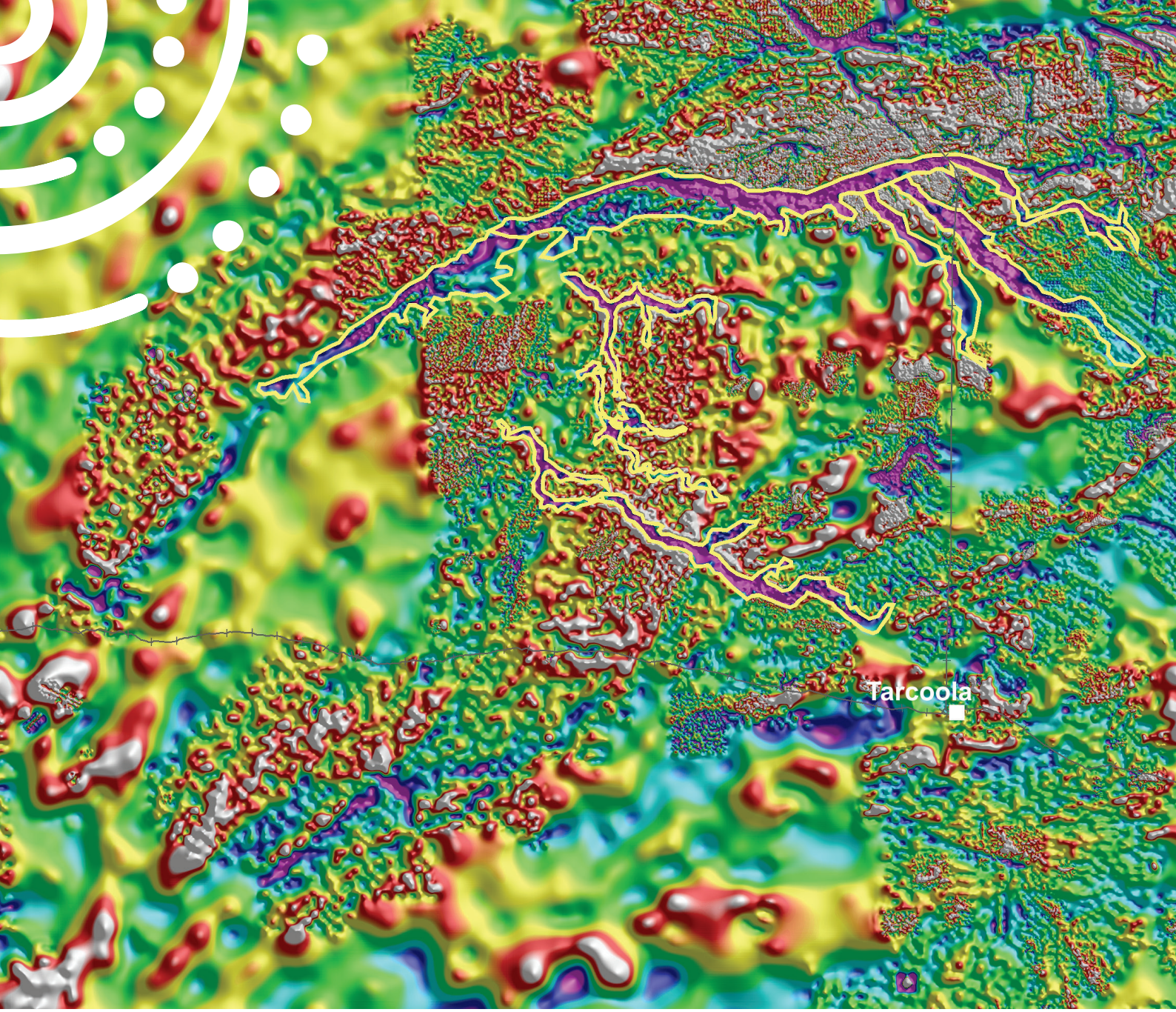


Remapping the paleovalley systems of the central-western Gawler Craton, South Australia

B Hou, A Petts, C Krapf, J Irvine,
L Stoian, P Heath, G Reed and C Foss

SOUTH AUSTRALIA

Government of South Australia
Department for Energy and Mining

Remapping the paleovalley systems of the central-western Gawler Craton, South Australia

B Hou, A Petts, C Krapf, J Irvine, L Stoian, P Heath, G Reed (GSSA) and C Foss (CSIRO)

Geological Survey of South Australia, Department for Energy and Mining

December 2023

Report Book 2023/00043

Department for Energy and Mining
Level 4, 11 Waymouth Street, Adelaide
GPO Box 320, Adelaide SA 5001
Phone +61 8 8463 3000
Email dem.minerals@sa.gov.au
dem.petroleum@sa.gov.au
www.energymining.sa.gov.au

South Australian Resources Information Gateway (SARIG)
SARIG provides up-to-date views of mineral, petroleum and geothermal tenements and other geoscientific data. You can search, view and download information relating to minerals and mining in South Australia including tenement details, mines and mineral deposits, geological and geophysical data, publications and reports (including company reports).
map.sarig.sa.gov.au



© Government of South Australia 2023
With the exception of the piping shrike emblem and where otherwise noted, this product is provided under a Creative Commons Attribution 4.0 International Licence.

Disclaimer
The contents of this report are for general information only and are not intended as professional advice, and the Department for Energy and Mining (and the Government of South Australia) make no representation, express or implied, as to the accuracy, reliability or completeness of the information contained in this report or as to the suitability of the information for any particular purpose. Use of or reliance upon the information contained in this report is at the sole risk of the user in all things and the Department for Energy and Mining (and the Government of South Australia) disclaim any responsibility for that use or reliance and any liability to the user.

Acknowledgement of Country
As guests on Aboriginal land, the Department for Energy and Mining (DEM) acknowledges everything this department does impacts on Aboriginal country, the sea, the sky, its people, and the spiritual and cultural connections which have existed since the first sunrise. Our responsibility is to share our collective knowledge, recognise a difficult history, respect the relationships made over time, and create a stronger future. We are ready to walk, learn and work together.

Preferred way to cite this publication
Hou B, Petts A, Krapf C, Irvine J, Stoian L, Heath P, Reed G and Foss C 2023. *Remapping the paleovalley systems of the central-western Gawler Craton, South Australia*, Report Book 2023/00043. Department for Energy and Mining, South Australia, Adelaide.

CONTENTS

ABSTRACT **1**

1. INTRODUCTION **2**

1.1 PROJECT RATIONALE 2

1.2 AIMS 4

1.3 METHODOLOGY 5

2. REGIONAL SETTING **7**

2.1 BASEMENT – ARCHEAN TO MESOPROTEROZOIC 7

Gawler Craton 7

Musgrave Province 7

Madura and Coompana Provinces 9

2.2 BEDROCK – NEOPROTEROZIC TO MIDDLE PALEOZOIC 9

Officer Basin 9

2.3 BASINS RELATED TO THE PALEOVALLEYS 10

Arckaringa Basin – Permo-Carboniferous 10

Eromanga Basin – Early Jurassic – Late Cretaceous (South Australia portion) 13

Eucla Basin and associated paleovalleys – Paleogene-Neogene 19

2.4 TECTONIC AND STRUCTURAL FRAMEWORKS 32

2.5 QUATERNARY GEOLOGY AND GEOMORPHOLOGY 33

3. PALEOVALLEY MAPPING AND GIS DATASET **34**

3.1 INTRODUCTION 34

3.2 DATA SOURCES 34

Satellite thermal imagery 35

GP2 geophysical surveys – AEM, Gravity, TMI 35

Stratigraphy 36

3.3 NEW MAP DATA LAYERS 38

3.4 NEW AND UPDATED PALEOVALLEY SYSTEMS 41

Late Paleozoic paleovalley systems 41

Mesozoic paleodrainage systems 46

Cenozoic paleovalley systems 47

4. ECONOMIC GEOLOGY **62**

4.1 PLACERS 62

Channel placers 62

Beach placers 63

Principal units and shorelines related to HMS 65

4.2 URANIUM 66

4.3 CLAY MINERALS 67

4.4 REE 67

4.5 COAL 67

4.6 GROUNDWATER 68

5. CONCLUSIONS **69**

ACKNOWLEDGMENTS **70**

REFERENCES **70**

APPENDIX **79**

TABLES

Table 3.1 Data sources used for identification of paleofeatures.....35
Table 3.2 Paleovalley map layers of the study area.....38

FIGURES

Figure 1.1 Location of the study area and the GP2 project area over SRTM 1 second DEM imagery in the central western Gawler Craton, South Australia. 3
Figure 1.2 Major geomorphic and sedimentary components of a modern drainage basin that can be used analogous to the paleodrainage developed in the Eucla Basin and its peripheral paleovalleys. 6
Figure 2.1 Geological framework of the study area. 8
Figure 2.2 A) Approximate area of the Arckaringa Basin, showing major structural elements, drillholes, coal deposits and location of cross section; B) schematic cross-section through the basin. 11
Figure 2.3 Stratigraphic chart of the Arckaringa Basin and sedimentary interpretation for the southern Arckaringa Basin based on the Arkeeta 1 petroleum exploration well 12
Figure 2.4 A) Mesozoic depression map in the study area showing components of Eromanga and Eucla basins; B) Eromanga Basin in South Australia portion.....15
Figure 2.5 Stratigraphic chart of the Eromanga Basin.....16
Figure 2.6 Eucla Basin of southern Australia, showing the geological relationships with surrounding highlands (cratons and older basin), Cenozoic coastlines and their approximate ages, paleovalleys and adjacent major features.....20
Figure 2.7 Landsat ETM7 imagery of the eastern Eucla Basin, showing location of major paleovalleys and shorelines of varying age superimposed on today's landscape 21
Figure 2.8 SRTM 1 second DEM imagery of the eastern Eucla Basin, showing major paleovalleys and shorelines of varying age 22
Figure 2.9 Comparison of A) NOAA-AVHRR (1.1 km pixel), ASTER Night-Time Thermal (NTT) (90 m Pixel) and B) ASTER Day-Time (30 m Pixel) images, showing eastern onshore Eucla Basin, major paleovalleys and shorelines of varying age; the textural difference between paleovalleys (dark tone) and the sand barriers (light tone) is apparent. 22
Figure 2.10 Cross-section through the eastern onshore area of the Eucla Basin, showing geologic relationships with underlain cratonic and bedrock geologies; location of the cross-section indicated in Figure 2.6. 24
Figure 2.11 Stratigraphic correlation chart and inferred depositional environments in the eastern Eucla Basin and associated paleodrainage system 25
Figure 2.12 Schematic stratigraphic diagram and cross section showing stratigraphical relationships across the eastern Eucla Basin and adjacent onshore sediments in marginal marine and paleovalley settings. 27
Figure 3.1 New paleovalley system map layers in the study area. 37
Figure 3.2 Example of attributed Kingoonya Paleovalley mapping on satellite images and associated ArcGIS attribute table. 39
Figure 3.3 Paleovalley mapping on MrVBF imagery. 40
Figure 3.4 Mapped Paleozoic paleovalleys on the GP2 gravity data (a), showing the relationship with the Arckaringa Basin, Mulgathing Trough and GP2 area (b). 41
Figure 3.5 Paleozoic paleovalleys (red) mapped over the GP2 gravity data, showing the relationship with the Arckaringa Basin, Mulgathing Trough and GP2 area. 42
Figure 3.6a Permian channel cross-section A–A' through the Mulgathing Trough in the study area, showing the stratigraphic relationships with both old (Cambrian?) and younger (Mesozoic) channel sediments 43
Figure 3.6b Gravity model of this study, showing the Permian channel cross-section B–B' through the Mulgathing Trough in the study area. 44
Figure 3.7 Paleovalley mapping on GP2 gravity data 1VD image. 45
Figure 3.8 Mesozoic paleovalleys mapped over ASTER ntt image (GSSA data), showing the relationship with the Eromanga Basin and GP2 area. 47

Figure 3.9 Comparison of Paleogene-Neogene coastal paleo-geomorphic components between the GP2 and 2nd edition of paleovalley maps, showing their relationship along the Eastern Eucla margin over DEM image. 48
Figure 3.10 Comparison of Paleogene–Neogene paleodrainage system components between the GP2 and 2nd edition of paleovalley maps, showing their relationship with the Eastern Eucla margin over DEM image. 49
Figure 3.11 Cross-sections through the Immarna lagoonal coastal area of the eastern Eucla margin based on drillholes 52
Figure 3.12 Cross-sections through the tidal inlet part of the Woldra Paleovalley based on drillholes 53
Figure 3.13a) Sequential cross-sections through length of Garford Paleovalley. 56
Figure 3.13b) Longitudinal section through the Garford Paleovalley. 57
Figure 3.14a) Sequential cross-sections through length of Kingoonya Paleovalley based on drillhole data 58
Figure 3.14b) Longitudinal section through the Kingoonya Paleovalley based on drillhole data 59
Figure 3.15 Cross-sections through the Anthony Paleovalley based on drillhole data 61
Figure 4.1 Known mineralisation in the study area new paleovalley data set, overlain by major mineral deposits and prospects. 63
Figure 4.2 Mineralisation model in the paleodrainage terrains of the study area (a), modelled from a detailed cross-section of the Kingoonya Paleovalley (b) 64

Remapping the paleovalley systems of the central-western Gawler Craton, South Australia

B Hou, A Petts, C Krapf, J Irvine, L Stoian, P Heath, G Reed and C Foss

ABSTRACT

The Geological Survey of South Australia's (GSSA) *Gawler Challenge Phase 2: next generation mineral systems mapping* (GP2) program presents the ideal opportunity to revisit some ground-breaking landscape evolution studies with new geophysical data and reprocessed remote sensing data in a region of high resource potential within South Australia. The study area, located in the central–western Gawler Craton of South Australia, comprises thin basin margin successions and paleovalleys. Three basins (Arckaringa, Eromanga and Eucla) contain nearshore to onshore coastal-channel sediments of late Paleozoic, Mesozoic and Cenozoic ages, linked to an extensive network of peripheral paleovalleys that drained the Precambrian Gawler Craton and Musgrave Province, as well as the Neoproterozoic – Early Paleozoic Officer Basin.

Understanding the geology and sedimentary evolution of these basins and peripheral paleovalleys has relevance to the exploration for placer deposits (e.g., gold, heavy minerals), secondary geochemical deposits (e.g., uranium), clay minerals and for saline and rarely, potable groundwater resources in the basin and channel sediments. Knowledge of the basin and paleovalley architecture and any concentration of minerals in the channels is also of interest as guides to the location of both paleochannel and bedrock lode deposits in the Gawler Craton. Geoscientific datasets have been integrated in an investigation of these basins and peripheral paleovalleys that have significance for mineral exploration. The objective of the study was to understand the basin characteristics and history, and to map the paleo-components related to these basins and paleovalleys, in order to assist exploration in GP2 basin-paleodrainage terrains. This was achieved through the combination of results from various geographical, geological and particularly new geophysical datasets. These include interpretations drawn from field observations, a compendium of geological and drilling data, topographic and evaluated digital elevation models, remote sensing imagery, geophysical data (e.g., magnetics, gravity, airborne and transient electromagnetics and radiometrics, where available), all of which have contributed to a systematic investigation of the basin-paleodrainage terrains. Physical property contrasts that exist between the basin/channel sediments and the underlying bedrocks/basement, for instance, can be differentiated by geophysical methods to locate the basin framework and paleoshorelines/paleovalleys. Evidence from sedimentological records was combined with other geological, geomorphological and geophysical characteristics to arrive at a general reconstruction of basinal and paleovalley architectures and depositional environments.

1. INTRODUCTION

1.1 PROJECT RATIONALE

The Geological Survey of South Australia's (GSSA) *Gawler Phase 2: next generation mineral systems mapping* (GP2) project encompasses three main components: data acquisition, data science, and insight. The central western Gawler has been the focus of much of South Australia's heavy mineral sand (HMS) and paleochannel-related uranium exploration, and prospectivity has not waned in the years since the initial discovery of Jacinth-Ambrosia in 2004 following the publication of new paleochannel maps and reports in 2008 (e.g., Hou, 2008; Hou et al., 2007, 2012). The GP2 project presents the ideal opportunity to revisit and update some of these ground-breaking landscape evolution studies by integrating the newly acquired ground gravity data as well as additional data from the Gawler Craton Airborne Survey (GCAS) program and reprocessed remote sensing data.

The two main objectives of this study were:

1. to map in higher resolution and detail the paleodrainage systems in the GP2 area in order to develop a better understanding of the newly mapped paleodrainage system components including the paleovalleys characteristics, geometry and geological/depositional environment of the associated sedimentary basins; and
2. to facilitate new exploration opportunities of the paleodrainage system components by reconstructing paleoshorelines and paleovalleys and reviewing and updating the cover stratigraphy.

In the study area of the central-western Gawler Craton three basins (Arckaringa, Eromanga and Eucla) and their peripheral paleovalleys are recognised (Fig. 1.1). Integral to these basins were the development of associated late Paleozoic, Mesozoic and Cenozoic paleodrainage systems that mostly discharged into these sedimentary basins. They comprised a few major river networks that drained large tracts of the Archean to Mesoproterozoic Gawler Craton and Neoproterozic to Cambrian-Devonian Officer Basin. Thus, the development of the paleodrainage systems and the basins are genetically related and form the overall depositional system. The sedimentary records of these basins and peripheral paleodrainage systems provide an understanding of the geological history of the study area since the Permian. The presence of these paleodrainage systemspresents numerous exploration difficulties (e.g., due to their thickness overlying mineralised basement) but also opportunities (e.g., mineralisation, groundwater), and challenges traditional usage of geological, geophysical and geochemical exploration techniques (Hou et al., 2000). The recognition of these paleodrainage systems and their detailed mapping can, to some extent, both highlight or disguise exploration targets and, when understood, can be applied to advantage in mineral exploration.

Interpreting the evolution of the paleodrainage presents several problems which can extend also to the marginal settings of the basins and the paleo-headwaters of these systems. The lack of linkage between the mapped channel patterns and the scarcity of suitable fossils in their sedimentary record for precision dating (e.g., compound weathering, particularly of onshore sediments, is a serious factor that can destroy part, or all, of what fossil record existed), as well as the difficulty in calibration of the reconstructed sedimentary record against regional and/or local sedimentary events, makes it difficult to place the records within the context of geological time scales. Uncertainty around depositional timeframes makes sequence recognition and correlation difficult. For the Paleozoic and Mesozoic paleodrainage systems some of these issues are magnified due to overprinting by tectonic events, weathering and erosion leading to loss of or reduced depositional sequences and with subsequent poor exposure, making the recognition and correlation difficult. In addition, too few suitable geological drillholes are available for detailed study and regional correlation. However, studying the margins of the Arckaringa, Eromanga and Eucla basins and their peripheral paleodrainage systems offers a rare insight into the evolution of the study area during late Paleozoic, Mesozoic and Cenozoic times.

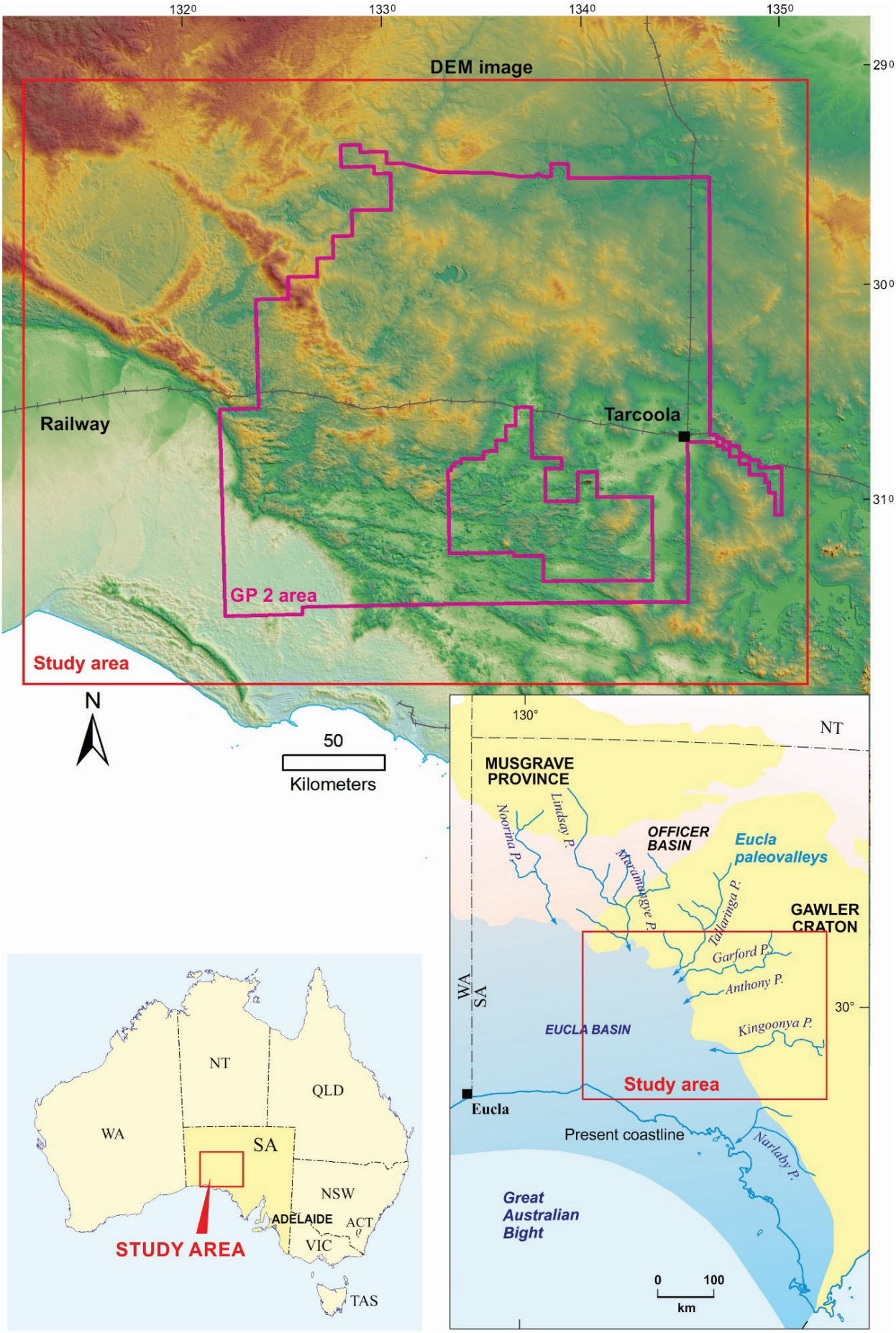


Figure 1.1 Location of the study area (red rectangle) and the GP2 project area (pink polygon) over SRTM 1 second DEM imagery in the central western Gawler Craton, South Australia.

Placer and other deposits (e.g., uranium, clay minerals, clay-hosted REEs, groundwater) associated with sediments in these basins and paleovalleys have been only known in the study area for the past few decades (see details in Chapter 4). The discovery of primary gold deposits and prospects (e.g., Challenger, Campfire Bore, Golf Bore, and Birthday) beneath cover in the study area provides significant opportunity for looking for placer gold deposits in the paleovalleys. Also, the discovery of heavy mineral (HM) deposits (e.g., Jacinth and Ambrosia) in the marginal sediments, and uranium (e.g., Woldra and Warrior) in the channel sediments of the Eucla Basin and its paleodrainage networks have established these as priority exploration targets. Over the three geological periods (late Paleozoic, Mesozoic and Cenozoic), the weathered sediments eroded from mineral-bearing surface rocks of the Musgrave Province, Gawler Craton and Officer Basin were carried by the paleo-rivers discharging into the Arckaringa, Eromanga and Eucla basins. Gold, diamond and heavy minerals may occur within the channels or as placers in their associated coastal barriers. Sandstone-hosted uranium (e.g., Binks and Hooper, 1984; Curtis et al., 1990) and palygorskite (Keeling et al., 1995) may be present in economic concentrations. Widespread coal deposits may be found to reach commercial significance in associated paleo-floodplains, while groundwater resources are known from the sediments within the paleochannels. Therefore, a systematic and detailed study of these paleodrainage systems and associated basins can provide the possibility of locating economic minerals in paleochannel/costal deposits and even give indication of nearby bedrock mineralisation.

In exploring and studying unknown buried basin and channel deposits, one of the major difficulties is how to explore for such deposits beneath many metres of cover over large areas without resorting to systematic, broad-spaced drilling. In exploration for mineral deposits in basin and channel sediments, precise geometric definition of the paleoshorelines and paleovalleys becomes important. In recent years, many attempts at using geophysical techniques to successfully delineate paleochannels have been reported; these have included magnetics, seismic, gravity, electromagnetics, and down-hole gamma logs (e.g., Smyth and Barrett, 1994; Deen et al., 2000; Leslie et al., 2000; Mackey et al., 2000; Hou et al., 2001a; 2003a,Pawley & Krapf, 2016; Munday et al 2013; Soerensen et al 2013; Krapf et al 2019). Additionally, remote sensing and digital topography assisted by computer techniques, have proven to be useful and important in delineation of paleochannels (e.g., Tapley and Wilson, 1985; Tapley, 1988; Statham-Lee, 1994; Hou et al., 2000; Hou and Mauger, 2005).

In the study area, there are considerable uncertainties due to the unknown characteristics of much of the subsurface geology, that is, subsurface sediments and bedrock beneath the surficial cover across this large area. Recognition of the paleogeographic setting and boundaries within the sedimentary sequences is variable and challenging. Even when guided by prior experience, the accuracy of geophysical models and the estimation of the parameters of marine and stream dynamics from both field and borehole observations is sometimes problematic. Although there exists a body of literature describing the geomorphology and geology of the study area, there have been few works studying its sedimentary history based on a whole-of-basin view, particularly paleoclimatic and tectonic impacts on the paleogeography, and the economic significance of the paleogeographic setting (depth of cover, accessibility, etc.). The new geophysical and newly processed remote sensing data provides a unique opportunity to detailed mapping and modelling of the study area and its resources.

1.2 AIMS

This paleodrainage system study investigates the geophysical and geological expression and related mineralisation in both transported and residual regolith and its relationship with paleodrainage landforms (Fig. 1.1). Previous projects have assisted exploration in the eastern Eucla Basin and provide fundamental data for building knowledge of geological processes and landscape evolution within this important region (e.g., Hou, 2008; Hou and Alley, 2003; Hou and Mauger, 2005; Hou and Warland, 2005; Hou et al., 2001, 2003a, b, 2007, 2012, 2021, 2022). In the study area (Fig. 1.1) the interest is extended to older paleodrainage systems, such as Paleozoic and Mesozoic, as these have strong affinities with other well-known commodity (e.g.,

heavy mineral sands and uranium) producing regions, but have been under-explored due to the widespread cover of the basins and paleodrainage sediments.

Existing ASTER data were re-processed, and studied with complementary remote sensing datasets (e.g., SRTM 1 second DEMs, multi-resolution valley bottom flatness (MrVBF), Landsat TM 5, Landsat ETM 7, NOAA-night-time thermal (ntt)). A desktop study included a review of existing paleovalley and regolith-landform maps followed by the use of the newly processed remote sensing to create updated map layers for the study area. In addition, providing a regional assessment of cover thickness and cover types as well as distribution of paleovalleys, will aid to better inform exploration in the study area.

Aims and expected outcomes / benefits of the project include:

- revised paleodrainage-landform maps: to use new and re-processed datasets for successfully delineating the paleovalleys.
- provide important constraints on the location and types of paleovalleys: to reconstruct the paleogeographic settings of the paleovalleys.
- describe and delineate types of cover present in the area, allowing the generation of more clearly defined cover type and cover thickness maps – extending on previous mapping work by GSSA.
- to study the stratigraphic framework of the paleovalleys.
- to predict exploration for sediment-hosted mineral deposits.

1.3 METHODOLOGY

A paleovalley landform is characterised as a paleodrainage basin (i.e., primary- and incised-valley networks; Fig. 1.2) bounded by continental drainage divides and occupied by drainage networks (Bates and Jackson, 1987), ranging from individual hillslopes surrounding small headwater tributaries, to large tracts of continents drained by major river networks. The major paleovalleys in the study area, such as Tallaringa, Garford and Kingoonya, are bounded by the regional divides in their headward tracts and then form a roughly radial pattern focussed on the basin margin (Fig. 1.1). While the landscape of the study area contains remarkably well-preserved and varied paleolandforms of Cenozoic, Mesozoic and Paleozoic ages, pervasive aeolian and alluvial sand and clay cover and widespread duricrusts in the present-day landscape hamper mapping of the paleovalley sediment fills. Mapping information presented here is based largely on techniques and procedures that are typically used in delineation and evaluation of these paleovalley deposits (e.g., drillcore/chips logging). Reconstructing the distribution, thickness and sedimentary facies of the paleovalley sediments therefore challenges the application of geological and geophysical exploration techniques and presents both difficulties and opportunities for mineral exploration (Hou et al., 2000). Data, including topography, digital elevation models (DEMs), Landsat, NOAA, ASTER, and radiometric, magnetic, seismic, gravity, and airborne electromagnetics (AEM), where available, were used to map out the paleovalleys, in addition to experience and knowledge in geomorphology and sedimentology (Fig. 1.2).

Evidence from existing geological maps and drillholes was used together with geomorphologic studies to improve knowledge of the dimensions, trends and continuity of the basins and associated paleodrainage systems. Samples used during the previous projects include material collected during previous field work and others taken from mining open-pits, cores and cuttings mainly stored at the South Australia Drill Core Reference Library, Tonsley. These samples were examined for determination of sedimentary type and facies, depositional environment, conditions of weathering, and some were subjected to petrological, mineralogical, and geochemical analysis. The stratigraphic framework for the paleodrainage system that underpins the interpretation relies to a large extent on stratigraphic drillholes. Sedimentological analysis has been integrated for the interpretation of the formation of the paleovalleys. Therefore, the methods of study on the paleodrainage systems in the study area can be summarised as below:

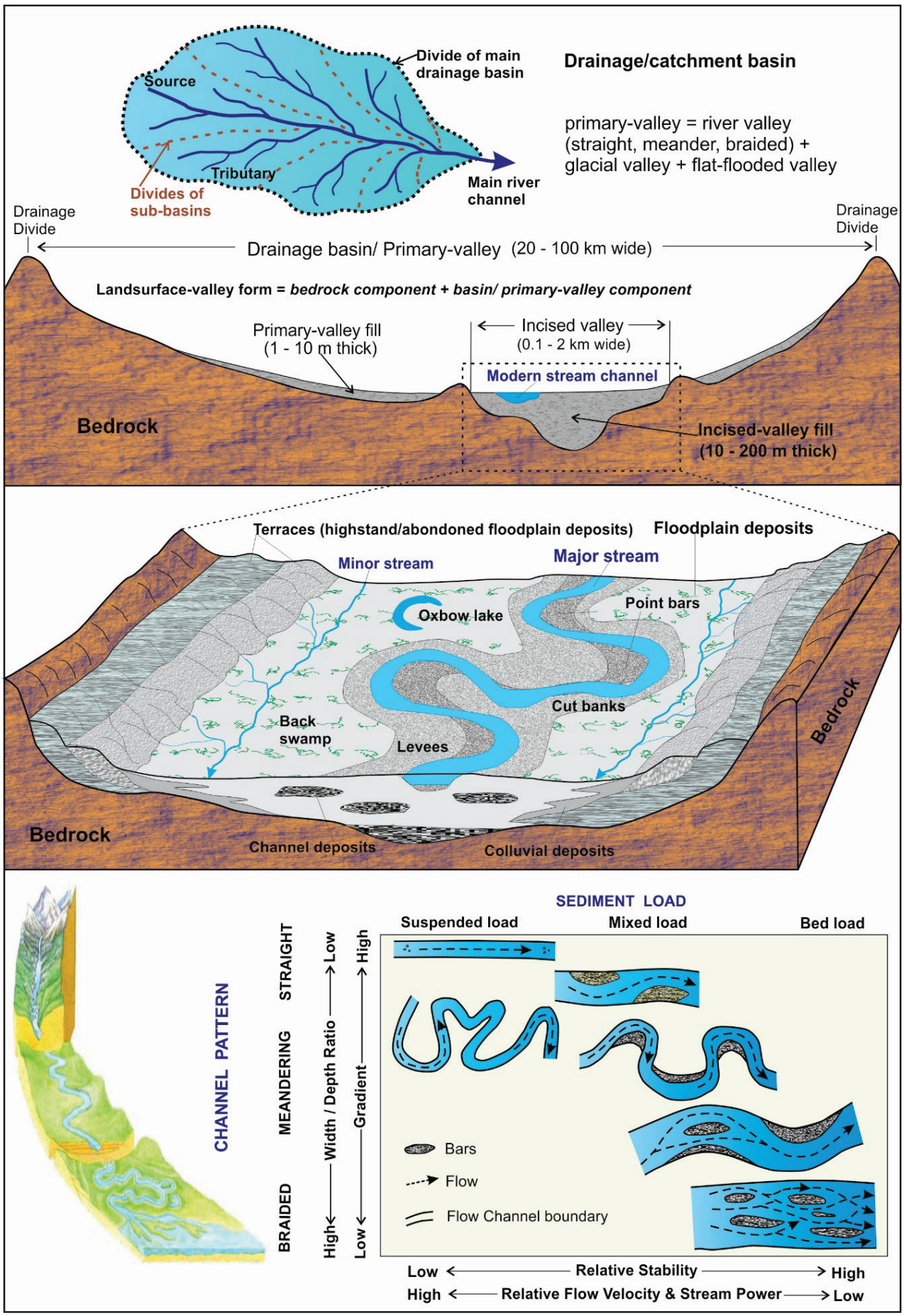


Figure 1.2 Major geomorphic and sedimentary components of a modern drainage basin that can be used analogous to the paleodrainage developed in the Eucla Basin and its peripheral paleovalleys (from Hou et al., 2022).

- overview of the region and review previous work;
- regional-scale mapping of the paleodrainage systems and, specifically, the individual paleovalleys by using various geological and geophysical techniques;
- relationship of the basin geography and provenance;
- petrological, mineralogical and geochemical analyses of the paleovalley fills;
- sedimentological analysis of the paleovalley sediments;
- review of economic significance.

2. REGIONAL SETTING

Geographically and geologically associated basement underlying the GP2 region's paleovalleys mainly includes the Gawler Craton, Musgrave Province (probably also Madura and Coompana provinces) and Officer Basin (Figs 1.1 and 2.1). The majority of these paleovalleys are incised into Archean to Mesoproterozoic Gawler Craton rocks over much of the southern and central GP2 region, and into the sedimentary rocks of the Officer Basin to the north and northeast.

2.1 BASEMENT – ARCHEAN TO MESOPROTEROZOIC

The Archean to Mesoproterozoic rocks that form the basement beneath and around the study area are the crystalline rocks of the Gawler Craton (Fig. 2.1). Several drillholes in this region have intersected these basement rocks (see Figs. 3.13–3.17 in Chapter 3), and some drill samples were retained and can be viewed at the Drill Core Library.

Gawler Craton

The basement rocks of the Gawler Craton consist of Archean to Mesoproterozoic metamorphic complexes (episodes over the interval c. 3200–1500 Ma) which are the products of three megacycles of orogenic events (late Archean – Early Proterozoic c. 2550–2420 Ma, Paleoproterozoic c. 1200–1620 Ma, and Mesoproterozoic c. 1600–1500 Ma (e.g., Daly, 1985; Daly and Fanning, 1993; Daly et al., 1979; Fanning et al., 1988). Major magmatic and mineralising events occurred at the beginning of the Mesoproterozoic (1620–1570 Ma) due to felsic magmatism, including the intrusion of the Hiltaba Suite granites (Hand et al., 2007; Reid and Hand, 2012). The GP2 area lies within the central-western Gawler Craton (Fig. 2.1), where the Gawler Craton is predominantly Mulgathing Complex (c. 2550–2440 Ma) that encompasses Archean to Paleoproterozoic rocks, together with rhyolite, dacite and granitic rocks associated with the c. 1592 Ma Gawler Range Volcanics and Hiltaba Suite (Daly et al., 1979; Daly, 1986; Daly and Fanning, 1993). The Archean to early Paleoproterozoic Sleaford and Mulgathing complexes form an older basement in the western and north-western portions of the study area and include gneiss and granulite-facies rocks formed during the Sleafordian Orogeny from sediments (including iron formation) and felsic to mafic igneous rocks. These rocks contain the Challenger gold deposit and numerous other gold prospects.

The Gawler Craton is overlain by Paleozoic, Mesozoic and Cenozoic rocks, in places, and locally by paleochannel fills of Permian, Mesozoic and Cenozoic-aged sediments. Quaternary sediments blanket most of the area.

Musgrave Province

The Musgrave Province occurs in the northernmost part of the study area (Fig. 2.1). The southern boundary of the Musgrave Province is defined by aeromagnetic data (Major and Conor, 1993). This boundary is partly coincident with the unconformable contact with the overlying Neoproterozoic sediments of the Officer Basin, and partly with thrusts along which the basement rocks have been transported over Officer Basin sediments during the Alice Springs Orogeny (Major and Conor, 1993). The eastern boundary of the Musgrave Block is poorly defined where the basement is concealed beneath the Phanerozoic cover of the Pedirka and Eromanga Basins.

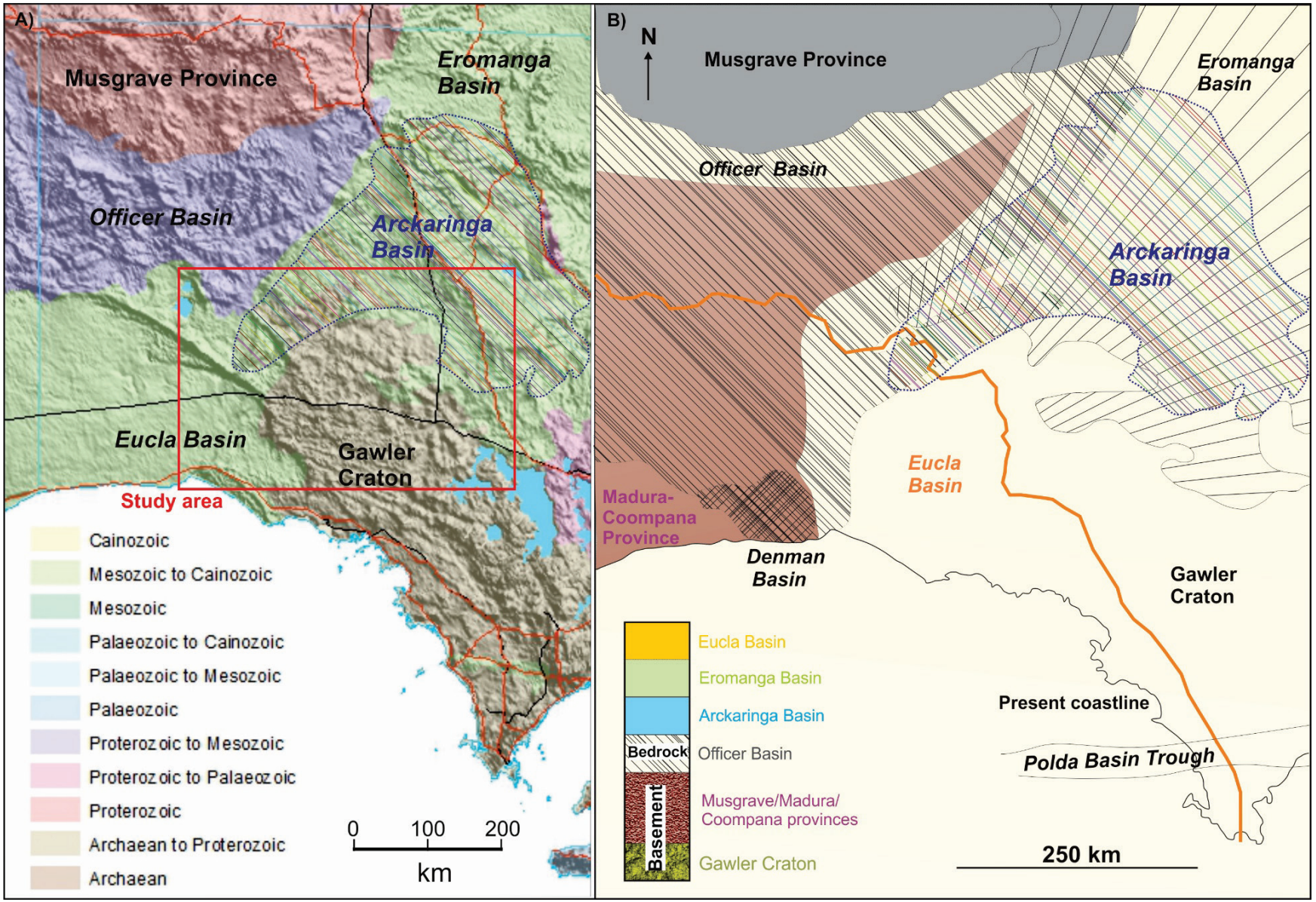


Figure 2.1 Geological framework of the study area. A) Time-slice geology draped over SRTM 1 second DEM; **B)** Schematic geological relationship diagram of the major geological provinces.

