DEPARTMENT OF MINES AND ENERGY

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REPORT BOOK 93/10

EXPLANATORY NOTES FOR THE WARRINA 1:250 000 GEOLOGICAL MAP

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Regional Geology Branch

with contribution from R.G. Aldam and G. Kwitko

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The oldest rocks on WARRINA outcrop in the Peake and Denison Inliers, which comprise the Davenport and Denison Ranges, and small inliers to the east. Basement in this area consists of Palaeoproterozoic metamorphics intruded by Palaeoproterozoic granite and Mesoproterozoic basic dykes. The bulk of the Peake and Denison Inliers is formed of a very thick sequence of Neoproterozoic (Adelaidean) sediments and minor basic volcanics deposited in a northern extension of the Adelaide Geosyncline. The Adelaidean rocks are intruded by Early Palaeozoic (Delamerian) intermediate and basic igneous rocks, and diapiric breccias. Rocks of interpreted Adelaidean and Palaeoproterozoic ages have been recorded in the subsurface east and west of the Peake and Denison Inliers.

Sediments of ?Neoproterozoic, Cambrian and possible Devonian ages were deposited in the Boorthanna Trough west of the Peake and Denison Inliers, and Early Palaeozoic sediments of the Warburton Basin are inferred in the subsurface in the northeastern corner of WARRINA. In Early Permian time, the Boorthanna Trough was part of the extensive Arckaringa Basin which contains a sequence of glacial-marine, marine and fluvial-lacustrine deposits. Small outcrops of Early Permian sediments occur along the western margin of the Peake and Denison Inliers.

Latest Jurassic-Early Cretaceous sediments of the Eromanga Basin outcrop extensively throughout the area surrounding the ranges, and rest on a remnant of a peneplain of interpreted Late Permian-Early Jurassic age within the Davenport Range.

Limited exposures of Tertiary sediments and silcrete east of the Peake and Denison Inliers mark the western limit of the Lake Eyre Basin. Other Tertiary deposits include terminal sequences of the Mirackina Palaeochannel, and local occurrences of lacustrine carbonate.

Widespread Quaternary units include fluvial channel, fan and floodplain deposits, colluvial deposits, gypsite, aeolian dune sands, claypan deposits and local mound spring deposits.

INTRODUCTION

The WARRINA 1:250 000 map area (referred to in these notes as WARRINA) lies in the arid interior of northern South Australia, between latitudes 28° and 29°S and longitudes 135° and 136°30'E (Fig. 1).

The Oodnadatta Track passes through the map area, skirting the western margins of the Davenport Range and Denison Range (previously informally known as the 'Peake and Denison Ranges'). The small settlement of William Creek, in the southeast corner of WARRINA, lies on the Oodnadatta Track, about halfway between Marree and Oodnadatta. The old Marree to Alice Springs Railway, now dismantled, follows approximately the alignment of the Oodnadatta Track. The Overland Telegraph line once traversed the eastern part of WARRINA, and the ruins of the repeater station at Peake are a prominent historical feature.

WARRINA is covered by three large cattle stations ('Anna Creek', 'Nilpinna' and 'The Peake') and part of a fourth station, 'Mount Barry', lies in the northwestern corner.

Station tracks provide good access to most parts of WARRINA. The Coober Pedy-William Creek Track and the Coober Pedy-Oodnadatta Track traverse the southern margin and northwestern corner respectively of WARRINA. A track between Coober Pedy and 'Nilpinna' traverses the western part of the map area.

The area has a hot dry desert climate with short cool to mild winters. Rainfall is low (mean of 125-150 mm/year) and unreliable, with no distinct seasonal pattern. There are rare periods of high rainfall, usually associated with inflow of warm moist air during the summer months. The last such event occurred in March 1989, when 180 mm of rain fell at Coober Pedy. Seasonal and diurnal ranges in temperature are high. At Oodnadatta, mean maximum and minimum temperatures for January are 38.2° C and 23.2° C, while the corresponding temperatures for July are 19.4° C and 5.8° C.

Adjacent geological maps are WINTINNA (Rogers and Freeman, in prep.), OODNADATTA (Freytag *et al.*, 1967), NOOLYEANA (Williams, A.F., 1973), MURLOOCOPPIE (Pitt, 1976), LAKE EYRE (Williams, 1975), COOBER PEDY (Benbow, 1981), BILLA KALINA (Ambrose and Flint, 1980a) and CURDIMURKA (Krieg *et al.*, 1992).

PREVIOUS INVESTIGATIONS

Systematic geological investigations on WARRINA commenced in 1953, with mapping of *Nilpinna, Conway, Umbum, Boorthanna, Cadlareena* and *Anna* 1:63 360 sheets (Dickinson *et al.*, 1954a, 1955a,b,c,d,e), along with the adjacent *Algebuckina* sheet (Dickinson *et al.*, 1954b). These maps portray Proterozoic rocks of the Davenport and Denison Ranges in some detail, but delineation of the surrounding Mesozoic and Quaternary sediments is very sketchy. The main purpose of this geological survey was to search for economic mineral deposits, particularly uranium. Reports on the geology of the ranges (Reyner, 1955) and groundwater resources of the surrounding plains (Chugg, 1957) were published in conjunction with the geological mapping.

A bulletin describing the Precambrian and Palaeozoic geology of the ranges (Ambrose *et al.*, 1981) is accompanied by a geological map at a scale of 1:150 000 (Ambrose and Flint, 1980b). The geology of the ranges as portrayed on WARRINA is based on the mapping of Ambrose and Flint, and the Proterozoic sections of these notes are summarised from the bulletin.

Geological Atlas mapping program

The latest program of geological mapping on WARRINA was carried out between 1987 and 1990. The three northern 1:100 000 sheets (Eurelyana, Warrina and Umbum) were compiled by P.J. Freeman, and the three southern sheets (Oolgelima, Boorthanna and Anna Creek) by P.A. Rogers. Colour aerial photographs at a scale of 1:87 000 (SA Department of Lands surveys 2762, 2764, 2765, 2777 flown in 1981) were used for field mapping and photo-interpretation. The six 1:100 000 sheets were compiled at photo-scale (1:87 000) and digitised for production of the 1:250 000 geological map.

To assist the geological compilation of WARRINA, a stratigraphic hole (Ruby Hill 1) was drilled near William Creek to investigate the Mesozoic sequence and the underlying unit (Freeman, 1991).

PHYSIOGRAPHY AND VEGETATION

The WARRINA area can be divided into six broad physiographic regions (Fig. 2), described below with notes on vegetation from Laut *et al.* (1977).

Ranges: The Davenport and Denison Ranges are the dominant landform features on WARRINA, and include the highest points in the area (maximum altitude is 410 m AHD at Mount Margaret). They consist of rocky ridges, gravel-covered slopes and pediments, and dissected high-level peneplain surfaces. The ranges are asymmetrical, with gentle western slopes that merge with adjacent plains, and steep range fronts on the faulted eastern margins. Vegetation comprises mulga (*Acacia aneura-A. brachystachya*) and native fuchsia (*Eremophila freelingii*), with a ground flora of kerosene grass (*Aristida contorta*), blackheads (*Enneapogon* spp.), cottongrass (*Digitaria brownii*), forbs and bindyi (*Bassia* spp.).

Plains adjacent to the ranges: On the eastern side of the ranges, this area consists of low-angle alluvial fans, gypsite surfaces and gravel-covered plains interspersed with large creeks and areas of dissected Mesozoic sediments. The creeks and older alluvial surfaces grade in easterly to north-easterly directions towards Lake Eyre North. Included in the zone is a large area of gravel-covered gypsite with scattered sand dunes northwest of the Neales River, and undulating plains of Mesozoic sediments west and southeast of the Davenport Range.

Vegetation is dominated by saltbush (*Atriplex* spp.), with kerosene grass, blackheads, bindyi and samphire. The larger creeks have groves of river red gum (*Eucalyptus camaldulensis*), coolabah (*E. microtheca*) and gidgee (*Acacia cambagei*).

Dunefields: The main area of sand dunes lies to the west and south of the ranges. Longitudinal and reticulate dunes up to 5 m high are separated by narrow interdune corridors with numerous small claypans, and scattered broad areas of Mesozoic sediments and gypsite.

The dunes are vegetated with sandhill wattle (*Acacia ligulata*), hopbush (*Dodonaea attenuata*), native fuchsia (*Eremophila* spp.) and sandhill canegrass (*Zygochloa paradoxa*), with kerosene grass, blackheads and rattlepod (*Crotalaria* spp.).

Gibber spreads: Large undulating areas of Mesozoic sediments in the western and southeastern parts of WARRINA are covered by colluvial red-brown soil with a mantle of red-brown, desert-varnished silcrete clasts (gibbers). Dissected gypsite surfaces and remnants of silcreted Tertiary sediments are present. The region is characterised by a gilgai microrelief of stony terraces and crabholes.

Vegetation consists of saltbush and samphire, with a ground flora of bindyi, blackheads, Mitchell grass (*Astrebla pectinata*), kerosene grass and forbs.

Floodplains and adjacent gravel plains: Extending across the north of WARRINA is the major floodplain of Peake Creek, formed by the confluence of Arckaringa and Lora Creeks. Peake Creek joins the Neales River east of the Denison Range. Broad, flat, gravel-covered plains lie adjacent to the major watercourses west of the Denison Range.

The plains are vegetated with saltbush, and a ground flora of kerosene grass, blackheads, bindyi, samphire and forbs. River red gum, coolabah and gidgee grow on the floodplains.

Oolgelima plains: This desolate region in the southwest corner of WARRINA consists of gently undulating Mesozoic sediments with a thin soil cover mantled by rounded quartzite cobbles and boulders. Sparse vegetation consists of saltbush, with blackheads, kerosene grass, bindyi, samphire and forbs. The area includes the extensive pan of Lake Cadibarrawirracanna which has a marginal vegetation of canegrass (*Eragrostis australasica*) and saltbush, with a ground flora of kerosene grass, aizoon (*Aizoon quadrifidum*) and samphire.

STRATIGRAPHY

The main basement and basin elements of the WARRINA region are shown in Figure 3.

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Palaeoproterozoic

The Peake Metamorphics and Wirriecurrie Granite form Palaeoproterozoic inliers within the Adelaide Geosyncline which are not correlated at present with either the Gawler or Curnamona Cratons or with other Palaeoproterozoic inliers in South Australia. The basement rocks are exposed mainly in the Denison Range, with smaller occurrences in the northern Davenport Range and in isolated inliers to the east including Spring Hill, Lagoon Hill and Mount Charles, and to the north (Algebuckina Inlier on OODNADATTA). Engenina Adamellite equivalent in AS MU 9 drillhole is interpreted to be part of the Coober Pedy Ridge (Christie Subdomain of the Gawler Craton).

Peake Metamorphics

Ambrose *et al.* (1981) divided the Peake Metamorphics into five units: unnamed metamorphics (Le_1); Tidnamurkuna Volcanics; unnamed schists (Le_2); Baltucoodna Quartzite; and unnamed metamorphics (Le_3). Their mapping of the sequence in the Denison Range has shown that Baltucoodna Quartzite overlies the unnamed schists (Le_2) which in turn overlie Tidnamurkuna Volcanics. However, the stratigraphic relationships of the unnamed metamorphics (Le_1 and Le_3) are not known.

Unnamed metamorphics (Le_1) occur in the Mount Kingston area, and also north of Murra Murrana Bore. The unit consists of 5 500 m (minimum) of quartz-biotite and quartz-muscovite schist, quartz-feldspar-biotite and plagioclase-hornblende gneiss, and quartzite. Diorite and pegmatite intrusions, and possible amygdaloidal metabasalt are common. Migmatite is locally developed, indicating middle to upper amphibolite facies metamorphism. K-Ar dating of hornblende from two diorite sills yielded ages of 1518 Ma and 1464 Ma. These are minimum estimates only for the age of metamorphism (Ambrose *et al.*, 1981).

The Tidnamurkuna Volcanics (Let) consist of more than 600 m of amygdaloidal basalt, with porphyritic rhyolite and minor epidosite, phyllite and tremolite marble, exposed in the Mount Denison-Peake ruins area. The altered basalt is composed mainly of actinolite, hornblende, plagioclase, epidote, chlorite and magnetite. The rhyolite comprises phenocrysts of K-feldspar, plagioclase and quartz in a fine-grained, strongly foliated groundmass of quartz, feldspar, muscovite, biotite and pyrite.

U-Pb dating of zircons from a rhyolitic unit yielded an age of 1806±27 Ma which is interpreted as the age of crystallisation (Fanning *et al.*, 1988). These felsic volcanics are geochemically very similar to the coeval Myola Volcanics (Moonta Subdomain of the Gawler Craton) and the Peake Metamorphics may have been similarly affected by later phases of the Kimban Orogeny.

Unnamed schists (Le_2) are poorly exposed in the Coppertop Hill area, and south of Peake ruins where they are 1 000 m thick. Upper and lower boundaries are gradational and conformable. Rock types include quartz-chlorite-muscovite and quartz-chlorite-epidote schist, and phyllite. Thin metasiltstone and metasandstone lenses are common, often with graded bedding and cross-bedding.

Baltucoodna Quartzite (Leb) outcrops south of Peake ruins and in the Mount Denison area, where the formation has a minimum thickness of 4 500 m. The unit consists of quartzite with interbedded quartz-muscovite-chlorite schist, amygdaloidal basalt flows and associated sediments, and possible metamorphosed basic sills. The basalt is strongly foliated and altered, and consists of plagioclase, hornblende, epidote, biotite and magnetite, with abundant plagioclase phenocrysts. Chlorotic phyllite, and rare epidote-actinolite quartzite and dolomite are interlayered with the basalt flows.

Quartzite, schist, gneiss, calc-silicate, marble and sillimanite gneiss occur in six rafted basement blocks within diapiric-brecciated zones in the northern Davenport Range. These varied lithologies are tentatively included in the Baltucoodna Quartzite.

Unnamed metamorphics (Le_3) occur as isolated, small inliers at Milne Spring, Mount Charles, Lagoon Hill, and the Spring Hill-Levi Spring area. The outcrops comprise a variety of rock types, including magnetite-rich metasandstone, calc-silicate and amphibolite. The metasandstone includes epidote quartzite, and quartzite with cross-bedding and heavy mineral lamination.

At Spring Hill, quartzite occurs as rafts or blocks in a porphyroblastic actinolite-quartz-albite gneiss of intermediate igneous origin. The gneiss also includes blocks of chert, banded iron formation, massive titaniferous haematite and epidote-phlogopite schist. The gneiss-metasedimentary block assemblage may represent the roof complex of a magma chamber (Ashton Mining Ltd, 1983).

Rocks from Lagoon Hill have been described as pyroxene-oligoclase-biotite granulite and pyroxene-oligoclase-hornblende granulite (Fander, *in* Dampier Mining Co. Ltd., 1980). Ambrose *et al.* (1981) recorded a quartz-plagioclase-clinopyroxene granulite from the same location.

Crystalline basement encountered in BHP WLE 2 drillhole (Anna Creek) consists of altered hornblende-oligoclase amphibolite and quartz-albite-magnetite microgneiss. Both lithologies are cut by thin veins mainly of chlorite, quartz and feldspar, with minor chalcopyrite. The amphibolite contains secondary biotite, epidote, carbonate and chlorite. The rocks are interpreted as metasediments of upper greenschist or amphibolite facies which have undergone retrograde metamorphism. A quartz-epidote rock (epidosite) with minor chlorite was cored in BHP WLE 1A drillhole (LAKE EYRE) (Fander, *in* Dampier Mining Co. Ltd, 1980). Basement rocks from these two drillholes are included in the unnamed metamorphics unit (Le_3).

Wirriecurrie Granite (L-w)

The Wirriecurrie Granite, exposed in the Peake ruins area, consists of augen gneiss, porphyritic granite, adamellite, granodiorite and minor aplite. Ovoid, red K-feldspar phenocrysts are common in the augen gneiss, and the foliation is defined by the preferred orientation of biotite parallel to the main foliation in adjacent metamorphic rocks. Margins of the granite are faulted, except to the west where granite grades into a zone of migmatite, pegmatite, gneiss and diorite.

Geochronology of the Wirriecurrie Granite consists of nine K-Ar (biotite) dates and twelve Rb-Sr whole rock analyses. The preferred interpretation of the Rb-Sr data is an age of 1648±21 Ma for the syn-deformational emplacement of the granite (Ambrose *et al.*, 1981), which may be tentatively correlated with a late Kimban orogenic phase of the Gawler Craton. Reset K-Ar biotite dates indicate later metamorphic events at about 1050-1000 Ma and 600-500 Ma.

Engenina Adamellite equivalent (Lle)

Grey, coarse-grained granite intersected in AS MU 9 drillhole (Oolgelima; Mason, 1975a) can probably be placed in the Engenina Adamellite which outcrops to the south in the Mount Woods Inlier (BILLA KALINA). Engenina Adamellite has been dated (Rb-Sr) at 1641±38 Ma (IR = 0.7081±0.0014) (Benbow and Flint, 1979) and its emplacement is possibly related to that of the Wirriecurrie Granite.

Mesoproterozoic

Mafic dykes (M_8 and Mbg)

The Wirriecurrie Granite is intruded by diorite dykes (M_8) up to several hundred metres thick. The dykes form a semicircular pattern within the granite and have also intruded along faults and parallel to foliation. The age of the dykes is unknown, but their intrusive relationship with latest Palaeoproterozoic granite suggests a Mesoproterozoic age.

Unnamed metamorphics (Le_3) at Spring Hill are intruded by northwest-trending dolerite dykes up to 2 m thick (Ashton Mining Ltd, 1983) which are geochemically similar to the Gairdner Dyke Swarm (Mbg), an extensive system of northwest-trending mafic dykes in the northeastern Gawler Craton and Musgrave Block. Inconclusive isotopic dating of the Gairdner Dyke Swarm indicates either a late Mesoproterozoic age (~1100 Ma) or, possibly, a Neoproterozoic age (~800 Ma) (Cowley and Flint *in* Flint, 1993). The latter would indicate a correlation between the Gairdner Dyke Swarm and basic volcanics of Willouran age in the Adelaide Geosyncline, including Cadlareena Volcanics.

The dolerite dykes at Spring Hill are correlated with the Gairdner Dyke Swarm, along with amygdaloidal andesine basalt (hawaiite) recorded from Lagoon Hill (Fander, *in* Dampier Mining Co. Ltd, 1980).

Neoproterozoic (Adelaidean)

Callanna Group

Arkaroola Subgroup

The basal Adelaidean sequence which unconformably overlies Peake Metamorphics on WARRINA was placed in the Callanna Beds (Thomson and Coats, 1964) by Ambrose *et al.* (1981). The Callanna Beds have now been upgraded to group status, and the basal sequence on WARRINA is included in the Arkaroola Subgroup, which is the older of the two major subdivisions of the Callanna Group (Forbes *et al.*, 1981).

The lowermost unit of the Arkaroola Subgroup on WARRINA is the Younghusband Conglomerate (Nay), which rests on basement in the Denison and northern Davenport Ranges. At the type section near Coominaree Mine (northeast of 'Nilpinna'), the unit consists of a lower member, 12 m thick, of basal sedimentary breccia, gritty and pebbly sandstone, minor siltstone, coarse dolomitic sandstone, and minor reddish shale, overlain by an upper member, 15 m thick, of red-brown fine sandstone with shale partings. The basal breccia, possibly a talus or regolith, is composed of angular clasts derived from the underlying basement. Small-scale cross-bedding is present in the sandstone layers.

Only the lower member of Younghusband Conglomerate is present in the sequence southwest of Peake ruins, where a maximum thickness of 7 m is recorded.

At the Coominaree Mine type section, the Younghusband Conglomerate grades up into the 77 m thick Coominaree Dolomite (Nao). This unit consists of pale brown silty and sandy dolomite with small-scale, low-angle cross-bedding, buff flaggy dolomite, and red-brown fine sandstone which passes up into stacked stromatolitic bioherms, with minor interbedded oolitic and non-stromatolitic dolomite and chert. Preiss (1987a) recorded the stromatolites *Gymnosolen* and *Acaciella* from these sediments, and noted their similarity to Late Riphean forms from the former Soviet Union and the Amadeus Basin (Bitter Springs Formation).

Coominaree Dolomite also occurs on the eastern flank of the War Loan Mine Block, but is largely absent from the sequence southwest of Peake ruins where it is represented by a 2 m lens of cross-bedded pebbly dolomite. The environment of deposition is interpreted as a shallow-water shelf with possible tidal channels along the basin margin.

The Cadlareena Volcanics (Nac) overlie Coominaree Dolomite south-east of 'Nilpinna' and fault-bounded blocks of the volcanics also occur in this area. Southwest of Peake ruins, the unit fills palaeovalleys eroded into Younghusband Conglomerate and Peake Metamorphics. A thick sequence of the volcanics occurs in the Douglas Well area. The unit ranges in thickness from 50-200 m in the Peake ruins area to 750 m near Douglas Well.

Cadlareena Volcanics are generally medium-grained, dark greenish grey, amygdaloidal sodic basalt, locally with minor flows of trachybasalt, andesite, rhyolite and dacite. Individual basalt flows are 20-30 m thick, and consist of coarse-grained dolerite passing up to vesicular basalt. The basalt has undergone extensive deuteric alteration, and primary minerals (basic plagioclase, pyroxene and olivine) are replaced by albite, tremolite-actinolite, chlorite and iron oxides. The volcanic flows were probably extruded subaerially, with minor interbedded sediments representing phases of shallow-water deposition. These sediments include red-brown shale and mudstone, lapilli tuff and crystal tuff. Dark red quartzite and arkosic sandstone, 4-100 m thick and locally with interlayered red, ripple-marked shale and calcareous siltstone, occur at the top of the unit.

Altered basaltic rocks encountered in Boorthanna 1 and Birribiana 1 (Holmes, 1970; Elliott, 1987) are tentatively correlated with the Cadlareena Volcanics.

The Cadlareena Volcanics are part of a large province of Willouran basaltic volcanism that extended through the central and northern Adelaide Geosyncline (Coats and Preiss, 1987a). The volcanic rocks are interpreted as flood basalts extruded from fissures during a period of tensional rifting (Coats, 1965). Cadlareena Volcanics show geochemical similarities to coeval volcanic rocks from elsewhere in the Adelaide Geosyncline, including the Wooltana Volcanics (Ambrose *et al.*, 1981; Crawford and Hilyard, 1990), and are genetically related.

Curdimurka Subgroup

Sediments stratigraphically between the Cadlareena Volcanics and Burra Group are structurally disturbed, and are difficult to place in stratigraphic order. Ambrose *et al.* (1981) referred to these units as "sequences of uncertain age (Willouran or Torrensian)". The stratigraphic sequence they interpreted is consistent with the order of similar, stratigraphically intact units from the type region of the Curdimurka Subgroup, the Willouran ranges.

Ambrose *et al.* (1981) interpreted the Rockwater Beds as the oldest of their 'sequences of uncertain age', equating them with Dunns Mine Limestone of the Willouran ranges. However, Coats and Preiss (1987a) suggested a correlation between two sandstone blocks in the Last Chance Mine diapiric zone and the Dome Sandstone (Nkd) which underlies Dunns Mine Limestone in the Willouran ranges.

The Rockwater Beds (Nko) occur as blocks within diapiric zones in the Denison Range and near Coominaree Mine and Rockwater Hill in the Davenport Range. Lithologies include blue-grey to black chert, grey-black pebbly dolomite, black shale, siltstone and quartzitic sandstone, with up to 100 m of sequence preserved. The blocks of Rockwater Beds occur in close proximity to Cadlareena Volcanics, suggesting a close stratigraphic relationship.

The War Loan Beds (Nkl) occur next to the War Loan Mine, 8 km SE of 'Nilpinna', where they are faulted against Cadlareena Volcanics. The unit consists of 600 m of laminated blue grey shale, dark grey dolomite and minor cross-laminated siltstone passing upwards into green-grey and blue-grey shale, brown friable sandstone and greenish gritty feldspathic sandstone.

The Nilpinna Beds (Nkp) form a fault-bounded sequence lying 1 km north of War Loan Mine. They are about 2 100 m thick, and the main lithologies are thinly bedded sandstone with festoon cross-beds and salt casts, green arkose, and grey-green silty shale with ripple marks, mud cracks and salt casts. Lithological similarities suggest that the Nilpinna Beds are a transitional sequence between War Loan Beds and Duff Creek Beds, although contacts between the units are faulted.

The Duff Creek Beds (Nkf) comprise sediments 5 500 m thick, with faulted upper and lower boundaries, in the area between 'Nilpinna' and Last Chance Mine. Characteristic lithologies include thin-bedded fine sandstone with ripple marks and cross-bedding, olive-green siltstone with ripple marks and mudcracks, flaggy, pale grey- yellow dolomite with gypsum casts and flat laminated stromatolites, medium to coarse gritty sandstone and quartzite, and black pyritic shale. Ambrose *et al.* (1981) interpreted supratidal (sabkha), intertidal and lagoonal environments of deposition for these sediments. Fault-bounded and diapiric blocks of Duff Creek Beds also occur southwest of Last Chance Mine, west of Douglas Well, west of Tarlton Springs, and at several locations in the Denison Range.

In addition, some faulted and diapirically rafted blocks are mapped as undifferentiated Curdimurka Subgroup (Nk). These were referred to as "undifferentiated blocks" in Ambrose *et al.* (1981) who described the larger blocks from the Denison and northern Davenport Ranges.

Burra Group

Ambrose *et al.* (1981) divided the Burra Group on WARRINA into the following units: an unnamed siltstone unit, Fountain Spring Beds, Mount Margaret Quartzite, Skillogalee Dolomite, an unnamed transition unit, and Kalachalpa Formation. The inferred youngest unit (Murrana Beds) of their "sequences of uncertain age (Willouran or Torrensian)" is now regarded as a basal unit of the Burra Group (Forbes *et al.*, 1981; Forbes and Preiss, 1987).

The Burra Group on WARRINA is divided into Emeroo Subgroup (lower arenaceous sequences - Murrana Beds and Mount Margaret Quartzite), River Wakefield Subgroup (lower silty and dolomitic sequences - unnamed siltstone unit and Fountain Spring Beds), Mundallio Subgroup (carbonate-dominated sequences - Skillogalee Dolomite) and a

Late Torrensian sequence (Kalachalpa Formation and unnamed transition unit) (Forbes and Preiss, 1987).

The Murrana Beds (Noa) at the type section in the southwestern Denison Range comprise 2900 m of shallow marine arenaceous sediments preserved in a faulted synclinal limb. The lower part of the unit consists of laminated gritty quartzite, fine sandstone, and feldspathic sandstone with intercalations of silty shale, and is dislocated and disrupted by faulting and intrusion of diapiric carbonate breccia. The remainder of the unit comprises gritty quartzitic sandstone and grey-green silty shale with small and medium-scale cross-bedding, ripples, flute casts, mud cracks and graded bedding. These lithologies pass up into green nodular siltstone, massive pebbly dolomite, fine to coarse gritty feldspathic sandstone, laminated quartzite and purplish shale. Ambrose *et al.* (1981) suggested a sedimentary transition, based on lithological similarities, between Murrana Beds and Duff Creek Beds, although the contact between the two units is faulted.

