TERTIARY-QUATERNARY LAND EVOLUTION OF THE NORTHWESTERN SOUTH AUSTRALIA

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INTRODUCTION

Northwestern South Australia contains a thick Neoproterozoic – Ordovician sequence, from the eastern Officer Basin, which is covered by a blanket of Tertiary-Quaternary sand dunes and palaeochannel deposits of the Eucla Basin. The Eucla Basin contains a sequence up to 300 m thick of Tertiary marine, coastal and channel sediments (Benbow *et al*., 1995; Hou *et al*., 2003, 2005). The surface dune fields of the Great Victoria Desert are considered to be of Late Pleistocene to Holocene age, established approximately 15 000 to 18 000 years ago during the cold, arid conditions of the last glacial period (Krieg, 1995; Figure 1).

Currently, the study area has a hot desert climate. The summer (January) and winter (July) average maxima /minima temperatures for Maralinga are 33ºC/16.3ºC and 17ºC/6.7ºC respectively (Krieg, 1995). Further into the desert temperature variation is more extreme as summer daytime maxima can rise to 50ºC and winter night time minima can reach sub-zero. Under such climatic conditions the natural vegetation is sparse, low and sclerophyllic. Typically, 3-4 m high open woodland of mulga and mallee is underlain by fewer shrubby cover species such as saltbush, bullock bush and sandhill wattle, with a ground cover of spinifex, bindyi, grasses and herbs (Laut *et al.,* 1977). In calcareous and gypsiferous areas, such as along playa lake systems, mallee and particularly the desert oak are prevalent. Vegetation, preservation, groundwater and other environmental issues are important topics in this region.

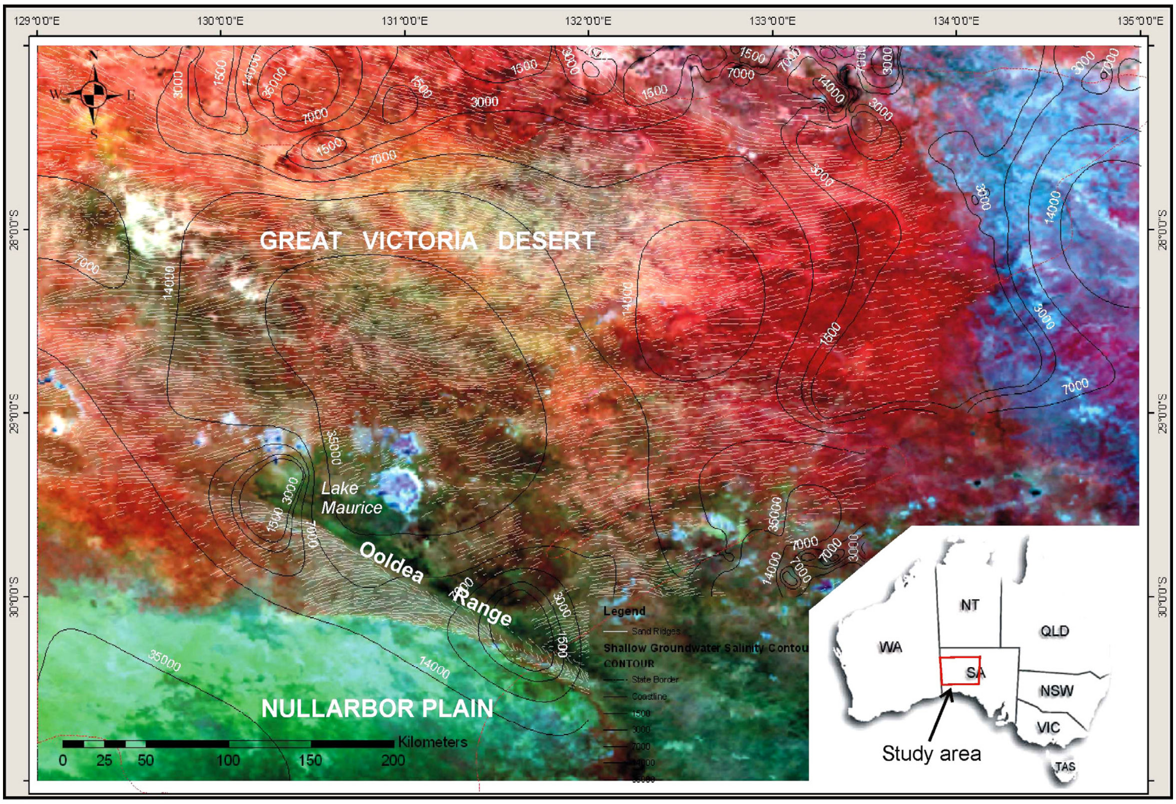

Figure 1. NOAA-AVHRR satellite daylight image (August 1991) of the study area, overlain by sand dunes and shallow groundwater salinity contour. Inserted map shows the study area.

