cainozoic data could be sufficient for delineating oil and gas-bearing structures in the Mesozoic.

Cainozoic tectonism reflects the interplay of ancient northerly trends perhaps associated with the Benagerie Ridge (via Tinga-Tingana Ridge and hinge zone; see Tectonic Sketch) and the northwest-southeast trends including the Koonenberry Lineament which can be projected onto STRZELECKI from the Wonominta block in western New South Wales, from a study of the Z-horizon, Phanerozoic sediments and the gravity contours (see map). The Koonenberry Lineament does not play the significant role that it did during the earlier Phanerozoic. There is a distinct difference in tectonic trends and behaviour between regions to the west and east of Strzelecki Creek, related to the north-south hinge zone. This can be clearly seen on the Eyre Formation and Namba Formation structure contour (stippled area on Tectonic Sketch) maps (Figs M1, M3).

The change in stress fields, which caused the change in tectonic style from early to late Tertiary, took place largely during the Middle Eocene and probably Late Eocene to Oligocene. They may have been induced by redistributed stress fields originating from tectonic plate movements, but this seems unlikely in view of the location of STRZELECKI in the centre of the Australian plate. Boucher (1991) suggested that lineament tectonics may be a better explanation. Tectonics in the Tertiary are certainly controlled by ancient trends. These tectonic features are depicted on Figures 20 and 21 and are best examined in conjunction with the tectonic sketch on the map.

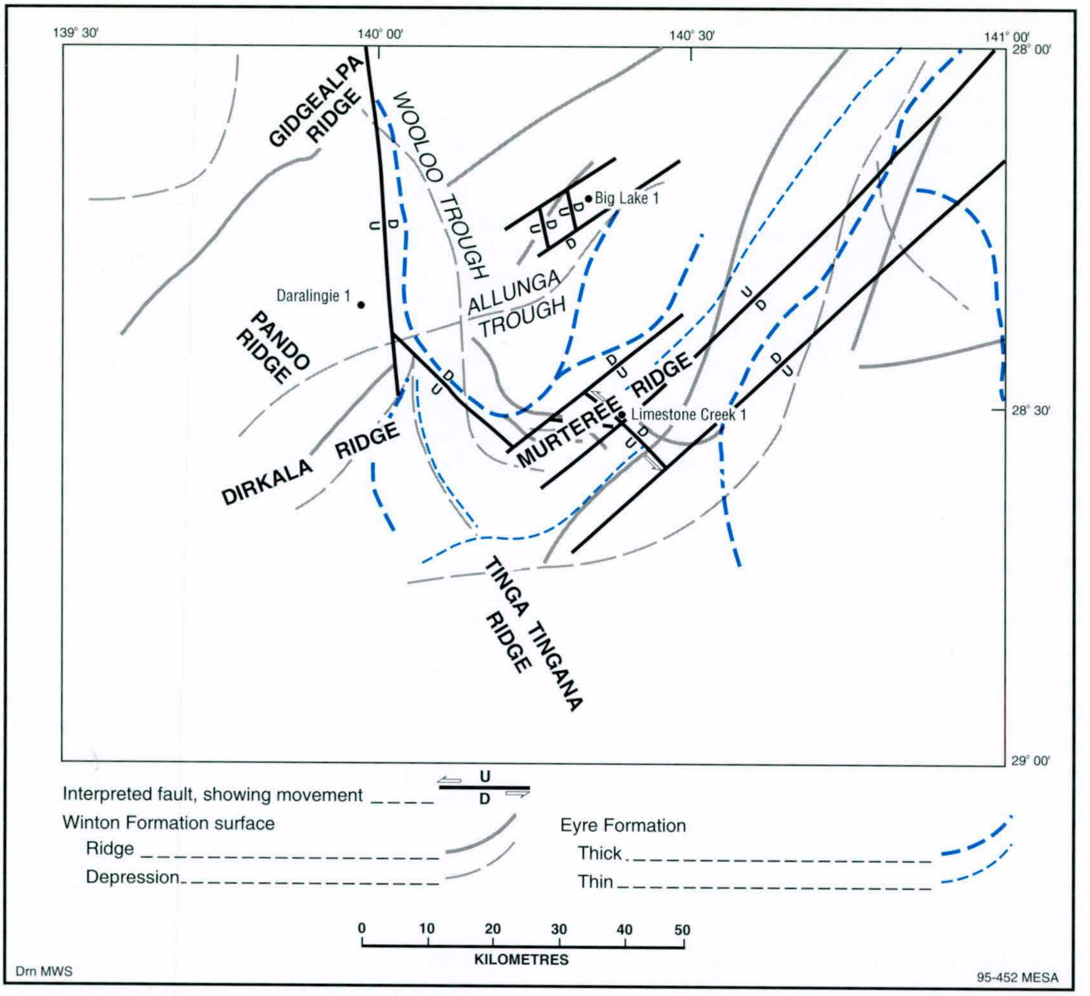

Fig. 20 Elements of early Tertiary tectonics.