Ambrose *et al.* (1981) recognised an unnamed siltstone (Nr_1) in a faulted block on the eastern side of Davenport Range, north of Mount Margaret. The unit is at least 1 200 m thick and is characterised by interlaminated pale grey quartz-dolomite siltstone and dark grey biotite-muscovite siltstone. Quartzite and silty pyritic dolomite beds occur towards the base of the unit, whereas grey pyritic dolomite, grey quartzite, green shale with ripples and salt casts, and fine sandstone with ripples, cross-lamination and salt casts become more common towards the top. Lithological similarities suggest sedimentary continuity between the fault-separated unnamed siltstone unit and Fountain Spring Beds.

The Fountain Spring Beds (Nrf) outcrop on the eastern and western flanks of the northern Davenport Range. The unit is about 1 100 m thick in the type section, 3 km north of Mount Margaret, where it grades into the overlying Mount Margaret Quartzite. Predominant lithologies include laminated dolomitic metasiltstone, fine sandstone with ripple marks, green siltstone with salt casts, and pale grey quartzite with clay galls which increases in proportion towards the top of the unit. Ambrose *et al.* (1981) suggested a marine influence for the Fountain Spring Beds, although the upper part of the unit may have been deposited in a fluvial environment.

The Mount Margaret Quartzite (Nom) lies conformably between underlying Fountain Spring Beds and overlying Skillogalee Dolomite. It is restricted to the northern Davenport Range where it forms much of the highest ground, including the Mount Margaret plateau. The formation is 2 500 m thick in the type section north of Mount Fox. The lower part of the unit consists of interbedded fine quartzitic sandstone and green-grey laminated silty shale, alternating with massive pale grey quartzite. Argillaceous sandstone and thinly bedded quartzite with minor interbedded sandy shale comprise the remainder of the formation, with massive quartzite becoming more common towards the top. Clay galls, cross-bedding, and interference and current ripple marks are common. Ambrose *et al.* (1981) suggested a possible deltaic depositional environment, with some marine influence near the base indicated by minor dolomitic siltstone layers.

The Skillogalee Dolomite (Nms) comprises 3 600 m of dolomite, siltstone, quartzite and sandstone, with minor chert and magnesite, exposed is a series of mainly synclinal folds that extends along the axis of the Davenport Range. Ambrose *et al.* (1981) divided the formation into three unnamed members. The basal member, 1 100 m thick, is mainly platy gritty sandstone, quartzitic sandstone, and green-grey silty shale with minor (5%) dolomite. Clay galls, cross-bedding, graded bedding and ripple marks are common. Ambrose *et al.* (1981) interpreted deposition in beach, bar and tidal environments.

The basal member grades into a middle member, up to 1 500 m thick, with a higher proportion (30%) of dolomite. The dolomite is conglomeratic, cross-bedded, commonly silicified and gritty, with some stromatolitic horizons containing *Baicalia*. Other lithologies include pyritic shale, gritty friable sandstone, quartzite, and minor dark chert and magnesite pebble conglomerate. Ambrose *et al.* (1981) proposed a depositional environment of lagoons and bays which received considerable influxes of terrigenous sediment. Alternation of siliciclastic and carbonate lithologies indicates cycles of marine regression and transgression, probably related to changes in sea level. A comparable repetitive sequence of marginal marine carbonates was described by Belperio (1990) from Skillogalee Dolomite in the Willouran ranges.

Dark grey-black, laminated to thinly bedded dolomite predominates (85%) in the upper member of Skillogalee Dolomite, which is approximately 1 000 m thick. Dolomitic intraclastic conglomerate and stromatolitic horizons are present, and minor black shale, grey quartzite, feldspathic sandstone, magnesite conglomerate and blue-black chert are interbedded with the dolomite. Deposition probably took place in shallow restricted coastal lagoons (Ambrose *et al.*, 1981).

An unnamed unit (Nb_1) 2 100 m thick, forms a lithological transition between Skillogalee Dolomite and overlying Kalachalpa Formation (Ambrose *et al.*, 1981). Contacts with Skillogalee Dolomite are tectonically disrupted, and part of the sedimentary record may be missing. The unnamed unit is exposed in the 'Boorthanna section' west of Mount Anna, where it comprises Units A-D described by Fairchild (1975).

Unit A consists of 1 500 m of laminated, gritty, feldspathic quartzitic sandstone, interbedded with grey-green shale and minor dolomite. Unit B is more dolomitic, comprising 190 m of alternating dolomite and fine-grained clastics, with interbeds of black chert and minor magnesite pebble conglomerate. The dolomite is conglomeratic, often silicified, and with several stromatolitic horizons containing *Baicalia*. The clastic content increases in Unit C, which is predominantly platy friable sandstone with minor carbonate pebble conglomerate (including magnesite) and dolomite. Unit D comprises chert and magnesite pebble conglomerates, black chert, and stromatolitic dolomite.

Mud cracks, ripple marks, cross-bedding, graded bedding and convolute bedding are common throughout, suggesting a shallow marine environment of deposition which was intermittently exposed and desiccated, with extensive penecontemporaneous erosion and reworking of intraclasts.

The unnamed unit is also exposed in the southern tip of the Davenport Range, but here the sequence does not appear to be divisible into Units A-D.

The upper 900 m of the 'Boorthanna section' west of Mount Anna is named the Kalachalpa Formation (Nbk). The formation is more argillaceous and much less siliceous than the conformably underlying unnamed unit, contains more oolitic sediment and stromatolites, and is lacking in magnesite conglomerate. Kalachalpa Formation is also exposed at two locations on the southern tip of the Davenport Range, and in a fault-bounded strip northeast of the old Box Creek siding.

The Kalachalpa Formation in the 'Boorthanna section' corresponds to Units E-G of Fairchild (1975). The basal unit E comprises 365 m of platy siltstone and fine sandstone, with minor dolomite. Dolomite content increases in Unit F, 380 m thick, which also contains slaty red and green siltstone, quartzite, and platy sandstone. The dolomite is often sandy, and becomes increasingly stromatolitic towards the top of the unit. Black chert and oolitic sediments are locally abundant. Unit G consists of 175 m of quartzite and sandstone, with minor slaty and sandy siltstone. Sedimentary structures indicate a shallow water environment of deposition similar to that of the underlying unnamed unit.

The Burra Group sequence exposed in the Boorthanna area (Skillogalee Dolomite, unnamed transition unit, and Kalachalpa Formation) is notable for the occurrence of microfossils preserved in black stromatolitic chert. The microfossils have been described by Schopf and Fairchild (1973) and Fairchild (1975) who recorded possible cyanobacteria, including filamentous and mat-building types, and solitary and colonial eucaryotic cells, possibly of green algae.

Umberatana Group

The Umberatana Group on WARRINA disconformably overlies Burra Group sediments on the southwestern margin of the Davenport Range. Ambrose *et al.* (1981) divided the group into the following units: Calthorinna Tillite, an unnamed sandstone unit, Tapley Hill Formation, Thora Dolomite, and an unnamed siltstone unit. Coats and Preiss (1987b) regarded the Tapley Hill Formation-Thora Dolomite interval as a possible correlative of Amberoona Formation, and they equated the overlying unnamed siltstone unit with the Angepena Formation. An angular discordance separates the glacially influenced units of Sturtian age (Calthorinna Tillite and unnamed sandstone unit) from the overlying Farina Subgroup-Willochra Subgroup interval.

The Calthorinna Tillite (Nuc) is at least 650 m thick at its type section on the northern limb of the Box Creek syncline. The unit also occurs as a large block within a diapir located 7 km to the east, and is faulted against Burra Group sediments on the southern limb of the Box Creek syncline.

Dominant lithologies in the Calthorinna Tillite are gritty quartzitic sandstone, medium to coarse feldspathic sandstone, thin-bedded pale yellow-grey pebbly dolomite and dolomitic siltstone, finely laminated pale grey-green shale, and interbedded diamictite and intraformational conglomeratic dolomite. Rapid lateral and vertical facies changes characterise the formation.

The diamictite units vary in thickness up to 100 m, with a predominantly silty matrix composed of quartz, dolomite and clay. Clasts are mainly pebbles and granules, with less common cobbles and rare boulders. Most clasts are locally derived from the Burra Group, Duff Creek Beds and Cadlareena Volcanics, while others have come from more distant sources to the south-west. These include red porphyritic granite and hornblende granite from the Mount Woods Inlier, and red porphyritic rhyolite from the Gawler Range Volcanics. Clasts of various quartzitic types include one with an inherited liesegang-type palaeoweathering, possibly derived from the Pandurra Formation of the Stuart Shelf.

Ambrose *et al.* (1981) interpreted Calthorinna Tillite as a glacial marine and marine unit. The quartz and clay-rich diamictite units may have been deposited from a temperate glacier grounded offshore. Other diamictite units, including carbonate-rich types, may represent reworked till deposited by mudflows, debris flows and turbidity currents from a floating glacier. Interbedded dolomite, shale and sandstone were interpreted as marine units, possibly deposited during interglacial periods of higher sea level.

An unnamed sandstone (Nu_1) conformably overlies Calthorinna Tillite at its type section on the southern limb of the Box Creek syncline. Here, the unit comprises 530 m of medium to coarse-grained, well-rounded, feldspathic sandstone with large-scale cross-bedding. Minor lithologies include thick-bedded quartzitic sandstone, micro-conglomerate and argillaceous sandstone. Red porphyry granules are common throughout. The unnamed sandstone interfingers with Calthorinna Tillite on the northern limb of the Box Creek syncline.

The unit is considered to mark the end of a glacial period, when meltwater streams transported large amounts of glacial sediment into a deltaic-marine environment of deposition (Ambrose *et al.*, 1981).

The succeeding unit was originally equated with the Tapley Hill Formation by Ambrose *et al.* (1981). However, Coats and Preiss (1987b) noted that the sediments on WARRINA are lithologically different from Tapley Hill Formation elsewhere in the Adelaide Geosyncline, and suggested that they may belong to the Amberoona Formation (Nfa).

The probable Amberoona Formation on WARRINA is exposed only on the southern limb of the Box Creek syncline, where it is 150 m thick. It consists of a basal pale yellow dolomite, 10 m thick, overlain by finely laminated, dark grey to black silty shale and silty dolomite. The sequence becomes more dolomitic towards the top.

There is an angular discordance between the probable Amberoona Formation and the underlying unnamed sandstone unit, which may represent an unconformity. Ambrose *et al.* (1981), however, suggested that this discordance resulted from the transgressive marine unit ('Tapley Hill Formation') truncating large deltaic foreset beds in the underlying unnamed sandstone unit.

The Thora Dolomite (Nfh) conformably overlies probable Amberoona Formation in the southern limb of the Box Creek syncline. It is a shallow marine deposit, comprising 30-40 m of flaggy, buff, cryptalgal laminated dolomite with some cumulate stromatolites, interbedded with green siltstone. Ambrose *et al.* (1981) correlated Thora Dolomite with Brighton Limestone, but Coats and Preiss (1987b) suggested that it could be regarded as a local member of Amberoona Formation.

A sequence of mainly fine-grained clastics conformably overlies Thora Dolomite on the southern limb of the Box Creek Syncline. Ambrose *et al.* (1981) referred to this unit as 'unnamed siltstone', and Coats and Preiss (1987b, table 12) placed it in the Angepena Formation (Nha).

On WARRINA, the Angepena Formation is 950 m thick, comprising basal grey-green siltstone, dolomitic siltstone and argillaceous fine sandstone overlain by interbedded, finely laminated, grey-green and red-brown silty shale with ripple marks, fine sandstone, thin grey-yellow dolomite, and silty dolomite. The dolomite layers are often silicified and occasionally gritty. Sand content generally increases in the upper part of the unit, with several thin, reddish coarse sandstone beds occurring towards the top.

Cambrian

The Cootanoorina Formation (ε-c; Townsend and Ludbrook, 1975) is a sequence of carbonates, evaporites and red beds underlying Permian units in the northern Boorthanna Trough. The formation in Cootanoorina 1 was originally assigned a Devonian age on the basis of a microflora obtained from shale cuttings (Allchurch *et al.*, 1973), which are now thought to have caved from the overlying Boorthanna Formation. Cootanoorina Formation is correlated with the Early Cambrian Ouldburra

Formation of the eastern Officer Basin (Brewer *et al.*, 1987).

In Cootanoorina 1, the formation consists of a lower part of dark grey-green dolomitic lime mudstone which is occasionally pyritic and magnesitic. Sedimentary structures include cryptalgal lamination, disrupted bedding and rare halite casts. There are intraformational breccias, and common interbeds and veins of anhydrite. The upper part of the formation is mainly flat to cross-bedded sandy dolomite with evaporitic concretions. Minor disrupted and reworked cryptalgal laminated lime mudstone, and irregular masses and veins of anhydrite are present (Gravestock, in prep.). Remobilisation of anhydrite in Cootanoorina 1 is likely to be associated with emplacement of the Mount Toondina diapir, located 8 km to the NNE (Allchurch, *et al.*, 1973).

A complete interval, 882.7 m thick, of Cootanoorina Formation was intersected in Weedina 1 (Papalia, 1970) which has been selected as the type section (Townsend and Ludbrook, 1975). Here, the unit comprises sandy peloidal dolomite, interbedded anhydrite and wavy algal laminite. Higher in the section, weakly bioturbated carbonate mud and algal boundstone with intraclasts predominate. The upper part of the section in Weedina 1 comprises pyritic shale, fine grained sandstone and sandy ooid grainstone (Gravestock, in prep.).

Cootanoorina Formation in Hanns Knob 1 (Martin, 1988) is a gently dipping sequence of predominantly wavy and ripple bedded red siltstone and very fine sandstone, with minor carbonate (dolomite, siderite and magnesite) and anhydrite. Coarse grains of quartz and feldspar occur as single-grain layers on foresets and as irregular layers in a carbonate matrix. Other features include pale grey-green clay drapes, tepee structures, mudcracks and small blebs of evaporitic minerals (Gravestock, in prep.).

The carbonates, evaporites and fine-grained red bed clastics of the Cootanoorina Formation are interpreted as supratidal carbonate sabkha and sandflat/mudflat deposits (Gravestock, in prep.). Similar lithologies occur in the Officer and Arrowie Basins, and the Boorthanna Trough may have formed a link between these two areas.

Flat-lying, pale grey to white, very fine grained quartzite underlying Cootanoorina Formation in Weedina 1 may be equivalent to the Early Cambrian Relief Sandstone (εmr; Brewer *et al.*, 1987) of the eastern Officer Basin (Gravestock, in prep.). The quartzite has a siliceous cement and irregular dark grey clayey layers (Papalia, 1970).

Early Palaeozoic

Basic dykes (εOd$_3$)

Several dolerite dykes, intruding Skillogalee Dolomite, trend northwesterly and intermittently across Davenport Range from the headwaters of Davenport Creek to the margin of the Last Chance Mine diapiric zone. A smaller dyke intrudes Duff Creek Beds about 4 km ENE of 'Nilpinna'. Dyke lithologies range from unaltered olivine-augite-plagioclase dolerite to altered quartz-chlorite-dolomite-muscovite rock. Ambrose *et al.* (1981) suggested that the dykes are late-stage orogenic intrusions, based on their linear, undeformed outcrop pattern. However, this is not supported by the total rock K-Ar age of 537 Ma obtained from dolerite near 'Nilpinna'.

Bungadillina Monzonite (εOdb)

A group of intrusive bodies, including two larger zoned plutons, smaller more homogeneous plutons, sills and dykes, intrudes Burra Group sediments and diapiric breccia in the northern Davenport Range. The igneous rocks were named Bungadillina Monzonite by Ambrose *et al.* (1981), and have been further described by Morrison (1989) and Morrison and Foden (1990).

The intrusives are composed mainly of intermediate rocks ranging from quartz monzonite and quartz syenite to monzogabbro and melanocratic syenite. Primary minerals include plagioclase, K feldspar, clinopyroxenes, hornblende, biotite and quartz, with accessory sphene, apatite, magnetite and zircon. The rocks have undergone varying degrees of alteration, most notably marginal albitisation of the larger plutons, and complete albitisation of some smaller intrusions. Alteration products include actinolite, chlorite, hematite, sericite, calcite, albite and epidote.

A swarm of sills, up to 6 km long and 20 m thick, intrudes Fountain Spring Beds and Mount Margaret Quartzite. The sills contain numerous xenoliths of quartz-chlorite schist and metasiltstone, and rounded quartz grains, derived from the intruded sediment. Other xenoliths include monzogabbro, dolerite and tonalitic gneiss which Morrison (1989) interpreted as being derived from mafic cumulates, chilled margins of earlier crystallised melt, and Palaeoproterozoic basement respectively. Late-stage intrusives include dykes of alkali syenite and biotite lamprophyre (Morrison, 1989), and rare spherulitic dykes (Ambrose *et al.*, 1981).

Morrison and Foden (1990) presented a model of passive, shallow intrusion of partially crystallised and fractionated magma, for emplacement of the western zoned pluton. Groundwater circulating in the intruded sediment would have dispersed heat from the magma, thus preventing contact metamorphism, and may also have contained sodium, providing a mechanism for marginal albitisation. The mafic phases of the intrusives may be best interpreted as cumulate fractions of a primary monzonitic or dioritic magma (Morrison, 1989).

Potassium-argon dating has yielded five hornblende dates ranging from 502 to 469 Ma, with four of these dates grouping closely between 502 and 492 Ma, and a significantly older biotite date of 679 Ma. From these dates, Ambrose *et al.* (1981) interpreted the Bungadillina Monzonite as a late-stage orogenic intrusive of the Delamerian Orogeny, of Early Ordovician age.

Morrison and Foden (1990) reported a Model 1 whole-rock Rb/Sr isochron of 521±35 Ma with an initial ratio of 0.70648±.00014. They also recorded a U/Pb isochron of 525±35 Ma for zircon from the same location that yielded the anomalously old K-Ar biotite date of 679 Ma. From these dates, Morrison and Foden (1990) suggested a pre-Delamerian age of intrusion. However, the large error precludes assignment of either a pre-, syn- or post-Delamerian age to the Bungadillina Monzonite.

Fission track dating of six apatite grains from a hornblende syenite yielded an average age of 266±23 Ma (Radke, 1973), which may indicate tectonism of Permian age.

Diapiric breccia (εOd_2)

Zones of disrupted and brecciated strata, usually referred to as diapirs, are an important feature of the Adelaide Geosyncline, including the Davenport and Denison Ranges. Ambrose *et al.* (1981) noted two styles of diapiric activity on WARRINA:

- broad disrupted zones of disoriented blocks in a carbonate-matrix breccia
- narrow zones of carbonate breccia intruded along planes of structural weakness.

The broad diapiric zones generally occur in a stratigraphic position immediately above the Cadlareena Volcanics, and contain large rafted blocks mostly of Curdimurka Subgroup lithologies. Some diapiric activity has also occurred stratigraphically below the Cadlareena Volcanics, resulting in detachment of blocks of basal Adelaidean (Arkaroola Subgroup) units and pre-Adelaidean basement. Bungadillina Monzonite occurs both as clasts and intrusive bodies in the diapiric zone northeast of 'Nilpinna' (Ambrose *et al.*, 1981; Morrison, 1989). Diapiric bodies have sharp contacts with largely undisturbed host strata, implying passive emplacement. In outcrop, the diapiric zones are characterised by resistant disoriented blocks, up to several kilometres across and often highly deformed, surrounded by low-lying areas of easily weathered and poorly exposed carbonate breccia.

In the diapiric zone in the southern Denison Range, Ambrose *et al.* (1981) noted a transition from a zone of complete disruption to a generally undisturbed sequence of basal Burra Group sediments (Murrana Beds) with minor intrusions of diapiric breccia. Morrison (1989) described five stages in the formation of the breccias. Compressional forces in stage 1 resulted in the development of kink folds in sediment surrounding an intruding diapir. In stage 2, further deformation of kink-folded strata forms very angular, often juxtaposed blocks with no matrix material. Limited displacement of blocks (Stage 3) results in the formation of angular clast-supported breccia. Further displacement (stage 4) forms a matrix-supported breccia with a greater variety of more rounded clasts in a matrix of carbonate-cemented sand and silt-sized clasts. The final stage 5 produces the typical diapiric material of rounded clasts of varied lithology in a coarse carbonate-cemented matrix. Morrison (1989) also noted that much of the brecciation on WARRINA comprises highly distorted beds of less competent siltstone and shale within more competent quartzite layers of the Burra Group.

Diapirism in the Davenport and Denison Ranges has mainly affected rocks of the Callanna and Burra Groups, and the Umberatana Group has also been intruded by diapiric breccia (Ambrose *et al.*, 1981). The presence of clasts and intrusions of Bungadillina Monzonite, the strong deformation of rafted blocks, and the intrusion of narrow breccia zones along faults and fold hinges, indicate that diapirism is largely synchronous with the Delamerian Orogeny, with phases that both pre-date and post-date the main orogenic period. Carbon and oxygen isotopic data from diapiric carbonate indicate low temperature formation from groundwater precipitation immediately after or during the Delamerian Orogeny (Morrison, 1989). This may be related to low-temperature and low-pressure metamorphic minerals of the zeolite facies, including chlorite, talc and magnesioriebeckite, recorded in diapiric carbonate elsewhere in the Adelaide Geosyncline (Mount, 1975).

At other locations, there is evidence of diapiric activity predating the Delamerian Orogeny. For example, Preiss (1985) thought that initial deformation, including formation of diapiric breccia, of the Callanna Group in the Worumba Anticline area occurred in late Torrensian to early Sturtian time. The breccia was later remobilised during the Delamerian Orogeny. Diapirs in the Boorthanna Trough (see p. 29) may have undergone a similar sequence of events.

There have been many theories put forward to explain the origin of the breccia intrusions in the Adelaide Geosyncline (see Preiss, 1985). It is now considered that the breccias were formed by upward movement of incompetent carbonate, mudstone and evaporitic lithologies of the Curdimurka Subgroup into structurally weak zones in the more competent overlying sequence. Mount (1975) suggested that mobility, related to the former presence of evaporitic salts, was a more important factor than density contrast in forming breccia intrusions.

?Devonian

Although no sediments of Devonian age have been identified on WARRINA, a small and poorly preserved Devonian microflora is recorded from Cootanoorina 1 (Allchurch *et al.*, 1973). The microflora was obtained from shale cuttings from the Early Cambrian Cootanoorina Formation interval, which are assumed to have caved from the overlying Late Palaeozoic Boorthanna Formation. In the latter unit, Devonian spores may have been reworked into the sediment, or may occur in reworked clasts.

Allender *et al.* (1987) recognised a unit underlying Boorthanna Formation and overlying Cambrian-Adelaidean rocks on seismic sections in the Boorthanna Trough. They informally named this unit the 'Nultaddy Formation' (here referred to as the Nultaddy seismic unit; D_1) and suggested a Devonian age. The acoustic transparency of the unit may indicate a predominantly shaly lithology.

The Nultaddy seismic unit appears to be restricted to lows between highs of Cambrian and Adelaidean rocks, and Allender *et al.* (1987) suggested from seismic evidence that the unit may correlate with a 244 m thick interval in Boorthanna 1, presently identified as lower Boorthanna Formation. However, Gravestock (in prep.) suggests alternatively that the basal 29 m of this interval may represent the seismic unit. This basal interval in Boorthanna 1 consists of brown and green shale, calcareous and sandy in part, and white, kaolinitic, fine to medium sandstone. Clasts of the underlying basic volcanic unit occur in the lower part of this interval.

The suggested presence of Devonian sediments in the Boorthanna Trough points to the possibility of a local source for the reworked Devonian microflora in Cootanoorina 1.

Late Palaeozoic

Sediments of Early Permian and possibly latest Carboniferous age occur in the largely subsurface Arckaringa Basin. The Davenport and Denison Ranges form part of the eastern boundary of the basin, and immediately to the west lies the Boorthanna Trough, one of several graben-like depressions that formed along the margin of the basement. The Late Palaeozoic sequence in the Boorthanna Trough overlies older Palaeozoic and Adelaidean rocks, and ranges in thickness from 660 m (Weedina 1) to 1194 m (Birribiana 1). Further west, a thinner sequence rests on shallow crystalline basement in the central platform of the Arckaringa Basin. On WARRINA, the Late Palaeozoic sequence is overlain by up to 200 m of Mesozoic sediments.

The Arckaringa Basin succession is divided into three units: Boorthanna Formation, Stuart Range Formation and Mount Toondina Formation (Townsend and Ludbrook, 1975) (Fig. 4). Five drillholes on WARRINA, all located in the Boorthanna Trough, have intersected all three units: Cootanoorina 1, Weedina 1, Boorthanna 1, Hanns Knob 1 and Birribiana 1. Numerous mineral exploration and water bores have also entered the Permian sequence, but most did not fully penetrate Mount Toondina Formation.

The oldest unit of the Arckaringa Basin sequence is the Boorthanna Formation (CP-b) which has a 419 m thick uncored type section in Boorthanna 1 (Townsend and Ludbrook, 1975). Gravestock (in prep.) has suggested that the basal

29 m of the type section may belong to the ?Devonian Nultaddy seismic unit. In other wells on WARRINA, Boorthanna Formation ranges in thickness from 69.2 m (Weedina 1) to 659.6 m (Birribiana 1).

The type section in Boorthanna 1 is divided into a lower unit of diamictite with shale interbeds and an upper unit of rhythmically bedded coarse and fine clastics. The diamictite consists of quartz, feldspar and basement clasts, ranging in size from fine sand to pebbles and occasional cobbles, in a grey or greenish grey claystone which is often calcareous or dolomitic. Thin intervals of sandstone, carbonate, and grey, green and brown shale and siltstone occur in the diamictite unit. The upper unit is predominantly medium to coarse sandstone, but grain size can range from silt to boulders (Hibburt, 1984). The diamictite facies is also present in Birribiana 1, but is absent from the other three drillholes in the Boorthanna Trough.

Cores from Cootanoorina 1 consist of pale grey, clayey, very fine to very coarse quartz sandstone, with pebble to boulder-sized clasts of dolomite, quartz, calcareous sandstone, shale, quartzite, limestone and gneiss, interbedded with grey claystone and siltstone and pale grey to black, microcrystalline dolomite. Sedimentary features include graded bedding and slump structures (Allchurch *et al.*, 1973).

A core taken from Boorthanna Formation in Weedina 1 comprises pale to dark grey, very fine to very coarse pebbly sandstone grading to conglomerate with pebbles of various igneous and sedimentary rock types. Grains are angular to subangular and are set in a calcareous and kaolinitic matrix. High-angle cross-bedding, cut and fill structures, and 'rock flour' intraclasts are present (Papalia, 1970).

