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GEOLOGICAL REVIEW OF THE SOUTHERN CURNAMONA REGION

Luisa Ruperto and Patrice de Caritat

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Headquarters: CRC LEME c/o CSIRO Exploration and Mining, PO Box 1130, Bentley WA 6102, Australia

This report presents a brief geological overview of the southern Curnamona Region in South Australia and New South Wales. This project commenced July 2004 and was completed July 2005. A complementary document entitled "Three-dimensional model of the Callabonna Sub-Basin sequence, southern Curnamona Region" by Luisa Ruperto and Malcolm Nicoll (2006) is recommended to be read in conjunction with this report.

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Addresses and affiliations of authors

Luisa Ruperto
Cooperative Research Centre for Landscape
Environments and Mineral Exploration
c/- Geoscience Australia
GPO Box 378
Canberra ACT 2601
Australia

Patrice de Caritat
Cooperative Research Centre for Landscape
Environments and Mineral Exploration
c/- Geoscience Australia
GPO Box 378
Canberra ACT 2601
Australia

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ABSTRACT

This report reviews the subsurface geology of the southern Curnamona region, as background information to the associated 3D model of the Cainozoic Callabonna Sub-basin.

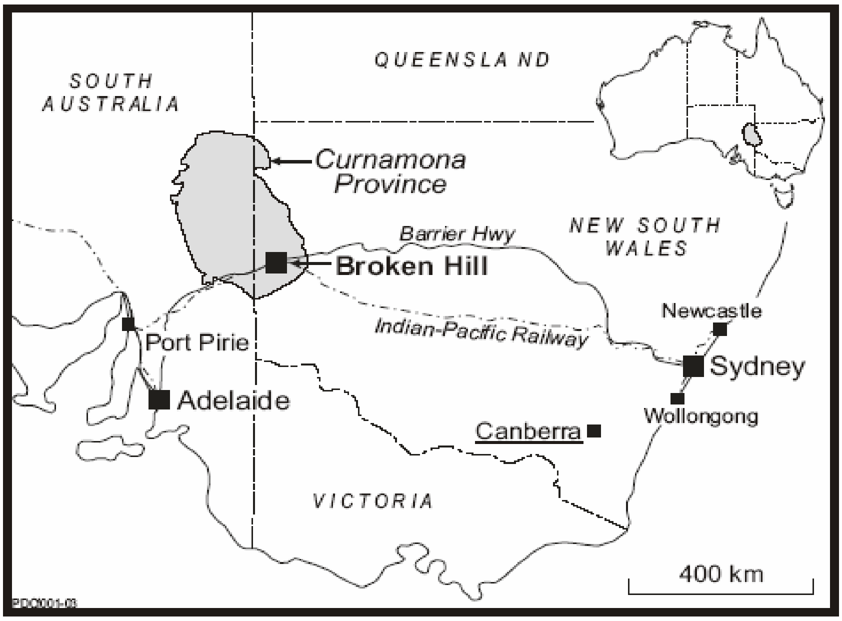
The geological setting of this region incorporates multiple basins with complex inter-relationships across the region. Proterozoic basement units are assigned to the Willyama Supergroup, including the Benagerie Ridge basement high. The overlying Arrowie Basin records a significant period of deformation when the Benagerie Ridge served as a structural divide between the Moorowie and Yalkalpo synclinal depocentres during the Late Cambrian. The Mesozoic Eromanga Basin sediments are distinguished based on their spatial relationship to the Denison-Willouran Divide. This predominantly marine succession is overlain by Tertiary Lake Eyre Basin units comprising the Eyre and Namba Formations. These comprise an alternating sequence of lacustrine and fluvial sediments with depositional environments dominated by river channels and/or a lack of major structural relief. Significant drying of the environment during the Quaternary has led to the development of sequences dominated by regolith materials.

INTRODUCTION

The purpose of this report is to describe the sub-surface geological environment of the Curnamona Region in eastern South Australia and western New South Wales (Figure 1). The region of interest occupies a large arid to semi-arid area located between the geographic co-ordinates: 139ºE/33ºS and 143ºE/30ºS. The relevant 1:250 000 map sheets are OLARY SI54-2, CURNAMONA SH54-14, BROKEN HILL SH54-15, FROME SH54-10 and COBHAM LAKE SH54-11. This review aims to serve as background information to the associated 3D model of the Cainozoic sedimentary fill (Ruperto and Nicoll, 2005).

The Curnamona Region has a complex geological history, including the development of several sedimentary basins that herald distinct depositional events in the area (Figure 2). In the broadest sense, the region can be subdivided into:

(1) Palaeo- to Neoproterozoic metamorphic basement, which encompasses the Willyama Supergroup, the 'Bimbowrie supersuite' and the Adelaidean sequence;
(2) Cambrian marginal marine/shelf facies of the Arrowie Basin;
(3) Mesozoic Frome Embayment of the Eromanga Basin;
(4) Cainozoic sedimentary fill of the Callabonna Sub-basin of the Lake Eyre Basin, including the fluvio-lacustrine Eyre and Namba Formations; and
(5) Recent sediments locally hosting gypsum, siliceous, ferruginous and carbonate regolith materials.



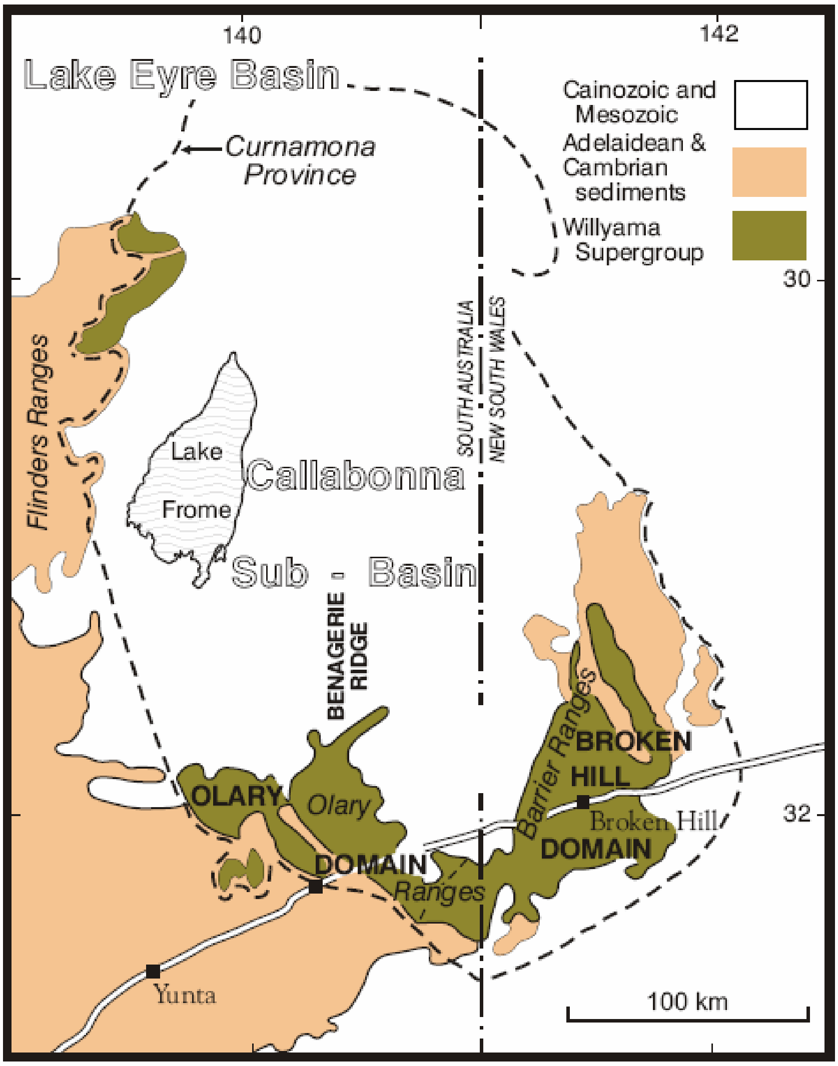


Figure 1. General location and spatial relationships between outcropping major geological units of the southern Curnamona Region. Source: Leyh and Conor (2000).