The Paleo- to Mesoproterozoic Musgrave Province comprises very high-grade metamorphics, with protoliths of still uncertain age and origin, and major mafic and felsic intrusives, developed over two major intervals of magmatism, sedimentation and metamorphism. An early c. 1600–1550 Ma phase of magmatism (Wade et al., 2006) was followed by sedimentation in the western Musgrave Province over the interval c. 1450–1350 Ma, (Smithies et al., 2009) and by a prolonged phase of magmatism and deformation over the interval c. 1345–1100 Ma known as the Musgravian Orogeny (Wade et al., 2008; Smithies et al., 2009, 2010). The final phase of significant magmatism within the Musgrave Province occurred c. 1080–1000 Ma associated with the Giles magmatic event (Wingate et al., 2004; Evins et al., 2010a, b). The Birksgate Complex and Wataru Gneiss of the Musgrave Province are high-grade metamorphic rocks formed during the Musgravian Orogeny (~1200 Ma), which acted upon sedimentary, volcanic and older metamorphic rocks of uncertain age, but partly at least 1605 Ma old (latest Paleoproterozoic). The Musgravian Orogeny was accompanied by intrusion of felsic rocks of the Pitjantjatjara Supersuite (formerly Kulgera Suite; 1225–1190 Ma; Smithies et al., 2009, 2010). Large intrusions of the mafic to ultramafic Giles Complex, with potential for nickel and platinum mineralisation, were emplaced about 1070 Ma. During the Petermann Orogeny (540 Ma), a huge fault zone, which filled with mylonite and partly melted rock (now solidified), allowed uplift of this part of the Musgrave Block from very deep in the Earth's crust and thrust it over the Olia Gneiss, which had formed at about 1600–1540 Ma in shallower parts of the crust.

Madura and Coompana Provinces

The Madura and Coompana Provinces are the regions of Precambrian crystalline basement that lie beneath the Eucla Basin and between the Gawler Craton to the east and the Musgrave Province to the north (Fig. 2.1; Spaggiari, et al., 2012; Dutch et al., 2018; Gartmair, 2022), which probably provided heavy mineral sources to the GP2 paleovalleys by reworking via Officer Basin sandstones (Gartmair, 2022; Hou et al., 2022). Rock-forming events of the Madura–Coompana provinces are very similar to those in the Musgrave Province, and include the Mesoproterozoic Moodini Supersuite (~1181–1125 Ma), the metamorphic episodes of the Toolgana and Undawidgi Supersuites (~1179, ~1167, ~1150, and ~1174 Ma) and the c. 1070 Ma Giants Head Suite being a mafic magmatic event of identical timing to the Giles event of the Musgrave Province (Neumann and Korsch, 2014; Wingate et al., 2015; de Gromard et al., 2016; Jagodzinski et al., 2018).

2.2 BEDROCK – NEOPROTEROZIC TO MIDDLE PALEOZOIC

The bedrock sedimentary sequences at the surface and beneath the sediments in the GP2 paleovalleys consist mainly of the sedimentary rocks of the Neoproterozoic to Middle Paleozoic Officer Basin. These are unconformably overlain by the fluvial-marginal marine sediments in the Permian-Cenozoic depressions.

Officer Basin

The Officer Basin onlapped the Musgrave Province and Gawler Craton and is overlain by the Arckaringa, Eromanga and Eucla basins in and around the study area (Fig. 2.1). It represents an intracratonic Neoproterozoic (Adelaidean) Middle Paleozoic (Devonian) basin in northwestern South Australia and Western Australia (e.g., Preiss et al., 1995; Gravestock et al., 1995). The Officer Basin contains abundant clastic sediments and minor, mostly mafic volcanism (e.g., Table Hill Volcanics; Grey et al., 2005). The northern margin is partly unconformable onto the Musgrave Block, but is largely overthrust by the basement, as defined by magnetic, gravity and seismic data. The south-eastern margin is defined by the Karari Fault, delineated by magnetic data, and forms the western margin of the Gawler Craton. The eastern part of the Officer Basin is overlain by Arckaringa Basin sediments, and the southern part by Denman, Bight and Eucla Basin sediments; the margin in these areas has been mapped with sparse drillhole and seismic data coverage.

The Officer Basin has been described by various authors, including Jackson and van de Graaff (1981), Townson (1985), Phillips et al. (1985), Brewer et al. (1987), Gravestock and Hibburt (1991), Hocking, (1994), Drexel and Preiss (1995), Harvey and Hibburt (1999), Carlsen et al. (1999), and Ghori (1998, 2002). Thick terrigenous clastic and carbonate sediments of the

Neoproterozoic-Middle Paleozoic Officer Basin underlie the Eucla Basin and thicken northwards beyond the Eucla Basin. The Paterson Formation of the Officer Basin (Wales and Forman, 1981) is characterised by poorly sorted sandstone, claystone, conglomerate, siltstone, basal diamictite and tillite, with varves and erratics in places pointing to a glacigene, lacustrine, to fluvioglacial depositional environment. The Ilma Formation on the northern margin of the basin is a medium-grained sandy oolite with a matrix of fine sparry calcite of probably Neoproterozoic age and thickens northwards into the basin (Lowry, 1970). To the northeast lie the margins of the Carboniferous-Permian Arckaringa Basin and the overlying and younger Mesozoic Eromanga Basin.

2.3 BASINS RELATED TO THE PALEOVALLEYS

The Arckaringa, Eromanga and Eucla basins are briefly described below because they are geologically related to their peripheral paleovalleys mapped in the study area. Therefore, the sedimentary information can be genetically used for understanding the mapped paleovalleys in this area. Understanding of the history of the sedimentary basins and the paleovalleys that drained from the Gawler Craton, Musgrave Province (probably also the Madura–Coompana provinces) and Officer Basin is important because they contain major mineral deposits, and the sediments derived from them contain remobilised gold, uranium, and heavy minerals. In particular, a remarkably preserved paleoshoreline sequence along the margin of the eastern Eucla Basin is highly prospective for heavy mineral sand deposits (Benbow, 1990b; Hou et al., 2003b; 2011a, b; 2021). The extent and complexity of these paleoshoreline deposits hampered early heavy mineral exploration.

Arckaringa Basin – Permo-Carboniferous

The Permo-Carboniferous intracratonic Arckaringa Basin is located in the southeast of the study area and is mostly restricted to the subsurface (Fig. 2.1). Permian sediments in the basin include (from the oldest) Boorthanna, Stuart Range and Mount Toondina formations as a subhorizontal succession unconformably overlying Cambrian sediments and/or Precambrian basement (Fig. 2.2; Alley, 1995). These formations may be overlain unconformably by up to 300 m of Late Jurassic to Early Cretaceous Eromanga Basin sediments and generally less than 10 m of Cenozoic cover.

The Early Permian depositional phase (Boorthanna Formation) in the Arckaringa Basin commenced with widespread glaciation. Following deglaciation, marine transgressive conditions prevailed (Stuart Range Formation), with eustatic rise in sea level and flooding of glacio-isostatically depressed lowlands (Alley, 1995). Paleontological data indicate that the sea transgressed from the west (Wopfner, 1980), northwest (Jones, 1987), or the southwest (McGowran, 1973); a south-eastern opening is also inferred from the presence of a marine facies in basal Mount Toondina Formation that is restricted to the Phillipson and southern Boorthanna Troughs. It is possible that the sea entered from several directions (Alley, 1995). Termination of marine sedimentation was brought about by crustal isostatic recovery and/or eustatic fall and return to freshwater conditions with development of coal swamps (Mount Toondina Formation). Sedimentation ceased as a consequence of positive epeirogenic movements (Wopfner, 1972).

STRATIGRAPHY

The age of these three formations has been determined by palynology to be Early Permian (Harris and McGowran, 1973; Jones, 1987; Gilby and Foster, 1988) but could be interpreted to extend into the Late Carboniferous (Fig. 2.3; Alley, 1995). The Carboniferous - Permian sediment outcrops in the study area are dissected by paleovalleys (e.g., Mulgathing Trough and Tallaringa Paleovalley). They include glaciogenic sediments of the Boorthanna Formation, marine fine clastics of the overlying Stuart Range Formation and coal bearing terrestrial sediments of the capping Mount Toodina Formation equivalents (Alley, 1995).

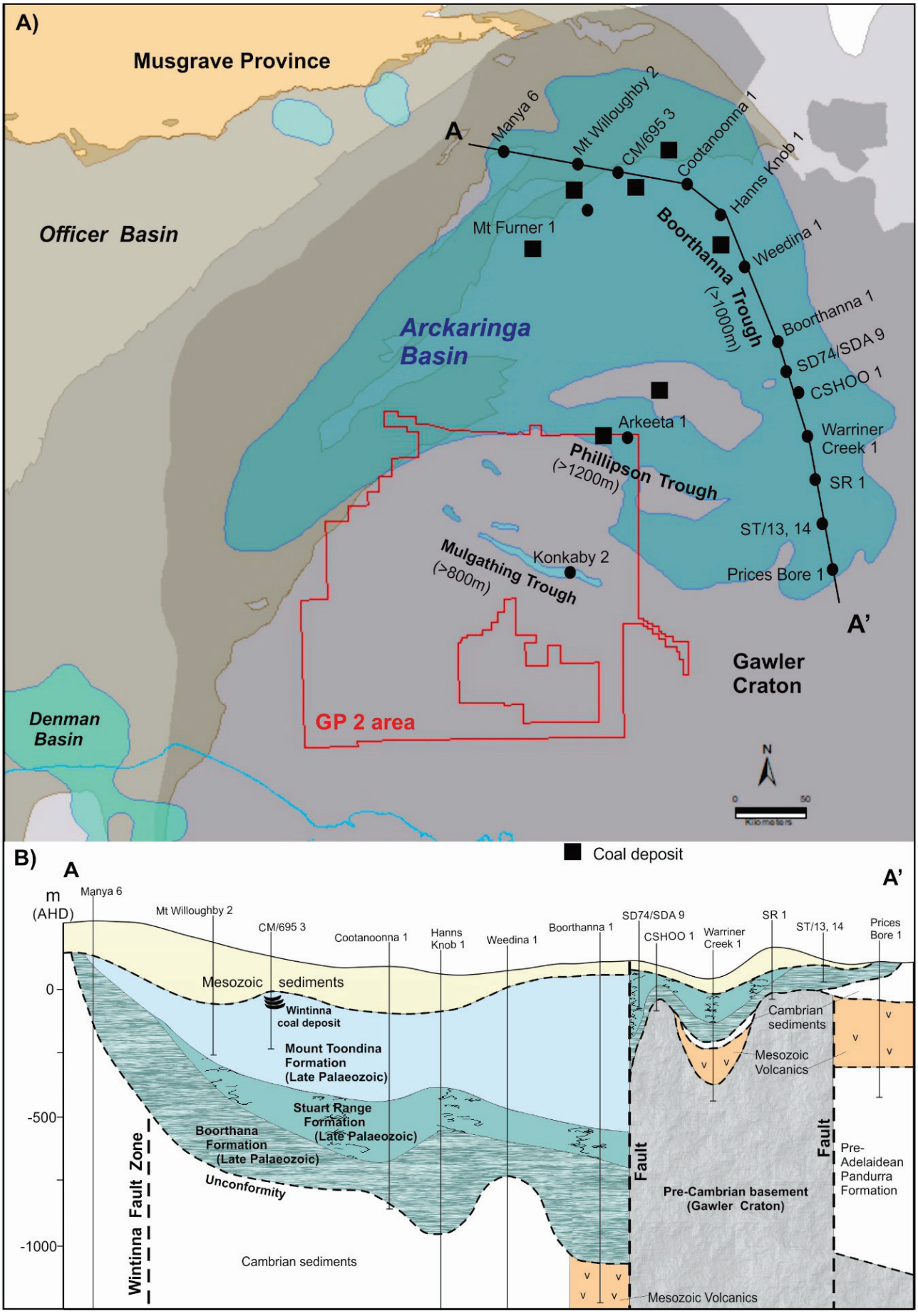


Figure 2.2 A) Approximate area of the Arckaringa Basin, showing major structural elements, drillholes, coal deposits and location of cross section; B) schematic cross-section through the basin (modified from Alley, 1995).

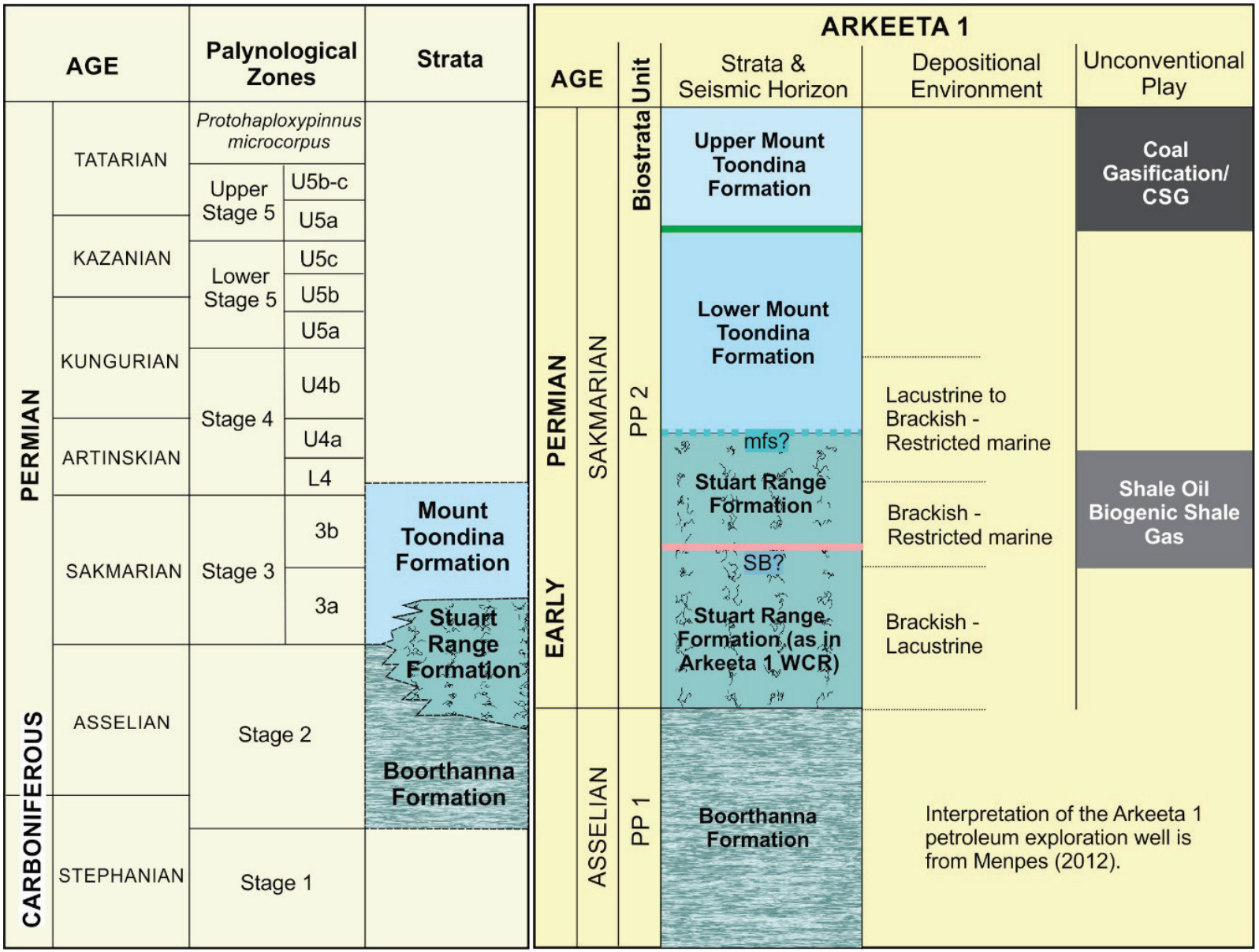


Figure 2.3 Stratigraphic chart of the Arckaringa Basin and sedimentary interpretation for the southern Arckaringa Basin based on the Arkeeta 1 petroleum exploration well (modified from Alley, 1995 and Menpes, 2012).

Boorthanna Formation

The Boorthanna Formation comprises a glacigene sequence with marine facies towards the top. Two units distinguished at the type section in drillhole Boorthanna 1 include a basal facies dominated by diamictite with shale intercalations and an upper unit of rhythmically bedded fine- and coarse-grained clastics. The diamictite facies is a sandy to boulder claystone, which is often calcareous and sometimes dolomitic, interbedded with shale and occasionally thin sandstone or carbonate. The rhythmically bedded facies is generally medium- to coarse-grained sandstone but ranges from siltstone to boulder beds. In the southwestern part (to the study area) of the Arckaringa Basin, diamictite and clastics are not confined to one stratigraphic level (Benbow, 1993). Paleontological and sedimentological evidence (Jones,1987) indicate an Asselian/Sakmarian marine transgression from the northwest with restricted marine conditions in the southeast and apparent younging of sediments in this direction.

Stuart Range Formation

The Boorthanna Formation is conformably (occasionally disconformably) overlain by the Stuart Range Formation, although seismic evidence indicates that the relationship is unconformable in the Boorthanna Trough (Fig. 2.2A; Allender et al., 1987; Wilmot, 1987).

The Stuart Range Formation, which directly overlies pre-Permian rocks locally, is generally a homogenous marine shale with minor siltstone and sandstone, deposited under quiet-water, restricted marine conditions (Wopfner, 1970; Harris and McGowran, 1973; Barnes et al., 1977; Gilby and Foster, 1988). Brief episodes of non-marine deposition are indicated in the Cootanoorina 1 and Mount Furner 1 successions (Gilby and Foster, 1988) and in the upper part of the formation in Arkeeta 1, suggesting alternating lacustrine and marine conditions (McBain, 1987). The formation may have oil-shale potential (Meyer, 1981; Moore, 1982).

Mount Toondina Formation

The Mount Toondina Formation overlies, usually conformably but occasionally disconformably, the Stuart Range Formation. In some parts of the basin, it may unconformably overlie Boorthanna Formation. Siltstone and sandstone interbedded with coal, shale and rare carbonate are the dominant lithologies with the coal generally restricted to the upper part of the formation. The formation contains three units (Wilmot, 1987): the basal unit contains marine shales in the lowermost 30 m of Boorthanna 1 (Cook, 1981) and interbedded anoxic marine lacustrine shales in the basal section of Arkeeta 1 (McBain, 1987); the middle unit is interpreted from seismic and comprises westward-prograding deltaic sandstone and siltstone (Wilmot, 1987); the uppermost unit is dominantly lacustrine shale and minor fluvial clastics with intervals of coal formed in peat swamps (Fig. 2.3).

Eromanga Basin – Early Jurassic – Late Cretaceous (South Australia portion)

Due to the extensive burial of the Eromanga Basin, uncertainty remains as to where to draw the boundary between the marginal deposits of the Cenozoic Eucla Basin and those of the Mesozoic Eromanga Basin to the northeast (Fig. 2.1). In the study area, the Mesozoic paleovalleys, now mostly covered by the Cenozoic deposits formed during the Jurassic and Cretaceous where crustal downwarping was accompanied initially by the deposition of a very widespread fluvial and lacustrine to marginal marine clastic blanket. This includes outcrop of largely Algebuckina Sandstone and Cadna-owie Formation of the Eromanga Basin, which are potential host units for heavy mineral sands (Hou et al., 2021).

In the Triassic, most of southern Australia was subjected to weathering and erosion, and sedimentation only occurred in a few places. In the Jurassic and Cretaceous, a time of profound geographic change for Australia, rifting initiated in the Jurassic led to the separation of Australia from Antarctica, and the resulting seaway south of the Australian continent widened as Australia drifted northwards (Frakes et al., 1987). This represented the latter stage of the disintegration of Gondwana. Meanwhile, global sea-level rise brought the last great marine flooding onto the

Australian continent from the north, and this shallow sea covered much of southern Australia's inland (Krieg et al., 1995).

The intracratonic Early Jurassic – Late Cretaceous Eromanga Basin (Krieg et al., 1995) in northern South Australia extends into Queensland, the Northern Territory and New South Wales (Fig. 2.4; Frakes et al, 1987). Regional weathering and development of extensive in-situ regolith profiles occurred at least around the margins of the Eromanga Basin prior to sedimentation. Eromanga Basin sediments crop out in places in the northeast of the study area (on the western and southern margins of the Eromanga Basin). The basin margin in South Australia is largely preservational, delineated by the limit of continuous outcrop of Mesozoic sediments (but minor outliers may be found beyond these limits), except where basin sediments onlap or are faulted against basement highs (e.g., Musgrave Province, Gawler Craton). Based on recent exploration targets, new depocentres for heavy minerals may exist on the onshore margin of the western Eromanga Basin, in paleovalleys developed during the Late Mesozoic (Krieg et al., 1995; Hou et al., 2007, 2012).

BASIN STRATIGRAPHY

The Eromanga Basin stratigraphy (Krieg et al., 1995) can be divided into three sequences - lower non-marine, middle marine, and upper non-marine (Fig. 2.5). In the Cooper region, the lower non-marine sequence consists of intertonguing braided fluvial sandstones (Hutton and Namur sandstones), lacustrine shoreface sandstone (McKinlay Member) and meandering fluvial, overbank and lacustrine sandstone, siltstone, shale and minor coal (Poolowanna, Birkhead and Murta formations). In the Poolowanna Trough, the Poolowanna Formation (up to 130 m thick) is overlain by a thick sand-dominated unit of Algebuckina Sandstone that is composed of fine- to coarse-grained quartzose sandstone with granule and pebble layers as well as shale intraclasts. West of the northern Birdsville Track Ridge, Birkhead and Murta formation's shales pinch out into Algebuckina Sandstone. Other thin, discontinuous occurrences of Algebuckina Sandstone and correlative clayey units, such as Birkhead Formation (mudstone and buff siltstone, fine- to medium-grained sandstone with thin, lenticular coal seams and thin silcretes and calcretes) and equivalents of the Namur Sandstone (fine- to coarse-grained sandstone with minor interbedded siltstone and mudstone deposited in a braided fluvial environment), extend southwest of the type section onto the Gawler Craton, southwards to Stuart Creek, and along the western margin of, and as outliers within, the northern Flinders Ranges. The Algebuckina Sandstone crops out on the western and southern basin margin.

The lower non-marine sequence is succeeded conformably by a sequence reflecting transition from non-marine to marginal marine to open marine shale and sandstone. The marine succession (also including some non-marine deposits near the base) represents the last great marine transgression onto the Australian continent; subsequent transgressions are pericontinental (Krieg et al., 1995). In ascending order, the sedimentary units are Cadna-owie Formation, Marree Subgroup and equivalents, and Mackunda Formation (Fig. 2.5).

The Cadna-owie Formation records the transition from terrestrial-freshwater to marine conditions; it is mainly a fine-grained unit that extends throughout the Eromanga Basin. Apart from quartz, the main mineral constituents of the Cadna-owie Formation are mica, fresh feldspar, heavy minerals, pyrite and glauconite (Krieg et al., 1995). The Cadna-owie Formation is typically 10–20 m thick in exposures around the basin margin, increasing to 75–100 m in the deeper parts of the basin (Moore and Pitt, 1985). Along the southwestern margin the Cadna-owie Formation is more continuous than, and in places overlaps, the Algebuckina Sandstone. The fluvial-deltaic Mount Anna Sandstone Member and the fluvial-tidal Trinity Well Sandstone Member have been identified near the top of the unit along the southwestern and southern margins of the basin, respectively (Krieg et al., 1995). The Parabarana Sandstone and Pelican Well Formation are the equivalents of to the Cadna-owie Formation occurring on the southern margin (Fig. 2.5).

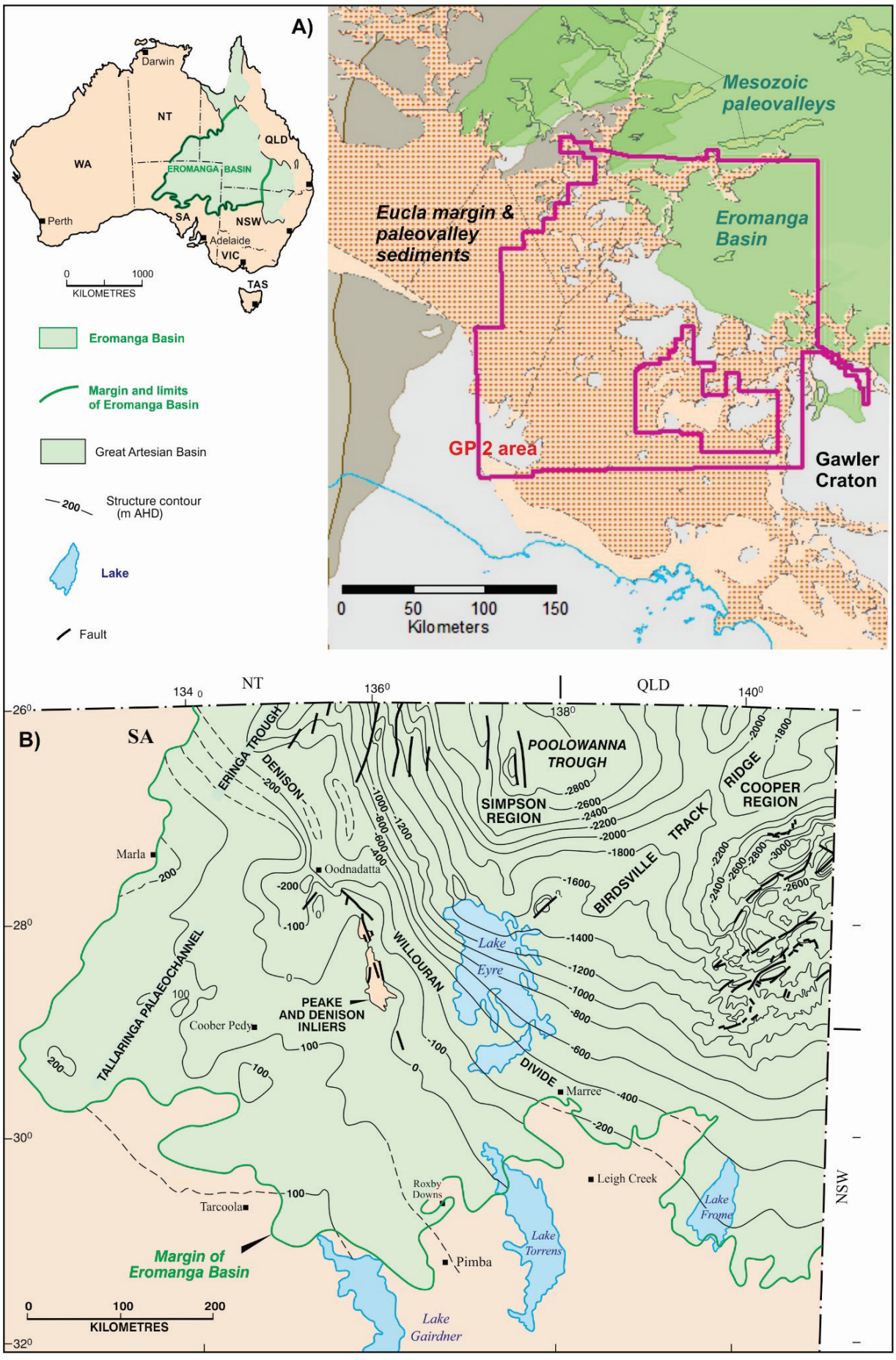


Figure 2.4 A) Mesozoic depression map in the study area showing components of Eromanga and Eucla basins; B) Eromanga Basin in South Australia portion (modified from Krieg et al., 1995).

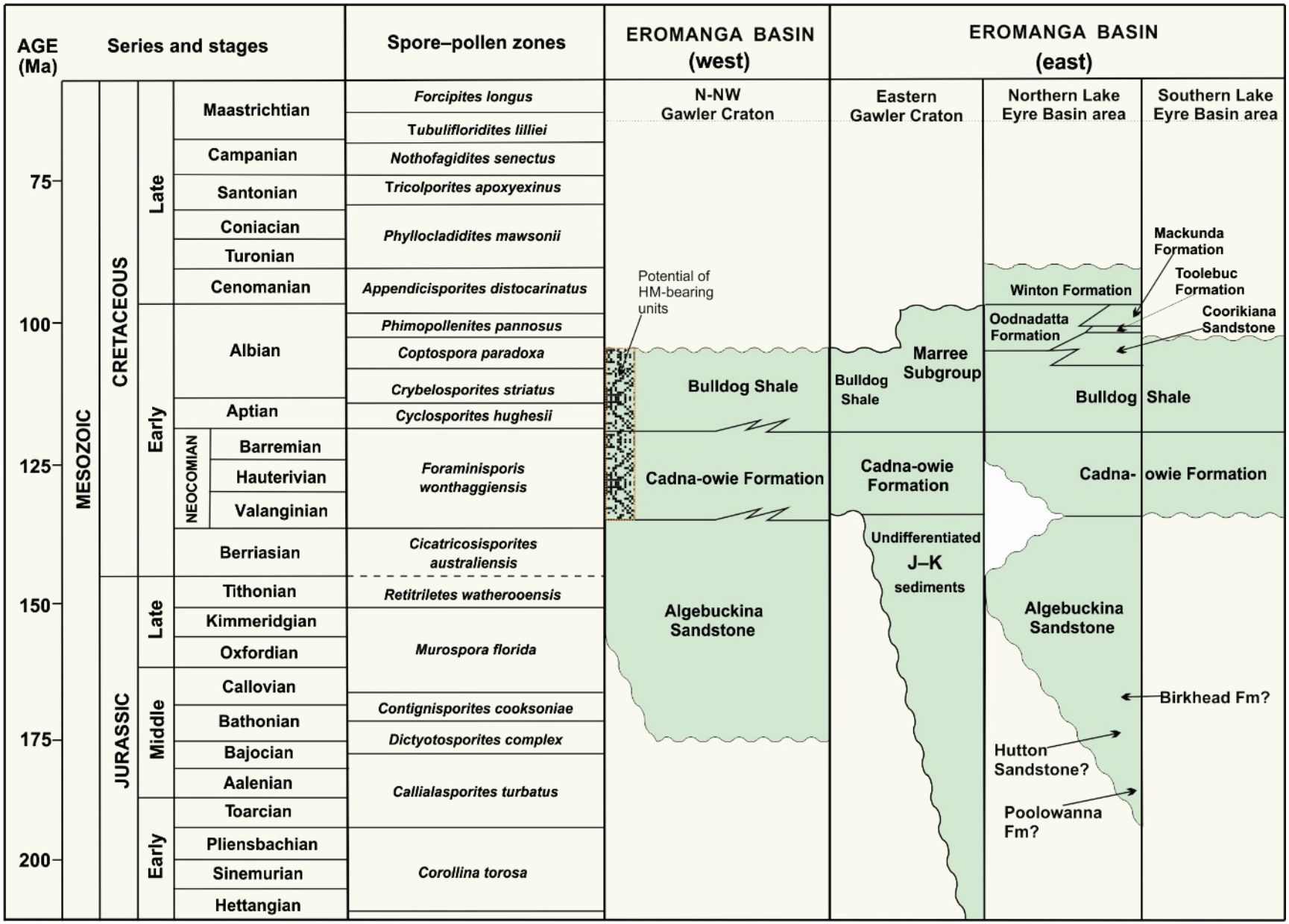


Figure 2.5 Stratigraphic chart of the Eromanga Basin (modified from Krieg et al., 1995; Hou et al., 2012; from Hou et al., 2021).

The marine shaley interval of the Eromanga Basin in South Australia comprises, in ascending order, the Bulldog Shale, Coorikiana Sandstone and Oodnadatta Formation of the Marree Subgroup (Fig. 2.5). The Bulldog Shale is a grey marine mudstone which locally includes the basal pebbly Wilpoorinna Breccia Member around the basin margin (Krieg et al., 1995). Its maximum known thickness is ~340 m in northeastern South Australia (Moore, 1986), but it thins to <200 m in the Oodnadatta and Marree regions in the exposed reference sections. Along the western basin margin, the Bulldog Shale includes several horizons, generally up to 5 m thick, of very fine to fine-grained sandstone with thin, planar bedding, small-scale cross-bedding, hummocky cross-stratification and bioturbation.

Along the southwestern margin of the Eromanga Basin, the Bulldog Shale is conformably overlain by Coorikiana Sandstone. This unit is exposed discontinuously between the South Australia-Northern Territory border and the Marree area, where Forbes (1966) named the unit the Attraction Hill Sandstone Member of the Marree Formation. The Coorikiana Sandstone passes laterally basinwards into marine shale of the upper Wallumbilla Formation.

The Oodnadatta Formation (<300 m), consisting of laminated and thin-bedded claystone and siltstone with interbeds of fine-grained sandstone, calcareous and ferruginous concretions, limestone, and celestite/barite veins, was deposited in a low-energy, shallow marine environment. The Toolebuc Formation consists of laminated black, carbonaceous, clayey mudstone with fish remains, dark grey, calcareous, clayey mudstone or coquinite with abundant *Inoceramus* shells and laminated dark grey, clayey mudstone (Moore et al., 1986). The Toolebuc Formation usually occurs where the Coorikiana Sandstone is absent. A sandy, regressive marine unit of the Mackunda Formation conformably overlies the Oodnadatta Formation and Allaru Mudstone (Vine and Day, 1965). In the southwestern Eromanga Basin, the Mackunda Formation comprises ~100 m of interbedded, partly calcareous sandstone, siltstone and shale (Moore and Pitt, 1985). Mackunda Formation (in Clayton 3) includes three shoreface sand units with basal erosive contacts, and two transgressive mudstone units (Kwitko, 1986).

The upper non-marine sequence (Winton Formation) was rapidly deposited — up to 1100 m over ~8 million years. The Winton Formation and Mount Howie Sandstone represent a final, non-marine phase of deposition in the Eromanga Basin. The Winton Formation (Whitehouse, 1955) is a sequence of non-marine shale, siltstone and sandstone, with minor coal layers, which reaches a maximum thickness of ~1200 m in the Patchawarra Trough (Moore and Pitt, 1985). The localised younger fluvial channel infills of Mount Howie Sandstone and equivalents consist of up to 45 m of large-scale cross-bedded, medium to coarse-grained quartz sandstone interbedded with shale and shale conglomerate. The upper non-marine sequence is usually overlain by thick Cenozoic sediments, A period of erosion in the Late Cretaceous, caused by a switch in drainage from the Cooper region to the Ceduna Depocentre on the rifted southern margin, was followed by deposition of non-marine sediments in the Cenozoic Lake Eyre Basin. The sand fraction of the Winton Formation contains a significant proportion of feldspar and ferromagnesian minerals, which were probably derived from a volcanic source.

MESOZOIC PALEOSHORELINES

The Cadna-owie Formation was deposited in the coastal regions of the Early Cretaceous ‘Eromanga’ sea and represents a variety of marginal-marine to non-marine environments associated with the transgressive front and adjacent coastland. The consistent thickness and lithological uniformity of the unit in the central part of the basin suggest a steady advance of the sea across a fairly uniform landscape, but the hiatuses (Dettmann and Williams, 1985; Alley, 1985, 1987) and rapid lithological changes around the basin margin indicate an irregularly advancing, perhaps oscillating, shoreline. Extended periods of stillstand were likely. Mild tectonism (Wopfner et al., 1970) superimposed on the eustatically induced transgression may have had a major effect on coastline configuration and local shoreline history (Krieg et al., 1995).

Particular depositional environments interpreted for the Cadna-owie Formation around the basin margin include near offshore or outer shoreface (hummocky cross-stratification), inner shoreface to foreshore (ripple marks, fine cross-lamination, minor bioturbation), shallow agitated waters of a

marine shoal or lagoonal shoreline (oolitic sandstone), intertidal (tidal bundle sequences), high-gradient gravelly beach (talus and swash zone lag deposits representing the depositional edge of the unit), back barrier lagoon or coastal marsh (fine-grained, pyritic and carbonaceous deposits) and fluvial (Mount Anna Sandstone). From the deeper part of the basin, a lacustrine environment passed up to paralic then to shoreface and beach for the Cadna-owie Formation (Moore and Pitt, 1985). During this time the climate was very seasonal and the winters cold enough to allow rivers and basin shorelines to freeze (Frakes and Francis, 1988). Diamictite deposit near the southern shoreline is ascribed by Alley and Frakes to a minor glacial episode (Alley and Frakes, 2003).

Fluvial to deltaic sandstone of the Mount Anna Sandstone Member was sourced from part of the Gawler Ranges Volcanic Province (Krieg et al., 1995). Large, high-energy streams transported abundant coarse detritus, notably porphyritic rhyolite and dacite clasts, north-eastwards to the coastline and built deltas into the sea. Near the source area, deltas were river-dominated as indicated by the abundance of plant remains (e.g., Ambrose and Flint, 1981) but deltaic tide-dominated environments may be represented by the Trinity Well Sandstone Member and Parabarana Sandstone.

The depositional environments described above were replaced in the early Aptian by a major marine transgression that set the conditions for the next cycle of sedimentation. The Bulldog Shale is a shelf mud unit deposited from suspension in an epicontinental sea. However, the sandy units of the Bulldog Shale along the western basin margin are interpreted as storm-related deposits (Krieg et al., 1995), which is favourable depositional environment for concentrating Heavy Mineral Sands (HMS). The regressive shoreface deposits of the Coorikiana Sandstone mark a eustatic sea-level fall in the Eromanga Basin in middle Albian (Morgan, 1980a).

The Toolebuc Formation was deposited during the highstand of a marine transgression that followed the middle Albian (Coorikiana) regression (Morgan, 1980a, b). A relative sea-level fall occurred after the Toolebuc transgression, and this is reflected in microplankton frequencies which show an upward decline in the Oodnadatta Formation (e.g., Morgan, 1980a). Apart from the Toolebuc transgression, it is likely that relative sea level during Oodnadatta time was generally lower than for the earlier transgressive phase of the Bulldog Shale. Evidence of a shallower sea in the middle to late Albian is provided by paleogeographic studies (Frakes et al., 1987), and by the higher proportion of silt and sand present in the Oodnadatta Formation.

Alternating shoreface sand, subtidal sand and mud, and marine mudstone of the Mackunda Formation indicate that several cycles of regression and transgression occurred during deposition of the Mackunda Formation. The regressive-transgressive cycles are superimposed on a general sea-level falling trend during Mackunda time, represented by the transition from marine Oodnadatta Formation and Allaru Mudstone to freshwater Winton Formation. The Winton Formation was deposited in a low-energy fluvial to lacustrine environment consisting of meandering streams on broad flood plains dominated by lakes and marshes. Coal seams and associated highly carbonaceous clays resulted from the accumulation of plant matter in swamps and lakes. Carbonate layers may have been deposited in response to lacustrine plant growth and dolomitised subsequently by magnesium-rich groundwater (Krieg et al., 1995). Active volcanoes in eastern Australia are thought to have contributed the volcanic component of the Winton Formation (Krieg et al., 1995).

Uplift of the Eromanga Basin region, combined with a rapid influx of sediment, resulted in withdrawal of the sea at the beginning of the Cenomanian, at a time when global sea level was rising to a maximum (Haq et al., 1987). However, in central parts of the basin, rates of subsidence and sediment accumulation appear to have increased during deposition of the Winton Formation, and considerable thicknesses occur in troughs which were actively subsiding during Late Cretaceous time. Uplift at the end of the Cenomanian caused a change in depositional regime from a widespread, low-energy, fluvial-lacustrine environment (Winton Formation) to localised, high energy, fluvial channels (Mount Howie Sandstone and equivalents). Erosion of the Winton Formation provided a source for fine-grained sediment and shale clasts in the Mount Howie Sandstone, while the coarser sand fraction was probably reworked from older Mesozoic units (e.g., Algebuckina Sandstone) exposed on the basin margin.

MESOZOIC UNITS RELATED TO HEAVY MINERALS SANDS AND POTENTIAL UNDISCOVERED RESOURCES

The shoreface, barrier and beach facies of the Cadna-owie Formation are the potential units hosting HMS. The sandy units of the Bulldog Shale along the western basin margin are also interpreted as storm-related (Krieg et al., 1995), again a favourable depositional environment for concentrating HM. Therefore, in the three packages of the Eromanga Basin stratigraphic sequences (i.e., lower non-marine, marine and upper non-marine; Fig. 2.5), HMS exploration effort should be focussed on the marginal marine facies of the transitional zones between the marine and non-marine sequences.

HMS exploration in the Eromanga Basin deposits in South Australia has historically a sparse record. Therefore, undiscovered HMS resources in this area are best estimated using methods that extrapolate discovery trends, for instance, areas to the west have already had HMS exploration effort (e.g., Diatreme, 2009). HMS found there, like those of the eastern Eucla Basin, are probably sourced from the nearby Musgrave Province, Officer Basin and/or the Gawler Ranges Volcanic Province.

In the western Eromanga Basin, new HMS discoveries are possible, particularly in areas overlying the older intracratonic basins (Pedirka and Simpson basins), but it is unlikely that HMS discoveries in this area would be economic as they would be relatively small. For a commercial discover of a HMS deposit in the western Eromanga Basin three essential components are required: 1) HMS sources; 2) high energy shorelines; 3) host horizons and geomorphological traps that will concentrate the HMS in economic quantities. When all three of these occur together, the potential for an HMS exploration target exists (Hou et al., 2021).

Eucla Basin and associated paleovalleys – Paleogene-Neogene

The Cenozoic Eucla Basin is a large onshore-offshore basin on the southern Australian passive margin adjoining the Yilgarn (WA) and Gawler (SA) cratons and Albany Fraser Province (WA). It is separated from the Musgrave Province to the north by the Officer Basin (Fig. 2.6). The study area is located in the eastern onshore part of the basin where the Paleogene to Neogene paleovalley sediments unconformably overlie older cover and basement rocks (Clarke et al., 2003; Hou et al., 2008). The present landscape of this part of Eucla Basin and its associated paleovalley system is dominated by extensive tracts of Quaternary deposits largely superimposed on the Paleogene to Neogene morphology, but the excellent preservation of the paleomorphology is still evident from regional topographic data and from satellite images (Figs 2.7, 2.8 and 2.9).