Diamictite cored in Ruby Hill 1 (Freeman, 1991) is tentatively correlated with Boorthanna Formation. It is a pale to medium grey, massive, well indurated rock with subangular to very well rounded, sand to cobble-sized clasts in a poorly sorted silty carbonate matrix. Clast types include pale grey calcareous siltstone, chert and oolitic chert, granite, and very well rounded and polished quartz sand grains. Alley (1991a) noted the presence of vitrinite and plant matter in samples from Ruby Hill 1, pointing to a correlation of the diamictite with Boorthanna Formation rather than the Adelaidean Calthorinna Tillite.

The Boorthanna Formation consists largely of redeposited glacial sediments. The presence of foraminifera and microplankton in the upper part of the unit (e.g. in Cootanoorina 1; Allchurch *et al.*, 1973) indicates a marine environment of deposition. Wopfner (1970) suggested that the diamictite facies was deposited by subaqueous mudflows, and that the rhythmically bedded facies was deposited by turbidity currents. Both these facies probably formed by redeposition of glacial sediment in submarine fans that developed offshore from glacial margins. The diamictite facies in Boorthanna 1 and Birribiana 1, on the southern and western margins of the Boorthanna Trough respectively, may represent proximal fan deposits, whereas the rhythmically bedded or turbidite facies may be more distal sediments deposited in the axial part of the trough. The latter facies is more widespread in the Boorthanna Trough in the upper part of the formation, possibly as a result of increasing meltwater flow and rising sea level at the end of a glacial period. The diamictite in Ruby Hill 1 may be a subglacial lodgement till (N.F. Alley, pers. comm., 1991).

Palynofloras from the Boorthanna Formation have been assigned a Stage 2 age (Evans, 1969) (e.g. Allchurch *et al.*, 1973). An anomalously young Stage 3a age from the formation in Birribiana 1 may be a result of poor control from a sparse assemblage (Jones *in* Elliott, 1987). These results indicate an Early Permian (Asselian) age for Boorthanna Formation, but as the Stage 2 - Stage 1 boundary may lie just below the Permian-Carboniferous boundary, the unit could also include sediments of latest Carboniferous age.

The overlying <u>Stuart Range Formation</u> (P-s) has a type section, 260.6 m thick, in Cootanoorina 1 (Townsend and Ludbrook, 1975). Thickness of the formation in other drillholes ranges from 27.7 m (Boorthanna Railway bore) to 98.5 m (Weedina 1). Boorthanna bore on Duff Creek encountered 87.8 m of Stuart Range Formation, but did not fully penetrate the unit. Contacts with Boorthanna Formation are generally conformable but may locally be disconformable or unconformable.

The type section in Cootanoorina 1 consists of shale and siltstone with minor calcareous pebbly sandstone. In core, the shale is dark grey, highly micaceous, and slightly silty, sandy and pyritic, with often lenticular and graded laminae of pale grey very fine quartz silt. A thin arenaceous interval cored in Cootanoorina 1 comprises pale grey, micaceous, pyritic, calcareous, sandy and silty claystone with scattered granules and pebbles of granite, gneiss, calcareous sandstone and shale, and irregular intraclasts of clayey sandstone. The siltstone is medium to dark grey, thinly laminated, micaceous, carbonaceous, pyritic and slightly sandy, with garnet and lithic clasts up to 2.5 mm in size (Allchurch *et al.*, 1973).

Stuart Range Formation is a relatively homogeneous unit, and lithologies encountered in other wells are similar to those in the type section. However, sections in the southern Boorthanna Trough (Weedina 1, Boorthanna 1, Boorthanna railway bore) have a higher proportion of sand to pebble-sized clasts.

Rising eustatic sea level in the post-glacial period following deposition of Boorthanna Formation resulted in marine transgression and deposition of Stuart Range Formation in a low-energy marine environment. Minor sandy and pebbly diamictites indicate a continuation, on a smaller scale, of the sedimentary processes that deposited Boorthanna Formation. The presence of acritarchs and arenaceous foraminifera has been regarded as indicating either restricted marine or cold-water marine conditions. Foraminiferal and acritarch assemblages become restricted or absent in the upper part of Stuart Range Formation, with sediments generally becoming more carbonaceous and pyritic (e.g. Cootanoorina 1, Hanns Knob 1, Boorthanna bore). This suggests that regressive, marginal marine to non-marine conditions prevailed during deposition of the upper part of the formation (Allchurch *et al.*, 1973; Gilby and Foster, 1988).

Ludbrook (1961) assigned an early Sakmarian age to foraminifera-bearing Stuart Range Formation in Boorthanna bore. A palynoflora of Stage 3 (Sakmarian) age was recognised in the upper part of the formation in Cootanoorina 1 (Allchurch *et al.*. 1973), and the formation in Birribiana 1 and Hanns Knob 1 contains palynofloras of Stage 3a age (Jones *in* Elliott, 1987; Jones *in* Martin, 1988). Stuart Range Formation is considered to extend into the underlying Stage 2, and is therefore assigned a late Asselian to early Sakmarian age.

The youngest unit of the Arckaringa Basin sequence is the <u>Mount Toondina Formation</u> (P-t) which has an exposed type section at the Mount Toondina piercement structure (Freytag, 1965) and a subsurface reference section (329.2 m) in Cootanoorina 1. Thickness ranges from 218.2 m (Boorthanna railway bore) to 597.4 m (Boorthanna 1). Mount Toondina Formation both conformably overlies and interfingers with Stuart Range Formation (e.g. Boorthanna railway bore), but in some areas, the contact may be disconformable or unconformable. The formation may rest on crystalline basement of the Mount Woods Inlier, and on Adelaidean strata at the eastern margin of the Boorthanna Trough (e.g. Boorthanna railway bore).

The subsurface reference section in Cootanoorina 1 comprises an upper part of siltstone interbedded with carbonaceous shale and coal, and a lower part of siltstone and silty shale interbedded with very fine to fine sandstone. In core, the siltstone is pale grey, very finely laminated, clayey, micaceous and carbonaceous; sandstone is pale grey to off-white, predominantly quartz and biotite, with clay pellets, carbonaceous fragments and some very thin lenticular beds of grey shale. The division of Mount Toondina Formation into an upper, carbonaceous and coal-bearing part, and a sandier and less carbonaceous lower part is apparent in other drillholes, but there is some lithological variation. The formation in Hanns Knob 1 is predominantly very fine to coarse sandstone, and sandstone ranging up to very coarse in grain size with occasional pebbles of quartzite and metamorphic rock is present in other holes. Thin pebbly claystone layers and minor quartz grit are recorded in a water bore (6140-30) at 'Anna Creek'.

A freshwater environment of deposition is indicated, in which coarser sands were laid down in fluvial channels, and the finer-grained sediments in floodplains and lakes. The more carbonaceous units in the upper part of the formation indicate a widespread development of coal swamps. A local marine influence is indicated by the presence of marine microfossils (tasmanitids) in basal Mount Toondina Formation from Boorthanna 1 (Cook, 1981).

Allchurch *et al.* (1973) assigned palynofloras from Mount Toondina Formation in Cootanoorina 1 to Stage 3, and to Stage 4 in the uppermost part of the formation. Gilby and Foster (1988), however, did not find the Stage 4 key species in any of the holes they examined, but they did identify a closely comparable species from the formation. Stage 3a palynofloras have been found in Mount Toondina Formation from Birribiana 1 and Hanns Knob 1 (Jones *in* Elliott, 1987; Jones *in* Martin, 1988) and Stage 3b assemblages have been recorded from the formation in Getty GN 13c (Wood and Williams, 1985). These results indicate a Sakmarian age.

Outcropping Permian sediments

Scattered exposures of Permian sediments occur along the eastern margin of the Arckaringa Basin on WARRINA, notably near 'Nilpinna' and southwest of Mount Anna on the western flank of the Davenport Range.

The sediments are mainly gritty and pebbly fine to coarse sandstone and diamictite, and thin-bedded and laminated siltstone, claystone and very fine sandstone. Other lithologies include cross-bedded and planar bedded coarse to very coarse calcareous quartz sandstone with pebbly layers and lenses, and dark grey, carbonaceous siltstone. The diamictite contains clasts ranging in size from 10 mm to nearly 3 m. The clasts are locally derived from Adelaidean units and include quartzite, siltstone, quartz, dolomite and diamictite. Many are striated and faceted and are clearly of glacial origin.

Diamictites exposed along the eastern margin of the Arckaringa Basin have matrix materials of clayey sandstone, poorly sorted sandstone, and calcareous or dolomitic sandstone. Wopfner (1970) interpreted these as moraine or near-moraine, esker, and subaqueous glacial deposits respectively. The thin-bedded and laminated fine-grained sediments are lacustrine, and the cross-bedded pebbly coarse sandstone is a fluvial deposit.

Southwest of Mount Anna, lags of striated and faceted clasts probably represent glacial till. These pass southwards and eastwards into subaqueous delta fan deposits (carbonate-cemented gritty and pebbly sandstone) and lacustrine thin-bedded fine-grained sediments. A comparable association of lithologies occurs near 'Nilpinna', where thin-bedded, fine-grained clastics appear to have accumulated in a proglacial lake. These sediments sometimes contain ice-rafted clasts of Adelaidean siltstone and sandstone, 10-20 mm in size. An area of diamictite, 7 km northwest of 'Nilpinna', may represent part of a moraine behind which the proglacial lake formed.

The Permian outcrops along the eastern margin of the Arckaringa Basin include sediments of undisputed glacial origin, and for this reason were correlated with Boorthanna Formation (Townsend and Ludbrook, 1975) although there is no palaeontological evidence to support this correlation. However, dark grey, carbonaceous, finely micaceous siltstone exposed in a cliff section adjacent to Anna Creek, WSW of Mount Anna, contains a Stage 3b palynoflora, implying a correlation with upper Mount Toondina Formation (Alley, 1991b). The preferred interpretation of the outcropping Permian sediments is that they are glacial and glacio-lacustrine deposits of Boorthanna Formation which are onlapped by lacustrine sediments of Mount Toondina Formation in the Mount Anna area.

It is possible that the outcropping Boorthanna Formation post-dates the main Boorthanna glacial period, which was a time of glacial erosion rather than deposition on the northeastern Arckaringa Basin margin. The extent of this erosion is revealed in the Boorthanna railway bore which intersected a Permian sequence about 250 m thick in close proximity to Adelaidean outcrop. In late Boorthanna time, the continental ice sheet may have retreated from the Arckaringa Basin with only small remnants remaining along the northeastern margin, possibly as valley glaciers in the vicinity of which the outcropping Boorthanna Formation was deposited. These deposits do not appear to be continuous with the Boorthanna Trough sequence, as indicated by their absence in Boorthanna railway bore.

Late Palaeozoic-Early Mesozoic

Mount Margaret Surface (pe_1)

Remnants of this ancient erosional peneplain are preserved on resistant Adelaidean and Early Palaeozoic rocks in the Davenport Range. One group of peneplain remnants extends from the Mount Fox area (390-420 m AHD) to Rockwater Hill (about 180 m), and is developed on Mount Margaret Quartzite and Bungadillina Monzonite. This geomorphological feature has been termed the Mount Margaret Plateau (Wopfner, 1968) of which Mount Margaret itself is a separate small outlier. Wopfner (1968) recorded float of Early Cretaceous Mount Anna Sandstone Member on the southern part of the plateau.

Another large remnant of the Mount Margaret Surface occurs in the Mount Anna area, at an altitude of about 200 to 230 m. It is developed mainly on the quartzitic basal member of Skillogalee Dolomite, and is overlain by Late Jurassic-Early Cretaceous Algebuckina Sandstone and Mount Anna Sandstone Member.

The Mount Margaret Surface has a veneer of Quaternary material (Qpr_2) comprising a lag, of large angular clasts derived from the underlying Adelaidean or Early Palaeozoic units, which rests on red-brown, sandy and gritty, gypsiferous clay. Wopfner (1968) noted the similarity between this Quaternary overlay and the gypsite surfaces that form the plain to the east, and he interpreted the Mount Margaret Surface as a gypsite surface that was upfaulted during the Pleistocene.

However, the stratigraphic relationships of the surface indicate a much older age, broadly constrained by the ages of the youngest underlying unit (Bungadillina Monzonite-Early Palaeozoic) and the oldest overlying unit (Algebuckina Sandstone-Late Jurassic). It is likely that the Mount Margaret Surface was formed during the period of weathering and erosion represented by a widespread zone of alteration in rocks underlying Algebuckina Sandstone. The youngest rocks affected by this alteration are of Early Permian age (e.g. glacial sediments at Mount Dutton; Heath, 1965). This suggests that the age of the Mount Margaret Surface lies between the Early Permian and Late Jurassic.

Mesozoic

WARRINA lies in the southwestern part of the Mesozoic Eromanga Basin, and contains sediments belonging to the lower (Late Jurassic-Early Cretaceous) part of the marginal basin sequence. These comprise Algebuckina Sandstone, Cadna-owie Formation (including Mount Anna Sandstone Member), Bulldog Shale, Coorikiana Sandstone and Oodnadatta Formation. The older units are well-exposed in places around the Davenport and Denison Ranges where they form a roughly concentric outcrop pattern with age increasing towards the ranges, reflecting post-depositional uplift. Numerous drillholes have penetrated the Mesozoic sequence, but sediments were generally not cored and detailed stratigraphic information is scarce. Palynological zonations of Helby *et al.* (1987) are used in these notes (Fig. 5).

Algebuckina Sandstone (J-Ka)

The basal unit of the marginal Eromanga Basin sequence is the Algebuckina Sandstone (Wopfner *et al.*, 1970) which outcrops extensively around the margins of the ranges, and rests on the Mount Margaret Surface in the Mount Anna area (Fig. 6). The formation occurs in the subsurface over most of the remainder of WARRINA, except along part of the southern margin of the sheet area and over bald-headed basement highs on Umbum. Thickness ranges from 10 m in Australian Selection MU 9 drillhole (Oolgelima) to 69.1 m in Chevron LHDH 1, east of the Davenport Range.

Algebuckina Sandstone is a fluvial unit composed mainly of fine to very coarse quartz sandstone with layers of rounded granule to cobble-sized clasts, predominantly of quartz with minor weathered Adelaidean clasts and porphyry, and mudstone intraclasts. Layers of claystone, siltstone and very fine sandstone are also present. Cross-bedding is widespread, with medium to large scale tabular and trough cross-bed sets commonly separated by gravel layers. The top of the unit is frequently silicified or cemented with carbonate. Outcropping Algebuckina Sandstone on WARRINA can be divided into a lower part of kaolinitic, pebbly sandstone and an upper part of clean, well sorted sandstone, as in the type section at Algebuckina (OODNADATTA) (Wopfner *et al.*, 1970).

The mineralogical maturity and abundant kaolin matrix of the lower Algebuckina Sandstone reflects the deep weathering of source rocks which occurred during the formation of the Mount Margaret Surface. Deposition probably occurred in an environment of large meandering or braided rivers flowing in a landscape of low to moderate relief. A moderate flow velocity is suggested by common tabular cross-bed sets which were probably formed by migrating sand waves. Periodic stronger flows, indicated by large-scale trough cross-bedding and conglomerate layers, may have been due to occasional rainstorms in an arid or semi-arid environment or, more likely, to seasonal melting of snow. The upper part of Algebuckina Sandstone was deposited by rivers of stronger, more uniform flow, as indicated by abundant large-scale trough cross-bedding, paucity of fines and absence of conglomeratic beds. This suggests a wetter climate with more uniform precipitation (Wopfner *et al.*, 1970; Krieg *et al.*, 1991).

The silicified top of Algebuckina Sandstone, about 3 km southwest of Mount Anna contains fossil leaves of ferns (*Cladophlebis* cf. *australis*, *Hausmannia* cf. *buchii*, *Microphyllopteris minuta*), a seed fern (*Rienitsia variabilis*), bennettites (*Otozamites* sp., *Ptilophyllum* sp.) and a conifer (*Brachyphyllum* sp.) (Harris, 1962; Hopgood, 1987). Some of the forms present at Mount Anna, in particular *Rienitsia variabilis*, are characteristic of the *Phyllopteroides laevis* megafloral zone of Cantrill and Webb (1987) which has been assigned a Neocomian age. Hopgood (1987) suggested that the Mount Anna flora may have grown in a subtropical to cool-temperate climate, with the presence of conifers possibly indicating warm-temperate to cool-arid conditions.

The only palynological dating of Algebuckina Sandstone on WARRINA comes from a siltstone layer in Ruby Hill 1, which was correlated with the lower *Cicatricosisporites australiensis* spore-pollen Zone, indicating a latest Jurassic to early Neocomian age (Alley, 1991a). Elsewhere along the southwestern margin of the Eromanga Basin, palynofloras from Algebuckina Sandstone can be placed in the *Retitriletes watherooensis* and *Cicatricosisporites australiensis* Zones, of Late Jurassic (Tithonian) to early Neocomian age (Alley, 1985, 1987). These palynofloras are dominated by conifers, with ferns, club-mosses and bryophytes also represented. This vegetation association suggests high rainfall and cool temperate to temperate conditions. The presence of pollen related to the sub-alpine conifer *Microcachrys* suggests that vegetation in nearby uplands was adapted to cool to cold conditions (Krieg *et al.*, 1991). These observations are in accord with palaeogeographic reconstructions based on palaeomagnetic data (Embleton, 1984) which place the southwestern Eromanga Basin in high latitudes (60°-70° S) throughout the Early Cretaceous.

Cadna-owie Formation (Knc)

Algebuckina Sandstone is disconformably overlain by the Cadna-owie Formation (Wopfner *et al.*, 1970) which marks the onset of Early Cretaceous marine transgression, thus forming a transition between the underlying fluvial Algebuckina Sandstone and the overlying marine Bulldog Shale. Cadna-owie Formation has a similar distribution to Algebuckina Sandstone. Thickness is typically between 6.5 m (BHP WLE 2) and >50.3 m (Chevron LHDH 2).

The formation consists mainly of silty and clayey, very fine to medium quartz sandstone with thin interbeds of claystone and siltstone, and irregular layers and lenses of pebbly, medium to very coarse sandstone. Detrital feldspar, muscovite and carbonaceous material are common to abundant. Rounded clasts of Adelaidean quartzite, sometimes exceeding 1 m in size, occur in the lower part of the formation. Sedimentary structures include planar lamination and very thin bedding, cross-lamination and bedding, flaser and wavy bedding, and bioturbation. Other lithological features are extensive ferruginisation (probably from oxidation of pyrite), and carbonate cementation which is particularly prominent as coarsely crystalline calcite cementing sandstone at the top of the formation.

Cadna-owie Formation was deposited in a variety of environments which formed along the advancing coastline. Environments which have been interpreted for the formation on WARRINA and at other locations along the southwestern basin margin include near offshore, shoreface and foreshore, marine shoal or lagoonal shoreline, intertidal, high energy beach, and back barrier lagoon or coastal marsh (Wopfner *et al.*, 1970; Krieg *et al.*, 1991).

The only palynological dating of Cadna-owie Formation on WARRINA comes from Ruby Hill 1 which yielded an assemblage assignable to the *Cyclosporites hughesii* spore-pollen Zone and *Odontochitina operculata* microplankton Zone, indicating an early to middle Aptian age (Alley, 1991a). Palynofloras from the Cadna-owie Formation type section are correlated with the lower *C. hughesii* Zone (Alley, 1988), and assemblages from Toodla 1 drillhole are placed in the *C. hughesii* and *O. operculata* Zones (Alley, 1985).

Palynological studies of Cadna-owie Formation from deeper parts of the basin in northeast South Australia place the bulk of the unit in the *Foraminisporis wonthaggiensis* spore-pollen Zone of Neocomian to Barremian age (Dettmann and Williams, 1985). Thus, only the youngest part of the Cadna-owie Formation, deposited during an early Aptian marine transgression, appears to be present in the WARRINA-OODNADATTA area.

Conifer pollen is common in the palynofloras from the Cadna-owie type section and Toodla 1, but is reduced when compared with palynofloras from Algebuckina Sandstone. This decrease is matched by a relative increase in spores of tree ferns, ferns, club mosses and bryophytes. There is also a decrease in the more temperate conifer species such as the *Araucaria* group and the podocarps, while pollen related to the sub-alpine *Microcachrys* increases significantly in the Cadna-owie (Krieg *et al.*, 1991). These changes may imply a shift towards colder temperatures and an increase in precipitation or a decrease in evapo-transpiration. The inferred deterioration in climate agrees with the concept of seasonal freezing of rivers and coastal sea water, and emplacement of the large boulders by ice rafting (Frakes and Francis, 1988).

Mount Anna Sandstone Member (Knca)

The Mount Anna Sandstone Member (Wopfner *et al.*, 1970) is a fluvial sandstone and conglomerate unit of the Cadna-owie Formation which occurs on the southwestern margin of the Eromanga Basin. On WARRINA, the member occurs west and southwest of the Davenport Range. There are also remnants within the range notably in the Mount Anna area, where it overlies Cadna-owie Formation or may rest directly on the Mount Margaret Surface. Mount Anna Sandstone Member extends to the eastern margin of the ranges but is not seen in drillholes further east.

The Mount Anna Sandstone Member interfingers with the upper part of Cadna-owie Formation (Wopfner *et al.*, 1970). Along the southern margin of Boorthanna, the member unconformably overlies Early Permian Mount Toondina Formation, and occupies the entire Cadna-owie interval. Here, it reaches a maximum thickness of 72 m (CRAE 83 LCR1). The member thins northwards, and is 11 m thick at the Mount Anna type section where it overlies 13.3 m of Cadna-owie Formation (Fig. 6). The northernmost occurrence of the member is at the Cadna-owie type section where it is represented by about 0.3 m of pebbly sandstone.

Mount Anna Sandstone Member is a well sorted, medium to coarse feldspathic quartz sandstone with rounded pebbles and cobbles, predominantly of partly weathered porphyritic rhyolite along with quartz, jasper and quartzite, forming layers with a coarse sand to granule matrix, or occurring as scattered clasts. Petrographic studies indicate that the rhyolite pebbles are derived from the Gawler Range Volcanics (Wopfner *et al.*, 1970). Large-scale trough cross-bedding is the predominant sedimentary structure. The sandstone is frequently cemented by carbonate (calcite) and the top of the unit is usually ferruginised.

The member is interpreted as a high-energy fluvial unit deposited in a large river system that drained in a northerly direction from the Lake Gairdner region of the southwestern basin margin. Tectonic uplift of the Mesoproterozoic Gawler Range Volcanics in this area of the Gawler Craton bordering the Eromanga Basin caused large quantities of clastics, including rhyolite clasts, to be eroded and transported northwards. The fluvial sediments extended as far as the northern and eastern margin of the Peake and Denison Inliers where they were intercalated with marginal marine sediments of upper Cadna-owie Formation. It is likely that the inliers existed as a moderate topographic high which marked the position of the coastline in late Cadna-owie time.

Mount Anna Sandstone Member contains no age-diagnostic fossils. However, its interfingering relationship with the upper part of Cadna-owie Formation indicates an early Aptian age.

Bulldog Shale (Kmb)

Cadna-owie Formation and Mount Anna Sandstone Member are conformably overlain by Bulldog Shale (Freytag, 1966). This unit outcrops extensively on WARRINA, and covers most of the 'bald-headed' Palaeoproterozoic basement highs east of the northern Davenport Range. A small remnant, resting on Mount Anna Sandstone Member, forms the summit of Mount Anna in the southern Davenport Range. Maximum thickness of Bulldog Shale on WARRINA is 198.7 m (top eroded) in Sunny Creek Bore (Anna Creek). In a reference section (Freytag, 1966) at Edith Spring (Umbum), steeply-dipping basal Bulldog Shale sharply overlies Cadna-owie Formation in a fault-bounded block.

Bulldog Shale is predominantly a medium to dark grey clayey and silty mudstone with thin laminae and lenticles of pale grey and yellow-grey, finely micaceous coarse silt and very fine sand. The fine sandy lenticles are up to about 10 mm thick and may be cross-laminated. The sediment is moderately bioturbated and contains small carbonaceous fragments. Large, ellipsoidal fossiliferous calcareous concretions, cone-in-cone limestone, gypsum veins, and minor celestite-barite are also present.

The lower part of the formation is characterised by the presence of numerous well-rounded clasts, mainly of Adelaidean quartzite, but including siltstone, porphyritic rhyolite and rare fossiliferous Devonian quartzite. The clasts range from pebbles to boulders up to 1 m in size and are usually associated with thin layers of coarse quartz sand to granules, but may also occur as 'lonestones'. The Devonian clasts are interpreted to have been derived from the Amphitheatre Group and Mulga Downs Formation of northern New South Wales (Flint *et al.*, 1980).

The lower Bulldog Shale was mapped separately as an 'unnamed transitional unit' on southeastern MURLOOCOPPIE, where its top is marked by a persistent, brown-weathering limestone horizon (Pitt, 1976). The lower part of Bulldog Shale is also recognised in the adjacent Oolgelima area of

WARRINA, but is not mapped as a separate unit. It is marked by an extensive lag gravel of rounded Adelaidean quartzite clasts, and by the presence of a distinctive thin mudstone to very fine sandstone with a coarsely crystalline calcite cement, and common fossil wood. Similar basal Bulldog facies are seen east and west of the ranges.

The upper part of Bulldog Shale contains a higher proportion of coarse silt to fine sand (up to about 50%). Sections in this part of the unit consist of mudstone with thick wavy laminae of coarse silt to fine sand. The formation in the Sunny Creek bore area (Anna Creek) contains thin irregular grit beds composed of angular to subrounded quartz grains ranging from coarse sand to granules.

The calcareous concretions in Bulldog Shale are frequently fossiliferous, with a macrofauna of bivalves, belemnites, less common gastropods, and rare ammonites, scaphopods, brachiopods and fish scales. Fossil wood and reptilian bone fragments are also present. Ludbrook (1966) described these macrofaunas and assigned them Aptian and Albian ages. McNamara (1980) described a fauna of ammonites from the Primrose Hill area (Umbum) and assigned late Aptian, middle Albian and late Albian ages to various elements of the fauna, the youngest of which may be from the Oodnadatta Formation. In addition, McNamara (1985) assigned a middle to late Albian age to the ammonite *Naramoceras* (*Falciferella*) *breadeni* found in the Peake Ruins (Warrina) and Wood Duck Creek (Umbum) areas.

Bulldog Shale in Cootanoorina 1 contains microfaunas of agglutinated and calcareous foraminifera which includes zonal species of the *Trochammina raggatti* - *Textularia anacooraensis* and *Hergottella jonesi* Zones of Ludbrook (1966) (Allchurch *et al.*, 1973). Ludbrook assigned early to late Aptian ages to these zones. Outcrops in the Peake Ruins and Wood Duck Creek areas contain *Verneuilina howchini* which is restricted to the *V. howchini* - *Trochammina flosculus* Zone of late Aptian to late Albian age (Ludbrook, 1966).