The high mineral prospectivity of the Curnamona Region arises primarily from the numerous base metal deposits in the Proterozoic basement, including the world-class Pb-Zn-Ag Broken Hill line of lode orebody hosted by the Willyama Supergroup. Other important mineral commodities in the region are Cu-Au, Au, polymetallic mineralisation, Co, rare earth elements, W, Sn and U. The latter mineralisation occurs both in the basement rocks and in the sedimentary sequence of Tertiary palaeovalley fills within the Callabonna Sub-basin as roll-front U deposits.

The prime focus of this study is the mid-late Cainozoic Callabonna Sub-basin, which represents the uppermost 250 m or so of sediments.

PALAEO- TO MESOPROTEROZOIC

The Curnamona Region encompasses a high-grade metamorphic and complexly deformed basement (Stevens et al., 1988; Stevens and Corbett, 1993; Stevens and Burton, 1998). The basement is generally described in the literature as pre-Adelaidean or Palaeoproterozoic to early Mesoproterozoic in age and evolved from a series of rifting events. It crops out in the Willyama Inliers (Olary and Broken Hill Domains) in the southern part of the Region, and at Mt Painter and Mt Babbage in the northwest (Burtt et al., 2004). The complex distribution of Palaeo- to Meso-Proterozoic units is illustrated in Figure 2.

The Curnamona Region abuts the Nackara Arc system within the Olary Ranges (Paul et al., 1999). The southernmost of the Proterozoic inliers, the Willyama Inlier, originated as a result of four phases of deformation culminating in high grade metamorphism and syn-tectonic plutonism associated with the Olarian Basin phase (~1700-1600Ma) (Teasdale et al., 2001).

One of the dominant features of this basement is the now-buried Benagerie Ridge, a north-south trending basement high situated to the east of Lake Frome (Figure 2). The ridge is composed of Willyama Supergroup metasediments and 'Bimbowrie Supersuite' felsic and mafic intrusives and bimodal volcanics (Burtt et al., 2004).

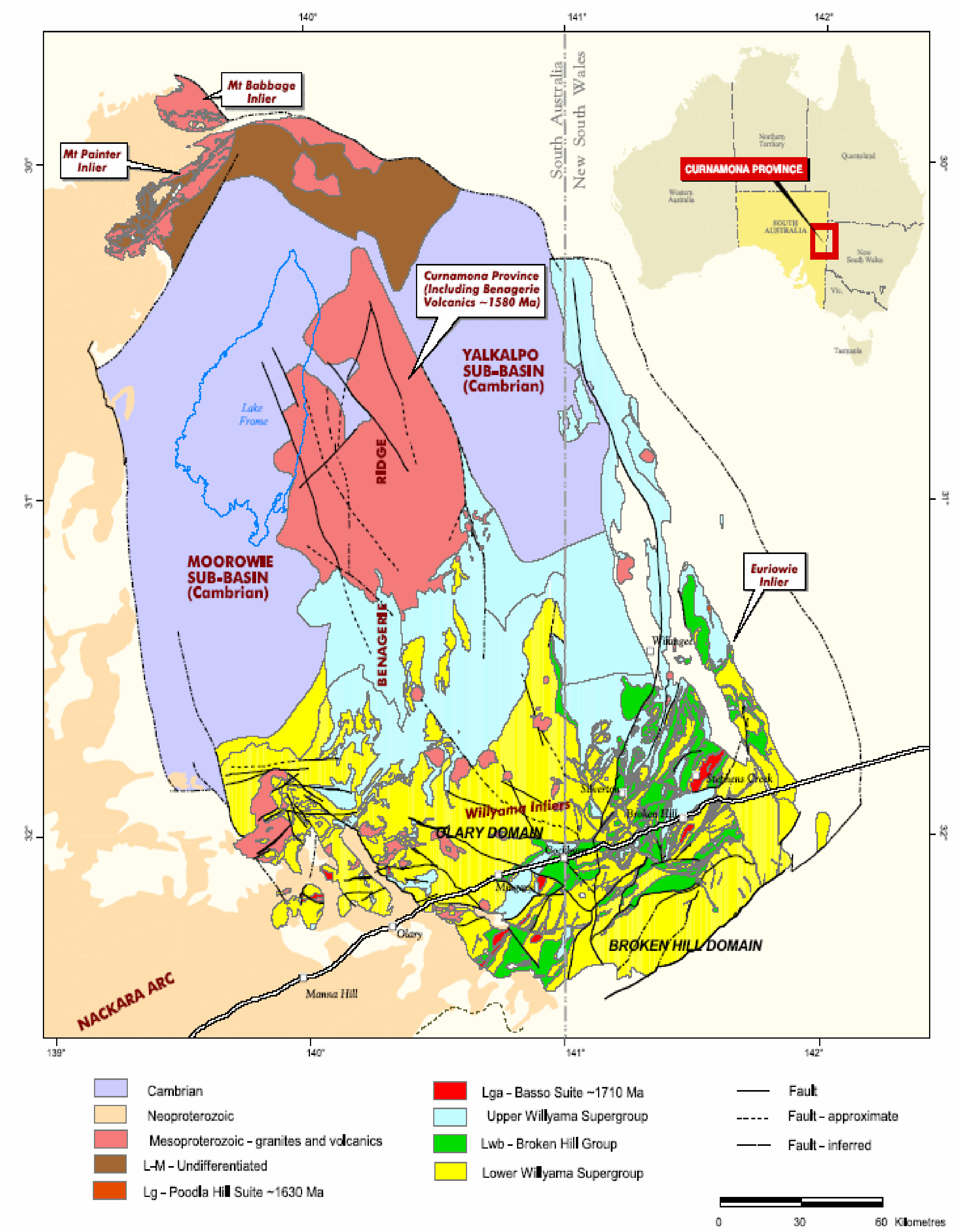


Figure 2. Major sub-surface geology (including inliers), outcrop areas and faults of the Curnamona Region. Source: PIRSA Image AV201310_014 http://www.pir.sa.gov.au/pages/minerals/geology/curnamona/curnamona_geology.htm.

Burtt et al. (2004) have summarised the stratigraphy and tectonic elements of the Curnamona Region as understood to date (see Figure 3). The Province encompasses two major groups of rocks, the Willyama Supergroup and the younger 'Bimbowrie Supersuite', which are recognised within the Olary and Broken Hill Domains and correlate reasonably well across them. Both groups comprise metasedimentary and metavolcanic rocks intruded by various gneiss/granitoid bodies. The Willyama Supergroup hosts the Broken Hill Pb-Zn-Ag deposit in the Broken Hill Group (Figure 2).

