



SRK Consulting

Integrated Science and Engineering Consultancy

Western Stansbury Basin SEEBASE Project

SRK Project Code: PI12

May 2001



**PRIMARY INDUSTRIES
AND RESOURCES SA**



Suite 7, Deakin House
50 Geils Court
PO Box 250
Deakin West ACT 2600
Australia

email: canberra@srk.com.au
URL: <http://www.srk.com.au>
Tel: +61 2 6283 4800
Fax: +61 2 6283 4801

Western Stansbury Basin SEEBASE* Project

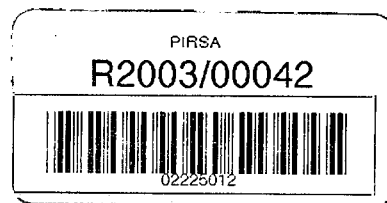
SRK Project Code: PI12

April - May 2001

Authors:

Jon Teasdale
Lynn Pryer
Mike Etheridge
Karen Romine
Peter Stuart-Smith
Jun Cowan
Tom Loutit
John Vizey
Phil Henley

Jon Teasdale
Consultant Geologist



Tom Loutit
Technical Director

***SEEBASE = Structurally Enhanced view of Economic Basement**

The conclusions and recommendations expressed in this material represent the opinions of the authors based on the data available to them. The opinions and recommendations provided from this information are in response to a request from the client and no liability is accepted for commercial decisions or actions resulting from them.



**PRIMARY INDUSTRIES
AND RESOURCES SA**



Stellen, Robertson & Kirwan (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Table of Contents

Introduction

Executive Summary	4
Recommendations	5
Project Background, Aims, Why SRK?	6

Data Compilation & Processing

Datasets, Project Area	7
Aeromagnetics	8
Bouguer Gravity	9
Digital Elevation Model	10
Seismic Coverage, Wells Coverage	11

Calibration & Methodology

Calibration of Potential Field Data, Why Basement?	12
SABRE, Basement Character & Petroleum Systems	13

Basement Geology of the Stansbury Basin

Basement Terranes	14
Basement Composition	15
Basement Structure – Overview	16
Basement-Involved Faults	17
Deep Crustal Fracture Zones	18
Proterozoic Basement Deformation	19

Geological Evolution of the Stansbury Basin

Basin Phase 1: Neoproterozoic Extension	20
Basin Phase 2: Early Cambrian Rifting	21
Basin Phase 3: Delamerian Orogeny	23
Basin Phase 4: Tertiary Uplift	25

SEEBASE Depth to Basement

SEEBASE Methodology	27
Model Magnetic Profiles	29
Stansbury Basin SEEBASE	30
3D Views of Stansbury Basin Architecture	31

Basement Controls on Basin Architecture

References	32
------------	----



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirwan (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Executive Summary

This project was initiated by PIRSA to augment their marketing campaign to attract new hydrocarbon explorers to the Stansbury by providing new insights into its geology and hence reduce exploration risk. SRK was contracted in March 2001 to provide an integrated regional interpretation of basement composition, structure and depth in the western Stansbury Basin, and investigate the effect of basement geology on basin evolution and petroleum systems.

SRK's approach primarily relies on the interpretation of magnetic and gravity data, calibrated with many other datasets including mapped geology, topography, event histories, wells and seismic. SRK utilizes a "bottom-up" approach to basin analysis, starting with a rigorous understanding of basement geology. By integrating the plate-scale kinematic event history for the area of interest, a interpretation of the basin's structural evolution through time can be mapped. Combined with a SEEBASE* map of depth to basement, this data can be used to understand basin phase distribution and petroleum systems.

The key findings of this project are as follows:

- The basement geology of the Stansbury is dominated by 3 contrasting terranes which have behaved very differently during basin evolution.
- Terrane boundaries are a first-order control on basin architecture in the Stansbury. Paleoproterozoic shear zones are a second-order control.
- Basin architecture is largely controlled by basement structures, composition, fabric and rheology.
- Four basin phases/tectonic events have shaped the Stansbury during the Neoproterozoic, early Paleozoic and Tertiary.
- Early Cambrian rifting and late Cambrian foreland flexure were the principal basin-forming events.
- A SEEBASE* model for the western Stansbury Basin shows basement topography, and can be used to map basin phase distribution, migration pathways and trap type/distribution.
- A previously unrecognised "new" sub-basin has been recognised just to the south of Yorke Peninsula.

**SEEBASE = Structurally Enhanced view of Economic Basement*



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirdan (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Recommendations

- This projects provides new base to investigate the stratigraphic evolution of the western Stansbury Basin. A sequence stratigraphic study based on the structural framework and SEEBASE model presented here would provide new insights into its evolution and petroleum potential.
- Acquire new aeromagnetic data, especially in gaps where no data exists. Use this data to revise the SEEBASE interpretation presented here.
- More detailed SEEBASE study of prospective areas/permits integrating all available seismic data. Full seismic calibration would provide additional constraints on structural geometries at depth and reactivation histories.
- Acquire new seismic in the deeper parts of the Stansbury aimed at resolving basement and the thickness/geometry of the early Cambrian and Adelaidean sections.
- Acquire new seismic and drill "new" sub-basin



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kieren (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Project Background

- The 1996 & 1999 PIRSA Petroleum Industry Surveys demonstrated that a perceived lack of knowledge and largely unfounded geological biases (e.g. poor source/reservoir quality, poor migration timing etc) were preventing petroleum companies from exploring in the Stansbury Basin.
- This project was initiated by PIRSA to augment their marketing campaign to attract new explorers to the Stansbury by providing new insights into its geology and hence reduce exploration risk. SRK Consulting was contracted by PIRSA in March 2001.
- This project was completed in 2 weeks' work by the SRK Energy Services team.

Project Aims

- To provide an integrated regional interpretation of basement composition, structure and depth in the Stansbury Basin, utilizing available gravity, magnetic, seismic and other data.
- To investigate the effects of basement geology on basin evolution and petroleum systems in the Stansbury Basin, focusing on structural evolution/reactivation, basin architecture and tectonic history.

Why SRK?

- SRK Consulting is one of the world's largest natural resource consultancies, with 22 offices in 5 continents.
- The SRK Energy Services group is based in Canberra, Australia. We are leaders in innovative, integrated *geological* interpretation of non-seismic and seismic data, principally magnetic and gravity data. We have worldwide experience in the petroleum, minerals and coal sectors.
- SRK Energy Services has worldwide experience in basin analysis, and has pioneered many new techniques for rapidly evaluating the structural framework and tectonic evolution of all types of basins, based largely on geopotential field data. SRK utilizes a "bottom-up" approach to basin analysis, starting with a rigorous understanding of basement geology. By integrating the plate-scale kinematic event history for the area of interest, a interpretation of the basin's structural evolution through time can be mapped. Combined with a SEEBASE* map of depth to basement, this data can be used to understand basin phase distribution and petroleum systems. (*SEEBASE = Structurally Enhanced view of Economic Basement)

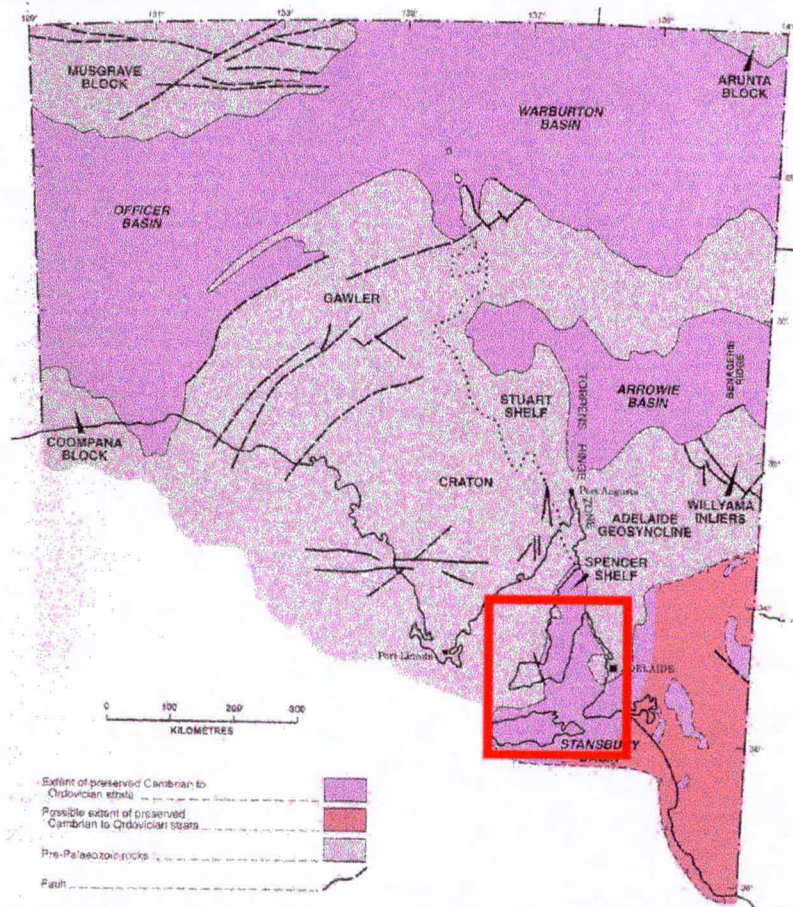


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirschen (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Project Area



The project area is shown in the above map of the Cambrian of South Australia (from Drexel & Preiss 1995). By definition, the Stansbury Basin includes all Cambrian sediment in the southern Adelaide Fold Belt. This study focuses on the relatively undeformed and unmetamorphosed part of the Stansbury to the west of the Adelaide Fold Belt.

Datasets

The following datasets were provided by PIRSA for the Stansbury SEEBASE project:

- Bouguer Gravity (state 500m grid)
- Magnetics (state 100m grid)
- DEM (Auslig 9 sec)
- Seismic (mainly 1993 AGSO data)
- Wells (completion reports, summary logs)
- PIRSA Minerals GIS's (SA_GIS, Western Gawler Craton, Northern Gawler Craton)

In addition, SRK integrated its extensive in-house knowledge of Australian geology, published literature, and plate tectonic reconstructions.

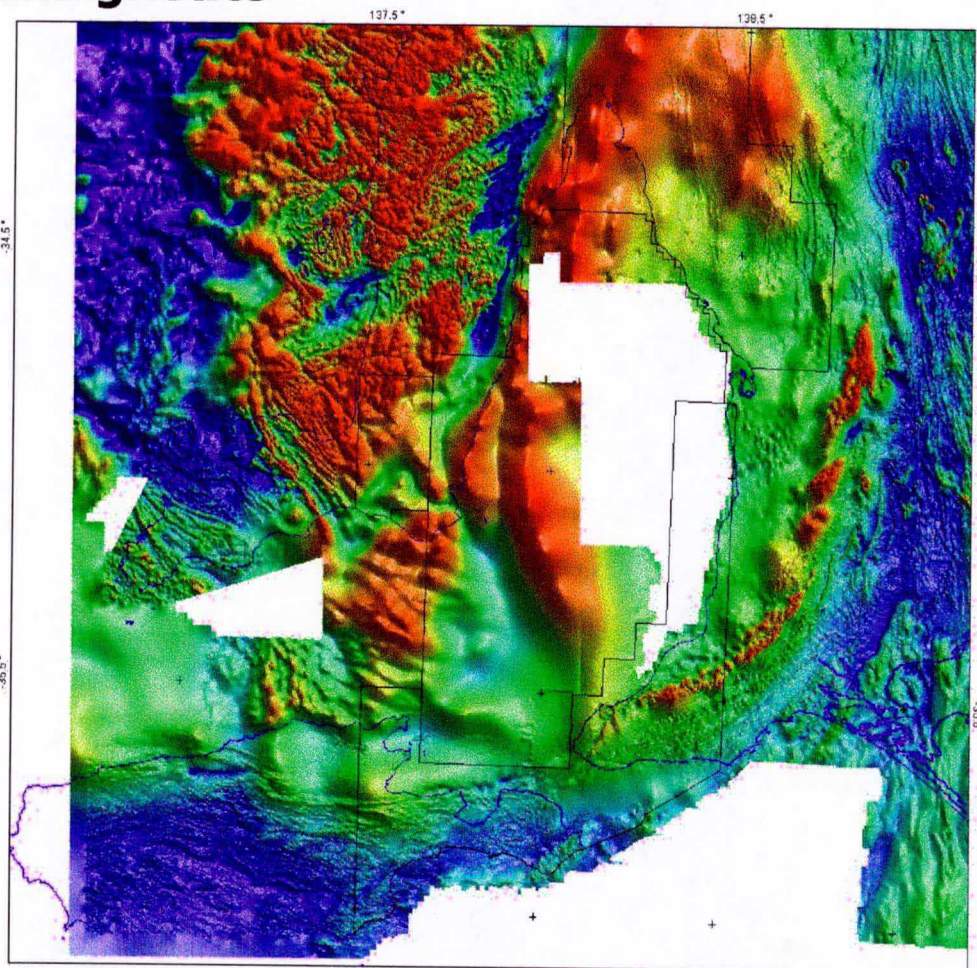


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffers, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Aeromagnetics



HSI image of Total Magnetic Intensity Reduced to the Pole (RTP)

Aeromagnetic data measures variations in the Earth's magnetic field caused by variations in the magnetic susceptibility of the underlying rocks. It provides information on the structure and composition of the magnetic basement. Most bodies within the basement have a distinctive magnetic signature which is characterised by the magnitude, heterogeneity and fabric of the magnetic signal. When calibrated with known geology, terranes can be mapped under a cover of sedimentary rock and/or water.

The most important and accurate information provided by magnetic data is the structural fabric of the basement. Major basement structures can be interpreted from consistent discontinuities and/or pattern breaks in the magnetic fabric. Once the structures have been evaluated and combined with those interpreted from the gravity data, a model for the evolution of the basement and overlying basins can be developed.

For the Stansbury Basin project, the SA state 100m stitched magnetic grid was reduced to the pole and imaged in ERMMapper using a Hue-Saturation-Intensity colour model. Various enhancement filters were applied to resolve the geometry and structure of the basement at depth (e.g. first vertical derivative, automatic gain control).

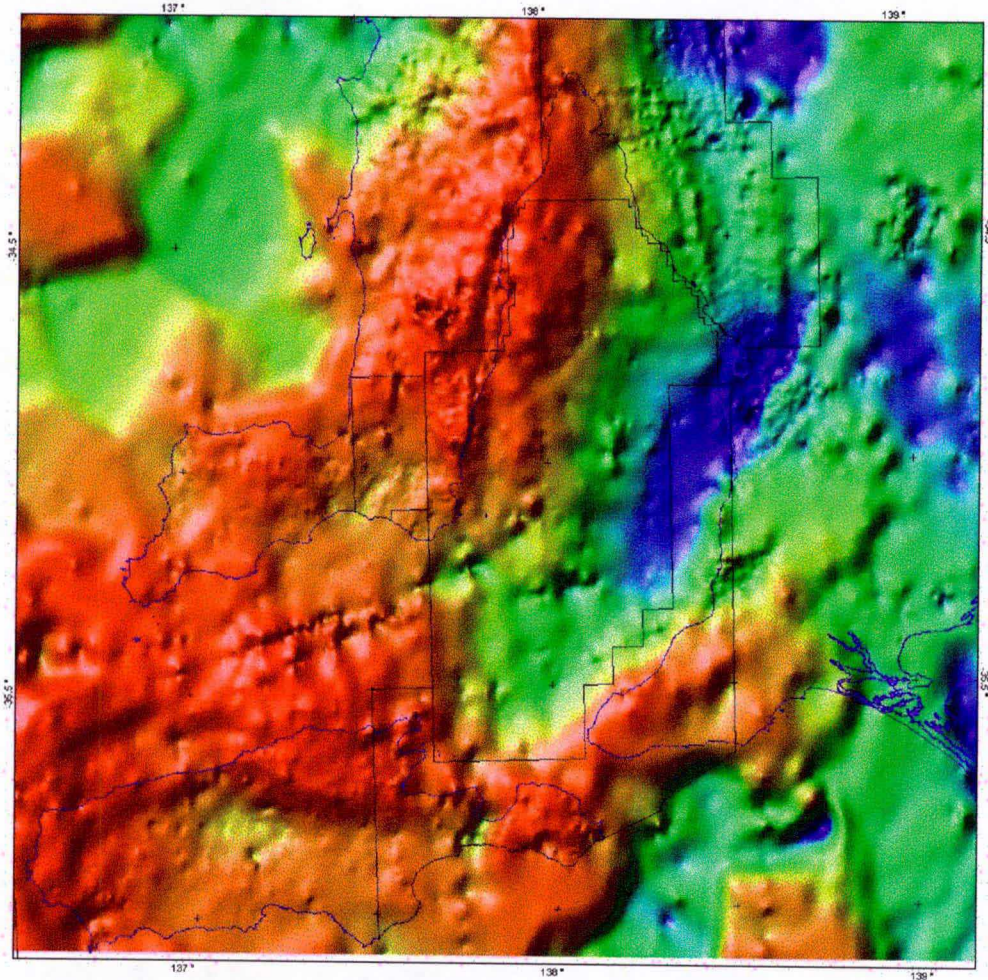


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kintan (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Bouguer Gravity



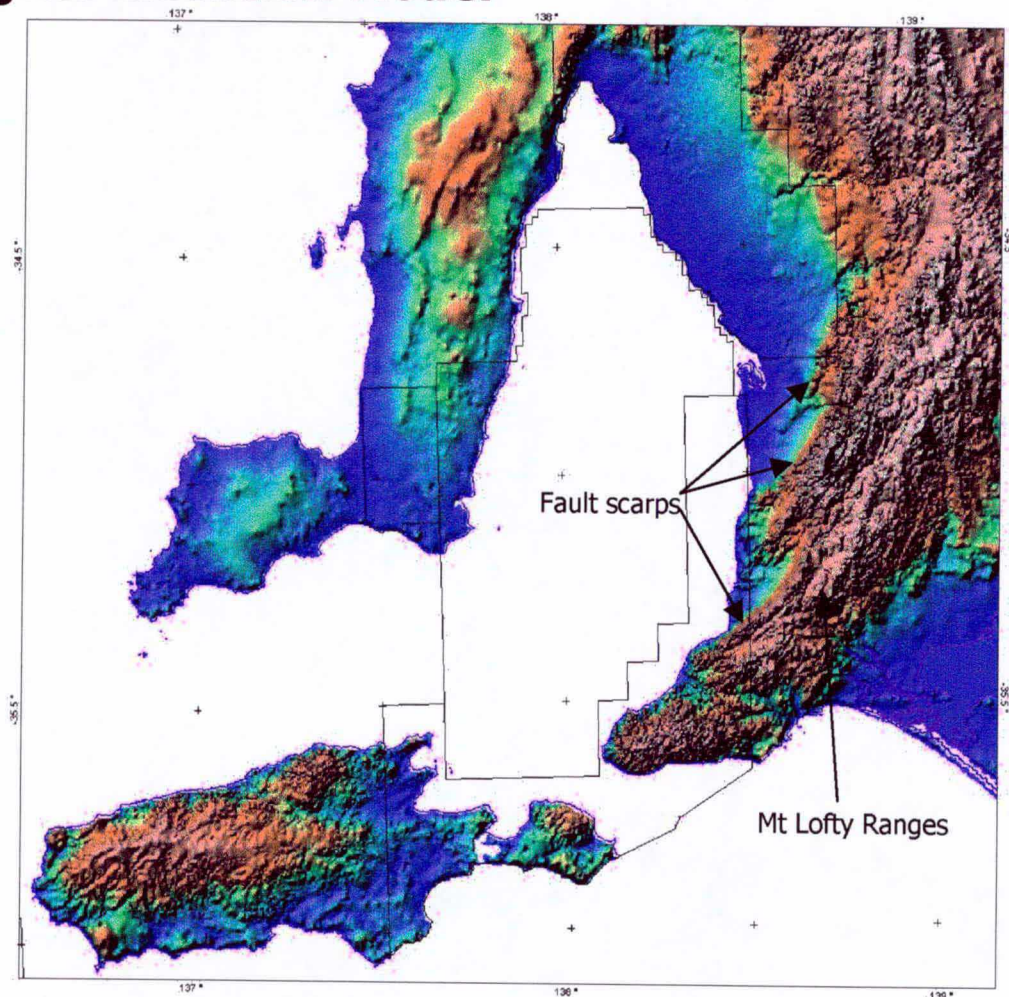
HSI image of Bouguer Gravity

Gravity data is a very important tool for interpreting basins. It maps subtle changes in the Earth's gravitational field caused by variations in the density of the underlying rocks. Although the resolution of this dataset is low (7km spacing), it provides valuable information on the nature of the deeper parts of the crust and mantle beneath the basins. Important intra-basin structures often have an associated gravity signature indicating that each element is related to a deep basement structure.

In order to evaluate the source of the gravity signature, the data must be calibrated with known geology and/or geophysical models. Gravity images show density contrasts within the crust and upper mantle but the source of the contrast is not unique. Thus the origin of each anomaly must be distinguished in this calibration process.

For the Stansbury Basin study, the SA state 500m stitched gravity grid was imaged in ERMapper using a HSI colour model. Data resolution in offshore areas is very poor.

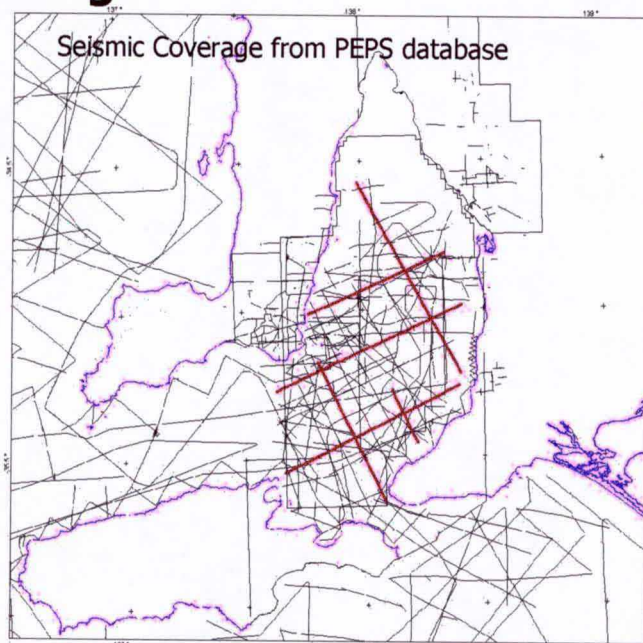
Digital Elevation Model



Digital Elevation Models (DEM's) often show the youngest structures, and any active geological structures. They are widely used for neotectonic analysis. The composition of eroding terrain controls its resistance to weathering, hence DEM's can be used to distinguish different compositional domains.

The DEM for the project area shows the Tertiary topography of the Mt Lofty Ranges, defined by major fault scarps.

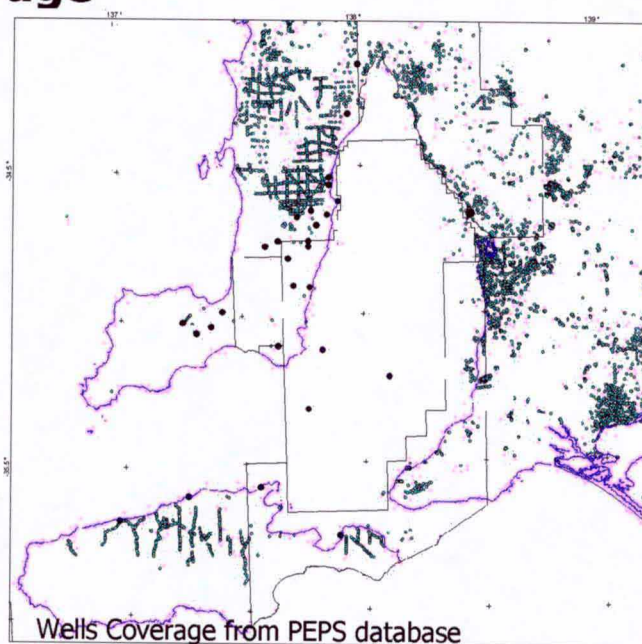
Seismic Coverage



Seismic coverage in the Stansbury Basin is very limited and generally poor quality. The top-basement unconformity is generally not clearly imaged.

In this study, limited seismic data has been used as a calibration tool for the depth to basement modeling and the structural interpretation (particularly timing of structural reactivation). Lines used are shown as bold in the above map.

Wells Coverage



Well coverage from the deeper parts of the Stansbury is very limited, with only a few basement penetrations in the shallower parts of the basin. Solid black dots represent wells used to calibrate this study.

Calibration of Potential Field Data

Calibration is a critical process in any potential field interpretation.

