“Source to Sink” Sedimentology and Petrology of a Dryland Fluvial System, and Implications for Reservoir Quality, Lake Eyre Basin, Central Australia.

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Thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

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March 2008
CHAPTER 1
INTRODUCTION

1.1 RATIONALE

An understanding of the geological processes in source-to-sink sedimentation provides a rational basis for reservoir quality analysis (Heins and Kairo, 2006). This approach involves the principles of basin analysis, source sediment generation, transportation, deposition and early diagenesis. Knowledge of the provenance, sediment dispersal and depositional processes that occur in a given sedimentary system, including the interactions between sediment grain size and composition, provides clues to the initial state of the sediment quality before significant burial in the subsurface (Bloch, 1994). Sub-surface correlation and prediction of reservoir quality are two significant outcomes resulting from the study of source-to-sink sedimentation (Morton and Hurst, 1995). In addition to the implications for primary porosity and subsequent diagenesis, sediment composition can also be used to assess the effectiveness of sandbody connectivity, which is important for reservoir modelling of oil and gas fields (Potter, 1994; Heins and Kairo, 2006).

Modern depositional analogues are used to develop models that attempt to predict subsurface sediment reservoir quality (Marchesini et al., 2000; Morton et al., 2003). It is important, however, to consider the tectonic, climatic and depositional settings for every analogue selected. This study provides one particular analogue from a well-defined catchment (Umbum Creek) in the Lake Eyre Basin, Central Australia. This analogue represents an example of an intracratonic basin adjacent to a basement-uplift, dominated by a dryland fluvial depositional environment during the late Quaternary to Recent (Zuffa, 1985).

The significance of this source-to-sink study is that it represents one of the few detailed semi-quantitative analyses of the nature of ‘original’ sediment detritus with respect to reservoir quality prediction in a dryland fluvial setting. Specifically, this study reflects an understanding of basin evolution, sediment dispersal patterns during climate change, spatial distribution of sediment mineralogy and implications for early diagenesis. The results of this study provide a valuable
dataset for forward modelling of reservoir quality in comparable basin settings (eg. SANDGEM© – Heins & Kairo, 2006).

1.2 AIM

The aim of this study is to assess ‘source to sink’ sedimentation (sediment source to sediment sink) in a modern dryland fluvial analogue setting within an intracratonic basin to improve prediction of reservoir quality in comparable ancient successions.

1.3 OBJECTIVES

The objectives of this study are to:

1. Evaluate the basin evolution history, including the provenance and sediment dispersal system that supplies sediment to the modern dryland Umbum Creek catchment, west of Lake Eyre. The key question is: How have the source(s) and dispersal paths evolved through time?

2. Provide a detailed analysis of the modern Umbum Creek sediment distribution system, using quantitative datasets focused on the processes that change the grain size, sorting, and composition of sediment from the source areas to the terminus at the shoreline of Lake Eyre. The key question is: To what extent does the present Umbum Creek sediment population reflect changes in tectonic, climatic and depositional settings from source to sink?

3. Determine the early diagenesis of modern dryland fluvial sediments, including their interaction with aeolian, lacustrine, pedogenic and associated groundwater processes. The key question is: What are the implications for predicting reservoir quality?

1.4 BACKGROUND

A small river network, Umbum Creek, western Lake Eyre Basin, Central Australia was selected as the focus for this study (Fig. 1.1). The Lake Eyre Basin is a wide, shallow, low-gradient, intracratonic basin that records a complex history of alluvial, lacustrine and aeolian sedimentation, reflecting several tens of million years of environmental change (Krieg et al., 1990). The modern
Lake Eyre drainage basin incorporates many diverse geographic regions, including a large saline playa to the far southwest, extensive ephemeral river systems to the northeast and southwest, smaller local catchments to the west and the continental dune fields of the Simpson and Strezlecki Deserts to the north and east (Alley, 1998).

Lake Eyre (28:30S, 137:20E) (Fig. 1.2) is the fourth largest terminal lake in the world and the largest salt lake in Australia (terminal playa and salina) (Callen et al., 1986). The Lake Eyre drainage basin lies in the interior of the Australian continent, 950 km north of Adelaide, and 900 km southeast of Alice Springs (Fig. 1.2). It is a vast down-warped area of low relief and internal drainage, extending for 1,140,000 km². The Lake Eyre Basin is one of the largest areas of internal drainage in the world, covering one sixth of the continental landmass of Australia. Lake Eyre itself lies in the southwestern part of this large area and is an extensive salt lake system lying on average 15.2 metres below sea level in the driest part of the world (Jessup and Norris, 1971). The hyper-arid desert environment around Lake Eyre is greatly augmented by high potential evaporation (about 2,000 mm per annum) generally exceeding average precipitation (less than 200 mm per annum).

The Neales River and Umbum Creek (Fig. 1.3) are the major western rivers of the Lake Eyre Basin and are ephemeral in nature. Umbum Creek is a small river system located approximately 30 km northeast of the township of William Creek, approximately 950 km north of Adelaide. It is formed by the joining of four tributaries and has approximately 100 kilometres of total river length. The Umbum Creek catchment is significantly smaller than the Neales River catchment. With of it's sediments having been derived from the foothills of the Davenport Ranges and from the reworking of local sources (Fig. 1.4). The Davenport Ranges themselves contain uplifted Palaeoproterozoic and Neoproterozoic (Adelaidean) metasediments, flanked by Palaeogene and Neogene alluvial fans and proximal fluvial sediments overlying Mesozoic sandstones and shales, which locally outcrop in creek channels and banks (Lang et al., 2004) (Table. 1.1).
Figure 1.1: The Lake Eyre Basin, showing the five major catchments covering an area of 1,140,000 km² and location of the study area (modified from Krapf and Lang, 2005).
Figure 1.2: Location of the study area on the western flank of Lake Eyre North.
Table 1.1: Geological table showing the stratigraphic summary of Umbum Creek catchment area by provenance lithotype (adapted from Drexel and Preiss 1995).

NOTE: This table is included on page 6 of the print copy of the thesis held in the University of Adelaide Library.
Figure 1.3: Detail location map incorporating the broader sedimentary basin evolution area and the Umbum Creek ‘source to sink’ sedimentation area.
1.5 STUDY AREA

Umbum Creek provides a variety of features that enable the study of modern sediments, from the sediment source in the Davenport Ranges to the local inputs, and finally to deposition in a modern ephemeral delta/terminal splay complex (Fig. 1.4). The sediments of Umbum Creek have gone through various processes which have drastically modified their sediment character, even though sediment transport distance is a ‘brief’ 100 kilometres from source to sink.

Two specific areas are focused on for this study; they are sedimentary basin evolution and ‘source to sink’ modern sediment analysis area (Figs 1.2 and 1.3). The larger of the two, referred to herein as the sedimentary basin evolution study area, covers approximately 100,000 km² of the western Lake Eyre Basin (27:00S, 133:00E and 29:30S, 137:00E) (Figs 1.1, 1.2 and 1.3). Sedimentary basin evolution study area provides the assessment of sediment provenance region through various basin successions. This area is characterised by modern sediments of the Neales River and Umbum Creek catchments, Cenozoic basin formations underlain by the Mesozoic Eromanga Basin succession, the remnants of the Late Palaeozoic Arckaringa Basin formations, and the Early Palaeozoic Officer Basin sediments which rest unconformably on moderately folded Proterozoic rocks (Wopfner, 1978).

A ‘source to sink’ modern sediment analysis study area is centred on Umbum Creek (28:10S, 135:50E and 28:50S, 137:00E) (Fig. 1.2, 1.3 and 1.4). This area is comparatively smaller and lies within the sedimentary basin evolution study area (Fig. 1.2 and 1.3). ‘Source to Sink’ study area provides modern sediment provenance analysis and their characteristics. Umbum Creek rises about 100 km west of the Lake Eyre playa margin in the Davenport Ranges (Fig.1.4). The Figure 1.4 illustrates that the catchment area drains the Davenport Ranges via four major tributaries and covers approximately 5000 km² of Palaeoproterozoic volcanics, Neoproterozoic metasediments and Mesozoic and Cenozoic sedimentary rocks of the Eromanga Basin. The area also features reworking of the Neogene gibber plains, aeolian sand dunes, and fluvial sands at the base of the Davenport Ranges (Callen et al., 1986; Krieg, 2000). Umbum Creek flows into a modern ephemeral braid-delta/terminal splay complex built into the arid Lake Eyre playa. The four major tributaries of Umbum Creek are: Sunny Creek, Davenport Creek, Hope Creek and George Creek. Sunny Creek is the longest (~ 75 km) and lies in the southern portion of the catchment. George Creek is the shortest (~ 18 km) located on the northern part of the catchment (Fig. 1.4).
NOTE: This figure is included on page 9 of the print copy of the thesis held in the University of Adelaide Library.