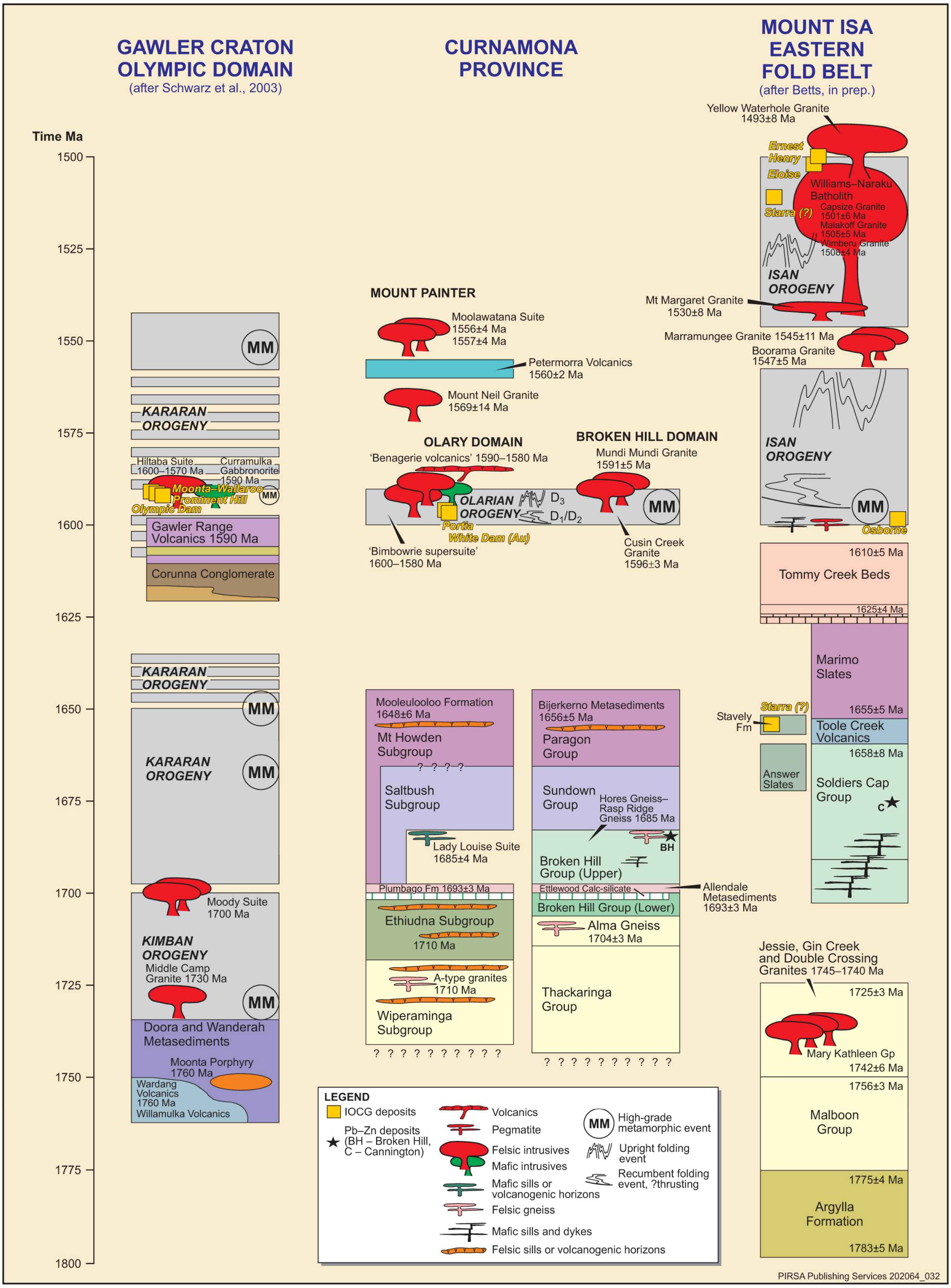


Figure 3. Stratigraphic comparison between the three major cratons in central Australia. The relationships described here compare deposition, metamorphism, intrusion, regional deformation and mineralisation (I0CG = iron-oxide copper-gold) events. Source: Burtt et al. (2004).

NEOPROTEROZOIC (ADELAIDEAN)

Neoproterozoic sedimentary rocks record deposition in cratonic, craton-margin and rift-basin settings, with relatively minor associated igneous activity (Preiss et al., 1993; Preiss, 2000), particularly to the west of the Curnamona Region. Sediments of Adelaidean age were deposited mainly in the Adelaide Geosyncline and fall within the Neoproterozoic. The sediments have been subdivided into four chronostratigraphic units: Willouran (oldest), Torrensian, Sturtian and Marinoan (youngest) (Preiss et al., 1993). The Adelaidean sequence is thickest in the Flinders Ranges (forming the western boundary of the Curnamona Region) and in the Mount Lofty Ranges.

The Adelaidean sequence records a transition from

1. mafic volcanism and dyke emplacement followed by deposition of a mixed sequence of evaporitic clastic/ carbonate sediments and minor mafic volcanics with rift basins (Willouran);
2. to minor mafic and local felsic volcanism followed by terrestrial to shallow marine clastics and minor carbonates, proximal clastic wedges interfingering with more distal fine-grained clastic and carbonate sediments, followed by the precipitation of dolomite and sedimentary magnesite in marginal marine and lagoonal environments and coarse sandy facies in source-proximal zones during the first major marine inundation of the Geosyncline (Torrensian);
3. to a phase of basin uplift followed by marine transgression, deposition of glacigenic sediments during a rifting episode (Sturtian);
4. to a low then rising sea level during which products of the waxing, maximum then waning stages of glaciation were deposited (Marinoan) (Preiss, 2000).

Subsurface Adelaidean units of the Curnamona Region commonly consist of quartzite, quartzite conglomerate, limestone, siltstone, sandstone, shale, dolomite and diamictite forming various groups (Willis et al., 1983; Stevens et al., 1988; Stevens and Corbett, 1993).

PALAEOZOIC (CAMBRIAN)

Up to 5 km of Early to mid Late Cambrian sediments of the vast Arrowie Basin crop out in the Flinders Ranges, unconformably overlying the Curnamona craton, Adelaide Geosyncline and Stuart Shelf basement rocks (Gravestock and Cowley, 1995; PIRSA, 2002). Within the study area, the Arrowie Basin consists of depocenters, the Moorowie and Yalkalpo synclines or depressions (Figures 4 and 5) separated by the Benagerie Ridge basement high. These two depocenters contain up to 2300 m of Cambrian strata (PIRSA, 2002; Zang, 2002). The Moorowie depocenter is bisected by the Poontana Fracture Zone, a northerly trending wrench fault complex subparallel to the Benagerie Ridge (Callen, 1990; Gravestock and Cowley, 1995). Granitic intrusions were emplaced within the Arrowie Basin sediments only in the Moorowie depocenter (PIRSA, 2002).