In order to extract as much reliable geological information as possible from potential field data, it is critical to calibrate the data. This is done initially using mapped geology or basement well intersections combined with rock property data (e.g. magnetic susceptibility, density). Once identified, mapped geological units can be traced offshore or under sedimentary cover. Knowing the particular geological units provides information about basement composition and allows for much better constrained depth models from magnetic data.

Away from outcrop control, seismic data are integrated (when available) to further constrain the development of a geological model. Basement penetration by wells and deep seismic data are particularly useful in constraining depth-to-basement estimates from the aeromagnetic data.

Why Basement?

The basement of any basin provides the foundation onto which the sediments are deposited. The rheology and mechanical behaviour of the basement controls the geometry and rate of subsidence of the evolving basin. Basement rheology and mechanical behaviour are determined by its composition and structural fabric. Thus it is important to understand basement evolution prior to basin development.

Understanding basement structures allows models to be developed that can predict which structures will reactivate, and how they will move under an applied stress. Using plate tectonic reconstructions, the far-field stress state during past events can be estimated and a kinematic reconstruction produced for each event. Basin sediments deform in response to movements in the basement and to gravity. Knowing how and when the basement moves provides a basis for predicting the most likely locations of depocentres and structures in the sediments.

Hence basement influences:

- basin phase architecture
- source-rock quality and distribution
- heat flow
- migration focusing, pathways and timing
- trap timing, distribution, type, integrity & size
- sediment supply and stratal geometry
- reservoir, seal quality & distribution



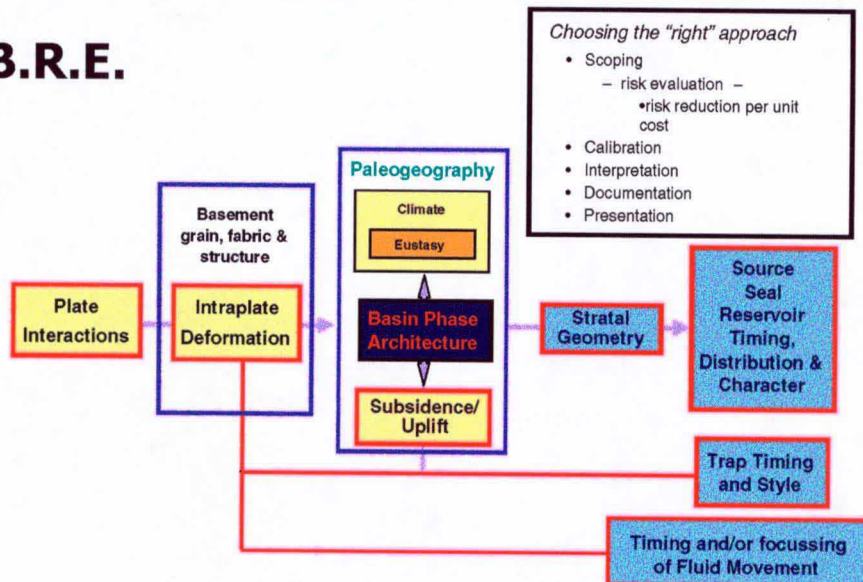
**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kieren (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Systematic Approach to Basin Resource Evaluation

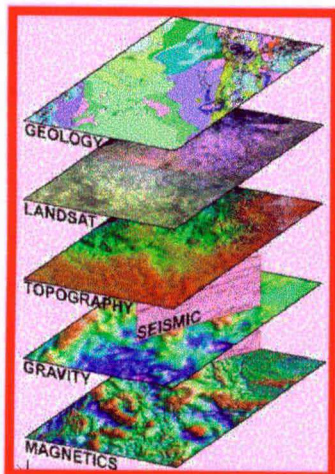
S.A.B.R.E.



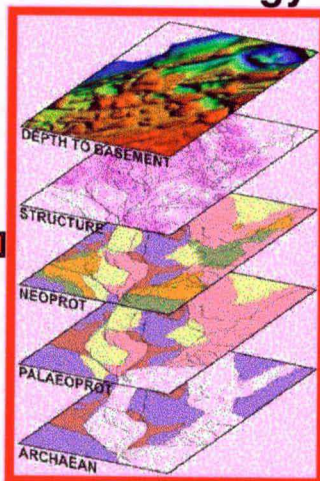
The methodology used to develop a comprehensive structural model relies on the integration of all available geological information. Individual datasets alone can be ambiguous and when isolated often produce poorly constrained interpretations. Through integration, the model can be tightly constrained. Integration provides the means with which to calibrate each dataset to the other.

Basement Character and Petroleum Systems

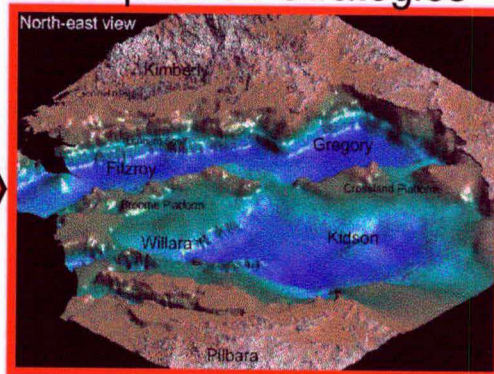
Old Data



Good Geology



New Exploration and Acquisition Strategies



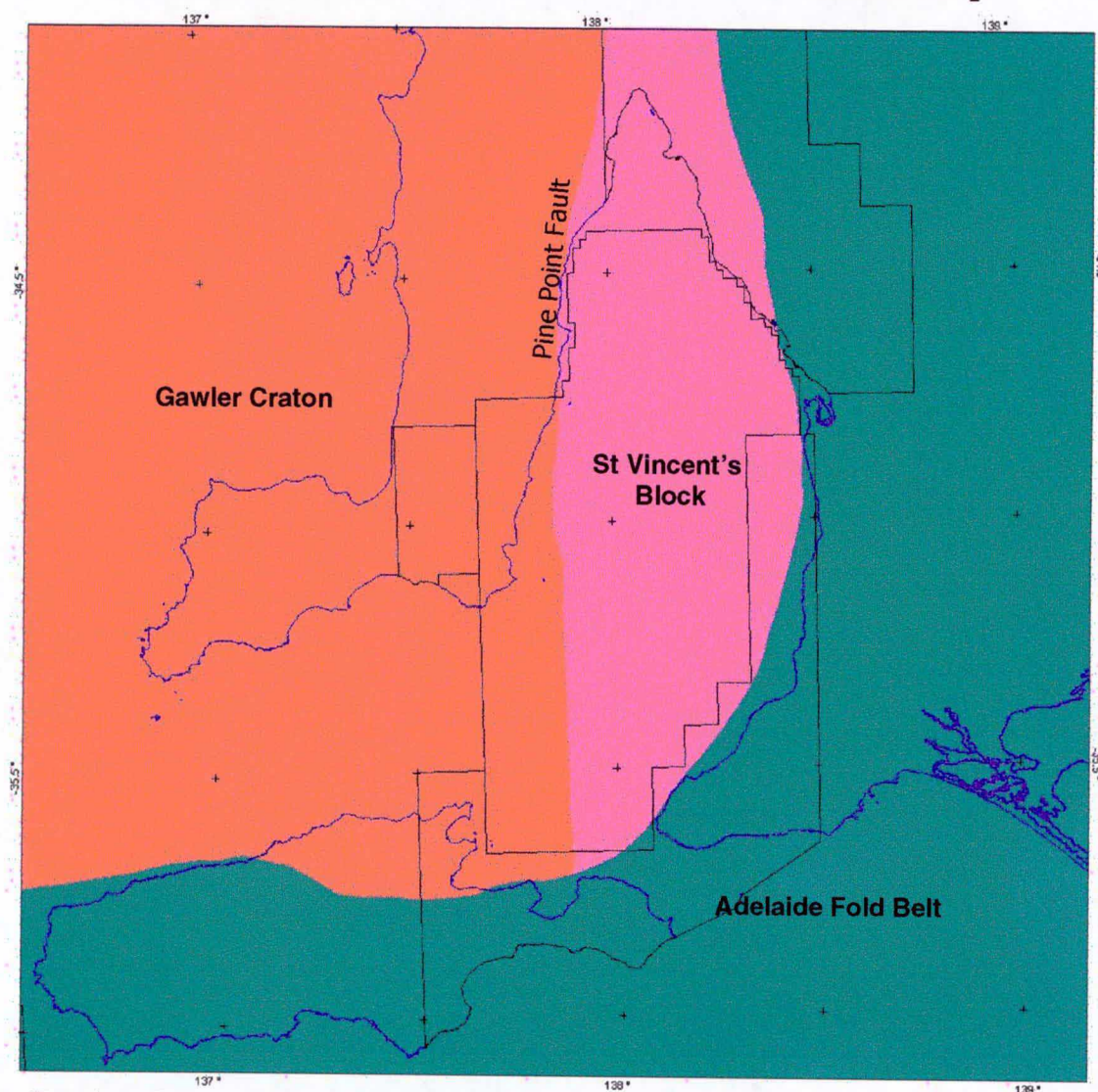
New Technology

Bottom-up

New Views in Old Basins

*Efficient and Effective
Exploration*

Basement Terranes beneath the Stansbury



The Stansbury Basin overlies three Paleo-Mesoproterozoic basement terranes: the southeastern Gawler Craton, the St Vincent's Block and the Adelaide Fold Belt.

The Gawler Craton underwent extensive tectonism during the ~1750-1700Ma Kimban Orogeny. Structural patterns in the St Vincent's Block and Adelaide Fold Belt terranes are different to the Gawler, implying different structural histories. Terrane boundaries are probably post-Kimban (?Mesoproterozoic) shear zones which are localised on long-lived deep crustal zones of weakness (e.g. Pine Point Fault).

The mechanical contrasts between the three basement terranes and the structures within and between them were a first-order control on the evolution of the Stansbury Basin. The terrane boundaries have acted as key reactivation zones and the terranes have behaved very differently under the stresses responsible for the basin formation due to their contrasting rheology and reactive fabrics. Hence the different mechanical behaviour of the basement terranes constitutes a first order control on basin architecture and evolution.

The Gawler Craton and St Vincent's block have remained relatively intact during basin formation. In contrast, the Adelaide Fold Belt basement has been repeatedly and significantly reworked during extension and compression. This emphasises the significant contrast in rheology due to the abundance of high-heat-producing granitoids in the Adelaide Fold Belt basement (see next page).

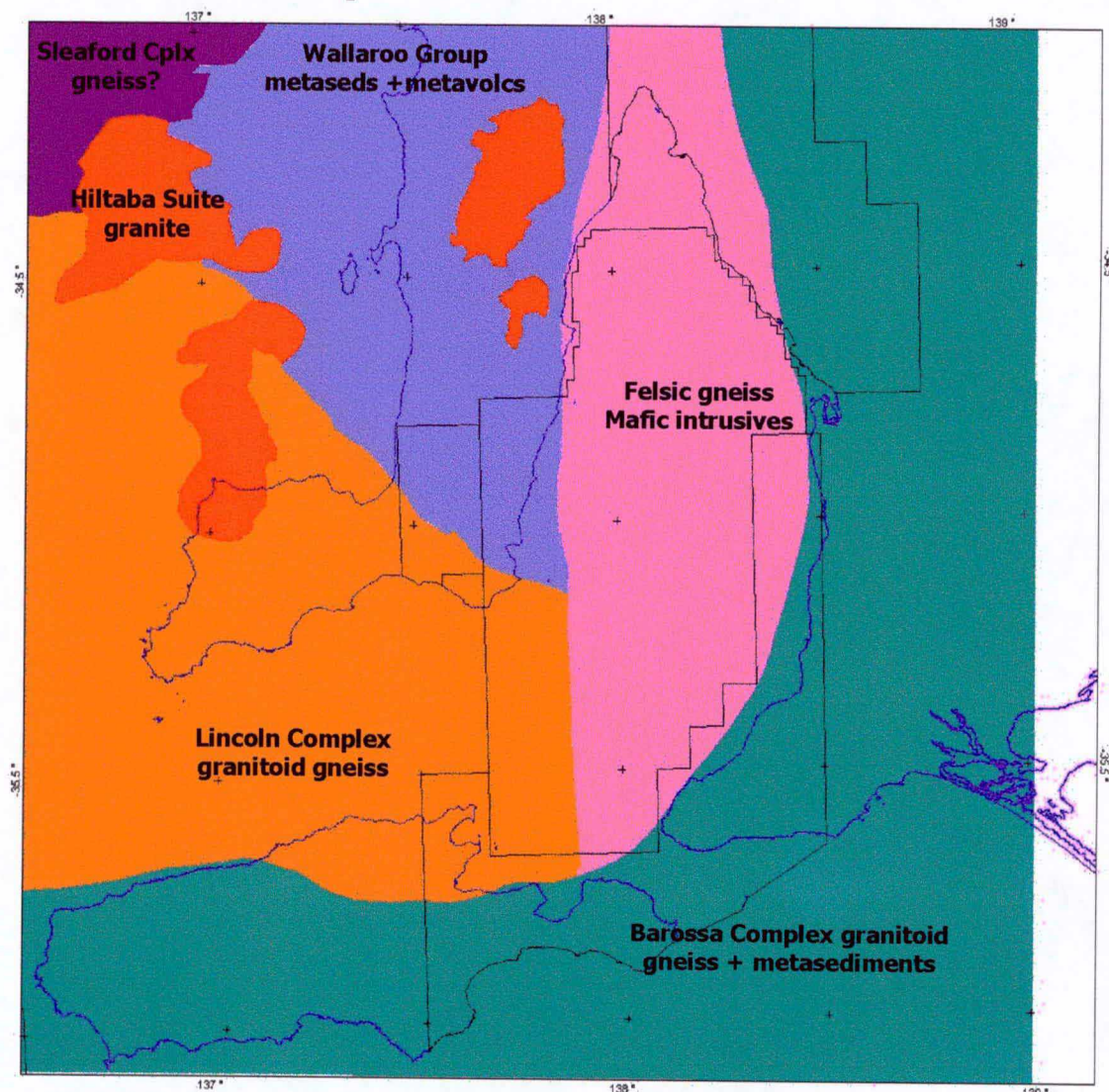


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basement Composition



The combination of gravity and magnetics is a powerful tool for distinguishing the lithological composition of and structural character of basement terranes. The interpretation of basement composition based on magnetic and gravity signatures is calibrated using mapped geology, well intersections and rock property data. The following compositional domains were interpreted:

- Sleaford Complex high grade metasedimentary gneiss (~2450Ma).
- Lincoln Complex granitoid gneiss (~1850Ma). Variably deformed, high grade, I-type intermediate-felsic intrusives.
- Wallaroo Group: variably deformed metasediments and metavolcanics (~1750-1700Ma).
- Hiltaba Suite granites (~1590Ma). Post-orogenic plutons.
- Highly magnetic ?mafic gneiss + low TMI granitoids of the St Vincent's Block
- Barossa Complex basement to the Adelaide Fold Belt. High heat production granitic gneiss + metasedimentary gneiss. Significantly reworked during basin formation.

Basement Structure - Overview

Basement structures are key reactivation zones during basin formation. The following basement structures have been interpreted during this project:

- Faults/shear zones
- Fabric/grain/foliation
- Deep crustal fracture zones
- Transfer/accommodation zones

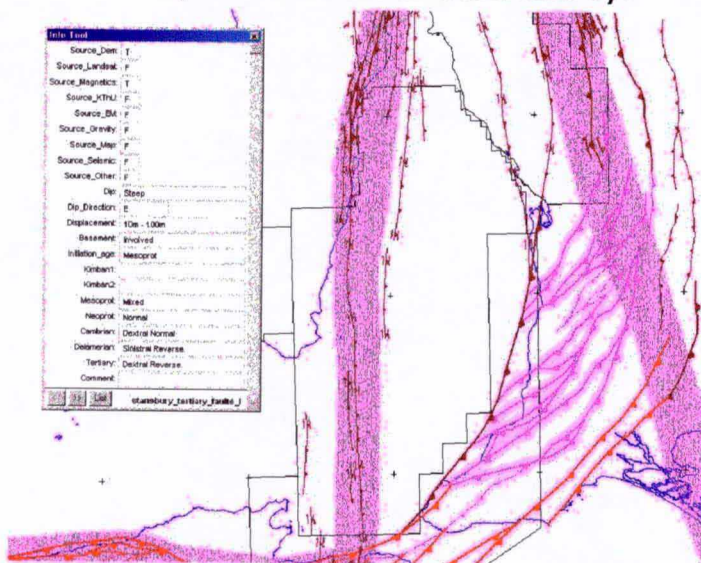
These structures have been interpreted using the following data sources:

- Mapped faults
- Magnetic anomalies & discontinuities
- Gravity anomalies & discontinuities
- DEM trends & breaks
- Seismic basement-involved faults

The history of the structures is quantified using the following criteria and calibration:

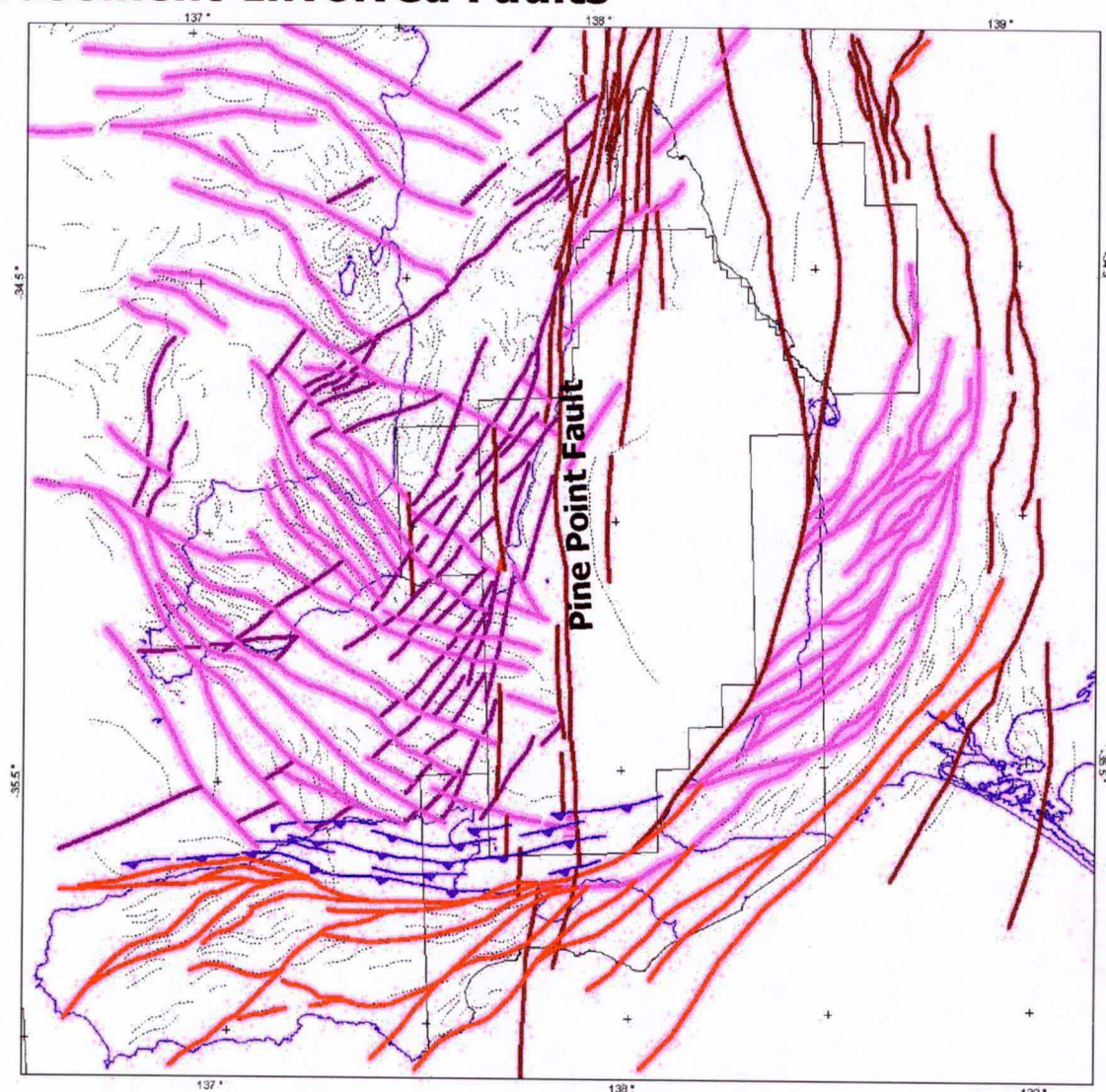
- Structural superposition
- Age of strata displaced
- Relationship to intrusive bodies
- Consistency of fault kinematics to regional paleo-stress regimes and plate movements
- Correspondence to: mapped structures, known movement history

In the GIS, the faults are all attributed by:






- Source (magnetics, gravity, DEM, map etc)
- Orientation
- Displacement
- Basement character (involved or detached)
- Dyke
- Initiation age
- Reactivation history

Basement-Involved Faults

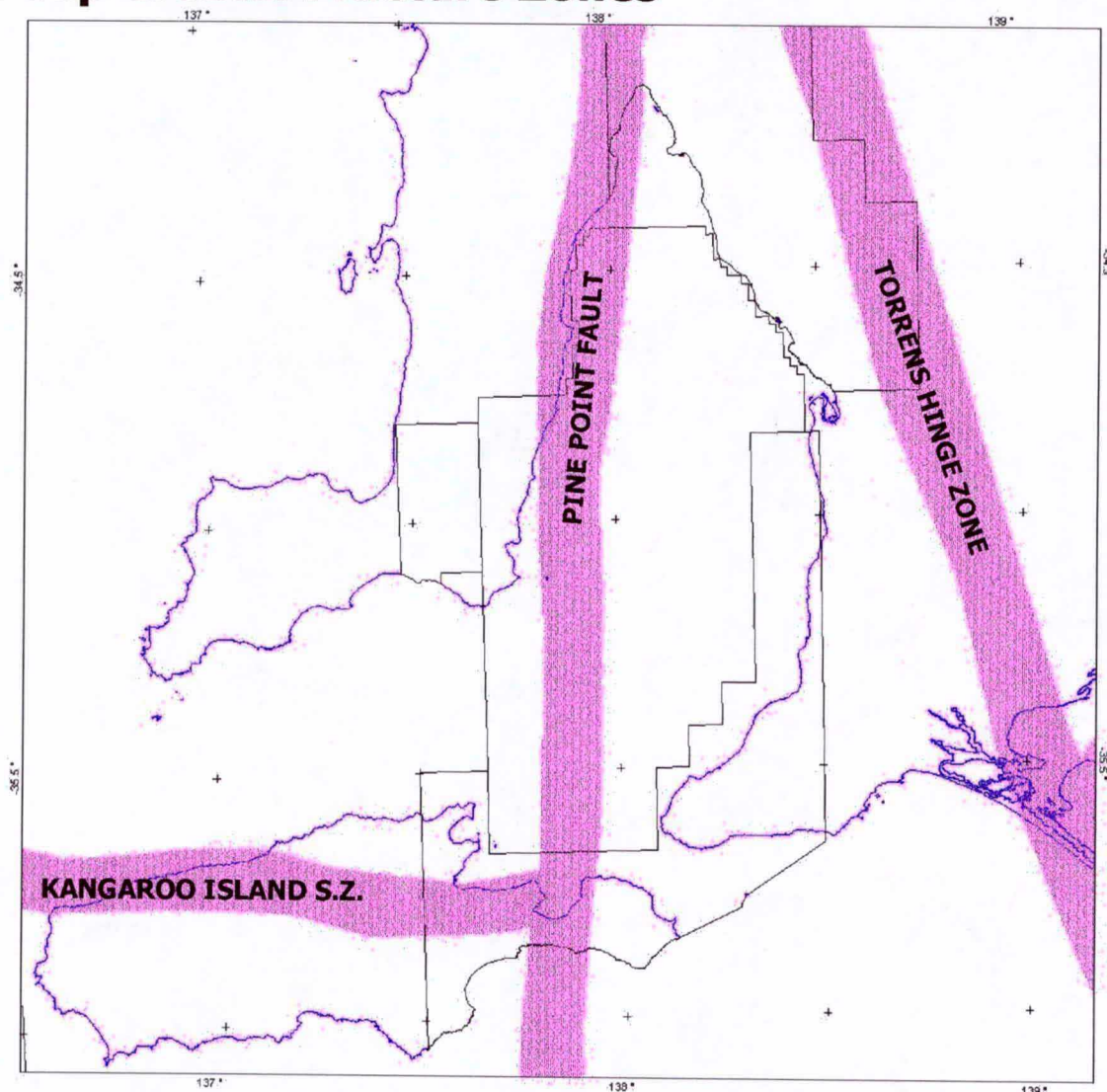


All interpreted basement-involved faults in the Stansbury Basin are shown in the above map, where colour represents initiation age:

-  Early Kimban
-  Late Kimban/Paleoproterozoic
-  Mesoproterozoic

Dashed fine lines represent the trend/fabric of basement lithologies.