The subsurface Officer Basin is a petroleum province and oil leads were found in Cambrian carbonate. Some zinc anomalies were recorded in the Meramangye 1 drillhole (hole location in Table 1; Zang and Jenkins, 2000). Cambrian bedded-salt deposits are present in the Manya and Wilkinson troughs. Groundwater and its salinity data are valuable information for regional future planning, whereas the Tertiary palaeochannels are focuses for uranium and groundwater exploration. This project will compile and generate a GIS data package for regional exploration and conservation.

REGIONAL GEOLOGY

The study area is adjacent of the Musgrave Province to the north and the Gawler Craton in the east and southeast. The majority of the area is covered by Quaternary sand dunes and Tertiary aeolian sediments. The Tertiary sediments, which mostly occur in palaeochannels, contain two units: Eocene fluvial Pidinga Formation and Miocene to Pliocene lacustrine Garford Formation. The two units unconformably overlie sediments of the Officer (Neoproterozoic – Devonian), Arckaringa (Permian) or Eromanga (Mesozoic) basins , and are overlain by Quaternary groundwater calcrete, aeolian sand and playa lake deposits. Other Tertiary units, such as the Hampton Sandstone, are occasionally found in drillholes.

Sediments of the Pidinga Formation are widely intersected in drillholes and in the Tallaringa Palaeochannel, up to 50 m thick in Meramangye 1. The formation consists of green-grey, poorly to moderately sorted, fine quartz sand to granule conglomerate, green-grey to green-black, fine to medium-grained quartz sandstone, pale green-grey and yellow-brown siltstone, with minor green-grey claystone, brown-black carbonaceous siltstone and lignite bed (Rogers, 2000). In the palaeochannels, carbonaceous and lignitic fluvial units comprise coarse-grained channel facies and fine-grained flood plain sediments. Palynological and foraminiferal studies of the Pidinga Formation have indicated a middle to late Eocene age (Alley &Beecroft, 1993). Recently, Hou *et al*. (2006) suggested the Formation ranging from early Eocene to early Oligocene and this age is confirmed in this paper.

The Garford Formation is exposed sporadically in the palaeochannel system. In the Meramangye palaeodrainage system, the formation is seen in low cliff sections adjacent to playa lakes, often resting unconformably on Officer Basin sediments (Rogers, 2000). The formation comprises pale green-grey and dark red-brown, poorly to moderately sorted, very fine to coarse sandstone, green-grey siltstone and minor claystone, predominantly lacustrine and floodplain deposits, with some fluvial channel sediments particularly at the base of the formation. The age of the Garford Formation may range from middle Miocene to early Pliocene (Alley & Lindsay, 1995).

The sand dunes of the Great Victoria Desert are composed of undifferentiated, predominantly Quaternary, orange-brown, quartz sand. The dunes have an average height of 6 to 7 m, up to 27 m in the Meramangye 1 drillhole (Rogers, 2000). The dune contains mainly hematitic quartz grains and locally, some pedogenic carbonate (Benbow, 1993). Mobile non-calcareous sand on dune crests was reworked during the Holocene.

Modern groundwater calcrete and gypsum playa-lake sediments are extensively developed in the area where sand dunes are absent, particularly in the Meramangye and Tallaringa palaeochannels. The calcrete sheet has a nodular structure and often contains carbonate fragments derived from the underlying sediments (Rogers, 2000).