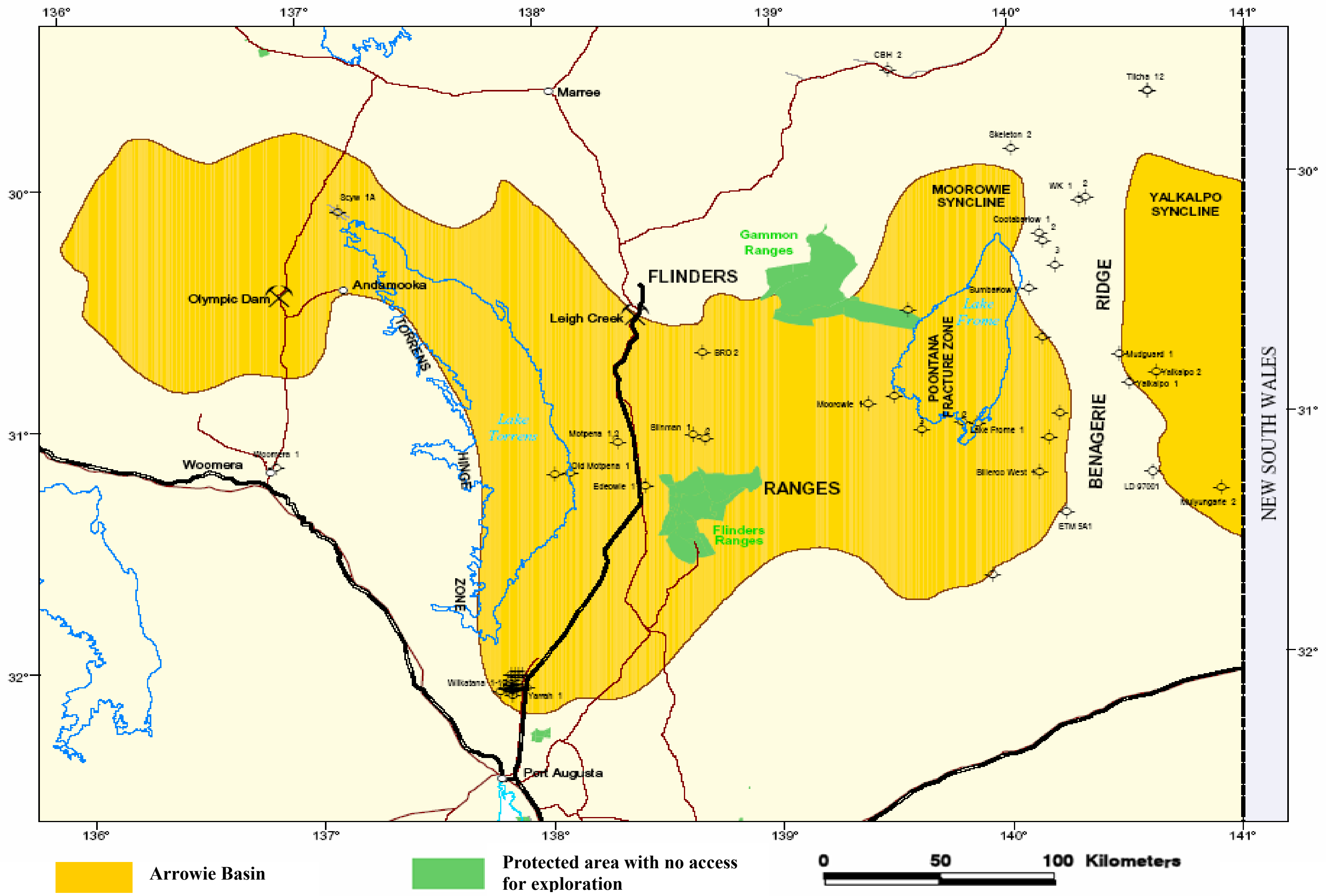


Figure 4. Extent of Arrowie Basin and location of Benagerie Ridge, Moorowie and Yalkalpo synclines, and Poontana Fracture Zone. Source:PIRSA (2002)

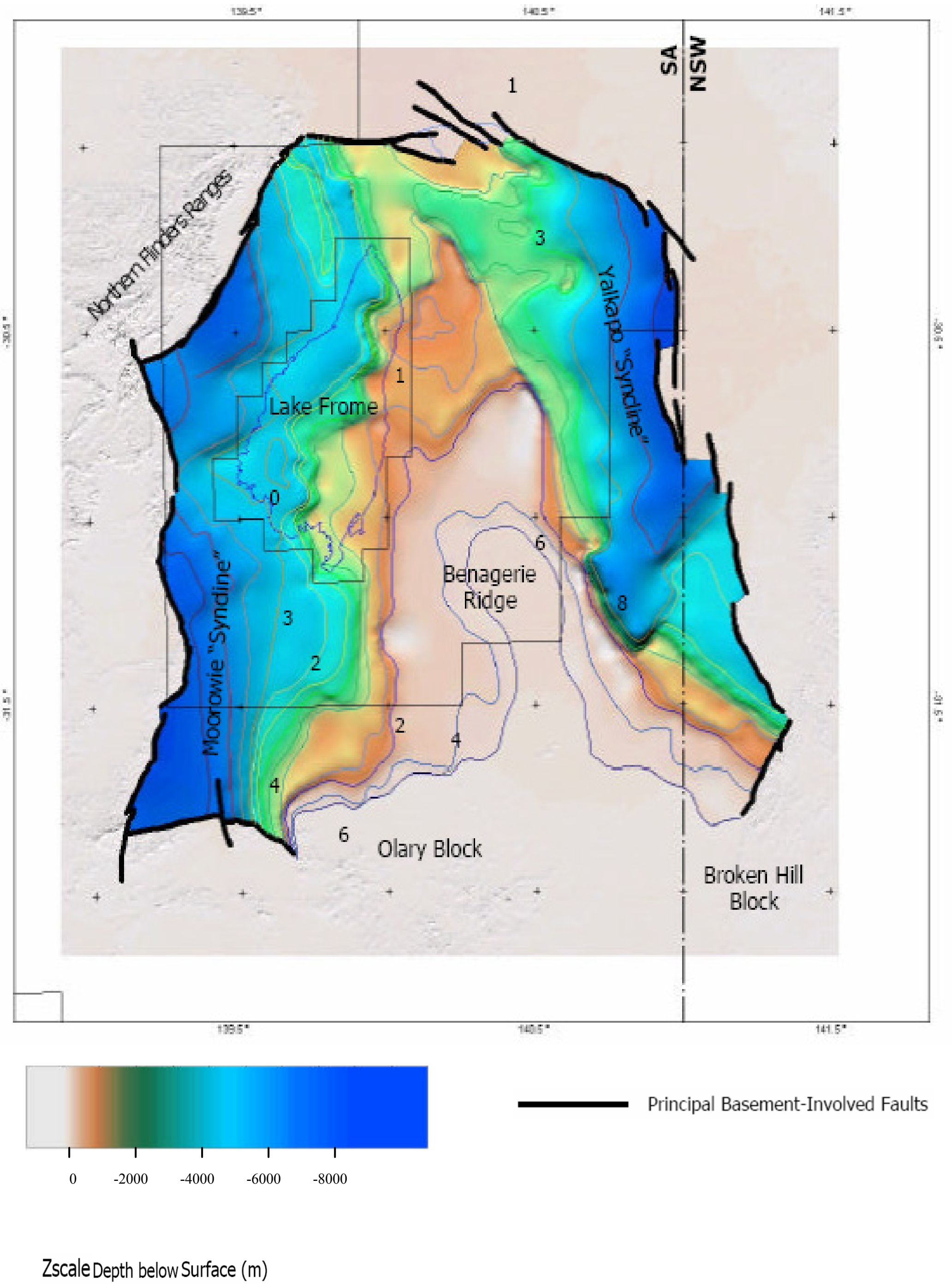


Figure 5. 3D representation of the depth to base of Cambrian surface. Source: Teasdale et al. (2001).

The predominantly subsurface Cambrian Arrowie Basin includes bedded limestone, shales and sandstones deposited within a regressive near-shore to shelf-deltaic marine environment (Callen, 1990). Overlying the Arrowie Basin is the Mesozoic Frome Embayment, a large-scale feature representing a south-eastern depocenter of the Eromanga Basin.