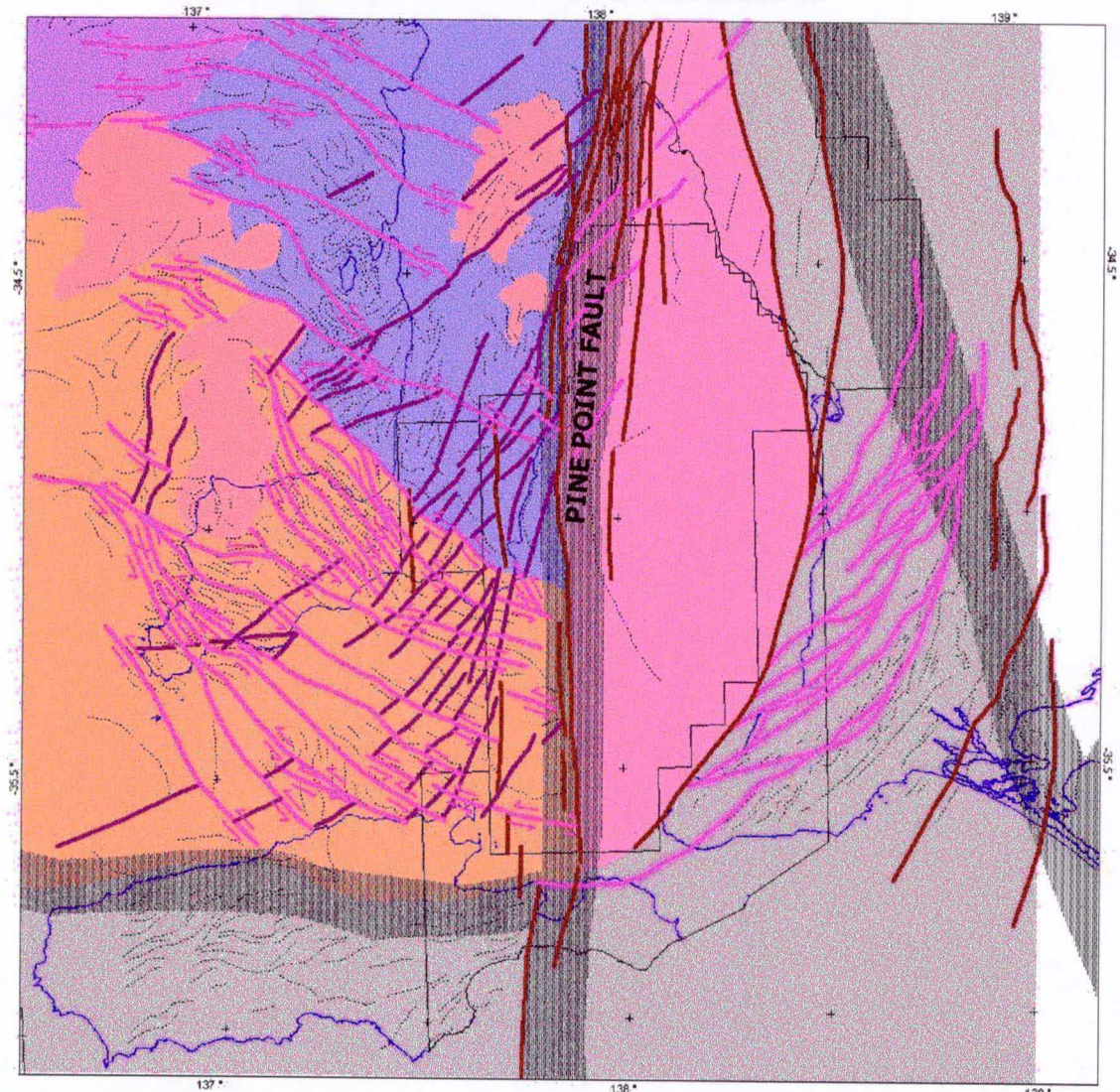
Deep Crustal Fracture Zones



Deep crustal fracture zones are seldom directly mappable in basins. They are deep seated (possibly mantle-derived), ancient zones of crustal weakness that directly or indirectly influence the subsequent development of structures and basins. They are often repeatedly reactivated. Often they coincide with terrane boundaries.

Deep crustal fracture zones in the Stansbury Basin form important boundaries between contrasting basement terranes. They were a first order control on basin evolution. The Torrens Hinge Zone is a well known but poorly understood deep crustal fracture zone that was initiated during Neoproterozoic rifting and reactivated during the Delamerian Orogeny.

Proterozoic Basement Deformation



There is a significant difference in basement structural style between the 3 basement terranes. Paleoproterozoic Kimban structures are largely restricted to the Gawler Craton, and are truncated by the Pine Point Fault; probably a Mesoproterozoic shear zone/terrane boundary.

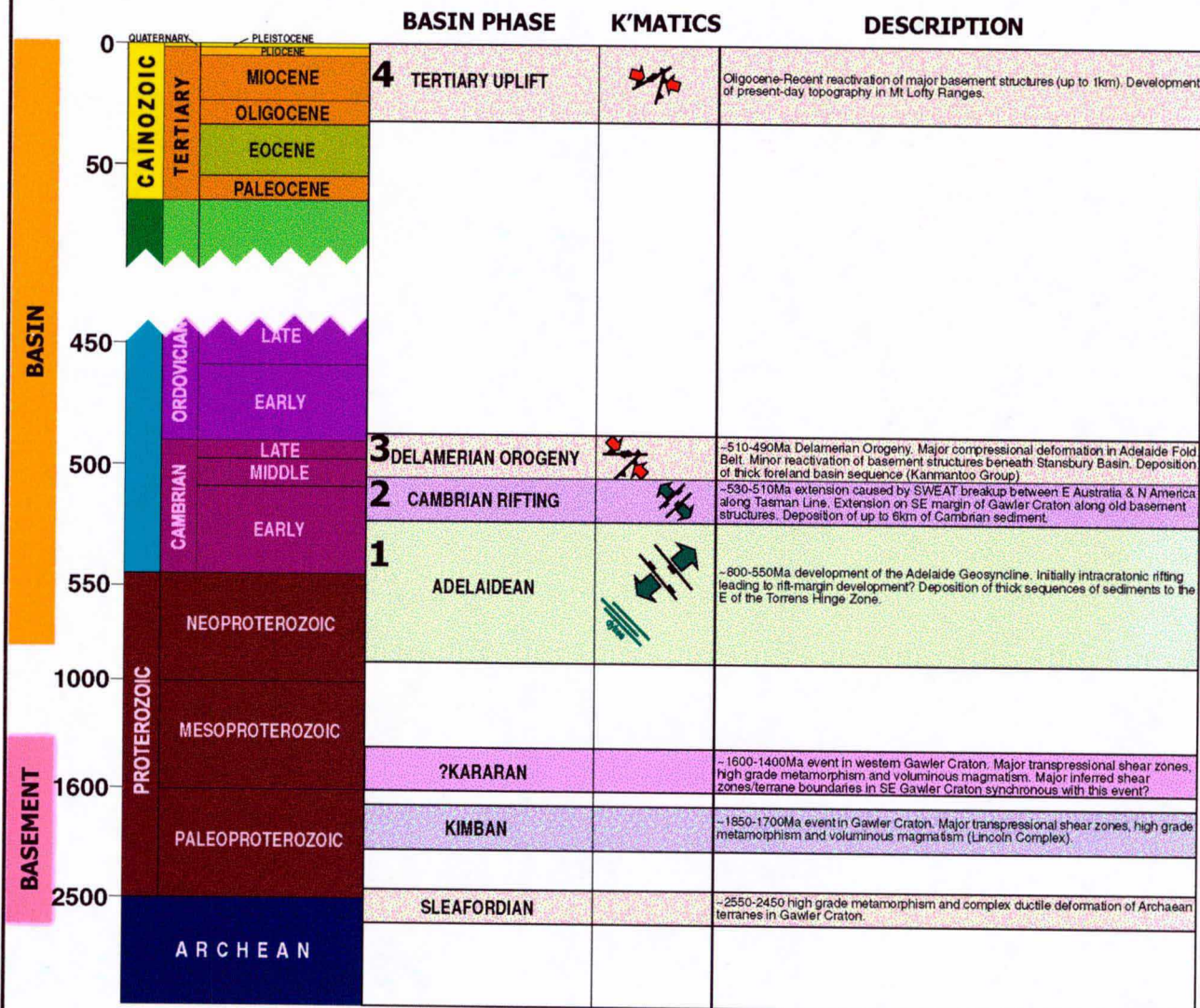
Little is known about the basement structural evolution of the St Vincent's Terrane and the Adelaide Fold Belt due to significant later reworking during Neoproterozoic extension and the Delamerian Orogeny, and poor data quality.

Four main sets of basement structures have been identified (oldest first):

- NE trending Paleoproterozoic shear zones (early Kimban?) ———
- NW trending Paleoproterozoic shear zones (late Kimban) ———
- NE trending ?Mesoproterozoic structures in St Vincent's Terrane and Adelaide Fold Belt ———
- N-S trending ?Mesoproterozoic shear zones/terrane boundary ———

Basin Evolution

The present-day geometry of the Stansbury Basin is the result of the superposition of 4 major tectonic “events” or basin phases spanning the late Neoproterozoic to Recent. The following chart details the tectonic history of the Stansbury Basin and its basement:



Stresses operating during these basin phases caused reactivation of basement structures and reactive fabrics, as well as the development of new structures. By understanding the kinematics of each tectonic event, a predictive model for structural reactivation can be applied to the interpreted faults. When calibrated with fault history data from geological observations (e.g. seismic, maps), event maps for each basin phase were be constructed.

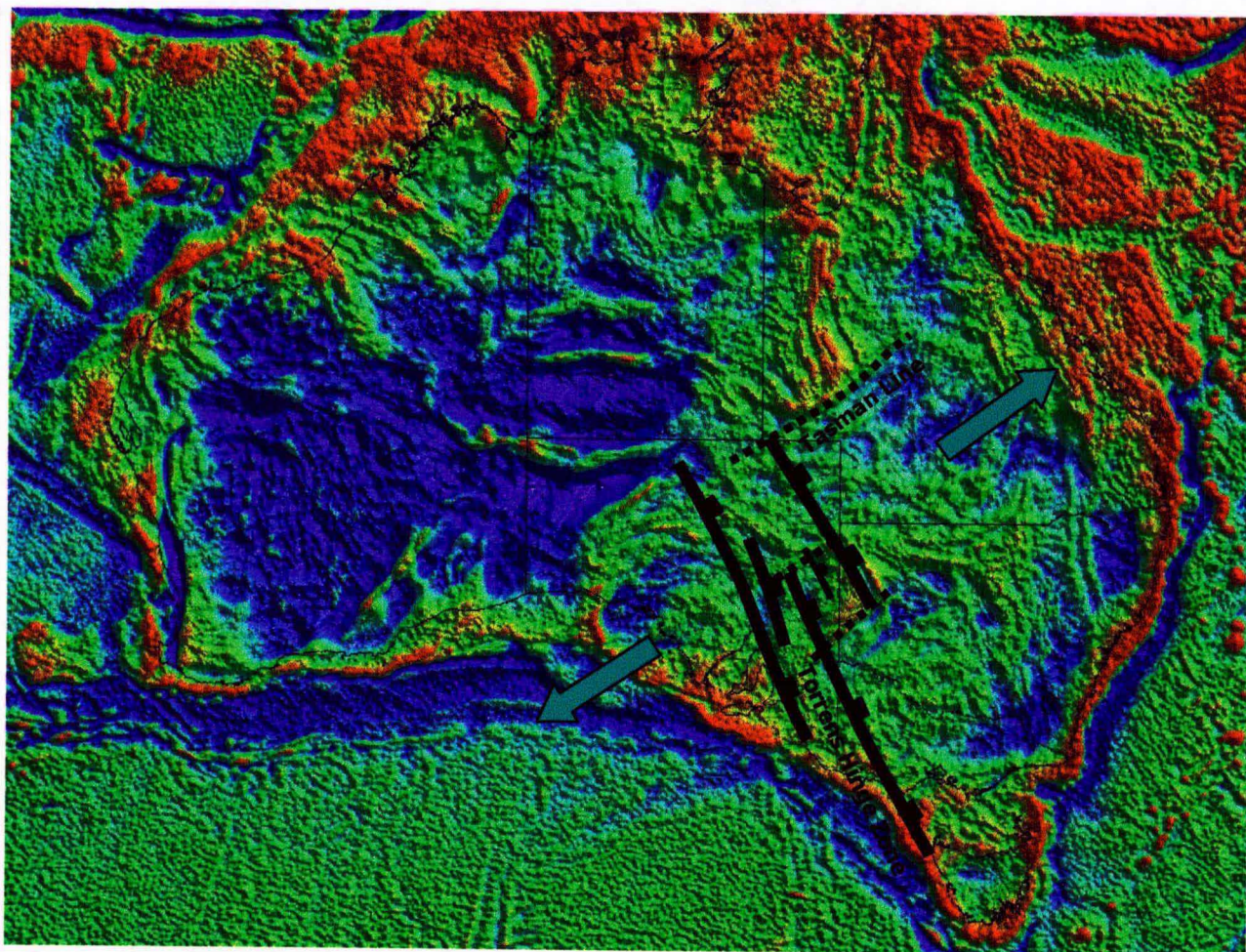


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Krstan (Australia) Pty. Ltd, ABN 56 074 271 720, trading as SRK Consulting

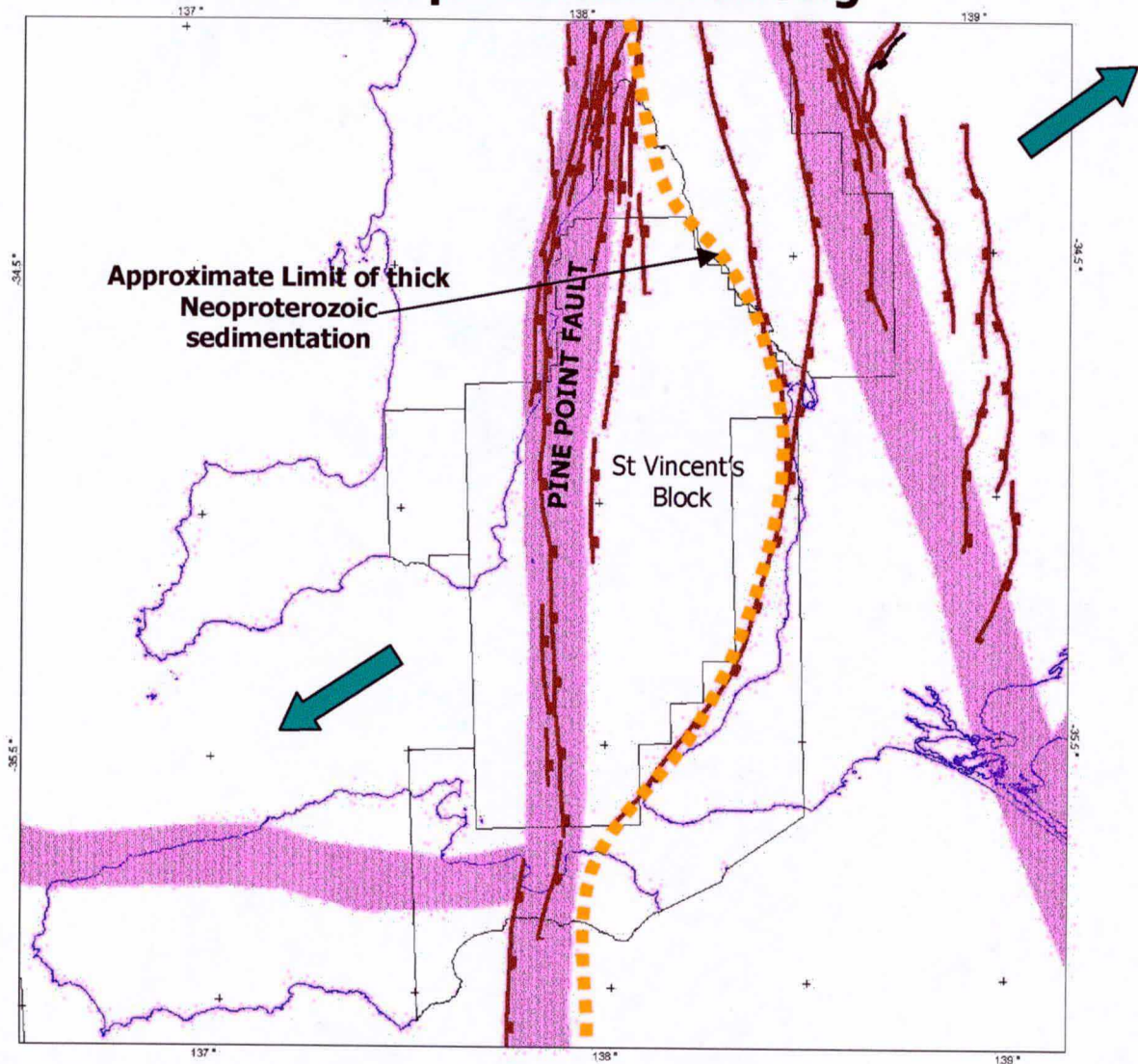
Basin Phase 1: Neoproterozoic Rifting



Intracratonic rifting between Proterozoic Australia and North America began during the Gairdner Dyke event at ~800Ma. Ongoing series of rift events through the Neoproterozoic led to the eventual breakup in the early Cambrian between Australia and North America. This rifting was synchronous with the flexural evolution of the Centralian Superbasin.

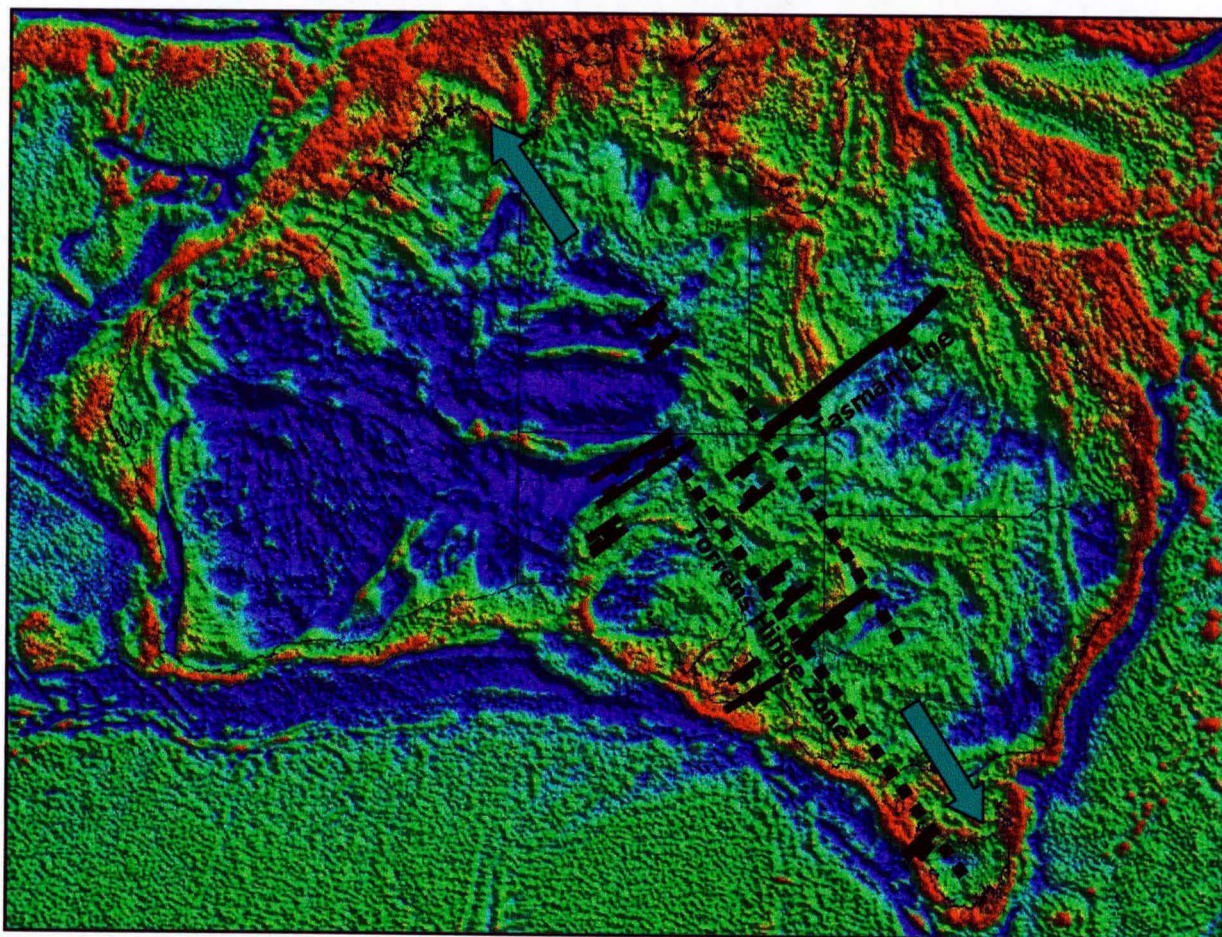
During this time the thick (up to 15km) sedimentary sequence of the Adelaide Geosyncline was deposited in ~ENE-WSW rift basins. At least 4 rift cycles have been recognised. (Preiss, 2000)

Basin Phase 1: Neoproterozoic Rifting



East of the Pine Point Fault, thick Neoproterozoic sequences were deposited in N-S and NNW trending rift basins. Only a thin veneer of Neoproterozoic sediment was deposited on the St Vincent's Block (needs confirming with seismic data). No Neoproterozoic sediment has been recognised in the Stansbury west of the Pine Point Fault.

Basin Phase 2: Early Cambrian Extension

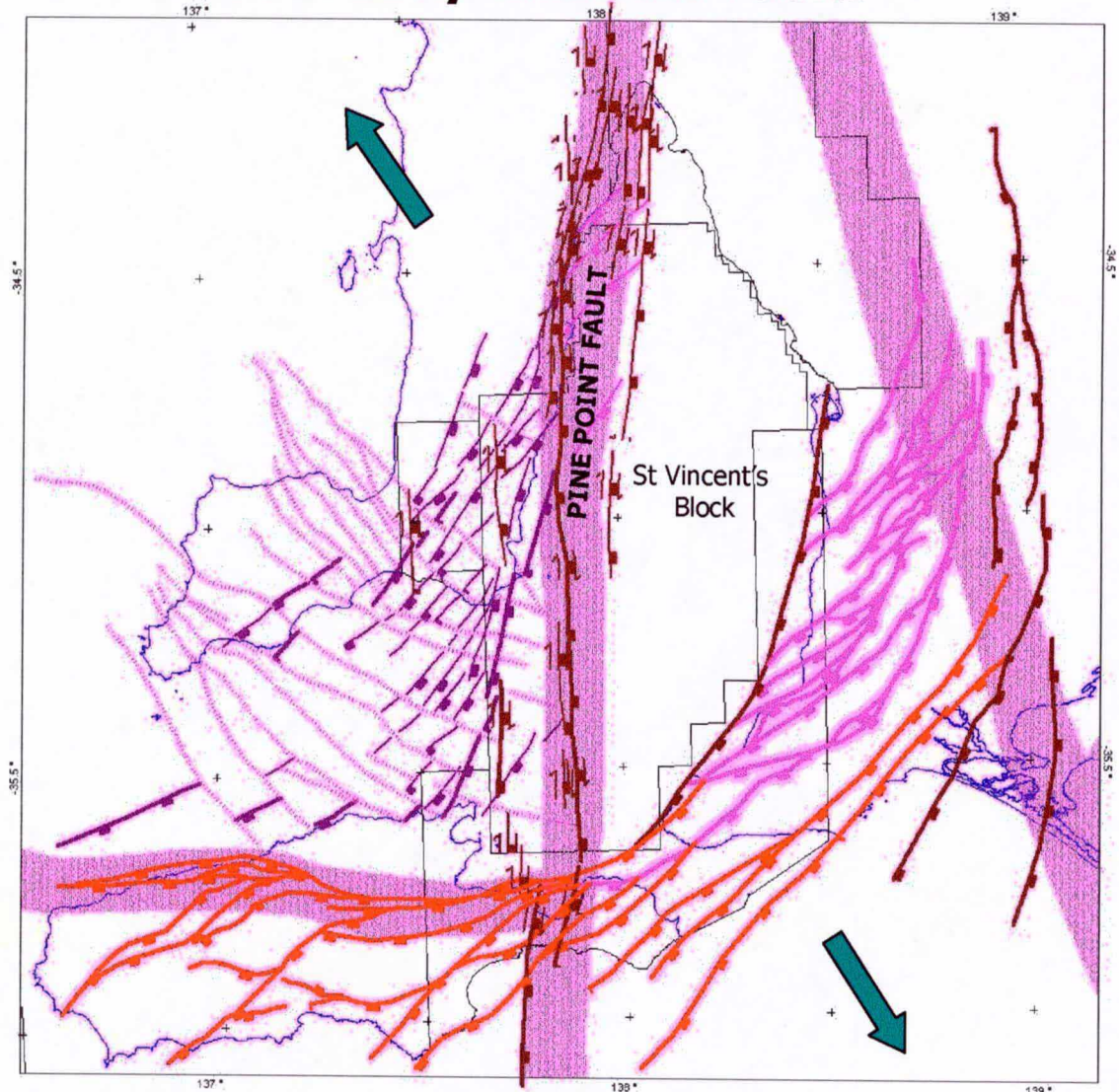


Early Cambrian extension in South Australia was caused by the onset of SWEAT rifting & breakup between Australia & North America along the Tasman Line. In the early Cambrian this extension was oriented ~NW-SE. Most of the extension was accommodated to the SE of the Tasman Line on structures in the present-day Tasman Fold Belt.