Palynological studies indicate that the lower part of Bulldog Shale, correlated with the *Cyclosporites hughesii* spore-pollen Zone and the *Odontochitina operculata* and *Diconodinium davidii* microplankton Zones, is present in Cootanoorina 1 and Ruby Hill 1 drillholes (van Niel, 1984; Alley, 1991a), and in outcrop near Hawker Spring and Lagoon Hill (Alley, 1989). Samples from the Primrose Hill area, correlated with the *Crybelosporites striatus* and *Coptospora paradoxa* spore-pollen Zones, are interpreted to come from middle to uppermost parts of the unit. A hiatus occurs in the middle part of Bulldog Shale in Toodla 1 and may also be present in the Primrose Hill area (Alley, 1985, 1993). This hiatus has been recorded elsewhere in the southern Eromanga Basin (Dettman and Williams, 1985), and may be related to a latest Aptian-earliest Albian regression in the sea level curve of Morgan (1980).

Bulldog Shale was deposited in a predominantly low to moderate energy, shallow marine environment during a period of maximum marine transgression. The bioturbated mud was deposited from suspension below normal wave base, and the silt-fine sand layers probably represent deposition from currents and waves generated by storms. Shell beds and thin pebbly and cobbly grit horizons may have been formed during less frequent but more intense storms.

The large boulders in the lower part of the formation were previously considered to have been emplaced by ice rafting, tree rafting, slow sediment creep, or debris flows (Wopfner *et al.*, 1970; Flint *et al.*, 1980). Palaeogeographic and other evidence supports the idea that the boulders and other clasts were emplaced by ice-rafting in a continuation of the processes that emplaced similar clasts in the Cadna-owie Formation (Frakes and Francis, 1988). Rounded Adelaidean quartzite clasts on high energy shorelines or in high gradient rivers were incorporated in ice rafts during periods of seasonal freezing. As the ice rafts drifted offshore and melted, their coarse sediment would have dropped into the seafloor mud, and further reworking may have occurred during intense storms. Further evidence for seasonal coldness comes from glendonites, calcite pseudomorphs mainly after ikaite, found in Bulldog Shale near the northeastern margin of the Flinders Ranges and elsewhere (Sheard, 1990), and fossil tree ring studies (Frakes and Francis, 1990).

Palynofloras in the lower part of Bulldog Shale are comparable with those in the Cadna-owie. Conifers were still abundant, although the *Araucaria* group was greatly diminished. The podocarps increased in relative frequency. Significantly, the sub-alpine *Microcachrys* continued as an important part of the flora (Krieg *et al.*, 1991).

The absence of large clasts in upper Bulldog Shale indicates that ice rafting did not occur during this phase of deposition. Further evidence for an amelioration in climate is provided by palynological studies. The sub-alpine *Microcachrys* decreases significantly in the upper part of the formation, while ferns exceed the frequency of conifers in some samples (Krieg *et al.*, 1991). A belemnite (*Peratobelus oxys*) from Primrose Springs produced an average oxygen isotope palaeotemperature of 13.8° C, with a range of 9°-17.5° (Dorman and Gill, 1959).

The lithology of the upper part of the formation suggests also a fall in relative sea level. The increase in the frequency of silt-fine sand laminae is probably a response to increasing wave and current activity in a shallower sea. Microplankton components of palynofloras also point to regressive conditions in upper Bulldog Shale as, for example, in Toodla 1 (Alley, 1985).

Shoreline features at Lagoon Hill

An exhumed, polished and grooved surface developed on Palaeoproterozoic basement at Lagoon Hill (Umbum) was previously interpreted as a glaciated surface of probable Early Permian age (SADME Annual Report 1987-88, p.25). An alternative interpretation is that it is a joint surface that was smoothed by wave action during the Early Cretaceous, and later modified by the development of desert varnish and shallow sub-horizontal grooves during the Quaternary. The grooves may have formed at consecutive subsurface weathering fronts as the land surface was lowered by erosion, in a manner similar to the formation of flares in granitic rocks (Twidale, 1982).

The basement inliers at Lagoon Hill are onlapped by Bulldog Shale which is generally a silty and very fine sandy mudstone with calcareous concretions containing molluscs and microplankton of Aptian age (J.G.G. Morton, SADME, pers. comm., 1988; Alley, 1989). A shallow water, low energy marine environment of deposition is interpreted.

However, adjacent to the basement outcrop, Bulldog Shale includes a sequence of thin coquinite resting on large rounded basement clasts, which is interpreted as a high-energy, boulder beach facies. The coquinite is 0.5 to 1 m thick and is composed of shell fragments and shells, wood fragments and well rounded pebbles. The fauna includes bivalves (*Inoperna rugocostata, Maccoyella* spp.), belemnites (*Peratobelus*? sp.), brachiopods (*Australiarcula artesiana*) and abundant crinoid ossicles (*Isocrinus australis*) (J.G.G. Morton, SADME,pers. comm., 1988). The boulder beach facies is at the same level as the smoothed joint surface immediately to the north and it is suggested that both features were formed by high-energy shore processes during the Aptian. Nearby flat-topped basement outcrops may be remnants of a wave-cut platform.

Further transgression in Bulldog time resulted in deposition of at least 10 m of mudstone above the boulder beach horizon. Transgression may have been more extensive, as rounded clasts occur above the present upper limit of Bulldog Shale outcrop, and the sea may have entirely covered the basement highs.

Beach deposits and possible wave-modified surfaces have also been seen at Spring Hill (Umbum), and Cretaceous wave-polished surfaces have been described from the northeastern end of the Flinders Ranges (Sheard and Flint, 1992).

Coorikiana Sandstone (Kmc)

Bulldog Shale is conformably overlain by Coorikiana Sandstone (Freytag, 1966; Moore and Pitt, 1982). This unit can be traced between Sunny Creek (Anna Creek) and Neales River (Umbum), on the eastern margin of WARRINA. A large area of outcropping Coorikiana Sandstone on Anna Creek is interpreted as a downfaulted block, and outcrops along the Neales River appear to be isolated fault blocks related to the Lake Eyre Fault. The only drillhole intersection of the formation on WARRINA is in Chevron LHDH 13 (Anna Creek) where it is represented by 16.8 m of interlayered grey-green fine sandstone and grey to dark grey siltstone and shale.

In outcrop, Coorikiana Sandstone is predominantly a yellow-grey to green-grey, micaceous, very fine to medium sandstone with very thin to thin planar bedding and large-scale, low-angle, trough cross-bedding. Other features include symmetrical wave ripples and interference ripples, abraded and aligned wood and plant fragments, mudstone intraclasts, trace fossils and irregular, tabular zones of carbonate cementation.

The formation is sparsely fossiliferous, and only rare belemnites were noted during field mapping. Ludbrook (1966, p.52) recorded a fauna of bivalves from Coorikiana Sandstone west of Wood Duck Creek, to which she assigned an Aptian age. There is no other biostratigraphic information for the unit on WARRINA, but palynological studies elsewhere in the basin placed Coorikiana Sandstone in the *Coptospora paradoxa* spore-pollen Zone and the *Pseudoceratium ludbrookiae, Canninginopsis* *denticulata* or *Muderongia tetracantha* microplankton Zones (Moore *et al.*, 1986; Alley, 1985; Krieg *et al.*, 1991). These zonations indicate a middle Albian age.

The Coorikiana Sandstone is a widespread regressive unit of the southwestern Eromanga Basin margin that was deposited in response to a eustatic fall in sea level (Morgan, 1980). The formation was deposited in a predominantly intermediate wave energy beach face environment. Thin planar-bedded and low-angle cross-bedded sandstone is interpreted as a shoreface or foreshore deposit of a beach or barrier island environment, while ripple laminated and bioturbated sandstone probably formed in a low-energy shoreface environment. Claystone overlying cross-bedded sandstone west of Wood Duck Creek (Umbum) is interpreted as a back barrier lagoonal deposit.

Oodnadatta Formation (Kmo)

The Oodnadatta Formation (after Freytag, 1966) is restricted to the eastern extremity of WARRINA, between Sunny Creek (Anna Creek) and Neales River (Umbum). A small, gypsite-capped outlier rests on the downfaulted block of Coorikiana Sandstone on Anna Creek, where the only drillhole section of the formation on WARRINA, in Chevron LHDH 13, consists of 6.1 m of grey to dark grey shale and siltstone. Oodnadatta Formation sediments also occur on the north bank of Neales River on the western margin of LAKE EYRE, and these probably extend into the northwesternmost corner of WARRINA.

Only the lowermost part of Oodnadatta Formation is present on WARRINA. The unit is generally poorly exposed, and outcrops consist of laminated to very thin bedded, yellow-grey and pale grey, micaceous siltstone, very fine sandstone and claystone. Oodnadatta Formation is well exposed at the junction of George and Umbum Creeks, 0.4 km east of the sheet boundary, where it comprises medium beds of siltstone to very fine sandstone interlayered with lenticular bedded and bioturbated mudstone and siltstone-very fine sandstone. The former show parallel and hummocky cross-lamination passing up to ripple cross-lamination. The sequence includes a 0.5 m bed of calcareous very fine to fine sandstone with large-scale, low-angle cross-bedding. Also present are elliptical calcareous concretions with *Inoceramus* fragments.

There is little biostratigraphic information for the Oodnadatta Formation on WARRINA. The unit contains bivalves (including *Inoceramus*) and belemnites of Albian age (Ludbrook, 1966). It is possible that some of the elements of the Primrose Hill ammonite fauna described by McNamara (1980), in particular the late Albian species *Anisoceras sweeti*, are from lower Oodnadatta Formation outcrops along the Neales River near the WARRINA-LAKE EYRE boundary. Palynofloras from this area have been correlated with upper *Coptospora paradoxa* spore-pollen Zone (Alley, 1993).

Elsewhere in the Eromanga Basin, Oodnadatta Formation contains palynofloras belonging to the upper *Coptospora paradoxa* and *Phimopollenites pannosus* spore-pollen Zones, and the *Canninginopsis denticulata* and *Pseudoceratium ludbrookiae* microplankton Zones (Moore and Pitt, 1985; Alley, 1985; Krieg *et al.*, 1991). These zonations indicate a middle to late Albian age.

The lower Oodnadatta Formation on WARRINA was deposited in a shallow marine shelf environment, with frequent episodes of high energy storm-generated wave and current activity marked by the parallel laminated and hummocky/ripple cross-laminated beds. Shoreface beach or bar sandstone units are also present. The lower part of the formation was deposited at the beginning of a transgressive phase that followed the Coorikiana regression. Depositional conditions were similar to those for upper Bulldog Shale, with water depths being perhaps even shallower.

Tertiary

Tertiary sediments on WARRINA are limited to the terminus of the Mirackina Palaeochannel, and scattered small outcrops of silcrete and clastic units, mainly around the margins of the ranges. Lacustrine limestone near Oolgelima Hill and Douglas Creek may also be of Tertiary age.

Mirackina Conglomerate and equivalents (Temm)

The Mirackina Palaeochannel (Barnes and Pitt, 1976) was formed by a Cainozoic palaeodrainage system that extended in a south-easterly direction through the WINTINNA and MURLOOCOPPIE sheet areas (Fig. 7). The palaeochannel is preserved as a series of silcrete-capped mesas of partly silicified and ferruginised fluvial channel sediments named the Mirackina Conglomerate (Barnes and Pitt, 1976). The formation generally consists of a basal conglomerate overlain by cross-bedded, medium to coarse quartz sandstone with conglomerate layers.

The Miracksina Palaeochannel becomes considerably broader near the WARRINA-MURLOOCOPPIE boundary, as it approaches its southwestern limit. Here, between Mount Euee and Derangunabula Hill (Oolgelima), the Tertiary sequence is up to about 15 m thick and consists mainly of variably silicified and ferruginised siltstone to very fine sandstone, with local channel fills of granule to boulder-sized silcrete clasts. Sections unconformably overlie weathered and locally silicified Bulldog Shale. The Tertiary sections on WARRINA contain a much higher proportion of fine-grained sediment than the more confined Mirackina Conglomerate channel facies seen further upstream, and were probably deposited in a floodplain environment.

Elsewhere, equivalents of Mirackina Conglomerate include small outcrops of Tertiary sediments scattered around the margins of the ranges, and in the Four Hills area (northeastern Anna Creek). The Four Hills sections are up to about 20 m thick and comprise pale grey and yellow-grey siltstone, very fine sandstone, claystone, pebbly very coarse sandstone and grit composed of rounded silcrete grains, and a basal silcrete pebble layer. The upper parts of the sections are bleached, fractured and silicified, and are capped by silcrete with 'reed mould' structures. A similar silcrete rests on silicified and ferruginised claystone at Davenport Creek (Anna Creek), which also has a basal conglomerate of rounded silcrete clasts. There are minor outcrops around the margins of the ranges of dark, ferruginous, medium to very coarse quartz sandstone with angular to rounded clasts of silcrete, quartz, quartzite and silicified mudstone. Impressions of plant fragments are also present.

There is little evidence for determining the age of the Mirackina Conglomerate and its equivalents. The Mirackina Palaeochannel has cut into the main silcrete surface in the WINTINNA area, and its deposits are in turn capped by a younger silcrete. In South Australia, there appears to have been two main phases of pedogenic silcrete development, with interpreted ages of Late Eocene - Middle Miocene and Late Miocene - Pleistocene (Benbow *et al.*, in prep.). This suggests an Eocene to Miocene age for the Mirackina Conglomerate and its equivalents.

Lacustrine limestone units (Tem_3)

In the Douglas Creek area (Anna Creek), a dissected, low-lying, resistant carbonate sheet about 1 m thick is composed of white, cream, pale grey, brown and pink, vughy, microcrystalline limestone. The limestone contains very coarse sand to granule-sized angular quartz grains, and larger clasts of Adelaidean lithologies, silcrete, iron oxide and silicified mudstone, and limestone intraclasts.

The limestone sheet is associated with local occurrences of ferruginous fine sandstone which are interpreted as coeval channel infills. The sandstone is correlated with Mirackina Conglomerate, suggesting an Eocene to Miocene age for the carbonate unit.

The main area of limestone outcrop overlies the contact between Bulldog Shale and Cadna-owie Formation/Mount Anna Sandstone Member. It is suggested that the carbonate was deposited in a lake fed by springs discharging from this aquiclude/aquifer contact. Sand and gravel were carried into the lake by streams. The limestone at Douglas Creek is similar in lithology and interpreted mode of origin to the limestone of the Alberrie Creek plateau on CURDIMURKA, interpreted to be of Miocene to Pleistocene age (Krieg *et al.*, 1991).

A thin, dissected sheet of limestone at Oolgelima Spring, on the southwestern margin of Lake Cadibarrawirracanna, is related to spring discharge along the Oolgelima Fault, and may be coeval with the limestone at Douglas Creek. The limestone is well-indurated, pale brown and pale grey, and microcrystalline, with calcareous coarse to very coarse sandstone and grit.

Silcrete (Tem_{si1}, TmQ_{si1})

Silcrete on WARRINA caps units of Adelaidean, Early Cretaceous and Tertiary age, and occurs as clasts in Tertiary and Quaternary sediments. Most of this is pedogenic silcrete, although there are some minor occurrences of groundwater silcrete.

Sediments underlying the silcrete caps are usually deeply weathered. Bleaching, caused by alteration of clay minerals to kaolinite, characterises the upper part of the weathering profile, and accumulations of iron oxide occur in the lower part of the profile. Sediments at the top of the profile are generally fractured, brecciated and silicified.

The stratigraphic distribution of silcrete on WARRINA, as elsewhere in South Australia (Benbow *et al.*. in prep.), suggests that there have been two main phases of formation of silcrete duricrusts and associated deep weathering profiles. The earlier phase (Tem_{si1}) is represented by silcrete clasts in Tertiary Mirackina Conglomerate equivalents. The younger phase (TmQ_{sil}) formed silcrete caps on these sediments. Silcrete caps on Early Cretaceous and older units are placed in Tem_{sil} but some of these may belong to the younger phase of silcrete formation (TmQ_{sil}), and others may be pre-Tertiary.

Quaternary

A wide variety of Quaternary units covers almost all of WARRINA, the most extensive being a regolith of gravelly colluvial deposits. Alluvial channel, fan and floodplain deposits record several episodes of fluvial activity during the early Pleistocene to Holocene. Gypsite crusts cap some of the older alluvial deposits and associated pediment surfaces. Aeolian dunes were formed largely during the last glacial period of aridity. Other units include lacustrine and associated deposits (notably at Lake Cadibarrawirracanna), and mound spring deposits.

Older fluvial units (Qpa_2, Qpa_3, Qpa_4, Qa_3)

Qpa_2

The oldest Quaternary fluvial sediments on WARRINA are channel deposits of unit Qpa_2. This unit is low in the landscape, and occurs adjacent to major watercourses draining the eastern side of the ranges, notably Davenport and Douglas Creeks (Anna Creek). Where Douglas Creek emerges from the Davenport Range, unit Qpa_2 forms a palaeochannel remnant with inverted relief. In the Douglas Creek area, unit Qpa_2 is overlain by gypsite (Qp_{gyl}) and aeolian sand (Qe_1). Fluvial sediments at the base of the gypsite surface north of the Neales River are also placed in unit Qpa_2.

Unit Qpa_2 consists of coarse to very coarse quartz sandstone and grit, and conglomerate composed of clasts of Adelaidean lithologies, silcrete, quartz and weathered Mesozoic mudstone. The sediments are cross-bedded, and cemented with carbonate or crystalline gypsum. Locally, the coarse channel deposits are underlain by mottled pale red-brown and grey claystone to pebbly very fine sandstone. Thickness ranges from 5 m at the eastern margin of Davenport Range to about 1 m near the eastern boundary of WARRINA. Maximum clast size also decreases downstream from about 0.3 m at the range front.

Channel deposits of Early or Middle Pleistocene age from upper Willawortina Formation (Callen and Tedford, 1976) and Telford Gravel (Firman, 1967) on the margins of the northern Flinders Ranges are likely equivalents of unit Qpa_2 on WARRINA. Another probable equivalent is the Katipiri Formation, a channel sand deposit of the Lake Eyre Basin (Callen *et al.*, 1986). Thermoluminescence dating of this unit has indicated fluvial episodes of penultimate interglacial (c. 270-220 ka) and last interglacial (c. 120-90 ka) ages (Nanson *et al.*, 1992).

Qpa_3 and Qpa_4

These units form dissected, low-angle, piedmont alluvial fans adjacent to the sharply upfaulted eastern margin of the Davenport Range, between Levi and Hope Creeks. Small eroded remnants of the unit also occur within the Davenport Range.

Units Qpa_3 and Qpa_4 consist of coarse gravel composed of various Adelaidean lithologies. Thickness ranges from 1 to 8 m, and maximum clast size is about 0.3 m. The older unit (Qpa_3) has a pale brown, gypsiferous, sandy matrix, with gypsum crusts coating clasts, and local irregular carbonate layers. Unit Qpa_4 has a similar gypsiferous matrix, with a higher proportion of red-brown silt.

The gravel units were deposited in the channels of braided streams that built up the alluvial fans. Units Qpa_3 and Qpa_4 are tentatively correlated with Late Pleistocene fan deposits described by Williams, G.E. (1973) from the western margin of the northern Flinders Ranges. These deposits, correlated with the Pooraka Formation (Firman, 1966), were interpreted to have been laid down between *c.* 30 000 years BP and >38 000 years BP from radiocarbon dating of carbonised wood and pedogenic carbonate (Williams and Polach, 1971; Williams, G.E., 1973). Williams interpreted a cold, arid palaeoclimate for the periods of fan deposition, with large quantities of detritus washed from the poorly vegetated ranges during brief periods of very high rainfall. The piedmont fans are probably related to the phase of fluvial activity dated at *c.* 50 000-30 000 years BP in the Lake Eyre Basin and southeastern Australia (Nanson *et al.*, 1992). Unlike the Late Pleistocene fans of the northern Flinders Ranges, the older fan deposits on WARRINA can be readily separated into two units, with the older unit (Qpa_3) being more elevated and dissected than unit Qpa_4. This suggests an intervening tectonic event, which affected the drainage gradient between Davenport Range and Lake Eyre North.

Qa_3

This is a widespread unit, forming broad, low-angle to flat gravel spreads mainly east of the ranges, and adjacent to the Arckaringa, Peake and Lora Creeks. It also forms terraces incised in older fan deposits (Qpa_3 and Qpa_4) on the eastern margin of Davenport Range. Unit Qa_3 is dissected by the modern watercourses.

Unit Qa_3 on the eastern margin of the Davenport Range represents a continuation of the low-angle fan deposition that formed units Qpa_3 and Qpa_4. It is a gravel sheet up to about 10 m thick, of similar lithology to the older units, but with a gypsum-free, red-brown, silty and clayey matrix. Its surface is often characterised by a greater development of gilgai and desert varnish coatings on clasts compared with the older gravel units, a result of the higher clay content of the matrix.

On the Eurelyana sheet, unit Qa_3 forms extensive interfluvial areas of gravelly floodplain and channel deposits at least 1.5 m thick. These consist of fine pebbly gravel with red-brown silty clay matrix, and coarser sandy and gritty gravel with large-scale cross-bedding. The gravel component is made up of subangular to well rounded silcrete, porcellanite and iron oxide clasts, derived from weathered Bulldog Shale profiles in the Stuart Range.

Alluvial fan deposits of unit Qa_3 along the eastern margin of the ranges are tentatively correlated with the latest Pleistocene to Holocene Eyre Gravel (Williams, G.E., 1973), described from alluvial fans of the northwestern Flinders Ranges. The Eyre Gravel was divided into two members, deposited between c. 12 000-5 000 years BP, based on radiocarbon dating of charcoal and pedogenic carbonate (Williams and Polach, 1971; Williams, G.E., 1973). The two members of Eyre Gravel are separated by a phase of erosion and soil formation, but this is not observed in unit Qa_3 on WARRINA.

Gypsite Surfaces (Qp_{gy1}, Qp_{gy2}, Qp_{gy})

About 10 to 15 km eastwards from the range front, the gypsiferous alluvial fan gravels (Qpa_3 and Qpa_4) grade into thinner and finer grained distal fan sheetwash/floodplain sediments. Some gravelly channel deposits may be present, e.g. in the Sunny Creek bore-Loudon Spring area (Anna Creek). Beyond the limit of alluvial deposition, the higher land surfaces are pediments formed on Early Cretaceous units.

The dominant feature characterising both the distal fan and pediment surfaces is the formation of gypsite crusts up to 2 m thick, composed of mixtures of crystalline and powdery gypsum. The gypsite crusts were formed largely by pedogenic processes on stable land surfaces elevated above the groundwater table. Most gypsite overlies Bulldog Shale and it is likely that the gypsum was produced in the zone of weathering from intraformational calcium carbonate and iron sulphide. Selenite veins are common in weathered Bulldog Shale, and reworking of these in soil profiles would have formed most of the gypsite, although it is probable that some surficial gypsum is aeolian in origin.

The gypsite surfaces east of the ranges (Qp_{gy1} and Qp_{gy2}) are coeval with the geomorphologically identical alluvial fan surfaces (Qpa_3 and Qpa_4 respectively), suggesting a late Pleistocene age. In this area, and also near William Creek, the gypsite surfaces show the same separation into two distinct levels as the corresponding fan surfaces, suggesting an intervening tectonic event. West of the ranges, however, undifferentiated gypsite surfaces (Qp_{gy}) are more or less at the same level, perhaps reflecting greater tectonic stability.

Aeolian deposits (Qe_1, Qhe)

Large areas of longitudinal and reticulate dunes of pale red-brown quartz sand occur west and south of the ranges, and south of Lake Cadibarrawirracanna. These aeolian deposits are reworked from underlying Mesozoic sand units (Algebuckina Sandstone, Cadna-owie Formation and Mount Anna Sandstone Member). Areas of dunes also occur east of the ranges adjacent to the Neales River; some of these are reworked from Coorikiana Sandstone. The dunes are composed of weakly indurated cores with mobile caps of loose sand.

The aeolian sands on WARRINA have not been dated, but they can be correlated with episodes of dune building established in the major dunefields of central Australia by thermoluminescence and radiocarbon dating. The most extensive chronology of aeolian activity in the central deserts comes from the Strzelecki Desert, where periods of dune building occurred at approximately 243 ka, 167 ka, 89 ka, 40-35 ka, 18-10 ka, and 4 ka to the modern period (Callen *et al.*, 1983; Wasson, 1983; Gardner *et al.*, 1987).

It is likely that only the younger of these dune building periods are represented on WARRINA. The major dune forms and the dune cores probably date back to the last glacial period (40-10 ka), and the mobile dune caps represent periods of reworking during the Holocene that continue to the present day. Holocene reworking has also formed areas of source-bordering dunes (Qhe) adjacent to large watercourses. The younger sands are generally paler in colour than the older dunes as a result of removal of iron oxide and clay coatings on quartz grains during aeolian and fluvial reworking.

The general dune orientation in the WARRINA area is northeasterly. Y-junctions also join in northeasterly directions indicating that the dunes were built up by winds from southerly and westerly quarters. Variations in dune orientation, from 020° west of the ranges to 080° west of 'Anna Creek', appear to be related to diverging wind patterns around the ranges.

Regolith (Qpr_2, Qr)

Unit Qpr_2 is a widespread colluvial unit of red-brown sandy and gravelly silt and clay which is developed primarily on Bulldog Shale and gypsite surfaces, and also on the Mount Margaret Surface. It is equivalent to Benitos Clay, described by Benbow (1983) from the Stuart Range area. The unit is covered with a lag of desert-varnished pebbles and cobbles, mainly of silcrete, with rounded quartzite clasts reworked from Bulldog Shale, and abundant Adelaidean clasts near the ranges. The surface of the colluvial deposits is characterised by abundant gilgai structures, ranging from 'crabholes' on near-flat surfaces to stony terraces on low-angle slopes. These are formed by shrinking and swelling movements of reactive clay soils, related to changes in soil moisture.

In most areas, unit Qpr_2 is a relatively thin unit, generally less than 2 m thick, and is shown as an overlay on older units on the map. In the Mount Euee area, breakdown of silicified Tertiary sediments of the terminal Miracklna Palaeochannel has resulted in the deposition of colluvium up to about 5 m thick. This forms elevated, dissected remnants of an older land surface which may be similar in age to the younger gypsite surfaces.

Other regolith deposits are grouped together as unit Qr. In the Oolgelima area, this comprises thin pale brown silt/clay soil resting on Bulldog Shale, with a veneer of rounded cobbles and boulders of Adelaidean quartzite reworked from Bulldog Shale, and minor silcrete clasts. This unit is lower in the landscape than unit Qpr_2 to the north and south, and is probably younger.

Elsewhere, unit Qr consists of sand and gravel overlays on older Mesozoic units, with a gravel component of rounded quartz pebbles (on Algebuckina Sandstone) and ferruginous clasts (on Cadna-owie Formation and Mount Anna Sandstone Member), and gravel spreads overlying Proterozoic units in the ranges. The latter include quartz gravels, sometimes gypsified, resting on pediment surfaces eroded on Adelaidean rocks southwest of Peake ruins. These gravels comprise angular clasts derived from quartz veins, and rounded pebbles reworked from Algebuckina Sandstone.