Kuang (1985) interpreted tectonics in the area in terms of a modified strain ellipsoid, and attempted to model fault directions and movements. His investigations agree with results from the Cainozoic suggesting northeasterly trending faults controlling the Big Lake and Limestone Creek fields, and possibly the Daralingie Field (Fig. 21); his west-northwest trending strike faults are not as well substantiated, though remain feasible.

Cretaceous-Tertiary unconformity and the Eyre Formation

The Eyre Formation was deposited on a surface dominated by structures trending northeast to southwest and northwest to southeast, with additional north-northeast trends in the central northern part of STRZELECKI. A set of possible northwest-trending sinistral strike faults (interpreted from isopach and structure contour maps) in the Limestone Creek Field area (Fig. 20) have cut the Murteree Ridge and appears to have displaced the north block northwesterly. These features were most active during Early Eocene sedimentation. The influence of the Big Lake Fault system on deposition can also be recognised (Fig. 20).

The locus of sedimentation corresponds closely with the axes of areas of subsidence, the overall control being rejuvenated Triassic highs which define the margins of the basins. Sediments are distributed in an arc around the northern margin of the Pando, Dirkala and Murteree ridges, reflecting Mesozoic distribution (Allunga and Wooloo Troughs). The Gidgealpa, Dirkala and Tinga-Tingana Ridges have also influenced deposition of the Eyre Formation.