Limited early Cambrian intracratonic rifting occurred to the NE in the Georgina, Stansbury, Stansbury, Arrowie and Warburton basins. These localised early ?pull-apart Cambrian depocentres may contain good source rocks (as discovered in the Georgina Basin).

Mid-late Cambrian extension in the Lachlan Fold Belt of eastern Australia was oriented ~NNE-SSW, however no evidence for such rifting was observed in this project in South Australia.

Basin Phase 2: Early Cambrian Faults

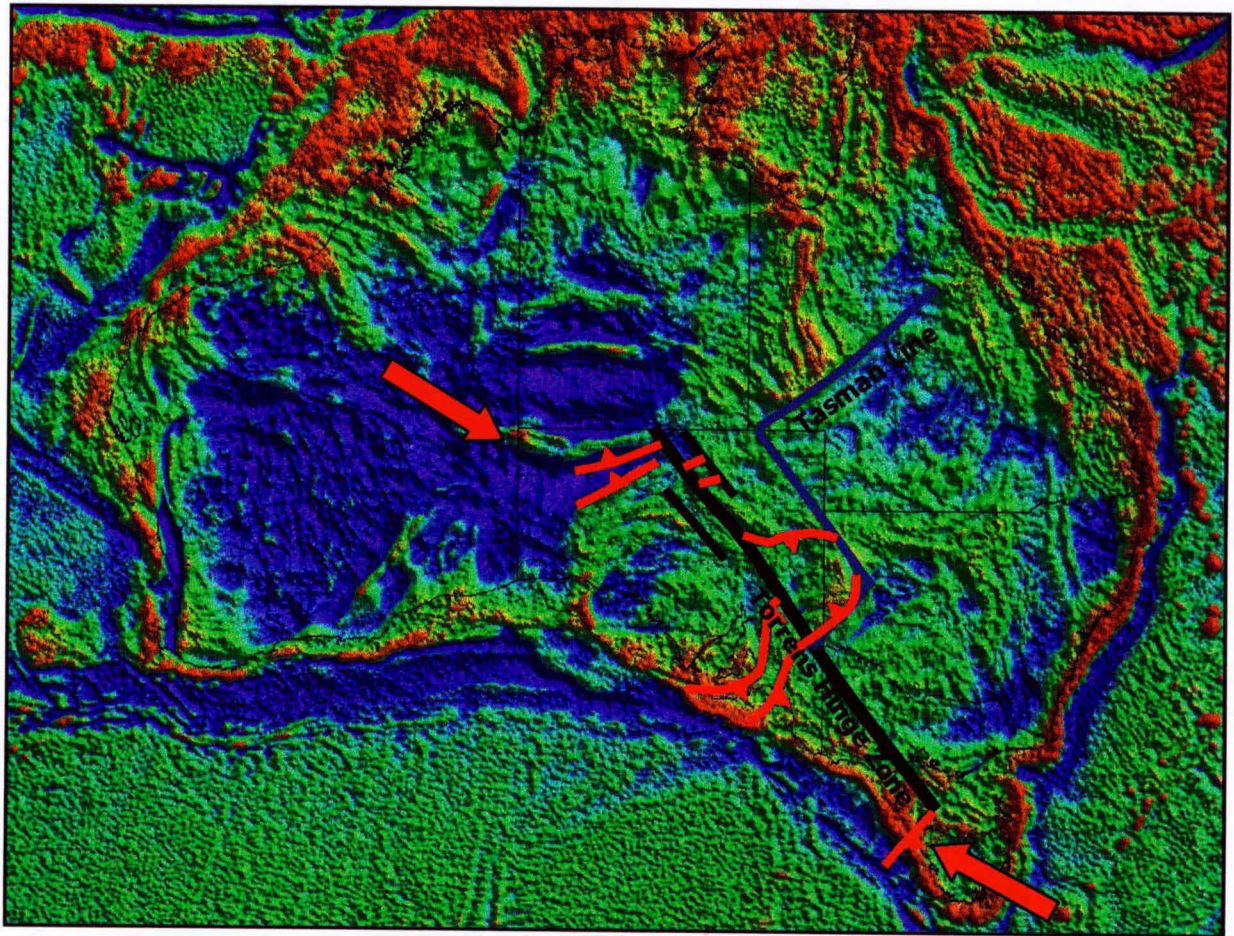


In the western Stansbury Basin, NW-SE extension in the early Cambrian caused normal reactivation of old NE trending basement structures in the Gawler Craton. Up to 3km of sediment was deposited in NE trending graben and half graben overlying the Gawler. NW trending Paleoproterozoic shear zones acted as transfer zones.

The N-S trending Pine Point Fault was reactivated as an east-dipping oblique normal fault at this time. A thin (<1km?) layer of platformal sediment was deposited on the St Vincent's Block at this time.

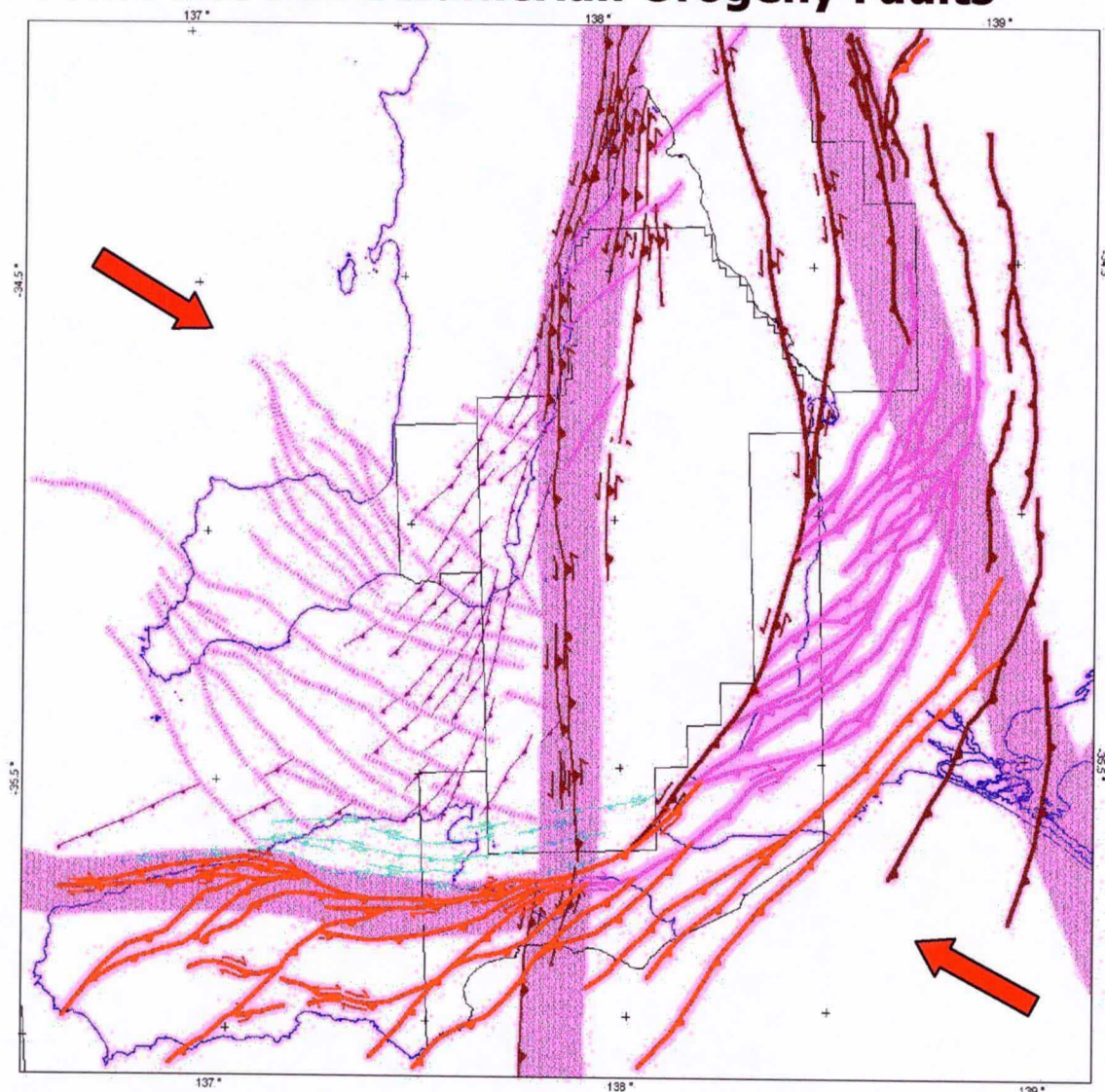
More extensive NE rifts are interpreted to have developed in what is now the Adelaide Fold Belt.

Basin Phase 3: Delamerian Orogeny



The Delamerian Orogeny was a kinematically complex compressional event marking the terminal stages of the Gondwana-wide Pan African "event" during the time interval ~520-460Ma (late Cambrian to early Ordovician). In South Australia it caused the deformation of a series of fold-thrust belts including the Adelaide Fold Belt, Flinders Ranges and Olary-Broken Hill Province. The main phase of compression was probably oriented NNW-SSE. Sinistral transpressional movement along the Torrens Hinge Zone during the Delamerian caused popup structures to form (e.g. Mt Woods Inlier).

Basin Phase 3: Delamerian Orogeny Faults



Extensive, kinematically complex deformation occurred during the Delamerian in the Adelaide Fold Belt. Internally the western Stansbury Basin only underwent very minor deformation via inversion of some Cambrian normal faults (potentially an important trap-forming event). Flexural loading in the foreland of the evolving Delamerian Orogen caused a thick sequence of turbiditic foreland basin sediments to be deposited (the Kanmantoo Group). Most of these sediments were later consumed by the Delamerian Orogen when they underwent extensive deformation and metamorphism.

Up to 6km of Kanmantoo-equivalent sediments were deposited on the St Vincent's Block during Delamerian flexure. These sediments have not undergone significant Delamerian deformation. Only a thin veneer of Kanmantoo-equivalent sediment was deposited on the Gawler (needs verification with seismic/well data).

The boundary between the St Vincent's Block and the Adelaide Fold Belt terrane was of fundamental importance in the Delamerian, and marked the boundary between extensive tectonism and undeformed platformal sediment.

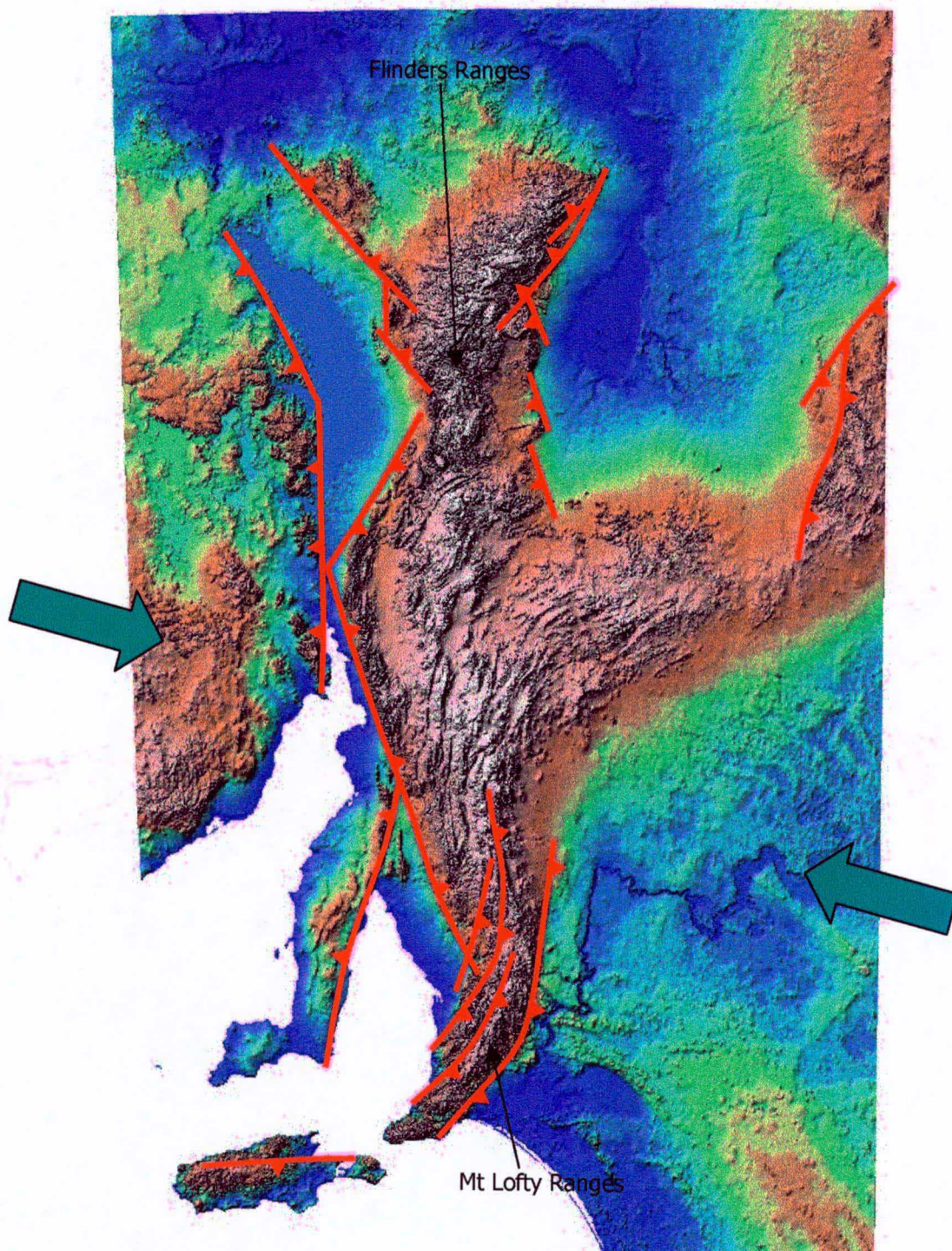


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Krieger (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basin Phase 4: Tertiary Uplift



During the Miocene-Recent, ~ENE directed intraplate stresses have reactivated "weak" basement structures in the Adelaide Fold Belt. This compression led to uplift which formed the present-day topography of the Mt Lofty and Flinders Ranges. Uplift continues today, as evidenced by recent seismicity. Up to 1km of uplift has occurred on major structures.

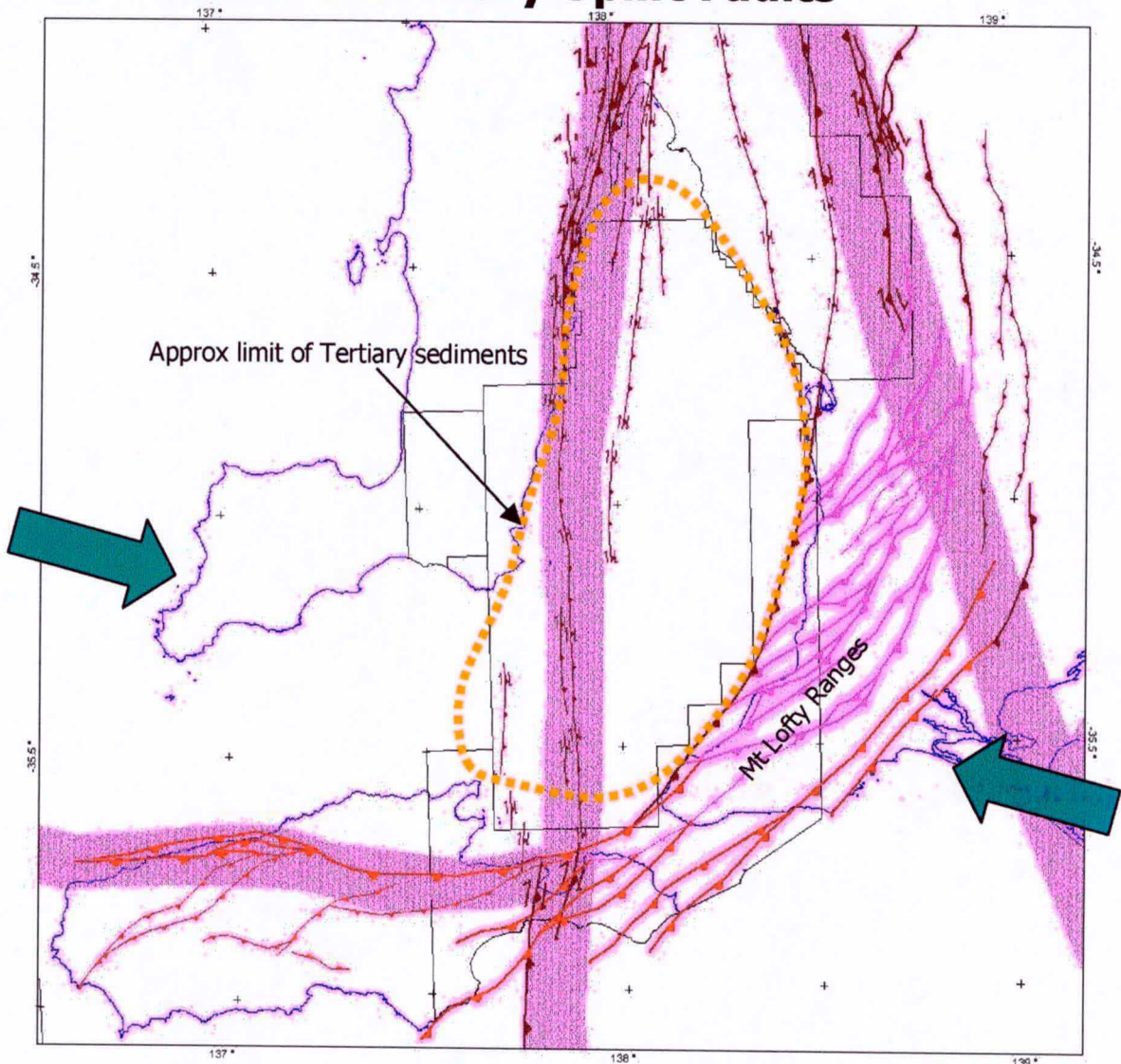


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

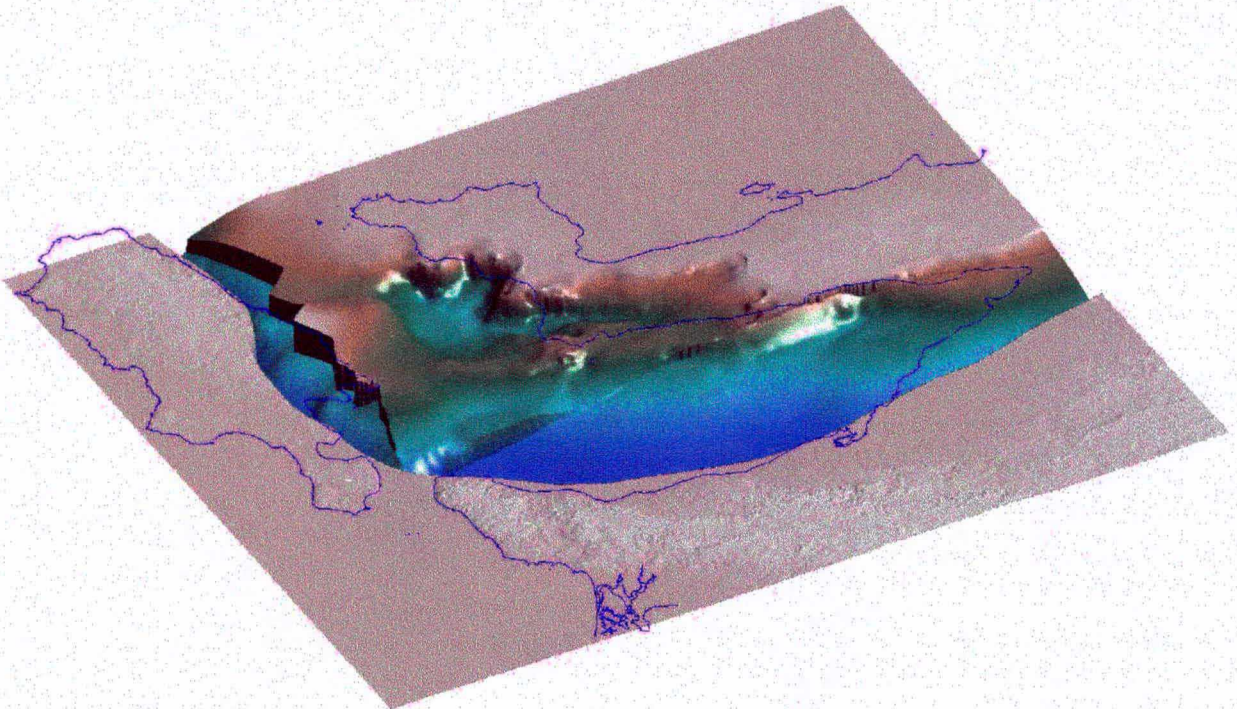
Steffen, Robertson & Kieren (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basin Phase 4: Tertiary Uplift Faults



Tertiary compression (Miocene to Recent) has caused reactivation of major faults to the east of the western Stansbury, most notably in the Mt Lofty Ranges. This uplift has caused minor foreland flexure in the western Stansbury, forming the Gulf of St Vincent. Up to 500m of clastic sediment has been deposited in the resulting basin, derived from the Mt Lofty Ranges.

Depth to Basement



SEEBASE (Structurally Enhanced View of Economic Basement)

What is SEEBASE?

SEEBASE is much more than just another magnetic depth-to-basement model. It is the culmination of a number of calibration and integration steps:

- Integrated structural/kinematic interpretation
- Geophysical modeling
- Seismic & well calibration
- Integration of tectonic events & responses

SEEBASE is a qualitative model of economic basement topography that is consistent with the structural evolution of the basin. SEEBASE defines basin architecture, and is a predictive model for exploration. It is a key base for understanding basin phase geometry/distribution and petroleum systems. As new data is acquired which allows more precise calibration, SEEBASE can be updated to reflect all new information.