PALYNOSTRATIGRAPHY AND PALAEOENVIRONMENT

Palynological data was collected to understand the Tertiary stratigraphy and palaeoenvironment. The investigation started with a compilation of the existing data and newly collected material. The presence of non-marine early Eocene sediments in the onshore palaeochannels of the Eucla Basin (drillhole CRAE RCH 2, 92-80m, the *Proteacidites asperopolus* Zone) suggests that the sedimentation of the Pidinga Formation had commenced since early Eocene (Hou *et al*., 2006), whereas the middle Eocene sediments (CRAE RCH 2, 79-37m; YL3, 82-80; BP MIN WL 55, 48-46m) contains palynofloras of the lower *Nothofagidites asperus* Zone. Lacustrine and freshwater depositional environments prevailed in the southern study area and mixed rainforest vegetation with *Nothofagus* and Podocarpaceae.

Late-middle to early-late Eocene sediments, equivalent to the middle *Nothofagidites asperus* Zone, are present across the Eucla Basin, and recognised in many drillholes. During this stage, marine influence increased from the Wilkinson 1 area (marine dinflagellate cysts are less than 1%) to the WS-WB drillhole area (with dinoflagellate cysts between 3-5%). In contrast, freshwater dinoflagellate *Saeptodinium* spp. and freshwater algae *Botryococcus* are present in high frequencies in the Wilkinson 1 drillhole (7%) and less than 1% in the WS-WB drillhole.

Late Eocene- ?Early Oligocene Upper *Nothofagidites asperus* Zone sediments have been identified in PIN-R19 (depth 30-25 m) and CRAE RCH 2 (depth 37-19 m) (Stoian, unpublished data). Marine influence is high (up to 5% marine dinoflagellate cysts). Freshwater algae *Botryococcus* (7-13%) is present in high frequencies.

Oligocene-Early Miocene marine sediments have been identified in the Maralinga 6 drillhole (144.78 m - 137.46 m), correlating with *Spiniferites ramosus* Zone, *Proteacidites tuberculatus* Zone and *Canthiumidites bellus* Zone respectively (Stoian, unpublished data). Dry rainforest was developed on lands and high-salinity lagoons, based on the abundance of dinoflagellate cysts including *Polysphaeridium zoharyi*. This species may indicate some unfavourable conditions, such as arid inland environment. The species *Lingulodinium machaerophorum* is abundant and responses to environmental changes by developing club-shaped processes in high salinity environments. *Spiniferites ramosus* and *S. scabratus* are the dominant neritic species during the warmest periods and they have today a limited distribution in the tropical and subtropical zones (Morzadek-Kerfourn, 1992). Local palaeo-climate of winter sea-water temperature above 15°C and summer sea-water temperature above 27°C, with shallow water depths up to 22 m can be estimated based on analysis of dinoflagellate assemblage.

Miocene sediments have been recognised in the Officer 1 drillhole (60.96-57.91m) with some reworked Early Cretaceous dinoflagellate cysts (Stoian, unpublished data). Key taxa include *Acaciapollenites miocenicus, Haloragacidites haloragoides, Chenopodipollis chenopodiaceoides, Tubulifloridites antipodica* and few dinoflagellate cysts (*Selenopemphix nephroides, Impagidinium* sp). This information will help to re-shape palaeochannel tributaries and regional palaeoclimate.

Table 1. Drillhole names and coordinates (PIRSA GIS data base).

DHNAME	MAP100	UNITNO	DHNUMBER	LONGITUDE	LATITUDE
BP MIN WL 55	5538	146	131691	133.4407942	-29.6130807
CRAE-RCH 2	5337	16	131344	132.1819162	-30.1791384
LAIRU 1	5341	10	1071	132.1481680	-28.1631694
MARALINGA 6	5237	9	622	131.5904961	-30.1622114
MERAMANGYE 1	5341	11	1072	132.2757828	-28.3680161
OBSERVATORY HILL 1	5340	41	710	132.0002928	-28.9703278
OFFICER 1	5342	1	1073	132.3014335	-27.5128099
P MIN WL 95	5538	167	131729	133.0135700	-29.5992520
PIN-R 19	5236	21	131115	131.9837615	-30.7214486
SDA 14	5438	54	132016	132.9680115	-29.5291270
SDA 17	5538	185	132019	133.0291284	-29.5680126
WILKINSON 1	5438	1	1575	132.5519980	-29.8670040
WS-WB	5236	16	131076	131.5313750	-30.8185900
YL-3	5136	10	471	131.1279581	-30.5274424

PALAEOCHANNEL SYSTEM

Currently, mean annual rainfall in the study area varies from ~150mm in the south to 200mm in the northern ranges and mean annual evaporation ranges from 3000mm in the south to 3600mm in the north (Laut *et al.,* 1977). Major connected surface drainages are absent in the study area and some minor streams in the northeastern region adjoin Musgrave Block and the Bulldog Shale of the Eromanga Basin. The groundwater is a valuable resource in the basin (Dodds *et al.,* 1995).