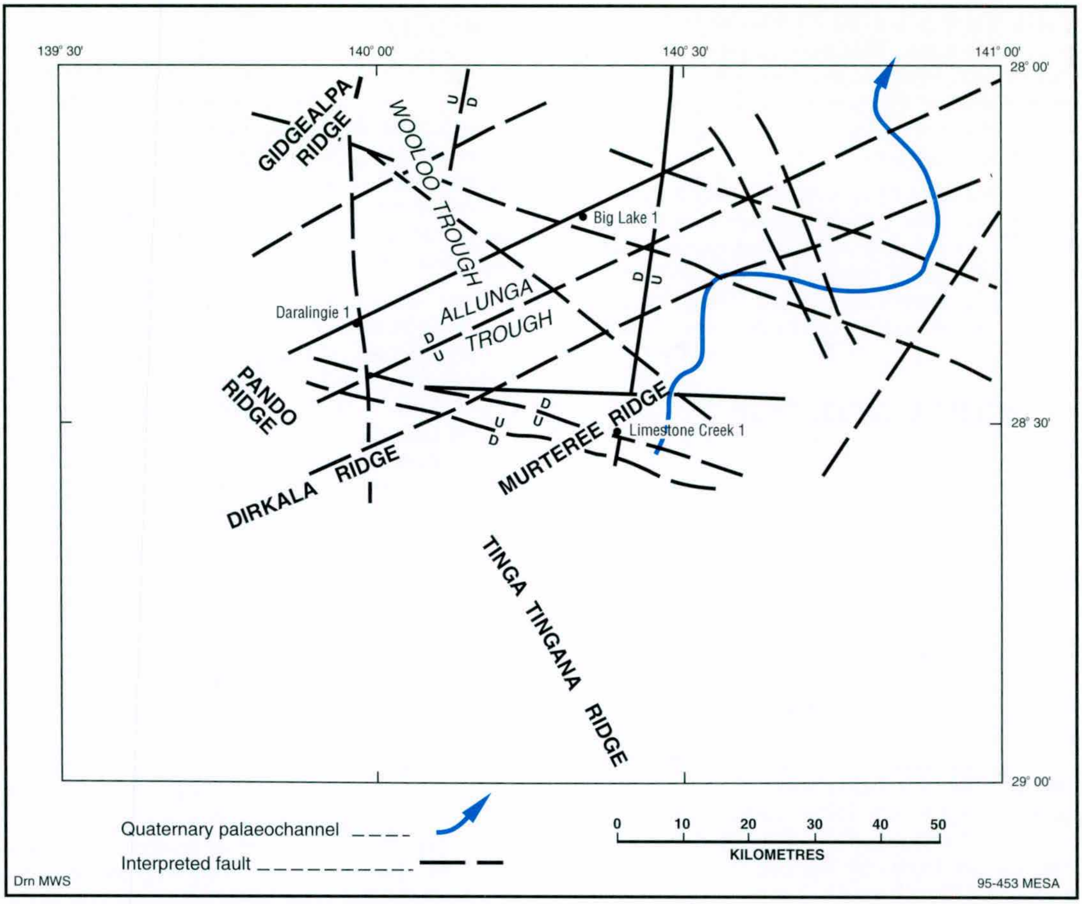

Fig. 21 Interpreted Mid-Late Cainozoic faults.

Eocene-Miocene unconformity and the Namba Formation

Isopachs of the Namba Formation reflect the underlying structure contour surface, and indicate a general filling of depressions remaining from deformation during the Middle to Late Eocene.

A major feature is the northerly trending hinge zone evident in northeastern STRZELECKI, represented in the strongly northerly trending structure contours on the top of the Eyre Formation (Fig. M3), but less evident in the Namba Formation itself. To the east of this zone is a structural high which has persisted throughout the history of the region; contours are more open and irregular than those to the west, which define a normal basinal subsidence.

During the Eocene to Miocene, east-west trending structures became dominant in the northeastern corner of STRZELECKI, and northerly trends in the northwestern part. The locus of sedimentation moved to the western part of the Moomba-Dullingari area. Uplift of the eastern area has prevented dolomite deposition at the base of the Namba Formation from extending east of Strzelecki Creek. Features such as the Warra, Gidgealpa, Moomba, Dirkala and Della-Nappacoongie Ridges are also recognisable on the structure contour map (Fig. M3).

Miocene-Quaternary unconformity and the Yandruwantha Sand

By the end of the Miocene, east-west and north-northeasterly trending structures were dominant across the central northern part of STRZELECKI. The subtle influence of uplift of the northeastern block is reflected in the structure contours on the top of the Namba Formation (Fig. M1) and the course of Strzelecki Creek and distribution of the Yandruwantha Sand. The creek deviates and splits into several channels across the Murteree Ridge, indicating that this feature is still rising or that compaction is proceeding around it. The Yandruwantha Sand is thickest in the Moomba-Big Lake area, as with the older Cainozoic, but to the east of Strzelecki

Creek it appears to be distributed in a sinuous, valley like zone. This may, however, be an artefact of difficulties in identifying the Namba Formation contact. Structure contours on the top of the Namba Formation dolomite (Fig. 19) reflect the earlier patterns.

The Big Lake Fault system is probably active, along with the Allunga Trough and Dirkala Ridge. At present, sedimentation is largely a passive filling of depressions; if subsidence is still taking place it is slight, as it must keep pace with sedimentation so as to produce a flat land surface.

ECONOMIC GEOLOGY

A.J. Hill

HYDROCARBONS

Exploration history

The South Australian portion of the Cooper and Eromanga Basins represents the largest onshore petroleum and natural gas province in Australia. Petroleum exploration commenced in South Australia in 1954 when licences covering the Cooper and Eromanga Basins were first acquired by Santos Ltd. This culminated in 1959 with the drilling of Innamincka 1 (on INNAMINCKA) following a reflection-refraction survey carried out over the Innamincka Dome by the Department of Mines with Delhi Petroleum Pty Ltd as operator of OEL 20 and 21. Additional reflection surveys over the ensuing years led to the discovery of the first Cooper Basin natural gas in Gidgealpa 2 (on INNAMINCKA) in 1963.

In 1969, PEL 5 and 6 were granted to Delhi Petroleum Pty Ltd and Santos Ltd (Fig. 22).

Commercial natural gas from the Eromanga Basin was recovered from Namur 1 in 1976.

The first Cooper Basin oil discovery was made in 1970 in Tirrawarra 1 (on INNAMINCKA) whilst the first oil discovered in the Eromanga Basin was an uneconomic flow from Poolowanna 1 (on POOLOWANNA). The first economic flow was recorded the following year from Strzelecki 3.