SEEBASE provides a foundation for petroleum systems evaluation, including play element distribution (source/reservoir/seal), migration pathways, zones of structural complexity, trap distribution, trap type & integrity, paleogeography, oil vs. gas distribution etc.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

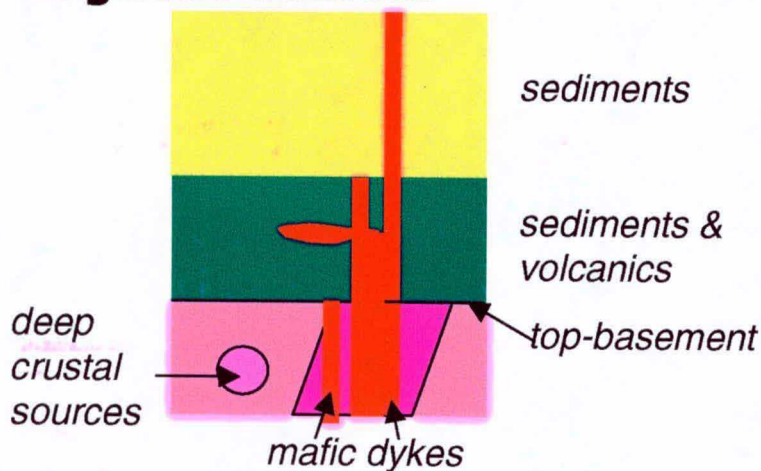
SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kireen (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

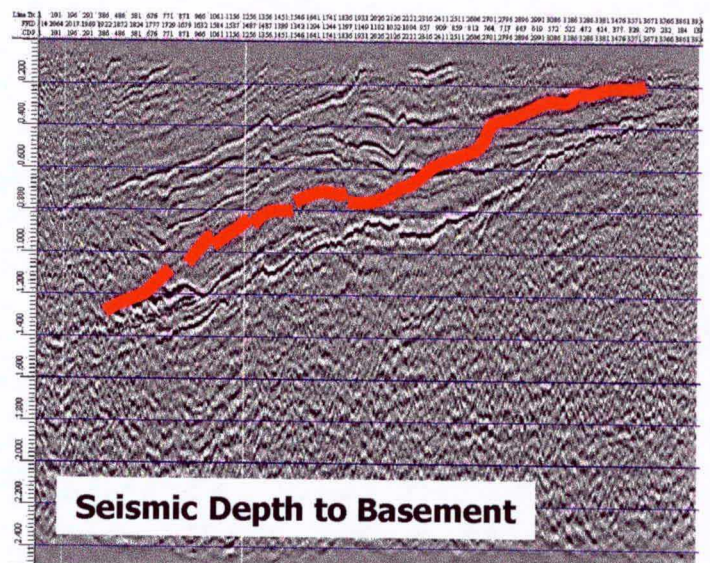
SEEBASE Methodology

- Depth models to magnetic basement sources, obtained from profiles across selected anomalies
- Attribution of source type to depth estimates (require top-basement sources)
- Identification of major basement-involved faults
- Integration of event/response history
- Integration of gravity modeling & interp (if available)
- Incorporation of refraction/seismic/well data (if available)
- Intelligent contouring of "top basement" depth estimates
- Grid construction using CPS-3
- 2D and 3D image processing in ERMapper

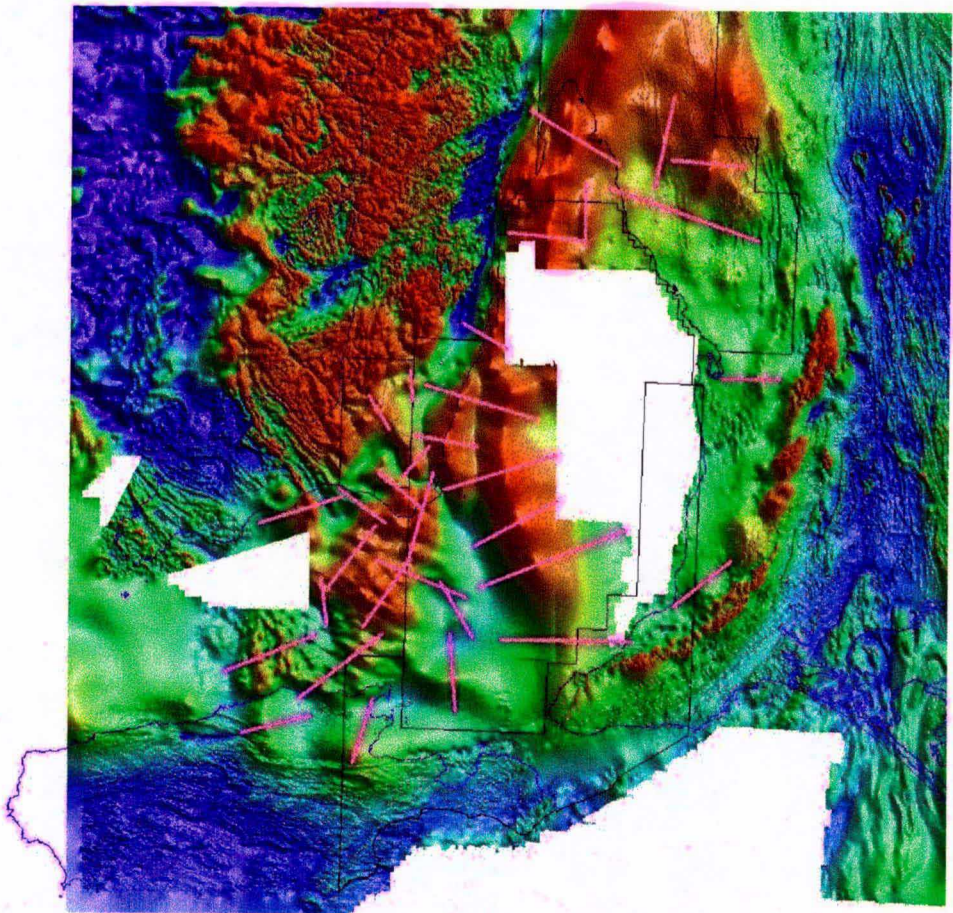
Magnetic Sources



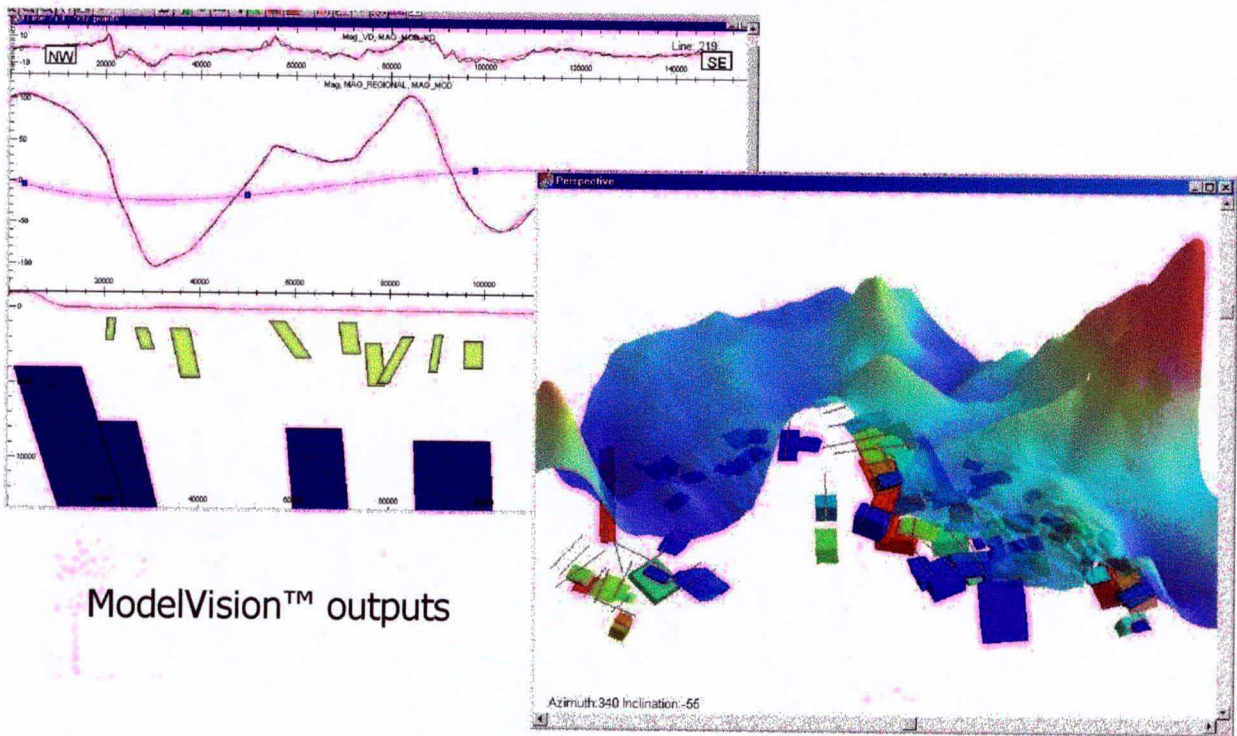
Calibration Example



Magnetic Profiles



Modeled Profiles & Modeled Bodies

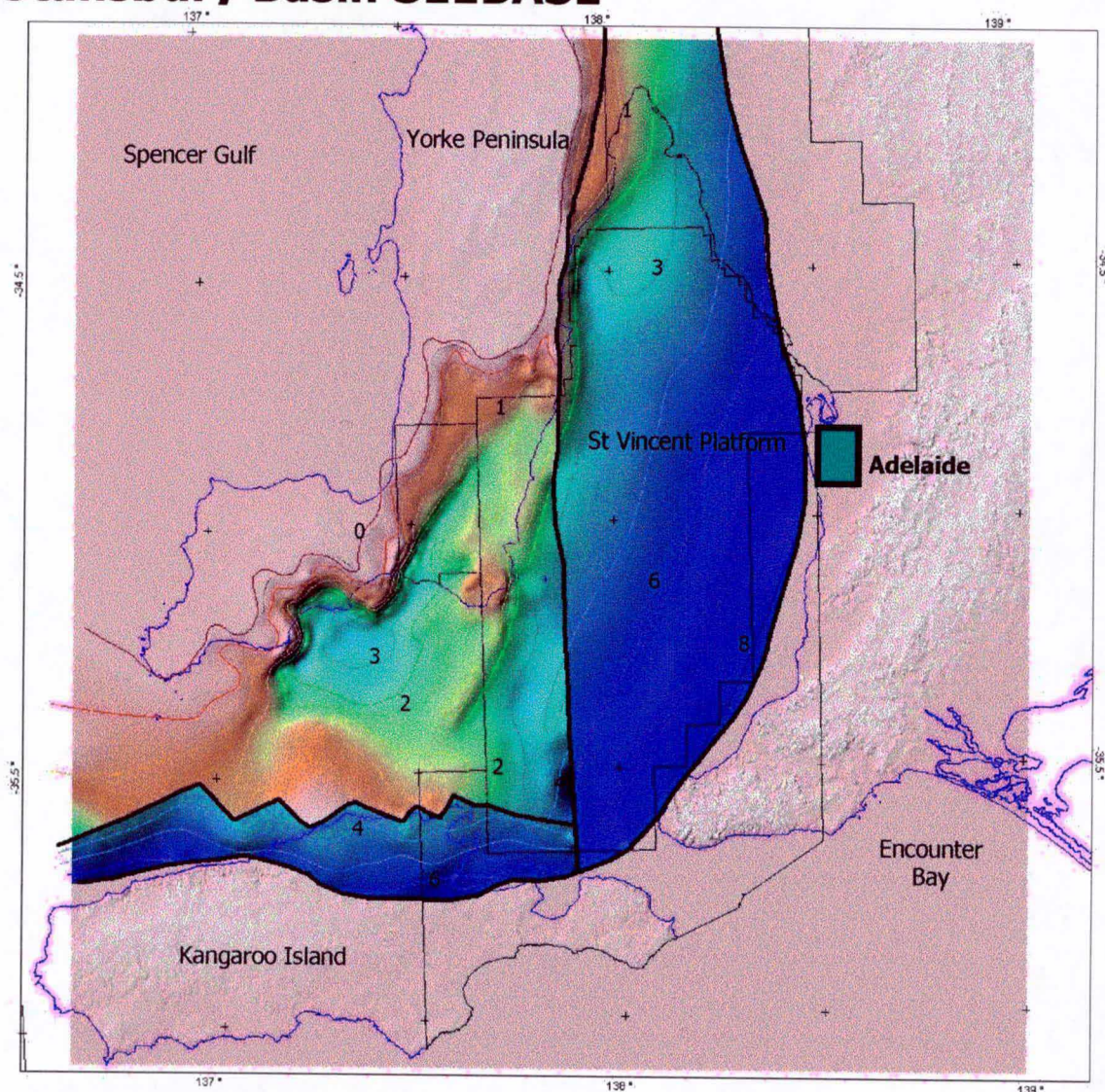


PRIMARY INDUSTRIES
AND RESOURCES SA

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kintan (Australia) Pty. Ltd, ABN 56 074 271 720, trading as SRK Consulting

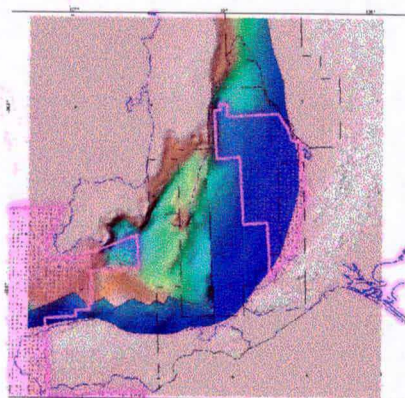
Stansbury Basin SEEBASE



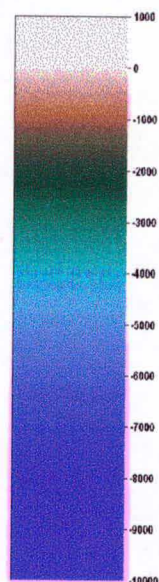
Numbers represent contour values in km

Principal Basement-Involved Faults

SA Petroleum Permits



Reliability map showing gaps in magnetic coverage where the SEEBASE model is less reliable



Zscale

Depth below Surface (m)



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kintan (Australasia) Pty. Ltd., ABN 66 074 271 720, trading as SRK Consulting

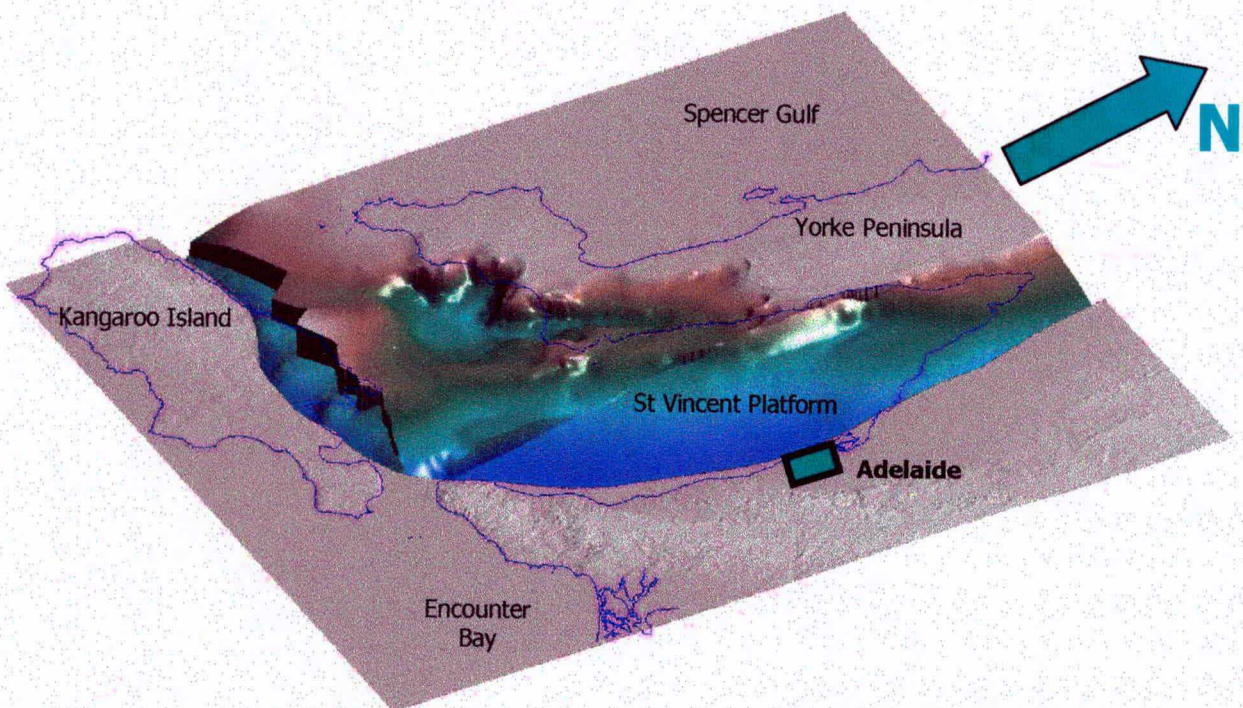
Stansbury Basin SEEBASE

Magnetic depth to basement modelling was successful in the western Stansbury Basin due to good data quality. As a result, this SEEBASE dataset is probably accurate to $\pm 10\%$ in areas where magnetic coverage exists (note gaps in magnetic coverage in reliability map on previous page).

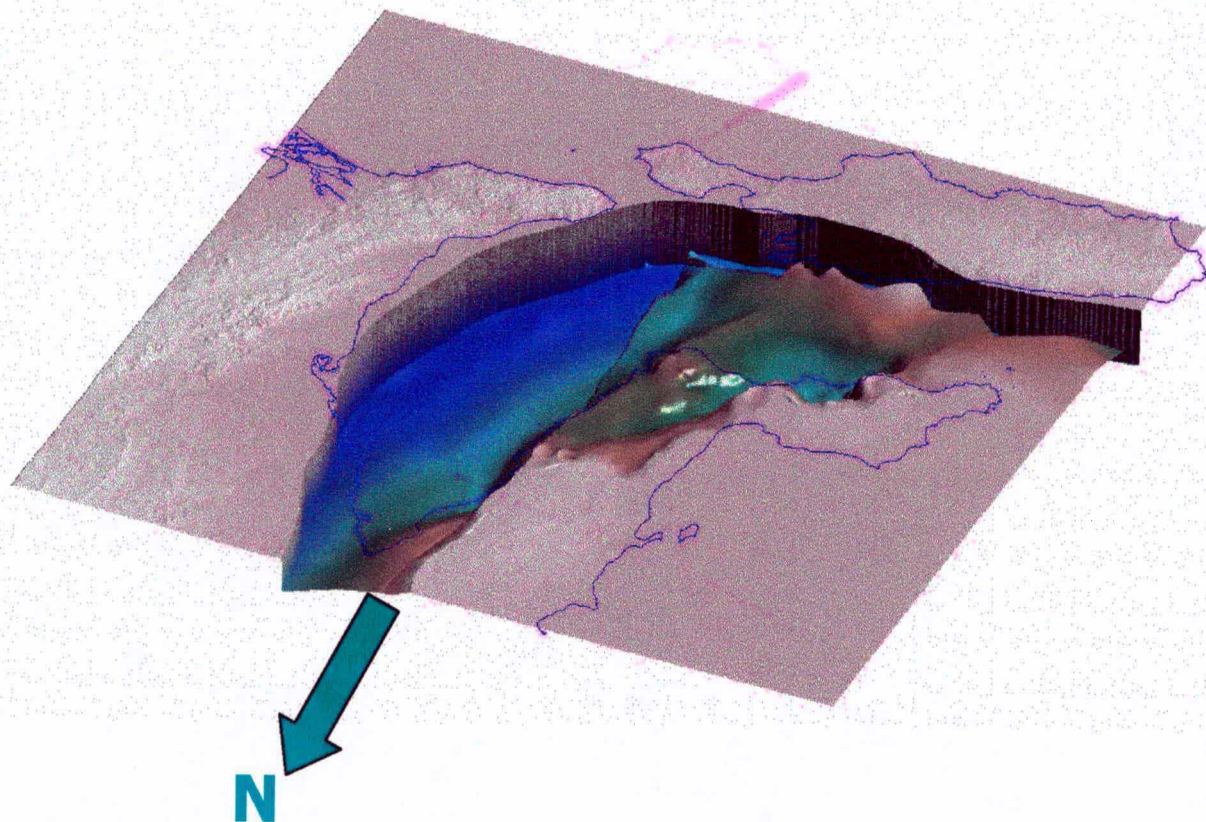
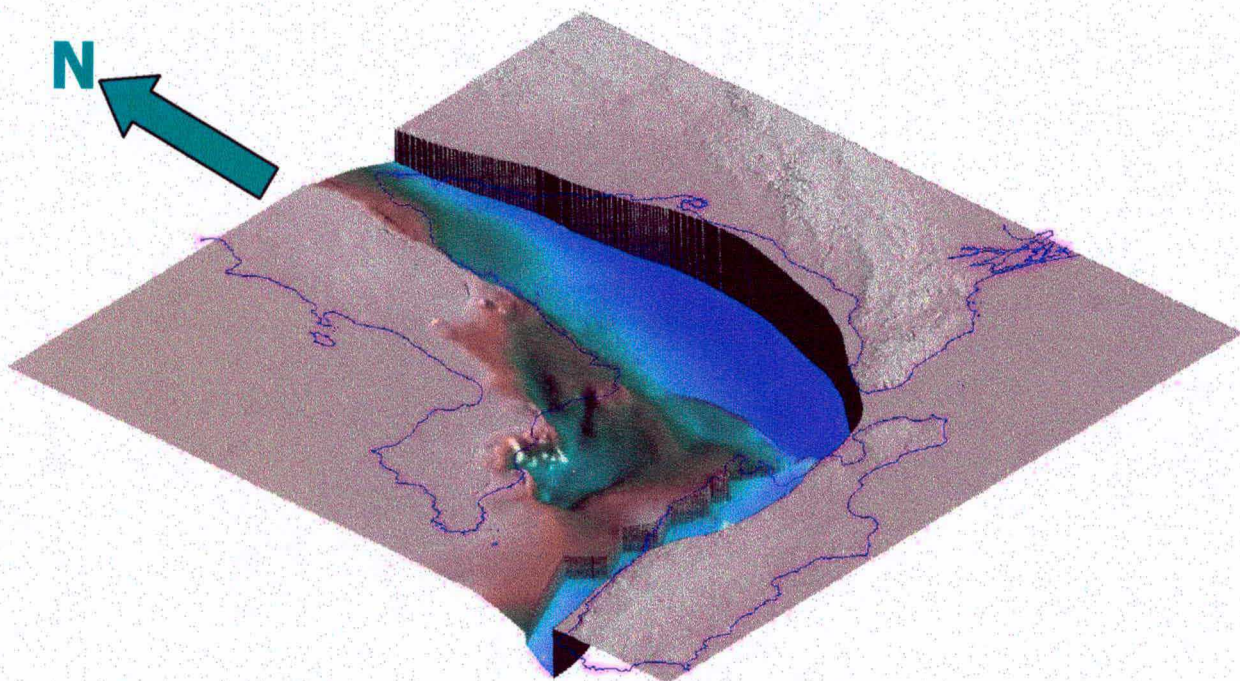
SEEBASE images of the eastern Stansbury Basin show basin architecture, and can be used to analyse petroleum systems and basin phases.

Significant features evident in the Stansbury Basin SEEBASE include:

- Previously unrecognised "new" sub-basin in the "instep" of Yorke Peninsula
- Major early Cambrian basin edge beneath northern Kangaroo Island
- Gently sloping basement topography of St Vincents Platform



3D Views of Basin Architecture

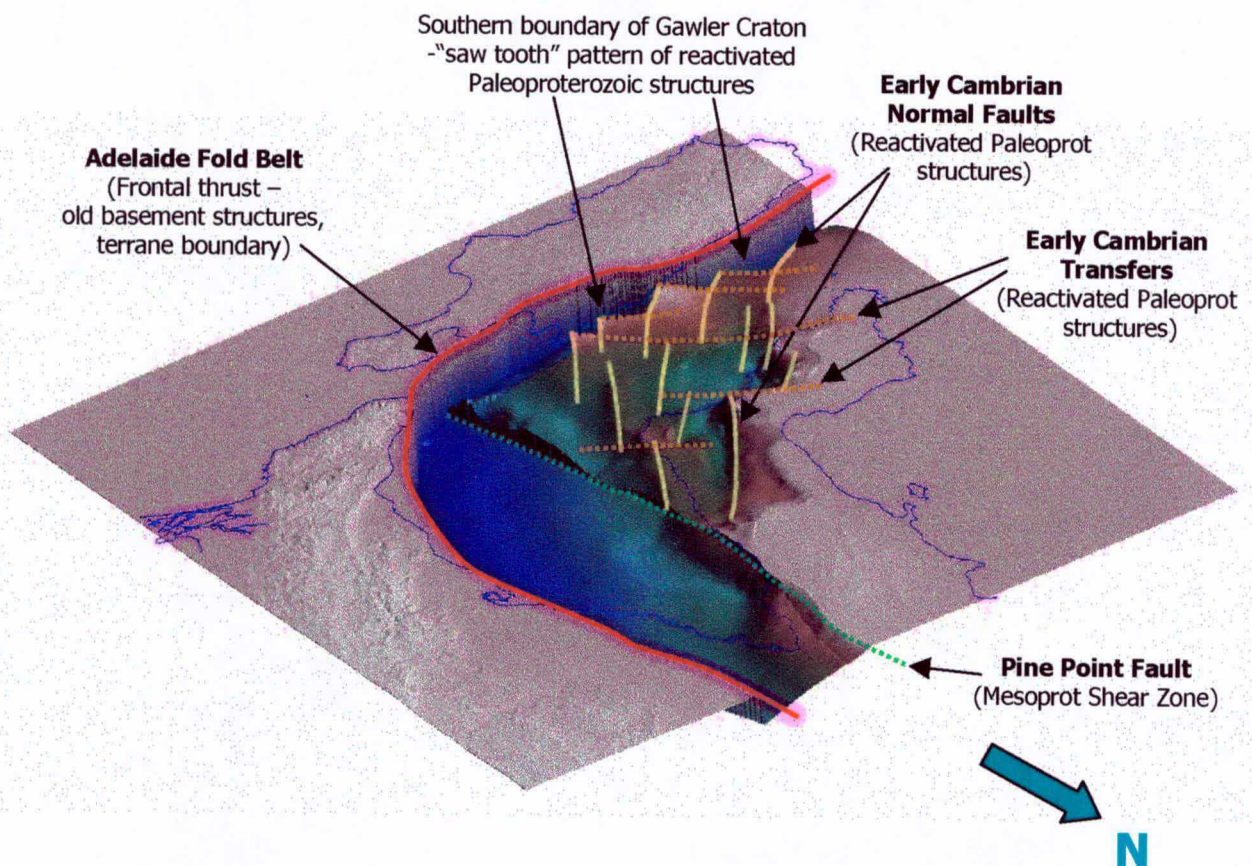


Basement Controls on Basin Architecture

This project emphasises the fact that the architecture of the Stansbury Basin is controlled by pre-existing basement structures and compositional contrasts. Key factors include:

- Rheologically strong , "brittle" Gawler Craton has not been effected by Delamerian and Tertiary deformation.
- NE and N-S trending basement structures have been reactivated during the early Cambrian extension, defining the architecture of the western Stansbury
- The "saw-tooth" geometry of the southern margin of the Gawler Craton was created by early Cambrian reactivation of NE & NW trending Paleoproterozoic basement structures

This 3D block diagram below illustrates the influence of basement geology on basin architecture in the western Stansbury Basin.