MESOZOIC (CRETACEOUS)

Evidence of global climate change within the southern Curnamona Region is visible in the Jurassic and Cretaceous geological sequences. Intra-plate tectonism throughout the Early Jurassic was the precursor for the formation of the epicratonic Jurassic-Cretaceous Eromanga Basin in a predominantly terrestrial freshwater environment (Krieg et al., 1995). It is the far south-western portion of this basin that overlies the Curnamona Region and is represented by a thin, variable cover. The structurally faulted Denison-Willouran divide (Figure 6) serves as a predominant partition of the South Australian portion of the Eromanga Basin including a small thin lobe situated beneath Lake Frome. Due to the irregular limits of the Eromanga Basin, it is difficult to definitely determine its spatial extent in the study area.

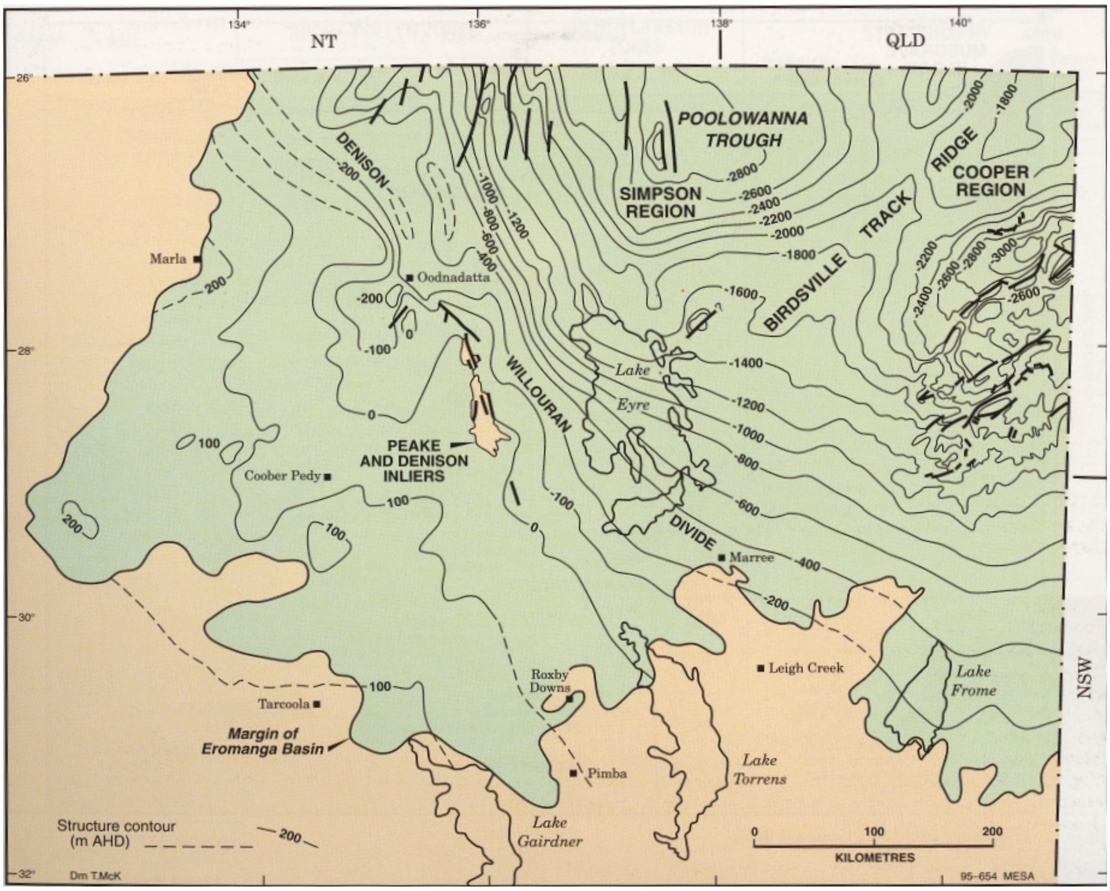


Figure 6. Highly irregular limits of the Eromanga Basin within the Curnamona Region of South Australia. Note the Denison-Willouran Divide and its location relative to the structurally prominent Birdsville Track Ridge. The contours depict the base of the Mesozoic. Source: Krieg et al. (1995)

According to Ker (1958) shale of Late Jurassic Maree Subgroup (of the Neales River Group) and Cadna-Owie Formation represents the Frome Embayment of the Mesozoic Eromanga Basin in this area. The Lower Cretaceous shales appear to be fairly widespread over the area and tend to accumulate to the east of the Benagerie Ridge, in the Yalkalpo syncline (Ker, 1958). The mostly sandstone Cadna-Owie Formation is identified through a fining upward sand sequence with a pebble bed, roughly marking the base of the Mesozoic at a maximum topographic height of 81 metres above sea level (Callen, 1990). Indicative of marginal and shelf marine conditions (Callen, 1990), this thickly laminated, often pebbly formation represents a minor succession of the Eromanga Basin and is significant as the last major transgression onto the continent (Krieg et al., 1995). Within this unit there is widespread evidence for shoreline oscillations along the basin margins (such as in the study area), whilst the central parts of the Eromanga Basin experienced much broader scale transgressive and tectonic effects at this time (Krieg et al., 1995). The Marree Subgroup includes the Bulldog Shale, Coorikiana Sandstone and Oodnadatta Formations with the distribution of these units within the Curnamona Region limited this far south in the Eromanga Basin.

The overlying Cainozoic basins are significantly more complex offering various examples of sedimentation and evidence of shifting depositional environments.

CAINOZOIC (TERTIARY)

Within the study area the broad regional Lake Eyre Basin is subdivided into two smaller basins – the Tirari Sub-basin (formerly known as the Tarkarooloo Sub-basin) and the Callabonna Sub-basin (Callen, 1990), separated by the Birdsville Track Ridge structural divide (Figure 6). Sediments in the Lake Eyre Basin were deposited in three phases:

i. Late Palaeocene - Mid Eocene (Eyre Formation),
ii. Late Oligocene - Pliocene (Etadunna and Namba Formations), and
iii. Pliocene - Quaternary (modern sands).

It is important to note that some units within the Callabonna Sub-basin also occur in adjacent basins. These spatial relationships are described in Table 1.

Lake Eyre Basin	Torrens Basin	Callabonna Basin (includes CURNAMONA)	Murray Basin
	Motpena Palaeosol	Billeroo or Moko Palaeosols	
	Lake Torrens Formation; Pooraka Formation of Port Augusta area	Coonarbine Formation	
	Wilkatana Palaeosol	Moko or Pinpa Palaeosols	
	Pooraka Formation on COPLEY	Eurinilla Formation	
Katipiri Formation Tirari Formation	Hindmarsh Clay and Telford Gravel	Coomb Spring and Millyera Formations Conglomerates of the Pasmore River (Willawortina Fm.)	
	?Avondale Clay	Willawortina Formation	
		Silcrete and mottled iron palaeosols	Karoonda and Ardrossan Palaeosols
?Mampuwordu sand			
Etadunna Formation		Namba Formation	Geera Clay (in part)
Eyre Formation	Eyre Formation	Eyre Formation	

Table 1. Spatial context of Cainozoic geology between the Callabonna Sub-basin and equivalent units in adjacent basins. Source: Callen, (1990).

The most widespread unit across this broad region is the Late Palaeocene - Mid Eocene Eyre Formation. This comprises a basal pebbly lag, fine to very coarse-grained pyritic and carbonaceous sands, lignite beds and montmorillonitic to kaolinitic clays. These are arranged in two spatially distinct facies: a multilayered aquifer/aquitard system within a formerly active braided river palaeochannel complex (Figure 7) and a blanket cover of fine-grained laminated swamp deposits (Callen, 1990; Callen et al., 1995; Krieg et al., 1990). At the base of this unit are numerous gravel horizons containing rounded quartz, chert and woody fragments that appear to have been sourced from underlying Mesozoic rocks (Krieg et al., 1990).