As at 1 January 1993, 942 wells had been drilled for the entire Cooper section of the Cooper and Eromanga Basins in South Australia, of which 781 wells intersected Cooper Basin sediments. This compares with 654 wells drilled on STRZELECKI, of which 522 penetrated Cooper Basin sediments; the remainder were drilled exclusively for Eromanga Basin targets. In addition, in excess of 90 000 km of seismic data have been acquired.

Distribution

Hydrocarbons have been recovered from a number of producing horizons (Fig. 8). The majority of Eromanga oil and gas has migrated from Cooper Basin sources, although there is evidence for self-sourced oil within the Murta Formation. Migration of Cooper Basin sourced hydrocarbons has occurred via breached seals, commonly on basin margins but also along faults (Fig. 23).

The composition of the hydrocarbons reflects the coaly nature of the source material, which largely consists of land plant remains and algal matter with significant liquids potential (Taylor *et al.*, 1988). Hydrocarbon occurrence is intimately linked to source maturity. Source rocks with a maturity represented by vitrinite reflectance (Rv) of 0.95% or greater have the capacity to fill structural culminations, whilst traps will be only partly filled if Rv falls in the range of 0.70-0.95% (Hunt *et al.*, 1989).

Occurrences of oil and 'wet' gas (natural gas rich in hydrocarbon liquids) within the Cooper Basin, which have mostly been discovered in the Tirrawarra Sandstone, basal Patchawarra Formation (mostly as oil legs beneath gas caps) and within sediments of the Nappamerri Group, correlate with source rock maturity (Heath *et al.*, 1989). The occurrence of dry gas is restricted to the deeper portions of the Nappamerri Trough where significant cracking of hydrocarbons has occurred. Initially, discoveries were made principally in faulted anticlines ranging in size from 0.05 to 135 km^2, although with the availability of information derived from more precise and detailed seismic studies, the discovery of discrete stratigraphic traps is becoming more common.

Production

Gas

Natural gas has been transmitted from Moomba to Adelaide and country centres by pipelines established, operated and maintained by Pipelines Authority of South Australia (PASA) since 1969.

Gas from individual wells passes via field gathering systems (flowlines) to field satellite stations which separate gas, condensate and water. The essentially water-free gas and condensate pass to the central Moomba treatment plant though trunklines. A total of 3 740 km of pipeline, nearly 900 km of trunklines and approximately 1 500 km of flowlines have been laid to the gas markets and to the Port Bonython facilities (Fig. 22).

Since 1976, gas has also been supplied to Australian Gas Light Company (AGL) for the New South Wales market under a 30-year contract that will expire in 2006.