References

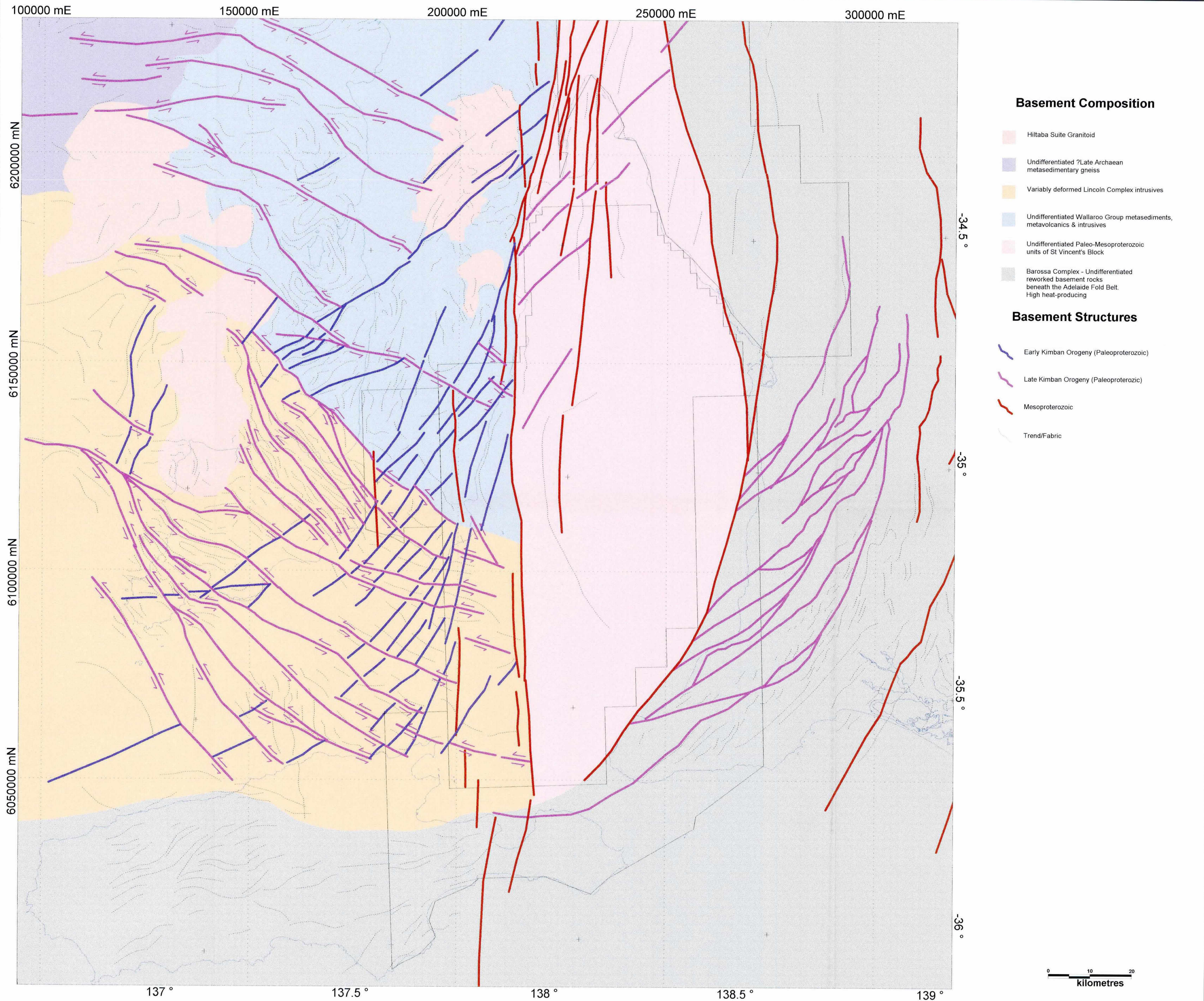
- Belperio, A.P., Preiss, W.V., Fairclough, M.C., Gatehouse, C.G., Gum, J., Hough, J. & Burt, A., 1998, Tectonic and metallogenic framework of the Cambrian Stansbury Basin – Kanmantoo Trough, South Australia. *AGSO Journal of Australian Geology & Geophysics*, 17(3), 183-200.
- Conor, C.H.H., 1995, Moonta-Wallaroo region: and interpretation of the geology of the Maitland and Wallaroo 1:100,000 sheet areas. *Department of Mines and Energy, South Australia, Open File Envelope 8886*.
- Drexel, J.F., Preiss, W.V. & Parker, A.J., 1993, *The Geology of South Australia, Volume 1: The Precambrian*, Mines and Energy South Australia, Bulletin 54.
- Drexel, J.F. & Preiss, W.V., 1995, *The Geology of South Australia, Volume 2: The Phanerozoic*, Mines and Energy South Australia, Bulletin 54.
- Flottmann, T. & Cockshell, C.D., 1996, Paleozoic basins of southern South Australia: new insights into their structural history from regional seismic data. *Australian Journal of Earth Sciences*, 43, p45-55.
- Flottmann, T. & James, P., 1997, Influence of basin architecture on the style of inversion and fold-thrust belt tectonics – the southern Adelaide Fold-Thrust Belt, South Australia. *Journal of Structural Geology*, 19(8), p1093-1110.
- Flottmann, T., Haines, P.W., Cockshell, C.D. & Preiss, W.V., 1997, An early Paleozoic foreland basin succession beneath Gulf St Vincent, South Australia? Implications for petroleum plays. *PESA Journal*, 25, p33-40.
- Flottmann, T., Haines, P.W., Cockshell, C.D. & Preiss, W.V., 1998, Reassessment of the seismic stratigraphy of the Early Paleozoic Stansbury Basin, Gulf of St Vincent, South Australia. *Australian Journal of Earth Sciences*, 45, p547-557.
- Flottmann, T., Haines, P.W., Jago, J., James, P., Belperio, A. & Gum, J., 1998, Formation and reactivation of the Cambrian Kanmantoo Trough, SE Australia: implications for early Paleozoic tectonics at eastern Gondwana's plate margin. *Journal of the Geological Society of London*, 155, p525-539.
- Haines, P.W., 1996, Integrated approach to the reinterpretation of the Cambrian Kanmantoo Group type section, South Australia. *Geological Society of Australia Abstracts*, 41.
- Haines, P.W. & Flottman, T., 1998, Delamerian Orogeny and potential foreland sedimentation: a review of age and stratigraphic constraints. *Australian Journal of Earth Sciences*, 45, p559-570.
- Marshak, S. & Flottmann, T., 1996, Structure and origin of the Fleurieu and Nackara Arcs in the Adelaide fold-thrust belt, South Australia: salient and recess development in the Delamerian Orogen. *Journal of Structural Geology*, 18(7), p891-908.
- McKirdy, D.M., 1994, Biomarker geochemistry of the Early Cambrian oil show in Wilkatana-1: implications for oil generation in the Arrowie & Stansbury Basins. *APEA Journal*, 3-17.
- Preiss, W.V., 2000, The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction. *Precambrian Research*, 100, p21-63.
- Sprigg, R.C., 1961, The oil and gas prospects of the St Vincents Gulf graben. *APEA Conference Papers*, p71.
- Struckmeyer, H.I.M. & Totterdell, J.M., 1992, *Australia: Evolution of a Continent*. BMR Publication, Canberra.
- Teasdale, J.P., 1997, *Understanding Poorly Exposed Terranes: The Interpretive Geology and Tectonothermal Evolution of the Western Gawler Craton, South Australia*. Unpublished PhD Thesis, University of Adelaide.
- Veevers, J.J. (ed.), 2000, *Billion Year Earth History of Australia and Neighbours in Gondwanaland*. GEMOC Press, Sydney.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Sieff, Robertson & Kirsan (Australasia) Pty. Ltd., ABN 66 074 271 720, trading as SRK Consulting

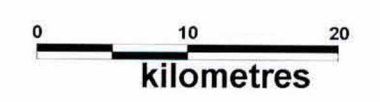


Basement Composition

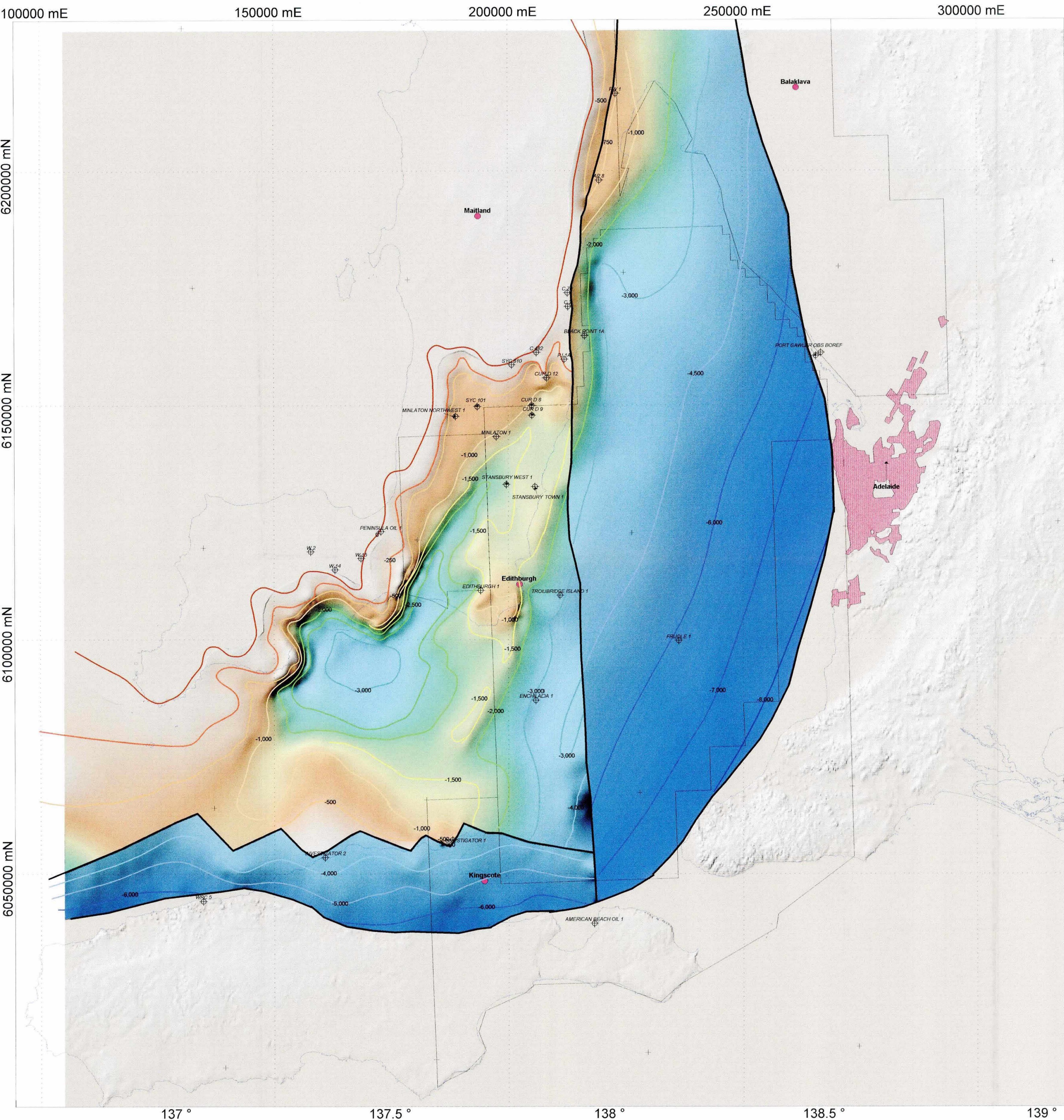
- Hiltaba Suite Granitoid
- Undifferentiated ?Late Archaean metasedimentary gneiss
- Variably deformed Lincoln Complex intrusives
- Undifferentiated Wallaroo Group metasediments, metavolcanics & intrusives
- Undifferentiated Paleo-Mesoproterozoic units of St Vincent's Block
- Barossa Complex - Undifferentiated reworked basement rocks beneath the Adelaide Fold Belt. High heat-producing

Basement Structures

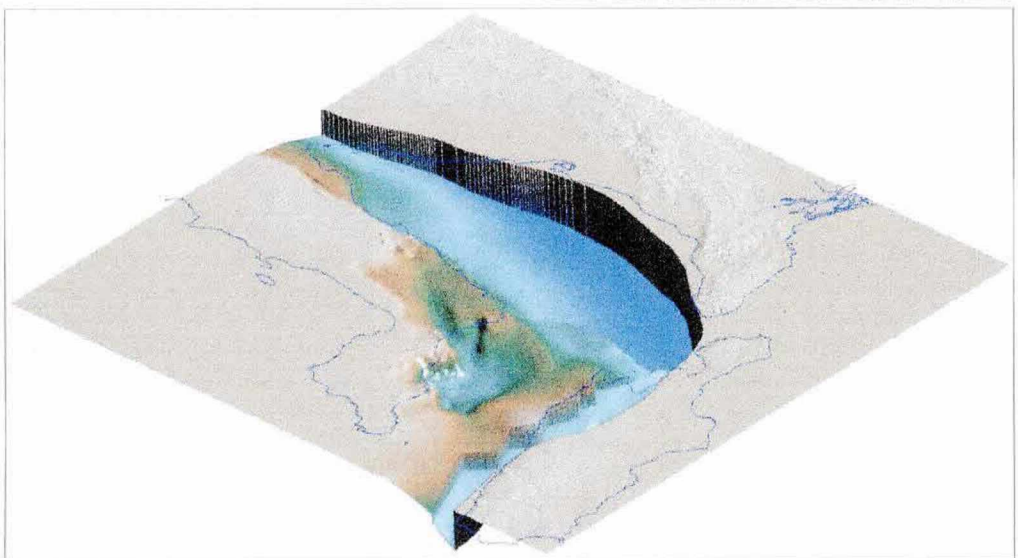
- Early Kimban Orogeny (Paleoproterozoic)
- Late Kimban Orogeny (Paleoproterozoic)
- Mesoproterozoic
- Trend/Fabric



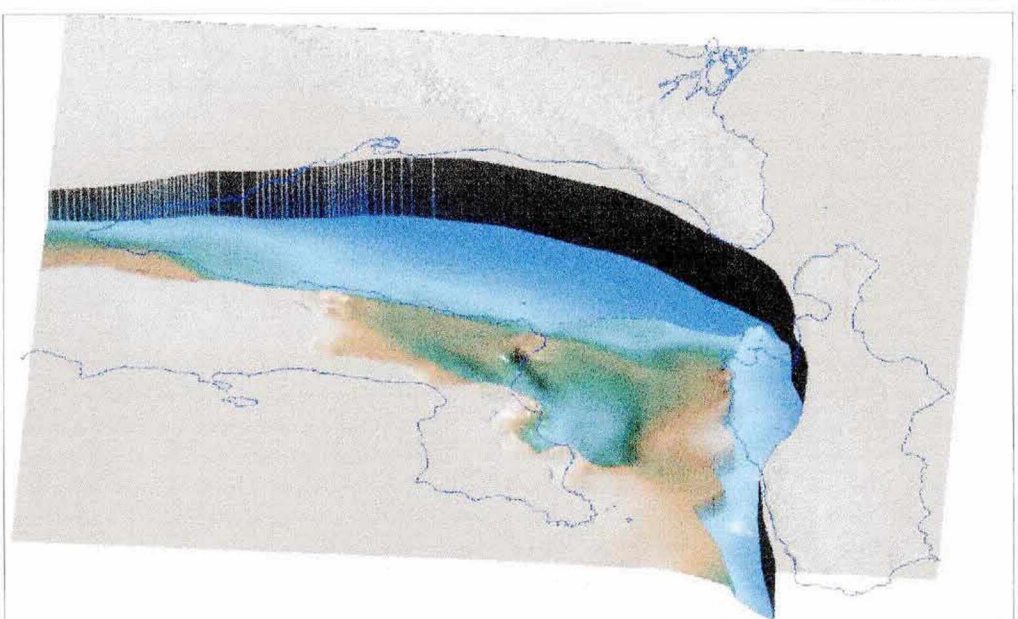
Title: Introduction and Methods (Preliminary) P112, AGD 66 (24 21 23), basing on 1986 Coordinates	
PIRSA - Stansbury Basin	
June, 2001	Basement Geology
SRK Job Code : P112	
Scale: 1: 500,000	
Projection: Australian Map Grid (AGD 66), Zone 54	



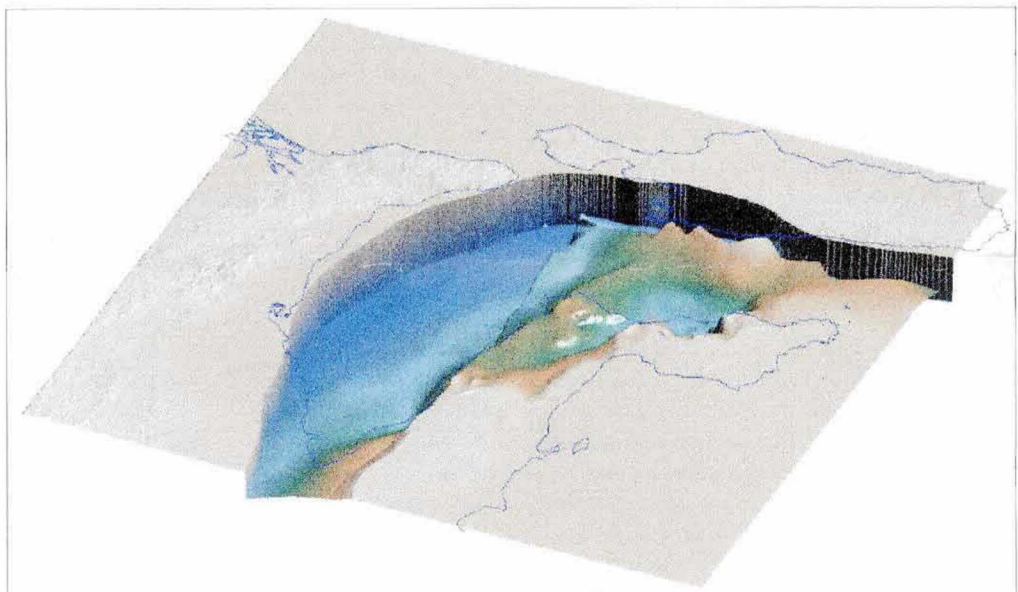
SEEBASE North-East View



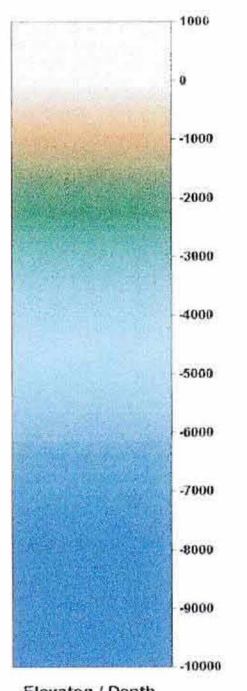
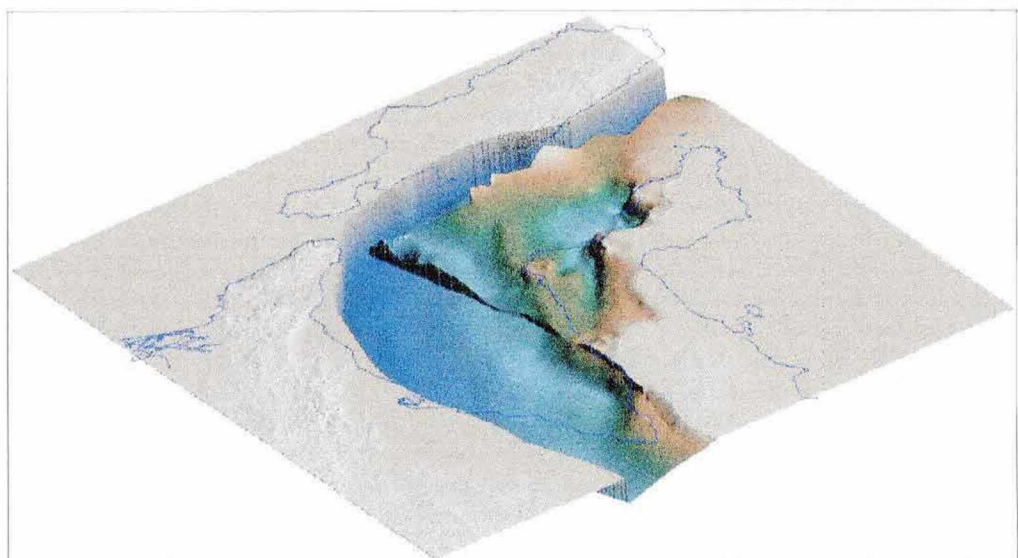
East View



South-South-East View



South-West View



0 10 20
kilometres



PRIMARY INDUSTRIES
AND RESOURCES SA



SRK Consulting
Integrated Science and Engineering Consultancy

Energy Services

6/50 Gellie Court
Deakin ACT 2600
Canberra, Australia
Tel: +61 2 6283 4800
Fax: +61 2 6283 4801
URL: www.srk.com.au

PIRSA - Stansbury Basin

June, 2001

SRK Job Code: PH12

Scale: 1: 500,000

Projection: Australian Map Grid (AGD 66), Zone 54

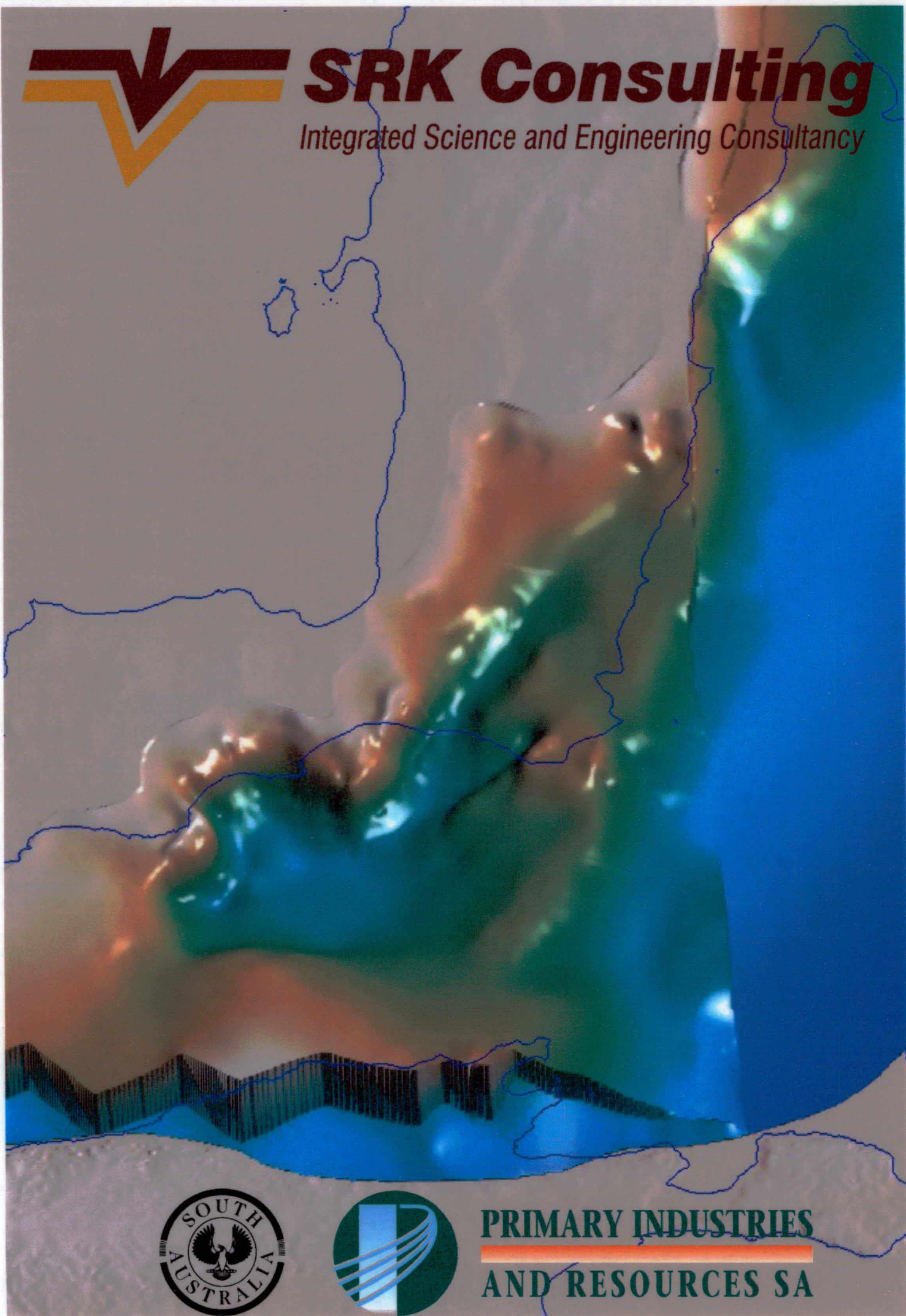
SEEBASE

Structurally Enhanced view of Economic Basement



SRK Consulting

Integrated Science and Engineering Consultancy



**PRIMARY INDUSTRIES
AND RESOURCES SA**



SRK Consulting

Integrated Science and Engineering Consultancy

Officer Basin SEEBASE Project

SRK Project Code: PI11

May 2001



**PRIMARY INDUSTRIES
AND RESOURCES SA**



SRK Consulting

Integrated Science and Engineering Consultancy

ENERGY SERVICES

Suite 7, Deakin House
50 Geils Court
PO Box 250
Deakin West ACT 2600
Australia

email: canberra@srk.com.au
URL: <http://www.srk.com.au>
Tel: +61 2 6283 4800
Fax: +61 2 6283 4801

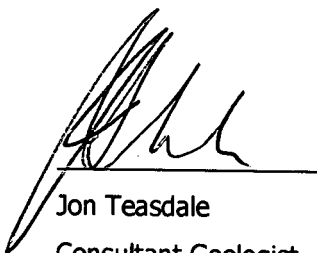
Officer Basin SEEBASE* Project

SRK Project Code: **PI11**

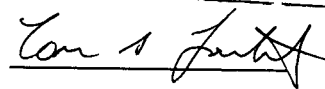
April - May 2001

Authors:

Jon Teasdale
Lynn Pryer
Mike Etheridge
Karen Romine
Peter Stuart-Smith
Jun Cowan
Tom Loutit
John Vizey
Phil Henley



Jon Teasdale
Consultant Geologist



Tom Loutit
Technical Director

***SEEBASE = Structurally Enhanced view of Economic Basement**

The conclusions and recommendations expressed in this material represent the opinions of the authors based on the data available to them. The opinions and recommendations provided from this information are in response to a request from the client and no liability is accepted for commercial decisions or actions resulting from them.