Deposits of Lake Cadibarrawirracanna (Qhl_1, Qha_1, Qhe)

Lake Cadibarrawirracanna occupies a Quaternary half-graben or graben with a major northwest-trending fault zone (Oolgelima Fault) controlling its southern shoreline. The lake floor consists of thin (about 1-2 m) deposits of mud of probable Holocene age overlying Bulldog Shale, with only minor development of evaporitic saline crusts (Wyatt, 1980). The western end of the lake is dominated by the delta of Oolgelima and Giddi Giddinna creeks, made up of mud derived from Bulldog Shale. Smaller deltas have formed at the mouths of Engenina and Balta Baltana Creeks at the eastern end of Lake Cadibarrawirracanna. Here, large areas of Holocene sand (Qhe), largely of aeolian origin, form a thin blanket on the lake surface. Some of this was blown in directly from the dunefield to the south, and some may have been reworked from fluvial sand washed in by Engenina Creek. The areas of sand have sharp boundaries that have been trimmed by flood waters. Areas of unit Qhe bordering the northwest margin of the lake are thought to be composed of clay pellets blown from the lake floor.

Spring deposits (Qs)

Artesian mound springs occur extensively throughout WARRINA, notably east of the Davenport Range and adjacent to the Weedina Lineament. Springs with areally insignificant deposits occur along the eastern margins of the ranges and near Lake Cadibarrawirracanna. Structural controls of the springs are discussed in Aldam and Kuang (1989). Generally, springs are associated with basement highs where the aquifer is close to the surface, and with faults which form pathways for the upward movement of groundwater.

Spring mounds are made up of carbonate, and grey mud, silt and fine sand reworked from underlying Cretaceous units (Bulldog Shale and possibly Cadna-owie Formation). Caps of aeolian sand rest on some of the mounds. Some springs have deposited pale grey, indurated, very finely crystalline limestone with reed fossils and impregnations of manganese oxide. Broad areas surrounding springs are characterised by saline flats, gypsite, gypsiferous sand spreads, and coppice mounds. Various sedimentary units in the vicinity of some springs have been cemented or impregnated with carbonate, e.g. fluvial gravel of unit Qa_3, and underlying Bulldog Shale near Tarlton Springs (Anna Creek).

None of the spring deposits have been dated, but their age is estimated to range from Late Pleistocene to Holocene.

STRUCTURAL OVERVIEW AND SUBSURFACE INTERPRETATION

The WARRINA map area can be divided into five geological provinces listed below in order of decreasing age:

- interpreted Palaeoproterozoic basement of the northeastern Gawler Craton
- Palaeoproterozoic and Mesoproterozoic basement of the Peake and Denison Inliers
- Neoproterozoic-Early Palaeozoic sediments and igneous rocks of the Peake and Denison Inliers, representing a northeasterly extension of the Adelaide Geosyncline and Delamerian fold belt
- Neoproterozoic-Early Palaeozoic volcanics and sediments of the Boorthanna Trough
- interpreted southwestern margin of the Early Palaeozoic Warburton Basin.

These older provinces are overlain by younger Phanerozoic basins (Late Palaeozoic Arckaringa Basin and Mesozoic Eromanga Basin) (Fig 3 and pre-Mesozoic Structural Sketch).

Basement of the Peake and Denison Inliers and northeastern Gawler Craton

Geochronological studies of Palaeoproterozoic basement of the Peake and Denison Inliers (Ambrose *et al.*, 1981) indicate two phases of Proterozoic tectonism:

- metamorphism of greenschist to upper amphibolite facies, foliation, and intrusion of Wirriecurrie Granite (~1650-1465 Ma), related to a late phase of the Kimban Orogeny or to the Olarian Orogeny (Parker, 1993).
- metamorphism of greenschist facies (~1 050-1 000 Ma), possibly related to a late phase of the Musgravian Orogeny (Ambrose *et al.*, 1981; Major and Conor *in* Flint, 1993).

Northeast-trending aeromagnetic features in the Spring Hill-Lagoon Hill area are probably related to structures formed by the earlier phase of tectonism.

Palaeoproterozoic basement at Spring Hill is intruded by northwest-trending dolerite dykes which are correlated with the Gairdner Dyke Swarm. Inconclusive isotopic dating of Gairdner dykes and the related Beda Volcanics has produced both Mesoproterozoic (~1 100 Ma) and Neoproterozoic (~800 Ma) ages (Cowley and Flint *in* Flint, 1993). If the former age is correct, then the dykes at Spring Hill would have been intruded during the younger (Musgravian?) phase of Proterozoic tectonism. Northwest-trending aeromagnetic features in the Umbum ruins area may also be Gairdner-type dykes.

The nature of the northeastern Gawler Craton basement underlying western WARRINA is almost totally unknown. This area is included within the Palaeoproterozoic component of the Nawa Subdomain of the Gawler Craton. Some of the basement may be similar to Palaeoproterozoic metasediments of the Peake and Denison Inliers, and to granulite-facies metasediments and gneiss of the Mount Woods Inlier, probably also of Palaeoproterozoic age (Ambrose and Flint, 1981; Fanning *et al.*, 1988). Other basement rocks of western WARRINA may be related to granitic gneiss of the Archaean to earliest Palaeoproterozoic Mulgathing Complex which lies west of the Mount Woods Inlier on the Coober Pedy Ridge. The only basement intersected by drilling on western WARRINA is granite in ASMU 9 drillhole which is correlated with Engenina Adamellite, a Palaeoproterozoic intrusive unit of the Mount Woods Inlier that has produced almost identical Rb-Sr dates to the Wirriecurrie Granite.

Adelaide Geosyncline and Delamerian fold belt

Major rifting in early Neoproterozoic (Willouran) time led to development of the Willouran Trough, a northward-narrowing extension of the Adelaide Geosyncline that was located in the area now occupied by the Willouran ranges and the Davenport and Denison Ranges (Preiss, 1987b).

Sediments of the lower Arkaroola Subgroup were laid down during an initial pre-rift phase of sedimentation. The overlying Cadlareena Volcanics were extruded during the succeeding phase of major crustal extension and rifting. Prominent aeromagnetic anomalies extending southeastwards from the Douglas Well area are interpreted as faulted blocks of Cadlareena Volcanics.

Deposition of at least 22 600 m of sediment continued in various depocentres of the subsiding Willouran Trough through the remainder of Willouran and Torrensian time, and limited drillhole and aeromagnetic data indicate an extension of Burra Group sediments east of the trough in southeastern WARRINA. Mild uplift in the early Sturtian resulted in a break in sedimentation, followed by deposition of a relatively thin Sturtian-Marinoan sequence. During this period, there was a gradual change in tectonic style from one dominated by rifting to one dominated by broad subsidence (Preiss, 1987b). The disconformity at the base of the Sturtian-Marinoan sequence was probably formed by glacial erosion, and concordance of bedding across the contact indicates an absence of significant Sturtian tectonism. The Sturtian-Marinoan sediments were probably more widespread than their present limited distribution, and have been largely removed by later erosion.

The Neoproterozoic rocks on WARRINA have been affected by the Early Palaeozoic Delamerian Orogeny. This tectonic event has caused deformation and resetting of K-Ar dates in Palaeoproterozoic basement but effects of the orogeny are largely confined to the Adelaide Geosyncline, and include:

- local greenschist facies metamorphism
- faulting
- folding, exemplified by major northwest to north-trending synclines in Burra Group sediments of the Davenport Range
- diapirism
- intrusion of Bungadillina Monzonite and dolerite dykes.

The zone of Bungadillina Monzonite and diapiric intrusions in the northern Davenport Range lies on a lineament which Ambrose *et al.* (1981) suggested is an extension of the Karari Fault Zone, although the characteristic magnetic signature of this structure can be traced northwestwards only as far as the Coober Pedy Ridge.

The former Willouran Trough on WARRINA coincides with a zone of gravity highs which is the northern limit of the Muloorina Ridge, a gravity feature which extends in the subsurface from outcropping Palaeoproterozoic and Mesoproterozoic basement of the Mount Babbage Inlier in the northern Flinders Ranges. On WARRINA, the individual gravity highs appear to correlate with Palaeoproterozoic basement and Early Palaeozoic Bungadillina Monzonite (Fig. 8).

Boundary faults of the Willouran Trough

The eastern boundary of the Willouran Trough is formed by the Kingston and Levi Faults. The earliest (Musgravian) evidence of movement on these faults is provided by K-Ar dates of 1 080 to 960 Ma from Wirriecurrie Granite which may be related to lateral displacement of this unit along the Kingston Fault (Ambrose *et al.*, 1981). Downfaulting to the west became the dominant style of movement during subsequent development and subsidence of the Willouran Trough. Major uplift along the western side of the Levi Fault in the late Tertiary is indicated by steeply dipping Early Cretaceous units adjacent to the fault, by dipping mid-Tertiary sediments on the eastern margin of Davenport Range, and by elevation of the Mount Margaret Surface and overlying Early Cretaceous sediments. Vertical displacement on the Levi Fault appears to have increased in a northerly direction during this period of movement. The Levi Fault does not appear to have been active in the Quaternary as there is no displacement of a Late Pleistocene alluvial gravel unit (Qpa_4) across the fault.

A southeasterly extension of the Levi Fault is probably marked by the sharp termination of an aeromagnetic anomaly extending eastwards from Douglas Well which is thought to be related to Cadlareena Volcanics. However, the subsurface location of the fault further to the southeast is unknown.

The western boundary of the Willouran Trough on WARRINA is presumably faulted like the eastern boundary, but the location and nature of the boundary fault is uncertain. However, it is thought that the Weedina Lineament corresponds to the western limit of thick, partly diapiric, Neoproterozoic sediment (see below). The western boundary of the Willouran Trough in the Willouran ranges area (the Norwest Fault) is thought to be offset by an interpreted transcurrent fault system, with its continuation through northwestern CURDIMURKA and southeastern WARRINA suggested by a prominent northwest-trending alignment of mound springs (Krieg *et al.*, 1991) ('mound spring lineament zone'). It is possible that a further zone of transcurrent faulting displaces the western boundary of the Willouran Trough on WARRINA. This fault zone may be represented by an aeromagnetic lineament extending southwestwards from 'Anna Creek'.

Boorthanna Trough and Arckaringa Basin

In the Neoproterozoic to Early Palaeozoic, the Boorthanna Trough developed along the western margin of the Adelaide Geosyncline. Interpreted seismic sections indicate maximum thicknesses of pre-Permian sediments of about 2 200-2 350 m in the deeper part of the trough on northern WARRINA (Allender *et al.*, 1987).

Cadlareena Volcanics are interpreted from drillhole and aeromagnetic data to occur along the southern end and part of the western margin of the trough. It is assumed that the volcanics rest directly on basement in these areas. Drillholes which bottomed in the volcanic unit (Boorthanna 1 and Birribiana 1) did not encounter any overlying Adelaidean units, but it is thought that much of the pre-Permian sequence interpreted from seismic sections in the deeper parts of the Boorthanna Trough may be Adelaidean.

Seismic reflection profiles indicate also the presence of diapirs in the same area. It is thought that the structures were generated initially by diapirism in interpreted Curdimurka Subgroup sediments, possibly in late Neoproterozoic time. Reactivation of the structures during the Delamerian Orogeny resulted in disruption of incompetent, anhydrite-bearing sediments of the overlying Cootanoorina Formation at the same time that diapirs were developing in the Adelaide Geosyncline to the east. The diapiric structures and associated Delamerian folds are in general truncated by the unconformity which lies at the base of sediments of Late Palaeozoic and possible Devonian ages. However, further remobilisation of diapiric structures during the Tertiary caused generally mild anticlinal warping of Late Palaeozoic sediments, with more intense disruption of Late Palaeozoic and Mesozoic sediments at Mount Toondina where a diapiric structure has reached the surface (Freytag, 1965; Jones, 1988).

The margins of the Boorthanna Trough are mostly not well-defined. The eastern margin is shown on interpreted seismic sections (Allender *et al.*, 1987) as a zone of west-dipping normal faults which may be a reactivation of structures associated with the Willouran Trough. As mentioned above, the Weedina Lineament appears to correspond to the boundary between thick, diapiric Adelaidean-Cambrian sediments and thin, 'shelf-type' cover resting on Gawler Craton basement, and is considered to mark the western boundary of the southern Boorthanna Trough. Reactivation of the Weedina Lineament in the Tertiary is indicated by faulting in Mesozoic sediments along Weedina Creek south of Duff Creek, and by fault-related spring activity in the Lake Conway area which may correspond to a subsurface diapiric structure.

The Boorthanna Trough continued as a zone of relatively thick sedimentation in the Late Palaeozoic when it formed one of several marginal troughs of the Arckaringa Basin. There appears to have been a westward migration of sedimentary depocentres from Neoproterozoic to Late Palaeozoic time, and the thickest Late Palaeozoic sections may lie along the western margin of the Early Palaeozoic trough, resulting in a westward offset of a zone of gravity lows (Fig. 8). Late Palaeozoic thicknesses of 700 to 1 200 m were deposited in this area compared with <500 m in the platformal basin area further west (Hibburt, 1984). Late Palaeozoic sediments are absent from a basement high in the southwestern corner of WARRINA.

The eastern margin of the Arckaringa Basin extends along the western flank of the Davenport and Denison Ranges, and the interpreted presence of Boorthanna Formation in Ruby Hill 1 suggests an easterly extension of previously interpreted limits of the basin south of the Davenport Range. Part of this basin extension may be bounded by the aeromagnetically-defined transcurrent fault system that is interpreted to pass through 'Anna Creek'. The extension of the Arckaringa Basin into the William Creek area points to a reinterpretation of the upper part of Sturtian glacial sediments in Newmont SR 13/2 on northern BILLA KALINA (Ambrose and Flint, 1981) as Boorthanna Formation. Freeman (1991) noted that core from this interval closely resembles the interpreted Boorthanna Formation in Ruby Hill 1.

Evidence of minor tectonic activity during deposition of the Arckaringa Basin sediments is provided by palynological and seismic reflection data from the Boorthanna Trough which indicate local unconformities at the tops of Boorthanna and Stuart Range Formations (Jones *in* Martin, 1988; Allender *et al.*, 1987; Wilmot, 1987).

A more significant tectonic event resulted in the widespread unconformity between Arckaringa and Eromanga Basin units. Moore (1982) interpreted uplift and erosion of ~0.5-1 km of Permian sediments from vitrinite reflectance data in the Boorthanna Trough. Tilting of the Permian sediments is indicated by eastward, low-angle truncations of Mount Toondina Formation coal reflectors in seismic profiles (Wilmot, 1987). This activity occurred in Late Permian or Early Mesozoic time and may be related to an average fission track age of 266±23 Ma obtained from apatite crystals in Bungadillina Monzonite (Radke, 1973). The Mount Margaret Surface was developed on the Peake and Denison Inliers during this period of uplift and erosion.

Warburton Basin and the Lake Eyre Fault

The southwestern margin of the Early Palaeozoic Warburton Basin is defined regionally by the Lake Eyre Fault which passes through the northeastern corner of WARRINA. No Warburton Basin sediments are recorded on WARRINA, and the nearest known occurrences are in Toodla 1 (Griffiths, 1980), Oodnadatta 1 (Hess, 1957) and Oodnadatta Town Bore 2 (Thornton, 1977). Toodla 1 bottomed in claystone, siltstone and fine-grained quartzite, possibly a sandy proximal facies of the Ordovician Dullingari Group which is widespread further east in the basin. Oodnadatta 1 and Oodnadatta Town Bore 2, near the western limit of the Warburton Basin, encountered fine grained sandstone and quartzite which may correlate with Early Palaeozoic sandstone units of the Officer Basin, such as Relief Sandstone or Mount Chandler Sandstone.

The Lake Eyre Fault forms a zone approximately 5 km wide on WARRINA with its southern margin marked by terminations of northeast-trending aeromagnetic features in the Palaeoproterozoic basement. Magnetic features suggest that basement is still relatively shallow within the fault zone. However, magnetic basement appears to be much deeper to the north, suggesting that maximum vertical movement has occurred on the northern margin of the fault zone, which may be the southern limit of Warburton Basin sediments. Aeromagnetic contours indicate a fault-bounded block of shallow basement north of the Lake Eyre Fault in the area west of Canegrass Ridge.

The Lake Eyre Fault was probably active at least as early as the Early Palaeozoic. It was also active during the Mesozoic, when it formed a hinge zone between a thin, marginal shelf or platform Eromanga Basin sequence to the southwest, and a thicker basinal sequence to the northeast. Movement during Tertiary time is indicated by palynological dating of Bulldog Shale in the Primrose Hill area (Alley, 1993).

ECONOMIC GEOLOGY

Groundwater (R.G. Aldam)

Water supplies on WARRINA are obtained almost exclusively from aquifers of the Eromanga (Great Artesian) Basin. The main aquifer consists of Cadna-owie Formation and Algebuckina Sandstone, and is artesian throughout a large portion of the map sheet area. Bulldog Shale forms the main confining bed. The Coorikiana Sandstone occurs stratigraphically above the Bulldog Shale in the eastern part of WARRINA and may contain small supplies of saline groundwater. Groundwater may also be obtained from fractures within Proterozoic rocks of the Davenport and Denison Ranges, but little is known of well yields and water quality. No studies have been made of groundwater occurring in the Permian sediments of the Arckaringa Basin. On WARRINA, groundwater is used predominantly for stock watering and, occasionally, mineral exploration and development.

Habermehl (1980, 1986) has studied the hydrogeology and groundwater chemistry of the Great Artesian Basin. Groundwater occurrences west of Lake Cadibarrawirracanna are discussed in Mason (1975b). Potentiometric contours indicate that WARRINA is part of a zone of mixing of two distinct groundwater types: bicarbonate-rich groundwater from the east (and north east) and sulphate-rich water from the west (and northwest). Large areas of Cadna-owie Formation are exposed west of the Davenport and Denison Ranges where groundwater does not flow to the surface, and it is possible that this area is a recharge zone. The main recharge area for the artesian aquifer is in the Great Dividing Range in Queensland. Recharge also occurs around the western basin margin. Salinity of the main aquifer water in this area is generally in the range 3000-6000 mg/l, and well head temperatures are generally less than 50° C. Well yields range up to 15 l/sec.

Discharge of water from the main aquifer occurs by withdrawals from artesian and nonflowing wells, by discharge from artesian springs and by diffuse discharge through the confining layers. Aldam (1989) has documented physical and chemical parameters of all flowing wells in the South Australian portion of the Great Artesian Basin (except the Frome Embayment) including WARRINA. Habermehl (1982) discussed the nature and origin of the artesian springs. Sampling and measurement of spring discharge are documented in Williams (1979), and biological and historical features are covered in Greenslade *et al.* (1985). Little is known of diffuse discharge through the confining bed in this area, but Woods *et al.* (1990) have conducted detailed investigation on CURDIMURKA, near the Roxby Management Services Borefield A.

Coal (G. Kwitko)

The target of coal exploration on WARRINA has been low-grade, sub-bituminous coal of Permian age in the Arckaringa Basin. Numerous coal seams occur in the upper part of the Early Permian Mount Toondina Formation and are interbedded with siltstone, carbonaceous mudstone and minor sandstone. The seams are flat-lying and undeformed, and thicker accumulations of coal are generally confined to the deeper troughs or sub-basins of the Arckaringa Basin. The extent of the coal deposits is governed by post-Early Permian erosional processes which formed the unconformity at the base of the overlying Algebuckina Sandstone.

A comprehensive review of coal exploration activity in the Arckaringa Basin (including WARRINA) is documented in Hibburt (1984). Coal exploration since 1984 has been actively undertaken by Meekatharra Minerals Ltd (1991) and Cyprus Australia Coal Co. (1990).

Significant deposits of coal delineated on WARRINA include the Weedina deposit (SADME, 1989; Kwitko, 1991) and the southeastern extension of the Wintinna deposit (SADME, 1990).

The Weedina deposit (Fig. 9) is a 150 m thick coal-bearing zone of Mount Toondina Formation which includes six major and several minor coal seams that range in thickness up to 8 m, with a cumulative thickness of 35 m. Depth to the top of the first coal seam ranges from 110 to 170 m. Drilling has delineated a very large coal resource estimated at 7 200 million tonnes, and preliminary mining studies have been undertaken to assess the potential for open-cut development to fuel a power station. Typical values of the coal are as follows:

	As-received	Dry basis
Moisture (%)	38	-
Ash (%)	7.6	12.21
Specific energy (MJ/kg)	16.5	26.7
Sulphur (%)	0.46	0.75
Sodium (%)	0.09	0.15
Chlorine (%)	0.05	0.07

Copper

Copper was mined on a small scale in the Davenport and Denison Ranges in the late 1890s and early 1900s. The various mines and prospects are described in Ambrose *et al.* (1981). Recorded production ranges from 150 tonnes of ore containing 19-37% Cu (War Loan Mine) to 243 tonnes averaging 4% Cu (mines near Peake ruins). Ore grades appear to have decreased rapidly with depth resulting in abandonment of the early mining ventures.

The copper deposits can be divided into two groups. The Denison Range group (Mount Kingston Prospect, Printa Mine, and mines near Peake ruins and Copper Top Hill) occurs in Peake Metamorphics, predominantly in basalt of the Baltucoodna Quartzite and Tidnamurkuna Volcanics. This group also shows a concentration of mineralisation along the Kingston Fault and related structures. The Davenport Range group (War Loan, Last Chance, Coominaree and Asbestos Mines) occurs mainly in Curdimurka Subgroup sediments, adjacent to and within diapirs.

Mineralisation is mainly secondary (malachite, azurite, chalcocite, cuprite, atacamite, chrysocolla and minor chalcopyrite), in ferruginous quartz veins from <0.3 to 1.8 m wide. These are frequently parallel to foliation or bedding of the country rock, but cross-cutting veins occur, for example in the Denison Range where they are parallel to the major faults.

The copper deposits are interpreted as low-temperature hydrothermal veins which formed during greenschist facies metamorphism of the Musgravian (Denison Range group) or Delamerian Orogeny. Subsequent weathering, probably related to formation of the Mount Margaret Surface, produced surficial oxidised zones and zones of supergene enrichment.

Company exploration data has outlined various zones of anomalous copper concentrations on WARRINA, particularly in the Peake Metamorphics. Assays of up to 810 ppm Cu were obtained from

Peake Metamorphics (Le_3) with sulphide-bearing veins in BHP WLE2 drillhole (Fander *in* Dampier Mining Co. Ltd., 1980), and amphibolite from the same unit at Melon Spring contained 400 ppm Cu (Circosta, 1989). Baltucoodna Quartzite (amphibolite and calc-silicate with quartz-malachite veins) at the head of Levi Creek gave values of up to 7 550 ppm Cu (Jarvis *et al.*, 1984). Basalt from the same unit near Copper Top Hill contained 150 to 450 ppm Cu (Donnelly, 1992a).

Anomalous copper concentrations occur also in the Cadlareena Volcanics, as disseminated native copper. A drillhole (CRA 81 RHP1) in the Douglas Well area encountered traces of copper over an interval of 38 m, with a maximum assay of 480 ppm over a 16 m interval (Andrews, 1982). Circosta (1989) recorded a value of 2 600 ppm Cu from basalt adjacent to a mineralised zone WSW of Peake ruins.

Minor anomalous zones in other Adelaidean units include up to 80 ppm Cu in coarse sandstone (Fountain Spring Beds) near Coominaree Mine. Small anomalies to 60 ppm in the unnamed siltstone unit (Nr_1) at the head of Levi Creek are related to dolomitic intervals and Delamerian veining. Assays of up to 1 150 ppm Cu have been recorded from this unit (Jarvis *et al.*, 1984).

Lead and Zinc

No lead and zinc mines or occurrences are recorded on WARRINA. However, North Broken Hill Ltd and Western Mining Corporation located the following anomalous zones (Robertson, 1988):

- up to 1 000 ppm Pb in soil samples adjacent to the Kingston Fault, on the eastern margin of Duff Creek Beds south of Peake ruins
- up to 670 ppm Pb and 165 ppm Zn in stream sediment samples from Peake Metamorphics and Wirriecurrie Granite near Peake ruins
- up to 205 ppm Pb and 165 ppm Zn in stream sediment samples, and up to 400 ppm Pb in soil samples from Rockwater Beds near Coominaree Mine. Jarvis *et al.* (1984) recorded anomalous Zn (155 ppm) and Pb (85 ppm) in rock chip samples from ferruginous veins in this area
- up to 3 500 ppm Pb and 610 ppm Zn in rock chip samples of ferruginous veins in undifferentiated Curdimurka Subgroup southwest of Peake ruins.

Gold

Old gold workings on the western margin of the Denison Range, southwest of Mount Kingston were noted by Brown (1894). Sas and Gates (1981) described the auriferous unit as a thin, unconsolidated, coarse, quartz conglomerate of Tertiary age, although it is more likely to be a Quaternary gravel unit derived from Algebuckina Sandstone. They reported an average gold content of 1.4 ppm from the matrix of the conglomerate. Subsequent bulk sampling of the conglomerate gave subeconomic values ranging up to 0.036 ppm and averaging 0.015 ppm (Watts, 1984).

There is a general low-level concentration of gold in the mineralogically mature Algebuckina Sandstone, notably in a basal conglomerate resting on Peake Metamorphics at Algebuckina (OODNADATTA). McBain (1982) noted that gold values from Algebuckina Sandstone (and overlying Cadna-owie Formation) in drillhole CRA 82 AWH4 were all above the detection limit, peaking at 0.125 ppm. Basal Algebuckina conglomerate from the Levi Creek area contained 0.03 ppm Au (Jarvis *et al.*, 1984).

Rock chip sampling of various Precambrian units has revealed the following zones of anomalous gold values (Circosta, 1989; Jarvis *et al.*, 1984):

- up to 0.1 ppm from the transitional boundary between Mount Margaret Quartzite and Skillogalee Dolomite in the Coominaree Mine area
- up to 0.04 ppm in unnamed siltstone unit (Nr_1) of the Burra Group at the head of Levi Creek
- up to 0.34 ppm in quartz-malachite veins cutting amphibolite and calc-silicate (Baltucoodna Quartzite) at the head of Levi Creek
- 0.43 ppm in sheared metabasalt of Tidnamurkuna Volcanics south of Peake ruins.

Uranium and thorium

Radiometrically anomalous areas on WARRINA are associated mainly with Palaeoproterozoic basement and adjacent sediments. Peake Metamorphics (Le_1) in the Mount Kingston area have assayed at 25-290 ppm U and 46 ppm Th, with surficial enrichment of up to 0.21% U and 0.025% Th. Mineralisation occurs as disseminated small grains of a uranium phosphate mineral

(Sargeant, 1970; Donnelly, 1992a). A cupriferous quartz vein in Baltucoodna Quartzite near Coominaree Mine contained 130 ppm U (Iliff *et al.*, 1974). The Wirriecurrie Granite is another radiometrically anomalous unit, and near Mount Kingston it has been assayed at 5 ppm U and 285 ppm Th (Iliff, 1975). Spring-deposited limestone adjacent to Wirriecurrie Granite at Sandy Creek Springs contained disseminated carnotite and was analysed at up to 75 ppm U and 15 ppm Th (Sas and Gates, 1981). Radiometric anomalies occur over mound springs (e.g. Brinkley Springs). The radiogenic material is possibly derived from uranium present in underlying basement (Donnelly, 1992b).