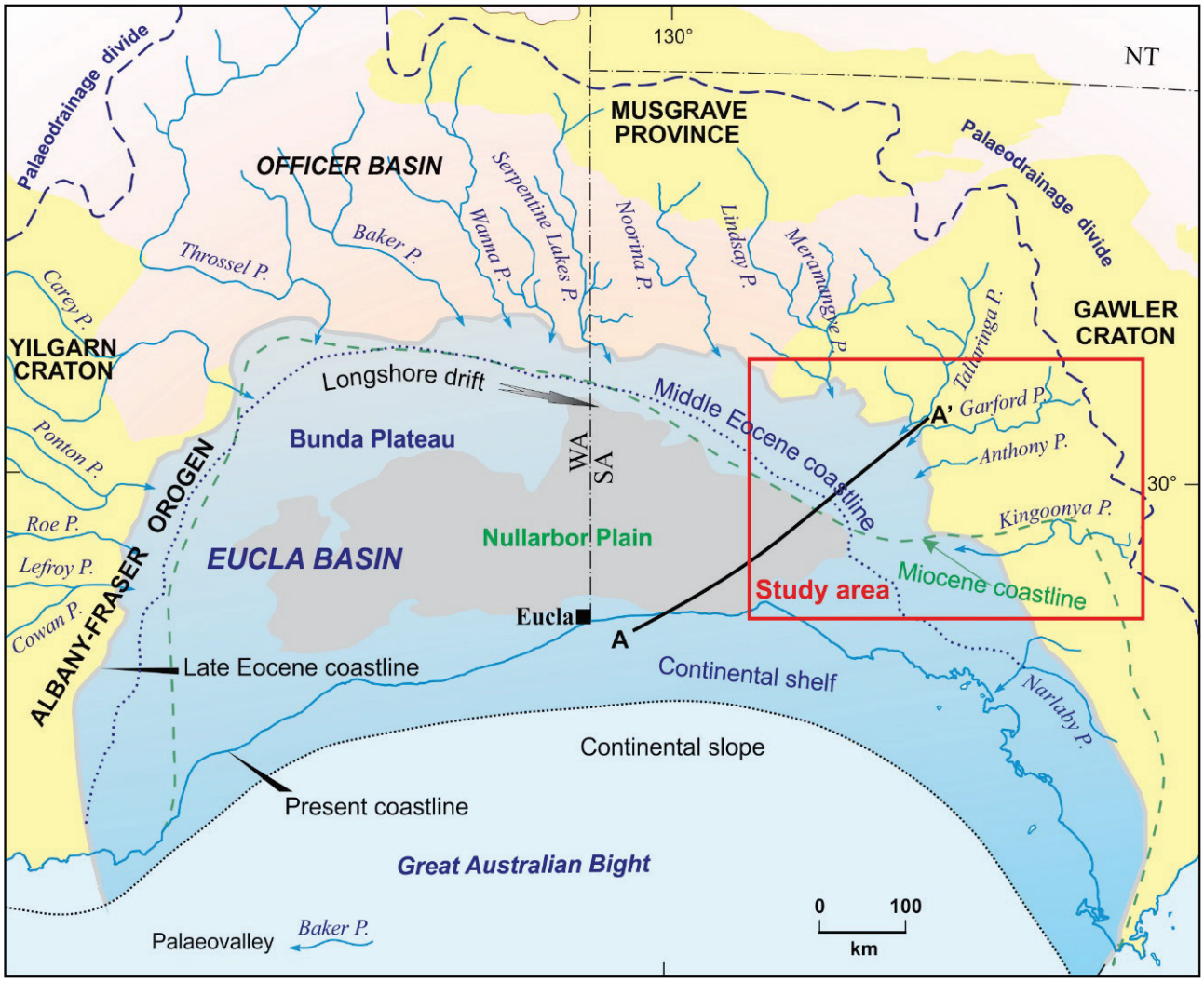


Figure 2.6 Eucla Basin of southern Australia, showing the geological relationships with surrounding highlands (cratons and older basin), Cenozoic coastlines and their approximate ages, paleovalleys and adjacent major features (from Hou et al., 2021). Cross section A-A' shown in Fig. 2.10.

Sediments of the eastern Eucla Basin were deposited unconformably over the pre-Paleogene landscape, including the Precambrian basement of the Gawler Craton, Neoproterozoic - Paleozoic (e.g., Officer Basin and Arckaringa Basin) and Mesozoic (e.g., Eromanga Basin) cover (Figs 2.1 and 2.10).

The eastern Eucla Basin contains remarkably well-preserved Cenozoic coastal barrier island features and peripheral paleovalley systems. Prolonged weathering of a generally subdued and tectonically stable landscape during much of the arid Neogene concentrated iron oxides and silica in hard layers forming ferricrete and silcrete within the near-surface portions of exposed rocks at various times. It is the extreme resistance to erosion of these indurated regolith materials that has given rise to the plateaus, mesas and breakaways typical of the landscape. The Paleogene and Neogene deposits contain important groundwater, coal, uranium, extractive, and industrial mineral resources.

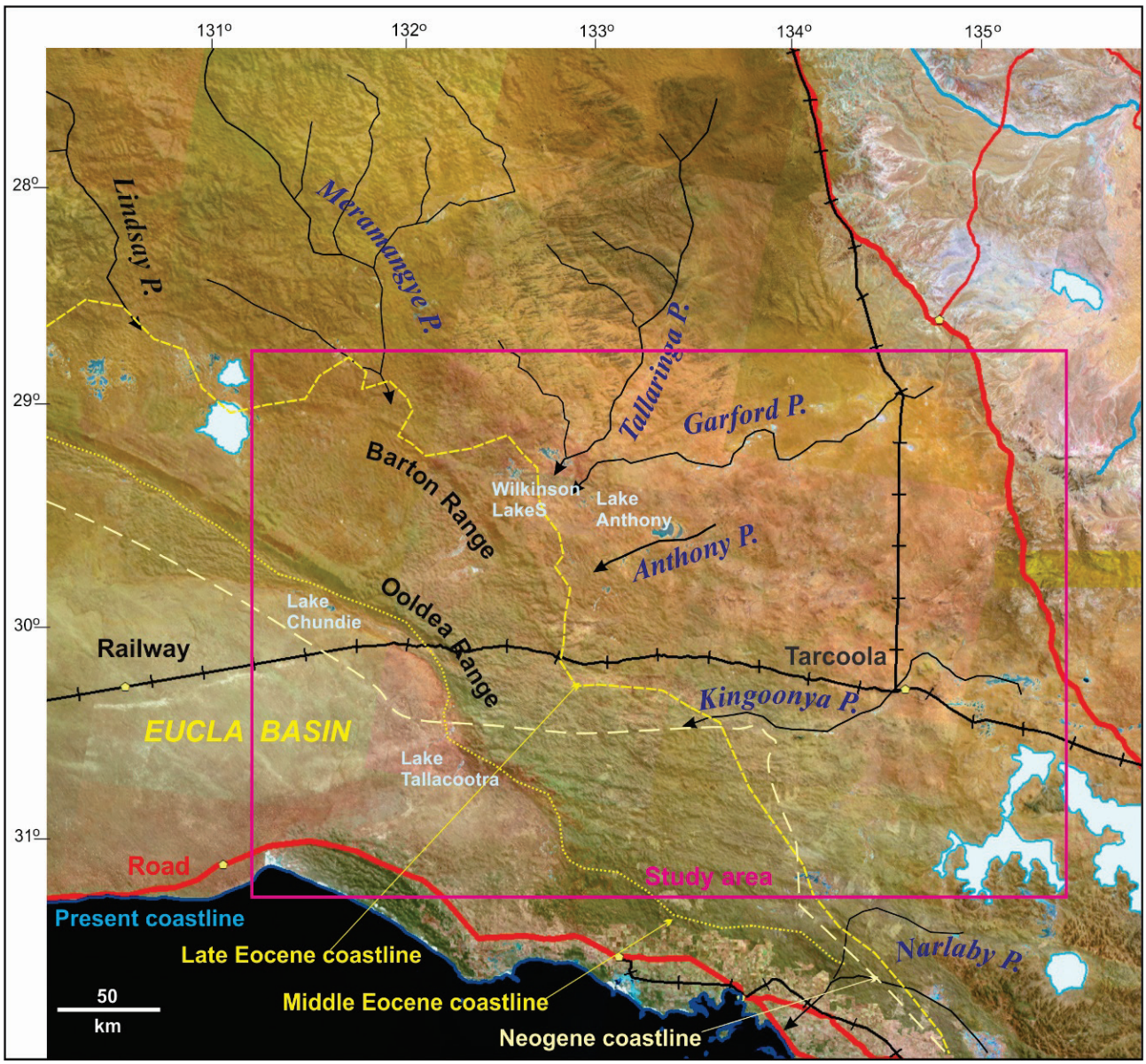


Figure 2.7 Landsat ETM7 imagery of the eastern Eucla Basin, showing location of major paleovalleys and shorelines of varying age superimposed on today's landscape (modified from Hou et al., 2021). Note that many of the Cenozoic landscape features of the Eucla Basin are still present on today's landscape.

The geologic-geomorphic evolution of the eastern Eucla Basin is summarised as below:

- The subsidence of irregular eastern basin areas (including paleovalleys) probably commenced during Late Cretaceous time with terrestrial and shallow marine sediments accumulated, the deposition and downwarping recommenced in the Eocene.
- Eocene downwarping and sedimentation within the basin and peripheral paleovalleys developed until the Eocene sea retreated and weathering and erosion recommenced.
- Early Miocene marine transgression followed, due probably to further downwarping of the central Eucla Basin.
- Middle to Late Miocene downwarping and sedimentation within the Eucla Basin and peripheral paleovalleys developed until the Miocene sea retreated and weathering and erosion recommenced.
- Pliocene sedimentation in places of the eastern Eucla margin and peripheral paleovalleys developed until the Pliocene sea retreated and weathering and erosion recommenced.
- Late Cenozoic weathering, erosion, in-situ regolith development and landscape evolution.

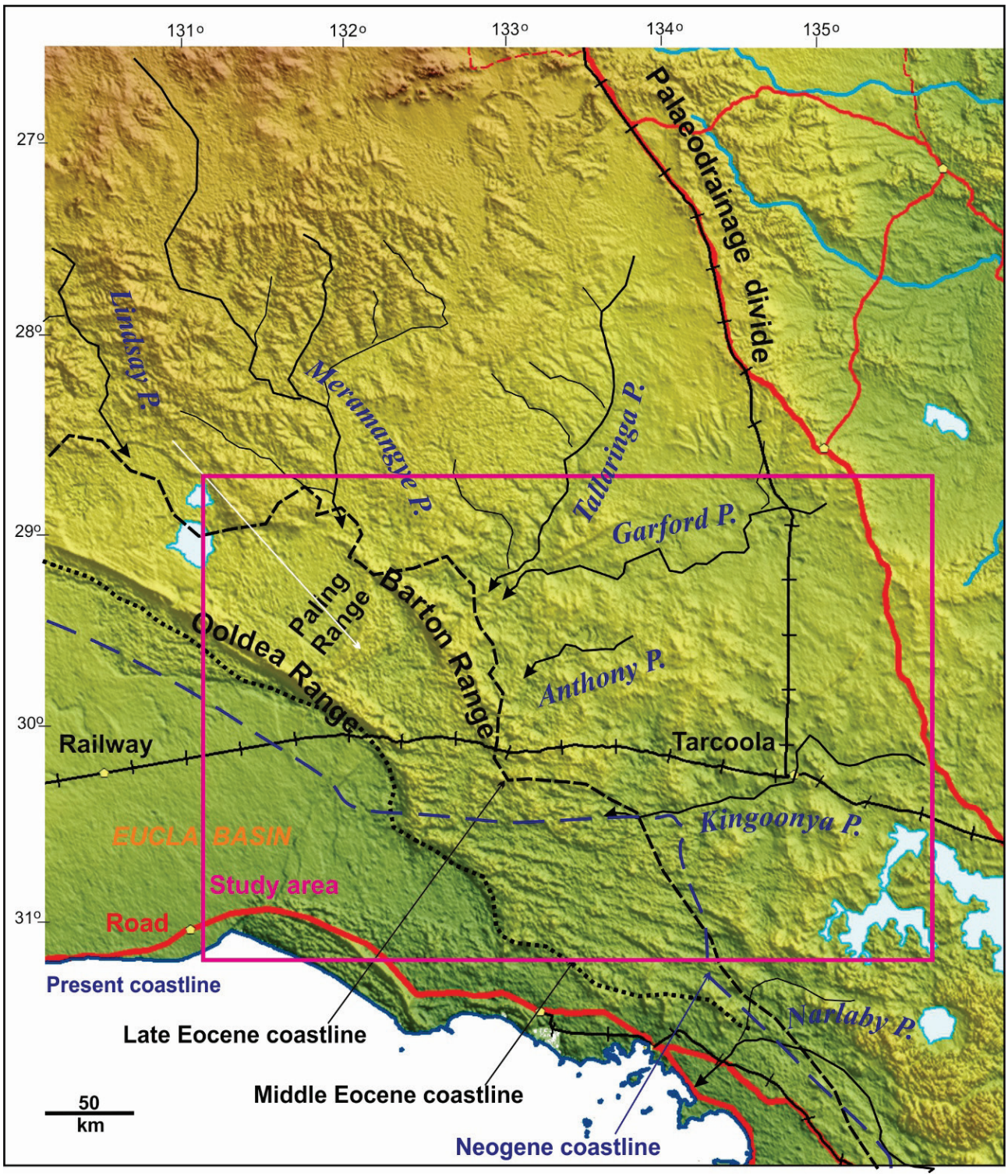
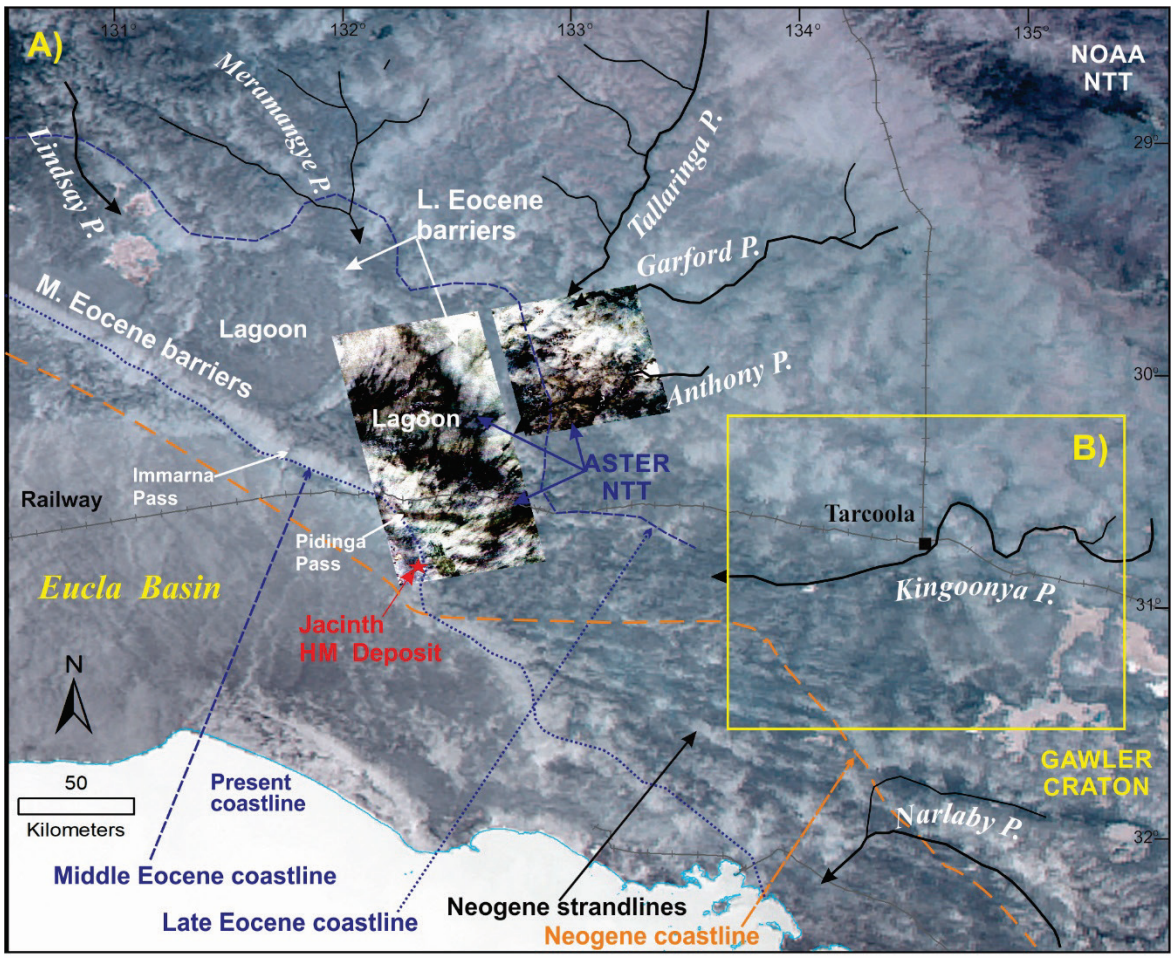


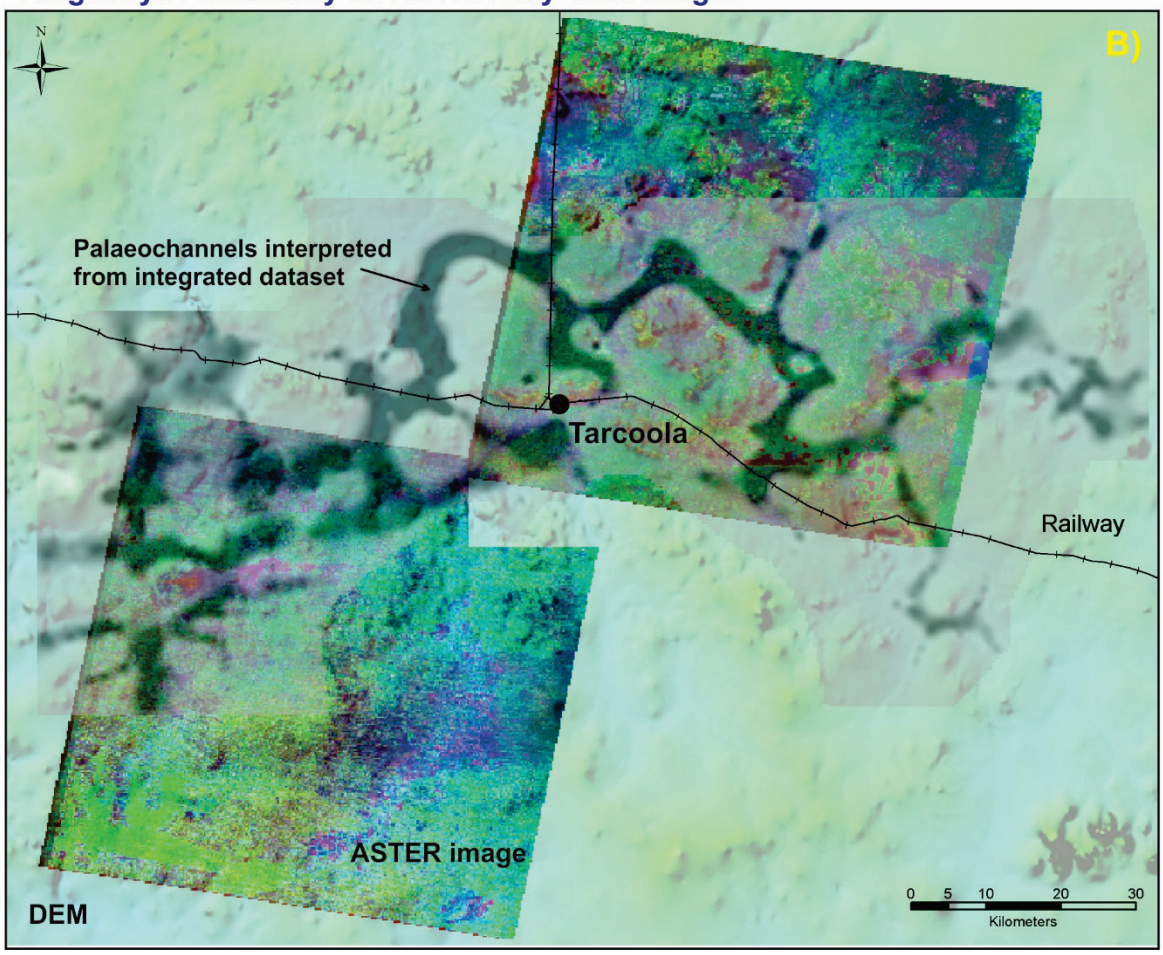
Figure 2.8 SRTM 1 second DEM imagery of the eastern Eucla Basin, showing major paleovalleys and shorelines of varying age (modified from Hou et al., 2021).

Next page:

Figure 2.9 Comparison of A) NOAA-AVHRR (1.1 km pixel), ASTER Night-Time Thermal (NTT) (90 m Pixel) and B) ASTER Day-Time (30 m Pixel) images, showing eastern onshore Eucla Basin, major paleovalleys and shorelines of varying age; the textural difference between paleovalleys (dark tone) and the sand barriers (light tone) is apparent (modified from Hou et al., 2011b and 2021). Note: in mapping the subsurface components (e.g., paleochannels and sandy barriers), both NOAA and ASTER NTT images are much better than the satellite Day-Time images (e.g., Landsat and DEM in Figures 2.7 and 2.8 as well as ASTER DT images, even though has higher resolution).



Kingoonya Paleovalley on ASTER Day Time Images



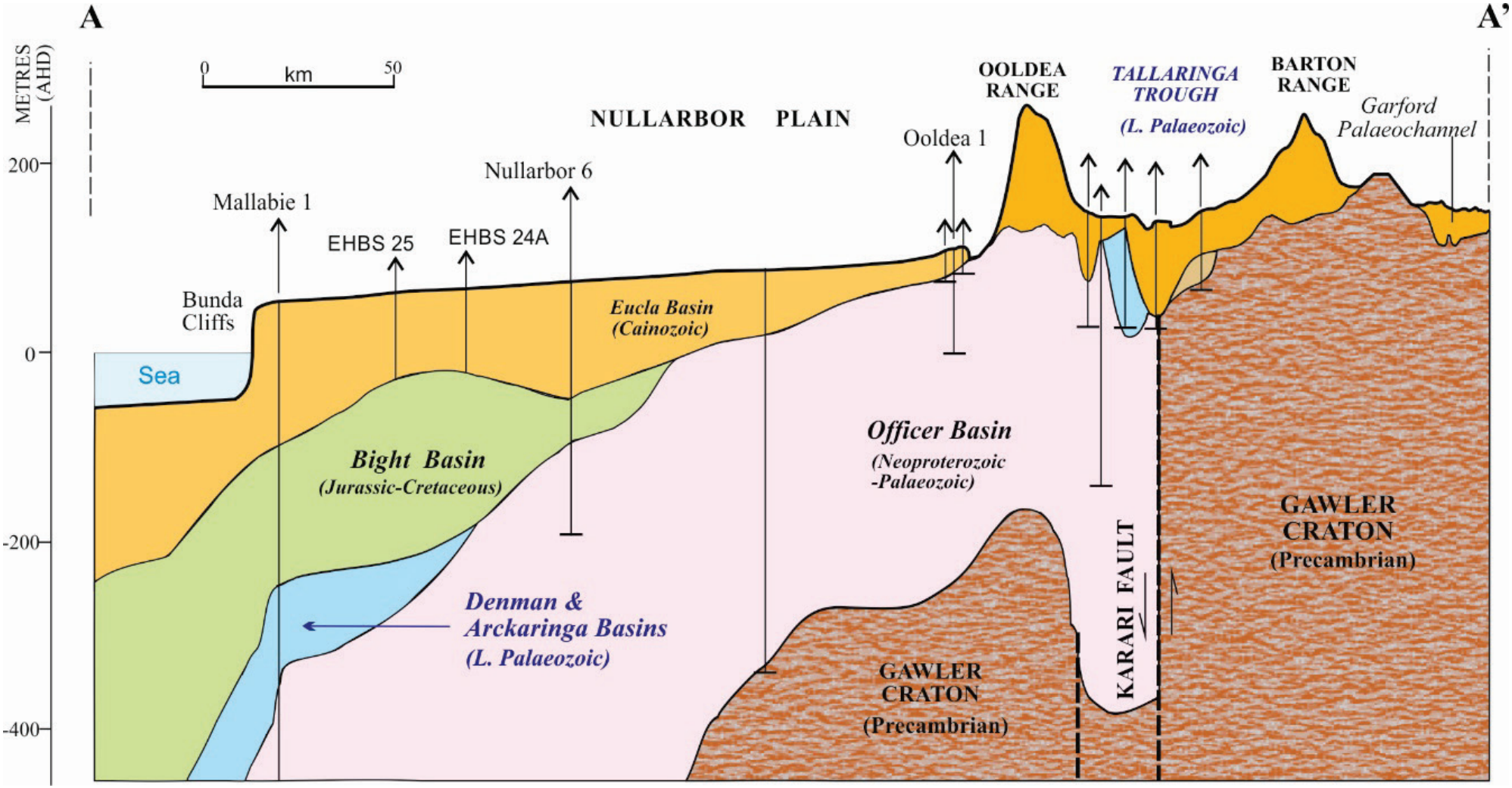


Figure 2.10 Cross-section through the eastern onshore area of the Eucla Basin, showing geologic relationships with underlain cratonic and bedrock geologies; location of the cross-section indicated in Figure 2.6 (modified from Hou et al., 2022).

BASIN STRATIGRAPHY AND LITHOLOGIES

The principal stratigraphic units of the eastern Eucla Basin and their relationship are shown on Figures 2.11 and 2.12. During the Paleogene-Neogene, the eastern Eucla Basin was largely a marine carbonate platform with inner margins dominated by terrigenous clastics. The marine sediments (mainly carbonates) of the Eucla Group are predominant over the central part of the basin, while the mainly terrigenous sediments of the Immarna Group are extensive around the eastern coastal plain and extend landward into the paleovalleys through estuaries (Benbow et al., 1995a).

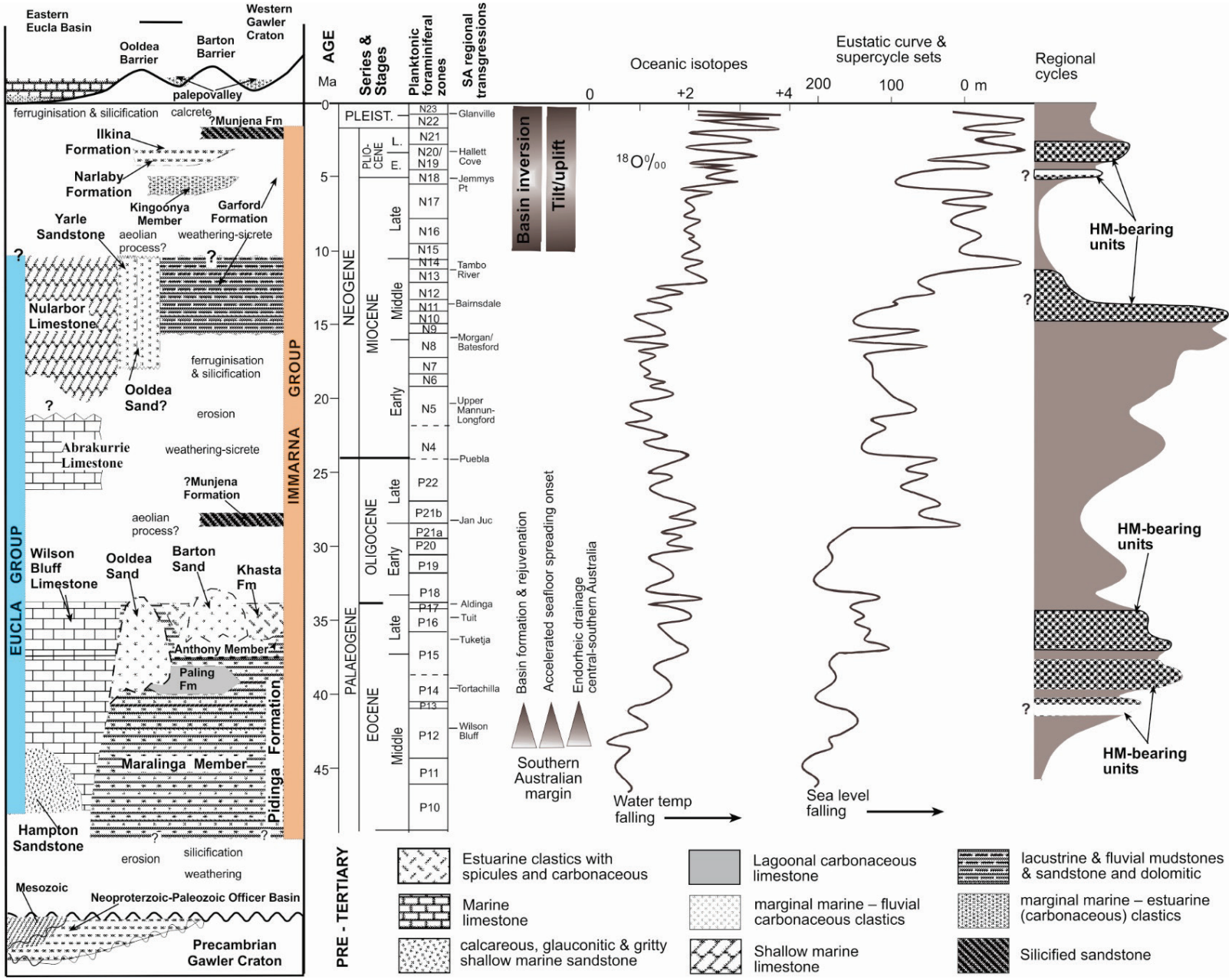
The Hampton Sandstone, mainly developed as a lensoid to sheet-like marine layer in the central basin, comprises very fine- to coarse-grained sand and grit and is partly clayey at the base and glauconitic and fossiliferous at the top, where it is overlain by Wilson Bluff Limestone (Lowry, 1970; Benbow, 1990a). The Middle Eocene to latest Eocene Wilson Bluff Limestone is a temperate water bryozoan limestone that formed during the Middle and Late Eocene (Singleton, 1954; McWhae et al., 1958). In the northeast of the study area, there are stratigraphically equivalent occurrences, such as the Paling Formation (Fig. 2.11). In the central basin, the Abrakurrie Limestone occurs stratigraphically and disconformably between the underlying Middle – Late Eocene Wilson Bluff Limestone and the overlying Early – Middle Miocene Nullarbor Limestone (Lowry, 1968a, 1970; Li et al., 1996; James et al., 2006), which do not occur in the study area.

The Nullarbor Limestone (Ludbrook, 1958; Lowry, 1970) is mostly a bioclastic and micritic limestone (grey or yellow hard indurated calcarenite, algal limestone) deposited over much of the emergent Eucla Basin, with the Ooldea Range acting as a barrier (Figs 2.7, 2.8 and 2.10), separating marine deposition on the platform from extensive lacustrine sedimentation inland in the eastern basin (Fig. 2.12) (Benbow, et al., 1995a). Around the eastern margin of the Nullarbor Plain (Figs 2.6 and 2.10), the Nullarbor Limestone unconformably overlies the Eocene sediments (Pidinga, Khasta and Wilson Bluff formations respectively) of the paleovalleys and of the margin of the Eucla Basin, but also older bedrock and crystalline basement. The Nullarbor Limestone is the youngest of the marine limestones of the Eucla Basin, and it is overlain by a variety of soils, dunes, and other Quaternary deposits.

The Immarna Group, deposited in the eastern margin of the Eucla Basin, includes marginal and non-marine costal and channel sediments (Fig. 2.12).

Next page:

Figure 2.11 Stratigraphic correlation chart and inferred depositional environments in the eastern Eucla Basin and associated paleodrainage system (modified from Hou et al., 2011b). Planktonic foraminiferal zones (Taylor, 1983, 1986; McGowran et al.,1997), regional transgressions (McGowran et al.,1997), tectonic events in southern Australia (Li et al., 2004), oceanic oxygen-isotopic cycles (Abreu et al., 1998), eustatic supercycle sets (Haq et al., 1987, 1988), and local cycles (McGowran et al., 2004) in relation to age of HMS-bearing units are shown. Modified from Hou et al. (2008, 2011b).


Eastern Eucla Basin
Western Gawler Craton
Ooldea Barrier
Barton Barrier
palepovalley
ferruginisation & silicification
calcrete
?Munjena Fm
Ilkina Formation
Narlaby Formation
Kingoonya Member
Garford Formation
Yarle Sandstone
aeolian process?
weathering-sicrete
Nularbor Limestone
ferruginisation & silicification
Ooldea Sand?
erosion
Abrakurrie Limestone
weathering-sicrete
?Munjena Formation
aeolian process?
Wilson Bluff Limestone
Ooldea Sand
Barton Sand
Khasta Fm
Anthony Member
Paling Fm
Maralinga Member
Pidinga Formation
Hampton Sandstone
erosion
silicification
weathering
Mesozoic
Neoproterzoic-Paleozoic Officer Basin
Precambrian Gawler Craton
EUCLA GROUP
IMMARNA GROUP
AGE
Ma
Series & Stages
Planktonic foraminiferal zones
SA regional transgressions
PLEIST.
PLIO-CENE
NEOGENE
MIOCENE
OLIGOCENE
EOCENE
PALAEOGENE
Glanville
Hallett Cove
Jemmys Pt
Tambo River
Bairnsdale
Morgan/ Batesford
Upper Mannun-Longford
Puebla
Jan Juc
Aldinga
Tuit
Tuketja
Tortachilla
Wilson Bluff
Basin inversion
Tilt/uplift
Basin formation & rejuvenation
Accelerated seafloor spreading onset
Endorheic drainage central-southern Australia
Southern Australian margin
Oceanic isotopes
18O‰
Water temp falling
Eustatic curve & supercycle sets
Sea level falling
Regional cycles
HM-bearing units
HM-bearing units
HM-bearing units
PRE - TERTIARY
Estuarine clastics with spicules and carbonaceous
Marine limestone
calcareous, glauconitic & gritty shallow marine sandstone
Lagoonal carbonaceous limestone
marginal marine – fluvial carbonaceous clastics
Shallow marine limestone
lacustrine & fluvial mudstones & sandstone and dolomitic
marginal marine – estuarine (carbonaceous) clastics
Silicified sandstone

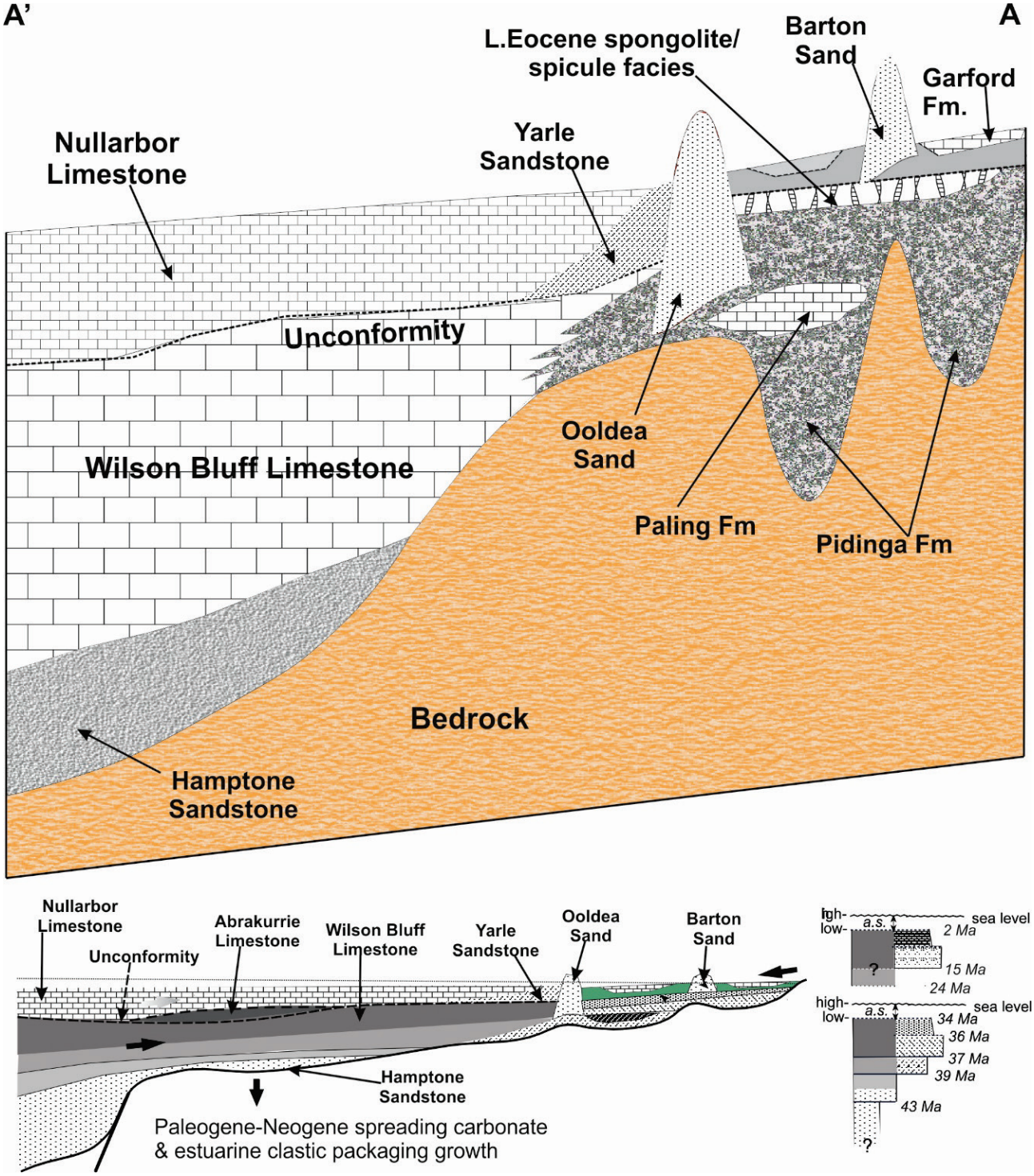


Figure 2.12 Schematic stratigraphic diagram and cross section showing stratigraphical relationships across the eastern Eucla Basin and adjacent onshore sediments in marginal marine and paleovalley settings. A schematic interpreted relationship between marine carbonate deposition and the extent of marginal marine carbonate and clastic equivalents over time is summarised in the inset diagram (modified from Hou et al., 2008). The location of the cross-section is indicated in Figure 2.6.

The Pidinga Formation, averaging 30–60 m in thickness, comprises marginal marine and non-marine lignitic and pyritic sands, clays, silts and lignite deposited during reactivation of paleorivers. The basal and lower part of the Pidinga Formation, particularly in the paleovalleys, consists of gravels and sands which fine upward into carbonaceous sediments. Color varies from pale grey to white where clean, to pale to dark brown and black carbonaceous sediments, which are occasionally bleached white. The reduced carbonaceous sediments are interbedded with oxidised

sediments in places (e.g., in the Barton region and Ooldea Range to the west, as in cored SADME Ooldea Range-6, eastern Eucla margin). Carbonaceous sediments and lignite may make up a minor but significant part of the sequence, occurring as single thin beds to stacked beds over 40 m thick in places. Oxidation is evidenced by orange to yellow-brown iron oxide staining on quartz and clays. Quartz is the major detrital component (generally >90%) and other minor minerals include muscovite, feldspar and polymineralic grains with carbonised wood and leaf remains, particularly in the carbonaceous sediments.

The Pidinga Formation displays a range of common sedimentary structures, including bi-directional cross-bedding, wavy cross-bedding and lamination in the tidal influenced channel sediments, but dominantly is massive in the fluvial sediments (Hou et al., 2001a). The degree of rounding varies generally from poor, particularly in areas of crystalline basement and at the base, trending to good, up through the sequence. Upward fining cycles can be recognised and these may be capped by carbonaceous mud (common) or clay (less common). Boundaries of sand overlying clay (e.g., the outcrop in the Ifould Lake area, eastern Eucla margin) and carbonaceous muds (e.g., in drillholes OR 6, WL2, WL15, WL23, WL38, WL43, CRAE4, CRAE8, LBR17 AND WILKINSON1, see Figs 3.13–3.17 in Chapter 3) are usually sharp, indicating clearly erosional conditions.

The Pidinga Formation is widespread along the eastern Eucla margin, particularly in the study area (e.g., Wilkinson Lakes region and the regions between the Ooldea and Barton Ranges and between Lake Tallacootra and Chundie swamps) is up to 100 m thick and 40 km wide and infills most paleovalleys in the eastern onshore part of the basin (e.g., Narleby, Kingoonya, Anthony, Garford, Tallaringa, Meramangye paleovalleys; Fig. 2.7). The deposits of the Pidigna Formation occur upstream at least up to 350 km inland from the present-day coast. The channel width of the Pidinga Formation infills averages between 2.5 and 5 km (Hou et al., 2001a).

In the study area the Pidinga Formation unconformably overlies Archean to Middle Proterozoic crystalline basement and locally sedimentary rocks of Neoproterozoic–Paleozoic or Mesozoic age (Figs. 2.1 and 2.12). Towards the west of the study area, the formation intertongues with the basal part of the overlying Wilson Bluff Limestone (zone P14/P15 age), where the youngest part (of latest Eocene age) of the Pidinga Formation intertongues with the Wilson Bluff Limestone and is overlain uncomformably by the Nullarbor Limestone. In the study area, the Pidinga Formation may be interbedded with the Khasta Formation or Paling Formation and is overlain by the Garford Formation. Along the eastern margin of the Eucla Basin, marginal marine sands of the Pidinga Formation were found to contain heavy mineral concentrations (Benbow, 1990b).