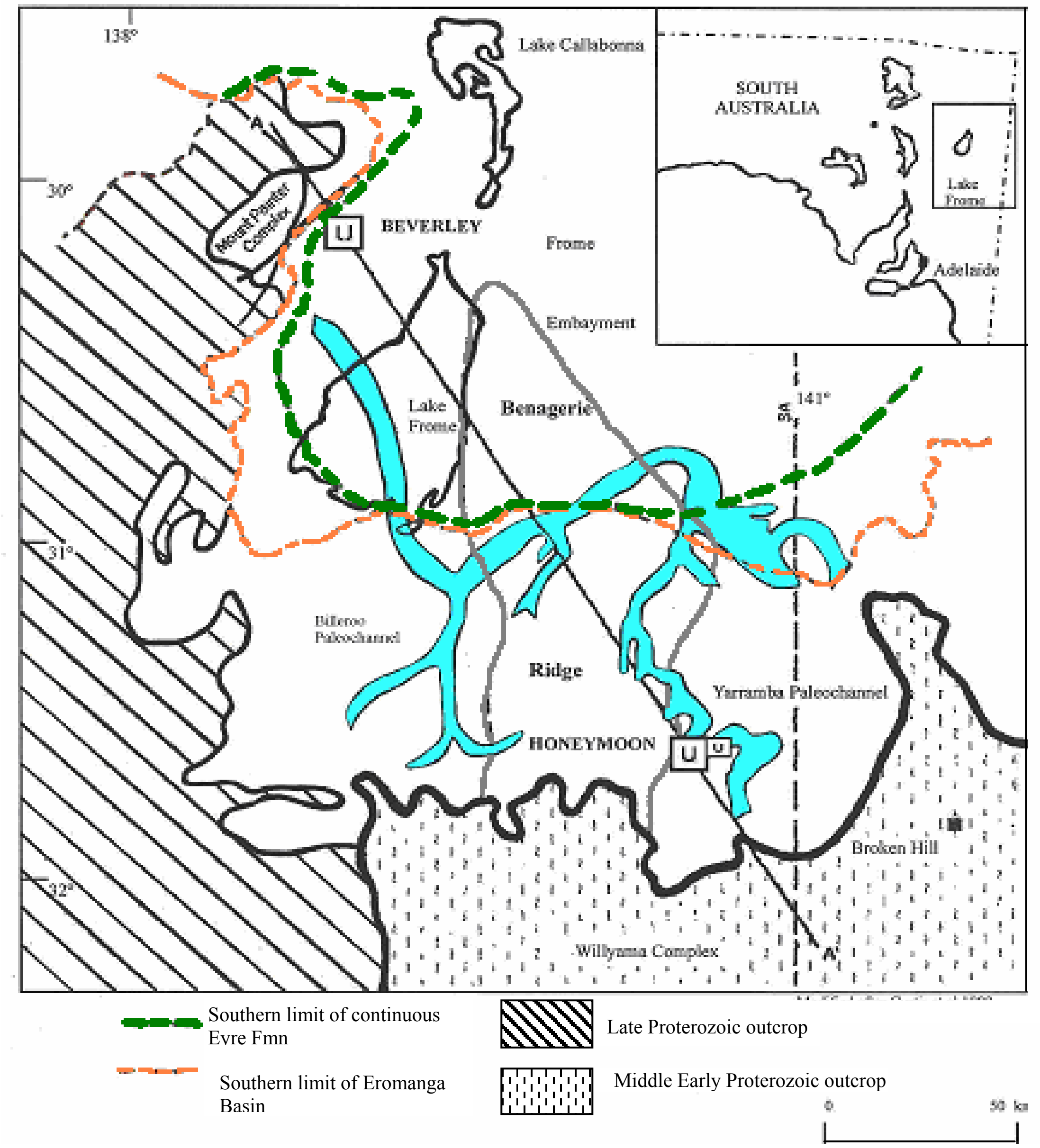


Figure 7. Palaeochannels within Tertiary Callabonna Sub-basin. Source: Modified after Curtis et al. (1990).

A series of alternating clay and sand layers of the Eyre Formation (Figure 8) have been deposited in a large-scale complex incising the Proterozoic basement. This effectively infills the sinuous Yarramba and Billeroo palaeochannels within the southern Curnamona region. The Yarramba palaeochannel containing ~50 m of fluviatile Eyre Formation sediments is situated 70 km south east of Lake Frome, with the base of the palaeochannel approximately 100-120 m below the modern-day land surface (Habermehl, 2000). It comprises a confined multi-layered aquifer system incorporating sandy units of the Upper, Middle and Lower Members of the Eyre Formation, each separated by relatively thin clay seals that separate each aquifer as confining beds (Callen, 1990). The channel sequence can be traced for ~100 km to the north where it connects to a more laterally extensive remnant blanket of Eyre Formation sediments (Habermehl, 2000).

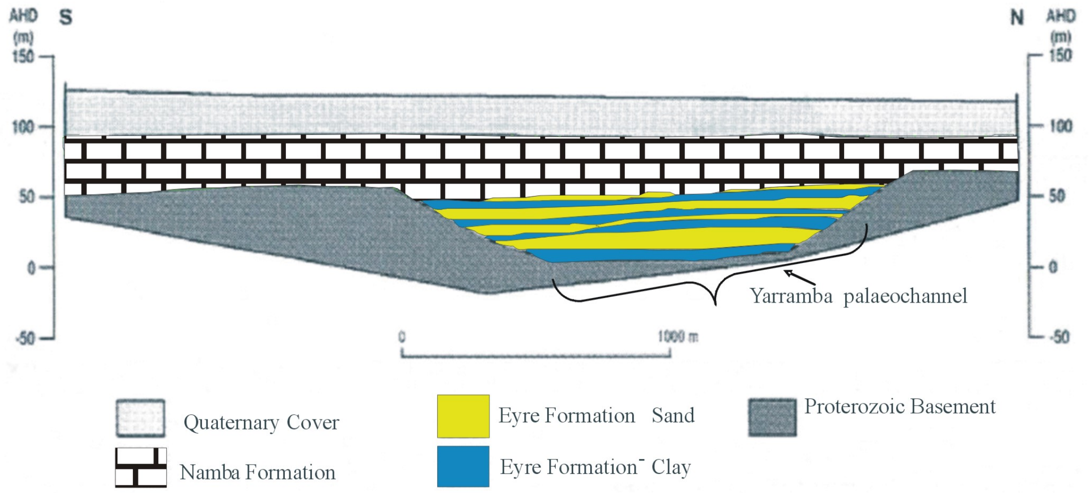


Figure 8. Schematic sketch of the Eyre Formation as it exists today north-south across the 1:250 000 CURNAMONA map sheet. The alternating clay and sand layers are evident particularly in the incised Yarramba palaeochannel displayed here. Source: Habermehl (2000).

Numerous sand bars, ripples and scour marks are buried within the area and are interpreted to reflect a humid environment possibly linked to two distinct depositional phases of Late Palaeocene to early Miocene (Krieg et al., 1990), and the Mid Miocene to Pliocene age. The former coincided with deposition of the Lake Eyre Basin. The latter consists of sandstones, carbonaceous clastics and conglomerates overlain by clays and fine-grained sands and carbonate. This configuration is largely due to incision by younger fluvial action and subsequent deposition of younger, finer-grained materials.