Cadlareena Volcanics in the Peake ruins area contains a disseminated uranium phosphate mineral and has assayed at 35-110 ppm U and 1-4 ppm Th (Iliff, 1975; Sas and Gates, 1981; Donnelly, 1992a). Other radiometrically anomalous zones in Adelaidean units include Duff Creek Beds from the War Loan Mine area (20 ppm U; Iliff *et al.*, 1974). A localised occurrence of radioactive material in the same unit at Last Chance Mine contained 1.2% U_3O_8 (Leeson, 1972).

Chevron Exploration Corporation undertook a drilling program east of the ranges, targeting sedimentary uranium deposits in Algebuckina Sandstone and Cadna-owie Formation. It was thought that the absence of reducing-oxidising fronts and the lack of significant groundwater flow from the ranges were factors resulting in the absence of significant anomalies (Teluk, 1974).

Diamonds

There has been considerable exploration for diamonds undertaken in the WARRINA region, stimulated by an early report of a one carat stone found in old gold workings on the western margin of the Denison Range (Brown, 1894). Most of the work was carried out by Stockdale Prospecting Ltd (Newell, 1984, 1985, 1987; Newell and Wilson, 1987; Robison, 1984, 1989, 1990). Exploration by other companies is described in Ashton Mining Limited, 1983; Cooper, 1990; Jones, 1990; and Sas and Gates, 1981. Much of the exploration involved identification of kimberlitic indicator minerals in heavy mineral fractions from samples of alluvial sediment, regolith, and outcropping and subsurface sedimentary rock units. Geophysical surveys and follow-up drilling of possible kimberlitic targets was also carried out.

Results of the heavy mineral sampling indicated a wide surficial scatter of kimberlitic indicator minerals, comprising mainly pyrope, picroilmenite and chromite. These indicator minerals are present also in Algebuckina Sandstone and Cadna-owie Formation/Mount Anna Sandstone Member, with some concentration occurring at the bases of these units.

Surface morphological features of the indicator mineral grains are ambiguous. Jones (1990) reported that many kimberlitic grains from Algebuckina Sandstone encountered in drillholes in the southern Boorthanna Trough area appeared to be little worn, implying a local source or transport by ice. However, the surface features of the grains could also be explained by secondary pitting. Conversely, Sas and Gates (1981) found worn and rounded indicator mineral grains in alluvial gravel samples from the southwestern Denison Range, suggesting either a long transport distance, or abrasion during emplacement of a kimberlitic intrusion.

During the recent phase of diamond exploration on WARRINA, microdiamonds were found in Algebuckina Sandstone and associated Quaternary stream sediment in the Edward Creek area (Newell, 1985; 1987). Boorthanna Formation crops out in this area, and it is tempting to regard that unit as a possible secondary source of the diamonds. However, sampling of the Boorthanna Formation for indicator minerals was negative (Newell, 1985).

The overall pattern of indicator mineral occurrences on WARRINA points to Algebuckina Sandstone being the main secondary source of kimberlitic minerals. Extensive geophysical surveys and follow-up drilling have failed to find any local primary sources. Kimberlitic minerals in the Mount Anna Sandstone Member could have been derived from the Gawler Ranges Volcanic Province of the Gawler Craton although it is more likely that they have been reworked from the underlying Algebuckina Sandstone. A possible source area for the indicator minerals and microdiamonds is the Eringa Trough on the eastern margin of the Musgrave Block, where recent high-resolution aeromagnetic imagery has revealed small discrete anomalies which could indicate kimberlitic intrusions, although these have not yet been tested by drilling at the time of writing.

Hydrocarbons

The most prospective area for oil and gas on WARRINA is the Boorthanna Trough. Petroleum exploration commenced in the 1960s with Delhi Petroleum Ltd's Oodnadatta aeromagnetic survey and was followed by gravity and limited reflection/refraction seismic surveys (Hibburt, 1984). The geophysical surveys indicated the presence of the deep Boorthanna Trough. The first wildcat well was DME Cootanoorina 1 (1967). There were no indications of hydrocarbons in the Late Palaeozoic section but traces of gas and bituminous material were recorded from the Cootanoorina Formation (Allchurch *et al.*, 1973).

In 1969, DME commenced a seismic and stratigraphic drilling program aimed at evaluating the Arckaringa basin. At the same time, exploration continued in the Boorthanna Trough (seismic surveys and one wildcat well-Weedina 1) commissioned by Pexa Oil as part of a farm-in commitment. No significant hydrocarbons were recorded.

The next phase of exploration was by Delhi Petroleum Ltd in the mid-1980s and included seismic surveys and two wells (Hanns Knob 1 and Birribiana 1). Traces of ditch gas were recorded in the latter. The Arckaringa Block was relinquished by Santos and Delhi in 1989. There are no current licences.

Reservoirs

Sandstone in the Mount Toondina Formation generally exhibits low porosity (6-9%). The Boorthanna Formation contains several thick units of porous and permeable sandstone (log porosity up to 13.5%).

Secondary vugular porosity and minor open partings along stylolites are observed in Cootanoorina Formation carbonates.

Structure and Seal

Traps range from simple domes and faulted anticlines to potential traps associated with diapiric structures. Attempts so far to drill a diapir have been unsuccessful or inconclusive.

Stuart Range Formation and Bulldog Shale (Eromanga Basin) provide regional seals. Intraformational shale and siltstone in the Boorthanna and Mount Toondina Formations are potential local seals.

Source Rocks

TOC values of six samples suggest the Cootanoorina Formation would provide a poor source rock if mature.

Basal Stuart Range Formation, and Boorthanna Formation range from immature to mature. Boorthanna Formation TOC is generally less than 0.5% although a sample from Weedina 1 yielded 1.8%. The Mount Toondina Formation and much of the Stuart Range Formation, while immature, have high TOC values indicating that they could be good oil-prone source rocks at depth. TOC ranges from 0.45-2.7% in Stuart Range Formation and as high as 5.95% in Mount Toondina Formation (Moore, 1982).

In many areas, depth of burial has not been sufficient for generation of hydrocarbons. Permian sediments are most likely to be thermally mature in southern deep parts of the Boorthanna Trough.

Celestite

Several occurrences of celestite ($SrSO_4$) were noted in Bulldog Shale during mapping of WARRINA. Most of these occurrences are close to major faults, such as the Lake Eyre Fault, the Weedina Lineament and the 'mound spring lineament zone'. The celestite occurs mainly as scattered crystalline aggregates derived from veins 5-10 mm thick.

A sample collected from the area between Neales River and Wood Duck Creek was assayed at 96.9% $SrSO_4$, and three samples from adjoining areas of LAKE EYRE and NOOLYEANA contained between 73% and 100% $SrSO_4$ (Olliver and Barnes, 1990).

Several factors appear to influence the distribution of celestite in the Eromanga Basin. In many cases, there is an association with marine fossils. For example, there are numerous ammonites at the Wooldridge Creek deposit (OODNADATTA), and belemnites and bivalves commonly occur near celestite occurrences on WARRINA and CURDIMURKA. Strontium could originally have been extracted from sea water by marine organisms and deposited in their shells.

Celestite occurs predominantly in the southwestern part of the Eromanga Basin where groundwater is eastward-flowing and high in chloride and sulphate. Strontium present in mollusc shells would have been dissolved and remobilised by the groundwater.

Celestite occurrences are often associated with faults. It is suggested that zones of fractures formed during the Cainozoic and were infilled with gypsum, which was subsequently replaced with celestite after coming into contact with Sr-rich groundwater.

Evaporites and brines

CRA Exploration Pty Ltd (Scott, 1983) defined a surficial, sulphate-rich zone in basal Bulldog Shale west of Lake Cadibarrawirracanna (MURLOOCOPPIE). The evaporitic zone is extremely variable in thickness and quality, and averages about 1 m thick with 10-15% of water-soluble sulphates. These are predominantly bloedite ($MgSO_4Na_2SO_4.4H_20$) with minor epsomite ($MgSO_4.7H_2O$) and hexahydrite ($MgSO_4.6H_2O$).

The presence of sulphates was thought to be related to groundwater movement, and subsequent drilling in the Lake Cadibarrawirracanna area encountered brines in the Cadna-owie Formation containing up to 55 400 ppm dissolved salts (~85% NaCl and 10% Mg SO_4; CRA 83 LCR1). There is an eastward increase in salt content of subsurface brines in the lake area (Scott, 1984).

Shallow drilling of lacustrine sediments (Qhl_1) in Lake Cadibarrawirracanna by AMAX Iron Ore Corporation encountered low K values (195-1290 ppm) in water samples. The higher values of K, Na, B and Ca were generally found around the southern lake margin. Total soluble K content of the lacustrine mud ranged from 0.3 to 1.7% (Wyatt, 1980).

Phosphate

Drilling for evaporites by Aminco and Associates in the Oolgelima Hill area encountered an indurated, ferruginous layer with phosphate values ranging from 1 000 to 5 000 ppm. Samples obtained from outcrops and float of this layer contained between 0.83 and 1.7% phosphate, with one sample assaying at 4.8%.

The phosphate layer overlies cone-in-cone limestone and is interpreted to be in uppermost Cadna-owie Formation. The layer is extensive, but thin, with an average thickness of 0.1 m (Seymour, 1982).

REFERENCES

Aldam, R.G., 1989. Great Artesian Basin field survey, 1986-1987. *South Australia. Department of Mines and Energy. Report Book*, 89/66.

Aldam, R.G. and Kuang, K.S., 1989. An investigation of structures controlling natural discharge of artesian waters in the southwestern Great Artesian Basin. *South Australia. Geological Survey. Quarterly Geological Notes*, 109:2-9.

Allchurch, P.D., Wopfner, H., Harris, W.K. and McGowran, B., 1973. Cootanoorina No. 1 well. *South Australia. Geological Survey. Report of Investigations*, 40.

Allender, J.F., Taylor, B.W. and Gilby, A.R., 1987. Geophysical interpretation report 1984 Hogarth-ARC. PELs 5 and 6 Arckaringa Block. *South Australia. Department of Mines and Energy. Open file Envelope*, 5561/6 (unpublished).

Alley, N.F., 1985. Preliminary report on the palynostratigraphy of SADME Toodla No. 1 well, southwestern Eromanga Basin. *South Australia. Department of Mines and Energy. Report Book*, 85/55.

Alley, N.F., 1987. Palynological dating and correlation of Late Jurassic and Early Cretaceous sediments around part of the southern margin of the Eromanga Basin. *South Australia. Department of Mines and Energy. Report Book*, 87/59.

Alley, N.F., 1988. Age and correlation of palynofloras from the type Cadna-owie Formation, southwestern Eromanga Basin. *Association of Australasian Palaeontologists. Memoir*, 5:187-194.

Alley, N.F., 1989. Palynological analysis of Early Cretaceous sediments east of the Peake and Denison ranges. *South Australia. Department of Mines and Energy. Report Book*, 89/31.

Alley, N.F., 1991a. Preliminary palynostratigraphy of Ruby Hill 1 well, southwestern Eromanga Basin. *South Australia. Department of Mines and Energy. Biostratigraphy Branch Report*, 91/3 (unpublished).

Alley, N.F., 1991b. Palynological dating of Mount Toondina Formation from outcrop, southwestern edge of the Peake and Denison ranges. *South Australia. Department of Mines and Energy. Report Book*, 91/24.

Alley, N.F., 1993. Palynological dating and correlation of Mesozoic rocks along the Neales River between the Peake and Denison ranges and Lake Eyre North. *South Australia. Department of Mines and Energy. Report Book*, 93/46.

Ambrose, G.J. and Flint, R.B., 1980a. BILLA KALINA map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SH53-7.

Ambrose, G.J. and Flint, R.B., 1980b. Geological map. Peake and Denison ranges. *South Australia. Geological Survey. Special Map*, 1:150 000.

Ambrose, G.J. and Flint, R.B., 1981. BILLA KALINA, South Australia, Sheet SH53-7. *South Australia. Geological Survey. 1:250 000 Series - Explanatory Notes.*

Ambrose, G.J., Flint, R.B. and Webb, A.W., 1981. Precambrian and Palaeozoic geology of the Peake and Denison ranges. *South Australia. Geological Survey. Bulletin*, 50.

Andrews, D.L., 1982. CRA Exploration Pty Limited, Fifth quarterly report on Ruby Hill EL 761, South Australia for the period ending 1st March, 1982. *South Australia. Department of Mines and Energy. Open file Envelope*, 4138 (unpublished).

Ashton Mining Ltd., 1983. Final report for EL 787, Aberfoyle Exploration Pty Ltd. *South Australia. Department of Mines and Energy. Open file Envelope*, 4223 (unpublished).

Barnes, L.C. and Pitt, G.M., 1976. The Mirackina Conglomerate. *South Australia. Geological Survey. Quarterly Geological Notes*, 59:1-6.

Belperio, A.P., 1990. Palaeoenvironmental interpretation of the Late Proterozoic Skillogalee Dolomite in the Willouran Ranges, South Australia. *In:* Jago, J.B. and Moore, P.S. (Eds), The Evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special publication*, 16:85-104.

Benbow, M.C., 1981. COOBER PEDY map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SH53-6.

Benbow, M.C., 1983. COOBER PEDY, South Australia, sheet SH53-6. *South Australia. Geological Survey. 1:250 000 Series, Explanatory Notes.*

Benbow, M.C. and Flint, R.B., 1979. The Engenina Adamellite and Balta Granite of the Mount Woods Inlier. *South Australia. Geological Survey. Quarterly Geological Notes*, 69:9-13.

Benbow, M.C., Callen, R.A., Bourman, R.P. and Alley, N.F. (in prep.). Deep weathering, ferricrete and silcrete. *In:* Drexel, J.F. and Preiss, W.V. (Eds), The geology of South Australia, Vol. 2, The Phanerozoic. *South Australia. Geological Survey. Bulletin*, 54.

Brewer, A.M., Dunster, J.N., Gatehouse, C.G., Henry, R.L. and Weste, G., 1987. A revision of the stratigraphy of the eastern Officer Basin. *South Australia. Geological Survey. Quarterly Geological Notes*, 102:2-15.

Brown, H.Y.L., 1894. Report on the Peake and Denison Ranges and adjoining country with special reference to the occurrence of gold. *South Australia. Parliamentary Papers*, 25.

Callen, R.A. and Tedford, R.H., 1976. New late Cainozoic rock units and depositional environments, Lake Frome area, South Australia. *Royal Society of South Australia. Transactions*, 100:125-167.

Callen, R.A., Dulhunty, J.D., Lange, R.T., Plane, M., Tedford, R.H., Wells, R.T. and Williams, D.L.G., 1986. The Lake Eyre Basin - Cainozoic sediments, fossil vertebrates and plants, landforms, silcretes and climatic implications. *Geological Society of Australia. Australasian Sedimentologists Group. Field Guide Series*, 4.

Callen, R.A., Wasson, R.J. and Gillespie, R., 1983. Reliability of radiocarbon dating of pedogenic carbonate in the Australian arid zone. *Sedimentary Geology*, 35:1-14.

Cantrill, D.J. and Webb, J.A., 1987. A reappraisal of *Phyllopteroides* Medwell (Osmundaceae) and its stratigraphic significance in the Lower Cretaceous of eastern Australia. *Alcheringa*, 11:59-85.

Chugg, R.I., 1957. The hydrogeology of a portion of the Great Artesian Basin near the Peake and Denison Ranges. *South Australia. Geological Survey. Report of Investigations*, 10.

Circosta, G., 1989. Peake and Denison Ranges. Report on exploration by Placer Exploration. *South Australia. Department of Mines and Energy. Open file Envelope*, 8254 (unpublished).

Coats, R.P., 1965. Diapirism in the Adelaide Geosyncline. *APEA Journal*, 5:98-102.

Coats, R.P. and Preiss, W.V., 1987a. Stratigraphy of the Callanna Group. *In:* Preiss, W.V. (Compiler), The Adelaide Geosyncline - Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics. *South Australia. Geological Survey. Bulletin*, 53:43-71.

Coats, R.P. and Preiss, W.V., 1987b. Stratigraphy of the Umberatana Group. *In:* Preiss, W.V. (Compiler), The Adelaide Geosyncline - Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics. *South Australia. Geological Survey. Bulletin*, 53:125-209.

Cook, A.C., 1981. The organic petrology of samples from a selected group of wells in or near the Arckaringa Block. *Delhi Petroleum Pty Ltd. Report* (unpublished).

Cooper, S.A., 1990. EL 1640 Mount Anna, SA. Second quarterly report 15 April to 14 July 1990. *South Australia. Department of Mines and Energy. Open file Envelope*, 8297 (unpublished).

Crawford, A.J. and Hilyard, D., 1990. Geochemistry of Late Proterozoic tholeiitic flood basalts, Adelaide Geosyncline, South Australia. *In:* Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special Publication*, 16:49-67.

Cyprus Australia Coal Co., 1990. EL 1168, El 1533, El 1169, El 1534, Cadaree Hill, Codna Hill. Reports for the period 4/5/84 to May 1990. *South Australia. Department of Mines and Energy. Open file Envelope*, 4317 (unpublished).

Dampier Mining Co. Ltd, 1980. Final report, EL 369, Appendix 4. *South Australia. Department of Mines and Energy. Open file Envelope*, 3754:200-209 (unpublished).

Dettmann, M.E. and Williams, A.J., 1985. The Cretaceous of the southern Eromanga Basin - a palynological review. *Delhi Petroleum Pty Ltd palynological report*, 274/26 (unpublished).

Dickinson, S.B., Parkin, L.W., Hughes, F.E., Reyner, M.L. and Pitman, R.K., 1955c. *Boorthanna* map sheet. *South Australia. Geological Survey. Geological Atlas 1:63 360 Series.*

Dickinson, S.B., Parkin, L.W., Hughes, F.E., Reyner, M.L. and Pitman, R.K., 1955d. *Cadlareena* map sheet. *South Australia. Geological Survey. Geological Atlas 1:63 360 Series.*

Dickinson, S.B., Parkin, L.W., Hughes, F.E., Reyner, M.L. and Pitman, R.K., 1955a. *Conway* map sheet. *South Australia. Geological Survey. Geological Atlas 1:63 360 Series.*

Dickinson, S.B., Parkin, L.W., Hughes, F.E., Reyner, M.L. and Pitman, R.K., 1954a. *Nilpinna* map sheet. *South Australia. Geological Survey. Geological Atlas 1:63 360 Series.*

Dickinson, S.B., Parkin, L.W., Hughes, F.E., Reyner, M.L. and Pitman, R.K., 1955b. *Umbum* map sheet. *South Australia. Geological Survey. Geological Atlas 1:63 360 Series.*

Dickinson, S.B., Parkin, L.W., Hughes, F.E., Reyner, M.L. and Pitman, R.K., 1955e. *Anna* map sheet. *South Australia. Geological Survey. Geological Atlas 1:63 360 Series.*

Dickinson, S.B., Parkin, L.W., Pitman, R.K., Reyner, M.L. and Hughes, F.E., 1954b. *Algebuckina* map sheet. *South Australia. Geological Survey. Geological Atlas 1:63 360 Series.*

Donnelly, M.J., 1992a. CRA Exploration Pty Limited. Combined fourth and fifth quarterly report for Mount Denison EL 1720, South Australia, for the period ending 12 th August, 1992. *South Australia. Department of Mines and Energy. Open file Envelope*, 8448 (unpublished).

Donnelly, M.J., 1992b. CRA Exploration Pty Limited. Second quarterly report for Mount Charles EL 1756, South Australia, for the period ending 8th June, 1992. *South Australia. Department of Mines and Energy. Open file Envelope*, 8563 (unpublished).

Dorman, F.H. and Gill, E.D., 1959. Oxygen isotope palaeotemperature measurements of Australian fossils. *Royal Society of Victoria. Proceedings*, 71:73-98.

Elliott, P., 1987. Birribiana 1 well completion report for Delhi Petroleum Pty Ltd and Santos Limited. *South Australia. Department of Mines and Energy. Open file Envelope*, 7034/6 (unpublished).

Embleton, B.J.J., 1984. Continental palaeomagnetism. *In:* Veevers, J.J. (Ed.), *Phanerozoic earth history of Australia*. Oxford University Press, pp.11-16.

Evans, P.R., 1969. Upper Carboniferous and Permian palynological stages and their distribution in eastern Australia. *Gondwana Stratigraphy. IUGS. 1st Gondwana Symposium*, Buenos Aires, 1967, UNESCO, pp. 41-53.

Fairchild, T.R., 1975. The geological setting and palaeobiology of a late Precambrian stromatolitic microflora from South Australia. *University of California. PhD. thesis* (unpublished).

Fanning, C.M., Flint, R.B., Parker, A.J., Ludwig, K.R. and Blissett, A.H., 1988. Refined Proterozoic evolution of the Gawler Craton, South Australia, through U-Pb zircon geochronology. *Precambrian Research*, 40/41:363-386.

Firman, J.B., 1966. Stratigraphic units of late Cainozoic age in the St. Vincent Basin, South Australia. *South Australia. Geological Survey. Quarterly Geological Notes*, 17:6-9.

Firman, J.B., 1967. Late Cainozoic stratigraphic units in South Australia. *South Australia. Geological Survey. Quarterly Geological Notes*, 22:4-8.

Flint, R.B., 1993. Mesoproterozic. *In:* Drexel, J.F., Preiss, W.V. and Parker, A.J. (Eds), The geology of South Australia, Vol. 1, The Precambrian. *South Australia. Geological Survey. Bulletin*, 54.

Flint, R.B., Ambrose, G.J. and Campbell, K.S.W., 1980. Fossiliferous Lower Devonian boulders in Cretaceous sediments of the Great Australian Basin. *Royal Society of South Australia. Transactions*, 104:57-65.

Forbes, B.G. and Preiss, W.V., 1987. Stratigraphy of the Burra Group. *In:* Preiss, W.V. (Compiler), The Adelaide Geosyncline - Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics. *South Australia. Geological Survey. Bulletin*, 53:73-123.

Forbes, B.G., Murrell, B. and Preiss, W.V., 1981. Subdivision of lower Adelaidean, Willouran Ranges. *South Australia. Geological Survey. Quarterly Geological Notes*, 79:7-16.

Frakes, L.A. and Francis, J.E., 1988. A guide to Phanerozoic cold polar climates from high-latitude ice-rafting in the Cretaceous. *Nature*, 333:547-549.

Frakes, L.A. and Francis, J.E., 1990. Cretaceous palaeoclimates. *In:* Ginsburg, R.N. and Beaudoin, B. (Eds), *Cretaceous Resources, Events and Rhythms*. Kluwer Academic Publishers, Dordrecht, pp.273-287.

Freeman, P.J., 1991. Well completion report: Ruby Hill 1. *South Australia. Department of Mines and Energy. Report Book*, 91/52.

Freytag, I.B., 1965. Mount Toondina beds — Permian sediments in a probable piercement structure. *Royal Society of South Australia. Transactions*, 89:61-76.

Freytag, I.B., 1966. Proposed rock units for marine lower Cretaceous sediments in the Oodnadatta region of the Great Artesian Basin. *South Australia. Geological Survey. Quarterly Geological Notes*, 18:3-7.

Freytag, I.B., Heath, G.R. and Wopfner, H., 1967. OODNADATTA map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SG53-15.

Gardner, G.J., Mortlock, A.J., Price, D.M., Redhead, M.L. and Wasson, R.J., 1987. Thermoluminescence and radiocarbon dating of Australian desert dunes. *Australian Journal of Earth Sciences*, 34:343-357.

Gilby, A.R. and Foster, C.B., 1988. Early Permian palynology of the Arckaringa Basin, South Australia. *Palaeontographica*, 209(B):167-191.

Gravestock, D.I. (in prep). Early Palaeozoic. *In:* Drexel, J.F. and Preiss, W.V. (Eds), The geology of South Australia, Vol. 2, The Phanerozoic. *South Australia. Geological Survey. Bulletin*, 54.

Greenslade, J., Joseph, L. and Reeves, A. (Editors), 1985. South Australia's mound springs. Nature Conservation Society of South Australia.

Griffiths, M., 1980. Toodla No. 1 well completion report. *South Australia. Department of Mines and Energy. Report Book*, 80/128.

Habermehl, M.A., 1980. The Great Artesian Basin, Australia. *BMR Journal of Australian Geology and Geophysics*, 5:9-38.

Habermehl, M.A., 1982. Springs in the Great Artesian Basin, Australia — their origin and nature. *Bureau of Mineral Resources, Geology and Geophysics, Australia. Report*, 235.

Habermehl, M.A., 1986. Regional groundwater movement, hydrochemistry and hydrocarbon migration in the Eromanga Basin. *In:* Gravestock, D.I., Moore, P.S. and Pitt, G.M. (Eds), Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia. Special Publication*, 12:353-376.

Harris, W.K., 1962. Plant remains of Upper Jurassic to Lower Cretaceous age from Cadlareena military sheet. *South Australia. Department of Mines and Energy. Report Book*, 55/128.

Heath, G.R., 1965. Permian sediments of the Mount Dutton Inlier. *South Australia. Geological Survey. Quarterly Geological Notes*, 14:3-5.

Helby, R., Morgan, R. and Partridge, A.D., 1987. A palynological zonation of the Australian Mesozoic. *Association of Australasian Palaeontologists. Memoir*, 4:1-94.

Hess, A., 1957. Geosurveys of Australia Limited. Drilling operations in the Oodnadatta area. *South Australia. Department of Mines and Energy. Open file Envelope*, 260 (unpublished).

Hibburt, J.E., 1984. A review of exploration in the Arckaringa Basin 1887-1983. *South Australia. Department of Mines and Energy. Report Book*, 84/1.

Holmes, D.A., 1970. Oxymin Boorthanna No. 1 well completion report for Occidental Mins Corp. (Aust.). *South Australia. Department of Mines and Energy. Open file Envelope*, 1241 (unpublished).

Hopgood, L.S., 1987. The taxonomy and palaeoclimatic interpretation of Late Mesozoic fossil floras from the southwestern Eromanga Basin. *University of Adelaide. B.Sc. Honours thesis* (unpublished).

Iliff, G.D., 1975. UAL report No. 29. Exploration 1974 on EL 110, Peake-Denison and Mount Kingston ranges, South Australia. *South Australia. Department of Mines and Energy. Open file Envelope*, 2381 (unpublished).

Iliff, G.D., Robinson, P. and Johnson, J., 1974. UAL Report No. 13. Exploration 1973 on EL 33. Mount Margaret Range, Peake and Denison block, South Australia. *South Australia. Department of Mines and Energy. Open file Envelope*, 2253 (unpublished).

Jarvis, D.M., Brady, S.A. and Dugmore, M.A., 1984. Exploration Licence 968 Nilpinna, South Australia. Report for the quarter ended 22nd November, 1984. *South Australia. Department of Mines and Energy. Open file Envelope*, 3771 (unpublished).

Jones, D.R., 1990. Exploration Licence Nos 1533, 1534, 1552 Final report. *South Australia. Department of Mines and Energy. Open file Envelope*, 5287 (unpublished).