Between the Ooldea and Barton ranges, the Pidinga Formation is divided into an upper and lower member by the Ooldea Sand and the correlative Paling Formation (if present; Figs. 2.11 and 2.12). The lower Pidinga Formation, and its correlative Maralinga Member of the Pidinga Formation (Zone P14 in Fig. 2.11) along the eastern margin, is the principal basal Paleogene sequence, locally unconformably overlying and onlapping onto Cretaceous and older sediments, and also Precambrian crystalline basement (Fig. 2.11). At Tietkins Well, to the northwest of the study area, the lower Pidinga Formation intertongues with the basal part of the overlying Wilson Bluff Limestone (Zone P14/15 in Fig. 2.11) and passes laterally (northwards) into the basal sand equivalents of the paleovalley fills (Benbow et al., 1995a). Massive to locally laminated, poorly sorted carbonaceous (gravelly) sands, clays, and (sandy/clayey) lignites, generally make up much of the carbonaceous sediments of the lower Pidinga Formation.

The Maralinga Member occurs entirely in the subsurface, and the type section is from drillhole CRAE-RCH 2 (in the study area, 98 m thick, extending from 35 to 133 m below surface; see Fig. 2.13). The upper contact of the Maralinga Member is gradational into the calcareous Paling Formation, where present, or else truncated by a disconformity, and the basal contact unconformably overlies older sediments or crystalline basement (Clarke et al., 2003).

The upper Pidinga Formation (Zone P16/17), and its correlative Anthony Member on the eastern margin, intertongues with the correlative facies (Paling Formation) of the Wilson Bluff Limestone. It is overlain disconformably and may be interbedded with the Khasta Formation (Figs 2.11 and 2.12; Clarke et al., 2003; Hou et al., 2003a, b, c, and 2006b). The Anthony Member lacks fluvial gravels

and coarser sands and consists of estuarine channel sediments. Relatively well-sorted carbonaceous sand units with clays, and (sandy/clayey) lignites, with black, carbonised wood and leaf fragments, are dominant in the upper Pidinga Formation (Hou et al., 2003a).

To the west of the study area, isolated occurrences of a thin sandy glauconitic and carbonaceous limestone, a marginal equivalent of the Wilson Bluff Limestone, named the Paling Formation, conformably overlies and is intercalated with the Pidinga Formation (e.g., in Tietkens Well; Hou et al., 2003a). Like the Pidinga Formation, the unit is also highly carbonaceous with abundant plant fragments. The Paling Formation was deposited during the late Middle Eocene (Zone P14/15, e.g., Tietkens section north of Maralinga; Fig. 2.11) Tortachilla Transgression (McGowran, 1989; Alley and Beecroft, 1993; Clarke et al., 2003), in lagoons along the northeastern margin of the Eucla Basin (landward of the Ooldea Range; Fig. 2.12; Benbow, 1990a). The Paling Formation, consisting of 75% carbonate, 20% quartz and 5% glaucony as sand- to silt-sized grains (Benbow et al., 1982), is not in stratigraphic continuity with the Wilson Bluff Limestone (of which it was formerly a member), although it is laterally equivalent to it. The limestone of the Paling Formation passes laterally into calcareous sand (see cross-sections in Rankin et al., 1996 and Alley and Benbow, 1989). The Paling Formation contains a diverse marine biota, together with abundant glauconite, which indicates normal marine salinities (Clarke et al., 2003). It is found landward of the Immarna and Pidinga passages through the Ooldea Range (Fig. 2.9; Clarke and Hou, 2000). Thus, either exchange between the ocean and the lagoon behind the barrier of the Ooldea Range was sufficient for normal salinity to be established and with it a normal marine biota, or carbonate sand from the shelf was swept through the passes and deposited as flood-tide delta lobes.

The sandy, glauconitic limestone was intersected in the subsurface in drillholes CRAE RCH 2 (the type locality, at depths between 28 and 35 m), KD 1 and OR 7, and Tietkens Well (Maralinga region) and has been previously referred to as Paling Member of the Wilson Bluff Limestone in the correlation chart of Alley and Beecroft (1993) (Rankin et al., 1996). The Tietkens Well provides the complete and best studied section (with 11.4 m of complete section over the interval 28.4–16.7 m below surface) with lower and upper boundaries clearly visible, making this an important section of the formation for this part of the basin. The deposits are indicative of a flood-delta in an inter-distributary bay setting (Hou et al., 2006b), and comprise very fine-grained skeletal (mainly bryozoal) grainstone or skeletal limestone or lime sand, with minor glauconite and quartz (Rankin et al., 1996). The transgressive sediments are carbonaceous in CRAE-RCH 2 adjacent to the Paling Range where the limestone is intercalated with the Pidinga Formation (Alley and Beecroft, 1993). This is interpreted as an equivalent of the Wilson Bluff Limestone deposited in the area of flood-delta adjacent tidal channels in the landward side of the Ooldea barrier (Hou et al., 2011b).

Benbow (1990a) recognised the Ooldea, Barton and Paling ranges as an Eocene barrier island complex and named the unit comprising them the Ooldea Sand. Clarke and Hou (2000) suggested that the Ooldea Sand in the Ooldea Range was deposited during the late Middle Eocene (i.e., Tortachilla Transgression), which was informally referred by Clarke et al. (2003) as the ‘lower’ Ooldea Sand that can be differentiated from the ‘upper’ Ooldea Sand deposited during the Late Eocene (i.e., Tuketja Transgression) where they occur in different dune systems. Hou et al., (2006a) redefined these two units as Ooldea Sand for the Ooldea barrier dominantly deposited in the Ooldea Range area and Barton Sand for the Barton barrier mainly deposited in the areas of the Barton and Paling ranges respectively, although no physical or boundary criteria are presently known that would allow them to be differentiated should they occur in the same stratigraphic section.

The only exposure of the Ooldea Sand is in the Immarna cutting on the Trans-Australian railway line, to the east of Immarna Siding. The Ooldea Sand is composed predominantly of barrier sands up to 112 m thick (at Maralinga; Benbow, 1988), conformably overlying the Pidinga Formation (Hou et al., 2006a). The western Eucla margin lacks the late Middle Eocene costal barrier facies of the Ooldea Sand. The Ooldea Sand contains heavy minerals (Benbow, 1990b), and is composed predominantly of white to pale grey medium- to fine-grained barrier/dune quartz sands that vary from clean to slightly clayey. The sand grains are well rounded and some show aeolian frosting. The top of the Ooldea Sand is usually overlain by red-brown sands of Quaternary age (Rankin et al., 1996; Hou et al., 2008, 2011b). It is almost impossible to directly determine the age of Ooldea

Sand due to the absence of fossils, but the sequence relationship of the lower stratigraphic unit suggests it is of late Middle Eocene age. Lithologically, there are no discernible differences between the Ooldea Sand and Barton Sand; heavy minerals are also present in the Barton Sand. The Barton Sand is conformably overlying Khasta Formation (Clarke et al., 2003; Hou et al., 2003a, b, c) and usually is overlain by red-brown sands of Quaternary age (Rankin et al., 1996; Hou et al., 2006a). As is the case with the Ooldea Sand, the Barton Sand is unfossiliferous, but the sequence relationship of the Barton Sand suggest it is of Late Eocene to Early Oligocene age (Benbow, 1990a). The western Eucla margin lacks the Late Eocene costal barrier facies of the Barton Sand.

Spicule-bearing sands and black, glauconitic, sapropelic muds containing abundant marine dinoflagellates, spicules, foraminifera, and bryozoal and echinoid fragments (Flint and Rankin, 1991) were mainly deposited along the eastern margin of the Eucla Basin during Late Eocene. This estuarine facies was revised as the Khasta Formation (Figs 2.11 and 2.12), mainly deposited on the landward side of the Ooldea and Barton ranges, representing the deposits of the highstand of the estuarine environment during the Late Eocene Tuit-Tuketja Transgression (Clarke et al., 2003; Hou et al., 2006b, 2008). The Khasta Formation (Clarke et al., 2003) encompasses the Late Eocene estuarine sand and two spicule-bearing units (former Bring Member (Benbow, 1986a) of the Pidinga Formation, and former Khasta Member (Benbow, 1993) of the Hampton Sandstone; Fairbridge, 1953; Lowry, 1970). In areas where deep post-depositional incision has not affected the Pidinga Formation, the Khasta Formation conformably overlies the Pidinga Formation. Lithologically, this formation consists of fine- to medium-grained sand and silt, with tidal-estuarine sedimentary structures including parallel and ripple lamination, cross-bedding, reactivation surfaces, compound bedding, wavy and lenticular bedding, rip-up clasts, trace fossils in the form of escape burrows and an abundance of siliceous sponge spicules. Sorting is commonly moderately well to well. These spicule-bearing fine-grained sediments occur mostly in areas of more confined deposition, such as the estuary and estuarine channels particularly landward of the Ooldea and Barton barriers over the eastern basin, and extended landward to the eastern margin of the basin in the paleovalleys, such as Anthony, Kingoonya, Cummins, Wanilla and Yaninee paleovalleys and are widespread in the Lake Maurice and Lakes-Anthony-Bring regions (Binks and Hooper, 1984; Rankin and Flint, 1991; Benbow et al., 1995a). They also extend landward as far inland as 15–20 km upstream of the paleovalleys (e.g., Garford and Narlaby Paleovalleys; Rankin et al., 1996).

To the west of the study area, during the Middle Miocene, a narrow coastal terrigenous belt (<10 km wide) of sandstones was deposited along the north-eastern margin of the Nullarbor Plain, adjacent to the Ooldea Range. The sandstones, at the Yarle Lakes type area, are referred to as the Yarle Sandstone (Benbow, 1990c), and are interpreted as of Middle Miocene age, based partly on the occurrence of *Marginopora vertebralis*-bearing clasts of Nullarbor Limestone (Benbow, 1989). At Yarle Lakes, this silicified and ferruginous sandstone contains rare clasts of syn-depositionally deformed Nullarbor Limestone and fossils. Equivalent sediments of the Colville Sandstone occur in a belt up to 120 km wide around the western and northern margin of the Nullarbor Plain (Figs 2.11 and 2.12; Lorry, 1970). The Yarle Sandstone consists of fine- to medium-grained quartz sand that is moderately to well-rounded and well sorted and may contain minor bioclastic sediments (Benbow, 1990c; Rankin et al., 1996). The Yarle Sandstone represents an upper shoreface facies that was deposited in a moderate energy shoreline (Rankin et al., 1996). Deposition occurred along a northwest-trending Middle Miocene shoreline comprising mainly reworked Ooldea Sand of the Ooldea barrier/dune system (Hou et al., 2008). In the Ooldea-Yarle Lakes region, where the formation is known to be most extensive, a shoreline of moderate energy is indicated for this part of the Eucla margin, at least during Middle Miocene deposition (Fig. 2.11; Rankin et al., 1996).

The Middle Miocene to Early Pliocene Garford Formation is restricted in occurrence to paleochannels and lakes along the eastern margin of the basin and associated paleodrainage, such as Tallaringa, Garford, Anthony, Kingoonya and Narlaby paleovalleys. In the northeastern margin of the Eucla Basin, the Garford Formation comprises argillaceous green to grey muds, white-grey to green-grey lacustrine carbonate muds and mudstones deposited in low lying areas between the Ooldea and Barton Ranges, in the Wilkinson Lakes area, and within the paleovalleys (Fig. 2.12; Rankin et al., 1996; Benbow et al., 1995a). Along the southeast Eucla margin (e.g.,

Kingoonya and Narlaby paleovalleys on the west and southwest margin of the Gawler Ranges), a marginal marine and estuarine channel sequence of the Garford Formation (Kingoonya Member, Hou et al., 2003a) and Narlaby Formation (Benbow et al., 1995a) were deposited during the Middle Miocene–Pliocene (Fig. 2.11). The sediments of the Garford Formation, unconformably overlie the Pidinga and Khasta formations (e.g., in the marginal basin) and older bedrocks as well as crystalline basement (e.g., in the paleovalley areas). they include stromatolitic, oncolitic and oolitic carbonate and argillaceous mudstones. It is possible that very marginal Garford Formation may intertongue with the youngest part of the Ooldea Sand. Upstream in the northeastern onshore basin (e.g., Tallaringa Paleovalley and in the Lake Phillipson area), the Garford Formation unconformably overlies Mesozoic sediments of the Eromanga Basin in places. To the south of the study area, within the Narlaby Paleochannel, the Garford Formation is overlain by the Narlaby and Ilkina formations (e.g., in the vicinity of Scrubby Peak Homestead), a sequence of up to 60 m thick comprising fluvial to estuarine, fine- to medium-grained, moderately to well sorted sand with minor clay (Benbow et al., 1995a). The Garford Formation is most commonly overlain by Quaternary aeolian and fluvial sand (e.g., of the Great Victoria Desert), but prior to deposition of these sands significant erosion of up to 20–25 m occurred in places, such as in the Narlaby Paleovalley, and thus the upper boundary can be irregular and is clearly unconformable.

The Kingoonya Member is up to 60 m thick and dominated by grey, green and cream to black mud, minor carbonate and local basal and interbedded carbonaceous sand and grit. The Kingoonya Member, representing the younger phase of the Garford Formation deposited in the southeast Eucla margin (e.g., Kingoonya and Narlaby paleovalleys on the west and southwest margin of the Gawler Ranges), is characterised by a marginal marine and estuarine channel sequence (Hou et al., 2003a) that was deposited during the Middle Miocene–Pliocene (Fig. 2.10). Palynological analysis and dating of samples from selected drillholes in the Kingoonya paleovalley (Stoian, 2004a, 2004b) indicates the presence of a Late Miocene to Early Pliocene interval and correlates with the *Monotocides galeatus* zone as defined by Macphail (1999). The palynomorphs assemblages indicate a gradation of marine influence ranging from an open water marine through estuarine to lacustrine environments, following a north-eastern arcing trend from NALARA NR 3-4 drillholes in the south through KINPC 1-2 to KIN45, and KIN20-21 and KIN 22 in the east and then back to CAR 37 in the north (Stoian, 2003a, 2003b, 2003c, 2004a, 2004b).

Overlying the Garford Formation in the Narlaby Paleovalley area (to the south of the study area) is the Narlaby Formation, a fluvial to estuarine fine- to medium-grained, moderately to well sorted sand with little clay, up to 60 m thick (Figs 2.11 and 2.12; Benbow et al., 1995a). These sediments are partly silicified, iron-stained and varicoloured.

Following deposition of the Garford Formation, the Ilkina Formation (to the south of the study area, e.g., the Narlaby Paleovalley) was laid down in the paleovalleys of the southeast Eucla Basin margin (on the southwest margin of the Gawler Ranges) during the Late Pliocene or Early Pleistocene (Benbow et al., 1995a). Extensive occurrences on the eastern margin of the Nullarbor Plain also occur along the northwest margin of Ifould Lake, where discontinuous outcrops occur as low-lying benches up to 2.5 m above the lake floor and as thin relatively indurated sheets on the lake floor. Possible occurrences have also been observed elsewhere, such as a ~2 m thick, horizontal, indurated and laminated gypsum bed localised on the southern margin of Lake Woorong east of the Garford Paleovalley (on COOBER PEDY; Benbow, 1982). The Ilkina Formation is a thin sequence of conspicuously laminated clays, silts, sands and minor carbonate up to 5 m thick in the Narlaby Paleovalley (Figs 2.11 and 2.12), and also forms the floors of playas such as Ifould Lake (to the west of the study area) where it contains clasts of silcrete and ferricrete (Benbow et al., 1995a). At Ifould Lake the formation sharply and unconformably overlies weathered Precambrian basement and carbonaceous sediments of the Pidinga Formation and near Ooldea ferruginised Yarle Sandstone. In the Narlaby Paleovalley the formation is comprised of pale to dark grey, very fine- to medium-grained sands (clayey in part, mostly weakly indurated to unconsolidated, moderately to well sorted), pale to dark grey and white clay (in part sandy) and ~1 m thick laminated gypsum cap. These sediments are laminated in part and very thin to medium horizontally bedded. In the Narlaby Paleovalley, the formation unconformably overlies green to grey clays and white dolomite of the Garford Formation. Actual contacts with the Garford Formation can be sharp and clear, however, in many instances the contact can be difficult to pin-

point precisely, presumably because of reworking. In both regions where the formation occurs it is unconformably overlain by aeolian sands of Quaternary age.

The Munjena Formation, commonly formed within a thin alluvial to colluvial unit around the eastern margin of the Nullarbor Plain and along the paleovalleys (Rankin et al., 1996), comprises poorly sorted conglomeratic sand, clayey sand and silcrete breccia, up to 3 m thick, that blankets wide areas of interfluves and paleochannels (Benbow, 1993). These sand-rich sediments may contain local reworked quartz pebbles from underlying Paleozoic and Mesozoic sediments (Benbow et al., 1995a). The formation has been silicified to pedogenic silcrete; rare polished and rounded silcrete clasts indicate reworking of older silcretes. The formation is believed to be Oligocene and possibly younger, since it overlies Khasta and Pidinga formations in the paleovalleys (Figs 2.11 and 2.12).

GEOLOGICAL HISTORY

Subsidence of the Eucla Basin probably commenced in the Late Cretaceous – Middle Eocene shortly before the earliest paleovalleys formed, concurrent with on-going slight epeiorogenic uplift of the cratonic margin and incision of the valleys (Frakes and White, 1997). Increase in sediment supply following tectonic uplift and rejuvenation of relief, which accelerated stream incision in headwater drainage basins, has long been regarded as a major cause for aggradation within stream networks and the construction of thick alluvial/fluvial sequences (Miall, 1996). Sedimentation in the Eucla Basin may have commenced in the Paleocene-Early Eocene with undifferentiated marine to fluvial clastics of the Hampton Sandstone and Pidinga Formation along the southern part of the basin, and terminated in the Pliocene with marine carbonates of the Nullarbor Limestone and fluvial clastics and carbonates in the onshore and nearshore areas (Taylor, 1975; Barten, 1975; Davies et al., 1989; Clarke et al., 2003, Hou et al., 2003c, 2006b, 2008, 2011b; Zang and Stoian, 2006). In the far west, Paleocene-Early Eocene sediments form a prograding wedge (Bein and Taylor, 1981).

Prior to the Wilson Bluff marine flooding, deposition of fluvial gravel and coarse sand was limited to the valley thalwegs near the coastline. This interpretation implies that unless the fluvial deposits were originally thicker and subsequently eroded, there was no significant fluvial aggradation in the landward extremities of the incised valleys during either lowstand or the subsequent Wilson Bluff sea-level rise (Hou et al., 2001a; 2003c). The later basin and channel sediments thicken and are inclined gently in a seaward direction, with the Middle Eocene sediments developed in the coastal-estuarine plain during the Tortachilla Transgression. The landward migration of the estuary and coastline during the Tuketja-Tuit Transgressions led to the formation of the Late Eocene sediments (Hou et al., 2008). The sea did partially invade the central Eucla Basin during the Late Oligocene – Early Miocene leading to deposition of the Abrakurrie Limestone (Li et al., 1996), and then more fully during the Early-Middle Miocene leading to deposition of the Nullarbor Limestone (McGowran et al., 1997). The Abrakurrie Limestone is up to 100 m thick in Western Australia, where syn-depositional subsidence was likely, and is generally <10 m thick in South Australia. The relatively thick and localised occurrence of Abrakurrie Limestone compared with the overlying thinner but more spatially extensive Nullarbor Limestone suggests local tectonic subsidence in the central part of the basin in the Early Neogene. Farther inland (?50–100 km), post-Abrakurrie erosion prior to and during initial deposition of the Nullarbor Limestone has removed any identifiable record of laterally equivalent Late Oligocene – Early Miocene terrigenous facies on the Eucla margin and paleovalleys (Benbow et al., 1995a, b; Alley et al., 1999; Hou et al., 2003a).

During the Middle Miocene and Early Pliocene transgression and highstand, controlled by base-level change in onshore setting, reactive erosion and incision of the Eocene channel deposits occurred while lacustrine sedimentation dominated in the lakes and channels (Hou et al., 2022). In Late Miocene – Early Pliocene time, the paleochannels were fragmented into chains of relatively small lakes, where dolomitic carbonates accumulated in the late arid stages.

2.4 TECTONIC AND STRUCTURAL FRAMEWORKS

Sedimentation in the Eucla Basin began after the Late Cretaceous and there were periods of gentle downwarping mainly in the Middle to Late Eocene and Miocene, followed by uplift with

continental tilting and faulting mainly in the Pliocene (Lowry, 1970; Sandiford, 2007; Hou et al., 2008). There is evidence for the existence of numerous faults up to 120 km long with displacements of up to about 60 m (Sandiford, 2007). SRTM DEM images reveal numerous linear scarps on the Nullarbor Plain, ranging up to 20 m in height, indicating fault scarps that have significant number of vertical displacements (Sandiford, 2007; Yang et al., 2022; Sellmann et al., 2023).

The Eucla Basin has yielded important evidence of continent-scale Cenozoic crustal deformation. Jennings (1963) suggested that the present surface of the Bunda Plateau represents the virtually unmodified Early Miocene sea floor and concluded that the slope of the plateau (about 1 m per 3 km) corresponds to the amount of post-Early Miocene tilting. However, this calculation ignores the differential erosion of the plateau and the differences in depth of deposition in different parts of the basin (Lowry, 1970). Sandiford (2007) presented a distinct latitudinal asymmetry in the geomorphology of the Australian landmass by showing a number of irregularities in the sedimentary record, implying that significant continent-scale tilting transpired throughout the Cenozoic (SW up, NNE down) generated a total differential vertical displacement of as much as 300 m over the last 15 million years. This apparent tilting uplift of the southwestern margin of the Eucla Basin is also evidenced by variability in the present-day elevations of coeval early Neogene paleoshorelines, which decrease eastward by approximately 150 m over a 760 km interval in the onshore Eucla Basin (Quigley et al., 2010; Sandiford, 2007). Cenozoic marine sediments of the Eucla Basin have been preserved up to 250 m above the present-day sea level. Based on the comparison of the Late Eocene marginal marine spicule facies deposition between the western and eastern onshore basin, it is indicated that the western Late Eocene Eucla margin has been tilted up at least 130 m compared to the eastern Late Eocene Eucla margin (Ruperto et al., 2006; Hou et al.,2008).

The present elevations of the Eocene marginal marine sediments on the western and eastern margins of the basin indicates that significant post-depositional deformation of basin sediments has occurred. By using the displacement of same-facies sediments deposited during the same transgression on both western and eastern margins of the Eucla Basin a differential uplift of ~138 m was determined. Ruperto et al. (2006) studied the marginal marine (lignitic) carbonates in the western margin (Norseman Limestone currently sits at 274 m asl in Lake Cowan) and eastern margin (Paling Limestone currently sits at 136 m asl in Immarna Lagoon, drillhole CRAE RCH4, west of the study area; see Fig. 3.13) of the Eucla Basin. Both carbonates were deposited during the Middle Eocene Tortachilla transgression (Fig. 2.11) and the variation in present-day elevation indicates that the western portion of the basin was uplifted by approximately 138 m, relative to the eastern portion of the basin.

2.5 QUATERNARY GEOLOGY AND GEOMORPHOLOGY

The Quaternary history of the study area is characterised by marked climatic and sea-level oscillations, which have impacted on many landscape features. In the interior, cold, arid phases were times of aeolian dune formation and evaporitic playa deposition, which alternated with periods of wetter climate, increased stream discharge and greatly extended lake systems, when extensive alluvial and fluvial sand, clay and gravel were deposited. Periods of weathering have formed hard carbonate soil profiles (calcrete) and a variety of karstic solution features, including extensive cave networks in carbonate rocks. In the most recent of the Quaternary sea-level oscillations, the sea advanced across the continental shelf, reaching its present level about 7000 years ago, since which time it has remained relatively stationary.

Most of the study area today is covered by Quaternary sand plains and aeolian dunes, which in part obscure or are superimposed on the paleo-landscape features. The western to south-eastern portion of the study area is covered by the Quaternary aeolian Yellabinna dunefield, which is part of the Great Victoria Desert, and characterised by predominantly east-west trending longitudinal dunes over several kilometres in length (Krapf et al., 2023). Beneath the thin surficial cover, the landscape of the eastern Eucla Basin contains remarkably well preserved and varied paleolandforms of Paleogene–Neogene age (Benbow, 1990a).

One of the significant geomorphic features in the area is a string of playa lakes and associated lunettes developed in topographic lows. These generally reflect and coincide with the underlying Eucla Basin paleodrainage systems, although its relief is subdued and drainage is generally disorganised. Other obvious features in the eastern Eucla Basin margin include the parallel Ooldea and Barton ranges, and the interconnecting Paling Range, well preserved coastal paleo-dunes or barriers of late Eocene or early Oligocene age (Figs 2.7, 2.8, 2.9, 2.10, 2.10; Benbow, 1989, 1990a; Clarke and Hou, 2000). These remarkable landforms can be interpreted by considering their topographic relief, by using digital elevation models, and by interpreting the Landsat and NOAA (and ASTER?) satellite imagery. A history of their recognition and delineation is described in Benbow (1989), and their origin is discussed in Benbow (1990a) and Clarke and Hou (2000). These large and extensive ranges have been interpreted as coastal dunes that formed along the north-eastern margin of the Eucla Basin during the highstands of two Eocene transgressions.

3. PALEOVALLEY MAPPING AND GIS DATASET

3.1 INTRODUCTION

The paleovalley mapping of the study area is based on the second edition of the state-wide *Paleodrainage and Cenozoic coastal barriers of South Australia* 1:2 million scale state map (Hou et al. 2012). An associated GIS data package was released by GSSA in 2012, and this project was completed under the *PACE* 2020 initiative's *PACE* Exploration program (Pathways to Prospectivity). Early compilations of paleodrainage by Rogers (1999, 2000) traced ancient river systems to outline an extensive paleo-drainage network in South Australia that developed primarily during Eocene time (~55–30 Ma). The first edition of the statewide paleovalley map (Hou et al. 2007) mainly focused on Paleogene and Neogene paleovalleys. Since its release in 2007, new data and interpretations arising from regional surveys and exploration activities in South Australia, particularly for uranium, heavy mineral sands and groundwater associated with paleodrainage and coastal sediments, have underscored the need for a second edition, including updates for revised sediment boundaries based on newly acquired datasets (e.g., Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) night-time thermal (NTT), satellite imagery, airborne electromagnetic (AEM) surveys), a modified approach to paleodrainage mapping following industry feedback (e.g. AEM interpretation workshops), new data from mineral exploration activity (e.g. drilling data), and geological sections to illustrate sediment and bedrock relationships (Hou et al. 2012). A main driver for this study was the collection of new geophysical data as part of the GP2 project, which resulted in the collection of new high resolution ground gravity and 5 km spaced TEMPEST AEM survey collected for Geoscience Australia (P6617) in 2022.

3.2 DATA SOURCES

New mapping in the study area includes new and revised Paleozoic and Mesozoic as well as Cenozoic channel boundaries of the interpreted paleovalleys based on newly acquired and/or reprocessed datasets, such as satellite imagery (ASTER-NNT, Landsat TM5 and ETM7), DEMs and derivative products (MrVBF) high resolution gravity, Total Magnetic Intensity (TMI) and AEM surveys, and a modified approach to paleovalley mapping following confirmation of available drillhole data (Table 3.1). A fundamental understanding of the geology and stratigraphy of the basins and their related paleodrainage systems (see Chapter 2) is the key for the interpretation of the updated paleovalley mapping. In particular, the use of high-resolution gravity, AEM and TMI surveys has resulted in the mapping of Paleozoic paleochannels that have previously not been compiled in the earlier paleodrainage map editions; also the re-processed ASTER NTT data (90 m pixel), have improved the discrimination and mapping of drainage channels, and the patterns of partially buried paleocoastal dune complexes in the study area. Previous information in the GIS data package of the second edition of SA's paleovalley map included links to biostratigraphic data and key reference drillholes (Hou et al. 2012). In this new dataset all polygons now include metadata that identifies the primary data sources used in the mapping process and the level of confidence in the interpretation. The principal components of the new map and GIS dataset GP2 study area are described below.

Table 3.1 Data sources used for identification of paleofeatures.

Derivation
Field observation
Drillhole log or sample
NOAA NTT image
Reprocessed ASTER NTT image
Landsat multispectral scanner image
NASA SRTM DEM
High-resolution geophysical data, i.e. gravity, AEM and TMI
Geology provinces GIS dataset
Geology 1:100 000 GIS dataset
Sample not from drillhole
Derivation undetermined
Type sites of palynology
Type sites of paleovalley formations
Referenced DEM report / open file article
Referenced company report
Referenced research paper
Deposit associated with paleovalleys/paleoshorelines

Satellite thermal imagery

Satellite thermal imagery provides a regional dataset useful for paleodrainage mapping, especially in areas where water-saturated sediments in paleodrainage channels provide a thermal contrast to low porosity bedrock, usually during night-time cooling. This is the situation over large areas of the semi-arid Gawler Craton. Previous interpretations from thermal imagery relied on NOAA imagery (1100 m pixel) with only few ASTER NTT scenes (90 m pixel) available. NOAA imagery can have excessive ‘noise’ (e.g., cloud and daily moisture variation in shallow sediments), and consistent interpretation required acquisition and interrogation of 28 NTT images across the state, taken at different times and from different satellites. Multiple scenes of the ASTER NTT data covering the whole study area were re-processed to assist with the GP2 paleodrainage system mapping. The combined datasets were used to refine the interpretation and improve the spatial resolution of thick paleochannel sands and paleocoastal dunes.

GP2 geophysical surveys – AEM, Gravity, TMI

The new geophysical surveys covered most of the study area.

AEM

The AEM data flown for this project includes both a 20 km spaced east-west lines as part of the AusAEM Western Corridor within the Exploring For The Future initiative, and 5 km NW-SE orientated lines. AusAEM is the Australian 20 km Airborne Electromagnetic Survey Objective, a collaborative, national goal of the Commonwealth, State and Territory geological survey agencies to acquire airborne electromagnetic (AEM) data at 20 km line-spacing across the Australian continent. The dataset contains full coverage of the lower southwest of South Australia including the southern Eucla basin, for the 20 km spaced lines.

The AusAEM Western Corridor module follows the 2017-2020 GA Exploring for the Future (EFTF) AusAEM project, which has covered a large part of northern Australia, including coverage of most of northern Western Australia (WA) as part of Year 2 of EFTF AusAEM. Xcalibur Aviation was contracted by Geoscience Australia and was flown by a fixed wing aircraft, which flew at low level, around 100 m above ground level.

GSSA and GA also collaborated to have flown a more local scale AEM survey within the larger AEM survey for the Western Corridor, labelled as GP2 Infill AEM. The 5 km infill over the GP2 region has been flown in a NW-SE orientation to capture the main MT station transect across the central region, as well as providing an effective cross section across inferred paleolandscape and basement-hosted structural trends.

The AusAEM data can be downloaded from the Geoscience Australia data and publications page https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/147688

Data for the 5 km infill within the GP2 study area can be downloaded from https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/261233a2-4850-4c62-9005-c51db676b4db

GRAVITY

The Department for Energy and Mining commissioned the Gawler Challenge Phase 2 regional gravity survey acquired by Daishat Geodetic Surveyors over a part of the Gawler Craton during August to September 2022. Gravity measurements are taken at set intervals of distance and the precise height at each location is recorded. This survey acquired 5,572 new gravity stations at spacings of 1 km and 2 km. The gravity survey for the GP2 project were carried out either by vehicle (4WD or quad bike) or helicopter depending upon remoteness.

The data and report for the newest regional gravity survey in South Australia as part of GP2 has been released. The dataset contains over 5,500 new gravity observations covering the region between the Challenger Gold Mine and the Jacinth-Ambrosia Mineral Sands Mine.

The data shows previously unseen geological features, including paleochannels, glacial paths and shear zones. The data are currently being incorporated into the South Australia state gravity grid (along with other newly released public domain surveys). Data can be downloaded from https://map.sarig.sa.gov.au/Shortcut/GP2%20Gravity

TMI

Total Magnetic Intensity (TMI) data has been sourced from the 2019 Gawler Craton Airborne Survey (GCAS). The survey captured over 1,660,000 line kilometres of new magnetic, radiometric and digital elevation data over an area of about 295,000 km2. The geophysical data was captured by four geophysical contractors, using fixed-wing aircraft flying approximately 60 m above the ground along flight lines spaced 200 m apart. Survey acquisition was completed in June 2019. The data can be downloaded from https://catalog.sarig.sa.gov.au/geonetwork/srv/eng/catalog.search#/metadata/1ce5ea8f-b6f6-42bb-9061-6a95862840d5

The Paleozoic channels are obviously shown on the high-resolution gravity images (Figs 3.4–3.7). The AEM data, although only available for some parts of the study, are regarded as the best dataset for mapping Cenozoic and Mesozoic channels in the GP2 area where thick sedimentary successions include stacked fluvial systems with channel sands saturated by variably saline groundwater are present (Fig. 3.5). Also, the revised positions of the Mesozoic, Paleogene and Neogene paleovalleys is supported by interpreted AEM data.

The new geophysical data has proved successful in revising and extending known paleodrainage networks in the study area. Delineation of the Paleozoic channels, to the southwestern of Arckaringa Basin, was undertaken entirely using the new high-resolution gravity data. These newly mapped paleovalley system, comprising the Permian paleodrainage channels in the GP2 area, was originally based on a sedimentological model derived from historic drillholes. However, these are now clearly imaged by the new gravity data (refer to Chapter 3.4).

It is difficult to determine paleovalley features from the TMI image, however, this data can be used for interpreting the relationship of paleovalleys and bedrock geology as well as structures.

Stratigraphy

In the study area well exposed paleochannel sediments are limited to a few isolated occurrences. The GP2 paleovalley mapping of Permian, Cretaceous, Paleogene and Neogene strata has been undertaken around the southwestern margins of the Arckaringa and Eromanga basins, and the eastern margin of the Eucla Basin (see the basin description in Chapter 2). Drillhole data was incorporated to provide further insight into the stratigraphy of the subsurface sediments.

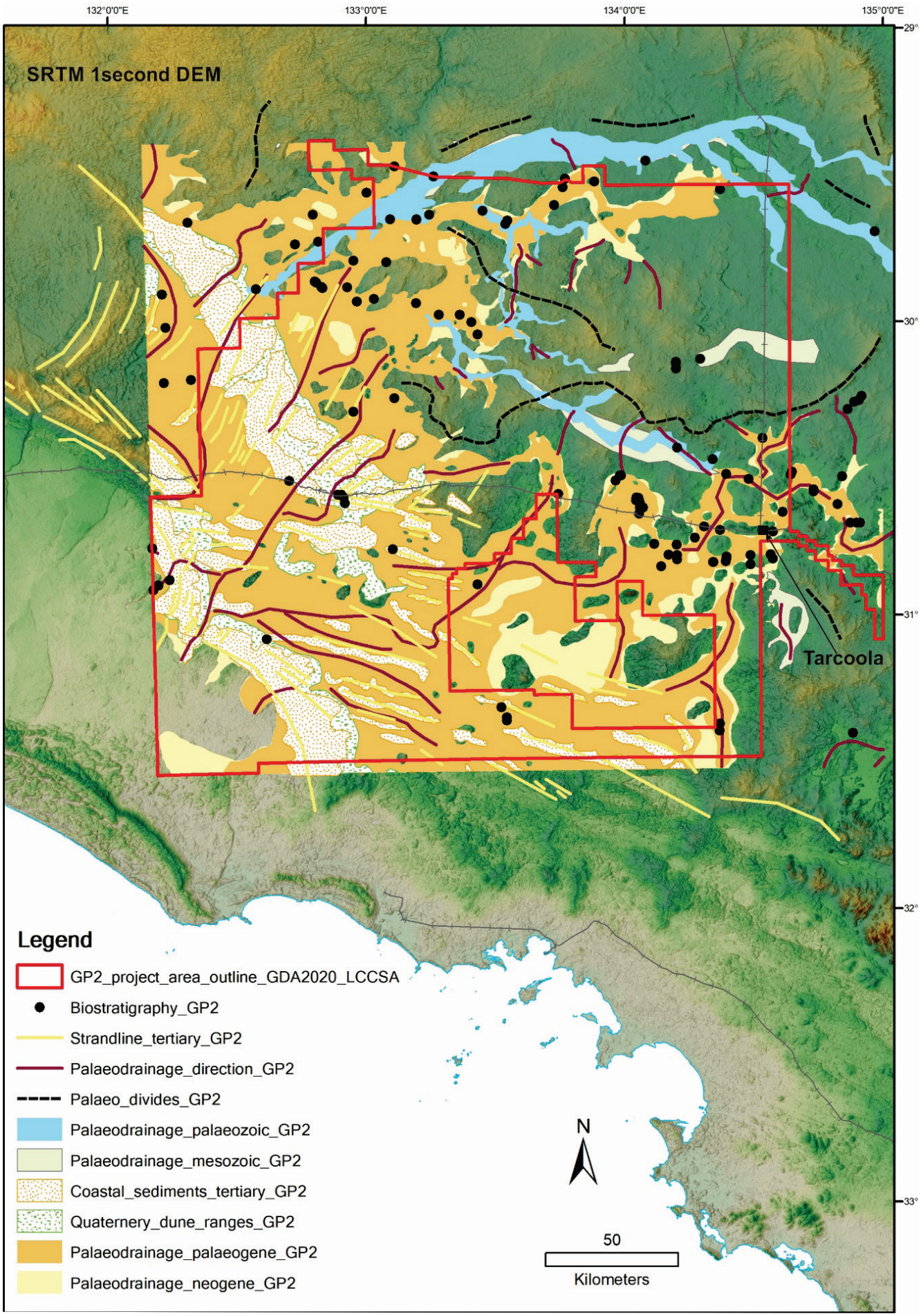


Figure 3.1 New paleovalley system map layers in the study area.

3.3 NEW MAP DATA LAYERS

The new (GP2 Paleovalleys) map consists of 10 main data layers (Fig. 3.1; Table 3.1) represented by these three feature types: polylines (i.e., strandline, paleodrainage direction and drainage divide), filled polygons (i.e., Mesozoic, Paleogene and Neogene fluviolacustrine sediments; coastal beach and dune deposits; and Quaternary dune ranges), and points (biostratigraphy).

Table 3.2 Paleovalley map layers of the study area.

Layer	Feature type
Quaternary dune ranges	Polygon
Cenozoic coastal barrier	Polygon
Neogene paleodrainage sediments	Polygon
Paleogene paleodrainage sediments	Polygon
Mesozoic paleodrainage sediments	Polygon
Paleozoic paleodrainage sediments	Polygon
Cenozoic strandlines	Polyline
Paleodrainage direction	Polyline
Paleodivides	Polyline
Amalgamated sands	Polyline

Each data layer is described by attribute data (Fig. 3.2) which includes: relevant GIS mapping information, such as age, derivations (e.g., NOAA and ASTER NTT and geophysical images, geology, drillhole logs or samples, company reports, type sites for paleovalley stratigraphy or palynology, and field observations). The approximate positions of paleodrainage divides are delineated based on (paleo-) topographic highs interpreted from paleodrainage patterns and basin geology combined with Landsat 7 and NOAA NTT images draped over SRTM DEM) and multi-resolution valley bottom flatness (MrVBF) images (Figs 2.7, 2.8, 2.9, 3.2 and 3.3). Surface expression of paleovalleys is confined mainly to the areas of topographic lows where channel sediments were not extensively silicified and the remnants of the paleodrainage are largely obscured by post-Neogene sedimentary cover or regolith, which ranges from a few metres to tens of metres thickness. Paleodrainage divides are mapped based on (paleo-)topographic highs interpreted from paleodrainage patterns combined with NOAA night-time thermal imagery draped over MrVBF and SRTM DEM images. Paleogene-Neogene barrier systems and strandlines were interpreted based on NOAA and ASTER night-time thermal images draped over SRTM DEM images with local drillhole confirmation.

For the Cenozoic and/or Mesozoic basin margins, the interpreted paleodrainage distribution was based on DEMs, geological maps, basin analysis and sedimentology, open-file exploration drilling data, and the integration of drillhole sample information with remotely sensed data, particularly ASTER NTT imagery, geophysical data and knowledge of basin evolution and stratigraphy. For the Paleozoic basin margin, however, the interpreted paleodrainage distribution was mainly based on the high-resolution geophysical data such as the new gravity and AEM, geological maps, basin analysis and sedimentology, open-file exploration drilling data, and the integration of drillhole sample information.