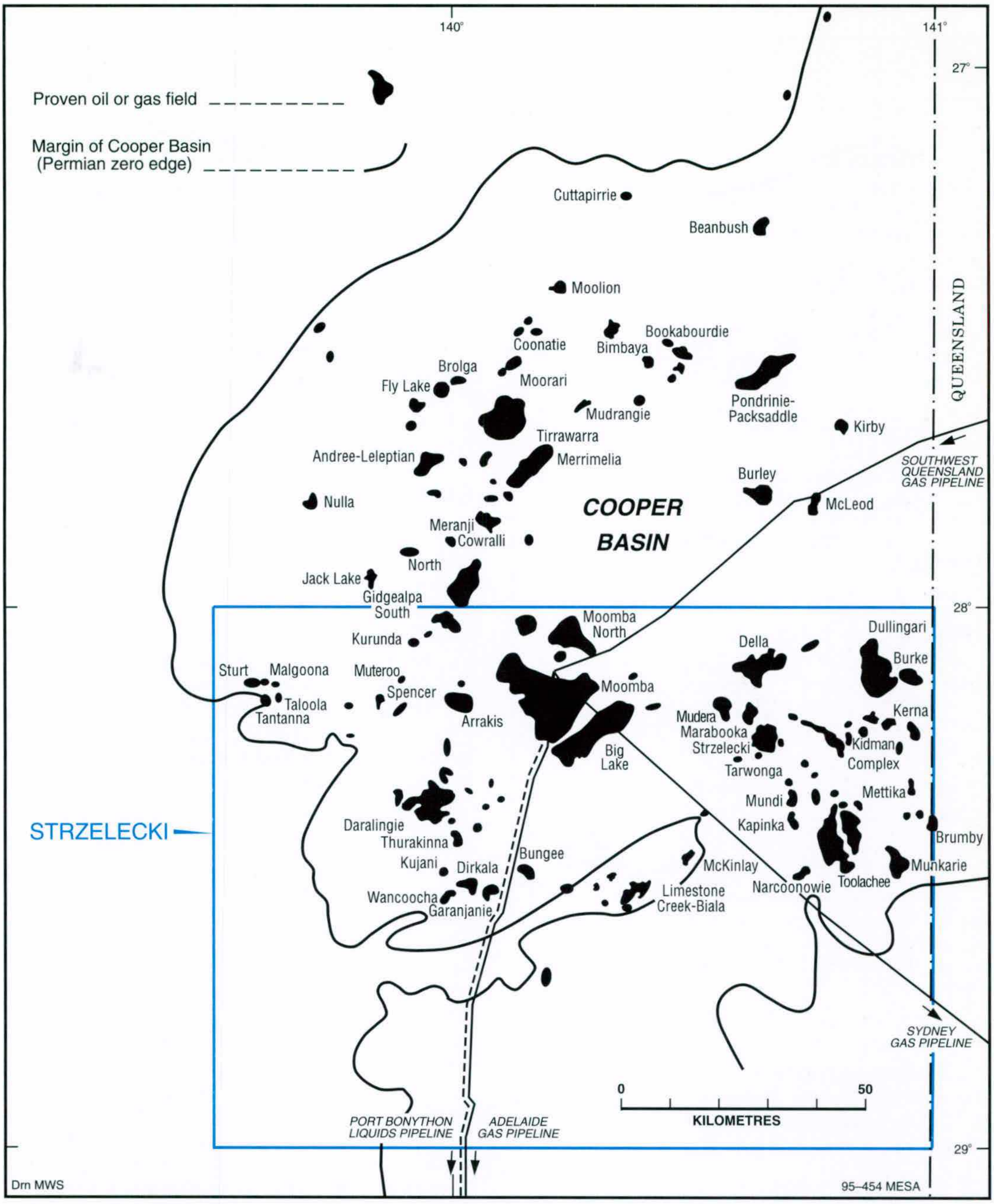

Fig. 22 Oil and gas fields of the Cooper and Eromanga Basins.

As at 1 January 1993, 68 gas fields (Fig. 22) with a total of 316 gas wells were on-line. Annual production for 1992 amounted to 6.3 million m^3 (224 Bcf) of raw gas which converts to 4.5 million m^3 (159 Bcf) of sales gas and 0.47 x 10^6 t of liquefied petroleum gas (LPG). Remaining South Australian Cooper and Eromanga reserves estimated by Santos Ltd are 73.8 x 10^9 m^3 (2 619 Bcf) of sales gas and 6.16 x 10^6 t (73.12 million bbl) of LPG. Cumulative production, as at 1 January 1993, was 75 x 10^9 m^3 of sales gas (2 667 Bcf) and 5.2 x 10^6 t of LPG. Of these 68 fields, 44 lie within STRZELECKI with the remainder on INNAMINCKA.

Significant gas reserves are contained in low permeability sands and may be recoverable by massive hydraulic fracturing techniques.

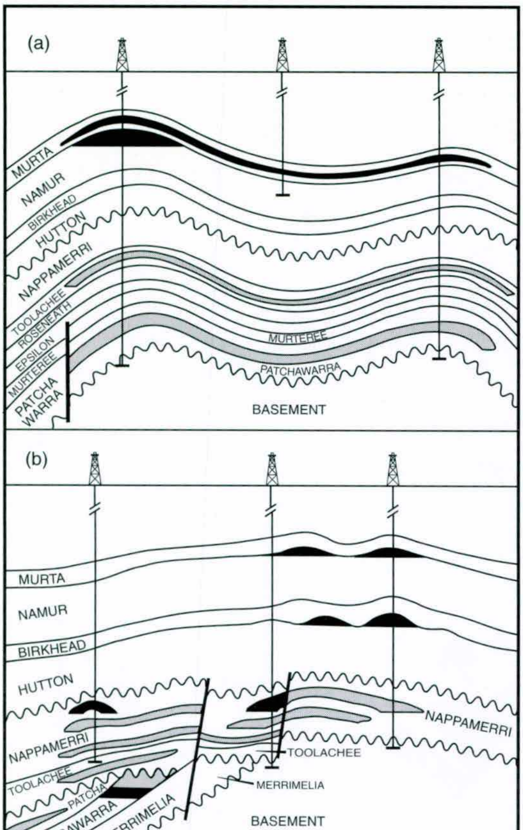

Fig. 23 Schematic sections showing typical petroleum traps of the Cooper and Eromanga Basins: **(a)** within sedimentary troughs, **(b)** GMI trend area (after Moore *in* Gravestock *et al.*, 1986).