Tertiary palaeodrainage systems initially formed in the Eocene during the maximum marine transgression of the Eucla Basin. This includes Noorina Palaeochannel in the west, Tallaringa Palaeochannel to the east and Meramangye Palaeochannel in the centre (Figure 2). The Hampton Sandstone and Pidinga Formation were deposited at this time and contain rich coal or lignite beds. The lacustrine facies deposits are widely interpreted in the Serpentine Lakes, Lake Maurice and Tietkens Plain areas. The palaeodrainage was reactivated during the Miocene-Pliocene transgression of the Eucla Basin when the Garford Formation was deposited (Benbow, 1993). Both periods of deposition imply the watertable in the palaeodrainage was at or above the current ground surface. At the southern end of the Meramangye Palaeochannel, west of Emu Junction, the watertable today is some 40m below ground level; a decline in water level of at least 40m since the Pliocene is suggested (Dodds *et al*., 1995).

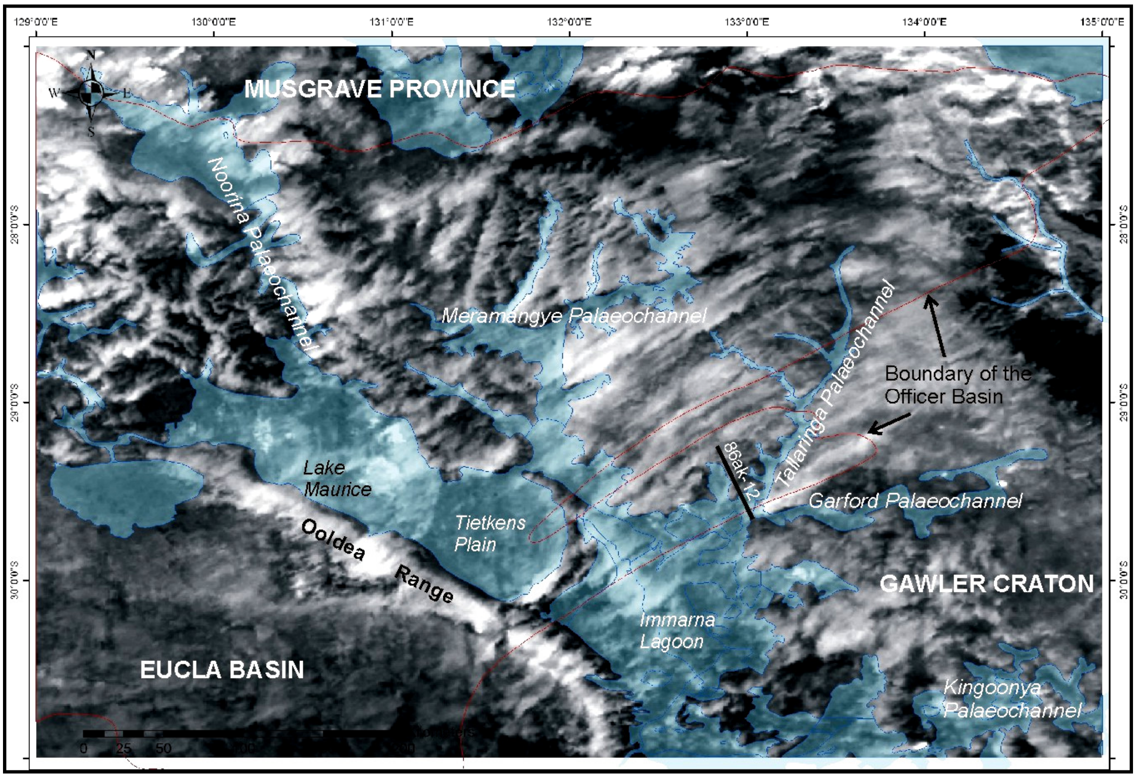

Figure 2. NOAA-AVHRR satellite pre-dawn image (August 1991), showing palaeochannels and structural elements. Tertiary palaeochannels depicted are after Rogers (1999).