Jones, P.J., 1988. Evidence for diapirism in the Arckaringa Basin – South Australia. *University of Adelaide. B.Sc. (Hons) thesis*, (unpublished).

Krieg, G.W., Rogers, P.A., Callen, R.A., Belperio, A.P. and Forbes, B.G., 1992. CURDIMURKA map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SH53-8.

Krieg, G.W., Rogers, P.A., Callen, R.A., Freeman, P.J., Alley, N.F. and Forbes, B.G., 1991. CURDIMURKA, South Australia, sheet SH53-8. *South Australia. Geological Survey. 1:250 000 Series - Explanatory Notes.*

Kwitko, G., 1991. Weedina coal deposit data index. *South Australia. Department of Mines and Energy. Report Book*, 91/106.

Laut, P., Keig, G., Lazarides, M., Loffler, E. Margules, C., Scott, R.M. and Sullivan, M.E., 1977. Environments of South Australia: Province 8, Northern Arid. Division of Land Use Research, CSIRO, Canberra.

Leeson, B., 1972. Geochemical and geophysical investigations near the Last Chance Mine. *Mineral Resources Review, South Australia*, 132:95-102.

Ludbrook, N.H., 1961. Permian to Cretaceous subsurface stratigraphy between Lake Phillipson and the Peake and Denison ranges, South Australia. *Royal Society of South Australia. Transactions*, 85:67-80.

Ludbrook, N.H., 1966. Cretaceous biostratigraphy of the Great Artesian Basin in South Australia. *South Australia. Geological Survey. Bulletin*, 40.

Martin, C., 1988. Hanns Knob 1 well completion report compiled for Santos Ltd. *South Australia. Department of Mines and Energy. Open file Envelope*, 7043 (unpublished).

Mason, M.G., 1975a. Final report, Murloocopie coal prospect EL 184, Australian Selection Pty Ltd. *South Australia. Department of Mines and Energy. Open file Envelope*, 2556 (unpublished).

Mason, M.G., 1975b. Groundwater near Giddi Giddinna Creek, northeast of Coober Pedy, South Australia. *South Australia. Geological Survey. Quarterly Geological Notes*, 56:2-6.

McBain, D.R., 1982. CRA Exploration Pty Limited. Wirrangula Hill EL 924, South Australia – report on the reconnaissance drilling program, April 1982. *South Australia. Department of Mines and Energy. Open file Envelope*, 4562 (unpublished).

McNamara, K.J., 1980. Heteromorph ammonites from the Albian of South Australia. *Royal Society of South Australia. Transactions*, 104:145-159.

McNamara, K.J., 1985. A new micromorph ammonite genus from the Albian of South Australia. *In:* Lindsay, J.M. (Ed.), Stratigraphy, palaeontology, malacology - papers in honour of Dr Nell Ludbrook. *South Australia. Department of Mines and Energy. Special Publication*, 5:263-268.

Meekatharra Minerals Ltd, 1991. EL 1589, Mt Barry. Reports for the period 12/5/80 to November 1990. *South Australia. Department of Mines and Energy. Open file Envelope*, 5910 (unpublished).

Moore, P.S., 1982. Hydrocarbon potential of the Arckaringa region, central South Australia. *APEA Journal*, 22:237-253.

Moore, P.S. and Pitt, G.M., 1982. Cretaceous of the southwestern Eromanga Basin: stratigraphy, facies variations and petroleum potential. *In:* Moore, P.S. and Mount, T.J. (Compilers), *Eromanga Basin Symposium summary papers.* Geological Society of Australia and Petroleum Exploration Society of Australia, Adelaide, pp. 127-144.

Moore, P.S. and Pitt, G.M., 1985. Cretaceous subsurface stratigraphy of the southwestern Eromanga Basin: a review. *South Australia. Department of Mines and Energy. Special Publication*, 5:269-286.

Moore, P.S., Pitt, G.M. and Dettman, M.E., 1986. The Early Cretaceous Coorikiana Sandstone and Toolebuc Formation: their recognition and stratigraphic relationship in the southwestern Eromanga Basin. *In:* Gravestock, D.I., Moore, P.S. and Pitt, G.M. (Eds), Contributions to the geology and hydrocarbon potential of the Eromanga Basin. *Geological Society of Australia. Special Publication*, 12:97-114.

Morgan, R., 1980. Eustasy in the Australian Early and Middle Cretaceous. *New South Wales. Geological Survey. Bulletin*, 27.

Morrison, R.S., 1989. Igneous intrusive rocks of the Peake and Denison ranges within the Adelaide Geosyncline. *University of Adelaide. PhD. thesis* (unpublished).

Morrison, R.S. and Foden, J.D., 1990. A zoned Middle Cambrian pluton in the Peake and Denison Ranges, South Australia. *In:* Jago, J.B. and Moore, P.S. (Eds), The evolution of a late Precambrian - early Palaeozoic rift complex: the Adelaide Geosyncline. *Geological Society of Australia. Special Publication*, 16:450-464.

Mount, T.J., 1975. Diapirs and diapirism in the Adelaide "Geosyncline", South Australia. *University of Adelaide. PhD. thesis* (unpublished).

Nanson, G.C., Price, D.M. and Short, S.A., 1992. Wetting and drying of Australia over the past 300 ka. *Geology*, 20:791-794.

Newell, B.H., 1984. Mount Kingston. Exploration Licence No. 1030. Eighth quarterly report and relinquishment report. *South Australia. Department of Mines and Energy. Open file Envelope*, 4912 (unpublished).

Newell, B.H., 1985. Stockdale Prospecting Limited. Exploration Licence No. 968. Edward Creek. Report for period ending 22nd February, 1985. *South Australia. Department of Mines and Energy. Open file Envelope*, 3771 (unpublished).

Newell, B.H., 1987. Stockdale Prospecting Limited. Exploration Licence No. 968: Edward Creek. Final and relinquishment report. *South Australia. Department of Mines and Energy. Open file Envelope*, 3771 (unpublished).

Newell, B.H. and Wilson, P.D., 1987. Stockdale Prospecting Limited. Exploration Licence No. 1295: Nilpinna Springs. Quarterly Report for the period ending 30th January, 1987. *South Australia. Department of Mines and Energy. Open file Envelope*, 6469 (unpublished).

Olliver, J.G. and Barnes, L.C., 1990. Celestite in South Australia. Review of production, use, tenure and geology. *South Australia. Department of Mines and Energy. Report Book*, 90/70.

Papalia, N., 1970. Pexa Oil N.L. Final report on Weedina No. 1 well, South Australia, *South Australia. Department of Mines and Energy. Open file Envelope*, 1374 (unpublished).

Parker, A.J., 1993. Palaeoproterozoic. *In:* Drexel, J.F., Preiss, W.V. and Parker, A.J. (Eds), The geology of South Australia, Vol. 1, The Precambrian. *South Australia. Geological Survey. Bulletin*, 54.

Pitt, G.M., 1976. MURLOOCOPPIE map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SH53-2.

Preiss, W.V., 1985. Stratigraphy and tectonics of the Worumba Anticline and associated intrusive breccias. *South Australia. Geological Survey. Bulletin*, 52.

Preiss, W.V., 1987a. Precambrian palaeontology of the Adelaide Geosyncline. *In:* Preiss, W.V. (Compiler), The Adelaide Geosyncline - Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics. *South Australia. Geological Survey. Bulletin*, 53:283-313.

Preiss, W.V., 1987b. Tectonics of the Adelaide Geosyncline. *In:* Preiss, W.V. (Compiler), The Adelaide Geosyncline – Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics. *South Australia. Geological Survey. Bulletin*, 53:255-281.

Radke, F., 1973. Fission-track dating. Amdel Project 1/1/148, progress report No. 1 (unpublished).

Reyner, M.L., 1955. The geology of the Peake and Denison region. *South Australia. Geological Survey. Report of Investigations*, 6.

Robertson, R.S., 1988. Review of lead-zinc mineralisation in South Australia – Adelaide Geosyncline and Inliers, Stuart Shelf. *South Australia. Department of Mines and Energy. Report Book*, 88/41.

Robison, H.R., 1984. Stockdale Prospecting Limited. Gem Joint Venture, EL 1187. Final report. *South Australia. Department of Mines and Energy. Open file Envelope*, 3562 (unpublished).

Robison, H.R., 1989. Stockdale Prospecting Limited. Exploration Licence No. 1179. Final report. *South Australia. Department of Mines and Energy. Open file Envelope*, 5288 (unpublished).

Robison, H.R., 1990. Boorthanna Trough. Final report – exploration licences numbers 1533 and 1534. *South Australia. Department of Mines and Energy. Open file Envelope*, 4317 (unpublished).

Rogers, P.A. and Freeman, P.J. (in prep.). WINTINNA map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SG53-14.

SADME, 1989. Coal Review-Weedina Deposit. *South Australia. Department of Mines and Energy. Mineral Industry Quarterly*, 55:20-22.

SADME, 1990. Review of Arckaringa Coalfield. *South Australia. Department of Mines and Energy. Mineral Industry Quarterly*, 58:24-25.

Sargeant, F.J., 1970. Australasian Mining Corporation. Special mining lease 270 South Australia. Report on exploration during period 15.2.70 to 15.8.70. *South Australia. Department of Mines and Energy. Open file Envelope*, 1015 (unpublished).

Sas, Z and Gates, A.H. 1981. Report on Mount Kingston Prospect Exploration Licence 491, South Australia (Pacific Exploration Consultants Pty Ltd). *South Australia. Department of Mines and Energy. Open file Envelope*, 3562 (unpublished).

Schopf, J.W. and Fairchild, T.R., 1973. Late Precambrian micro-fossils: a new stromatolitic biota from South Australia. *Nature*, 242:537-538.

Scott, A.K., 1983. CRA Exploration Pty Limited. First quarterly report for Oolgelima Hill EL 1165, South Australia, for the period ending 14th October, 1983. *South Australia. Department of Mines and Energy. Open file Envelope*, 5250 (unpublished).

Scott, A.K., 1984. CRA Exploration Pty Limited. Second quarterly report for Oolgelima Hill EL 1165, South Australia, for the period ending 14 January, 1984. *South Australia. Department of Mines and Energy. Open file Envelope*, 5250 (unpublished).

Seymour, D.L., 1982. Progress report on the Lake Cadi Potash project. *South Australia. Department of Mines and Energy. Open file Envelope*, 4823 (unpublished).

Sheard, M.J., 1990. Glendonites from the southern Eromanga Basin: palaeoclimatic indicators for Cretaceous ice. *South Australia. Geological Survey. Quarterly Geological Notes*, 114:17-23.

Sheard, M.J. and Flint, R.B., 1992. Cretaceous wave-polished granite surfaces, northern Mount Babbage Inlier, South Australia. *South Australia. Geological Survey. Quarterly Geological Notes*, 122:19-23.

Teluk, J.A., 1974. Completion report. Exploration Licence 22. Lagoon Hill area – South Australia. *South Australia. Department of Mines and Energy. Open file Envelope*, 2182 (unpublished).

Thomson, B.P. and Coats, R.P., 1964. The Callanna Beds. *South Australia. Geological Survey. Quarterly Geological Notes*, 9:3-5.

Thornton, R.C.N., 1977. Oodnadatta Town Bore 2. Well completion report. *Mineral Resources Review, South Australia*, 141:51-63.

Townsend, I.J. and Ludbrook, N.H., 1975. Revision of Permian and Devonian nomenclature of four formations in and below the Arckaringa Basin. *South Australia. Geological Survey. Quarterly Geological Notes*, 54:1-5.

Twidale, C.R., 1982. *Granite Landforms*. Elsevier, Amsterdam.

Van Niel, J., 1984. Palynology of upper Proterozoic and Cambrian samples from 11 wells in South Australia. SDA (Shell Development (Australia) Pty Ltd) 641. *South Australia. Department of Mines and Energy. Open file Envelope*, 6846 ((unpublished).

Wasson, R.J., 1983. The Cainozoic history of the Strzelecki and Simpson dunefields (Australia), and the origin of the desert dunes. *Zeitschrift für Geomorphologie*, 45:85-115.

Watts, J.A., 1984. Alluvial gold testing program, EL 1187. Peake and Denison Ranges, South Australia (final report). *South Australia. Department of Mines and Energy. Open file Envelope*, 3562 (unpublished).

Williams, A.F., 1973. NOOLYEANA map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SG53-16.

Williams, A.F., 1975. LAKE EYRE map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series*, sheet SH53-4.

Williams, A.F., 1979. Sampling and measurement of mound springs in the Great Artesian Basin South Australia, progress report No. 3. WARRINA, OODNADATTA, BILLA KALINA and CURDIMURKA sheets. *South Australia. Department of Mines and Energy. Report Book*, 79/66.

Williams, G.E., 1973. Late Quaternary piedmont sedimentation, soil formation and paleoclimates in arid South Australia. *Zeitschrift für Geomorphologie*, 17:102-125.

Williams, G.E. and Polach, H.A., 1971. Radiocarbon dating of arid-zone calcareous paleosols. *Geological Society of America. Bulletin*, 82:3069-3086.

Wilmot, J.G., 1987. Geophysical interpretation report. 1985 Morphett-ARC survey, Arckaringa Block. *South Australia. Department of Mines and Energy. Open file Envelope*, 5995:15-41 (unpublished).

Wood, G.R. and Williams, A.J., 1985. Arckaringa Basin Getty Oil hole GN13c. Palynological report. Report No. 13/289. *South Australia. Department of Mines and Energy. Open file Envelope*, 4317:303-309 (unpublished).

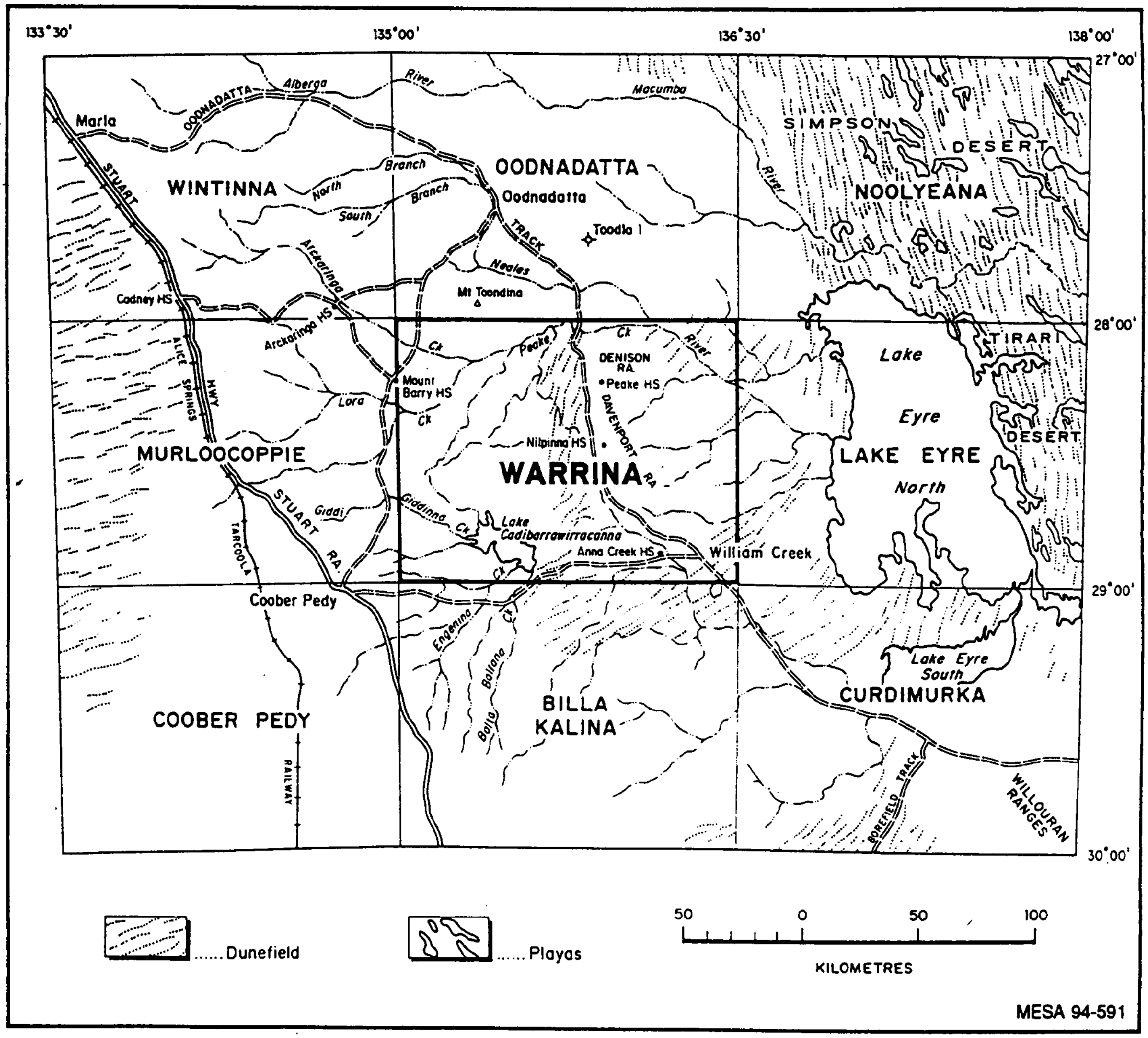
Woods, P.H., Walker, G.R. and Allison, G.B., 1990. Estimating groundwater discharge at the southern margin of the Great Artesian Basin near Lake Eyre, South Australia. *In: International conference on groundwater in large sedimentary basins. Conference working papers*. University of Western Australia.

Wopfner, H., 1968. Cretaceous sediments on the Mount Margaret Plateau and evidence for neotectonism. *South Australia. Geological Survey. Quarterly Geological Notes*, 28:7-11.

Wopfner, H., 1970. Permian palaeogeography and depositional environment of the Arckaringa Basin, South Australia. *In: Second Gondwana Symposium, South Africa, 1970. Proceedings and papers*, pp.273-291.

Wopfner, H., Freytag, I.B. and Heath, G.R., 1970. Basal Jurassic-Cretaceous rocks of the western Great Artesian Basin, South Australia: stratigraphy and environment. *AAPG Bulletin*, 54:383-416.

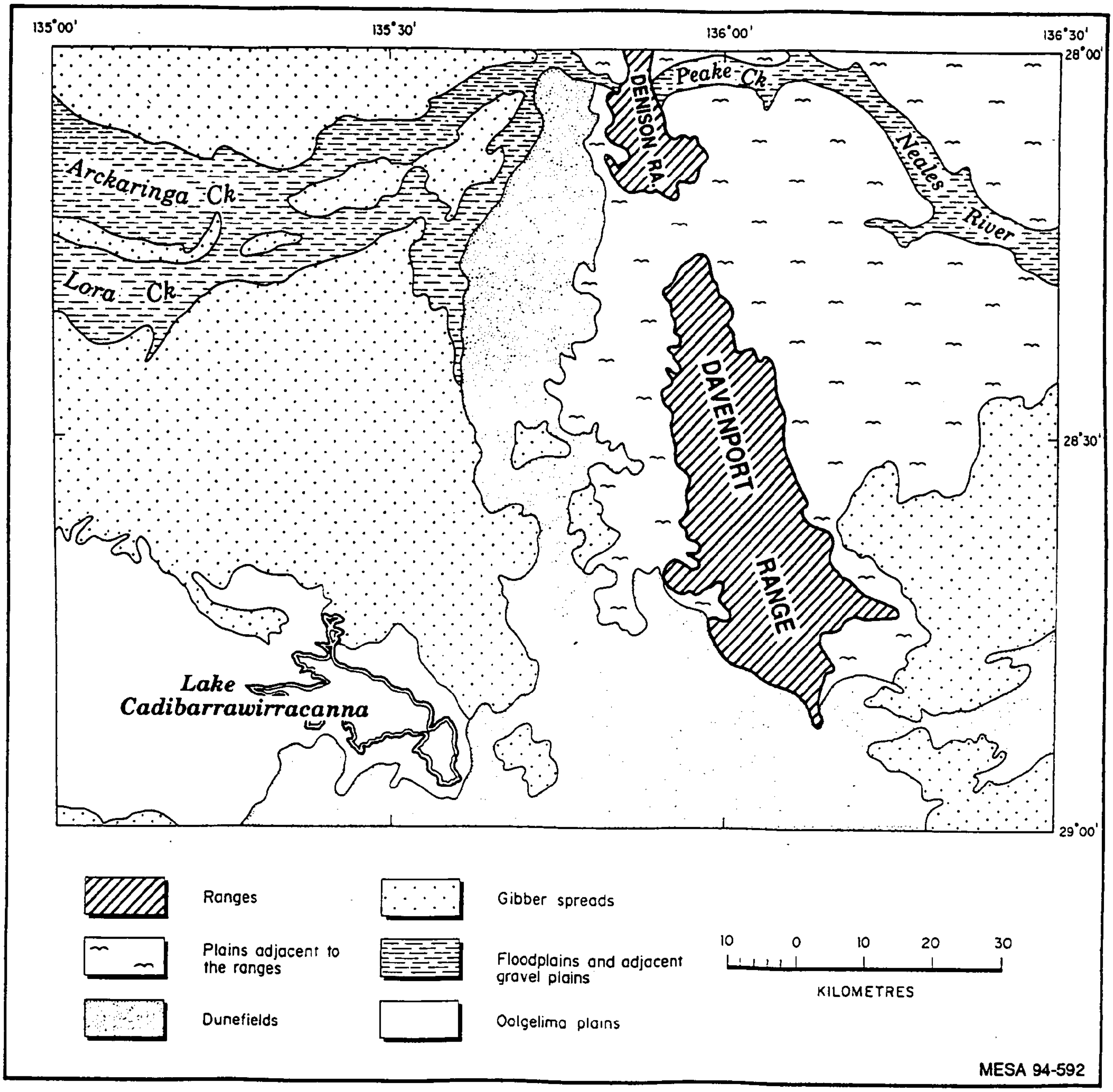
Wyatt, D.H., 1980. Second quarterly and final report on EL 641 (Lake Cadibarrawirracanna) for the period Sept. 3-Dec. 2, 1980. AMAX Iron Ore Corp. Minerals Exploration Division. *South Australia. Department of Mines and Energy. Open file Envelope*, 3885 (unpublished).



WARRINA 1 : 250,000

LOCALITY PLAN

Figure 1



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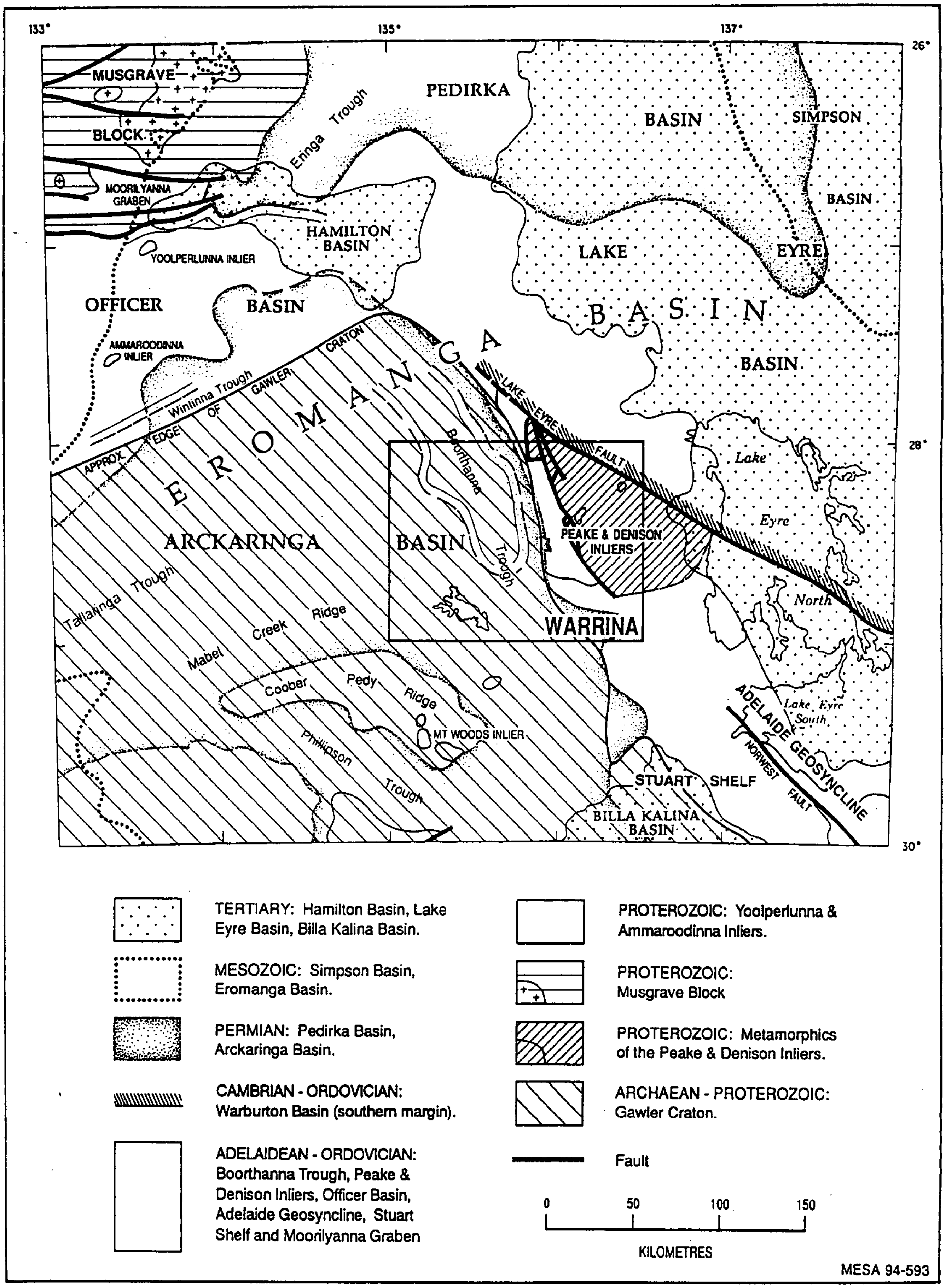
PHYSIOGRAPHIC REGIONS