Regional tectonism during the Oligocene and Early Miocene led to the formation of a series of structural domes preceding the configuration of the Birdsville Track Ridge (BTR) (Figure 6), followed later by early Tertiary uplift of the BTR's western portion, the Lake Eyre Basin and the eastern Callabonna Sub-basin (Krieg et al., 1990). Eyre Formation deposited throughout the Palaeocene-Eocene is overprinted by silcrete development. The Cambro-Ordovician Benagerie Ridge to the east of Lake Frome is concealed beneath a thin sequence of micaceous silts of Eyre Formation affinity (Callen, 1990). Krieg et al. (1990) suggested that this may be related to Eocene erosion while the Mid-Late Miocene succession may represent a lacustrine phase within this area, expressed as laminated lacustrine clays in the south-western Callabonna region.

The Eyre Formation is broadly covered by the Miocene Namba Formation (Figure 8), which was deposited in a low-energy lacustrine and braided fluvial environment. This unit forms sheet deposits in the north and is confined to channels to the south-east of Lake Frome (Callen 1990), with the thickest sequences lying east and west of the Benagerie Ridge (Callen et al., 1995). It can be loosely sub-divided into an upper dolomite/smectite unit and a lower kaolinite/illite rich unit. (Callen, 1977; Callen, 1990). The environment at the time of deposition of the Namba Formation was one of fresh to brackish water with distinct channels and floodplain facies which spanned all over the Eyre Formation including the Benagerie Ridge (Callen, 1990).

The widely distributed Namba Formation is generally clastic and carbonaceous with sandy deposits in the channels, and dolomite horizons confined to the western side of the Benagerie Ridge (Callen, 1990). In the vicinity of the Beverley palaeochannel complex, the Namba Formation consists of an interbedded sequence of aquitards and aquifers comprising the basal Alpha Mudstone, overlying Beverley Clay and uppermost Beverley Sands (Figure 9). The latter is a prominent aquifer occupying palaeochannels approximately 120 m below the topographic land surface (Habermehl, 2000). Significantly, these channels have eroded into the Alpha Mudstone restricting water movement between the underlying Cadna-Owie Formation (aquifer) and the overlying Beverley Clay (Habermehl 2000).

The Cainozoic units of the Callabonna Sub-basin have undergone various degrees of weathering as discussed in Tonui and Caritat (2003) and Tan et al. (2004).

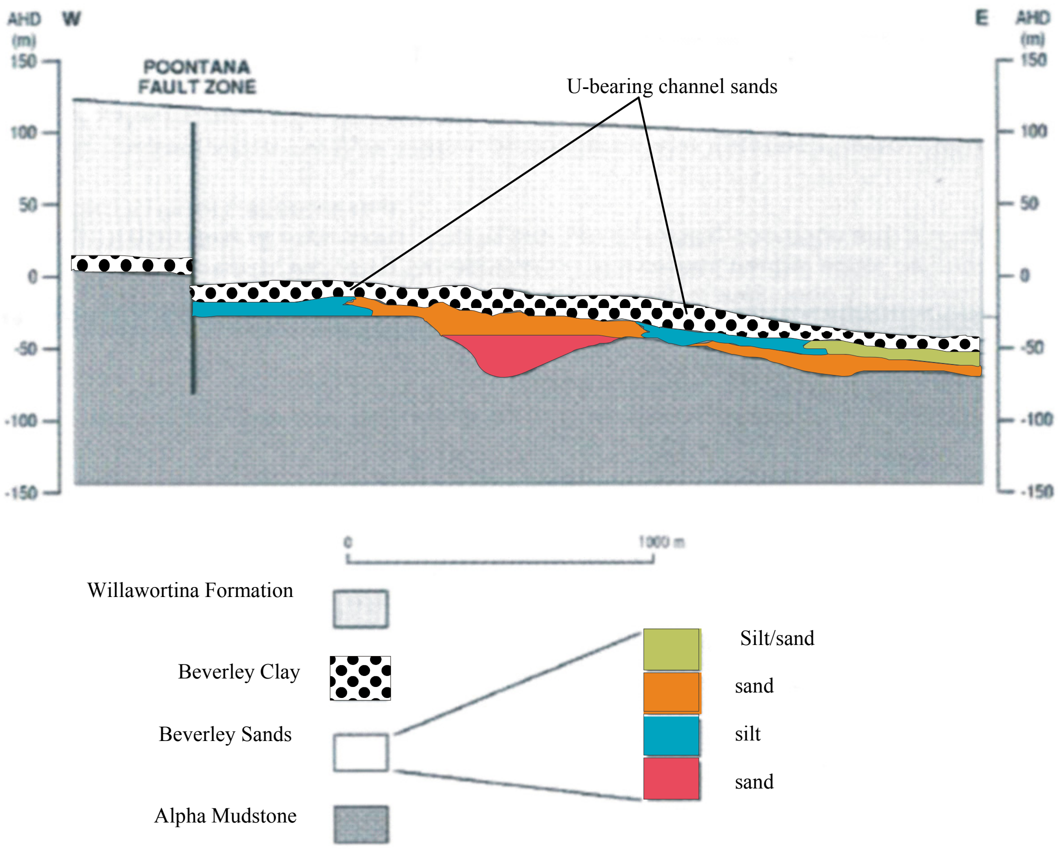


Figure 9. Schematic cross-section showing the main components of the Namba Formation at Beverley. The Beverley Sands are important as host units to the economic uranium mineralisation here. Source: Habermehl (2000).

Towards the end of the Late Neogene period, a significant drying phase resulted in a transition from predominantly lacustrine conditions to the development of dunefields and beach ridges. Silicification of sediments occurred in inter-ridge areas resulting in localised indurations of sands and carbonates. Widespread silcretes and silcrete horizons are a prominent feature and reflect the impact of groundwater or fluctuations in lake levels on the sediments (Krieg et al., 1990). The Late Quaternary period in this region is characterised by major flooding events at about 25-40 ka possibly displaying coastal-like features (Krieg et al., 1990). As well as playa, fan and aeolian deposits, stream networks also appear to have become disconnected at this stage probably as a consequence of the climate drying during the last glacial period (~18 ka) up until the present. A significant phase of dune construction followed (until ~13 ka) with large-scale transverse, longitudinal dune development and even reactivation of older dunes (Krieg et al., 1990).

CAINOZOIC (QUATERNARY)

Sediments deposited over the Callabonna Sub-basin are represented by Quaternary units shown on the 1:250 000 CURNAMONA map sheet. This fluvial upward-fining sequence incorporates dune-dominated fan-like deposits in the west and centre, and laterally extensive undifferentiated brown sands in the east (Callen, 1995).

Overlying the Namba Formation is the ~100 m thick fluvial Willawortina Formation in the western portion of the study area, adjacent to the Flinders Ranges (Habermehl, 2000) (Figures 9 and 10). Associated with anastamosing/single low-sinuosity channels situated in the western and eastern parts of the CURNAMONA 1:250 000 map sheet, this unit is known to extend beneath Lake Frome and crops-out in the Pasmore River in the far west where it is dominated by channel deposition (Callen, 1986). Both fine and a coarse facies appear to be represented, the former comprising a fining-upward cyclical sequence of sandy mud and silty dolomite (Callen et al., 1995). Carbonate-cemented channel conglomerates are overlain by a more gypsiferous variant representing a debris flow derived from braided fan gravels (Callen et al., 1995).