**PRIMARY INDUSTRIES
AND RESOURCES SA**



SRK Consulting
Integrated Science and Engineering Consultancy

Stellen, Robertson & Kivian (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Table of Contents

Introduction	
Executive Summary	4
Recommendations	5
Project Background, Aims, Why SRK?	6
Data Compilation & Processing	
Datasets, Project Area	7
Aeromagnetics	8
Bouguer Gravity	9
Seismic Coverage, Wells Coverage	10
Calibration & Methodology	
Calibration of Potential Field Data, Why Basement?	11
SABRE, Basement Character & Petroleum Systems	12
Basement Geology of the Officer Basin	13
Basement Terranes	14
Basement Composition	15
Basement Structure – Overview	16
Basement-Involved Faults	17
Deep Crustal Fracture Zones	18
Proterozoic Basement Deformation	19
Geological Evolution of the Officer Basin	20
Basin Phase 1: Neoproterozoic Extension	21
Basin Phase 2: Neoproterozoic Sag	22
Basin Phase 3: Petermann Orogeny	23
Basin Phase 4: Early Cambrian Extension	25
Basin Phase 5: Delamerian Orogeny	27
Basin Phase 6: Ordovician Extension	29
Basin Phase 7: Alice Springs Orogeny	31
SEEBASE Depth to Basement	33
SEEBASE Methodology	34
Model Magnetic Profiles	35
Officer Basin SEEBASE	36
3D Views of Officer Basin Architecture	38
Basement Controls on Basin Architecture	
Officer Basin Cross Section	39
3D Block Diagram	40
References	41



Executive Summary

This project was initiated by PIRSA to augment their marketing campaign to attract new hydrocarbon explorers to the Officer by providing new insights into its geology and hence reduce exploration risk. SRK was contracted in March 2001 to provide an integrated regional interpretation of basement composition, structure and depth in the Officer Basin, and investigate the effect of basement geology on basin evolution and petroleum systems.

SRK's approach primarily relies on the interpretation of magnetic and gravity data, calibrated with many other datasets including mapped geology, event histories, wells and seismic. SRK utilizes a "bottom-up" approach to basin analysis, starting with a rigorous understanding of basement geology. By integrating the plate-scale kinematic event history for the area of interest, a interpretation of the basin's structural evolution through time can be mapped. Combined with a SEEBASE* map of depth to basement, this data can be used to understand basin phase distribution and petroleum systems.

The key findings of this project are as follows:

- The basement geology of the Officer is dominated by NE trending, contrasting terranes which amalgamated during the Mesoproterozoic along a network of major NE trending shear zones.
- The present-day geometry of the Officer Basin was established in the late Cambrian-early Neoproterozoic Petermann Orogeny
- Basin architecture is largely controlled by basement structures, composition, fabric and rheology.
- NE trending Mesoproterozoic shear zones/terrane boundaries were a first-order control on basin evolution during the Paleozoic.
- NW trending Neoproterozoic fractures were a second-order control on basin evolution during the Paleozoic.
- The Officer Basin has largely evolved during compression, and has been significantly influenced by intracratonic processes operating in the Musgrave and Arunta Blocks to the north.
- Seven basin phases/tectonic events have shaped the Officer during the Neoproterozoic and Paleozoic.
- A SEEBASE* model for the Officer Basin shows basement topography, and can be used to map basin phase distribution, migration pathways and trap type/distribution.

*SEEBASE = Structurally Enhanced view of Economic Basement



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd. ABN 56 074 271 720, trading as SRK Consulting

Recommendations

- This projects provides new base to investigate the stratigraphic evolution of the Officer. A sequence stratigraphic study based on the structural framework and SEEBASE model presented here would provide new insights into the evolution of the Officer.
- More detailed SEEBASE study of prospective areas/permits integrating all available seismic data. The existing magnetic dataset can support much more detailed work than done in this project, and a full seismic calibration would provide additional constraints on structural geometries at depth and reactivation histories.
- Integrate new aeromagnetic data into the SEEBASE model to improve its reliability. Such data would also enable interpretation of intrasedimentary features such as basin floor fans/deltas, basement-detached faults and volcanics.
- Paleogeographic analysis and basin modelling to track accommodation space through time. Was there "space" in the Officer during the early Paleozoic due to Petermann Orogen flexure?
- Integrate structural and stratigraphic observations from the Officer Basin in Western Australia into this SEEBASE project. Over half of the Officer Basin lies in WA, and many observations there may shed new light on the evolution of the Officer in SA. This project has integrated basic knowledge from key publications in the WA Officer.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

 **SRK Consulting**
Integrated Science and Engineering Consultancy

Steffen, Robertson & Krause (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Project Background

- The 1996 & 1999 PIRSA Petroleum Industry Surveys demonstrated that a perceived lack of knowledge and largely unfounded geological biases (e.g. poor source/reservoir quality, poor migration timing etc) were preventing petroleum companies from exploring in the Officer Basin.
- This project was initiated by PIRSA to augment their marketing campaign to attract new explorers to the Officer by providing new insights into its geology and hence reduce exploration risk. SRK Consulting was contracted by PIRSA in March 2001.
- This project was completed in 4 weeks' work by the SRK Energy Services team.

Project Aims

- To provide an integrated regional interpretation of basement composition, structure and depth in the Officer Basin, utilizing available gravity, magnetic, seismic and other data.
- To investigate the effects of basement geology on basin evolution and petroleum systems in the Officer Basin, focusing on structural evolution/reactivation, basin architecture and tectonic history.
- To provide a MapInfo GIS containing all interpretive layer.

Why SRK?

- SRK Consulting is one of the world's largest natural resource consultancies, with 22 offices in 5 continents.
- The SRK Energy Services group is based in Canberra, Australia. We are leaders in innovative, integrated *geological* interpretation of non-seismic and seismic data, principally magnetic and gravity data. We have worldwide experience in the petroleum, minerals and coal sectors.
- SRK Energy Services has worldwide experience in basin analysis, and has pioneered many new techniques for rapidly evaluating the structural framework and tectonic evolution of all types of basins, based largely on geopotential field data. SRK utilizes a "bottom-up" approach to basin analysis, starting with a rigorous understanding of basement geology. By integrating the plate-scale kinematic event history for the area of interest, a interpretation of the basin's structural evolution through time can be mapped. Combined with a SEEBASE* map of depth to basement, this data can be used to understand basin phase distribution and petroleum systems. (*SEEBASE = Structurally Enhanced view of Economic Basement)



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Stellen, Robertson & Kirsan (Australia) Pty. Ltd. ABN 56 074 271 720, trading as SRK Consulting

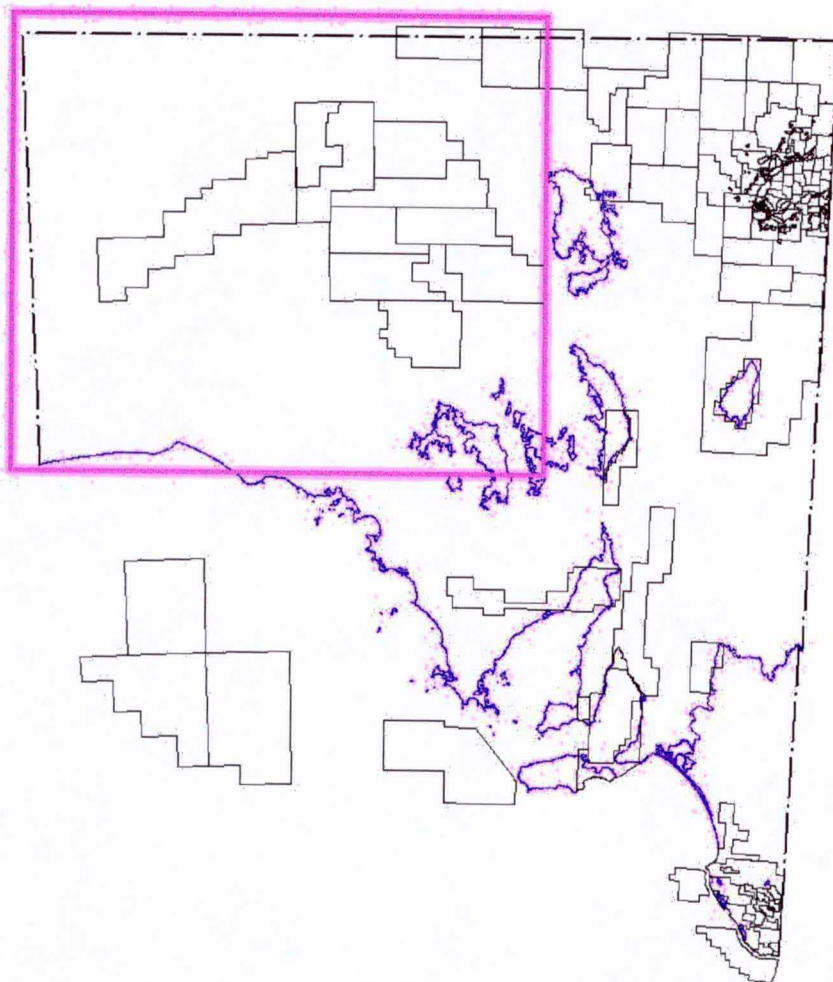
Datasets

The following datasets were provided by PIRSA for the Officer SEEBASE project:

- Bouguer Gravity (state 500m grid)
- Magnetics (state 100m grid)
- DEM (Auslig 9 sec)
- Seismic (mainly 1993 AGSO data)
- Wells (completion reports, summary logs)
- PIRSA Minerals GIS's (SA_GIS, Western Gawler Craton, Northern Gawler Craton)

In addition, SRK integrated its extensive in-house knowledge of Australian geology, published literature, and plate tectonic reconstructions

Project Area

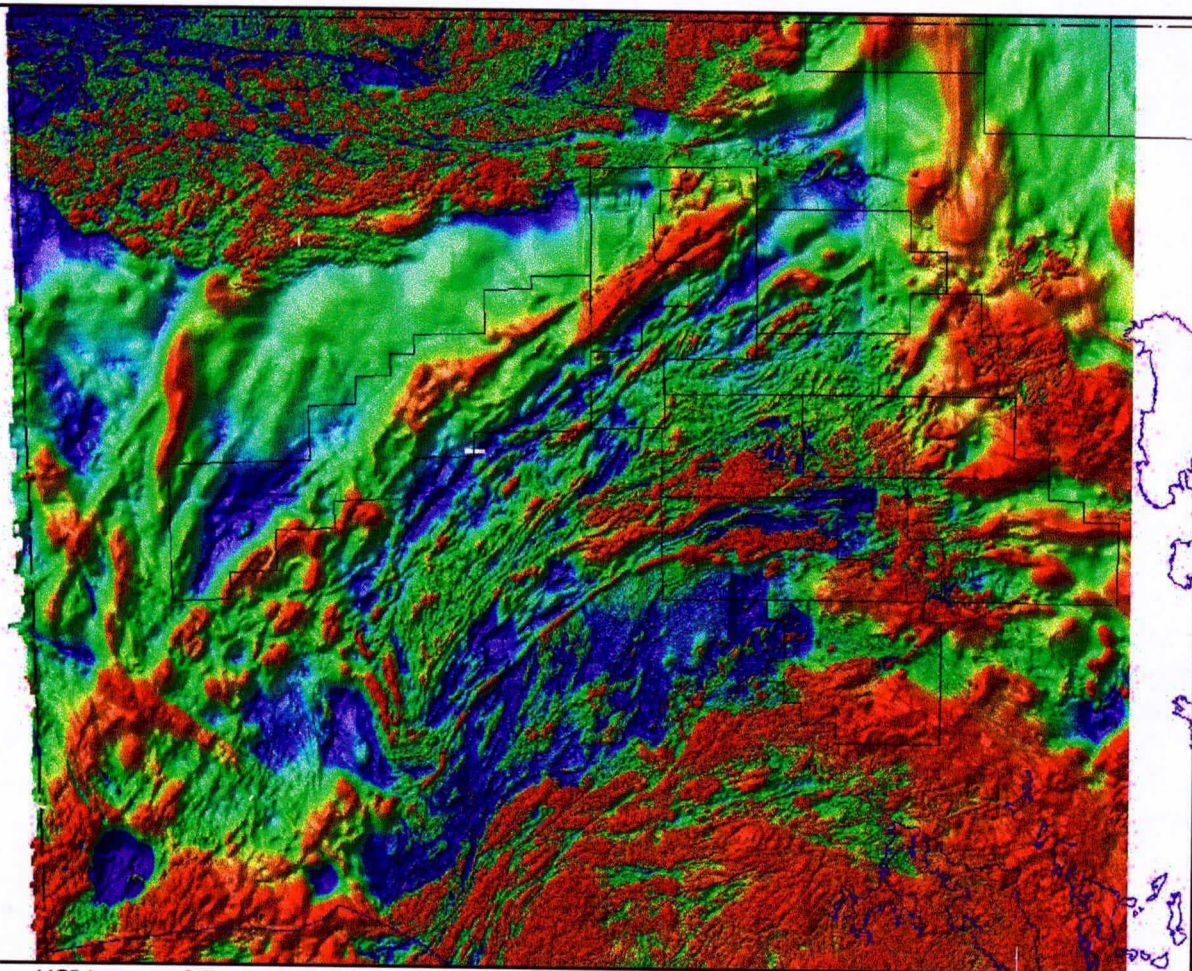


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Krieken (Australasia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Aeromagnetics



HSI image of Total Magnetic Intensity Reduced to the Pole (RTP)

Aeromagnetic data measures variations in the Earth's magnetic field caused by variations in the magnetic susceptibility of the underlying rocks. It provides information on the structure and composition of the magnetic basement. Most bodies within the basement have a distinctive magnetic signature which is characterised by the magnitude, heterogeneity and fabric of the magnetic signal. When calibrated with known geology, terranes can be mapped under a cover of sedimentary rock and/or water.

The most important and accurate information provided by magnetic data is the structural fabric of the basement. Major basement structures can be interpreted from consistent discontinuities and/or pattern breaks in the magnetic fabric. Once the structures have been evaluated and combined with those interpreted from the gravity data, a model for the evolution of the basement and overlying basins can be developed.

For the Officer Basin study, the SA state 100m stitched magnetic grid was reduced to the pole and imaged in ERMMapper using a Hue-Saturation-Intensity colour model. Various enhancement filters were applied to resolve the geometry and structure of the basement at depth (eg 1st vertical derivative, automatic gain control).

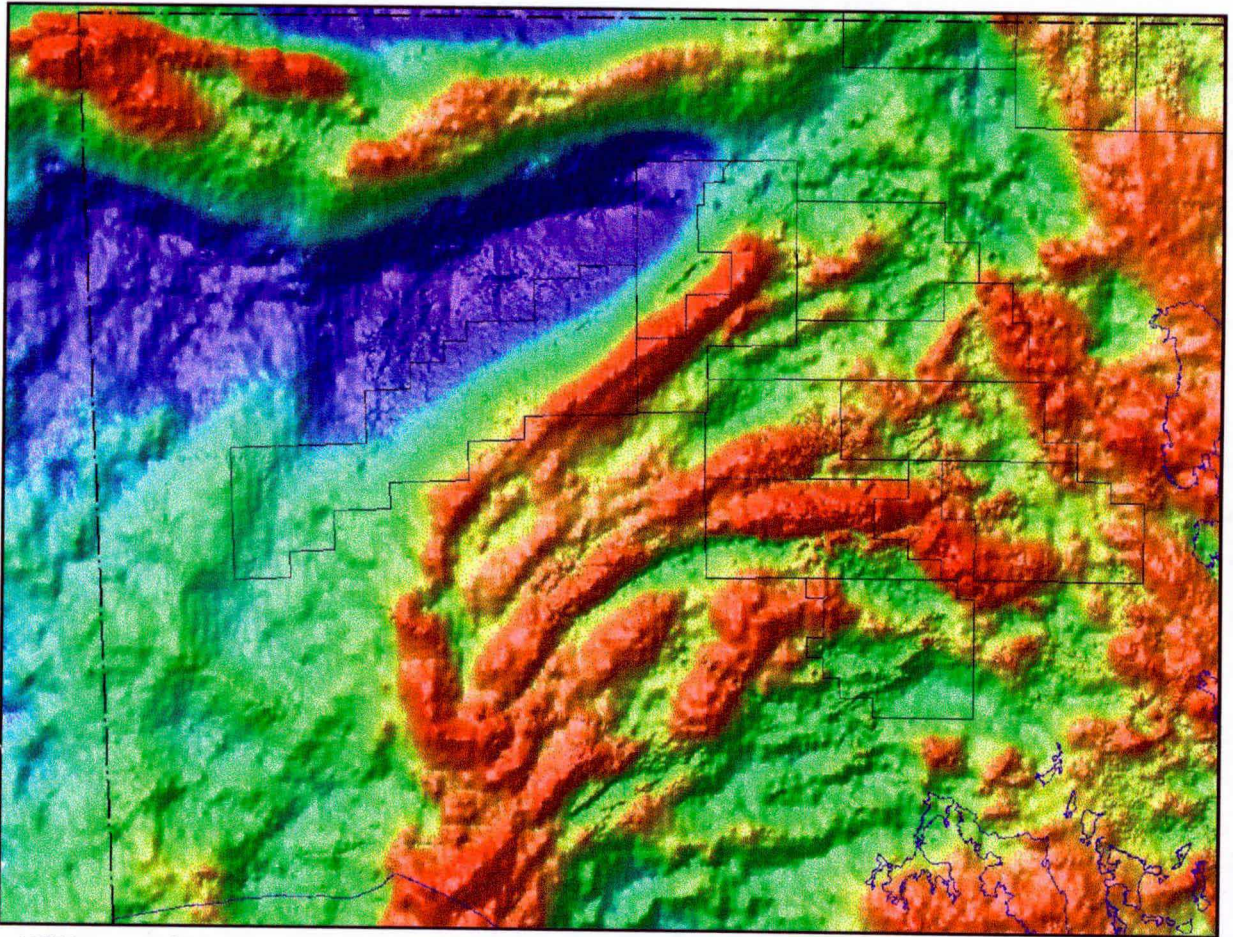


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kieren (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Bouguer Gravity



HSI image of Bouguer Gravity

Gravity data is a very important tool for interpreting basins. It maps subtle changes in the Earth's gravitational field caused by variations in the density of the underlying rocks. Although the resolution of this dataset is low (7km spacing), it provides valuable information on the nature of the deeper parts of the crust and mantle beneath the basins. Important intra-basin elements often have an associated gravity signature indicating that each element is related to a deep basement structure.

In order to evaluate the source of the gravity signature, the data must be calibrated with known geology and/or geophysical models. Gravity images show density contrasts within the crust and upper mantle but the source of the contrast is not unique. Thus the nature of each anomaly must be distinguished in this calibration process.

For the Officer Basin study, the SA state 500m stitched gravity grid was imaged in ERMMapper using a HSI colour model.

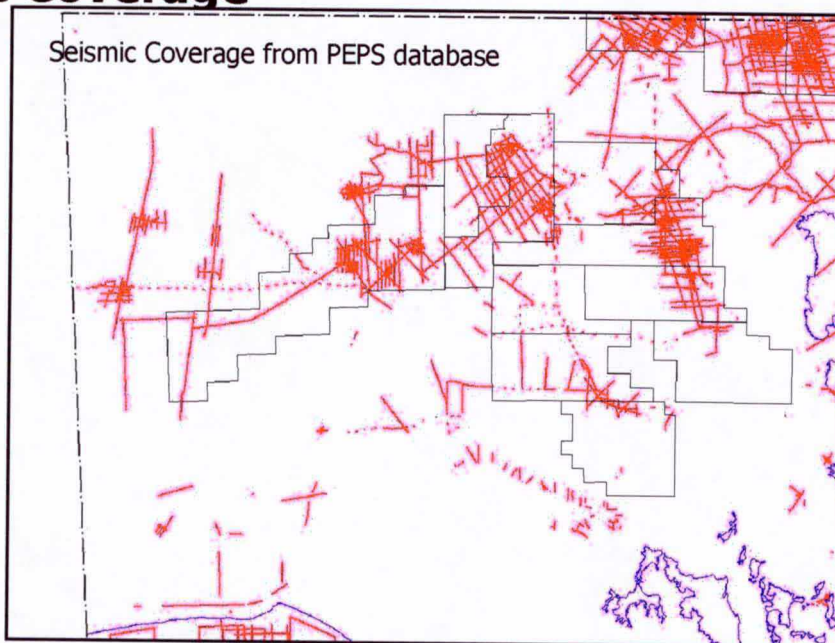


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kieren (Australasia) Pty. Ltd., ABN 66 074 271 720, trading as SRK Consulting

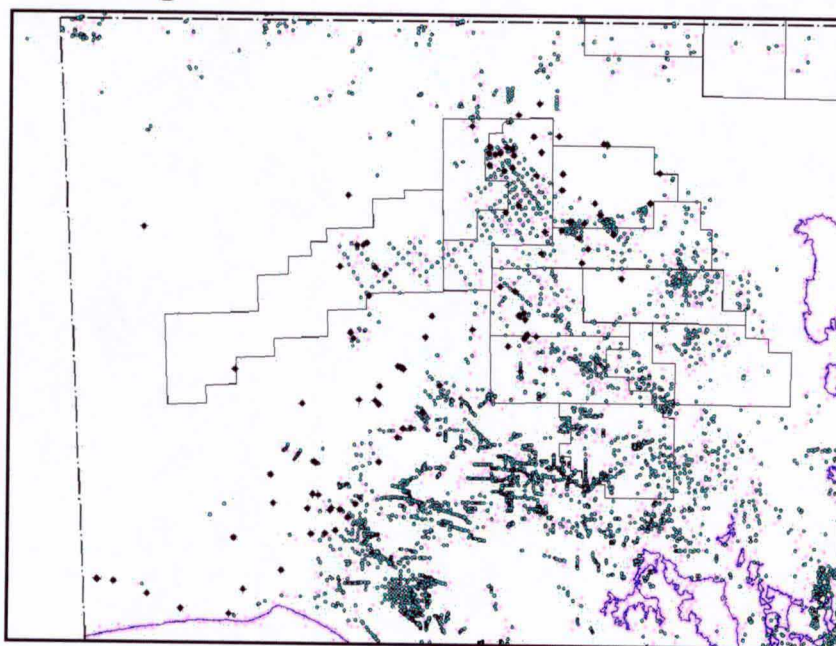
Seismic Coverage



Seismic coverage in the Officer Basin is very limited and generally poor quality. The top-basement unconformity is generally not clearly imaged.