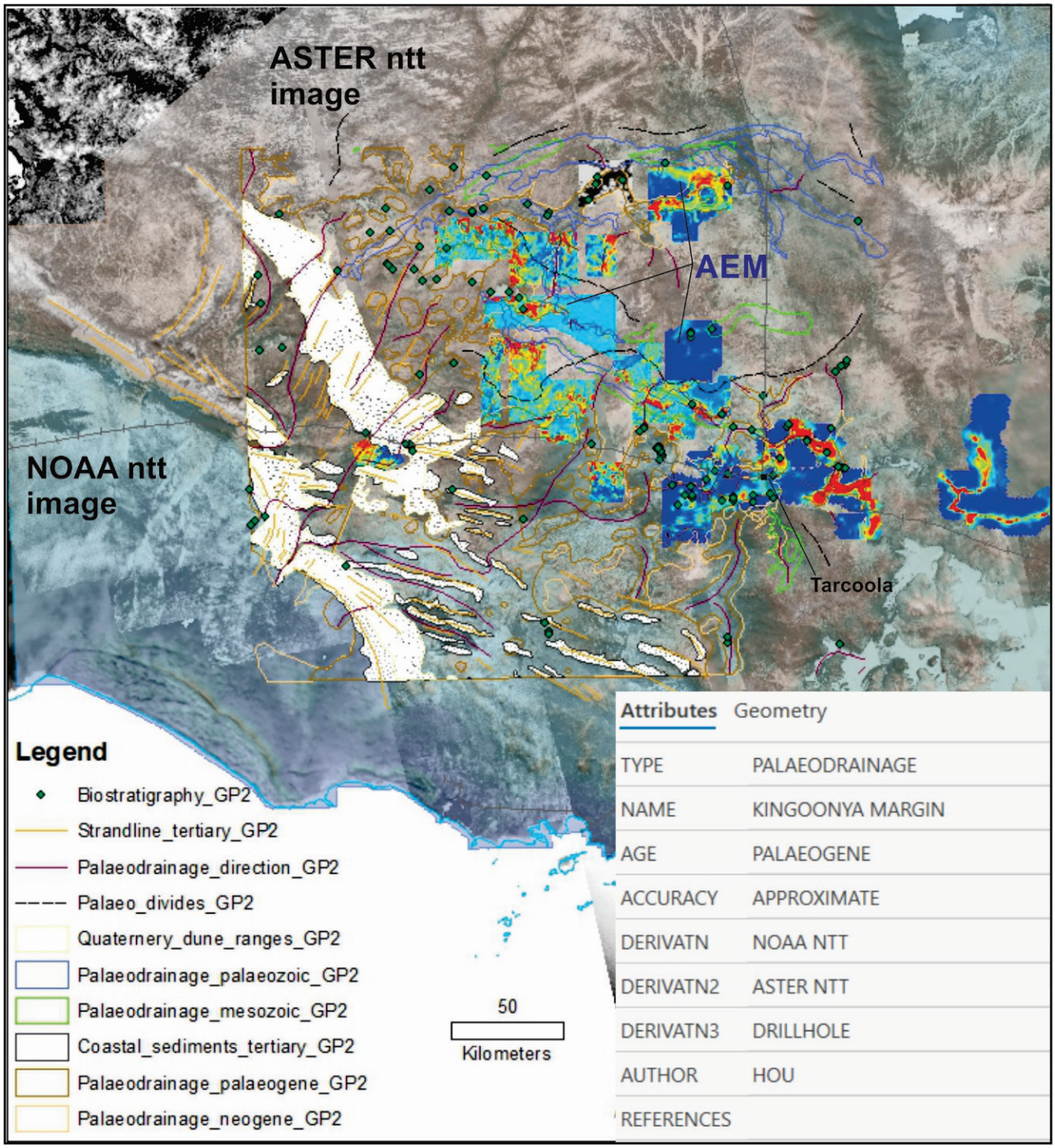


Figure 3.2 Example of attributed Kingoonya Paleovalley mapping on satellite images and associated ArcGIS attribute table.

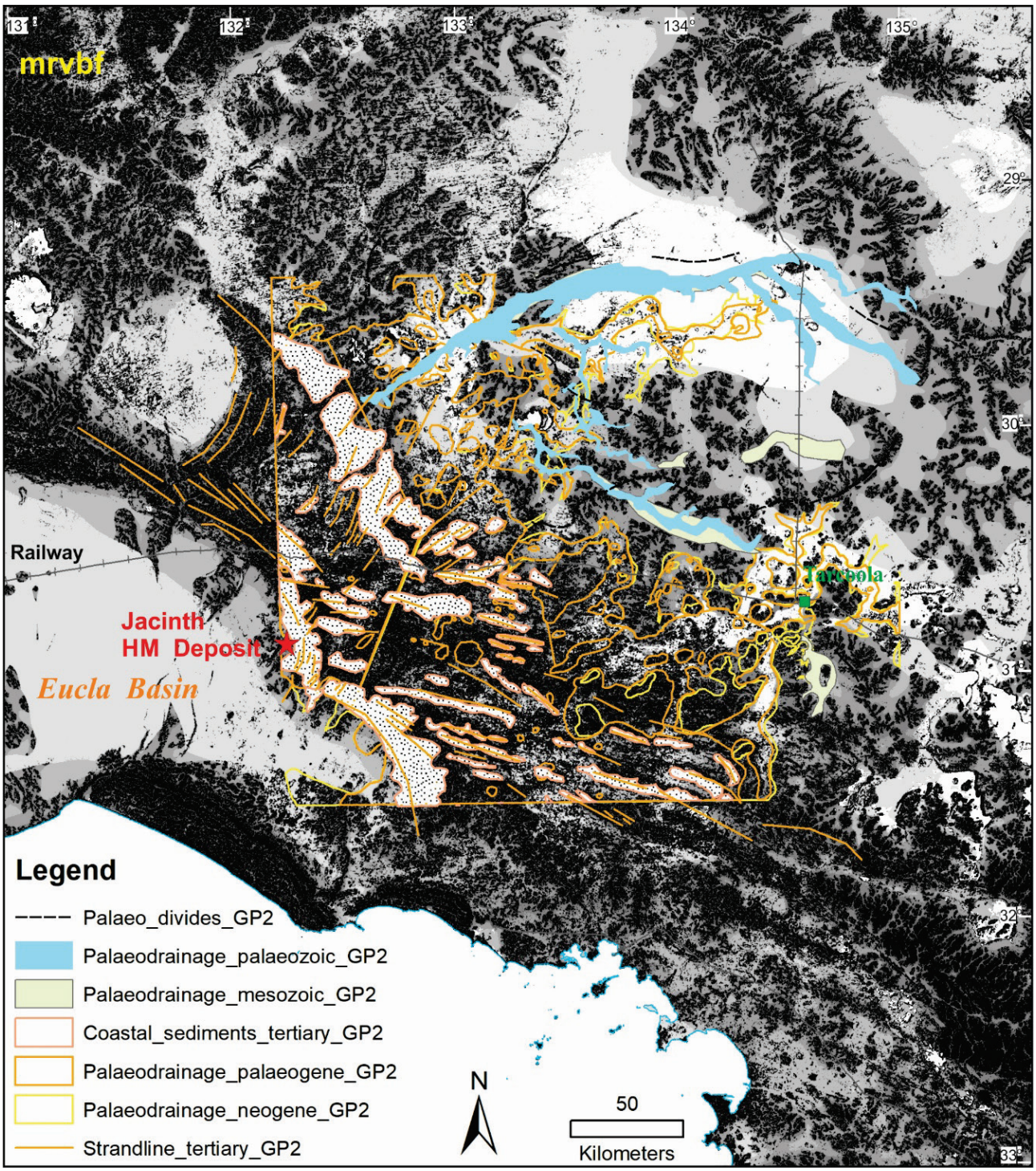


Figure 3.3 Paleovalley mapping on MrVBF imagery. Surface expression of paleovalleys is confined mainly to the areas of topographic lows.

Paleozoic, Mesozoic, Paleogene and Neogene channels were mapped separately and confirmed by geological and drillhole information, as available. In the southwestern margin of the Arckaringa Basin, interpreted Paleozoic channels that formed mostly during late Paleozoic glacial period, are overlain by the Mesozoic channel sediments in places, and extensively by Cenozoic sediments. In the Eromanga Basin, interpreted Mesozoic channels that formed mostly during the late Mesozoic marine regression, are overlain extensively by Cenozoic sediments. The interpreted positions of Mesozoic channels are more speculative than for the Paleogene and Neogene drainage systems and were derived largely from NOAA and ASTER NTT images, together with geological maps and drillhole information.

The basemap for the paleodrainage layers is the pre-Permian geology for the study area derived from the statewide solid geology (Late Mesoproterozoic to Archean-early Mesoproterozoic time slices) and selected statewide geological provinces (Neoproterozoic to Late Carboniferous to Triassic) GIS datasets maintained available on SARIG (Figs 2.2 and 2.10). Boundaries are valid as at the time of map production.

Based on the GIS version of the 2nd edition of the South Australian paleodrainage map, each layer that included attribute information has been upgraded in the GP2 paleovalley mapping (Fig. 3.2), including the data source used to determine or infer the presence of paleofeatures (Table 3.2) and their positional accuracy. Positional accuracy for a given feature can be accurate, inferred, or approximate, as determined by the interpreter, based upon the available data source(s) for that feature. The benefit to the end user is the opportunity to discover and understand the interpretation process behind the mapping of individual paleofeatures.

3.4 NEW AND UPDATED PALEOVALLEY SYSTEMS

Late Paleozoic paleovalley systems

Mapping Paleozoic paleovalleys in the study area, remote sensing images or DEMs are generally not working well as these paleovalleys are deeply buried and subsequently not, or poorly, exposed (Fig. 3.4). The new GP2 high-resolution gravity data, in combination with available drillhole data, provides a dataset to map these 'old' paleovalleys (Figs 3.5, 3.6 and 3.7) that were not recognised in the first and second editions of the State paleovalley map (Hou et al., 2007, 2012).

Permian sediments in these paleovalleys (Fig. 3.6) can be correlated to those of the Arckaringa Basin including the Boorthanna Formation (glacial-dominated), the Stuart Range Formation (marine transgressive dominated with eustatic rise in sea level and flooding of glacio-isostatically depressed lowlands) and the Mount Toondina Formation (marine deposition followed by an eustatic fall and return to freshwater conditions with development of coal swamps) as a subhorizontal succession unconformably overlying Cambrian sediments or Precambrian sediments, metasediments and crystalline rocks (Fig. 2.3). These channel sediments are in places unconformably overlain by the Late Jurassic to Early Cretaceous sediments (Eromanga Basin) and Cenozoic channel deposits (Eucla Basin).

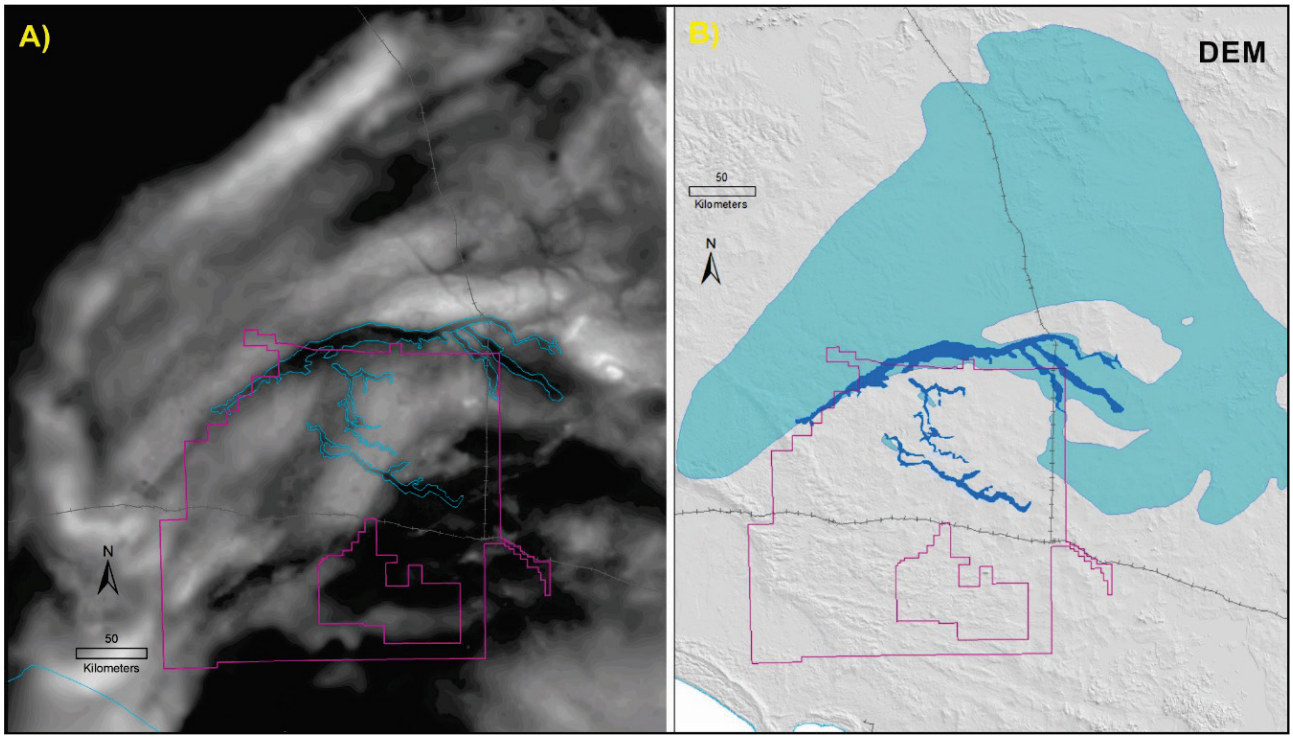


Figure 3.4 Mapped Paleozoic paleovalleys on the GP2 gravity data (a), showing the relationship with the Arckaringa Basin, Mulgathing Trough and GP2 area (b).

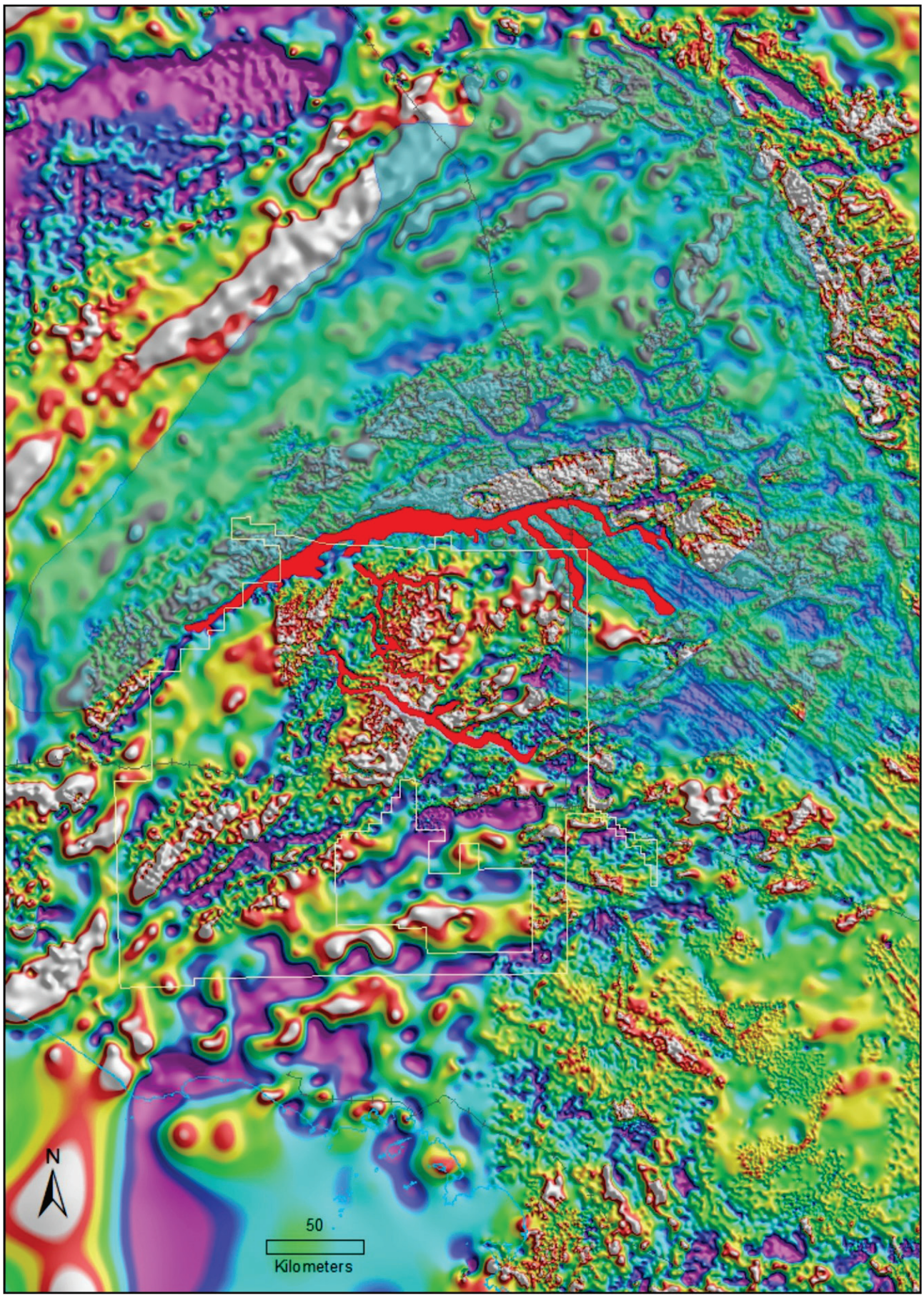


Figure 3.5 Paleozoic paleovalleys (red) mapped over the GP2 gravity data, showing the relationship with the Arckaringa Basin, Mulgathing Trough and GP2 area.

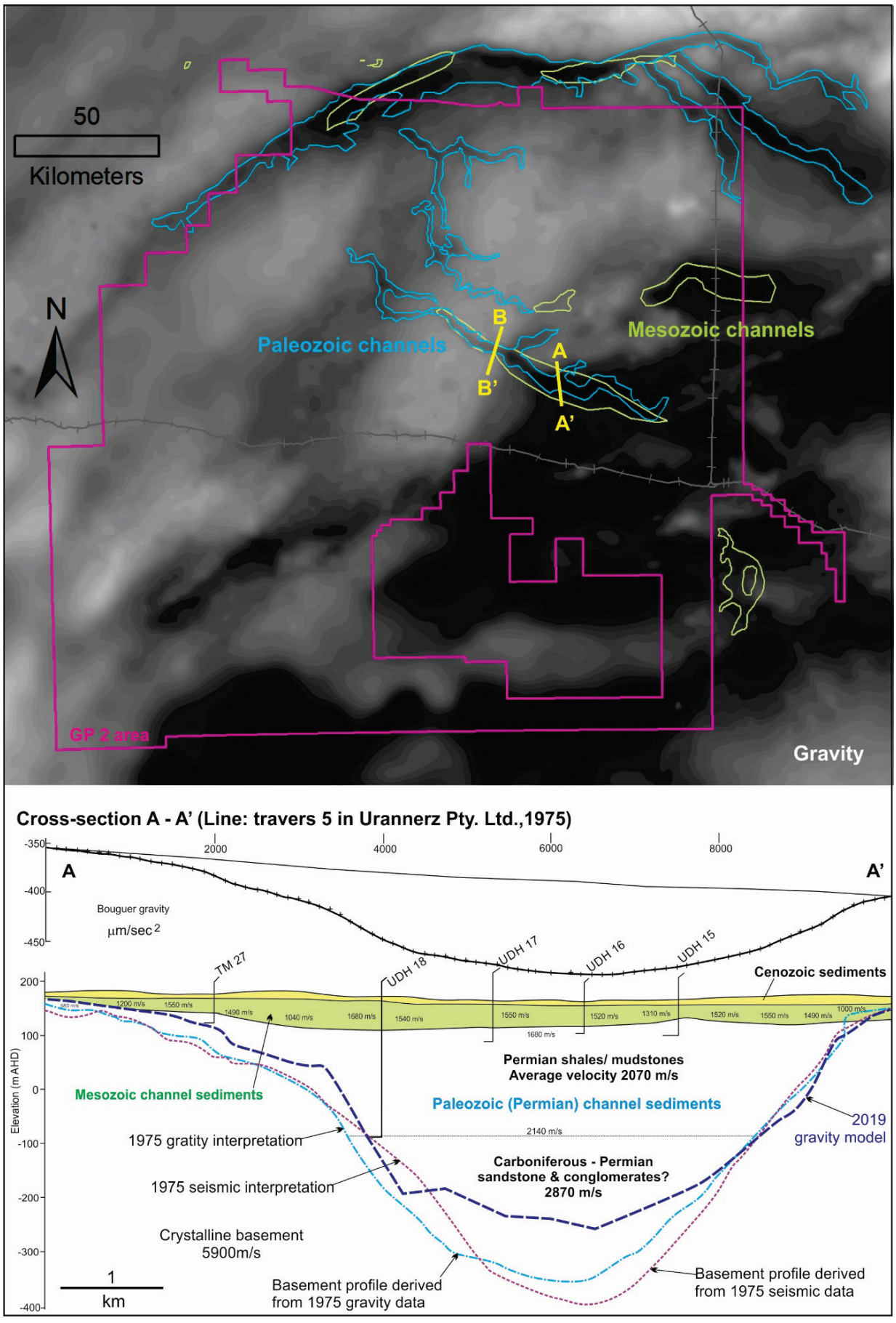


Figure 3.6a Permian channel cross-section A–A' through the Mulgathing Trough in the study area, showing the stratigraphic relationships with both old (Cambrian?) and younger (Mesozoic) channel sediments (modified from Urannerz Pty. Ltd.,1975 and Foss et al., 2019).

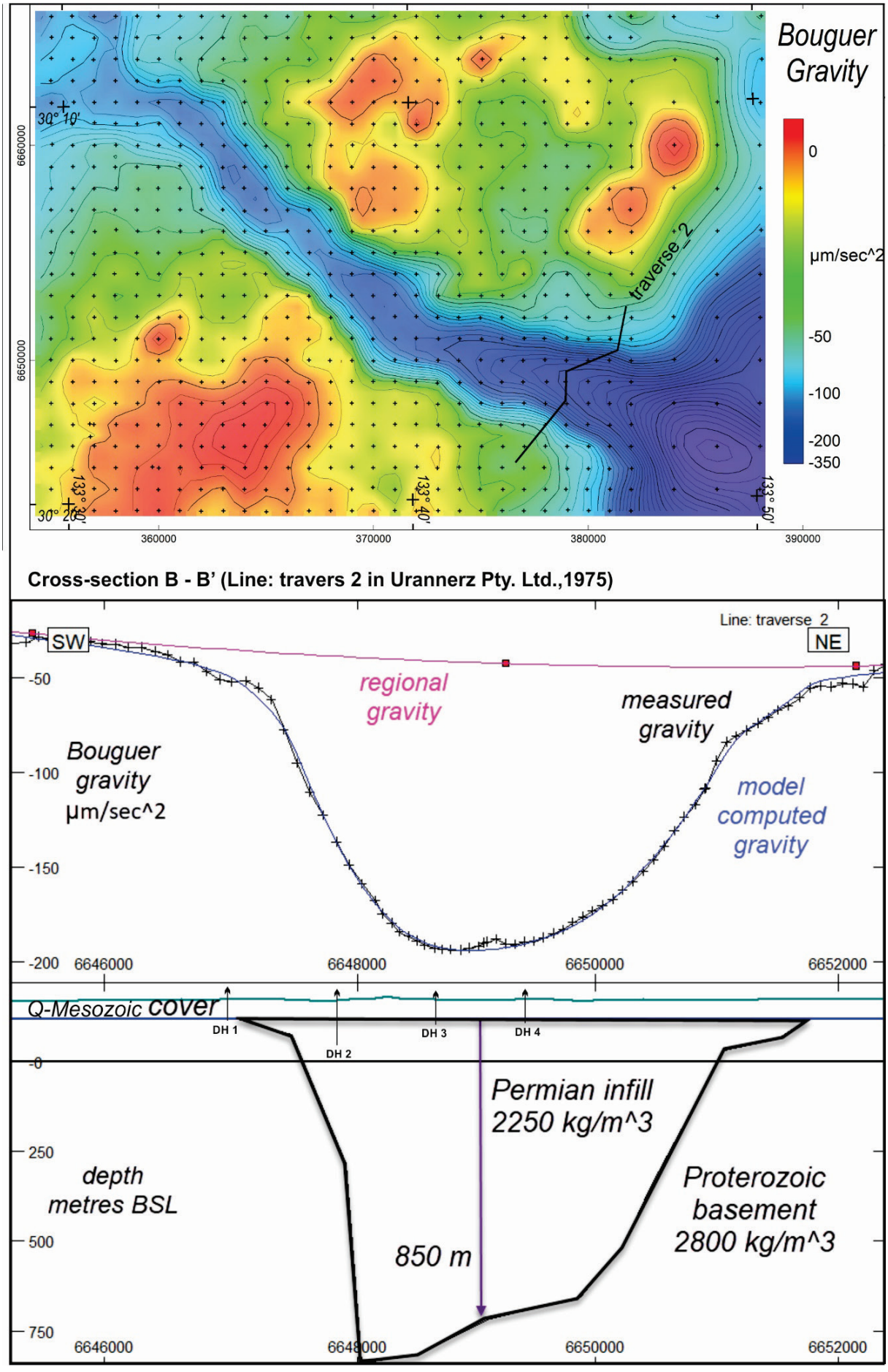


Figure 3.6b Gravity model of this study, showing the Permian channel cross-section B–B' through the Mulgathing Trough in the study area.

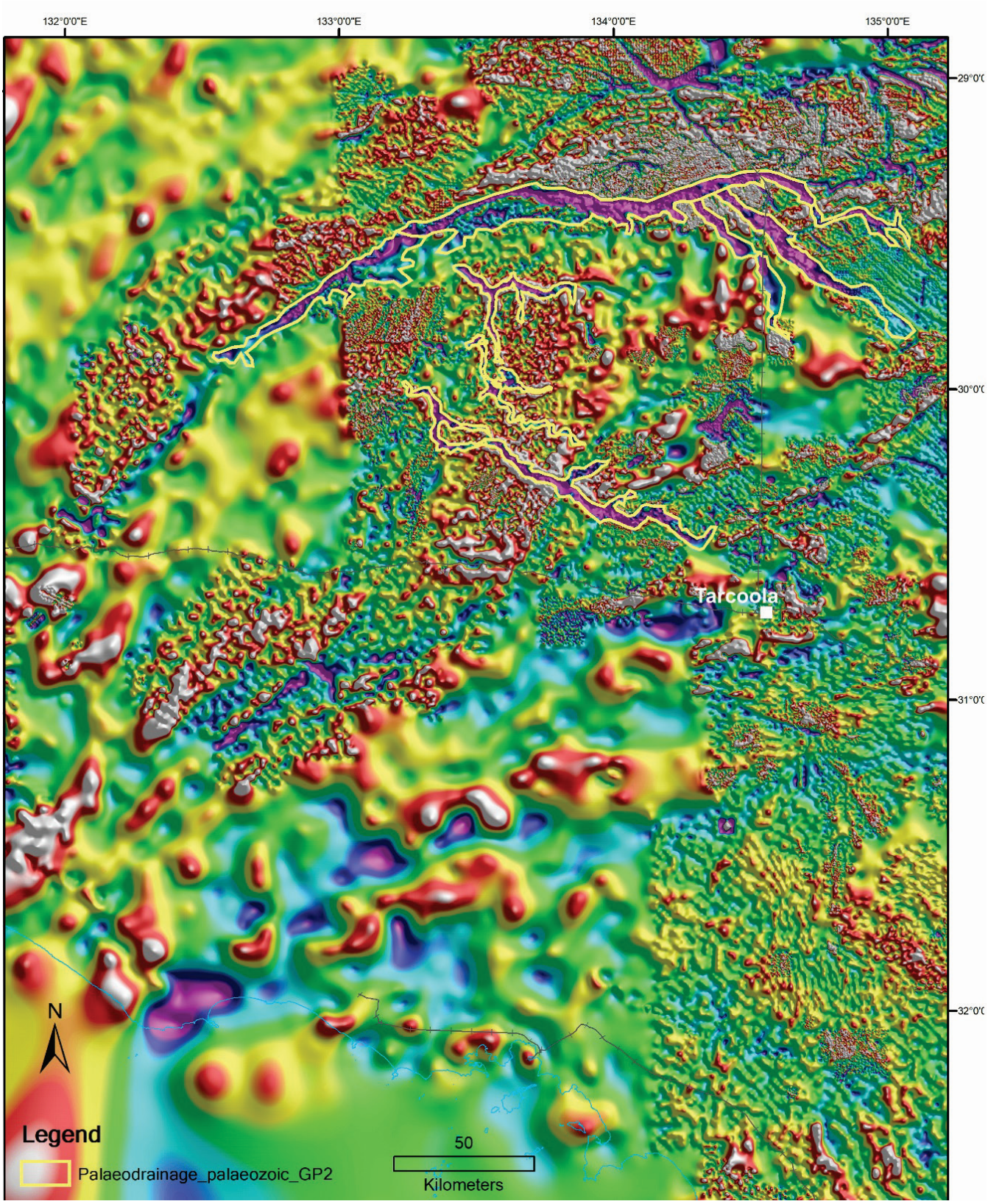


Figure 3.7 Paleovalley mapping on GP2 gravity data 1VD image.

Within the survey area the Mulgathing Trough contains an estimated thickness of 800 m or more of Permian glacial sediments. These sediments have lower density than the surrounding Proterozoic basement rocks and generate a prominent, sharp negative gravity anomaly. The linear and steep flanking gradients of the gravity anomaly suggest that the trough is fault-bounded. Figure 3.6b shows the Bouguer gravity image over a 27 km long and 3.5 km wide northwest to southeast trending section of the trough along which the trough narrows and shallows to the northwest as revealed by a decrease in width and amplitude of the gravity anomaly.

The prime advantage of the new one-kilometre spaced gravity data is in mapping the horizontal location, extent and trend of the trough but unfortunately, the station spacing is too wide to well constrain the vertical extent of the trough. The amplitude of the measured gravity anomaly depends both on the thickness of sediments in the trough and on the contrast in density values between the sediments and the surrounding basement rocks. Without knowledge of the density contrast value the thickness of sediments cannot be resolved directly from the gravity data. An industry study by Uranerz Australia in 1975 acquired seismic refraction data and 100 metre spaced gravity measurements on 5 traverses across the trough (Fig. 3.6a). They also drilled 18 holes, but only two to any considerable depth (261 and 158 m) through Tertiary cover and Permian shales without intersecting basement. Unfortunately, the seismic data quality was reported as very poor due to high velocity near-surface layers of silcrete and calcrete and a survey design based on expectation of a maximum depth of 150 m (Uranerz, 1975).

We estimate the density contrast to be between 550 and 600 kg/m^3 by determining depths to the top of magnetisation beneath the trough and then testing to find the density contrast values that give sediment thicknesses consistent with those depths. For the magnetic field modelling we used the recent Gawler Craton Airborne Survey (GCAS) data acquired on north-south flight-lines at 200 m spacing and 60 m terrain clearance. Magnetic field anomalies suitable for generating depth estimates are only found at a few locations along the axis of the trough and the uncertainties on those depth values are at least +/- 10%. However, with the estimated density contrast value we were able to map the depth of the trough along the 27 km length we modelled. The most informative modelling is of the Uranerz traverse 2 with the advantage of the 100-metre station spacing rather than the one-kilometre station spacing of the regional survey data. This additional detail as shown in Figure 3.6b reveals that the cross-section of the trough approximately matches the cross-section of the gravity anomaly, with steep gravity gradients over the southern margin of the trough due to a steeply dipping fault surface and the lower gravity gradients over the northern half of the trough. This pattern appears to vary along the axis of the trough but is only partially constrained with the one-kilometre spaced data. With the estimated density contrast value of 550 kg/m^3 the model depth of the trough on the Uranerz traverse 2 is approximately 850 m.

Mesozoic paleodrainage systems

Due to the extensive burial and erosion of the southwestern margin of the Eromanga Basin, there is uncertainty on where to map the Mesozoic paleodrainage systems (Figs 3.6 and 3.8). In the study area, the Mesozoic paleovalleys were started with very widespread fluvial and lacustrine to marginal marine sedimentation. Sediments were deposited along the southwestern margin of the Eromanga Basin, mainly including Algebuckina Sandstone, Cadna-owie Formation (terrestrial-freshwater to marine) and Bulldog Shale (Fig. 2.5)

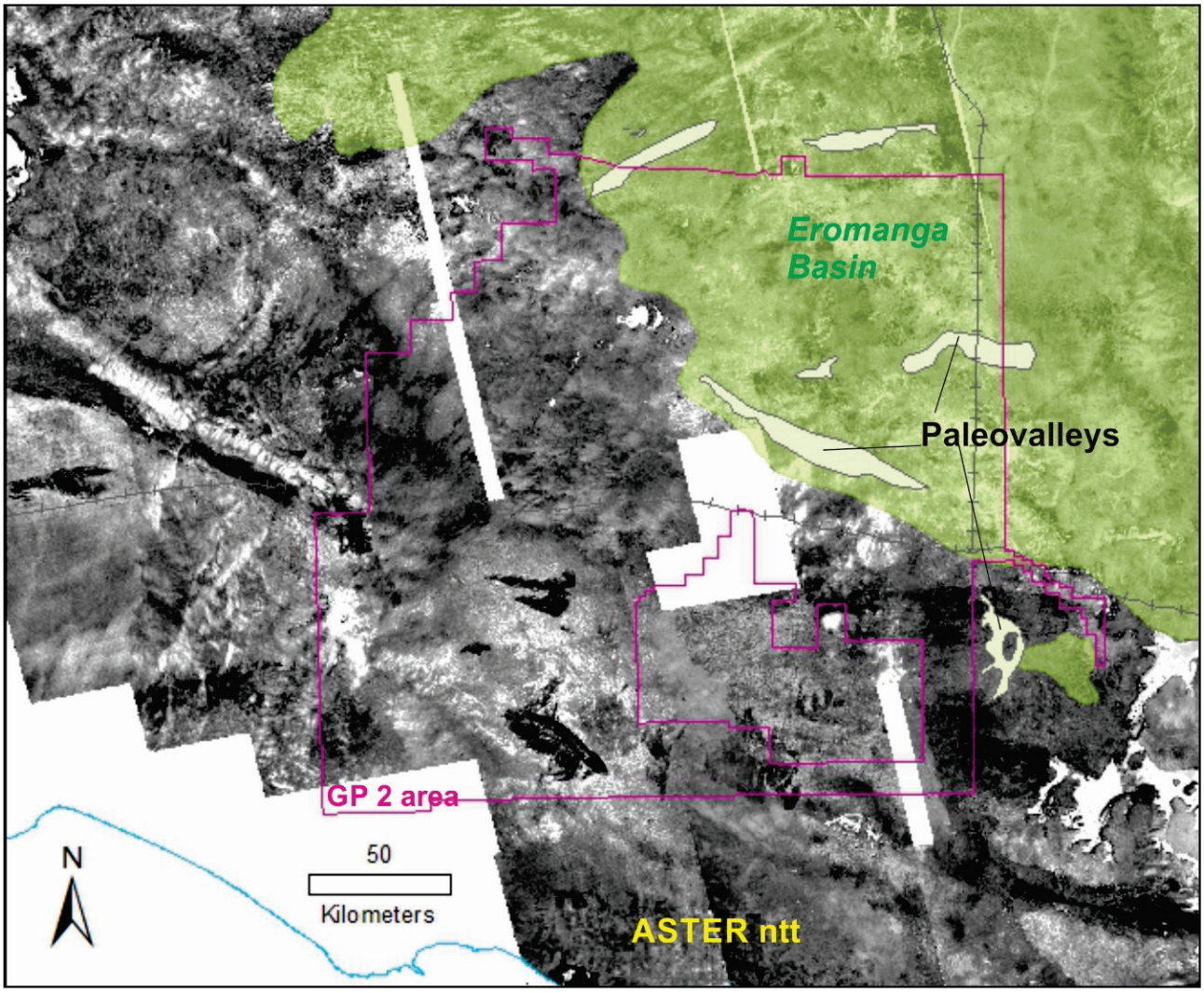


Figure 3.8 Mesozoic paleovalleys mapped over ASTER ntt image (GSSA data), showing the relationship with the Eromanga Basin and GP2 area.

Cenozoic paleovalley systems

OOLDEA, BARTON AND PALING RANGES/BARRIERS

The Ooldea, Barton and Paling ranges are a preserved assemblage of Eocene coastal aeolian landforms that include coastal dunes, dune ridges and possible beach ridges (also named Ooldea, Barton and Paling Barriers; Fig. 3.9; Benbow, 1990a). In each of the ranges, sedimentary successions, marine and fluvial Middle – Late Eocene Pidinga Formation occur in the lower part and are overlain by the aeolian Ooldea and Barton Sands in the upper part.

The Ooldea Range is trending northwest–southeast over a distance of 650 km, is 10–25 km wide, and standing 40–180 m above the Bunda Plateau (Benbow, 1988). In the Ooldea Range, dune crests reach 300 m AHD, which is 40–180 m above the top land surface of the Nullarbor Plain. The range is composed of coastal dune ridges that mark the edge of the sea during the Middle Eocene (e.g., Benbow, 1990a). A number of segments occur long the Ooldea Range, which are separated by low saddles or breaches or tidal inlets that are the termination of, or through which flowed paleorivers such as those associated with the Serpentine Lakes, Karari, Woldra and Wynbring paleovalleys (Fig. 3.10). The north-western major segment consists of several gently curved small segments that are characterised by broad flat crests on which are superimposed numerous distinct dune ridges that are usually 2–5 km apart and have a height of 10–15 m. These may also include less distinct smaller ridges that can be recognised from satellite and DEM images.

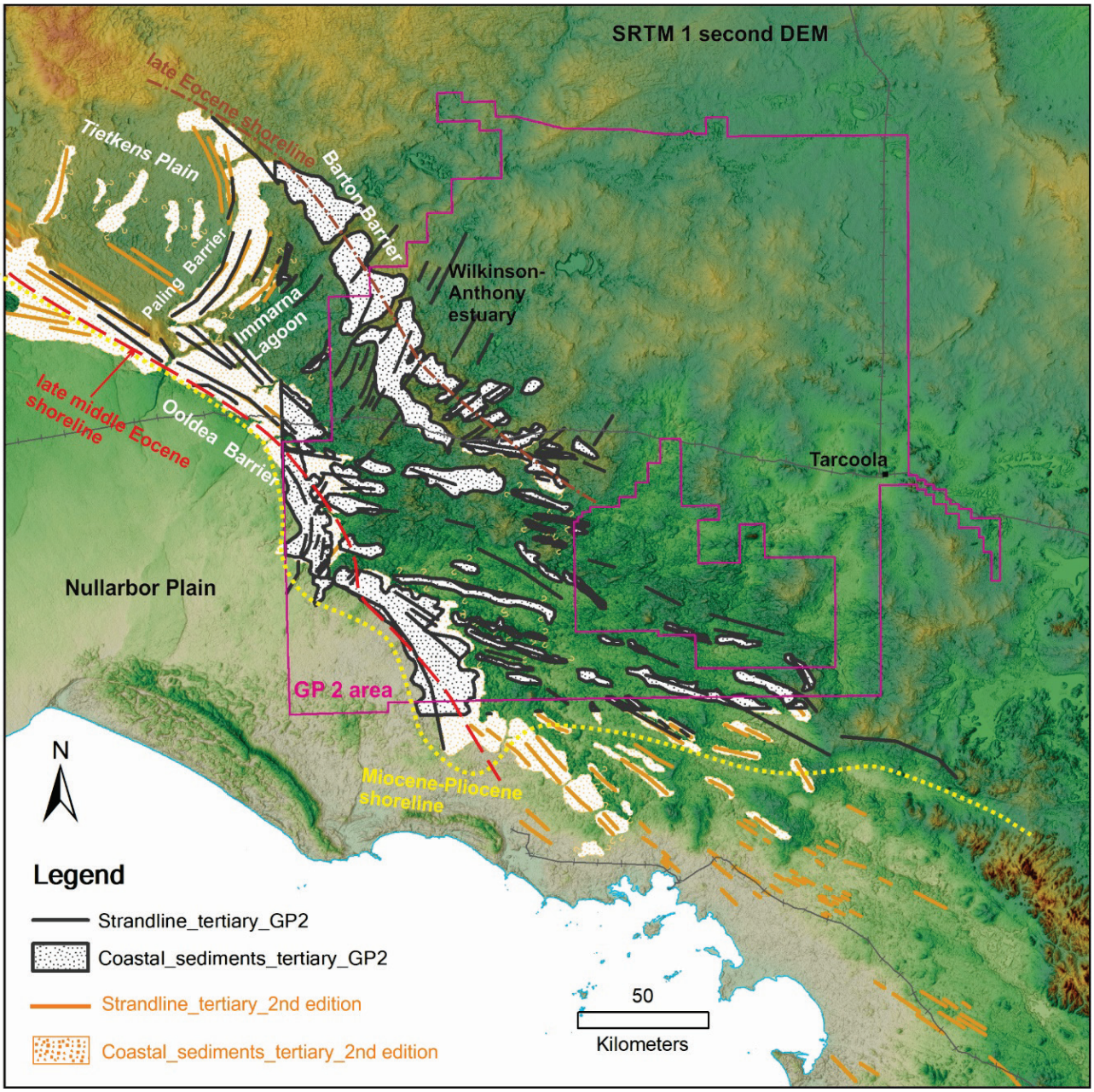


Figure 3.9 Comparison of Paleogene-Neogene coastal paleo-geomorphic components between the GP2 and 2nd edition of paleovalley maps, showing their relationship along the Eastern Eucla margin over DEM image.