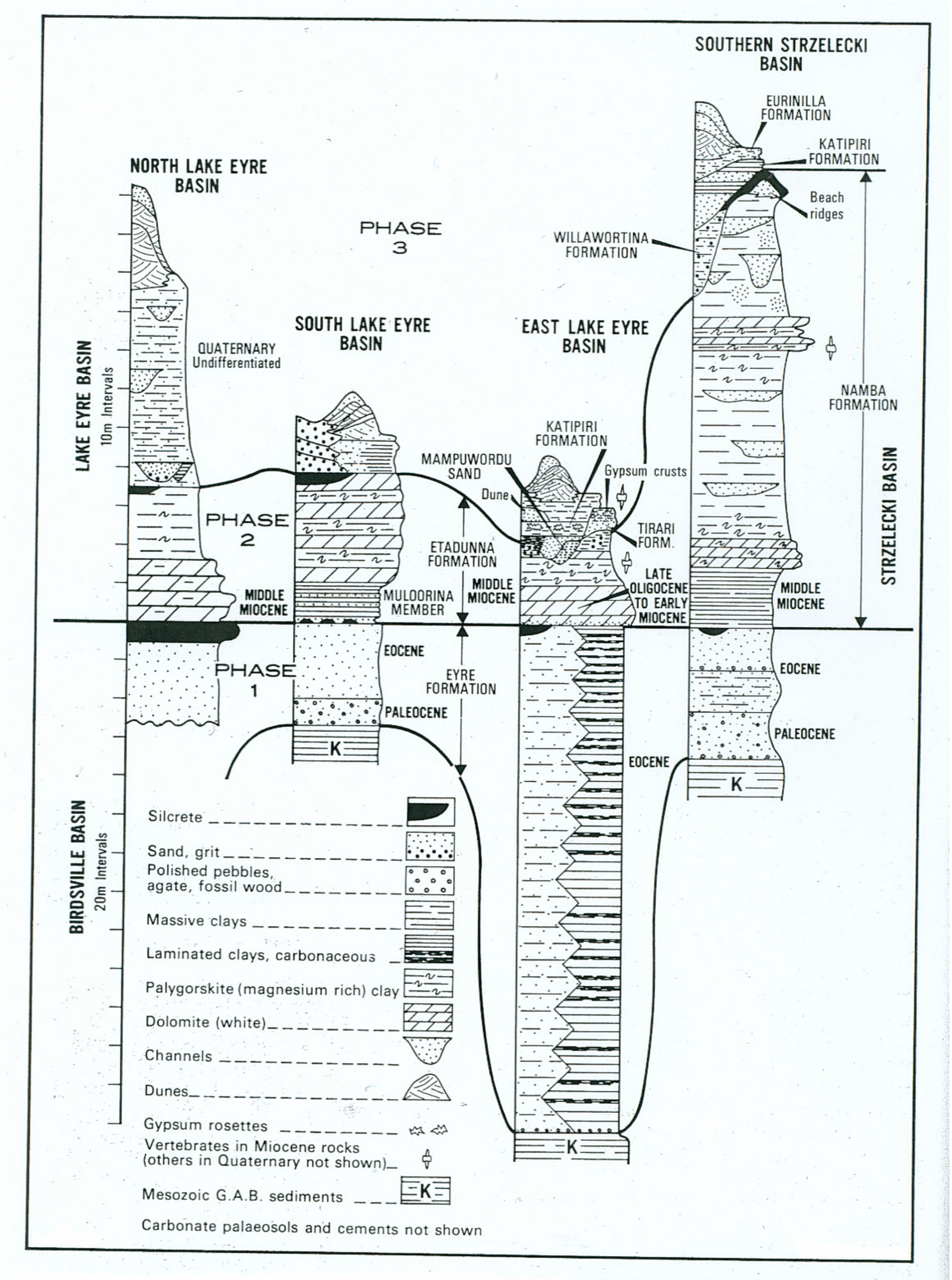


Figure 10. Diagram showing the complex stratigraphy in the vicinity of the Lake Eyre Basin and adjacent areas (comprising the Eyre and Namba Formations and overlying Willawortina Formation as seen in the western portion of the study area). Source: Krieg et al. (1990).

The Millyera (lacustrine) and Coomb Spring (shoreline) Formations, which are the predominant units covering the central parts of the CURNAMONA sheet area (where the Willawortina Formation is absent), interfinger with each other and comprise laminated green clays and sands, respectively. The Coomb Spring Formation is represented by coarse-grained well-sorted nearshore sandy beach deposits adjacent to Lake Frome and consists of sands (Callen, 1990), while the Millyera Formation represents the lacustrine floodplain depositional phase expressed as green coloured clays, sands and algal limestone (Callen and Benbow, 1995). The spatial distribution of the Millyera Formation is variable and typically overlies the Namba Formation (Callen, 1990).

Fine-grained aeolian sands/clays of the Eurinilla Formation (inclusive of the Moko and Billeroo Palaeosols) overlie the Coomb Spring and Millyera Formations. Channels incised into the Willawortina Formation contain aeolian fill of the Eurinilla Formation typically towards the western edge of Lake Frome which has a broad, thin, almost sheet-like distribution across the basin as gravels derived from overbank deposits and intermittent streams (Callen and Benbow, 1995).

The Late Pleistocene - Holocene Coonarbine Formation is an aeolian unit spatially associated with falling sea levels where dune construction was prominent and in which distinct palaeofeatures such as lunette sands, marine faunal artefacts and gypsum dunes are well preserved (Callen, 1990). Aeolian sands are often disconformable over the Late Pleistocene alluvial and lacustrine sediments and tend to display features of several (older) dune building phases associated with the last glacial maximum and subsequent temperature stabilisation (Callen and Benbow, 1995). The mobile Holocene sands and clays tend to be red-brown in colour and often are found proximal to watercourses, fan deposits, playas and terraces (Callen, 1986).

CONCLUSION

This report reviews the geology of the southern Curnamona Region. This region presents evidence of considerable depositional, deformation and incision events in its complex basin configuration. Comprising sediments and structures spanning from Palaeoproterozoic to Recent in age, the southern Curnamona Region is subdivided into five separate local and regional entities (namely depositional basins) each representative of a significant geological phase in the region's compilation. These five entities include the Palaeo- to Mesoproterozoic Willyama Supergroup basement which is spatially limited to the southern ranges and is demonstrative of numerous phases of deformation. Unconformably overlying this unit is the marine influenced Cambrian Arrowie Basin. The Benagerie Ridge was a basement high that influenced deposition within the Moorowie and Yalkalpo synclines at this time. Mesozoic sediments of the Eromanga Basin, which formed as a result of intra-plate tectonic activity, and its southeastern Frome Embayment, recorded a transgressive depositional phase. The overlying Lake Eyre Basin, comprising Cainozoic Callabonna Sub-basin sediments describes a somewhat intricate pattern of facies deposition. The spatially continuous fluvial Eyre Formation forms the basal unit within the Callabonna Sub-basin and is incised into the Proterozoic basement. Miocene in age, the overlying Namba Formation almost replicates the Eyre Formation in that its sequential arrangement of interbedded sands and clays is discriminated by age but is marginally thicker and more continuous throughout the region. Although it may be argued that the Quaternary sediments within this region should be inclusive of the Callabonna Sub-basin, this largely fluvial sequence is dominated by the Willawortina Formation and in its absence, the Millyera and Coomb Spring Formations dominate. Conformably overlying these units are the Eurinilla followed by the Coonarbine Formations all significant in demonstrating an environment of gradually increasing aridity.

The framework outlined in this geological overview forms the basis of ongoing project work centered on a 3D model of the Callabonna Sub-basin, Southern Curnamona Region (Ruperto and Nicoll, 2005). The present document supplements the 3D model which facilitates visualisation of the uppermost units described in this text.

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