Figure 1.4: Landsat Imagery showing the Umbum Creek catchment illustrating ‘Source to Sink’ sedimentation study area. (Provided by Exxon Mobil Upstream Research Houston).
1.6 PREVIOUS STUDIES

The earliest studies centred on the Lake Eyre includes Madigan et al. (1986) and Callen et al. (1986). The latter authors present a comprehensive discussion on the geological history of the region, including palaeontological information, following regional geological mapping by the South Australian Department of Mines and Energy (PIRSA). Kotwicki (1986) published details of the floods and hydrology of the Lake Eyre Basin. More recently Magee, (1993) and Magee et al. (1995) undertook detailed work on the sediments of Madigan Bay in the southeast corner of Lake Eyre North. While Croke et al. (1996) conducted sediment dating on the bank of a small section of the Neales River 35 km upstream from the delta to establish the quaternary climatic history of the region and to detail the fluvial and lacustrine units in the Neales River immediately to the west of Lake Eyre (Figs 1.3 and 1.4). This latter body of work describes the high-resolution stratigraphy associated with lacustrine deposition in the Miocene and the nature of fluctuating wet-dry fluvial and lacustrine deposition in the Pleistocene to present, illustrating increased aridity in the Lake Eyre region associated with the last glacial maximum.

Alley (1998) interpreted palaeo-environmental changes in the Palaeogene and Neogene periods across the Lake Eyre Basin. Similarly the work by Nanson et al. (1992) provided evidence for the wetting and drying of the Lake Eyre Basin, with pronounced aridity and tropical rainfall during the Neogene period. In addition Krieg (2000) studied the complex and discontinuous record of continental sedimentation from the Cretaceous to the Cenozoic, providing evidence of major changes in Palaeogene climate, flow regime, lake levels and biota for an extensive area of Central Australia.

The first studies undertaken on the Lake Eyre rivers, with a view to their potential as analogues for fluvial-lacustrine reservoirs were done by Hicks (1998) and Lang et al. (2000). The detailed work by Lang et al. (2004), as part of the Lake Eyre Reservoir Analogues program, focused on modern ephemeral fluvial-terminal splay-lacustrine delta analogues based on the low-accommodation, arid to hyper-arid Lake Eyre Basin, specifically in relation to the Neales River fan and terminal splay area. They documented the sedimentary processes and reservoir-scale facies, geometry and stratigraphic architecture within dryland successions. Also part of this program is Waclawik (2006), whose study describes the regolith distribution and landscape evolution of the catchment area of Umbum Creek to the west of Lake Eyre and Reilly (2007) (PhD in progress), which focuses on the
reservoir geometry of the Umbum Creek terminal splay complex (Reilly et al. 2004), on the western side of the Lake Eyre Basin.

1.7 STUDY STRUCTURE AND METHODOLOGY

Datasets for this study were developed to enable both the qualitative and quantitative assessment of key subsurface sandstone properties with a view to ultimately improving reservoir quality predictions. These ‘predictive’ datasets are based on the integration of sedimentary basin evolution observations, sediment analysis and subsequent diagenetic processes. Consequently, this study involved three parts, as outlined in Table 1.2. ‘Part 1’ examines aspects of the large-scale sedimentary basin evolution applicable to the modern western Lake Eyre Basin. ‘Part 2’ studies the characteristics of modern sediments, and ‘Part 3’ focuses on the inferred types of early diagenetic processes and their relationship to reservoir quality, with particular emphasis on the surficial sediments of the modern western Lake Eyre Basin. The sequential order of each stage of the study and analytical techniques used in this study is illustrated in Table 1.3. The ‘Source to Sink’ phrase is commonly used throughout this study means the sediment source (provenience) to sediment sink. The term ‘source rocks’ in the wider petroleum geology filed relates specifically to oil/gas/condensate generating rocks or ‘source rocks’. However, in this thesis, the term ‘source rock’ is used to describe the provenance of the sediments or sediment origin region.

1.7.1 BASIN ANALYSIS

Systematic basin analysis has much to offer sedimentary provenance studies and is an ideal method for understanding sedimentary routing systems and establishing temporal relationships between source evolution and sedimentation in adjacent basins. The interest in the study of modern sediments from source to sink is because sink sediments almost invariably comprise mixtures of source material.

The first part of this study focuses on the “sedimentary basin evolution study area” (Fig. 1.1) and aims to define the processes that control the evolution of sediment composition regionally and to ascertain the extent to which cratonic blocks and their sedimentary mantles may be viewed as a dynamically coupled evolutionary system. Petrography of the hinterland rocks (provenance candidates) and isopach maps were used to develop palaeogeographic reconstructions from which
the sediment source routing from past to present day basins could be inferred. The isopach thickness maps were produced from using core data samples. Whereby formation dips of $<5^\circ$ were typical rendering isocore thicknesses in vertical well penetrations equivalent to an isopach. A detailed outline of the isopach methods used in this study can be found in Chapter 3. Provenance lithotype petrographic data for the various deposits in sedimentary basin evolution study were derived from provenance lithotype thin sections analysis. A detailed description of the petrography methods and provenance lithotype petrographic data used in this study is given in Chapter 4. Integrating isopach maps and petrographic data enabled the determination of present day geologic settings and modern sand composition from different types of sediments generated by the tectonic and structural evolution phases of the source areas through time.

### 1.7.2 MODERN SEDIMENT ANALYSIS

Although the generalised basin evolution study outlined above provides constraints regarding the Umbum Creek sediment source age and general provenance, a more detailed analysis was carried out on sediments from Umbum Creek so they could be fingerprinted more accurately to their original provenance (source). Sand samples were collected along the Umbum Creek catchment at strategic locations for analysis chiefly sediment composition, texture, grain size and sorting.

The second part of this study analyses the mineralogy of these modern sediments, interpreting sediment provenance and relating the textures and associated mineralogy to fluvio-aeolian processes as observed in the Lake Eyre Basin dryland fluvial setting. The objective was to identify the main controls on sediment composition when the process is dominated by an almost closed sedimentary system. Where the sediment reworking is dominates, plus the continuous supply of new sediment originated from the hinterland metamorphic and igneous sources in combination with the mixing effect of aeolian sands blown in from surrounding dune fields. Provenance exerts a significant influence on reservoir quality by controlling the composition of sediments, which in turn impacts both mechanical properties and chemical diagenetic processes that decrease, preserve or increase porosity and permeability.
Table 1.2: A work flow chart of the three parts of the study.

### Work Flow Chart

#### PART 1: Basin Evolution
- Geological time
- Drill core analysis
- Isopach maps
- Tectonic setting
- Palaeoclimate
- Depositional environment

#### PART 2: Sedimentary Basin Evolution
- Provenance lithotype - Rock sample analysis (Petrology)
- Provenance lithotype characterisation
- Modern sand sediment - Analyses
- Sampling
- Chemical analysis
- Sieve analysis
- Petrography
- Cathodoluminescence
- X-ray powder diffraction
- Stereo-zoom binocular microscopy
- Scanning electron microscopy

#### PART 3: Interpretation of modern sand sediment
- Provenance lithotype control
- Transport processes control
- Depositional processes control
- Quantitative analysis of sand composition and texture
- Forward modelling of sand composition and texture

#### Modern sand sediment characterisation
- Overview of Diagenesis
- Potential diagenesis of Umburn Creek sands

#### Reservoir quality
Table 1.3: Schematic diagram illustrating the research procedures employed for this study.
The most important aspect of this sediment composition study is the recognition of provenance which in turn enables the identification of sediment source rock and therefore the relief and climate in the ‘source’ area; tectonic setting; transport history and diagenetic modifications. Standard petrographic approaches to the identification of the source rocks (provenance) of sedimentary grains are used and include investigations of undulosity and polycrystallinity of quartz grains (Basu, 1976), the types of feldspar present (Pittman, 1970), and determination of rock fragments present (Pettijohn et al., 1987). The transport history of a sedimentary grain can be derived from the examination of roundness and sphericity of grains, along with textural and mineralogical maturity determination (Pettijohn et al., 1987). Relief and climate of the ‘source’ area can be inferred from grain roundness and average degree of feldspar alteration (Arribas et al., 2000; Folk, 1974). The nature of tectonic settings can also be determined from the relative proportion of quartz, feldspar and rock fragments (Dickinson, 1985).