The estimated undiscovered potential of gas in the southern Cooper Basin in January 1993 was 1 257 PJ (petajoules). There is currently a 1:2.3 chance of an exploration well discovering gas.

Oil and gas liquids

Oil is transmitted to Port Bonython via a liquids pipeline which also carries condensate and LPG from Moomba. In 1991, condensate production from Port Bonython was replaced by full range naphtha, which has a greater market value.

There are currently 37 oil fields with a total of 225 oil wells on production, of which 26 are on STRZELECKI.

As at 1 January 1993, 13 x 10^6 m^3 (82 million bbl) of oil and 6.40 x 10^6 m^3 (40 million bbl) of condensate had been produced. Production in 1992 of oil and condensate totalled 0.76 x 10^6 m^3. Estimated remaining reserves are 5.9 x 10^6 m^3 (37 million bbl) of oil and 4.1 x 10^6 m^3 (26 million bbl) of condensate.

Enhanced oil recovery (EOR) methods are used in the basin. In 1986, fracture stimulation and ethane injection commenced in the Tirrawarra Sandstone reservoir of the Tirrawarra and Moorari Fields. Combined, these methods have lifted production by 300% in some wells, and the potential exists for further EOR developments.

The estimated undiscovered potential for oil in the southern Cooper Basin in January 1993 was 0.6 x 10^6 m^3 (3.8 million bbl). There is currently a 1:10 chance of an exploration well discovering oil.

Ethane

Between 2 and 3% of the ethane produced remains in the sales gas stream. A further 7% is consumed for fuel and flare requirements at both the Moomba and Port Bonython plants (Fig. 22), while the remainder is currently injected at 29 PJ/year into gas storage reservoirs at Moomba and the enhanced oil recovery (EOR) scheme at Tirrawarra and Moorari. Approximately 18 PJ/year are bled into the sales gas stream as required to meet periods of peak demand on the Moomba plant facilities.

The Natural Gas (Interim Supply) Act 1985 reserved all ethane for South Australia (except that needed to ensure sales gas specifications were met). In September 1994, the State Government released the Cooper Basin Producers from the condition of having to reserve ethane for a local petrochemical plant. Santos signed a contract with ICI Australia to supply 160 PJ of ethane to the Botany Bay petrochemical plant over a period of 10 years, commencing in June 1996. A pipeline to transport the ethane will be built along the present Moomba-Sydney gas pipeline right-of-way. Ethane can be used as a feedstock for the manufacture of ethylene dichloride and vinyl chloride monomer (both are intermediate products in the manufacture of plastics).

Celestite

The location of celestite nodules in a palaeochannel on a salt lake in southeastern STRZELECKI suggests that it may be worthwhile prospecting for economic deposits of this mineral, particularly in areas where lake deposits are present (Millyera Formation). Celestite on CALLABONNA and elsewhere is discussed by Callen and Kennedy (1993) and Callen and Short (in prep.).

Heavy Minerals

Possibilities for heavy minerals in the Coomb Spring Formation have been mentioned by Callen (1981) in association with beach ridges related to the palaeo-Lake Frome or 'Lake Millyera' (Wasson, 1983), particularly in areas fed by streams draining the Mount Painter Inlier. However, it is unlikely that this unit (if it can be distinguished on STRZELECKI) would be prospective. Another possibility is the fluvial Yandruwantha Sand, though the source of this material in the Mesozoic is a disadvantage.

Clay

The Namba Formation contains beds of palygorskite (attapulgite) clay (Callen, 1984; Barnes *et al.*, 1978), usually associated with the basal dolomite. There may be some areas where this unit is near the surface in the northeastern part of the area as a result of faulting, but elsewhere the thick Yandruwantha Sand cover makes this unlikely.

Construction sand and road ballast

The Yandruwantha Sand has been used to make concrete at Moomba, and road materials have been derived from the silicified surface of the Namba Formation, which is widespread and readily available.

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