Parallel to the Ooldea Range and some 40–70 km northeastwards lies the shorter Barton Range that marks the edge of the sea during the Late Eocene. In the study area, the Barton Range is a broadly sinuous coastal dune belt, which is about 250 km long, and 5–7.5 km wide at its northwestern end and up to 25 km wide over a significant part of its length (Fig. 3.9). The Barton Range is 20–120 m above the surrounding land surface, with the elevation varying from 200–300 m AHD (Benbow, 1990a). The northwest 78 km-long segment of the Barton Range is like the middle segment of the Ooldea Range, but to the southeast appears to broaden in a width of about 35 km (middle segment), coinciding with elevated shallow crystalline basement and older basin deposits in the eastern part (Benbow, 1988). Further to the southeast the Barton Range is broad but low, lying only 20–40 m above the surrounding land surface (Benbow, 1990a). The less well-defined southeastern segment of the Barton Range appears to split into two major branches of similar elevation, where there are many isolated to partly connected areas of topographically low relief within it (Benbow and Crooks, 1988). The southern branch is irregular, and drilling indicates the presence of substantial sands at its northwest end, suggesting this feature is a continuation of the coastal dune (Benbow, 1988).

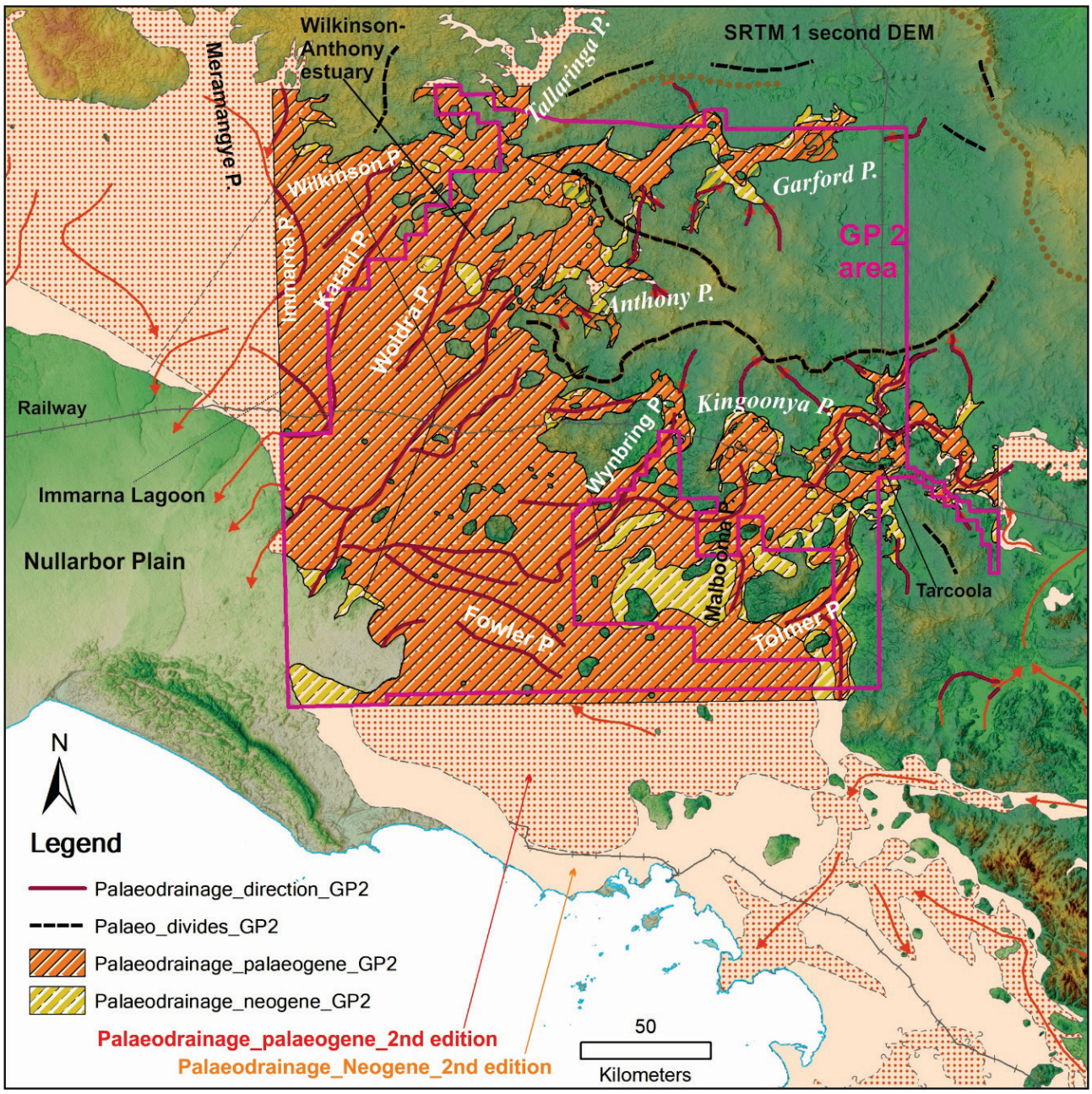


Figure 3.10 Comparison of Paleogene–Neogene paleodrainage system components between the GP2 and 2nd edition of paleovalley maps, showing their relationship with the Eastern Eucla margin over DEM image.

To the northwest of the study area, both, the Ooldea and Barton Ranges, are joined by the Paling Range that is 71 km long and arcuate shaped, connecting the Ooldea Range near Maralinga to the northwest end of the Barton Range (Fig. 3.9). A detailed account of the paleo-geomorphology of these landforms is provided by Benbow (1989). The Paling Range averages 20 km width along most of its length and narrows to 5–7.5 km at its northern end, where it is less well defined (Benbow, 1988). In the Paling Range there are parallel dune ridges and a number of small, disconnected depressions which may indicate the existence of a former paleochannel (Benbow, 1989; Roger, 2000; Hou et al., 2007a). Largely, the Paling Range has an orientation that parallels the major fabric of the underlying crystalline basement of the western part of the Gawler Craton, laying along the boundary between aeromagnetic provinces of contrasting character (Benbow, 1988).

PALEOSHORELINES

The Cenozoic shorelines, defined as bodies of coastal sand, comprise beach, shoreface, barrier, dune, tidal inlet, washover and lagoonal deposits (Hou et al., 2003b), regionally representing third-order highstands (Clarke et al., 2003; Hou et al., 2003c). Along the eastern Eucla margin, the paleoshorelines and paleoriver mouths are characterised by deposits that reflect a series of former estuaries (e.g., mouth of Wilkinson and Anthony Paleovalleys), as well as lagoons and coastal barriers (e.g., Ooldea and Barton Barriers). In the study area, three distinct constructional/depositional phases for the development of shorelines can be recognised and correlated with major third-order sea-level events, established from the marine depositional record, occurring during the late middle Eocene (39–36 Ma), late Eocene (36–34 Ma), and Miocene–Pliocene (15–2.6 Ma; Clarke et al., 2003; Hou et al., 2003c; Figs 2.11 and 3.9).

The influence of late Middle Eocene Tortachilla and Late Eocene Tuketja-Tuit transgressions (Fig. 2.11) extended some several hundred kilometres up paleovalleys (e.g., Tallaringa, Garford and Kingoonya paleovalley systems) that drain the Gawler Craton and into the Eucla Basin (Alley et al, 1999; Clarke et al., 2003). Initial development of the late Middle Eocene shoreline during the Tortachilla Transgression is expressed as marginal marine and estuarine (carbonaceous) sand, silt and mud onlapping an erosional surface in the coastal plain and adjacent paleovalleys along the Eucla margin (Hou et al., 2022). The highstand deposits of this sequence are locally intercalated with carbonaceous, calcareous and glauconitic limestone (e.g., Paling Formation), and with barrier sands of the Ooldea Sand (Zone P14-15, Fig. 2.10) in the eastern part of the basin. The Tortachilla shoreline is characterised by the Ooldea Barrier along the northern and eastern margin of the basin. Shortly afterwards, a yet higher sea level led to further marine transgression during the Tuketja-Tuit transgressions and resulted in the shoreline migrating farther inland (Figs 2.11 and 3.9). The shoreline position extended to the inland margin of the Barton Barrier–Wilkinson Estuary in the study area (Hou et al., 2003b; Fig. 3.9), as characterised by the Barton Range.

The Barton and Paling barrier systems are characterised by a series of Late Eocene (36-34 Ma) coastal sand barriers, oriented SW-NE, while the Ooldea Barrier was partly submerged to form a string of offshore barrier islands (Clarke and Hou, 2000; Hou et al., 2003a, c; 2006b). The ‘Ooldea and Barton barriers’, characterising early Cenozoic morphology, are not strictly equivalent to the present day ‘Ooldea and Barton Ranges’, which reflect additional aeolian reworking following several marine regressions and later dry and windy conditions that accompanied cycles of Southern Hemisphere glacial maxima during the Quaternary (Sheard et al., 2006). Landward of the Ooldea Barrier, parallel beach ridges developed in the Late Eocene that reflect the interaction of localised sediment supply along paleodrainage networks and continuous, westerly long-shore drift processes operating behind the Ooldea Barrier ‘islands’ (Hou et al., 2022). Sediments comprise both lagoonal facies and barrier facies with beach placer potential (Reid and Hou, 2006), although wave energy was likely much less than that for the seaward Ooldea Barrier. The elevation of the Barton–Paling barrier/ridge decreases toward the southeast, following the long-shore drift direction, reflecting the combined effects of a decrease in sand supply from the northwest and a broader-scale, relative east-down vertical movement (Hou et al., 2008). Paleoclimate modeling (Kemp, 1978) indicates westerly winds predominated across southern Australia at latitudes between 60° and 80°S in the Paleocene and Eocene. This is consistent with the occurrence of coastal dune barriers along the eastern Eucla Basin margin and the apparent absence of substantial dunes along the western Eucla margin. ‘J-shape’ barriers behind the Ooldea Barrier that formed during the Late Eocene may indicate a more north-westerly component to the prevailing winds at that time (Hou et al., 2011b).

The Neogene shorelines mainly followed those of the late Middle Eocene in the northeastern margins of the Eucla Basin (Fig. 3.9). Towards the southeast, however, analysis of the geomorphology of Cenozoic coastal deposits and sequences in selected drillholes across the southeastern basin provide a record of progressive Mio- to Pliocene coastal progradation, followed by a series of regressive strandlines that show the orientation at an angle to the Ooldea Barrier (Fig. 3.9; Hou et al., 2008; 2011b). This pattern of sedimentation, reflecting Mio- to Pliocene sea-level change, is not apparent along the western margin of the basin because of continental scale tilting and relative uplift of the region (Hou et al., 2008, 2011b). More extensive inundation of this area was due to downward tilting of the basin towards the east. The prolonged nature of the

dynamic tilting is indicated by a relative north-eastward decline in elevation of the key Eocene surfaces and 'reverse flow' features in Neogene paleovalleys in the western Gawler Craton (Hou et al., 2008). Thus, the Neogene shoreline that developed in the southwestern Gawler Craton following maximum marine transgression extend farther inland than those of the Eocene (Hou, 2008). These may prove also to be prospective for heavy mineral deposits.

To the northwest of the study area, a recent groundwater drilling program conducted within Lindsay East Paleovalley, followed by palynology analysis and dating (Krapf et al, 2019), indicates inland marine influence during the Late Miocene to Early Pliocene. The marine influence reaches as far as the foothills of the Musgrave Ranges, where alternating freshwater, lacustrine and marginal marine to estuarine conditions during the Late Miocene – Early Pliocene are documented in drillhole DH1A (Krapf et al, 2019). Palynological evidence for similar marine influence during Late Miocene – Early Pliocene are also identified in adjacent areas in drillholes Officer 1 and MAN1 (Zang and Stoian, 2006).

IMMARNA LAGOON AND WILKINSON-ANTHONY ESTUARY

Northwest of the study area (southeast of the Paling Range), situated between the parallel Ooldea and Barton ranges, Immarna Lagoon is a mostly buried coastal terrain of lagoonal origin. To the northwest, beyond Lake Maurice, there is also evidence for another similar landform (Figs 3.9 and 3.10).

The Anthony Paleovalley mouth is characterised as a wide estuarine funnel with islands and/or basement highs, suggesting a persistent swamp environment during the Eocene (Hou et al., 2011a, 2022). The channel was likely blocked by basement highs or beach barriers that built up as the sea advanced up the Anthony Paleovalley, where, together with the Wilkinson, Karari and Woldra paleovalleys, the area is known as the Wilkinson–Anthony Estuary (Figs 3.9 and 3.10) (Hou et al., 2001a). In the subsurface Karari Fault (Fig. 3.11) runs through the Wilkinson–Anthony estuary and probably influenced the development of the central part of the funnel. The well-developed carbonaceous facies in the Pidinga Formation indicates that the floodplain in the estuarine funnel area formed in a climate suitable for the growth of abundant vegetation. Silicification at the top of the Khasta and Pidinga formations indicates post-Eocene weathering. The Wilkinson, Karari and Woldra paleochannels in the estuary are characterised by tidal inlet deposition with a strong marine influence as indicated by tidal sedimentary structures and relatively abundant siliceous spiculate facies (Hou et al., 2001a). The facies evolution from channel to estuarine to marginal marine can be recognised in drillholes (Figs 3.11 and 3.12) and from palynological evidence (Zang and Stoian, 2006; Hou et al, 2022) Locally, tidal current erosion prior to deposition of the Khasta Formation can be observed.

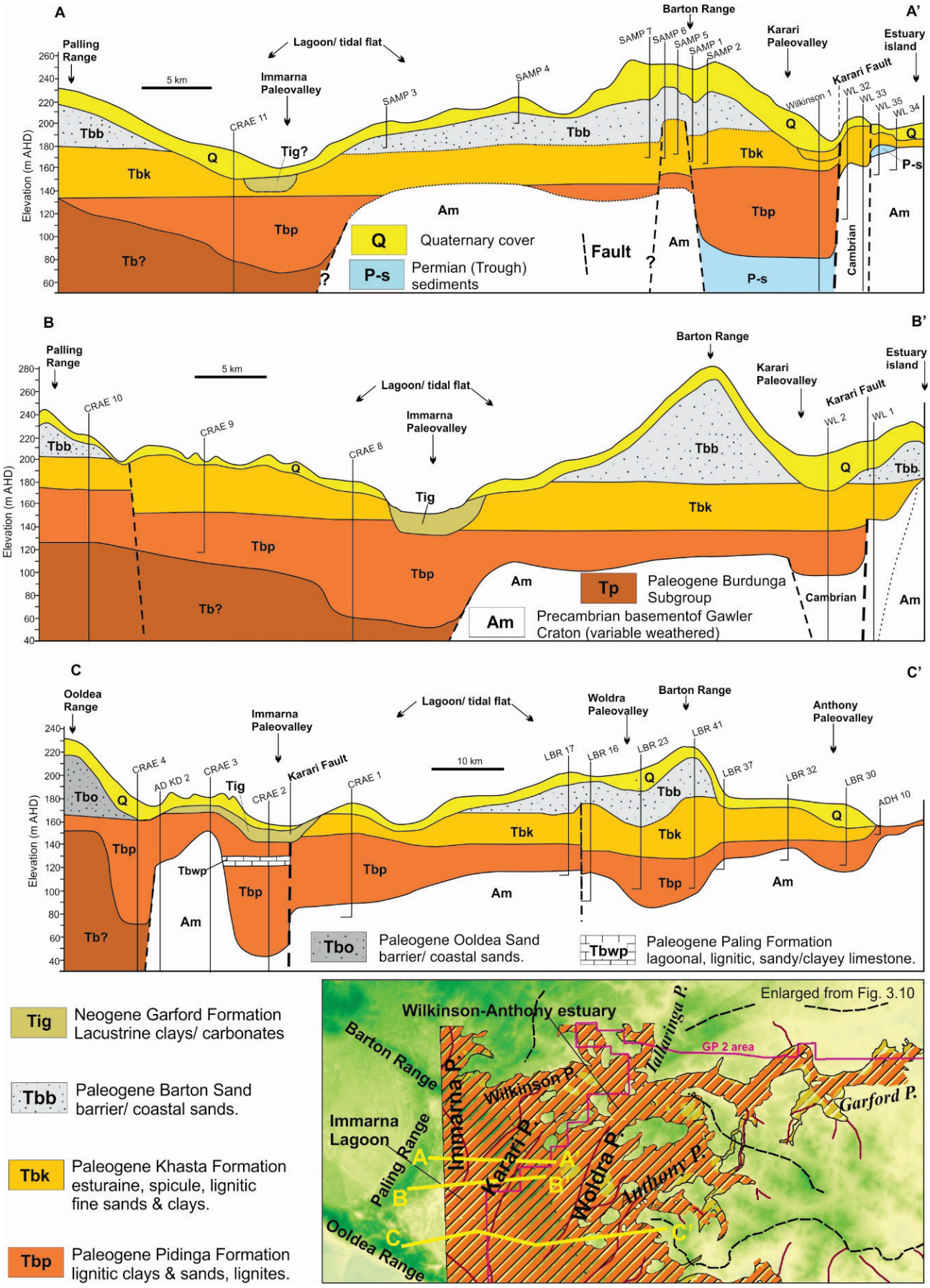


Figure 3.11 Cross-sections through the Immarna lagoonal coastal area of the eastern Eucla margin based on drillholes (name of drillholes are given, all drillhole data is available from SARIG; modified from Hou et al., 2001a).

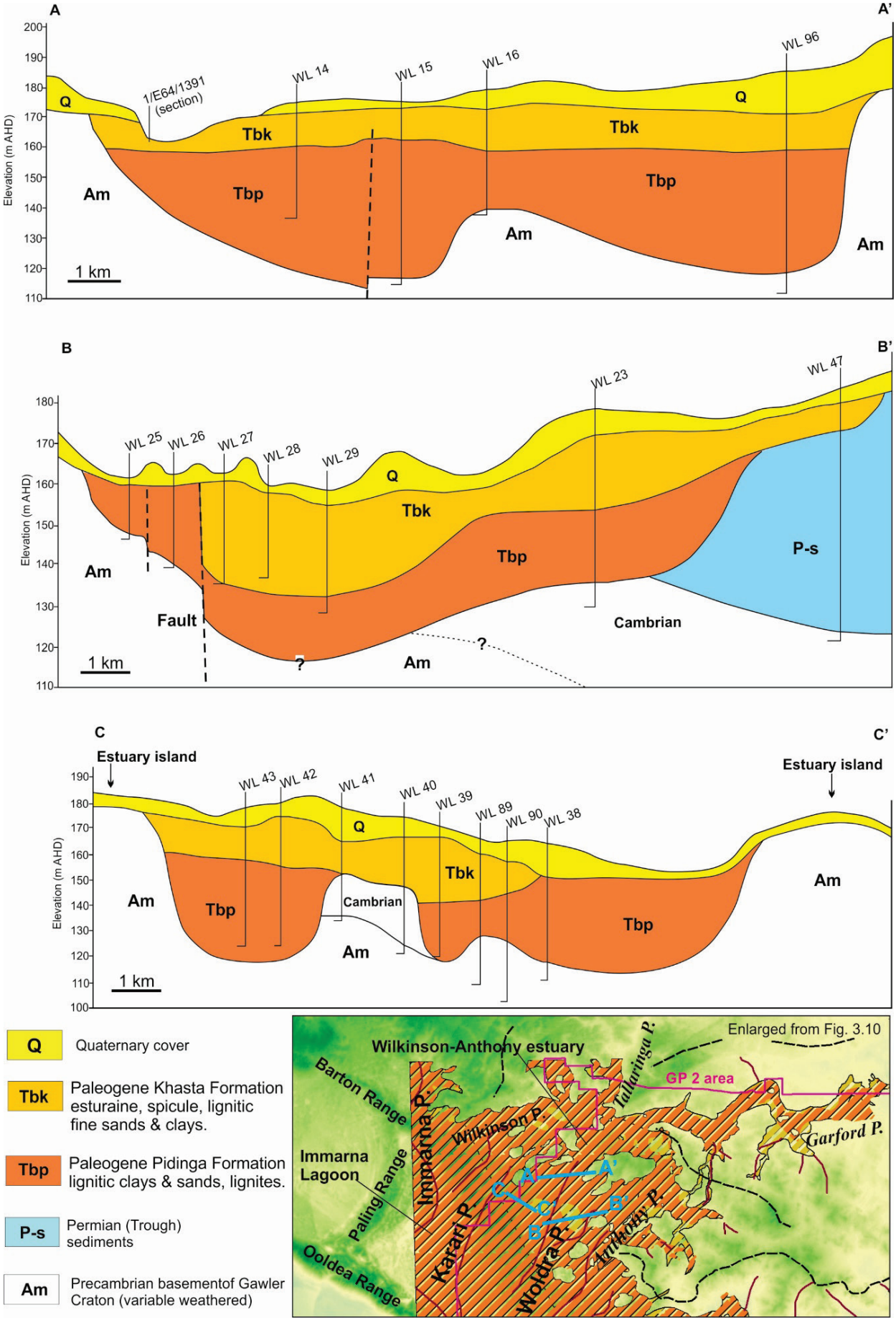


Figure 3.12 Cross-sections through the tidal inlet part of the Woldra Paleovalley based on drillholes (name of drillholes are given, all drillhole data is available from SARIG; modified from Hou et al., 2001a).

EUCLA PALEOVALLEY SYSTEM

The Eucla Paleovalley System is composed of several paleovalleys (Fig. 2.6) that merge towards the margin to one large system. The dendritic pattern of paleovalleys is a prominent feature of the eastern onshore Eucla Basin (Fig. 3.12). Some paleorivers had their source towards the continent's center in the region of the Musgrave Province, Officer Basin and Gawler Craton (Fig. 2.1). Many of these paleovalleys had their origins prior to the Late Eocene and after the Early Cretaceous, such as those on the southwestern margin of the Eucla Basin where they have been developed in the Late Cretaceous, during separation of Australia from Antarctica (Ollier et al., 1988). For instance, the paleochannel of the Tallaringa Paleovalley has dissected sediments of Early Cretaceous age and was subsequently infilled with Eocene sediments (Benbow, 1993). Also, the paleovalleys clearly defined in the region of dissected crystalline basement of the Gawler Craton are likely to be considerably older than Late Eocene (Hou, 2008).

The Eucla paleovalley system in the study area has been recognised and delineated using SRTM DEM, Landsat ETM7 and NTT images, and geological data (e.g., maps and drillhole). These paleovalley systems formed in the onshore extensions of the Eucla Basin and are today covered by Quaternary sediments (Benbow et al., 1995a; Hou et al., 2003a). They are largely superimposed on and locally obscure the older Paleogene and/or Neogene landforms. Other subsurface features such as those interpreted from NOAA and geophysical datasets (where available) have also been valuable in delineating the paleochannels.

In the western Gawler Craton paleovalleys preferentially follow the topographic lows within weakly resistant, deeply weathered bedrock (Benbow et al., 1995a; Hou et al., 2003a). The dimensions of the Eucla paleovalley system vary greatly. Paleovalley widths range from a few tens of metres to more than 30 km, depths can be up to 100 m, and main channel lengths extend typically 100 to 700 km into the hinterland (Alley et al., 1999). The principal direction of the paleodrainage flow was directly towards the Eucla Basin from the continent, but, locally, some paleochannels feeding the eastern Eucla Basin show apparent reversed gradients at key stratigraphic horizons (Hou et al., 2001a). The lower reaches of the major paleovalleys are characterised by a series of estuaries (e.g., Wilkinson), coastal barriers and lagoons (Figs 3.9 and 3.10). Drillhole-controlled transects in the western Gawler Craton (e.g., for the Garford Paleovalley) indicate that irregularities along the paleovalley floor dominantly occur as highs with an elevation of about 10–20 m above the regional gradient (Hou et al., 2003a; de Broekert and Sandiford, 2005). Changing sediment patterns and flow reversals observed within the eastern Eucla paleovalley fills suggest that the paleovalleys were affected by post-Eocene tectonic movements (Hou et al., 2008). The paleovalleys form a well-integrated contributory pattern. They typically have a V- (mostly upper reaches), U- (mostly middle reaches) or W-shaped (mostly lower reaches) cross-sections (Hou et al., 2001b).

There are several exit points of Paleogene to Neogene major paleovalleys through the paleoshorelines in the study area (Figs 3.9 and 3.10). Major Eucla paleovalleys (e.g., Tallaringa, Garford, Anthony and Kingoonya) are bounded by regional drainage divides and occupied by drainage networks (Bates and Jackson, 1987), ranging from individual hillslopes surrounding small headwater tributaries, to large tracts of hinterland drained by major river networks. These major paleovalleys form a roughly radial pattern focussed on the eastern Eucla Basin margin (Fig. 3.10). Within some drainage basins (e.g., Kingoonya Paleovalley), locally, the tributaries are left free to branch in almost any direction and to follow irregular courses with many random bends. Sedimentation within these paleovalleys was similar to that described in the Garford Paleovalley.

GARFORD PALEOVALLEY

The Garford Paleovalley drained the northern part of the GP2 area, with the paleo-headwaters near the Stuart Range (to the east of the study area) and the channel mouth in the Wilkinson-Anthony Estuary (Figs 1.1, 3.9 and 3.10). Within this paleodrainage system, channel-fill lithologies are highly variable and show complex facies relationships and erosional contacts (Fig. 3.13; Hou et al. 2003). The Garford Paleovalley was studied in detail by Hou et al. (2001a) using sedimentary analysis of numerous cross- and longitudinal sections, depth-to-basement maps, and TEM and gravity surveys in places across the paleovalley. The basal unit in the Garford Paleovalley is the Pidinga Formation, consisting of carbonaceous sand, silt and clay horizons, with occurrences of

lignite (Lindsay and Harris 1975; Alley 1985; Alley and Benbow 1989). The Pidinga Formation overlays unconformable the Archean–Proterozoic crystalline basement, and locally sedimentary rocks of Paleozoic age (Permian trough) and/or deposits of the Jurassic–Cretaceous Eromanga Basin (Fig. 3.13).

Throughout the Pidinga Formation, the presence of overbank deposits that laterally replace the trough-cross-bedded, fining upward coarse-grained sediments of the channel fills, and the abundance of marsh and swamp deposits, suggests that discharge was at least periodically strong. The Pidinga Formation is unconformably overlain by dolomitic clays, clayey sands and dolomitic limestones of the Garford Formation (Benbow and Pitt 1978; Keeling, Ferris and Statham-Lee 1995). The Garford Formation is unconformably overlain by Quaternary deposits (Sheard et al. 2006).

The general trend for the base of the paleovalley is to rise from ~80 m asl. at the bayline (Posamentier et al., 1988) to 120 m asl. as seen in drillhole 5638-253 in the middle reach of the Garford Paleovalley, providing a gradient of ~0.1% (Fig. 3.13b). The negative gradient in the lower channel reach (-0.16‰) may be due to post-Eocene uplift along the northeastern margin of the Eucla Basin (Hou et al., 2008). Therefore, the current expression of the drainage lows and channel bases rarely coincides with the actual deepest parts of the paleovalley, particularly in their lower reaches.

KINGOONYA PALEOVALLEY

The Kingoonya Paleovalley, which joins Wynbring Paleovalley to the west is one of several incised-valley systems that contain Paleogene-Neogene marine-influenced fluvial sediments (Fig. 3.10; Hou, 2008). Paleochannel mapping and sampling with test drilling has indicated that the Kingoonya Paleovalley drained across the western Gawler Craton from east to west. Significant gold mineralisation is known in the area (e.g., Tarcoola and Glenloth) and there is potential for channel-hosted mineralisation (e.g., gold, uranium, groundwater; Hou, 2008). The vast blanket of surficial cover masks much of the geology of the Kingoonya Paleovalley drained region, including the deposits of the paleovalleys and underlying older basin and basement rocks.

Today's land surface indicates little of the complex paleovalley architecture that lies beneath. Drilling revealed Quaternary sediments concealing a complex pattern of Paleogene-Neogene paleochannels that incised and overly weathered bedrock, with paleochannel deposits ranging in thickness from a few metres to 145 m (Figs 3.14; Hou, 2008). Complex relationships between the Quaternary sediments, Paleogene-Neogene channel fills, and older (e.g., Mesozoic) sediments and deeply weathered basement can make paleochannel identification difficult. Paleogene-Neogene fluvial, lacustrine and even estuarine to marginal marine sediments accumulated in the Kingoonya Paleovalley during the Middle to Late Eocene and Middle to Late Miocene and Pliocene (Hou, 2008).

TALLARINGA PALEOVALLEY

Only the very lower reach of Tallaringa Paleovalley occurs in the study area (Fig. 3.10). It has a maximum channel length of over 280 km upstream of the present-day Wilkinson Lakes. Although it can be identified by numerous methods, such as DEM, Landsat ETM7 and NOAA images (Figs 2.6, 2.7 and 2.8), drilling is sparse and the information provided is limited, and therefore few factual profiles and sections are available for interpreting facies variation and sediment history. Same as with the Garford Paleovalley, the Miocene lacustrine clay facies (Garford Formation) fill depressions eroded into the Eocene carbonaceous sandy facies (Pidinga Formation; Hou et al., 2001a). The top of the channel-fills has been silicified and ferruginised, forming a duricrust along the valley (Benbow et al., 1995a). The drainage channel is prominent as a dark linear feature on the NOAA NTT imagery due to the cooling response of the water-saturated channel fill (Fig. 2.4).

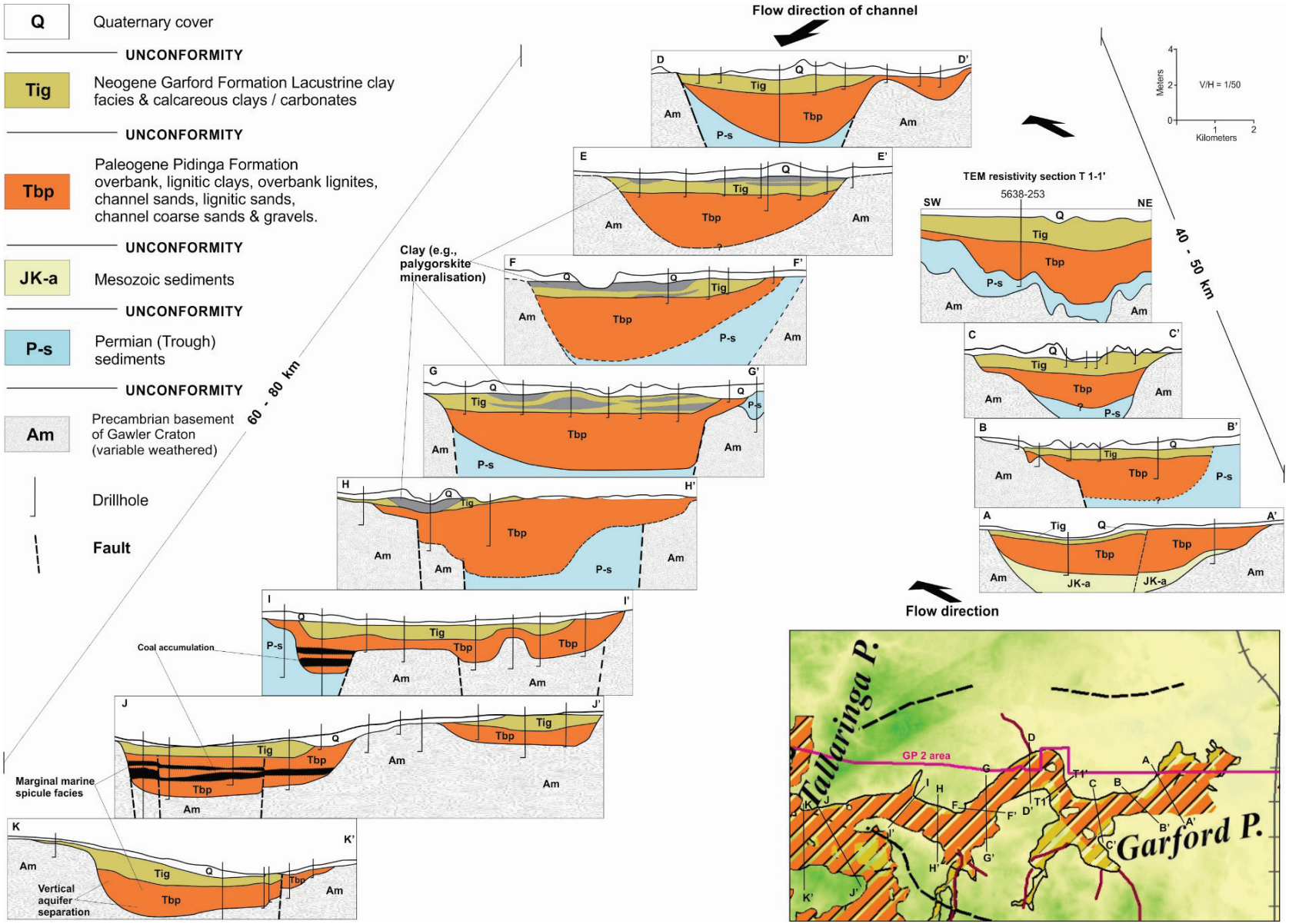


Figure 3.13 a) Sequential cross-sections through length of Garford Paleovalley. The boundaries between units are interpreted by transient electromagnetic (TEM; Dodds, 1996, 1997) and drillhole data (modified from Hou et al., 2001a).

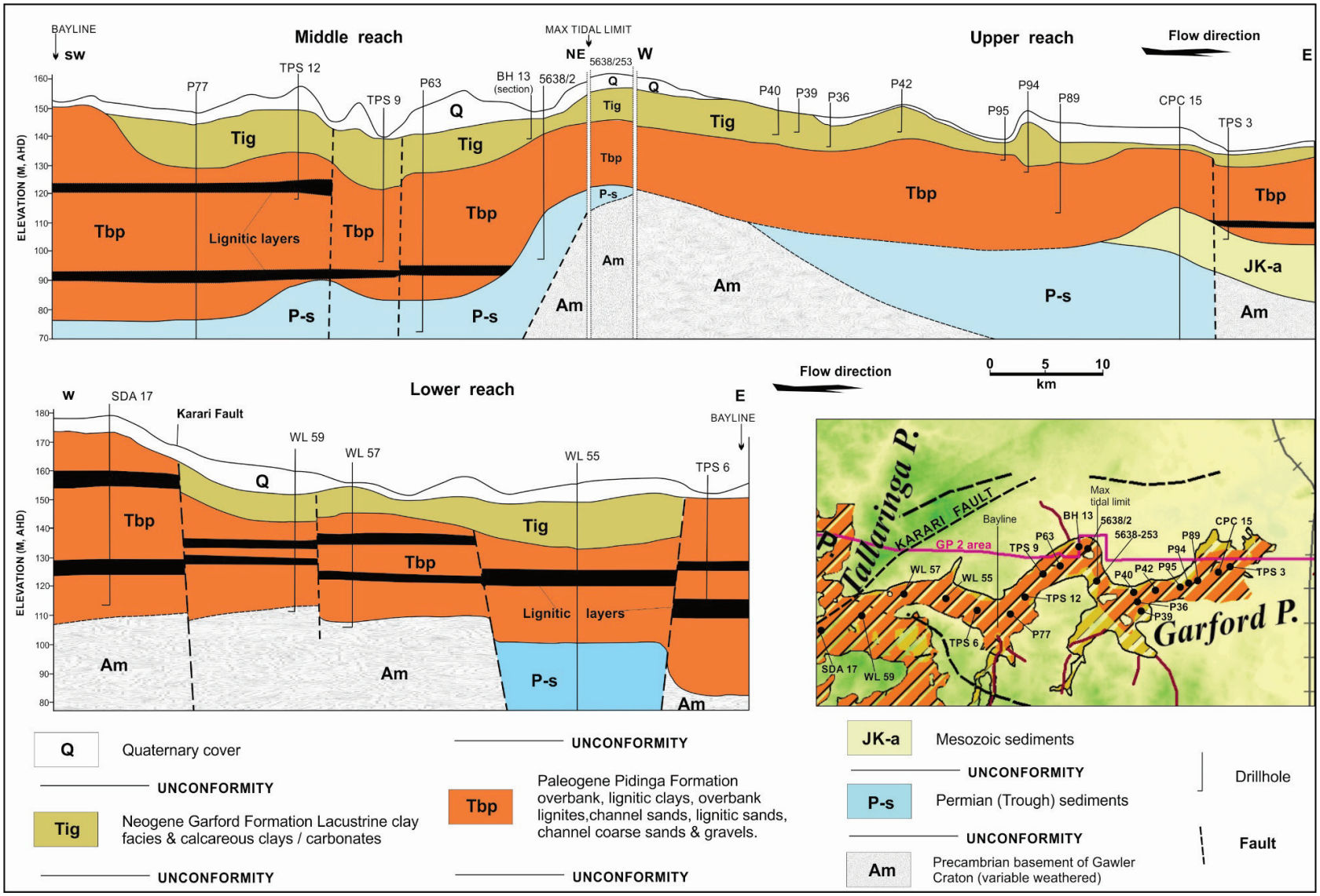


Figure 3.13 b) Longitudinal section through the Garford Paleovalley. The boundaries between units are interpreted by depth to basement contours, transient electromagnetic (TEM; Dodds, 1996, 1997) and drillhole data. Note: some drillholes are not exactly located at the deepest part of the valley (e.g., CPC 15). Stronger post-Eocene tectonic effects are seen in the west than in the east (modified from Hou et al., 2003a).

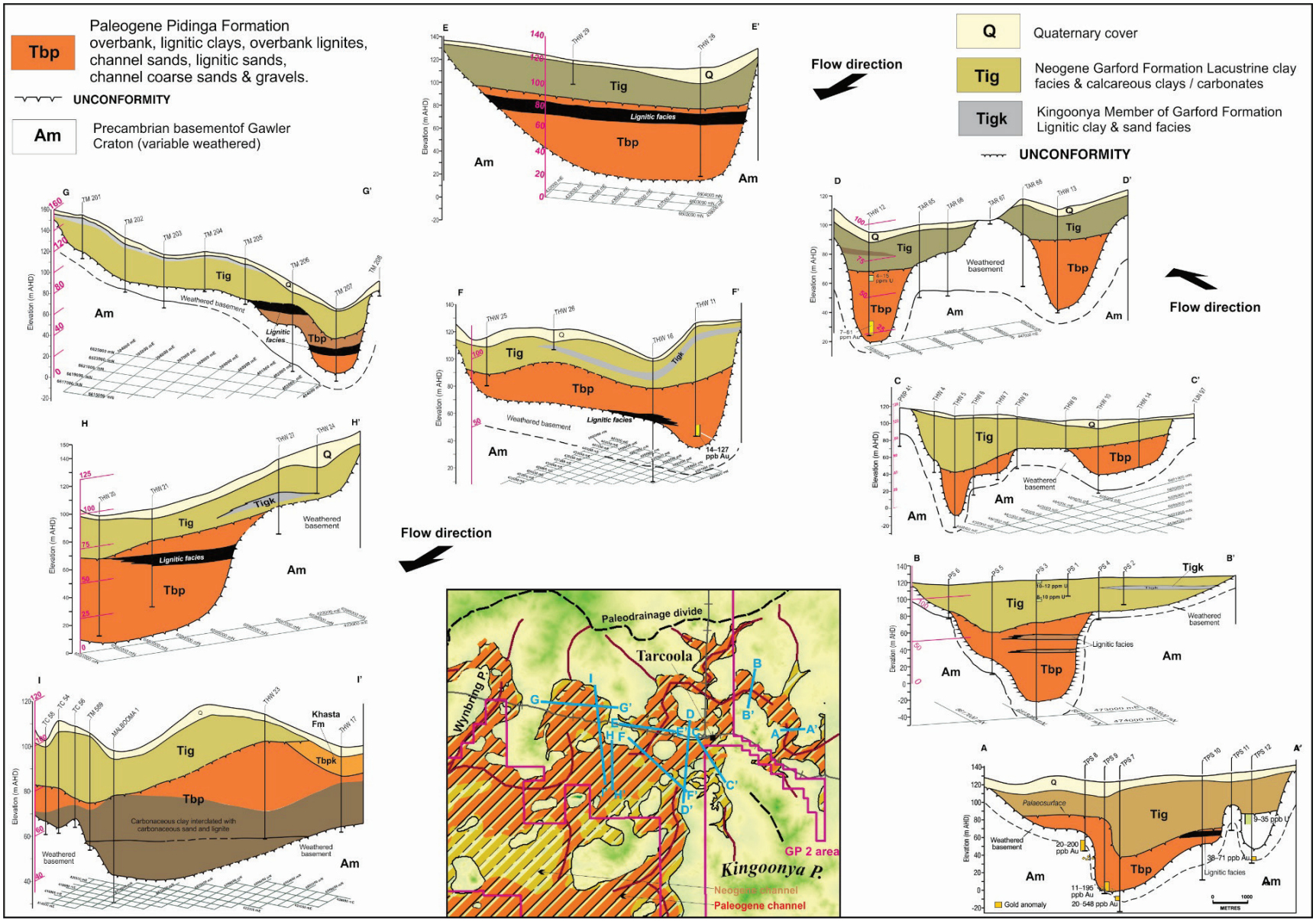


Figure 3.14 a) Sequential cross-sections through length of Kingoonya Paleovalley based on drillhole data (name of drillholes are given, all drillhole data is available from SARIG; modified from Hou, 2008).