Sediment mineralogy has a significant influence on early diagenetic processes, and therefore may determine reservoir quality. In a modern setting, sediments in the sediment sink can be tied to the sediment source area and the numerous intermediate sedimentary steps. If a clear link between the source provenance lithotypes and the sediment sink area can be established, then this process can help predict subsurface composition of potential reservoir units and thus potential reservoir quality at undrilled depths, can be ‘forward’ modelled with greater confidence.

1.7.3 REVIEW OF DIAGENESIS

The third part of this thesis focuses on early diagenetic processes and how they affect reservoir characteristics in the subsurface. A fundamental challenge in clastic reservoir characterisation is predicting the spatial distribution of early diagenesis, which is often a critical control on ultimate reservoir quality (porosity and permeability heterogeneity). Diagenetic patterns often correlate with environment of deposition (facies) and sediment composition because of their profound influence on initial porosity and permeability trends. Understanding the processes and products of diagenesis is thus a critical component in the analysis of the evolution of sedimentary basins, and has practical implications for prediction of subsurface reservoir effectiveness.
Diagenetic implications are reviewed in chapter 8 and extrapolated from the modern unconsolidated sediment characteristic petrographic data set. Early diagenetic processes and changes in mineralogy that can impact on reservoir quality are described. Modern sediment clay fractions are studied to review their role in early diagenetic alterations. Fluvio-aeolian grains are also studied to determine the reservoir quality aspects of interactions between aeolian, fluvial and playa environments in the study area. The study of modern sediments is important as it provides valuable analogues for reliable forward modelling subsurface reservoir quality predictions in undrilled areas.
CHAPTER 2
SEDIMENTARY BASIN EVOLUTION

2.1 INTRODUCTION

Understanding the tectonic setting is vital to unraveling the evolution of a sedimentary basin or, in the case of poly-history basins, changing regimes through time (Zuffa, 1980; Zuffa, 1985). Timing and style of deposition in relation to the temporal and spatial distribution of subsidence, largely controlled by the structural style, is also important (DeCelles and Giles, 1996). Definition of the hinterland and transport route to the depocentre provides essential constraints on the mechanism of basin formation (Carter and Bristow, 2003). Intracontinental areas are characterised by formation of sedimentary basins in reaction to far-field stresses transmitted to the plate interiors, as well as plume-driven thermal events (DeCelles and Hertel, 1989; DeCelles and Giles, 1996). A major role is played in such basins by reactivation of inherited basement structures (Wilson, 1993). The tectonic settings of the basin and hinterland are tightly linked, particularly in foreland basins associated with fold and thrust belts (Critelli et al., 2003), where the sediments of the basin reflect the assemblage of provenance lithotypes in the hinterland.

Understanding the origin of ancient terrestrial depositional systems can be problematic. A common issue is poor biostratigraphic control, which hinders correlation between sedimentation and regional geodynamic events. For some basins, post-depositional tectonic displacement has resulted in uncertain geographical relationships, whereby the original source regions are ‘missing’ or are unclear. In such cases, sediment provenance indicators may provide the only evidence of hinterland composition. However, because a source terrain usually lies within an area of broadly uniform geology, methods such as analysis of cores, sediment petrography and depositional isopach thickness maps can tie sediment lithotypes and depositional environment to a specific location or terrain.

The purpose of this chapter is to elucidate more fully the evolutionary history of the complex Lake Eyre tectono-sedimentary basin in relation to the analysis of provenance lithotypes derived from various basins throughout the region through time as tectonic regimes, climate and depositional environments change. These aims were achieved by ‘tracking’ the generation and evolution of
Sediments from the sediment source to the site of ultimate deposition, using isopach maps and thin section based provenance analysis. This will establish the evolutionary history of the modern western Lake Eyre Basin sediments from basin to basin through time.

2.2 PREVIOUS KNOWLEDGE

Sedimentary provenance studies have mainly concentrated on the sedimentary relationship between the hinterland and the depositional basin through the location and nature of sediment source areas, the pathways by which sediment is transferred from source to basin of deposition, and the factors that influence the composition of sedimentary rocks. Previous works by Folk (1974), Basu (1985), Dickinson (1985), McBride (1985), Zuffa (1987) and Critelli et al. (2003), highlighted the importance and validity of provenance studies in order to determine the evolutionary history of sedimentary rocks. The development of petrographic techniques has widened the scope of provenance studies, allowing more precise sediment source reconstruction/correlation, as well as ‘opening up’ an avenue of investigation in which petrology based provenance data can make a significant contribution (Haughton et al., 1991).

Previous work of specific relevance to the study area includes Jessup and Norris (1971), Wopfner (1980), Ambrose et al. (1981), Magee et al. (1995), and Moussavi-Harami & Gravestock (1995). These authors studied the different sedimentary basins in the study area and contributed valuable interpretations with respect to the tectonic setting, basin evolution, sedimentary units and depositional environments of the Lake Eyre Basin.

Lindsay & Leven (1996) and Lindsay (2002) studied the evolution of the Neoproterozoic to Palaeozoic intracratonic Officer Basin and observed many features of architecture and sedimentary fill that suggested common large-scale extrinsic causal mechanisms. Haddad et al. (2001) assessed the evolution of the intracratonic Officer Basin on the basis of well data and provided a data grid of sedimentary thicknesses from the eastern part of the basin. Their gravity modelling results suggest that the eastern Officer Basin evolved from a broad continental sag into a region of intracratonic flexural subsidence in the latest Neoproterozoic, when flexure of the lithosphere deepened beneath the northern basin.
Gravestock (1995) studied the sedimentation and depositional history of the western Warburton Basin where Cambro-Ordovician sediments occupy the intracratonic basin. The Arckaringa Basin was interpreted by Hibbert (1995) as an intracratonic feature comprising a central platform of gently undulating shallow crystalline basement surrounded by depressions. Krieg et al. (1995) interpreted the Eromanga Basin as an epicratonic basin. This interpretation resulted from an assessment of evolutionary and depositional history which indicated that sedimentation occurred in epicontinental depressions during the Jurassic-Cretaceous (Frakes and Barron, 2001).

The studies by Callen et al. (1995), Croke et al. (1996), Alley (1998) and Croke et al. (1998) detailed the evolution of the intracratonic Lake Eyre Basin, including the interpretation of sedimentary units and the identification of changing tectonic conditions and changing depositional environments, based on sedimentologic and palaeontologic evidence. Frakes and Barron (2001) contributed knowledge about the climate of Australia in the Phanerozoic in their study of Phanerozoic general circulation and quantitative climate data for Australia.

2.3 REVIEW OF BASIN HISTORY

The study area incorporates the Precambrian crystalline basements of the Gawler Craton and the Musgrave Block, the Peake and Denison inliers containing the Palaeo- and Neoproterozoic basement, and no less than five sedimentary basins. The sedimentary basins within the study area include the Officer Basin to the northwest and the early Palaeozoic Warburton Basin to the northeast. The Arckaringa Basin lies in the central to western part of the study area having been deposited during the late Palaeozoic. Whilst the Mesozoic Eromanga Basin covers almost the entire study area. The Lake Eyre Basin, the youngest basin in the study area, developed as an intracratonic Cenozoic basin. Present day sedimentation continues in the Lake Eyre Basin.