The palaeochannels were interpreted from NOAA-AVHRR satellite pre-dawn thermal imagery (Statham-Lee, 1995). The palaeochannels appear dark in the NOAA image because the channel fill sediments have a lower thermal inertia and are cooler than the surrounding basin sediments. Consistant with drillhole stratigraphy, the palaeochannels, such as the Tallaringa Palaeochannel system and its fluvial sediments provide the cooler response compared with the warmer, denser ranges in the NOAA image (Statham-Lee, 1995). Recent Landsat and radiometric data also image similar channel systems. The Tallaringa Palaeochannel System is dated by palynology as Eocene to Pleistocene age (Barnes & Pitt, 1976) and flows south until it is met by the Garford Palaeochannel from the east.

The Meramangye Palaeochannel in the central area forms a broad gentle depression ranging from 4.5 km to about 11 km wide (Rogers, 2000). Scattered Tertiary outcrops in the Observatory Hill area form part of a tributary of and Lairu 1 intersected an estimated 2.8 m of calcrete in the headwaters of another tributary located north of Lake Meramangye (Rogers, 2000). Statham-Lee (1995), in comparison with current PIRSA interpretation (Rogers, 1999), suggested the palaeochannel continued flow from northern Musgrave Province to southern Tietkens Plain and the occurrence of the Miocene deposits in the Officer 1 drillhole may support the suggestion.

The study area has more than 6000 km seismic line data and many those lines cross palaeochannel systems. Seismic line 86ak-12 in the Wilkinson area suggests that the Tallaringa Palaeochannel is about 8km wide and more than 150m deep (Figure 3). A detailed study will help to model the palaeochannel formation and exploration drilling.

The Ooldea Range is a prominent feature controlling palaeodrainage systems in the study area. The Range is known to be Tertiary coastal dunes (Benbow *et al.,* 1995), representing Tertiary shorelines. To the south of the Range, Eocene marine deposits are present. Rare Tertiary and Quaternary marine sediments are known to the north of the Range.

Palaeochannel sediments are known to contain uranium and other mineral anomalies in the study area. The Kingoonya Palaeochannel in the southeast hosts the Warrior uranium deposits. Mineralisation data are limited in the Garford and Tallaringa palaeochannels and no data exists for the Meramangye and Noorina palaeochannels.

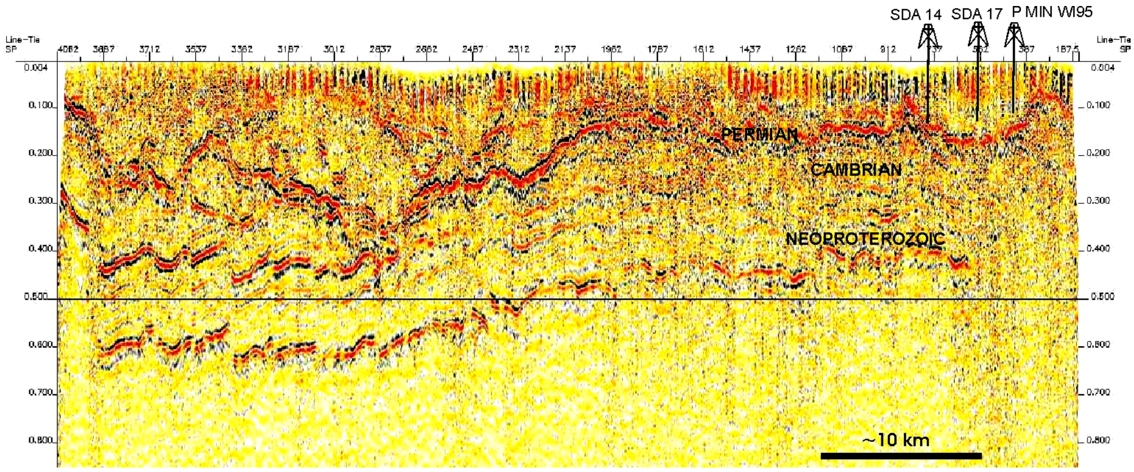

Figure 3. Seismic line 86ak-12, showing the Tallaringa Palaeochannel and drillhole locations.

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