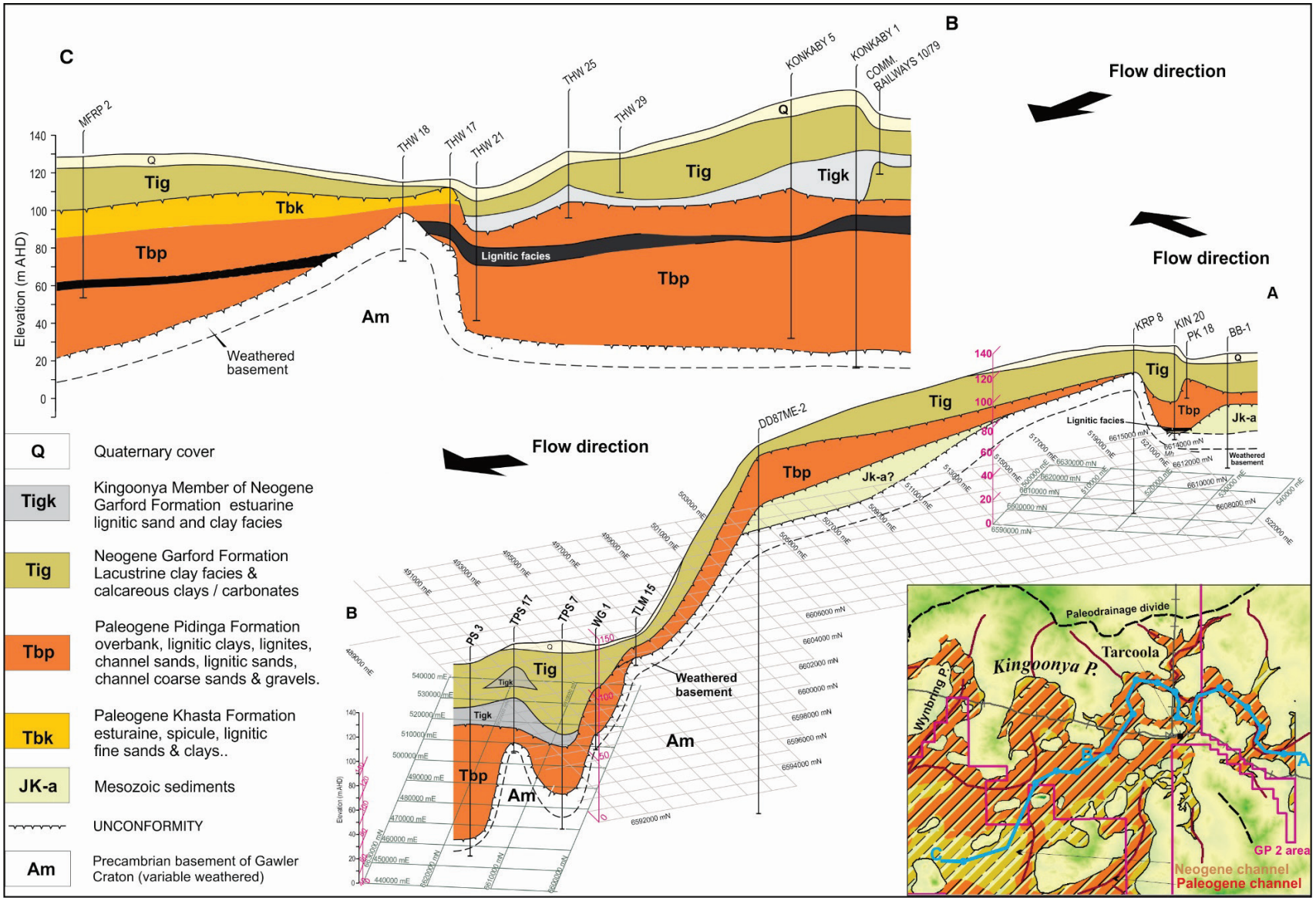


Figure 3.14 b) Longitudinal section through the Kingoonya Paleovalley based on drillhole data (name of drillholes are given, all drillhole data is available from SARIG. Note some drillholes are not exactly located at the deepest part of the valley; modified from Hou, 2008).

ANTHONY PALEOVALLEY

The Anthony Paleovalley occurs ~200 km northwest of the Kingoonya Paleovalley (Fig. 3.10). Due to an absence of drillhole data in most parts of this paleovalley, the distribution and sedimentation of the channel deposits are poorly understood. In the Anthony Paleovalley, the relative thin succession of poorly sorted and silicified gravelly alluvial sands in the upper reaches of the channel is probably related to the high elevation of this area; clay-rich carbonaceous deposits do not occur because marine transgression did not reach this far into this area (Fig. 3.15; Hou et al., 2001a). The lack of Miocene lacustrine clays in the Anthony Paleovalley indicates either a depositional environmental different from the Garford and Tallaringa paleovalleys north to the Anthony Paleovalley, or post-Miocene erosion in the Anthony Paleovalley (Hou et al., 2001a).

TIDAL INLET CHANNELS

Besides the major paleovalleys described above that make up the Eucla paleovalley system, there are also a few named small paleovalleys in the study area, such as the Meramangye, Immarna, Wilkinson, Karari, Woldra, Wynbring, Malbooma, Tolmer and Fowler paleovalleys, which were studied in more detail by Hou et al. (2001a, 2003a). Most of these paleochannels are characterised as tidal inlet channels (Fig. 3.10). The Tallaringa, Garford and Kingoonya paleovalley mouths are characterised as a few wide estuarine funnels with islands or basement highs, suggesting persistent swamp environments. The lower reaches of these channels were probably blocked by basement highs or beach barrier builds up as the sea advanced up these paleovalley systems, such as the Immarna, Wilkinson, Karari, Woldra Wynbring, Malbooma, Tolmer and Fowler paleovalleys, where a number of tidal inlet channels developed, (Fig. 3.10; Hou et al., 2001a). The well-developed spicule and carbonaceous facies in the Khasta and Pidinga formations indicate that the marginal marine influenced floodplain in the estuarine funnel area formed in a climate suitable for the growth of abundant vegetation. These tidal inlet paleochannels in the estuary are characterised by deposition with strong marine influence as indicated by tidal sedimentary structures and relatively abundant siliceous spiculate facies (Hou et al., 2001a). The facies evolution from channel to estuarine to marginal marine can be recognised in drillhole logs, such as in the sections of Figures 3.11 and 3.12, in which tidal inlet channels of the Immarna, Karari, Woldra and Anthony occur.

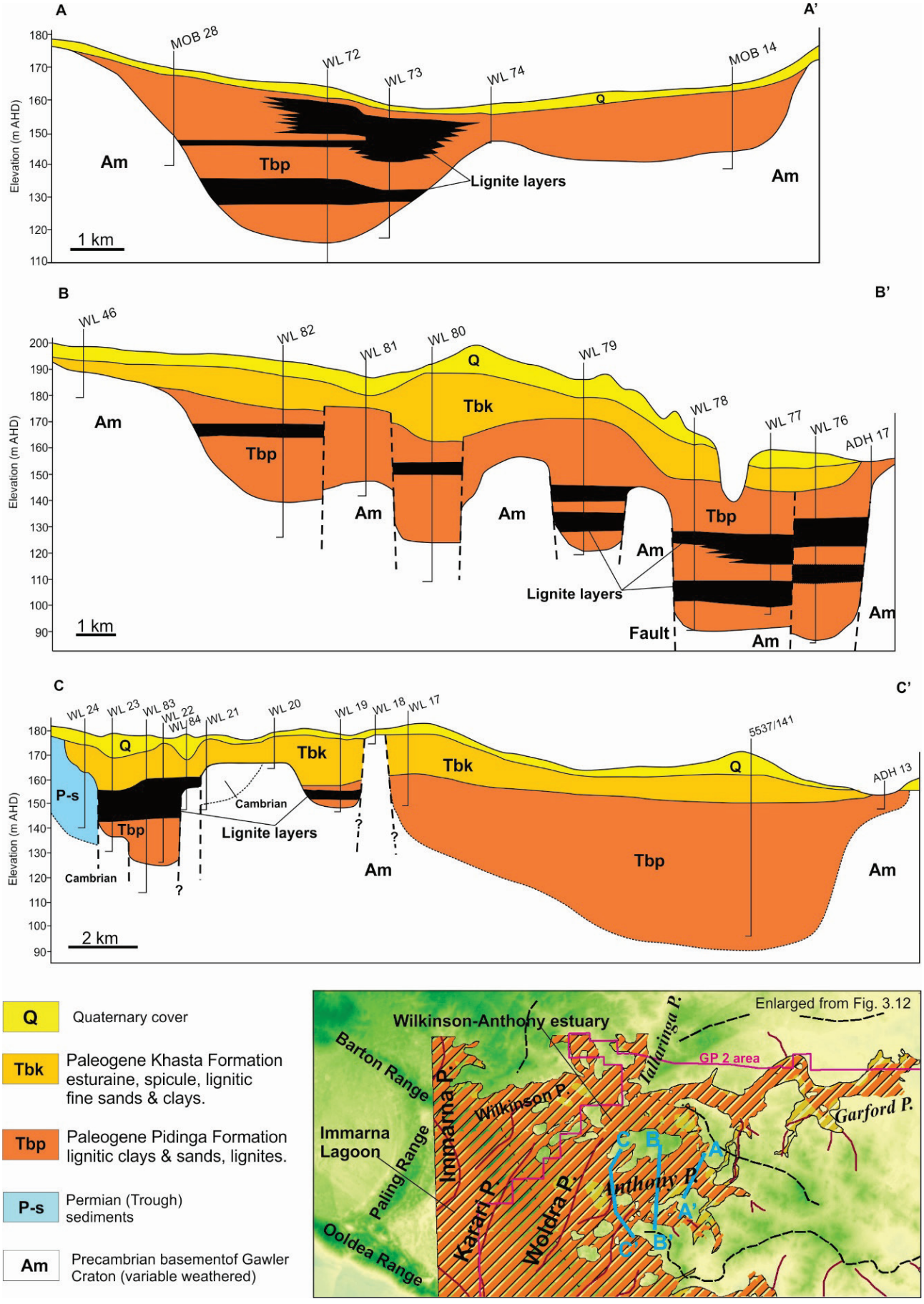


Figure 3.15 Cross-sections through the Anthony Paleovalley based on drillhole data (name of drillholes are given, all drillhole data is available from SARIG; modified from Hou et al., 2001a).

4. ECONOMIC GEOLOGY

The study area has had a long but intermittent history of exploration for coal, placers and uranium as well as for groundwater, with a focus on the paleoshorelines and paleovalleys that drained the Musgrave Province, Officer Basin, and western Gawler Craton (e.g., Close, 1973; Benbow, 1990b, 1993; Ferris, 1994; Benbow et al., 1995a; Hou and Alley, 2003; Hou and Warland, 2005; Hou and Keeling, 2008; Hou et al., 2001a, 2003b, 2006a; 2010; 2011a, b; 2014; 2017a, b; 2021; Krapf et al., 2019). Due to the extensive surficial cover, drillholes provide the best insight into the underlying geology of this region. This would advance the understanding of the stratigraphy of the basins and adjacent paleovalleys further and would also elevate the economic potential of the basins and channel-confined sediments for previously explored commodities as well as new and emerging commodities, e.g., critical minerals.

The onshore and nearshore basin settings are favourable for the formation of placer and uranium deposits. So far, the channel placers (e.g., placer gold) have not been found in the region, but the most significant beach placers have been discovered in and around the study area (Fig. 4.1). In the eastern Eucla paleovalleys, for instance, some favourable areas for the concentration of placer gold and other heavy mineral deposits were predicted where the headwaters could be traced to areas of known basement gold mineralisation and deposits, such as Challenger and Barton (Fig. 4.2; Hou, 2008; Hou et al., 2001a). Mineral exploration drilling has identified variable grades of gold mineralisation in basement rocks in areas of the Garford, Anthony and Kingoonya paleovalleys. These may have provided sources for placer mineralisation in the paleochannels and their tributaries. For example, traces of placer gold were found in channel sediments located in South Hilga and nearby Tarcoola gold deposits (S. Daly, pers. comm., 1998). These remain to be further investigated. Although no placer gold deposits have been discovered in the eastern Eucla paleovalleys, their presence is likely, particularly in tributaries spatially located near basement gold mineralisation.

4.1 PLACERS

Channel placers

In the study area, there are a number of primary gold deposits/prospects (e.g., Tarcoola, Challenger and Golf Bore), where paleodrainages drain these primary gold mineralised domains (Fig. 4.1). Reid et al. (2009) studied the detrital zircons from the Garford Paleovalley, concluding that these grains derived from two main sources: (i) local Archean–Mesoproterozoic rocks of the Gawler Craton exposed in the paleo-catchment, including the 2525–2440 Ma Mulgathing Complex and 1595–1575 Ma Gawler Range Volcanics–Hiltaba Suite; and (ii) Phanerozoic sedimentary rocks in the catchment that contribute a Late Mesoproterozoic to Cretaceous component of recycled zircons from a variety of primary sources. These sources were transported to and deposited in the Paleozoic, Mesozoic and Cenozoic paleovalleys. Given the presence of significant gold mineralisation in the Archean- to Mesoproterozoic rocks of the Gawler Craton, the abundance of locally derived Archean zircons suggests potential for paleoplacer gold deposits in these paleodrainage system (Reid et al., 2009).

A thorough investigation of the sedimentological regime in the vicinity of the channels sediments may yield insights into the paleoplacer gold potential for the study area.

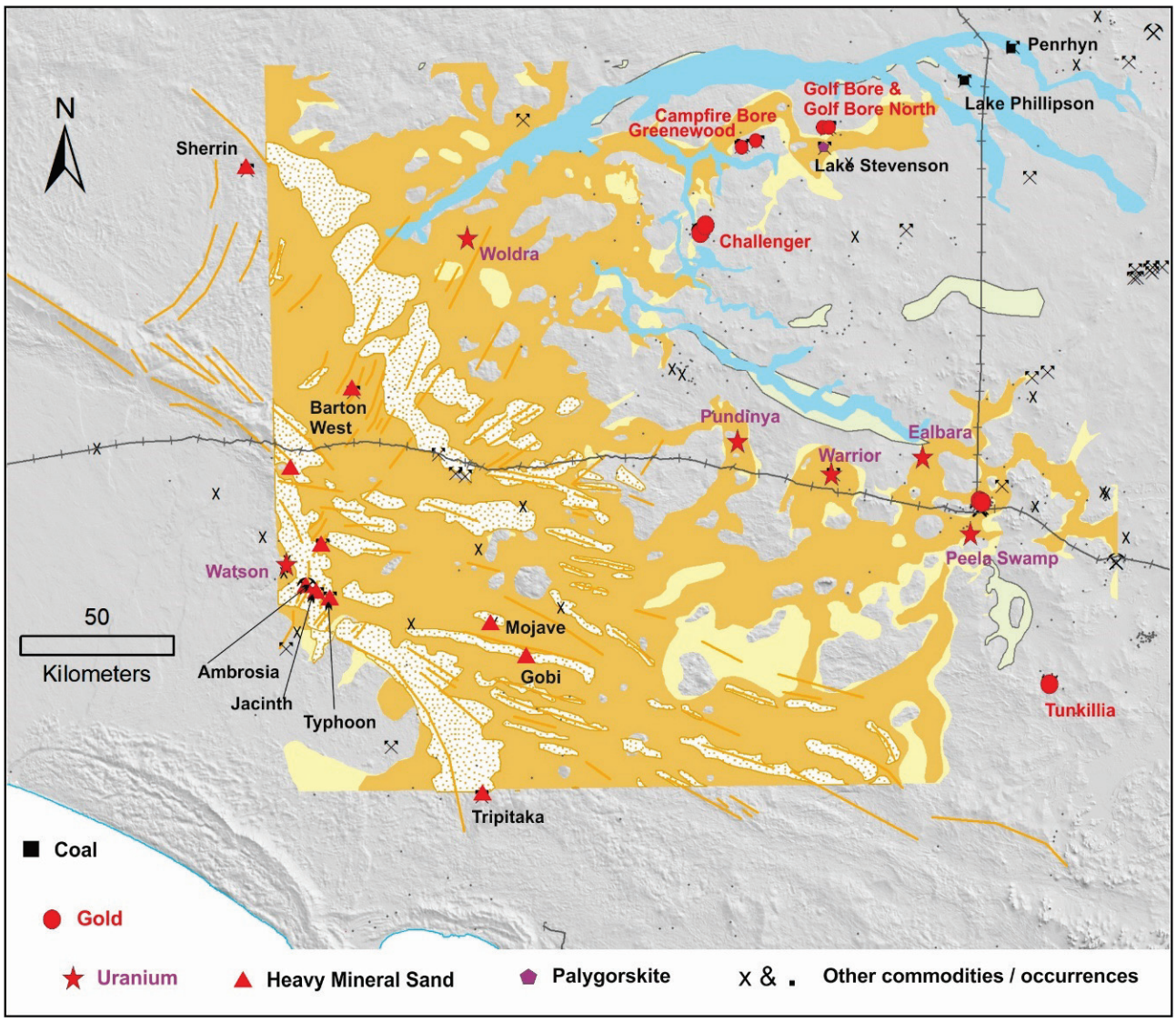


Figure 4.1 Known mineralisation in the study area new paleovalley data set, overlain by major mineral deposits and prospects. Background image SRTM 1 second DEM imagery.

Beach placers

The vast majority of the heavy mineral (HM) deposits of the Eucla Basin are hosted by ancient beach and dune deposits that formed along Middle Eocene to Pliocene shorelines (Hou et al., 2011a, b). Extensive exploration for HMs was carried out in and around the study area during the mid-1980s to the early 1990s, with HMs grades of 1–10% reported in some drill samples (Ferris, 1994). Early samples of Eocene deposits from the Lake Anthony-Lake Bring area of the eastern Eucla margin showed little enrichment of HMs (hematite, degraded ilmenite, rutile, zircon, xenotime, kyanite, garnet and other silicates (up to 8.27 wt%), but the mineral assemblage comprised predominantly ilmenite (37%) and goethite (41%), with lesser amounts of zircon and rutile (Close, 1973). Trace amounts of HMs were reported also from the Ooldea, Paling and Barton ranges (Benbow, 1990b), which were confirmed by further investigations during the 1990s, with HM concentrations of 0.16–1.59% comprised of 65–85% altered ilmenite, 10–20% zircon, and trace rutile and leucoxene (Ferris, 1994). Since 2004, several large and high-grade HM deposits have been discovered in the western part of the study area (Fig. 4.1; Hou and Warland, 2005;). The discovery of the first economic deposits at Jacinth and Ambrosia) in the eastern Eucla margin alerted the world to a vast new greenfields HM province that contained deposits with exceptionally high zircon concentrations that made up to ~50% of the HM suite (Hou and Keeling, 2008). The world-class zircon-dominated HM deposits of Jacinth and Ambrosia contain a combined resource of over 9.5 Mt HMs, and HM average content amounts to 4.7%, up to about 50% of which is zircon

(Hou et al., 2011a, b). Some deposits (e.g., Jacinth, Ambrosia, Tripitaka) are characterised by zircon-dominant HM assemblages throughout, and in this respect they differ from most HM deposits worldwide. The discoveries of high-grade, zircon-dominant, HM deposits in the eastern Eucla paleoshoreline systems (Fig. 4.1), established the region as a new paleobeach placer province of major economic significance (Hou et al.,2011a, b).

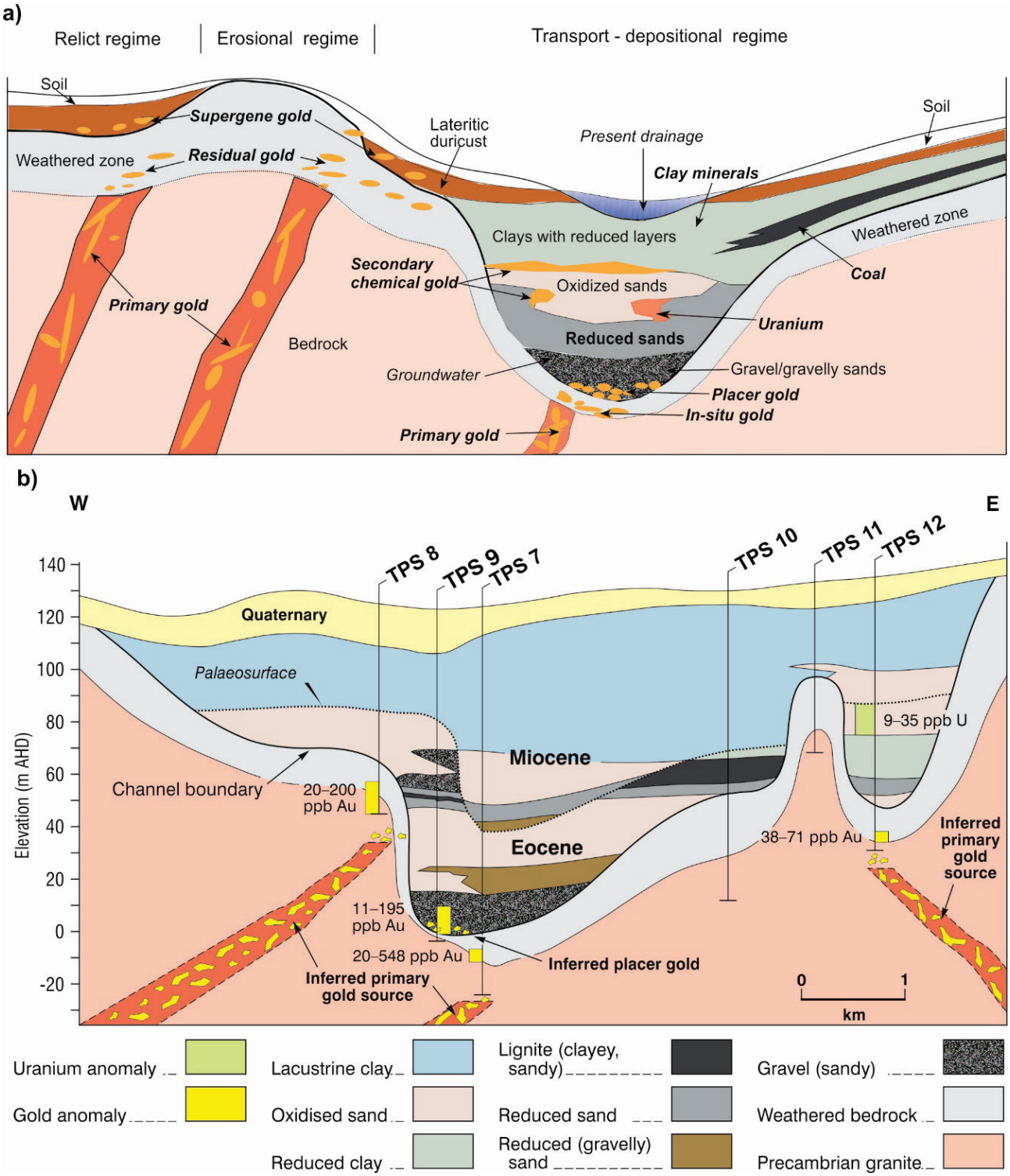


Figure 4.2 Mineralisation model in the paleodrainage terrains of the study area (a), modelled from a detailed cross-section of the Kingoonya Paleovalley (b) (section A-A' in Figure 3.14a; from Hou and Alley, 2003).

Principal units and shorelines related to HMS

Several HM deposits/prospects have been found in and around the west, northwest and southwest of the study area, which have been described in detail in Chapter 7 of Hou et al. (2021), including:

- in the study area:
  - Jacinth, Ambrosia, Tripitaka, Typhoon and Atacama deposits
  - Immarna, Barton West, Notrab, Sonoran, Gobi and Mojave prospects
  - and a few other occurrences.
- northwest of the study area:
  - Willy Willy, Thar, Maurice and Gobi HM prospects.
- south of the study area:
  - Gullivers deposit
  - Dromedary prospect
  - and a few other occurrences.

Historically, the Hampton Sandstone and Ooldea Sand were considered prospective for heavy minerals across the eastern Eucla Basin (Benbow et al*.,* 1995a; Rankin et al*.,* 1996; review by Ferris, 1994; Hou et al., 2003a, b). Thus, HM exploration in the eastern Eucla Basin primarily involved exploring along the Ooldea Range (Ferris, 1994). Subsequently, the terms Ooldea and Barton Sands have been introduced, which allows different age barrier systems to be independently characterised (Hou et al., 2006a), although the distinction between barrier systems is not everywhere apparent. These HM-bearing barrier island sand complexes are extensive along the eastern and northern basin margin and cover an area that is up to 30 km wide and 1,000 km long.

There have been five major marine incursions into the Eucla Basin during the last 50 million years, of which four sets of shorelines, ranging in age from middle Eocene to Pliocene, have the potential to host HM deposits (Fig. 4.1). The middle-late Eocene paleoshorelines of the northern and eastern Eucla basin are highly prospective for beach sand-hosted HMs related to sea-level changes (Hou and Warland, 2005; Hou and Keeling, 2008). Prevailing westerly winds built extensive barrier/dune systems by longshore drift. The geomorphic features of the northern and eastern Eucla Basin are very favourable for the formation of beach placers by long-shore drift. Effective delivery of sand by the longshore drift was the transport agent instrumental in the formation of extensive coastal barriers. Sediment movement was from west to east. Detrital zircon grains from the paleoshorelines show a distribution of zircon age that is consistent with the Proterozoic Musgrave, Coompana, Madura provinces as the dominant primary source areas of the heavy minerals, with a contribution from the Albany Fraser Orogen, Yilgarn and Gawler cratons (Hou et al., 2006a; Reid and Hou, 2006; Hou et al., 2011a, b; Gartmair, 2022; Gartmair et al., 2021). The likelihood is that these HMs have been recycled via sedimentary basins that flank the Musgrave Province, including the Neoproterozoic to Cambrian Officer Basin and Permian to Mesozoic deposits of the Bight Basin.

The most prospective strata include the barrier and associated sandstones of the paleoshorelines that were located in the southwestern part of the study area and buried by voluminous sand dunes over 40 Ma. The geographic and stratigraphic distributions of HM-bearing sandstone in Paleogene and Neogene sediments suggest contemporaneous transport through paleovalleys predominantly draining Precambrian settings. Ideas on the formation and reworking of paleostrandlines of the Eucla Basin continue to evolve. Earlier models that identified dominant sediment input from large paleovalley networks that drained across the Precambrian Gawler Craton were revised after detrital zircon ages clearly identified rocks of the same crystalline age in the Musgrave Province as an important source area for barrier sands (Reid and Hou, 2006; Reid et al., 2013). Recent work of Gartmair (2022) suggests that the main sources of the HMs derived from Musgrave, Coompana, Madura provinces. Continental-scale tilting during the Late Cenozoic in response to northward drift of the Australian continent (Veevers, 2000; Sandiford, 2007) is supported by Eucla Basin studies (e.g., Hou et al., 2008, 2011b). The influence of such a dynamic topography is evident in the changing pattern of sedimentation and explains the greater extent of marine inundation on the

eastern margin and the discordant alignment of younger paleobarrier deposits formed during Miocene–Pliocene sea level highstands (Hou et al., 2008).

The evolution of paleoshorelines in the Eucla Basin (Fig. 2.6) is characterised by a landward stepwise migration of the coastline. The paleoshorelines, formed during third-order sea-level rises, contain beach placers, mostly formed at sites where there was supply of HMS and conditions for concentration and preservation favourable for HM deposits. In aggregate, the accumulation of barrier island sands is up to 30 km wide and their complexity conceals numerous individual strandlines, deposited during high order events of sea-level rise that are mostly undocumented and remain highly prospective for HMS.

Apart from the relatively well-known Ooldea and Barton barriers, other shorelines are prospective for hosting HM deposits, including the Neogene strandlines in the southern part of the study area (Fig. 3.9). Tracing the extent of Neogene shorelines, especially in the more prospective areas near paleoriver outlets and across older coastal barrier islands, is difficult due to extensive surficial cover of younger aeolian dunes. Further research to delineate these systems may provide additional heavy mineral targets.

The geological setting of HMs and understanding of coastal evolution in the study area have significance for regional exploration for Eocene and/ or Miocene–Pliocene HM deposits, in that concealed deposits may exist in areas that have received little or no previous exploration. Major points arising from the present study are as follows:

- the study area has potential for discovery of new HMS resources, particularly in the Neogene barriers (Fig. 3.9)
- the known deposits here are in mostly unconsolidated sands above the water table and generally have a favourable ore thickness - to - overburden ratio
- recent stratigraphic investigations (e.g., Hou et al., 2021, 2022) and new data from mineral exploration suggest that more than four generations of Cenozoic shorelines comprise many HM-bearing strandlines
- the valuable HM assemblage consists mostly of zircon and altered ilmenite with lesser proportions of rutile and leucoxene. Zircon is the dominant HM in parts of the study area.

4.2 URANIUM

The eastern Eucla Basin and its peripheral paleovalleys host numerous uranium prospects (Fig. 4.1; Hou et al., 2014). Known uranium occurrences are presently confined to the eastern margins of the Eucla Basin where underlying crystalline basement rocks are potential source rocks for uranium mineralisation in the overlying paleovalley deposits (Fig. 4.1). Exploration for paleovalley-hosted uranium commenced in the mid-1970s, initially focusing on the eastern Eucla paleodrainage system, specifically the Kingoonya, Narlaby and Yaninee paleovalleys (Binks and Hooper, 1984; Curtis et al., 1990; Flint and Rankin, 1991). This resulted in the discovery of the Warrior prospect (discovered in the 1970s in Warrior Paleovalley), and Ealbara prospect (discovered in the early 1980s), both situated in tributaries of the Kingoonya Paleovalley, the four Yarranna prospects (up to 3550 ppm U_3O_8) in the Narlaby Paleovalley, and the Yaninee prospect in the Yaninee Paleovalley.

In the Cenozoic paleovalleys, the abundance of zircons derived from the Gawler Range Volcanics–Hiltaba Suite supports the potential for secondary uranium mineralisation in the paleovalleys derived from Mesoproterozoic volcanics and granites, some of which are known to be uranium-enriched (Reid et al., 2009). Uranium present in the eastern Eucla paleovalleys may have been sourced from Hiltaba Suite granites that are widespread on the Gawler Craton, variably weathered, with typically uranium content 2-3 times background levels. The eastern Eucla paleodrainage system actively incised and eroded weathered basement during the early to middle Eocene with flow rates decreasing over time such that sandy valley fill and lignitic clay deposits (Fig. 4.2), were replaced by largely chemical carbonate sedimentation in a series of discontinuous lakes along the major drainage lines during Miocene time (e.g., Hou et al., 2007b). Anomalous levels of uranium

have been reported also in other parts of the study area, including the Woldra Paleovalley and Lake Bring Estuary (16 to 643 ppm U_3O_8; Curtis et al., 1990).

4.3 CLAY MINERALS

Palygorskite has been identified within the palygorskitic and dolomitic clays of the Garford Formation in the middle and upper reaches of the Garford Paleovalley (Figs 3.15a and 4.1; e.g., Pitt et al., 1978), and is likely to be present also within equivalent sediments of the Tallaringa Paleovalley. Exploration carried out by Steetley Industries Limited during 1983–84, investigated numerous aspects of these deposits confirming some economic potential within the Garford Formation in the Garford Paleovalley (Robertson, 1984, 1988; Warne, 1987; Churchman et al., 1994; Raven et al., 1995; Keeling et al., 1995; Self et al., 1996). Highest concentrations of palygorskite are generally confined to the zone of transition from illite/smectite clay to dolomitic clay, where palygorskite constitutes >50% (the best result 70–90%, ~1 m thick; Raven et al., 1995) of the sediment but is mostly less than 2 m in thickness (Keeling et al., 1995). The potential for palygorskite clay in other Eucla paleovalleys has not been evaluated or explored.

4.4 REE

South Australia currently has no rare earths production, but there are a number of up and coming rare earth focussed projects within and close to the GP2 area. The Victory U-REE Prospect, which is approximately 150 km northeast of Coober Pedy, demonstrated REE potential associated with uranium, including 412 ppm uranium and 0.39% REE. Significant REE intercepts have been reported in the northern Gawler by Petratherm Limited within clays, usually as a high-grade blanket of mineralisation over 2000 ppm Total Rare Earth Oxides (TREO), at Meteor prospect.

Within areas of the western Gawler Craton crystalline basement, radiogenic granitic rocks (e.g., Gawler Range Volcanics – Hiltaba Suite volcano-plutonic association) are highlighted as potential source areas for uranium, which may ultimately have been incorporated or transported into nearby paleodrainage sediments. The possibility of REE associated with uranium dispersion and concentration in paleochannel sediments remains largely untested. The locations of known deposits and selected occurrences of uranium in paleovalley sediments, and heavy minerals in paleocoastal shoreline sediments are shown on Figure 4.1.

4.5 COAL

The sequences the Arckaringa and Eucla Basins contain coal and lignite deposits within lignitic and coal facies strata. Coal-bearing strata mainly occurs in the Arckaringa Basin (Fig. 4.1), and lignite occurrences recorded in the eastern Eucla Basin occur within the Eocene Pidinga Formation of the marginal Eucla Basin and associated paleovalleys. A review of exploration for lignite in the eastern Eucla Basin is provided in Rankin et al. (1996). In the Arckaringa Basin, six deposits of lignite A/Sub-bituminous C rank coal (American Society for Testing and Materials classification) aggregating more than 20 Gt of measured, indicated and inferred resource have been identified in the upper part of the Mount Toondina Formation (SADME, 1991; Fig. 8.12). These are multi-seam deposits with individual seams ranging up to 10 m in thickness, with a cumulative thickness of up to 30 m. A Mines and Energy of South Australia (MESA) drilling program in early 1995 discovered a new coal-bearing trough (Penrhyn Trough) north of Lake Phillipson. Also, some exploration activities focused on petroleum potential. For instance, McBain (1987) noted possible higher heat flow in the Phillipson Trough at ~150 Ma. Hydrocarbon potential within the trough has been evaluated by Moore (1982b) and Delhi Petroleum Pty Ltd and Santos Ltd (1989a, b). In the study area, lignites appear to be widespread but lenticular and thin (0.5–7 m). In the low-grade lignites of the Pidinga Formation of the Eucla Basin, ash content is generally well above 30% and the moisture content ranges between 12% and 60% (Pitt et al., 1978).

Drilling data obtained since the 1970s by companies, MESA and the Electricity Trust of South Australia (ETSA) indicate that vertical and lateral changes in both coal thickness and quality are rapid, in particular in the gradation of carbonaceous clay to clayey lignite or lignite. This, together

with partial removal of a few metres of Pidinga Formation by tidal/wave events, make seam correlation and coal-value calculations difficult. Although the deposits are at shallow depth, with only 10–15 m overburden, lignite seams (including clayey or sandy lignite) are scattered throughout (carbonaceous) clay and sand units up to 40 m thick. Lithofacies analyses and correlations suggest that most of the Wilkinson-Anthony estuarine plains may be prospective for lignite within fluvial and estuarine deposits tracing the highstand condensed intervals. But results of drilling to date, together with the high variability of the fluvial-related facies suggest the lignite deposits in the area are presently negligible and uneconomic.

In the study area, lignites appear to be widespread but lenticular and thin (0.5–7 m). In the low-grade lignites of the Pidinga Formation of the Eucla Basin, ash content is generally well above 30% and the moisture content ranges between 12% and 60% (Pitt et al., 1978).

4.6 GROUNDWATER

Water supply is crucial to local communities as well as for exploration and mining developments, but particularly in the study area because of the lack of surface water resources due to the low and unreliable rainfall and high evaporation rate. Groundwater is the only viable source for human and livestock consumption and mineral processing, and therefore it is vital to assess its resource potential. However, most of the groundwater is known to be saline and therefore of limited use for human consumption without desalination and limited use as stock water.

In the paleovalleys of the study area, groundwater has been obtained from the sandstone horizons of multiple stratigraphic units and age (e.g., Permian and Cenozoic sediments near the Challenger Gold deposit; Hou et al., 2001a, 2003a,b).

The salinity, depth, and yield of supplies from aquifers of the Arckaringa, Eromanga and Eucla paleovalleys are largely controlled by conditions of local intake, the permeability of the sediments, and the distribution of the sandstone, which is highly variable. Sandstones are present in the paleovalleys of the study area and appear to have adequate water supplies in places (e.g., Garford Paleovalley) where the sandstone deposits are relatively thick. Available drilling has indicated a 10–15 m thick aquifer containing up to 300,000 ML of saline groundwater in place in the Garford Paleovalley and also a considerable thickness of sand with ~900,000 ML of water in storage (Russell, 1998). The extensive network of Cenozoic paleovalleys represents a potential source of saline groundwater suitable for mineral processing (Martin, 1998; Martin et al., 1998). The limited investigations conducted indicate that aquifers are localised and of highly variable quality and quantity (e.g., Read, 1987; Weber, 1980). Potential aquifers with groundwater of both high quality and quantity probably exist locally in the Eocene Pidinga Formation, as this formation generally shows vertical and lateral rapid changes in lithology, particularly in the channel areas.

Other paleovalleys (e.g., Anthony, Kingoonya, Narlaby) in the study area show similar trends, but no estimates of groundwater resources have been made to date. Aquifer tests need to be carried out to determine potential yields and drawdowns from pumping wells in the paleovalley area, including a number of tidal inlet channels. Other paleotopographic lows (including major tributaries and paleoswamps) can be investigated as a lower priority basis due to their less well-known groundwater potential. Since the controls that determine the occurrence of groundwater in the area are still not properly understood, the new geophysical data, mainly AEM and gravity, and the improved paleovalley mapping from this investigation will aid future surveys for undiscovered groundwater resources in the study area.

5. CONCLUSIONS

Greater understanding of the geological history and development of the basins and associated paleovalleys in the GP2 study region raises awareness of the potential economic opportunities within the cover sediments. New data are provided on geological processes and landscape evolution of the paleodrainage systems of the central-western Gawler to assist mineral exploration planning and aid with conceptual mineral targets.

- The study of the GP2 paleodrainage systems investigated the geophysical and geological expressions of the basins and paleovalleys together with associated resources, including heavy mineral sands, uranium, REE and coal, chemically or physically concentrated in paleocoastal and paleochannel environments.
- Sedimentological evidence was combined with geological and geophysical characteristics to reconstruct basinal and paleovalley architectures and depositional environments.
- The newly mapped paleodrainage system (e.g., paleovalleys and paleostrandlines) represent various aspects of the drainage components that were active during late Paleozoic, Mesozoic and Paleogene–Neogene periods.
- Sedimentary environments varied from glacial and fluvial, through to estuarine and marginal marine.
- Evolution of the Eucla Basin paleoshorelines was characterised by a landward stepwise migration of the coastline. The extensive paleoshorelines were formed during several third-order sea level rises and contain heavy mineral beach placers.
- Post-Eocene uplift in the western Eucla Basin led to tectonic tilting influencing basin evolution and the development of discordant Neogene strandlines in the southern part of the study area, from the Middle Miocene onwards.
- Detailed mapping in the study area can provide important information for the exploration of placer gold, HMS, uranium, REE, coal and groundwater resources. The paleovalleys originally incised into the weathered basement and bedrocks. They then transported the placer/U-bearing sediments to the paleo-coasts through paleovalleys, where the heavy minerals and/or uranium concentrated. The paleorivers to the paleocoasts, the placer/U-bearing clastics were deposited in a variety of environments, such as alluvial/fluvial channels, beach barriers, estuaries, embayments and lagoons.
- The basis for the geologic model of placers and uranium deposition in the study area is the integration of paleogeography (particularly of paleoshorelines and paleovalleys) with regional and global evidence for paleoclimate and relative sea-level change and major eustatic events, together with the identification of placer and uranium source and dispersion, and any associated tectonic activity, particularly during the time of deposition of the placer/U-bearing sediments.
- Knowledge of the basin and paleovalley sytems architecture in combination with an understanding of the potential sources of minerals are key factors in guiding exploration in this area.
- The extensive surficial cover over parts of the study area has resulted in some paleodrainage system components being relatively underexplored and potential exists for further significant new mineral discoveries in in these areas. Complex paleogeography of the paleoshorelines and paleochannels determine the sites of placers and uranium accumulation. For example, the high specific gravity of placers tends to concentrate HM components in lags and transgressive/ regressive barriers/dunes or ‘J-shape’ bays; uranium tends to precipitate at redox fronts in the channel environments.
- In the study area, the accumulation and aggregation of paleochannel and coastal sands conceals numerous individual paleostrandlines and paleochannel lags, many of which remain undocumented and prospective for placer deposits.
- Traces of indicator minerals in the paleoshorelines (e.g., beach placers) and paleochannels (e.g., placer gold) can be of interest also as a guide to locating underlying or adjacent basement/bedrock mineralisation.

Newly acquired datasets from the GP2 project have increased confidence in the mapping of defined paleovalley systems and assisted to redefine the basal units of these systems within the GP2 study area.

ACKNOWLEDGMENTS

Study of the GP2 paleovalleys has benefited from several parallel GP2 projects, including new geophysical surveys processed by the GSSA Geophysical team, GIS package of GP2 paleovalleys and processed ASTER ntt images by Laz Katona. The authors therefore express their appreciation to all GP2 participants (Rohan Cobcroft, Anthony Reid, Ziauddin Durrani, Stephan Thiel, Adrian Fabris, Claire Wade, Louise Baida and Peter Buxton) who contributed to this study. We greatly appreciate the many detailed discussions and valuable suggestions on various aspects of the study from those such as Adrian Fabris and many others. The report benefited from review by John Keeling.

REFERENCES

Abreu VS, Hardenbol J, Haddad GA, Baum GR, Droxler AW and Vail PR 1998. Oxygen isotope synthesis: A Cretaceous icehouse: *Society of Sedimentary Geology (SEPM) Special Publication*, 60: 75-80.

Allender JF, Taylor BW and Gilby AR 1987. Geophysical interpretation report. 1984 Hogarth-Arr. seismic survey, Arckaringa Block PEL 5 and 6, for Delhi Petroleum (Pty) Ltd. *South Australia. Department of Mines and Energy. Open file Envelope,* 5561: 126-162 (unpublished).