The Precambrian geological record of the study area spans a period from the late Archaean (~2700 Ma) to the end of the Neoproterozoic (~540 Ma). These sediments consists of quartzite, shale, limestone and ironstone were deposited about 2700 Ma and were highly folded, deformed and intruded by granites, granodiorites and amphibolites around 2500 Ma. After the deformation and metamorphism of the Archaean rocks, there was a 300 to 500 million year period of tectonic quiescence and erosion. The Archaean and Precambrian crystalline basement of the Gawler Craton and Musgrave Block were the main source provenances of the Peake and Denison inliers,
and of the Officer and Warburton Basins. The latter two sedimentary basins are filled with sediments originating either from the Gawler Craton or the Musgrave Block, as well as with reworked older sedimentary units.

The order of geological succession in the study area of the Umbum Creek and Neales River catchment is presented chronologically from ancient crystalline basement to the present modern sediments in Table 1.1. The array of palaeogeographic maps of Australia (Fig. 2.1) illustrates the changing climate conditions (tropical to polar) during the Neoproterozoic to present of the study region whereby the Lake Eyre Basin study region is located 30°S in an intra-continental dryland setting.

2.3.1 THE GAWLER CRATON

The Gawler Craton is a stable crystalline basement province comprising Archaean to Mesoproterozoic rocks, mantled in part by thin platform sediments and regoliths of Neoproterozoic to Cenozoic age (Fig. 2.2). It is defined as that region of crystalline basement that has not been substantially deformed or remobilised, except by minor epeirogenic movements, since about 1450 Ma (Drexel et al., 1993). The Gawler Craton comprises the most diverse association of rocks. The late Archaean to very early Palaeoproterozoic form an older basement of para- and orthogneisses along with mafic to ultramafic intrusives and extrusives. In addition Palaeoproterozoic meta-sedimentary and meta-volcanic successions were multiply deformed and metamorphosed mainly in the eastern Gawler Craton. These successions comprise gneissic, schistose, quartzitic and granitoid units (Drexel et al., 1993). The Mesoproterozoic succession in the Gawler Craton is represented by the intrusion of mafic plugs, subaerial felsic and minor mafic volcanism, and the emplacement of granite batholiths and plutons (Lindsay and Leven, 1996). Sedimentation was restricted to the other parts of Gawler Craton, and is not recorded in the study area. Widespread Neoproterozoic sedimentary rocks were deposited in cratonic, craton-margin and rifted-basin settings with relatively minor associated igneous activity. The Neoproterozoic rocks range from meta-sedimentary to sedimentary in origin, being both carbonate and clastic.
Figure 2.1: Palaeogeographic maps of Australia during the Neoproterozoic to present, changing from tropical to polar and progressing to 30°S subtropical. Yellow box indicates location of study area. (Compiled from Betts et al. 2002, Brock et al. 2000, Frakes and Barron 2001).
2.3.2 MUSGRAVE BLOCK

The Musgrave Block is the broad Mesoproterozoic crystalline basement that dips shallowly beneath Neoproterozoic and early Palaeozoic sediments of the Officer and Warburton basins. The Musgrave Block is a Mesoproterozoic crystalline basement domain extending in an east-west direction along the north-western corner of the study area (Fig. 2.2). The Musgrave Block is flanked by Neoproterozoic and Palaeozoic sedimentary basins: the Officer Basin to the south and west and the Warburton Basin to the north and east. The Mesozoic Eromanga Basin oversteps the Officer and Warburton Basins from the east onto the Musgrave Block (Clarke and Powell, 1991). The Musgrave Block served as a provenance region for sediments deposited in the Officer, Warburton and Eromanga Basins. The Musgrave Block comprises various types of rocks such as granites, gneisses, basic dykes, volcanics and different metamorphic complexes.

2.3.3 SEDIMENTARY BASINS

The Peake and Denison Inliers, situated northeast of the Gawler Craton and south of the Musgrave Block (Fig. 2.2), comprise a number of composite Palaeo- and Neoproterozoic inliers within the Mesozoic Eromanga Basin. Faults along the western margin of the Peake and Denison Inliers separate this geologic domain from the Boorthanna Trough of the mainly Permian Arckaringa Basin. Mesozoic sediments are draped onto and around the eastern edges of the inliers, but thicken rapidly to the northeast into the Eromanga Basin, along a major northwest-trending lineament (the Lake Eyre Fault) (Fig. 2.2). This lineament also defines the boundary between the early Palaeozoic Officer and Warburton Basins.

The Officer Basin is a broad, undeformed, intracontinental basin composed of mostly flat-lying Neoproterozoic and early Palaeozoic clastic sediments, with folding and thrusting occurring locally near the margin of the Musgrave Block (Drexel et al., 1993). The Arckaringa intracratonic basin (Fig. 2.3) developed in the late Palaeozoic with sedimentation occurred during the late Carboniferous to Permian. Sediments, largely of continental origin, thicken locally in the basin trough. Mesozoic Jurassic to Cretaceous sedimentation is represented by the intracontinental Eromanga Basin (Fig. 2.3). In aerial extent, the Jurassic-Cretaceous Eromanga Basin is the largest continental basin in Australia (Drexel et al., 1993). The sediment of this basin form a thin veneer of clastic sediments less than a few hundred metres thick blankets older formations east of the sedimentary basin evolution study area.
Figure 2.2: Distribution of the Officer and Warburton Basins in and around the study area (modified after Gravestock et al., 1995).

NOTE: This figure is included on page 23 of the print copy of the thesis held in the University of Adelaide Library.
Figure 2.3: Distribution of Late Palaeozoic to Cenozoic basins in and around the study area (modified after Parker & Rankin 1993).
Palaeogene, Neogene and Recent sediments of the Lake Eyre Basin unconformably overlie the Eromanga Basin (Fig. 2.3). Palaeogene structural configuration and sedimentation patterns were strongly influenced by reactivation of pre-existing structural elements in the Officer, Warburton, Arckaringa and Eromanga Basins (Alexander et al., 1996). The sediments of the Lake Eyre Basin are subdivided into three units: the Eyre Formation (Late Palaeocene to Middle Eocene), the Etadunna Formation (Late Oligocene to Miocene), and the Pliocene-Holocene sediments (Croke et al., 1998). Modern sediments represent the latest phase of sedimentation in the present day Lake Eyre Basin.

Details of the geologic setting, palaeoclimate and depositional environments of the Peake and Denison Inliers, along with the Officer, Warburton, Arckaringa, Eromanga and Lake Eyre Basins are summarised in Table 2.1. The distribution of basins in the study area is shown in Figures 2.2 and 2.3. Stratigraphic summaries of these basins are given in Figure 1.1.

### 2.4 HISTORY OF UMBUM CREEK SEDIMENT SOURCES

Modern sands from the Umbum Creek and its tributaries offer an excellent opportunity to evaluate the importance of sediment generation, lithology and basin physiography in determining detrital compositions having been derived from mixed igneous, metamorphic and sedimentary provenance terrains. The present day geological setting of the sedimentary basin evolution study area suggests several sources for the Umbum Creek sediments. These include sediments from the uplifted Peake and Denison inliers (Davenport Ranges), alluvial sediments from the Davenport Ranges, sediments generated from fluvial activity through the Mesozoic and Cenozoic deposits and detritus from localised aeolian processes.
Table 2.1: Summary of geologic setting, palaeoclimate and depositional environments of the Peake and Denison Inliers, and the Officer, Warburton, Arckaringa, Eromanga and Lake Eyre basins (Drexel and Preiss, 1995).

NOTE: This table is included on page 26 of the print copy of the thesis held in the University of Adelaide Library.
The sources of the Umbum Creek sediments are divided according to the basin affiliation of the sediments and the tectonic setting of the present geographical conditions. As previously stated, this thesis aims to demonstrate that the basin evolutionary history suggests that the Umbum Creek sediments were initially derived from the Proterozoic, and then recycled via the successive sedimentary basins involved in the evolution of the study area. The present day tectonic setting has led to the unroofing of the Palaeo- and Neoproterozoic sediments and the Palaeozoic Arckaringa Basin sediments of the uplifted Peake and Denison Inliers (Davenport Ranges), part of erosion of Mesozoic Eromanga Basin sediments and the reworking of the Cenozoic Lake Eyre Basin sediments. Furthermore, this thesis aims to show how the difference in Lake Eyre Basin settings resulted from changing tectonics through geological time.