Figure 2



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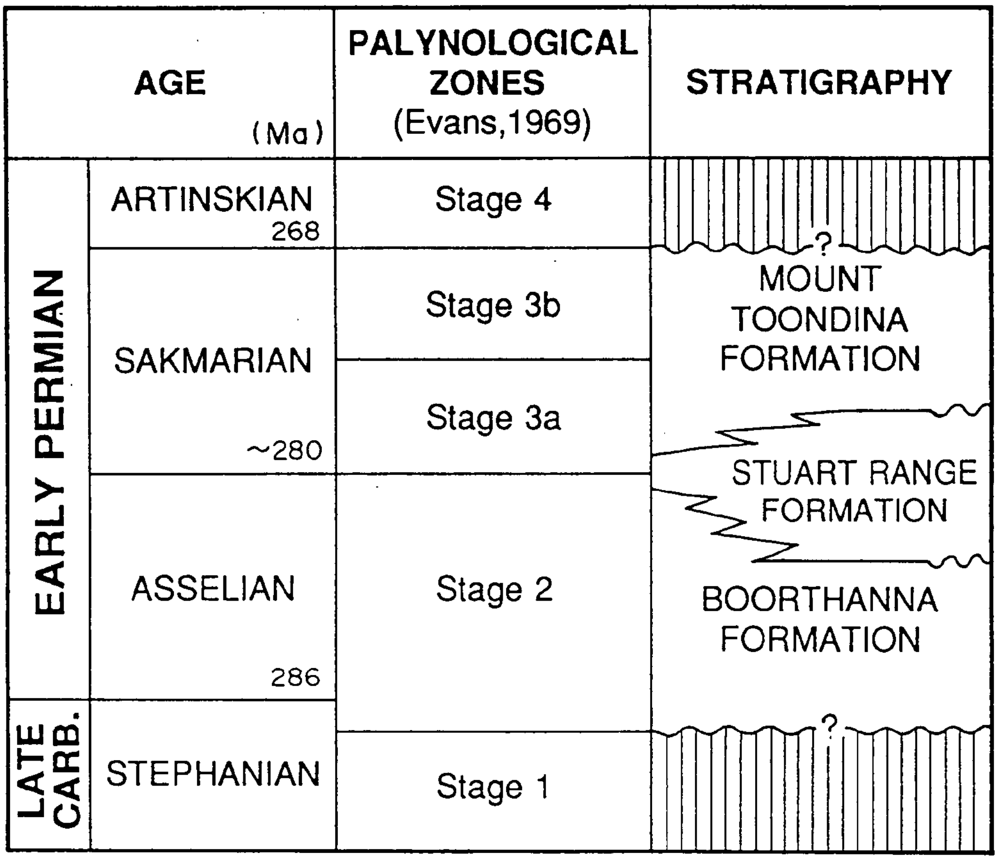
GEOLOGICAL SETTING

Figure 3



MESA 94-594

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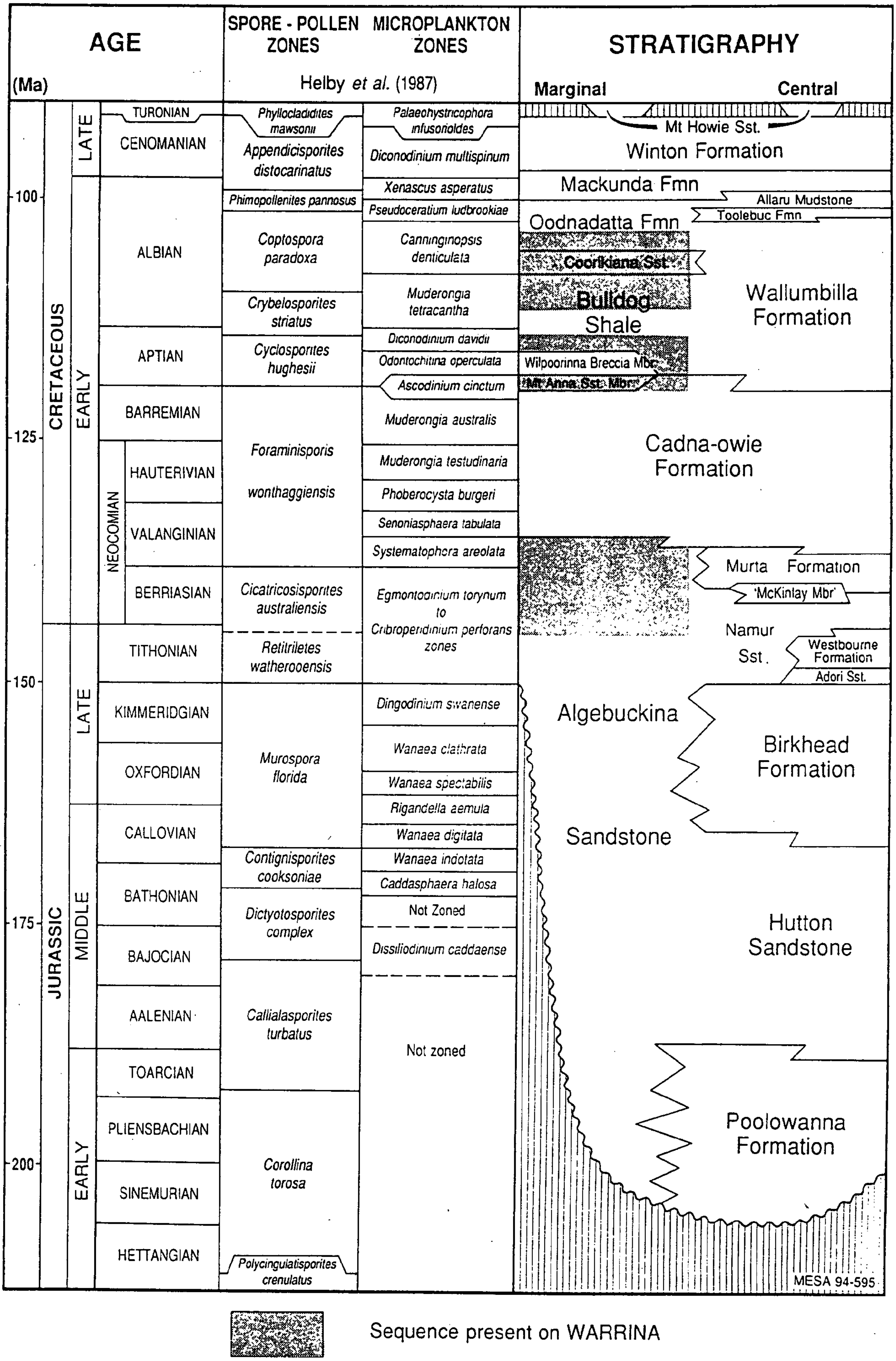
LATE PALAEOZOIC STRATIGRAPHY OF THE ARCKARINGA BASIN

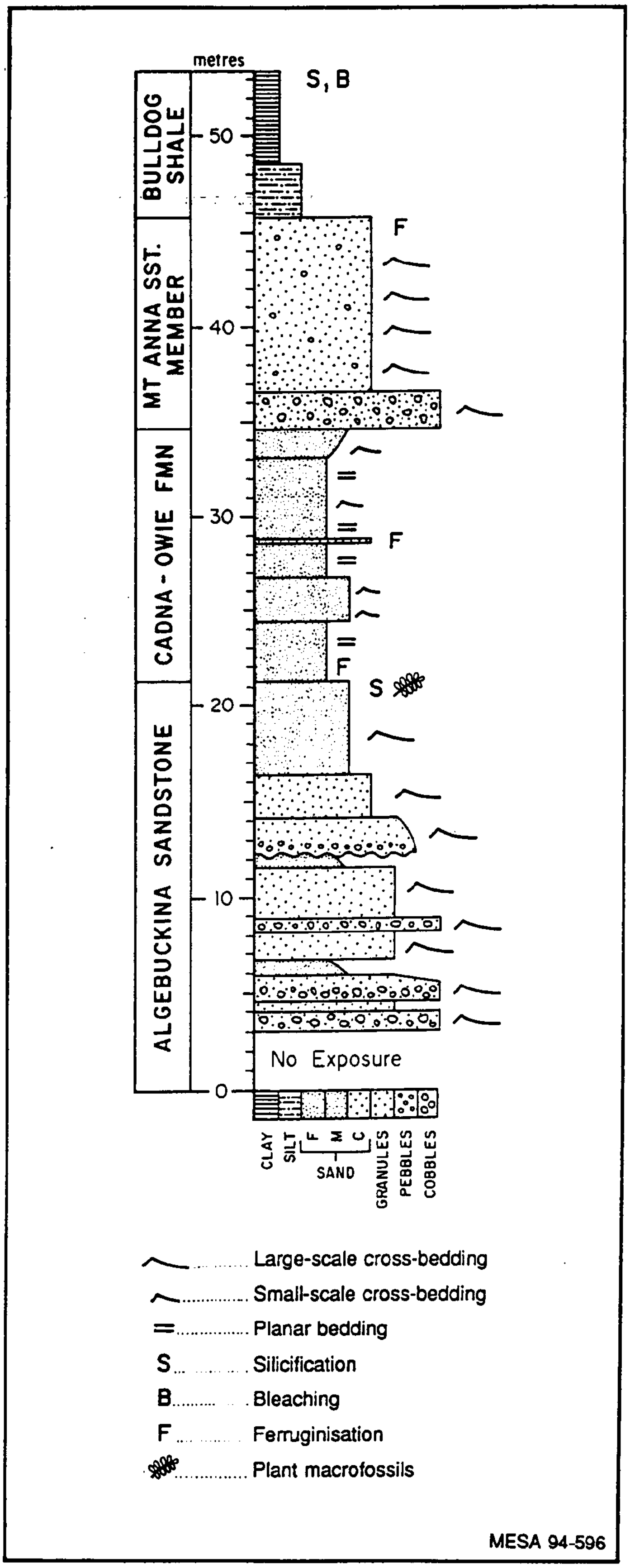
Figure 4



WARRINA 1 : 250,000

STRATIGRAPHY AND PALYNOLOGICAL ZONATIONS, SOUTHWESTERN EROMANGA BASIN

Figure 5



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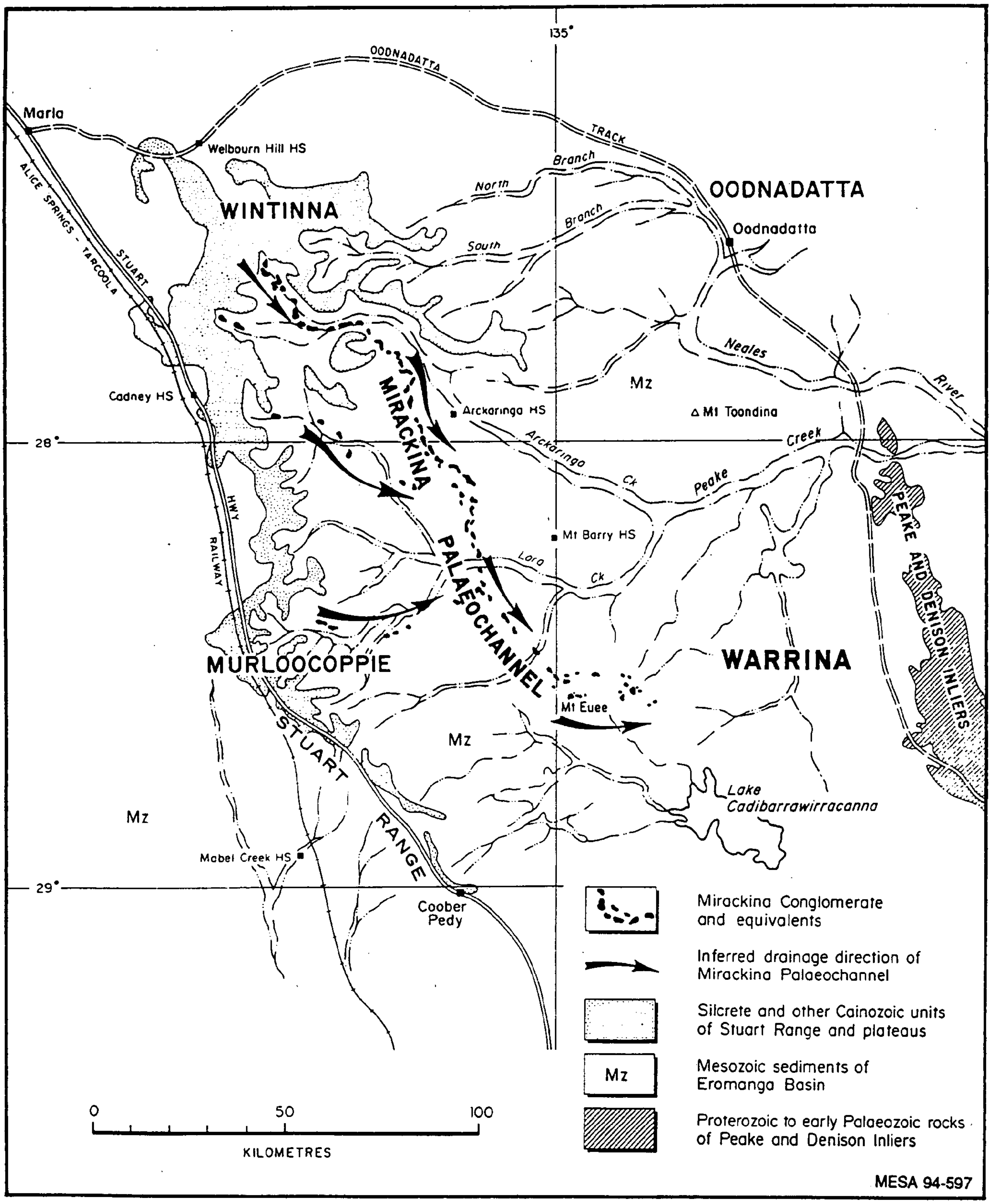
COMPOSITE MESOZOIC SECTION, MT ANNA AREA

Modified from Wopfner *et al.* (1970)

Figure 6



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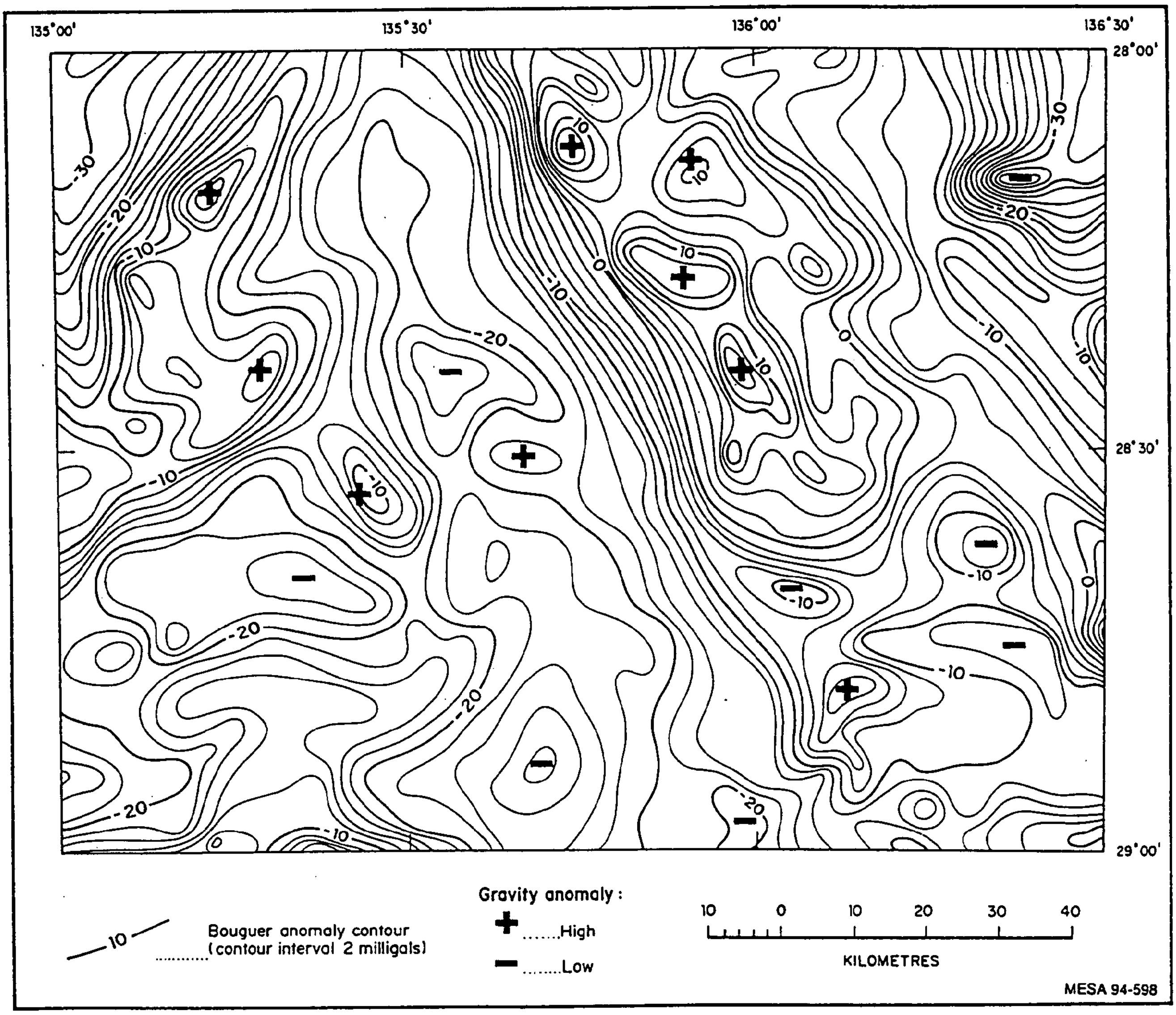
THE MIRACKINA PALAEOCHANNEL

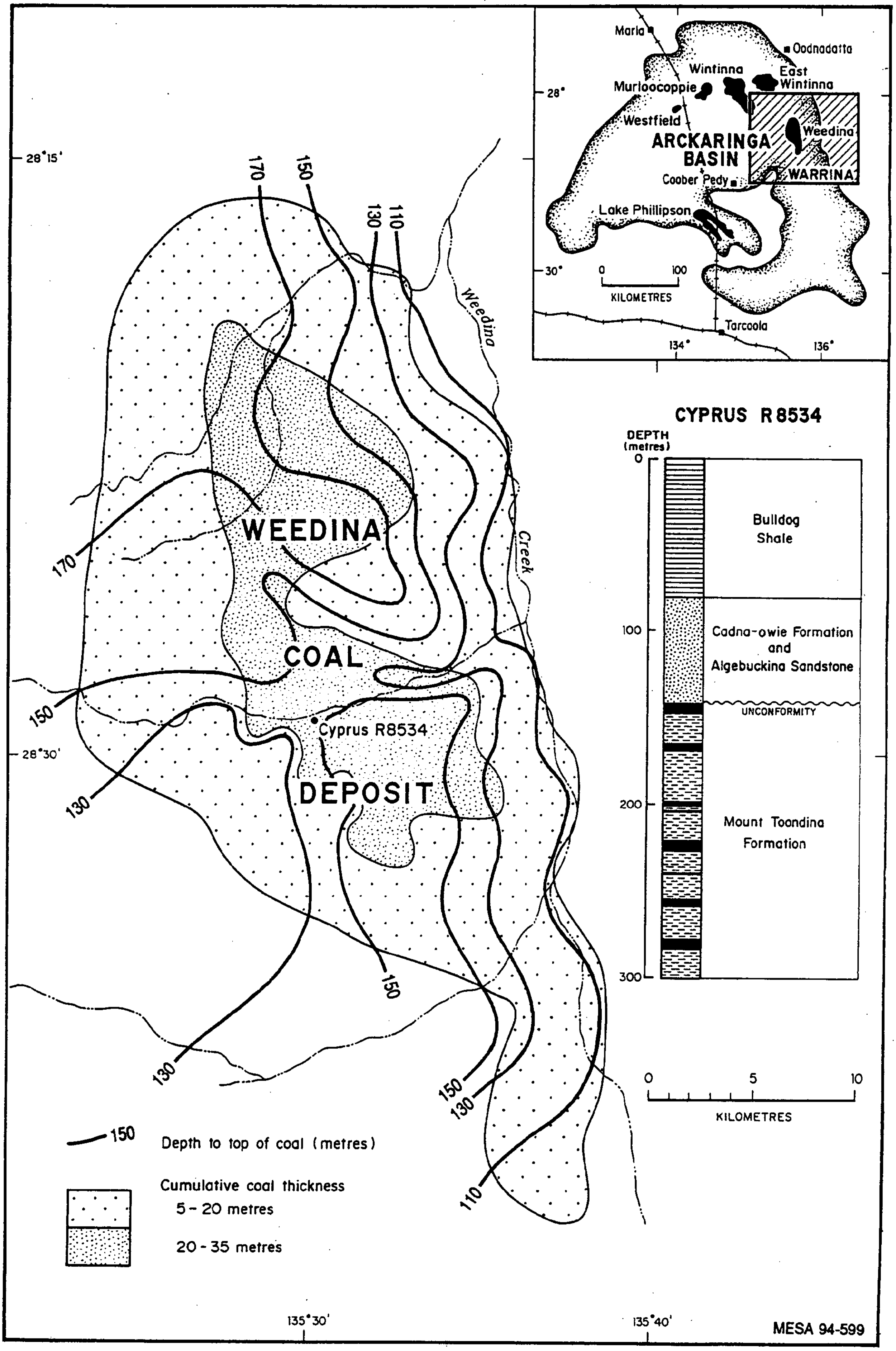
After Barnes and Pitt (1976)

Figure 7



WARRINA 1 : 250,000
BOUGUER GRAVITY ANOMALY MAP

Figure 8



WARRINA 1 : 250,000

Figure 9

WEEDINA COAL DEPOSIT AND SUMMARY STRATIGRAPHIC LOG FOR CYPRUS R 8534 DRILLHOLE

Plate 1 Upper surface of stromatolites, Skillogalee Dolomite, eastern margin of Davenport Range (41923)

Plate 2 Stromatolites, Kalachalpa Formation, west of Mount Anna (41924)

Plate 3 Striated quartzite clast, Calthorinna Tillite, southern Davenport Range (41925)

Plate 4 Kink folding in Burra Group (Nr_1) adjacent to diapiric zone near Edith Spring (41926)

Plate 5 Disrupted Burra Group (Nr_1) forming angular breccia, diapiric zone near Edith Spring (41927)

Plate 6 Diapiric breccia with carbonate matrix, diapiric zone near Edith Spring (41928)

Plate 7 Core of probable Boorthanna Formation diamictite with cobbles of granite and smaller clasts of calcareous siltstone, Ruby Hill 1, 221.0-221.34 m (39458)

Plate 8 Large erratic of Calthorinna Tillite resting on Boorthanna Formation, southwest of Mount Anna (41929)

Plate 9 Aerial view of Mount Margaret Surface developed on Mount Margaret Quartzite, looking south along western margin of Davenport Range (14472)

Plate 10 Fossil fern fronds (*Cladophlebis* cf. *australis*) in silicified top of Algebuckina Sandstone, near Mount Anna (41930)

Plate 11 Bulldog Shale with pebbly quartz grit and quartzite boulder, Bulldog Creek (41931)

Plate 12 Fossil log resting on Bulldog Shale, north of Sunny Creek (41932)

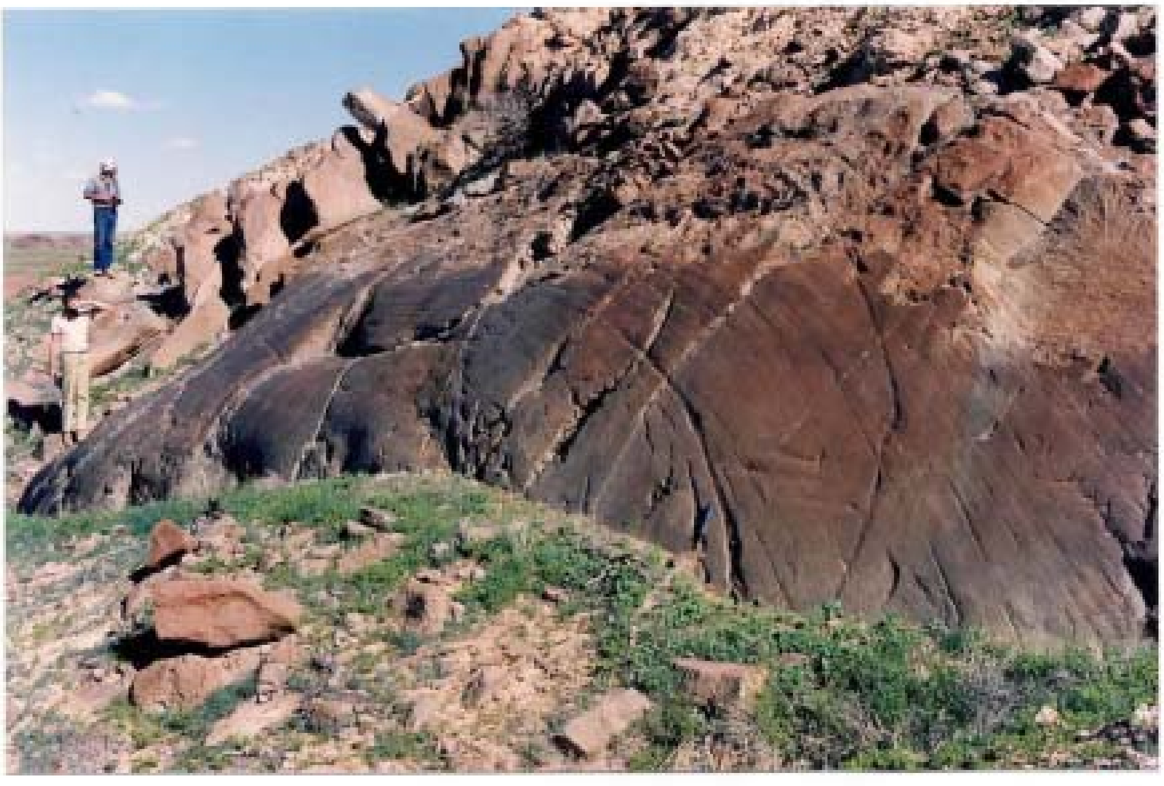


Plate 13 Bulldog Shale with quartz grit layer showing ball-and-pillow structures, Sunny Creek bore (41933)

Plate 14 General view of interpreted Cretaceous wave-smoothed surface developed on Palaeoproterozoic granitic gneiss (Lc_3), Lagoon Hill (41934)

Plate 15 Bulldog Shale beach deposits comprising coquinite and large wood fragments resting on rounded boulders of Palaeoproterozoic basement (Le$_3$), Lagoon Hill (41935)

Plate 16 Possible Cretaceous shore surface with small potholes developed on Palaeoproterozoic basement (Le$_3$), Spring Hill (41936)

Plate 17 Symmetrical wave ripples and trace fossils, Coorikiana Sandstone, Old Umbum ruins (41937)

Plate 18 Interference ripples, Coorikiana Sandstone, Old Umbum ruins (41938)

Plate 19 Ripple cross-lamination, Coorikiana Sandstone, Old Umburn ruins (41939)

Plate 20 Sand volcano, Coorikiana Sandstone, Old Umburn ruins (41940)

Plate 21 Interlayered siltstone to very fine sandstone and mudstone, Oodnadatta Formation, junction of George and Umbum Creeks (41941)

Plate 22 Gypsite surface (Qp_{g1}) developed on Bulldog Shale north of Neales River, looking southwest to Davenport Range (41942)

Plate 23 View looking south along Levi Fault of steeply-dipping ferruginous sandstone (Cadna-owie Formation) faulted against Burra Group (Nr_1), Edith Spring. Section in background is alluvial gravel (Qpa_4) overlying Bulldog Shale (41943)

Plate 24 Terrace of alluvial gravel (Qpa_4) resting on Burra Group (Nr_1) west of Levi Fault, Edith Spring (41944)