Alley NF 1985. Latest Eocene palynofloras of the Pidinga Formation, Wilkinson No. 1 well, western South Australia. Report Book, 85/13. *Department of Mines and Energy, South Australia.*

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

Alley N 1995. LATE PALAEOZOIC. In JF Drexel and WV Preiss eds, The geology of South Australia, Vol. 2, The Phanerozoic, Bulletin 54. Geological Survey of South Australia, Adelaide. pp 63–92.

Alley NF and Beecroft A 1993. Foraminiferal and palynological evidence from the Pidinga Formation and its bearing on Eocene sea level events and palaeochannel activity, eastern Eucla Basin, South Australia. *Association of Australasian Palaeontologists. Memoir,* 15: 375-393.

Alley NF and Benbow MC 1989. Late Eocene palynofloras from the Pidinga Formation, SADME Ooldea Range 6, eastern Eucla Basin. *South Australia. Geological Survey. Quarterly Geological Notes,* 111: 2-12.

Alley NF and Frakes LA 2003. First known Cretaceous glaciation: Livingston Tilllite Member of the Cadna-Owie Formation, South Australia. *Australian Journal of Earth Sciences,* 50: 139-144.

Alley NF, Clarke JDA, Macphail M and Truswell EM 1999. Sedimentary infillings and development of major Tertiary palaeodrainage systems of south-central Australia. *Spec. Publs int. Ass. Sediment.* 27: 337-366.

Ambrose GJ and Flint RB 1981. BILLA KALINA, South Australia, sheet SH53-7. *South Australia. Geological Survey. 1:250 000 Series-Explanatory Notes*.

Barnes LC, Benbow MC, Krieg GW, Pitt GM, Harris WK and Lindsay JM 1977. Permian outcrops on the southwestern margin of the Arckaringa Basin. *South Australia. Geological Survey. Quarterly Geological Notes,* 63: 1-6.

Bates RL and Jackson JA (Editors) 1987. Glossary of Geology. 3rd edn. American Geological Institute, Alexandria, Virginia, 788 pp.

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

Benbow MC 1989. History of recognition and delineation of coastal aeolian land forms of the Eucla basin, South Australia. Quarterly Geological Notes, 109: 9-14, *Geological Survey of South Australia*.

Benbow MC 1990a. Ancient coastal dunes of the Eucla Basin, Australia. *Geomorphology,* 3: 9-29.

Benbow MC 1990b. Heavy mineral sand province of western South Australia. *In*: South Australia – Exploration towards 2000. Extended Abstracts. Seminar, Adelaide, 1990. Report Book, 90/78, Department of Mines and Energy. South Australia.

Benbow MC 1990c. The Yarle Sandstone: a Miocene coastal terrigenous sequence of the Eucla Platform. Quarterly Geological Notes of the Geological Survey of South Australia, 113: 2-6.

Benbow MC 1993. TALLARINGA, South Australia, sheet SH53-5. *South Australia. Geological Survey. 1:250 000 Series - Explanatory Notes.*

Benbow MC and Crooks AF 1988. Topographic contour maps and data, western South Australia. *Report Book,* 88/44*, Department of Mines and Energy, South Australia.*

Benbow MC, Lindsay JM and Alley NF 1995a. Eucla Basin and palaeodrainage. In JF Drexel and WV Preiss eds, The geology of South Australia, Vol. 2, The Phanerozoic, Bulletin 54. Geological Survey of South Australia, Adelaide. pp 178-186.

Benbow MC, Alley NF, Callen RA and Greenwood DR 1995b. Geological history and palaeoclimate. In JF Drexel and WV Preiss eds, The geology of South Australia, Vol. 2, The Phanerozoic, Bulletin 54. Geological Survey of South Australia, Adelaide. pp 208-217.

Binks PJ and Hooper GJ 1984. Uranium in Tertiary palaeochannels 'West Coast Area', South Australia. *Australian Institute of Mining and Metallurgy. Proceedings,* 289: 271-275.

Birt T and Reid A J 2007. Archaean gold systems of South Australia. MESA Journal 46, 29–33.

Brewer AM, Dunster JN, Gatehouse CG, Henry RL and Weste G 1987, A revision of the stratigraphy of the eastern Officer Basin: South Australia Geological Survey, Quarterly Notes no. 102: 2-15.

Carlsen GM, Apak SN, Ghori KAR, Grey K and Stevens MK 1999. Petroleum potential of the Neoproterozoic Western Officer Basin, Western Australia, based on a source-rock model from Empress-1A. The Australian Petroleum Production and Exploration Association (APPEA) Journal, 39(1): 322-342.

Churchman JG, Ferris GM, Keeling JL, McClure SG, Raven MD, Self PG and Slade PG 1994. Absorbent clay project: Progress report No.1 – Characterisation of the selected clays. CSIRO – Division of Soil, Report to Mines and Energy, South Australia. *Open file Envelope*, 8785 (unpublished).

Clarke JDA and Hou B 2000. Eocene coastal barrier evolution in the Eucla Basin. *MESA Journal,* 18: 36-41. Department for Energy and Mining, South Australia, Adelaide.

Clarke JDA, Gammon PR, Hou B and Gallagher SJ 2003. Middle to Upper Eocene stratigraphic nomenclature and deposition in the Eucla basin. *Australian Journal of Earth Sciences,* 50: 231-248.

Close SE 1973. Annual report, Lake Anthony SML 710 and Lake Bring SML 711, South Australia, for CRA Exploration Pty Ltd. *South Australia, Department of Mines and Energy. Open file Envelope,* 2092 (unpublished).

Cook AC 1981. The organic petrology of samples from a selected group of wells in or near the Arckaringa block. *South Australia. Department of Mines and Energy. Open file Envelope,* 4878: 354-396 (unpublished).

Cowley WM and Martin AR 1991. KINGOONYA, South Australia, sheet SH53-5. *South Australia. Department of Mines and Energy. 1:250 000 Series - Explanatory Notes.*

Curtis JL, Brunt DA and Binks PJ 1990. Tertiary palaeochannel uranium deposits of South Australia. *In:* Hughes, F.E. (Ed.), Geology of the mineral deposits of Australia and Papua New Guinea. *Australasian Institute of Mining and Metallurgy. Monograph,* 14: 1631-1636.

Daly SJ 1985. TARCOOLA map sheet. *South Australia. Geological Survey. Geological Atlas 1:250 000 Series,* sheet SH53-10.

Daly SJ 1986. The Mulgathing Complex. Report Book 1986/41. Department for Energy and Mining, South Australia, Adelaide.

Daly SJ and Fanning CM 1993. Archaean. In JF Drexel and WV Preiss eds, The geology of South Australia, Vol. 1, The Precambrian. South Australia, Bulletin 54. Geological Survey of South Australia, Adelaide. pp 32–49.

Daly SJ, Benbow MC and Blissett AH 1979. Archaean to Early Proterozoic geology of the northwestern Gawler Craton. In Parker, A.J. (Compiler), *Symposium on the Gawler Craton, Adelaide, 1979. Extended abstracts.* Geological Society of Australia (SA Division), pp.16-19.

Davies HL, Clarke JDA, Stagg HMJ, Shafik S, Mcgowran B and Alley NF 1989. Maastrichtian and younger sediments from the Great Australian Bight. *Bureau of Mineral Resources Report* 288.

de Gromard RQ, Wingate MTD, Kirkland C, Smithies R and Howard H 2016. Geology and U-Pb Geochronology of the Warlawurru Supersuite and MacDougall Formation in the Mitika and Wanarn Areas, West Musgrave Province. *Geological Survey of Western Australia, Record 2016/4*, 29. Retrieved from http://hdl.handle.net/20.500.11937/55206

Deen TJ, Gohl K, Leslie C, Papp E and Wakw-Dyster K 2000. Seismic refraction inversion of a palaeochannels system in the Lachlan Fold Belt, Central New South Wales. *In:* Exploration Geophysics. Spec. Edis. Mike Dentith & Mike Middleton. The Bulletin of the Australian Society of Exploration Geophysicists, 31: 389-393.

Delhi Petroleum Pty Ltd and Santos Ltd 1989a. PEL 5 and PEL 6, Arckaringa block. Arckaringa Basin. Farmout block progress and exploration reports for the period November 1982 to February 1989. *South Australia. Department of Mines and Energy. Open file Envelope,* 4878 (unpublished).

Delhi Petroleum Pty Ltd and Santos Ltd 1989b. PEL 5 and PEL 6, Dalhousie block. Pedirka, Arckaringa, Amadeus, Officer and Eromanga Basins. Farmout block progress and exploration reports for the period March 1982 to February 1989. *South Australia. Department of Mines and Energy. Open file Envelope,* 4881 (unpublished).

Dettmann ME and Williams AJ 1985. The Cretaceous of the southern Eromanga Basin — a palynological review. *Delhi Petroleum Pty Ltd. Palynological Report,* 274/25 (unpublished).

Diatreme Resources Limited 2009. Exploration Activities Report Quarter ended 31 March 2009. *www.diatreme.com.au*.

Dodds AR 1996. Report on a Transient Electromagnetic survey around Garford palaeochannel, SA. Report Book 96/43. *Department of Mines and Energy, South Australia.*

Dodds AR 1997. A groundwater and basement surface study of the northwest Gawler Craton, SA. *Report Book* 97/6. *Department of Mines and Energy*, *South Australia.*

Drexel JF and Preiss WV eds 1995. The Geology of South Australia. Geological Survey of South Australia, Bulletin, 54. Geological Survey of South Australia, Adelaide.

Dutch R, Pawley M, Wise T, Jagodzinski L, Tylkowski L, Lockheed A and McAlpine S 2018. Breaking down the Coompana Drilling Project. MESA Journal, 87: 10-11. Department for Energy and Mining, South Australia, Adelaide.

Evins PM, Smithies RH, Howard HM, Kirkland CL, Wingate MTD and Bodorkos S 2010a. Devil in the detail; The 1150-1000 Ma magmatic and structural evolution of the Ngaanyatjarra Rift, west Musgrave Province, Central Australia. *Precambrian Research*, 183: 572-588.

Evins PM, Smithies RH, Howard HM, Kirkland CL, Wingate MTD and Bodorkos S 2010b. Redefining the Giles Event within the setting of the 1120-1020 Ma Ngannyatjarra Rift, west Musgrave Province, Central Australia. Record, 2010/6, 36 pp, Geological Survey of Western Australia, Perth.

Fairbridge RW 1953. Australian stratigraphy. 2nd edition. University of Western Australia, Text Books Board, Perth.

Fanning CM, Flint RB, Parker AJ, Ludwig KR and Blissett AH 1988. Refined Proterozoic evolution of the Gawler Craton, South Australia, through U-Pb zircon geochronology. *Precambrian Research,* 40/41: 363-386.

Ferris GM 1994. Review of heavy mineral sand exploration in South Australia – the Eucla Basin. *Report Book,* 94/22. *Department of Mines and Energy, South Australia.*

Flint RB and Rankin LR 1991. KIMBA, South Australia, sheet SI53-7. *South Australia. Geological Survey. 1:250 000 Series- Explanatory Notes.*

Forbes BG 1966. The geology of the Marree 1:250 000 map area. *South Australia. Geological Survey. Report of Investigations,* 28.

Foss C, Wilson T, Gouthas G, Katona L and Heath P 2019. Magnetic source depth delineation of the Mulgathing Trough beneath cover in the Gawler Craton, South Australia. CSIRO and GSSA workshop presentation (unpublished).

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

Frakes LA and White M 1997. Tertiary palaeochannels draining the Gawler Craton. MESA Journal, 6: 10-11. Department for Energy and Mining, South Australia, Adelaide.

Frakes LA, Burger D, Apthorpe M, Wiseman J, Dettmann ME, Alley NF, Flint RB, Gravestock DI, Ludbrook NH, Backhouse J, Skwarko S, Scheibnerova V, McMinn A, Moore PS, Bolton RB, Douglas JG, Christ R, Wade M, Molnar RE, McGowran B, Balme BE and Day RA 1987. Australian Cretaceous shorelines, stage by stage. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 59:31-48.

Gartmair G 2022. Integrating Zircon Grain Shape Analysis with Detrital Mineral Geochronology and Geochemical Fingerprinting, Eucla Basin, Australia. Unpublished Master thesis, Curtin University, Australia.

Gartmair G, Barham M and Kirkland CL 2021. Detrital Zircon Perspectives on Heavy Mineral Sand Systems, Eucla Basin, Australia. Economic Geology, 117(2): 383-399.

Gartmair G, Barham M and Kirkland CL 2023. One size does not fit al: refining zircon provenance interpretations via integrated grain shape, geochronology, and Hf isotope analysis. Geoscience Frontiers 101579, https://doi.org/10.1016/j.gsf.2023.101579.

Ghori KAR 1998. Petroleum generating potential and thermal history of the Neoproterozoic Officer Basin, Western Australia. In Purcell, P.G. & Purcell, R.R., (Editors). The Sedimentary Basins of Western Australia 2: Proceedings of Petroleum Exploration Society of Australia Symposium, Perth, Western Australia, 1998, 717-730.

Ghori KAR 2002. Modelling the hydrocarbon generative history of the Officer Basin, Western Australia. PESA Journal, 29: 29-43.

Gilby AR and Foster CB 1988. Early Permian palynology of the Arckaringa Basin, South Australia. *Palaeontographica. Abteilung B: Palaeophytologie,* 209(4-6): 167-191.

Gravestock DI and Hibburt JE 1991. Sequence stratigraphy of the eastern Officer and Arrowie Basins - a framework for Cambrian oil search: APEA Journal, 31(1): 177-190.

Gravestock DI, Benbow MC, Gatehouse CG and Krieg GW 1995. Eastern Officer Basin. In JF Drexel and WV Preiss eds, The geology of South Australia, Vol. 2, The Phanerozoic, Bulletin 54. Geological Survey of South Australia, Adelaide. pp 35-41.

Grey K, Hocking R, Stevens M, Bagas L, Carlsen G, Irimies F, Pirajno F, Haines P and Apak S 2005. Lithostratigraphic nomenclature of the Officer Basin and correlative parts of the Paterson Orogen, Western Australia. Report 2005/93, Geological Survey of Western Australia, Perth.

Hand M, Reid A and Jagodzinski E 2007. Tectonic framework and evolution of the Gawler Craton, South Australia. *Economic Geology*, 102: 1377-1395.

Haq BU, Hardenbol J and Vail PR 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, 235: 1156-1167.

Haq BU, Hardenbol J and Vail PR 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In: Wilgus, C.K., Posamentier, H., Ross, C.A., Kendall, C.G.S.C. (Eds.), Sea-level Changes: An Integrated Approach. SEPM Special Publication, pp. 71-108.

Harris, W.K. and McGowran, B., 1973. South Australian Department of Mines Cootanoorina No. 1 well. Part 2: Upper Palaeozoic and Lower Cretaceous micropalaeontology. *South Australia. Geological Survey. Report of Investigations,* 40: 57-89.

Harvey SC and Hibburt JE (Compilers) 1999. Petroleum exploration and development in South Australia. 12th edition. Report Book, 99/3. Department for Energy and Mining, South Australia, Adelaide.

Hawlader HM 1990. Diagenesis and reservoir potential of volcanogenic sandstones Cretaceous of the Surat Basin, Australia. *Sedimentary Geology*, 66: 181-185.

Hocking RM (compiler) 1994. Subdivisions of Western Australian Neoproterozoic and Phanerozoic sedimentary basins. Geological Survey of Western Australia, Perth, Record 1994/4.

Hou B. 2008. Palaeochannel studies related to the Harris Greenstone Belt, Gawler Craton, South Australia: Architecture and evolution of the Kingoonya Paleochannel System. CRC LEME OPEN FILE REPORT 154, 122pp.

Hou B and Alley NF 2003. A model for gold and uranium dispersion and concentration in residual and transported regolith along palaeodrainage systems. - A case study from the central Gawler Craton, SA. *MESA Journal,* 30: 49-53.

Hou B and Mauger AJ 2005. How well does remote sensing aid paleochannel identification? -an example from the Harris Greenstone Belt, SA. *MESA Journal*, 38: 46-52. Department for Energy and Mining, South Australia, Adelaide.

Hou B and Warland I 2005. Heavy mineral potential of Eucla Basin, SA. - A world class paleo-beach placer province. *MESA Journal,* 37: 4-12.

Hou B and Keeling J 2008. Eucla Basin - Emerging as a new Heavy Mineral province of global significance, Old province - New idea, *MESA Journal*, 49: 20-26. Department for Energy and Mining, South Australia, Adelaide.

Hou B, Frakes LA, Alley NF, Stamoulis V and Rowett A 2000. Geoscientific signatures of Tertiary palaeochannels and their significance for mineral exploration in the Gawler Craton region. *MESA Journal,* 19: 36-39.

Hou B, Frakes LA and Alley NF 2001a. Development of geoscientific models for the exploration in Tertiary paleochannels draining the Gawler Craton, SA. Report Book 2001/021. Department for Energy and Mining, South Australia, Adelaide.

Hou B, Frakes LA and Dodds AR 2001b. Recent drilling in the Garford Paleochannel, Gawler Craton, – testing of a model derived from interpreted geological, geophysical and spectral methods. MESA Journal, 20: 24-27. Department for Energy and Mining, South Australia, Adelaide.

Hou B, Frakes L.A, Alley NF and. Clarke DA 2003a. Characteristics and evolution of the Tertiary paleochannels in the NW Gawler Craton, South Australia. *Australian Journal of Earth Sciences,* 50: 215-230.

Hou B, Frakes LA, Alley NF and Heithersay P 2003b. Evolution of beach placer shorelines and heavy-mineral deposition in the eastern Eucla Basin, South Australia. *Australian Journal of Earth Sciences,* 50: 955-965.

Hou B, Frakes LA, Alley NF, Gammon P and Clarke JDA 2003c. Facies and Sequence stratigraphy of Eocene valley fills in Eocene paleovalleys, the eastern Eucla Basin, South Australia. *Sedimentary Geology,* 163: 111-130.

Hou B, Warland I, Frakes LA and Paine MD 2006a. Success and development in discovering beach placers in the Eucla Basin, southern Australia. *The Australian Earth Sciences Convention 2006*, Melbourne, 2-6 July 2006. 4pp.

Hou B, Alley NF, Frakes LA, Stoian L and Cowley WM 2006b. Eocene stratigraphic succession in the Eucla Basin of South Australia and correlation to major regional sea-level events. *Sedimentary Geology*, 183: 297-319.

Hou B. Zang W, Fabris A, Keeling J, Stoian L and Fairclough M 2007a. (compilers), CRC LEME, Geological Survey Branch, Primary Industries Resources South Australia. Palaeodrainage and Tertiary Coastal Barrier of South Australia. *Digital Geological Map of South Australia, 1:2 000 000 Series* (1st Edition).

Hou B, Fabris AJ, Keeling JL and Fairclough MC 2007b. Cainozoic palaeochannel-hosted uranium and current exploration methods, South Australia. *MESA Journal* 46: 34–39. Department for Energy and Mining, South Australia, Adelaide.

Hou B, Frakes LA, Sandiford M, Worrall L and Keeling J and Alley NF 2008. Cenozoic Eucla Basin and associated paleovalleys, southern Australia - climatic and tectonic influences on landscape evolution, sedimentation and heavy mineral accumulation, *Sedimentary Geology*, 203: 112-130.

Hou B, Keeling J, Reid AJ, Warland I, Belousova E and Frakes LA 2010. Heavy minerals in the Eucla Basin, Southern Australia. 13th IAGOD Symposium, 6-9 April 2009, Adelaide, Australia, *the 13th IAGOD Symposium Proceedings*, p. 336-337.

Hou B, Keeling J and Hocking RM 2011a. Heavy Mineral Prospectivity in the Eucla Basin. *AusIMM Eighth International Minerals Conference,* Perth, WA, Western Australia International Conference and Exhibition, 5-6 October 2011, p. 135-145.

Hou B, Keeling J, Reid AJ, Warland I, Belousova E, Frakes .A, Hocking R and Fairclough, M 2011b. Heavy mineral sands in the Eucla Basin, southern Australia: Deposition and province-scale prospectivity. *Economic Geology,* 106: 687-712.

Hou B, Fabris A, Michaelsen B, Katona L, Keeling J, Stoian L, Wilson T, Fairclough M, Cowley MW and Zang W (compilers) 2012. Geological Survey of South Australia, Department of Manufacturing, Innovation, Trade, Resources and Energy. Palaeodrainage and Cenozoic Coastal Barriers of South Australia. *Digital Geological Map of South Australia, 1:2 000 000 Series* (2nd Edition).

Hou B, Michaelsen B, Li Z, Keeling JL, Fabris JA and the participants of IGCP-514 2014. Paleovalley-related uranium: exploration criteria and case-studies from Australia and China. *Episodes*, 37(3): 150-171.

Hou B, Keeling J and Van Gosen BS 2017a. Geological and exploration models of beach placer deposits, Integrated from case-studies of southern Australia. *Ore Geology Reviews*, 80: 437-459.

Hou B, Keeling J and Li Z 2017b. Paleovalley-related uranium deposits in Australia and China: A review of geological and exploration models and methods. *Ore Geology Reviews,* 88: 201-234.

Hou B, Keeling JL, Reid AJ, Pobjoy R and Wu E 2021. Models, geology and exploration of heavy minerals deposits in South Australia. Report Book, 2021/0001. South Australia, Department for Energy and Mining, South Australia, Adelaide.

Hou B, Keeling J, Reid A, Petts A and Stoian L 2022. Eucla Basin and peripheral paleovalleys. Report Book 2022/00011. Department for Energy and Mining, South Australia, Adelaide.

Jackson MJ and Van D E Graaff WJE 1981. Geology of the Officer Basin, Western Australia. *Aust. Bur. Miner. Resourc. Bull.,* 206, 102 pp.

Jagodzinski EA, Bodorkos S and Crowley JL 2018. PACE Copper Coompana Drilling Project: U-Pb Dating of Basement and Cover Rocks. Report Book 2018/00028, 211. Department for Energy and Mining, South Australia, Adelaide.

James NP, Bone Y, Carter RM and Murray-Wallace CV 2006. Origin of the Late Neogene Roe Plains and their calcarenite veneer: implications for sedimentology and tectonics in the Great Australian Bight. Australian Journal of Earth Sciences, 53: 407 – 419.

Jennings JN 1963. Some geomorphological problems of the Nullarbor Plain. Transaction of the Royal Society of South Australia Trans., 87: 41-62.

Jones MJ 1987. Review of palynology, Arckaringa Basin, (NB/SR 12, Birribiana 1 and Hanns Knob 1). Palynological laboratory report No. 542/1. South Australia. Department of Mines and Energy. Open file Envelope*,* 4878: 739-756 (unpublished).

Keeling JL, Ferris GM and Statham-Lee L 1995. Palygorskite clay investigation, Garford Palaeochannel, South Australia: Results of drilling April-May, 1995. Report Book, 95/48, *Department of Mines and Energy, South Australia.*

Krapf CBE, Irvine JA, Pawley MJ, McMaster M and González-Álvarez I 2023. Connecting the cover to the basement in the central-western Gawler Craton. Manual- and automated-derived surface and subsurface lineaments for the Gawler Phase 2 area of South Australia. Report Book 2023/00036. Department for Energy and Mining, South Australia, Adelaide.

Krapf C, Costar A, Stoian L, Keppel M, Gordon G, Inverarity K, Love A and Mundy T 2019. A sniff of the ocean in the Miocene at the foothills of the Musgrave Ranges – unravelling the evolution of the Lindsay East Palaeovalley. MESA Journal 90: 4-22.

Krapf C, Costar A, Keppel M, Inverarity K, Love A, Stoian L, Gordon G, Soerensen C & Munday T 2019. Backing up the AEM– unravelling a palaeovalley fill for groundwater exploration in the APY Lands, ASEG Extended Abstracts, 2019:1, 1-6, 10.1080/22020586.2019.12073103

Krieg GW 1995. Mesozoic. In JF Drexel and WV Preiss eds, The geology of South Australia, Vol. 2, The Phanerozoic, Bulletin 54. Geological Survey of South Australia, Adelaide. pp 92-149*.*

Kwitko G 1986. Coal exploration drilling in the Clayton area, Marree. *South Australia. Department of Mines and Energy. Report Book,* 86/85.

Leslie C, Jones L, Papp E, Wakw-Dyster K, Deen TJ and Gohl K 2000. High-resolution seismic imagery of palaeochannels near West Wyalong, New South Wales. *In:* Exploration Geophysics. Spec. Edis. Mike Dentith & Mike Middleton. The Bulletin of the Australian Society of Exploration Geophysicists, 31: 383-388.

Li Q, James N P, Bone Y and McGowran B 1996. Foraminiferal biostratigraphy, and depositional environments of the mid- Cenozoic Abrakurrie Limestone, Eucla Basin, southern Australia. *Australian Journal of Earth Sciences* 43, 437–450.

Li Q, Simo JA, Mcgowran B and Holbourn A 2004. The eustatic and tectonic origin of Neogene unconformities from the Great Australian Bight. *Marine Geology*, 203: 57–81.

Lindsay JM and Harris WK 1975. Fossiliferous marine and non-marine Cainozoic rocks from the eastern Eucla Basin, South Australia. *Mineral Resources Review, South Australia,* 138: 29-42.

Lowry DC 1968. Tertiary stratigraphic units in the Eucla Basin in Western Australia: West. Australia Geol. Survey Ann. Rept. 1967, p. 40-44.

Lowry DC1970. Geology of the Western Australian part of the Eucla Basin. Bulletin 122. Geological Survey of Western Australia, Perth, pp 1-200.

Ludbrook NH 1958. The Eucla Basin in South Australia. In Glaessner MF and Parkin LW (Eds). The geology of South Australia. *Geological Society of Australia. Journal,* 5:127-135.

Mackey T, Lawrie K, Wilkes P, Munday T, Kovaces NDS, Chan R, Gibson D, Chartres C and Evans R 2000. Palaeochannels near West Wyalong, New South Wales: A case study in delineation and modelling using aeromagnetics. *In:* Exploration Geophysics. Spec. Edis. Mike Dentith & Mike Middleton. The Bulletin of the Australian Society of Exploration Geophysicists, 31: 1-7.

Martin R 1998. Spencer Regions strategic water management study. MESA Journal 10: 7-9. *Department of Mines and Energy, South Australia.*

Martin R, Sereda A and Clarke D 1998. Spencer regions strategic water management study. Report Book 98/19*, Department of Mines and Energy, South Australia*.

McBain DR 1987. Arkeeta No. 1, PEL 24, South Australia, well completion report. *South Australia. Department of Mines and Energy. Open file Envelope,* 7036(6) (unpublished).

McGowran B 1973. Rifting and drift of Australia and the migration of mammals. *Science,* 180:759-761.

McGowran B 1989. The later Eocene transgressions in southern Australia. *Alcheringa*, v. 13: 45-68.

McGowran B, Moss G and Beecroft A 1997. The Cenozoic record of southern Australia: the biogeohistorical framework. *Society of Economic Paleontologists and Mineralogists. Special Publication,* 56:185-204.

McGowran B, Holdgate GR, Li Q and Gallagher SJ 2004. Cenozoic stratigraphic succession in southeastern Australia. *Australian Journal of Earth Sciences*, 51: 459-496.

McWhae JRH, Playford PE, Lindner AW, Glenister BF and Balme BE 1958. The stratigraphy of Western Australia: Journal, Geological Society of Australia 4, pt. 2, 161 p.

Menpes S A, 2012. Unconventional Hydrocarbon Potential of the Arckaringa Basin, South Australia. In: Ambrose GJ and Scott J. eds Central Australian Basin Symposium III. Petroleum Exploration Society of Australia, Special Publication.

Miall AD 1996. The Geology of Fluvial Deposits. –Sedimentary Facies, Basin Analysis, and Petroleum Geology. Springer-Verlag Berlin Heidelberg New York, 582 pp.

Moore PS 1982. Oil shale potential of the Arckaringa region. *South Australia. Department of Mines and Energy. Open file Envelope,* 4848: 729-738 (unpublished).

Moore PS and Pitt GM 1985. Cretaceous subsurface of the southwestern Eromanga Basin: a review. *In:* Lindsay, J.M. (Ed.), Stratigraphy, palaeontology, malacology — papers in honour of Dr Nell Ludbrook. *South Australia. Department of Mines and Energy. Special Publication,* 5: 269-286.

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

Morgan RP 1980a. Eustacy in the Australian Early and Middle Cretaceous. *New South Wales. Geological Survey. Bulletin,* 27.

Morgan RP 1980b. Palynostratigraphy of the Australian Early and Middle Cretaceous. *New South Wales. Geological Survey. Memoirs, Palaeontology,* 18: 1-153.

Munday T, Adbat T, Ley-Cooper Y and Gilfedder M 2013. Facilitating long-term outback water solutions (G-FLOWS) Stage-1: Hydrogeological framework, Technical Report Series No. 13/12. Goyder Institute for Water Research, Adelaide.

Neumann N and Korsch RJ 2014. SHRIMP U-Pb zircon ages for Kutjara 1 and Mulyawara 1, Northwestern South Australia. Geoscience Australia, Canberra, Record 2014/5, 18.

Ollier CD, Chan RA, Craig MA and Gibson DL 1988. Aspects of landscape history and regolith in the Kalgoorlie region, Western Australia. *BMR Journal of Australian Geology and Geophysics,* 10: 309-321.

Pawley MJ and Krapf CBE 2016. Investigating the potential for bedrock aquifers in the APY Lands, Report Book 2016/00021. Department of State Development, South Australia, Adelaide.

Phillips BJ, James AW and Philip GM 1985. The geology and hydrocarbon potential of the western Officer Basin: APEA Journal, v. 25(1): 52-61.

Pitt GM, Benbow MC, Barnes LC and Harris WK 1978. Report on drilling in the Tallaringa Palaeodrainage System. Report Book, 1978/38. Department for Energy and Mining, South Australia, Adelaide.

Posamentier, H.W., Jervey, M.T. and Vail, P.R., 1988. Eustatic controls on clastic depositional - conceptual framework. *In:* Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A. and van Wagoner, J.C. (Eds), Sea level change - an integrated approach. *Society of Economic Paleontologists and Mineralogists. Special Publication,* 42: 110-124.

Preiss WV, Belperio AP, Cowley WM and Rankin R 1995. Neoproterozoic. In JF Drexel and WV Preiss eds, The geology of South Australia, Vol. 1, The Precambrian, Bulletin 54. Geological Survey of South Australia, Adelaide. pp 171-203.

Quigley MC, Clark D and Sandiford M 2010. Tectonic geomorphology of Australia. Geological Society of London Special Publication 'Australian landscapes', 346: 243-265.

Rankin LR, Benbow MC, Fairclough MC and Daly SJ 1996. BARTON, South Australia, sheet SH53-9. *South Australia. Geological Survey. 1:250 000 Series — Explanatory Notes.*

Raven MD, Abolins N, Keeling JL and Self PG, 1995. Absorbent Clay Project: Supplementary report. – Mineralogical characterisation of Garford palaeochannel clays. CSIRO – Division of Soil, Report to Mines and Energy, South Australia. *Open file Envelope*, 8785 V4 (unpublished).

Read RE 1987. Maralinga lands, 1986 water drilling. Report Book, 87/42. *Department of Mines and Energy, South Australia.*

Reid JA and Hou B 2006. Source of heavy minerals in the Eucla Basin palaeobeach placer province, South Australia: age data from detrital zircons. *MESA J.*, 42: 10-14. Department for Energy and Mining, South Australia, Adelaide.

Reid AJ, Korsch, RJ, Hou B and Black LP 2009. Sources of sediment in the Eocene Garford paleovalley, South Australia, from detrital-zircon geochronology, Australian Journal of Earth Sciences,56:1, S125 - S137.

Reid A, Keeling J, Boyd D, Belousova E and Hou B 2013. Source of zircon in world-class heavy mineral placer deposits of the Cenozoic Eucla Basin, southern Australia from LA-ICPMS U-Pb geochronology. *Sedimentary Geology*, 286-287: 1-19.

Robertson RS 1984. Reconnaissance sampling of palygorskitic clay - Garford palaeochannel. – Coober Pedy. Report Book, 84/52. *Department of Mines and Energy, South Australia.*

Robertson RS 1988. Reconnaissance sampling of palygorskitic clay in Garford palaeochannel. *Mineral Resources Review, South Australia,* 156: 104.

Rogers PA 2000. Tertiary palaeodrainage of South Australia. *South Australia, Geological Survey. Digital Geological Map of South Australia, 1:2 000 000 Series* (2nd edition).

Ruperto L, Paine MD, Worrall L, Hou B, Evans N, Welch S, Stoian L and Pillans B 2006. Eucla Margins Heavy Minerals Project – Final Report. CRC for Landscape Environment and Mineral Exploration. Restricted Report, 245R.

Russell M 1998. Gawler Craton water plan. MESA Journal, 4: 18-20. *Department of Mines and Energy, South Australia.*

Sandiford M 2007. The tilting continent: a new constraint on the dynamic topographic field from Australia. *Earth and Planetary Science Letters*, 261: 152-163.

Self PG, Keeling JL and Raven MD 1996. Absorbent Clay Project: Additional report. – Mineralogy and physical properties of samples containing palygorskite collected during the MESA 1995 drilling programme in the Garford palaeochannel, South Australia. CSIRO – Division of Soil, Report to Mines and Energy, South Australia. *Open file Envelope*, 8785 V5 (unpublished).

Sheard MJ, Lintern MJ, Prescott JR and Huntley DJ 2006. Great Victoria Desert: New dates for South Australia's? oldest desert dune system. MESA Journal 95: 41–48. Department for Energy and Mining, South Australia, Adelaide.

Singleton OP 1954. The Tertiary stratigraphy of Western Australia, a review: Pan-Indian Ocean Sci, Cong., Perth, 1954, Prox. Sect. C, p. 59-65.

Smithies RH, Howard HM, Evins PM, Kirkland CL, Bodorkos S and Wingate MTD 2009. The west Musgrave Complex - new geological insights from recent mapping, geochronology, and geochemical studies. *Geological Survey of Western Australia Record*, 2008/19.

Smithies RH, Howard HM, Evins P, Kirkland CL, Kelsey DE, Hand M, Wingate MTD, Collins AS, Belousova EA and Allchurch S 2010. Geochemistry, geochronology and petrogenesis of Mesoproterozoic felsic rocks in the west Musgrave Province, Central Australia, and implications for the Mesoproterozoic tectonic evolution of the region. *Geological Survey of Western Australia, Report*, 106.

Smyth EL and Barrett DM 1994. Geophysical characteristics of the Tertiary palaeochannel in the Yilgarn Block, Western Australia. *In* Geophysical signatures of Western Australian Mineral Deposits. Edited by Dentith et al., 1994, p. 417-426.

Soerensen CC, Munday TJ, Ibrahimi T, Cahill K and Gilfedder M in press. Musgrave Province, South Australia: Processing and inversion of airborne electromagnetic (AEM) data: preliminary results, Technical Report Series. Goyder Institute for Water Research, Adelaide.

Spaggiari CV, Kirkland CL, Smithies RH and Wingate MTD 2012. What lies beneath –interpreting the Eucla basement, in GSWA 2012 extended abstracts: promoting the prospectivity of Western Australia: Geological Survey of Western Australia, Record 2012/2, 25-27.

Statham-Lee L 1994. Palaeodrainage and its economic potential in the Officer Basin and Musgrave Block. Report Book, 94/30. *Department of Mines and Energy, South Australia,*

Stoian LM 2003a. Palynological evidence for Late Miocene-Early Pliocene deposits in the eastern Eucla Basin, South Australia. Report Book 2003/023. *Department of Primary Industry and Resources, South Australia*.

Stoian LM 2003b. Palynological analyses and dating of eight cutting samples from Konkaby 1 drillhole, Eucla Basin, South Australia.

Stoian LM 2003c. Palynological examination of samples from KINPC1 and KINPC2 wells, Eucla Basin, South Australia. Report Book 2003/029. *Department of Primary Industry and Resources, South Australia*.

Stoian LM 2004a. Late Miocene-Early Pliocene palynofloras from selected drillholes in the eastern Eucla Basin, South Australia. Report Book 2004/011. *Department of Primary Industry and Resources, South Australia*.

Stoian LM 2004b. Eucla Basin – Late Miocene-Early Pliocene palynofloras. MESA Journal 34: 42-45

Tapley IJ 1988. The reconstruction of palaeodrainage and regional geologic structures in Australia's Canning and Officer Basin using NOAA-AVHRR Satellite Imagery. *Earth Science Reviews*, 25: 409-425.

Tapley IJ and Wilson P 1985. The discrimination of potentially economic palaeodrainage in the sedimentary basins of central and western Australia using NOAA-AVHRR imagery. *Fourth Thematic Conference: 'Remote Sensing for Exploration Geology',* San Francisco, California, April 1-4, 1985.

Taylor DJ 1975. Palaeontological Report — Potoroo-1. Appendix V in well completion report SDA 196, Potoroo 1, Permit SA-5, Great Australian Bight Basin, for Shell Development (Australia) Pty Ltd. *South Australia. Department of Mines and Energy. Open file Envelope,* 2494 (unpublished).

Taylor DJ 1983. The Gippsland Basin Enigma–top Latrobe. Report to Phillips Australia Oil Company (unpubl.).

Taylor DJ 1986. Multum in Parvo Gippslandiana: a compilation of offshore Gippsland Basin biostratigraphy and palaeogeography based on reappraisal of 59 drilled sequences. Prepared for Marathon Petroleum Exploration Limited, Singapore (unpubl.).

Tomkins A G and Mavrogenes J A 2002. Mobilization of gold as a polymetallic melt during pelite anatexis at the Challenger Deposit, South Australia: a metamorphosed Archean gold deposit. Economic Geology 97, 1249–1271.

Townson WG 1985. The subsurface geology of the western Officer Basin - results of Shell's 1980-1984 petroleum exploration campaign: APEA Journal, 25(1): 34-51.

Uranerz Australia Pty Ltd 1975. First quarterly report on exploration work carried out on exploration licence No 157covering the period October 21st, 1974, to January 20th 1975. Report to Mines and Energy, South Australia. *Open file Envelope* 2477 (unpublished).

Veevers IJ ed., 2000. Billion-year history of Australia and neighbours in Gondwanaland: Sydney, GEMOC Press, 400 p.

Vin, RR and Day RW 1965. Nomenclature of the Rolling Downs Group, northern Eromanga Basin, Queensland. *Queensland Government Mining Journal,* 66: 416-421.

Wade B, Barovich K, Hand M, Scrimgeour IR and Close DF 2006. Evidence for early Mesoproterozoic arc-related magmatism in the Musgrave Block, central Australia: implications for Proterozoic crustal growth and tectonic reconstructions of Australia. *Journal of Geology*, 114: 43-63.

Wade BP, Kelsey DE, Hand M and Barovich KM 2008. The Musgrave Province: stitching north, west and south Australia. *Precambrian Research,* 166: 370-386.

Wales DW and Forman DJ 1981. Geological evolution of the Canning Basin, Western Australia, Bureau of Mineral Resources, Australia. Bulletin, 210.

Warne SB 1987. Roebuck Resources N.L.: Report for the period 19th September 1986 to 18th December 1987, Sandstone EL 1371, South Australia. *South Australia, Department of Mines and Energy. Open file Envelope,* 6809 (unpublished).

Weber GB 1980. 1979 geochemical water sampling programme. Wilkinson Lakes area South Australia. BP Mining Development Australia Pty Ltd. *South Australia, Department of Mines and Energy. Open file Envelope,* 3570 (unpublished).

Whitehouse FW 1955. The geology of the Queensland portion of the Great Artesian Basin. *In:* Artesian water supplies in Queensland. *Queensland. Parliamentary Papers. Report,* A56: 1-20.

Wilmot JG 1987. Geophysical interpretation report 1985 Morphett-Arc seismic survey. Arckaringa block. Arckaringa North, Central and South areas. *South Australia. Department of Mines and Energy. Open file Envelope,* 5995 (unpublished).

Wingate MTD, Pirajno F and Morris PA 2004. Warakurna large igneous province; a new Mesoproterozoic large igneous province in west-central Australia. *Geology*, 32: 105-108.

Wingate M, Kirkland C, Spaggiari C and Smithies R 2015. U–Pb geochronology of the Forrest Zone of the Coompana Province. Eucla basement stratigraphic drilling results release workshop: extended abstracts compiled by CV Spaggiari and RH Smithies: Geological Survey of Western Australia, Record 2015/10, 37-40.

Wopfner H 1970. Permian palaeogeography and depositional environment of the Arckaringa Basin, South Australia. *In:* Haughton, S.H. (Ed.), *2nd Gondwana Symposium, Pretoria, South Africa, 1970. Proceedings and papers.* Council for Scientific and Industrial Research, pp.273-291.

Wopfner H 1972. Depositional history and tectonics of South Australian sedimentary basins. *Mineral Resources Review, South Australia,* 133: 32-50.

Wopfner H 1980. Development of Permian intracratonic basins in Australia. *In:* Cresswell, M.M. and Vella, P. (Eds), *Gondwana five.* Proceedings of the 5th International Gondwana Symposium, Wellington, New Zealand, 1980, pp.185-190.

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

Zang WL and Stoian L 2006. Tertiary-Quaternary land evolution of north-western South Australia. *Regolith 2006:* 372-376

APPENDIX

GP2 biostrata table (XLSX). Click to open attachments pane.

GP2 Paleovalley systems GIS data package
http://dsd-gdp.s3.amazonaws.com/2044125/GDP00130.zip
Data package GPD00130 accompanies this report book. Explanatory notes on the contents and how to use the contained data are included within the Zip file.