The Peake and Denison Inliers metasediments and associated igneous rocks were uninterrupted until uplift occurred during the Palaeogene (Alley, 1998). Sediments of the Arckaringa and Eromanga Basins were widespread in the study area, but were later stripped off because of the uplift of the Peake and Denison Inliers (Davenport Ranges) (Callen et al., 1995; Magee et al., 1995). These sediments were then redeposited in the Lake Eyre Basin during the Cenozoic. The uplift of the Peake and Denison Inliers accelerated sediment generation from the Davenport Ranges increasing the gradient of the Umbum Creek drainage network and in addition capturing and redepositing Mesozoic Eromanga Basin sediments. Thus, proportions of the bedrock lithologies in the drainages are the main detrital modes of the Umbum Creek tributaries.

Cenozoic Lake Eyre Basin sediments also form part of the sediment supply to the Umbum Creek towards the distal end of the river system. These Cenozoic sediments comprise reworked older sedimentary deposits, reworked gibber plains, aeolian sand dunes, fluvial sands and the metasediments of the Davenport Ranges.
2.5 NEW WORK

The new work mainly focused on a) isopach mapping b) petrology based sedimentary provenance identification. Applications such as isopach mapping (Goggin et al., 1997) in combination with petrology based provenance studies (Basu, 1985; Dickinson, 1985; Zuffa, 1985; Critelli et al., 2003) are used to verify and characterise sediment generation through time to the present modern sediments. Regional time-isopach maps and provenance lithotype characterisation were used to identify the provenance of the various basin successions and, thereby highlighting details of basin development and eroded areas that acted as sediment source regions. Characteristics of modern sediments and their generation can also be inferred from this information (Carter and Bristow, 2003).

By analysing borehole core data and determining the provenance lithotypes via petrography, the main controlling parameters of a sedimentary basin history can be identified. Results of this work, isopach mapping and provenance lithotype characterisation are presented in the following two chapters.
CHAPTER 3
ISOPACH MAPPING

Regional isopach maps of twelve stratigraphic levels (successions from the Cambrian to the Recent) were constructed in order to establish basin geometry and the location of the eroded margins of the four major sedimentary basins located within the basin evolution study area.

Isopach maps of Proterozoic to Cenozoic stratigraphic and lithologic units were made for representing the Officer, Arckaringa, Eromanga and Lake Eyre Basin successions. The Officer Basin is represented by one isopach map; the Arckaringa Basin is represented by three isopach maps; the Eromanga Basin is represented in six isopach maps whilst the Lake Eyre Basin is represented by two isopach maps (the Neogene and Palaeogene levels maps). Stratigraphic units of each formation are interpreted and discussed with respect to their basin evolution as indicated by isopach mapping.

The theme developed in this chapter is that the ultimate character of the Umbum Creek sediments was inherited from a complex pathway of sand genesis from all of the preceding basins and associated hinterland.

3.1 METHODOLOGY

Drill-hole data were used to construct the isopach maps for this study. An isopach map is constructed from this data allowing for the preserved thickness of the formations, rather than producing isocore maps using the determined volume of the stratigraphic succession present in the area of interest. The archive drill hole database was obtained from Minerals and Energy Resources within Primary Industries and Resources, South Australia (PIRSA)—an agency of the Government of South Australia. Most of the boreholes were drilled between 1960 and 1980, although others came from various drilling studies conducted during the last 20 years. The broad structural and stratigraphic composition of sedimentary basin evolution was determined from 783 drill core samples (Fig. 3.1). All stratigraphic and lithologic data are presented within Excel spreadsheets that contain information including unique well identifiers, well location co-ordinates...
(Eastings and Northings; UTM 1984), and geological tops and thicknesses (isopach) for given geological units (Appendix 1).

PIRSA used the drill-hole database signatures to interpret the geological tops for the given lithostratigraphic units. Each geological top was critically reviewed and those accepted were extracted for use in this study. Isopach maps were produced from these data according to the stratigraphic correlation of each formation with respect to geological time and sedimentary basin. All isopach and structure maps were generated using ‘Petrosys 14.3’ and ‘Surfer 8’ mapping software. In Surfer 8, kriging was used as the preferred gridding method after experimentation with other gridding methods. Kriging tends to express trends in the data rather than creating ‘bull’s-eyes’. Although Surfer 8 allows for significant customisation and enhancement of data anisotropy, no attempt was made to manipulate trends indicated in the formations. All defaults given for the kriging method in the construction of these maps were accepted with the exception of grid spacing. Experimentation suggested that grid spacing of 2 m, 10 m, 20 m or 50 m respectively produced a map that honoured the data more accurately. Thus the above mentioned grid spacing were therefore used in generating all maps.

Different grid spacing was selected to produce different isopach maps, according to formation thickness. The larger grid spacing 50 m was used for the thicker isopach maps and the ‘tighter’ grid spacing parameters were used for the thinner isopachs. All thicknesses shown on the maps are preserved thicknesses and no attempt was made to calculate the volume of sediment that was removed by erosion or to allow for differential compaction. These maps do provide evidence for the unroofing of parts of particular formations during erosional periods, and subsequent deposition of the resulting sediments into younger units. For example, where a formation is truncated to a zero edge by an overlying unit, the assumption is that the formation will contribute sediment to the adjacent depositional system. If a thinning edge occurs where the overlying unit is conformable, then the assumption is that reworking may not occur.
Figure 3.1: Landsat imagery with all 783 well locations used to construct isopach maps in the sedimentary basin evolution study area.
3.2 RESULTS

3.2.1 OFFICER BASIN: CAMBIAN – ORDOVICIAN

The Cambrian-Ordovician Officer Basin represents the oldest preserved sedimentary basin in the study area. The basal surface lies unconformably over the metamorphosed Proterozoic basement. The Officer Basin isopach map was generated in order to gain an understanding of this basin’s broad depositional history and subsurface stratigraphic distribution.

Description

The isopach map (Fig. 3.2) shows that the Officer Basin in the study area is characterised by relatively small, locally preserved depocentres separated by relative palaeohighs. Most Officer Basin sediments were deposited during the Cambrian-Ordovician period in the northeast-trending Wintinna Trough, Manya Trough and northwest-trending Boorthanna Trough. The sedimentation represented by the Boorthanna Trough was possibly late stage deposition and fills topographic hollows on an unconformity surface.

The Officer Basin sediments in the Umbum catchment area have not been completely stripped away, especially in the Davenport Ranges. The isopach map indicates that the thickness of sedimentation in the Manya and Wintinna troughs is greater than in the Boorthanna Trough. The maximum thickness of the Officer Basin sediments is preserved in the Wintinna and Manya Trough regions (~450 m). A wider range of sedimentary rocks is represented in the Manya and Wintinna troughs than in the shallow depocentre of the Boorthanna Trough region. Officer Basin sedimentary rocks represented in the Davenport Ranges are mostly from the Boorthanna Trough. The isopach map shows non-deposition or erosion of sediments in the central and southwest part of the study area.

Interpretation

The Officer Basin sediments were deposited in three major depocentres: Manya Trough, Wintinna Trough and Boorthanna Trough. These northeast-trending and northwest-trending troughs play an important role in the geometry of sediment deposition. The palaeotectonic setting during Officer Basin development suggests that most of the sediment for the Wintinna and Boorthanna troughs...
was derived from the Gawler Craton and adjacent areas, although for the Manya Trough, a combination of Gawler Craton volcanics and Musgrave Block sediments is probable. The Middle Bore Ridge and Mabel Creek Ridge (Fig. 2.2) are the main structural palaeohighs in the central and southwest part of the study area, that controlled the sedimentation in the Officer Basin (Drexel and Preiss, 1995; Lindsay, 2002).

Officer Basin sediments were partly removed by Permo-Carboniferous glacial erosion (Fig. 3.3) as part of a widespread glaciation event resulting in the redeposition of these sediments into the Arckaringa Basin, and to a lesser extent into the Cooper Basin farther to the east.

### 3.2.2 ARCKARINGA BASIN: LATE CARBONIFEROUS-PERMIAN

**Description**

The Arckaringa Basin represents a second phase of sedimentary basin development within the sedimentary basin evolution study area. The Early Permian depositional phase (Boorthanna Formation) commenced with widespread glaciation (Drexel and Preiss, 1995; Frakes and Barron, 2001). Following deglaciation, marine transgressive conditions prevailed (Stuart Range Formation), with a eustatic rise in the sea level and flooding of glacio-isostatically depressed lowlands. Termination of marine sedimentation was brought about by crustal isostatic recovery and/or eustatic sea level fall and a return to freshwater conditions with the development of coal swamps observed (Mount Toondinna Formation) (Hibburt, 1995). Sedimentation spread from the Karkaro and Wallira Troughs across the less disturbed areas of basement highs (Wopfner, 1980). The basal surface of the Arckaringa Basin lies unconformably on the Early Palaeozoic rocks of the Officer Basin. Isopach map of ‘top’ surfaces of these three formations were generated.

Three stages in the development of the Arckaringa Basin were recognised. These are listed below.

1. **First Stage: Boorthanna Formation; Early Permian** (Fig. 3.4).

The Isopach map of this formation is characterised by relatively small, localised depocentres separated by relative palaeohighs. Most of these sediments were deposited in the northwest-trending Boorthanna Trough, and the northeast-trending Mount Furner, Wallira and Karkaro Troughs. Preserved sediments in the Wallira and Karkaro Troughs are very thin according to the
Figure 3.2: An isopach map showing the preserved thickness and distribution of Officer Basin sediment within the study area. The zero edge represents erosion by the overlying Arckaringa Basin.
Figure 3.3: Approximate path of major ice caps as they migrated across Gondwana from Devonian to Permian times. The limit of the area affected by late Palaeozoic glaciation is indicated by the blue area. The position of the South Pole at the Permian-Carboniferous boundary is shown (adapted from Alley 1995).
Figure 3.4: An isopach map illustrating the preserved thickness and distribution of Boorthanna Formation sediment within the study area. The sediment were deposited in a depocentres either side of the central basement high.
isopach map. The maximum thickness of the Boorthanna Formation sediments is preserved in the Mount Furner and Boorthanna Trough regions (~140 m). The major palaeohighs (Central Basement High, Mable Creek Ridge and Coober Pedy Ridge) were controlled by the entire Arckaringa Basin sediments distribution.

2. **Second Stage: Stuart Range Formation; Early – Middle Permian** (Fig. 3.5).

   This formation was also deposited in the northwest-trending Boorthanna Trough and the northeast-trending Mount Furner, Wallira and Karkaro Troughs, although the isopach map indicates only this preservation in these troughs. The maximum thickness of Stuart Range Formation sediments is observed in Mount Furner and Boorthanna Trough regions (~140 m).

3. **Third Stage: Mount Toondinna Formation; Late Permian** (Fig. 3.6).

   These sediments are widely deposited throughout the basin area and are particularly represented in the northwest-trending Boorthanna Trough, and the northeast-trending Mount Furner, Wallira and Karkaro Troughs according to the isopach map. The maximum thickness of the Mount Toondinna Formation sediments is preserved in the Mount Furner (~150 m) and Boorthanna Trough (~400 m) regions. Gawler Craton and Officer Basin sediments are the source of Arckaringa Basin sedimentary rocks (Hibburt, 1995).

**Interpretation**

Arckaringa Basin sediments were deposited in association with structural trends such as the northwest-trending Boorthanna Trough and the northeast-trending Mount Furner, Wallira and Karkaro Troughs. These troughs played a vital role in Arckaringa Basin sediment distribution in the study area. The palaeohighs such as the Central Basement High, Mable Creek Ridge and Coober Pedy Ridge separated the depocentres within this basin. During the formation of the Arckaringa Basin, minor depocentres shifted slightly within the major depocentres (troughs) (Fig. 3.7) due to tectonic movements, followed by pre-Jurassic uplift and erosion in order of 0.5 to 1 km (Moore, 1982). The rate of accommodation space created and increased deposition towards the eastern side of the Arckaringa Basin, in the Boorthanna Trough, and rapidly decreased towards the western and southwestern margins.
Figure 3.5: An isopach map illustrating the preserved thickness and distribution of Stuart Range Formation sediment within the study area. The sediment were deposited in a depocentres either side of the central basement high and were sourced from the eroded Officer Basin.
Figure 3.6: An isopach map illustrating the preserved thickness and distribution of Mount Toondinna Formation sediment within the study area. The sediments were deposited in a depocentre surrounding the central high where the ‘zero edge’ onlaps the basin margins.
Figure 3.7: Shifting depocentres (troughs) and palaeohighs within the Officer and Arckaringa Basins through time.

The arrows indicate the migration routes of troughs (Officer Basin troughs to the youngest Arckaringa Basin Mount Toondina Formation depocentres).
The isopach map illustrated in Figure 3.8 suggests that sediments deposited during the Arckaringa Basin development are mainly preserved within the Mount Toondinna Formation. Boorthanna Formation and Stuart Range Formation sediments appear to be only partially preserved in the main depocentres. The sedimentary record of the Boorthanna Formation is not seen widely throughout the Arckaringa Basin. This may be the result of non-deposition because of emergence, or uplift and erosion prior to deposition of the Stuart Range Formation. A widespread erosion surface in the late Permian underlies the Mount Toondinna Formation sediments that are widely preserved throughout the basin. A vitrinite reflectance profile from the Boorthanna Trough indicates that the Stuart Range Formation was eroded prior to deposition of the Mount Toondinna Formation (McBain, 1987).

The palaeotectonic setting during Arckaringa Basin development suggests that most of the sediment for the Boorthanna, Mount Furner, Wallira and Karkaro Troughs were transported from the Gawler Craton and Officer Basin (Moore, 1982).

Localised tectonic movements resulted in differential erosional surfaces throughout the basin which were partially associated with retreating glaciation to the south. These sediments were deposited and preserved as a consequence of a local increase in accommodation space. The Mount Toondinna Formation shows similarities with the Toolachee Formation in the Cooper Basin (Hill and Gravestock, 1995).

The isopach maps of the Arckaringa Basin successions suggest that the basin is an intracratonic feature comprising a central platform of gently undulating shallow crystalline basement surrounded by depressions. Most of Arckaringa Basin sediment were stripped off during the uplift in the mid to late Triassic through to the earliest Jurassic. Subsequently, late Miocene tectonism caused minor late-stage structuring of the Permian rocks, and the uplift blocks of Precambrian rocks (Peake and Denison Inliers) in the study area (Wilmot, 1987). The unroofing of the Boorthanna and Stuart Range formations probably moved sediments, mainly to the Cooper Basin, east of the study the area. The eroded sediment resulting from the mid to late Triassic uplift was also possibly transported to the Cooper and Simpson Basins. Whilst the early Jurassic uplift moved ‘unroofed’ sediments into the Eromanga Basin, whereas during the Miocene, eroded sediments from the uplifted Peake and Denison Inliers and Permian basin formations were deposited in the Lake Eyre Basin.
Figure 3.8: Isopach maps of key Arckaringa Basin formations and its sedimentation pattern within the basin evolution study area.
3.2.3 EROMANGA BASIN: EARLY JURASSIC-LATE CRETAUCEOUS

Early in the Jurassic there emerged a new geo-tectonic regime that produced a fundamental palaeogeographic change. Plate movements induced crustal instability and created an epicratonic basin (Eromanga Basin), representing the third phase of sedimentary basin evolution within the basin evolution study area (Veevers, 1984; Betts et al., 2002). The Eromanga Basin consists of broad, continental downwarps which developed in response to distant plate-boundary interactions north and east of the Australian continent (Drexel and Preiss, 1995; Krieg et al., 1995). The sedimentary successions of the Eromanga Basin are thin, blanket-like and widespread. The isopach maps of each succession were generated in order to understand the preserved thickness, depositional history and subsurface stratigraphic distribution.

The northeast-trending Karari Fault Zone and the northwest-trending fault-bounded Mulgathing Trough in the study area controlled Eromanga Basin sedimentation patterns (Fig. 3.9). The Denison-Willouran Divide and the folded Stuart Range also produced a structural grain in the Mesozoic sediments by controlling palaeocurrent directions and channel alignments of fluvial deposits (Rankin et al., 1989).

Six stages of Eromanga Basin evolution were recognised (Drexel and Preiss, 1995). These are listed below.

1. **First Stage: Algebuckina Sandstone; Early – Late Jurassic** (Fig. 3.10).
   The Isopach map shows a relatively broad and widespread distribution of Algebuckina Sandstone in the study area. The northeastern and southwestern depocentres were separated by relative palaeohighs and the northwest-trending Denison-Willouran Divide. The maximum thickness of sediments in the southwestern area ranges from approximately 80 to 140 metres, northwest of the Karari Fault extension zone.

2. **Second Stage: Cadna-owie Formation; Early Cretaceous** (Fig. 3.11).
   This formation is deposited in a south-southwestern trending depocentre. Thickness and depositional pattern indicates changes in the tectonic setting occurred during deposition. Maximum thickness ranges from 60 to 80 metres southeast of the Karari fault extension zone and northwest of the Karari Fault Zone.
Figure 3.9: Structural framework of the Eromanga Basin (from Krieg et al., 1995). Outline of the basin evolution study area is shown in red. Note the importance of NE trending Karari Fault extension, and the NNW trending structures that surround the Boorthanna Trough. The NW trending Lake Eyre lineament and Muloorina Gravity Ridge demarcates the buried margin of the Eromanga Basin.
Figure 3.10: An isopach map showing the preserved thickness of the Algebuckina Sandstone and its distribution within the basin evolution study area. Illustrating the NE and NW trending fault zones associated depocentres.
Figure 3.11: An isopach map showing the preserved thickness of the Cadna-owie Formation and its distribution within the basin evolution study area. Illustrating the NE and NW trending fault zones associated depocentres.
3. **Third Stage: Mount Anna Sandstone; Early Cretaceous** (Fig. 3.12).

This sandstone formation is equivalent to the upper Cadna-owie Formation. This sequence was only preserved in the western margin of the Eromanga Basin and is localised to the depocentre adjacent the Peake and Denison Inliers. The maximum thickness of Mount Anna Sandstone sediments (~150 m) was observed southeast of the Karari Fault extension zone.

4. **Fourth stage: Bulldog Shale; Early to mid-Cretaceous** (Fig. 3.13).

This isopach map illustrated two main depocentres of Bulldog Shale sedimentation. However the northeast-trending Poolowanna Trough represents the main Bulldog Shale depocentre. The other depocentre is in the southeast-trending Cooper Basin region, which is only partly represented in the study area. This succession is characterised by relatively broad, widespread deposits with maximum thickness ranging from 200 to 240 metres. The maximum thickness of the Bulldog Shale sediments is also preserved in troughs (~220 m) either side of the Karari Fault extension zone. As noted in other Eromanga Basin successions, the Denison-Willouran Divide still controls the deposition of depocentres. Preserved thicknesses of this succession along with the depositional patterns suggest a change in tectonic regime with depocentres migrational towards the northeast part of the study area during Bulldog Shale deposition.

5. **Fifth Stage: Coorikiana Sandstone; Mid-Cretaceous** (Fig. 3.14).

This formation is only preserved in the western margin of the Eromanga Basin. The isopach map indicates relatively thin deposition in emergent depocentres. The maximum thickness of the Coorikiana Sandstone sediments is observed in troughs northwest of the Karari Fault zone (~60 m) and north of the Karari Fault extension zone (~60 m) towards the Poolowanna Trough.

6. **Sixth Stage: Oodnadatta Formation; Mid – Late Cretaceous** (Fig. 3.15)

The Oodnadatta Formation isopach map shows a thick sequence of sediments widely deposited in the northeastern part of the basin evolution study area. This formation is only preserved in the western margin of the Eromanga Basin and was deposited in the same emergent depocentres as the Coorikiana Sandstone. The maximum thicknesses of Oodnadatta Formation sediments are preserved in troughs northwest of the Karari fault zone (~20 m) and north of the Karari fault extension zone (~100 m) towards the Poolowanna Trough. The isopach map suggests that the sedimentation of this formation is very thin and comparatively widespread across these depocentres.
Figure 3.12: An isopach map showing the preserved thickness of the Mount Anna Sandstone and its distribution within the basin evolution study area. Illustrating the restricted deposition of Mount Anna Sandstone south of Karari Fault zone.
Figure 3.13: An isopach map showing the distribution and preserved thickness of the Bulldog Shale sediments within the basin evolution study area. Map illustrates the wide spread distribution which onlaps the west and south, associated with greatest thickness in Poolowanna Trough.
Figure 3.14: An isopach map showing the preserved thickness of Coorikiana Sandstone sediments and its distribution within the study area. Illustrates that Coorikiana Sandstone was eroded NE of the Peake and Denison Inliers and subsequently provided sediments for Cenozoic deposits.
Figure 3.15: An isopach map showing the preserved thickness of Oodnadatta Formation sediments and its distribution within the study area.

Map suggests that the Oodnadatta Formation was eroded in the region NE of the Peake and Denison inliers.
Interpretation

The subsidence history of the Eromanga Basin, as derived from sediment accumulation rates in a number of exploration drill-holes, shows initial steady subsidence followed by a period of very rapid subsidence from the early-mid Cretaceous to late Cretaceous (Moore and Pitt, 1984). Following this a cessation of subsidence occurred when the basin was filled. Whatever the mechanism for initial formation and shaping of the basin, the subsequent tectonic development and eventual structural design of the basin were controlled by two major factors—the inherited pattern of pre-Jurassic structures and post-depositional (mainly Palaeogene) continental compression (Krieg et al., 1995) (Fig. 3.9). The tectonic setting and overall depositional pattern of the Eromanga Basin in the basin evolution study area suggests that the main source of sediments is from the Gawler Craton and from the previous sequence of older basins.

After general uplift in the Triassic, the beginning of the Jurassic involved local movement and changing depocentres activated by a structural resetting. The area had become elevated and erosional. The crustal events that followed caused a continental downwrap to form the Eromanga Basin where contiguous deposition resumed over a very wide area (Wopfner, 1985). The sedimentary record of the Eromanga Basin extends without a major break from the early Jurassic to the late Cretaceous and consists of a cyclic succession of sandstone and mudstone units thought to reflect oscillating sea level (Burger, 1986; Drexel and Preiss, 1995).

Structurally, the Eromanga Basin within the basin evolution study area is divided into northeastern and southwestern parts by the northwest-trending zone, known as the Denison-Willouran Divide (Fig.3.16). The sedimentary succession thickens rapidly eastwards across this divide. West and southwest of the divide, the contiguous basin succession is much thinner because of depositional thinning and erosional stripping of the younger stratigraphic units.
Figure 3.16: Figure showing the migration of various depocenters (troughs) during the Eromanga Basin deposition. The arrows indicate the migration of depocenters from the oldest to the youngest.
In the region covered by the basin evolution study area, the Denison and Willouran Divide played an important role in the depositional history of early Eromanga Basin sediments such as the Algebuckina Sandstone, Mount Anna Sandstone and Cadna-owie Formation (Veevers, 1984; Wopfner, 1985). During deposition of these formations, the depocentres migrated from northwest to southeast, whilst sediment accumulation patterns remained the same and was controlled by the tectonic setting and the palaeo-drainage pattern (Moore and Pitt, 1984). These early depocentres shifted significantly in the early stages of deposition (Fig. 3.16).

The central and southwest parts of the basin show strong isopach gradients within a complex zone of alternating sediment thicknesses. During deposition of the Bulldog Shale, the depositional trend changed toward northeast trending depocentres. The thin isopachs in the central and southwest parts reflect onlaps against the Stuart Range palaeohighs. Tectonics controlled the sedimentation patterns throughout Eromanga Basin deposition (Rankin et al., 1989) as evidenced by the alignment of most depocentres with northeast-oriented faults as well the northwest-trending fault zones (Fig. 3.16). The rates of accommodation space generation and sedimentation were uniform throughout this period (Krieg et al., 1995).

The isopach map trends indicate that Algebuckina Sandstone and Cadna-owie Formation sediments were evenly preserved within the basin, whereby zero-edges are interpreted to be the result of later erosion. In addition, the Mount Anna Sandstone is preserved only west of the Denison and Willouran Divide. Whilst the Cadna-owie Formation is a comparatively widespread but thin unit which when considered in relation to its depositional time-span, suggests either slow sedimentation, or more likely, numerous erosional breaks, a view supported by palynological evidence (Alley, 1988).

The isopach map of the Bulldog Shale shows a new depocentre in the northeast, suggesting that there was a migration of accommodation space east of the Denison and Willouran Divide. The thicker isopachs also reflect higher accommodation rates when compared to previous depositional cycles, a pattern which develops farther to the northeast than that seen for earlier cycles. The main depocentre, Poolowanna Trough, is positioned to the northeast outside the study area (Moore and Pitt, 1984). The northeast trend of this depocentre suggests subsequent uplift and erosion along the western margin of the basin because as the maximum preserved thickness is focussed in these northeast depocentres (Hill and Gravestock, 1995).
The isopach map of the Coorikiana Sandstone reveals that sedimentation was restricted to a smaller depocentres. Thickness ranges from 60 to 80 metres. The main area of sedimentation in the study area shifted to the east, indicating that the Denison and Willouran Divide was no longer a major control over sedimentation in the basin. Decreasing accommodation in the depocentres also reflects slowing of subsidence rates and/or a fall in relative sea level controlled by eustacy (Veevers, 1984). The result was an extensive sand sheet, with localised ‘zero-edges’ observed on the isopach map, especially in the vicinity of the Neales River east of the Denison-Willouran Divide which reflects during Cenozoic erosion.

The Oodnadatta Formation isopach map has a similar pattern of deposition to the Coorikiana Sandstone. The migration of the depocentres evident on the last two isopach maps is probably due to the changing local stress pattern associated with continental uplift (Krieg et al., 1995; Sun, 1997). The palaeotectonic setting during Eromanga Basin development suggests that most of the sediment for this basin was transported from the Gawler Craton, Musgrave Block and the older basin sediments.

The preserved thickness and accommodation pattern of each formation in the Eromanga Basin succession are shown in Figure 3.17. Algebuckina Sandstone exposures around the western basin margin are less thick and widely represented throughout the basin, although they are subjected to erosion. The Cadna-owie Formation is also typically thin and widely represented throughout the basin, and may be either erosional as in the type section on the basin margin, or gradational into the older units (Moore and Pitt, 1984). Mount Anna Sandstone is not seen widely throughout the basin, probably due to non-deposition as a result of uplift and erosion prior to deposition of the Bulldog Shale. The Bulldog Shale has as a widespread distribution being deposited and preserved as a consequence of a local increase in accommodation space and rate of global sea level rise, as well as decrease in the rate of erosion. The sediments deposited during the mid-late Cretaceous, represented by the Coorikiana Sandstone and the Oodnadatta Formation was subsequently removed by erosion to an easterly and southeasterly direction in the early to late Palaeocene.
Figure 3.17: Isopach maps showing of shifting depocentres of Eromanga Basin successions and their distribution of preserved depositional patterns.
The Winton Formation was not recorded in the study area. This could have been due either to non-deposition or to uplift and erosion prior to deposition of the Palaeogene sediments during the Late Cretaceous. Alternatively, it could have been caused by stripping off sediments during the early to late Palaeocene uplift and erosion. Later, late Miocene uplift caused minor late-stage structuring of the Jurassic and Cretaceous strata including uplifted blocks of Precambrian rocks (Peake and Denison Inliers) in the study area (Krieg et al., 1995; Wopfner, 1985). The unroofed Eromanga Basin sediments from the uplifted Peake and Denison Inliers were transported and deposited into the western Lake Eyre Basin through the Neogene to the present.

3.2.4 LAKE EYRE BASIN: PALAEOGENE AND NEOGENE

Description

The Lake Eyre Basin represents a fourth phase of sedimentary basin evolution and preserved fill within the basin evolution study area. The Lake Eyre Basin was created via tectonic subsidence in Central Australia during the late Palaeocene. Palaeogene and Neogene sediments are preserved in the western basin margin whose distribution was controlled by the northwest-trending Stuart Range and the uplifted Peake and Denison Inliers (Davenport Ranges) (Callen et al., 1995). The Lake Eyre Basin consists of a thin sedimentary succession in the western margin where the sedimentary fill is significantly thinner and more discontinuous than elsewhere (Alley, 1998). The basal surface of the Lake Eyre Basin form an unconformable contact with Eromanga Basin sediments (Johns, 1989). The Lake Eyre Basin isopach maps were generated in order to understand the depositional history and subsurface stratigraphic distribution.

The isopach map generated for the late Palaeocene to middle Eocene, Eyre Formation and the Late Oligocene to Miocene, Etadunna Formation (Fig. 3.18) suggests that Palaeogene to early Neogene sediments (56.5-10 Ma) of the Lake Eyre Basin are characterised by widespread, thin deposits separated by subtle palaeohighs. These deposits are relatively thin throughout the basin, however rarely exceed maximum thicknesses of between 10 to 20 m.

The isopach map shown in Figure 3.19 indicates that mid-late Neogene sediments (5.3-0 Ma) are well represented in the Western Lake Eyre Basin. These sediments are thin but widespread, with thickness ranging up to 8 m. The general trend of sediment transportation and deposition is
towards the Lake Eyre Basin, but there is a small concentration of sediments in the study area which is controlled by the uplift of the Stuart Range and the Peake and Denison Inliers.

**Interpretation**

Lake Eyre Basin isopach maps suggest that sediments in this basin were deposited mainly in the Lake Eyre intracratonic basin. The thin nature of the Palaeogene to early Neogene sediments with respect to the Lake Eyre Basin sedimentary record is probably due to combination of non-deposition, as well as uplift and erosion prior to Neogene deposition. The fact that Neogene sediments are also widely represented throughout the basin, but thin, may also be due to non-deposition and/or uplift and erosion (Croke *et al.*, 1998).

An alternative interpretation for the thin succession within the Lake Eyre Basin is centered on basin margin deposition which may have been subject to erosion via successive tectonic events. In addition, the Palaeogene the amount of accommodation space was limited due to a slow subsidence rate. Most of the Palaeogene sediments are therefore preserved in the basin centre. The late Palaeogene uplift of the Peake and Denison Inliers associated with a new transitional stress field induced the formation of accommodation space in the western Lake Eyre Basin margin (Callen *et al.*, 1995; Alley, 1998). A later Neogene deposit in the Lake Eyre Basin was observed in similar depositional patterns like Palaeogene deposits as a result of more accommodation space generated due to uplift. Both of the isopach maps (Fig. 3.20) suggest that the sedimentation patterns of both Palaeogene and Neogene deposits were followed a similar trend, even though slightly change in tectonic regime in east side of the basin evolution study area.

The palaeotectonic setting during Lake Eyre Basin development, suggests that the most of the Palaeogene sediment was transported from the Gawler Craton and overlying sedimentary basin cover. The Neogene sediments probably represent a combination of reworked Precambrian rocks, Arckaringa sediments from the uplifted Peake and Denison Inliers, Eromanga Basin sediments, as well as sediments from the Palaeogene Eyre and Etadunna Formations.
Figure 3.18: An isopach map showing the preserved thickness and distribution of Eyre and Etadunna Formations (Palaeogene) sediments. Illustrates ‘widespread’ sheet-like sedimentation is evident with onlaps around subtle palaeo-highs (Stuart Range and Peake & Denison Inliers).
Figure 3.19: An isopach map showing the preserved thickness of Neogene sedimentation and its distribution within the study area.

This isopach illustrates widespread sheet-like sedimentation. However, units were locally eroded during the Neogene.
Figure 3.20: Isopach maps showing the Lake Eyre Basin successions and preserved accommodation patterns.
Eyre and Etadunna Formations sediments deposited in the western Lake Eyre Basin margin were eroded during the late Miocene tectonism which uplifted blocks of Precambrian rocks (Peake and Denison Inliers) along with younger sedimentary basin deposits (Neogene). The Eyre Formation was subjected to extensive erosion in the early Eocene followed by a cycle of deposition. The Etadunna Formation was also subjected to erosion during the late Miocene being deposited in the Lake Eyre Basin before Neogene sedimentation prevailed. It is significant that the late Miocene uplift did not cause any significant change in Lake Eyre Basin sedimentation (Callen et al., 1995; Croke et al., 1998).

The unroofing of Palaeogene Lake Eyre Basin sediments from the uplifted Peake and Denison Inliers and adjacent areas resulted in transportation and deposition into the western Lake Eyre Basin through the Neogene to the present. However, there is no indication that subsidence rates have changed significantly during the late Cenozoic in the Lake Eyre intracratonic basin (Wopfner, 1985; Croke et al., 1998).