In this study, limited seismic data (principally the 1993 AGSO data) has been used as a calibration tool for the depth to basement modeling and the structural interpretation (particularly timing of structural reactivation).

Wells Coverage



Seismic Coverage from PEPS database

Well coverage from the deeper parts of the Officer is very limited, with only a few basement penetrations in the shallower parts of the basin. Wells used to calibrate this study are shown as solid black dots.

Calibration of Potential Field Data

Calibration is a critical process in any potential field interpretation.

In order to extract as much reliable geological information as possible from potential field data, it is critical to calibrate the data. This is done initially using mapped geology or basement well intersections combined with rock property data (e.g. magnetic susceptibility, density). Once identified, mapped geological units can be traced offshore or under sedimentary cover. Knowing the particular geological units provides information about basement composition and allows for much better constrained depth models from magnetic data.

Away from outcrop control, seismic data are integrated (when available) to further constrain the development of a geological model. Basement penetration by wells and deep seismic data are particularly useful in constraining depth-to-basement estimates from the aeromagnetic data.

Why Basement?

The basement of any basin provides the foundation onto which the sediments are deposited. The rheology and mechanical behaviour of the basement controls the geometry and rate of subsidence of the evolving basin. Basement rheology and mechanical behaviour are determined by its composition and structural fabric. Thus it is important to understand basement evolution prior to basin development.

Understanding basement structures allows models to be developed that can predict which structures will reactivate, and how they will move under an applied stress. Using plate tectonic reconstructions, the far-field stress state during past events can be estimated and a kinematic reconstruction produced for each event. Basin sediments deform in response to movements in the basement and to gravity. Knowing how and when the basement moves provides a basis for predicting the most likely locations of depocentres and structures in the sediments.

Hence basement influences:

- basin phase architecture
- source-rock quality and distribution
- heat flow
- migration focusing, pathways and timing
- trap timing, distribution, type, integrity & size
- sediment supply and stratal geometry
- reservoir, seal quality & distribution



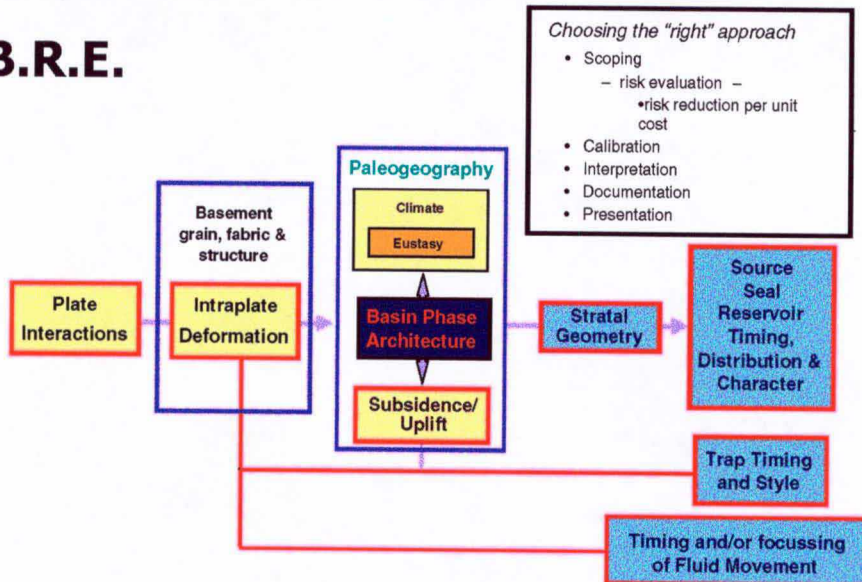
**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Stellen, Robertson & Kraen (Australasia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Systematic Approach to Basin Resource Evaluation

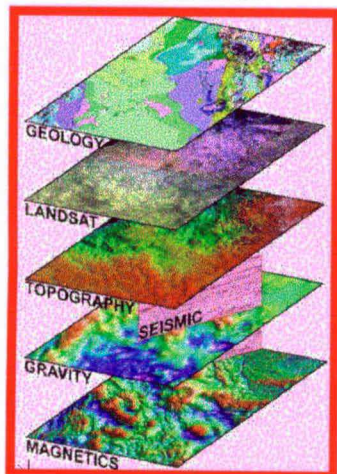
S.A.B.R.E.



The methodology used to develop a comprehensive structural model relies on the integration of all available geological information. Individual datasets alone can be ambiguous and when isolated often produce poorly constrained interpretations. Through integration, the model can be tightly constrained. Integration provides the means with which to calibrate each dataset to the other.

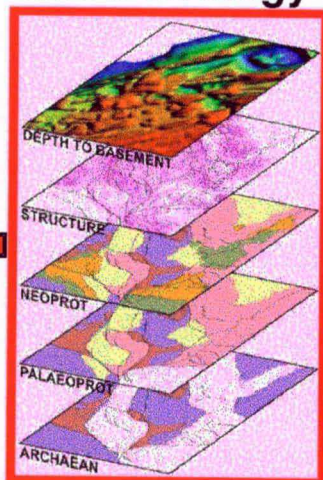
Basement Character and Petroleum Systems

Old Data



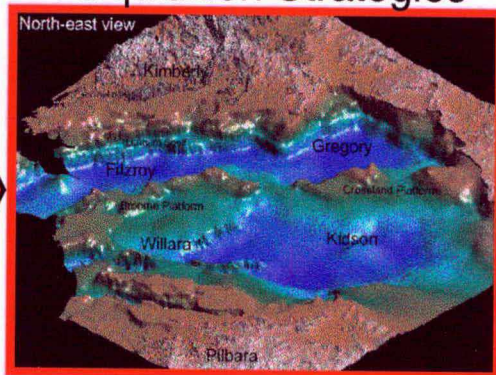
New Technology

Good Geology



Bottom-up

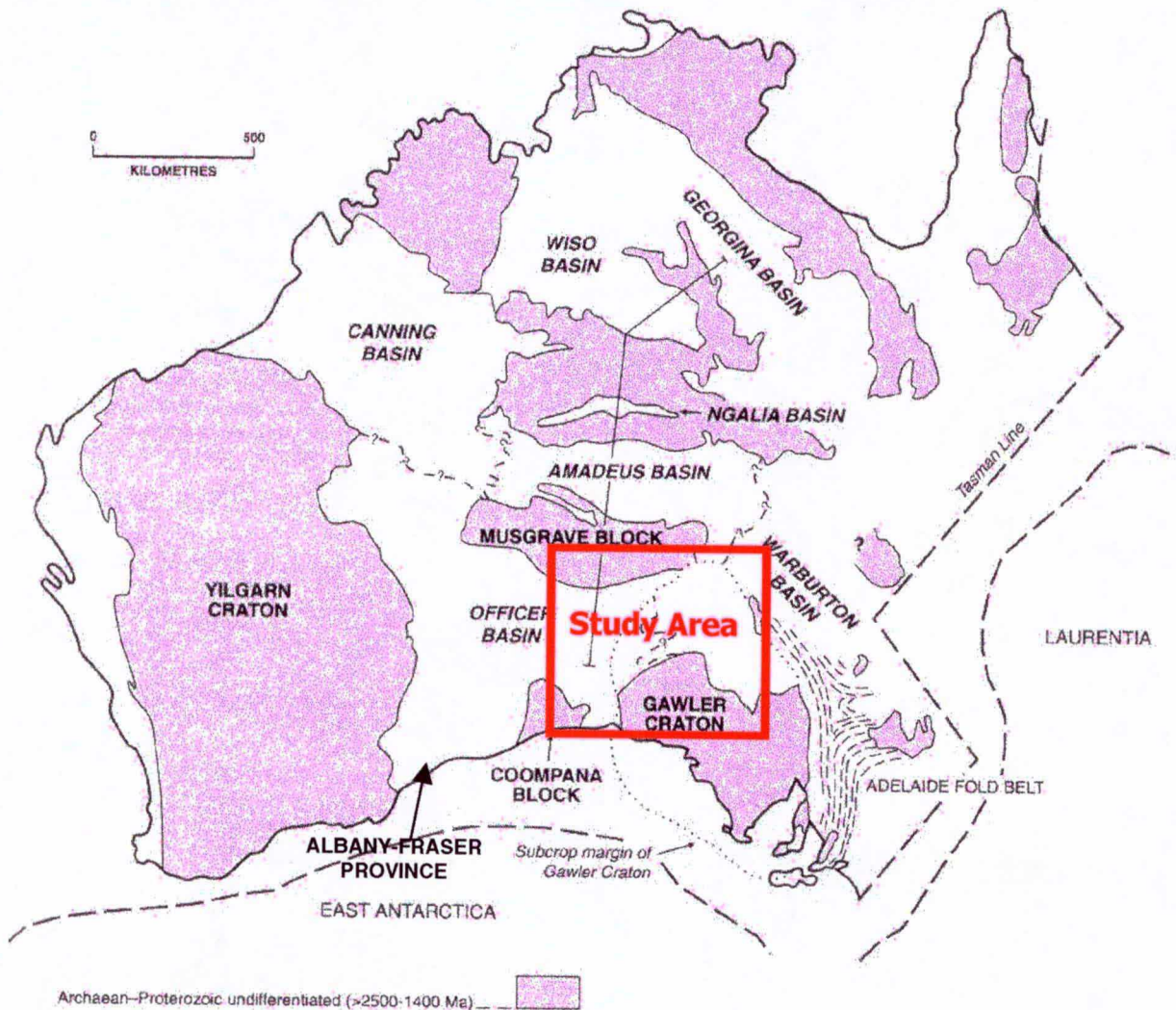
New Exploration and Acquisition Strategies



New Views in Old Basins

*Efficient and Effective
Exploration*

Basement Geology of the Officer Basin



Precambrian tectonic elements of Australia (from Morton & Drexel, 1997), showing the project area.

The Officer Basin overlies basement of the "Southern Australian Craton", which includes terranes amalgamated during the assembly of Rodinia (1200-1000Ma). The Southern Australian Craton (SAC) includes the Gawler Craton, Musgrave Block, Coompana Block and Albany-Fraser Province.

The SAC is dominated by contrasting ~NE trending terranes separated by major NE trending shear zones. These terranes have undergone a complex tectonic history spanning the late Archaean to the late Mesoproterozoic, with multiple periods of magmatism, high grade metamorphism and ductile deformation.

The contrasting basement terranes and the structures within and between them were a first-order control on the evolution of the Officer Basin.

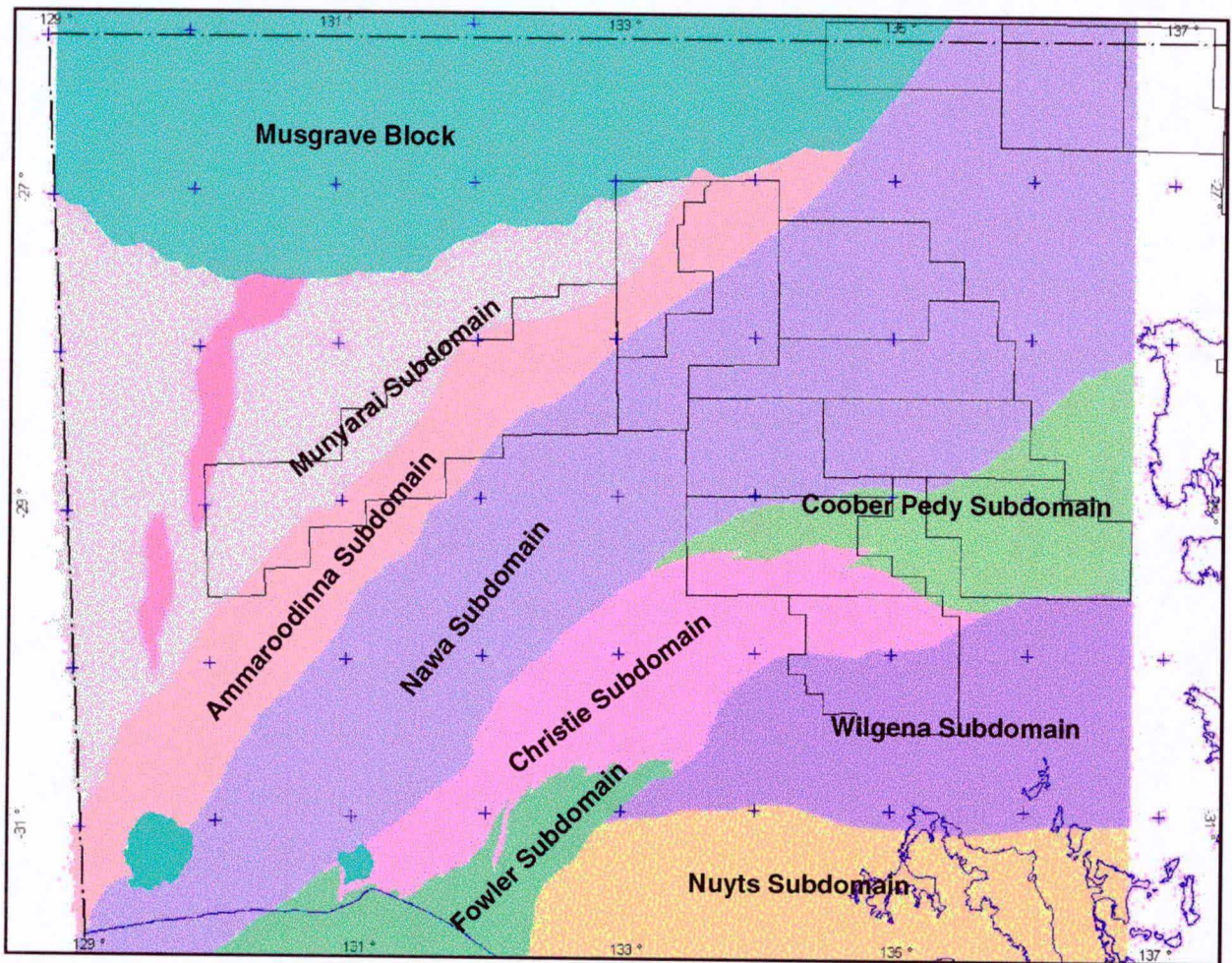
This report outlines the basement composition, structure, terranes and depth, and the influence these have on basin evolution and character.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy
Steffen, Robertson & Kieren (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basement Terranes



Basement beneath and adjacent to the Officer Basin is dominated by ~NE trending terranes separated by major shear zones. These terranes were amalgamated and juxtaposed during the Mesoproterozoic, culminating in the 1200-1000Ma "Grenvillian" event which assembled the supercontinent Rodinia. The terrane boundaries have acted as key reactivation zones during the evolution of the Officer Basin.

Three basement terranes underlie the Officer Basin (see details on next page):

- Nawa Subdomain
- Ammaroodinna Subdomain
- Munyarai Subdomain

The combination of gravity and magnetics is a powerful tool for distinguishing the lithological composition of and structural character of basement terranes.

Basement Composition

The basement terranes beneath and adjacent to the Officer Basin exhibit major lithological contrasts:

Nuyts Subdomain: Mainly relatively undeformed early Mesoproterozoic upper crustal felsic intrusives and volcanics (Hiltaba & St Peters Suites, GRV).

Fowler Subdomain: High grade Paleo-Mesoproterozoic mafic-intermediate gneiss terrane with some metasediments.

Christie Subdomain: High grade Archean metasedimentary gneiss terrane intruded by Paleo-Mesoproterozoic granitoids.

Coober Pedy Subdomain: High grade Paleoproterozoic metasedimentary gneiss terrane.

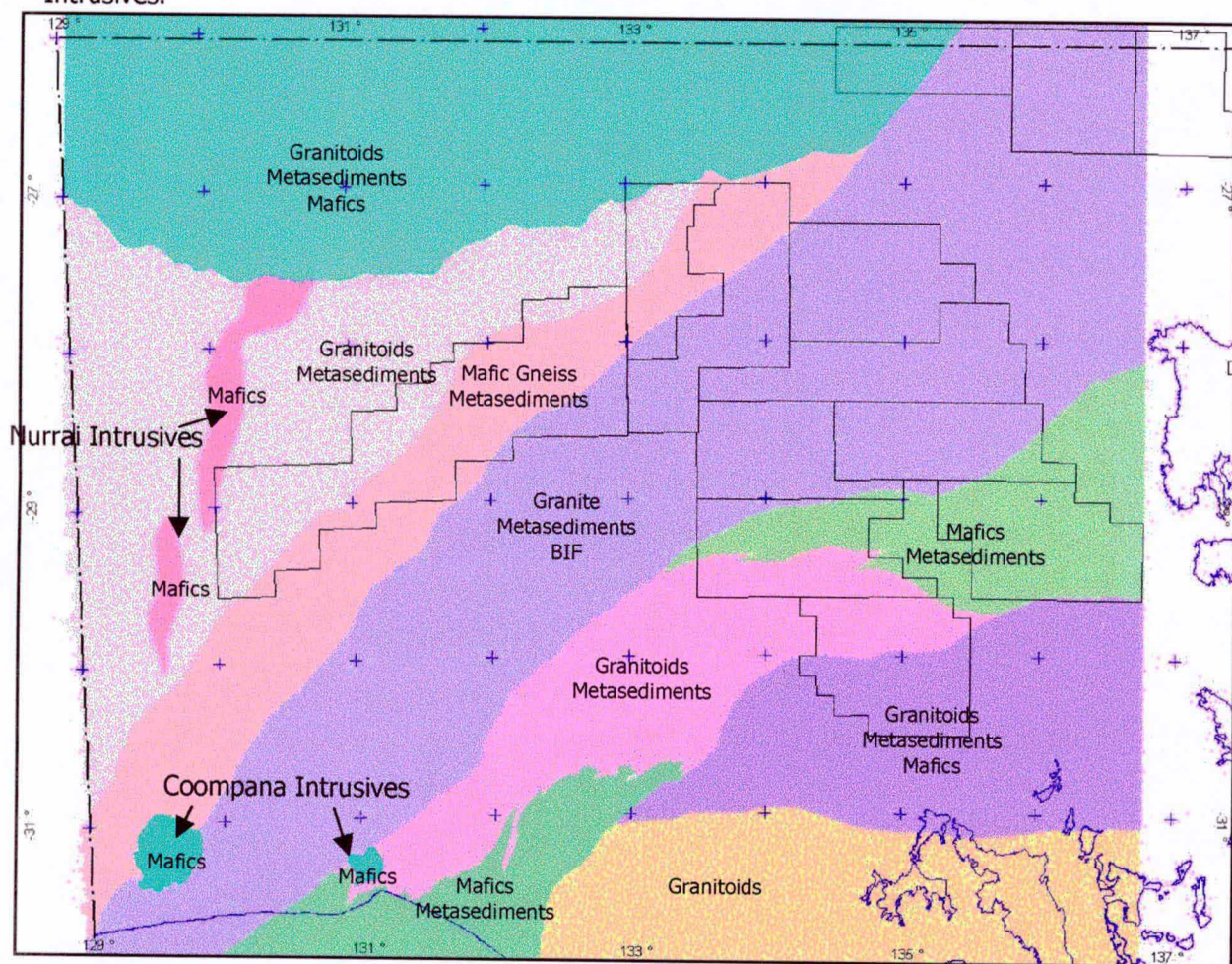
Nawa Subdomain: Complex Archean – Mesoproterozoic high grade gneiss terrane with abundant Paleoproterozoic intrusives.

Ammaroodinna Subdomain: High grade, highly magnetic, ?Paleo-Mesoproterozoic metasedimentary+mafic gneiss terrane.

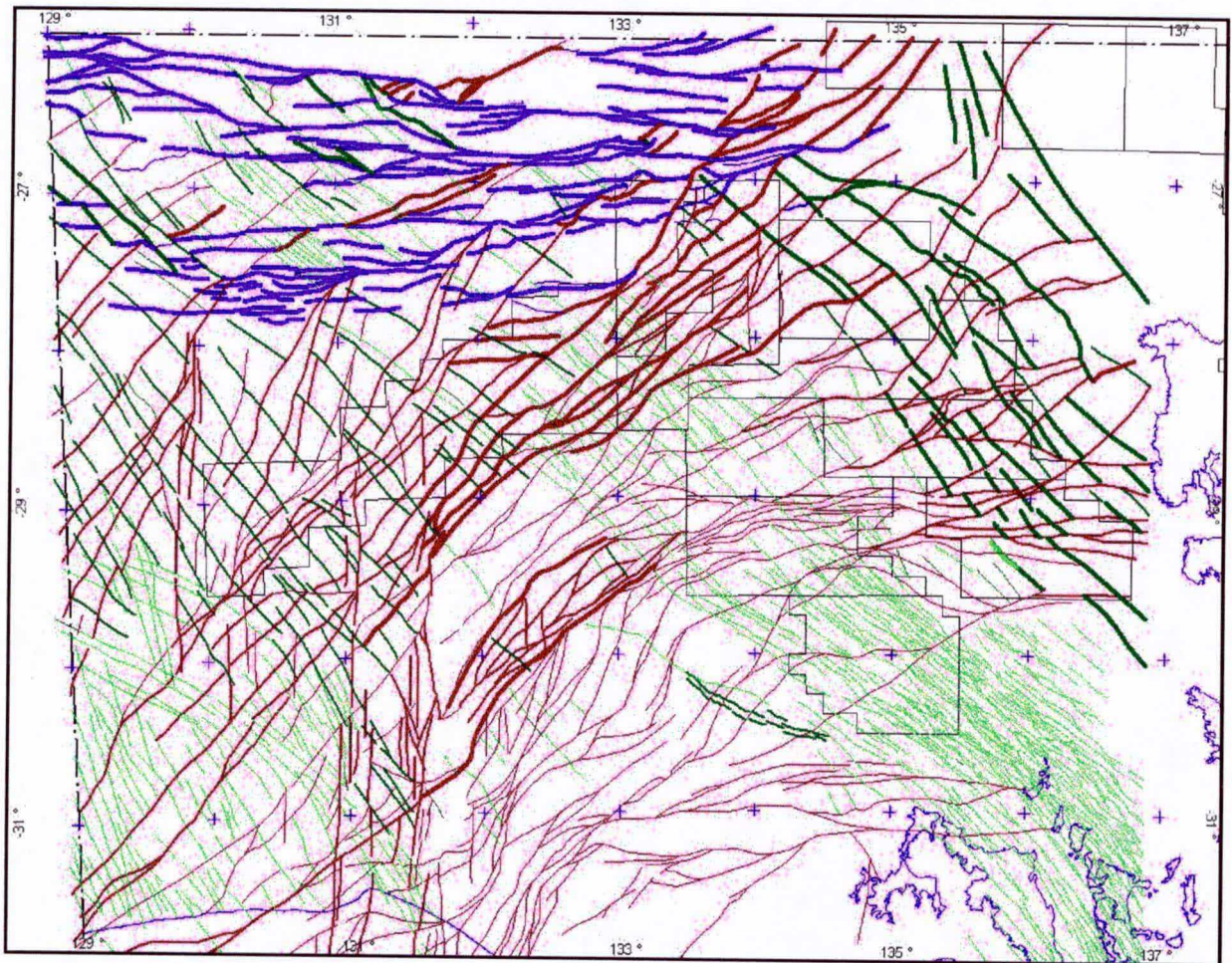
Munyarai Subdomain: High grade, low TMI, ?Paleo-Mesoproterozoic felsic-metasedimentary gneiss terrane (significantly different magnetic signature to Ammaroodinna Subdomain).

Musgrave Block: High grade Mesoproterozoic gneiss terrane extensively reworked in the Petermann and Alice Springs Orogenies.

In addition, at least two phases of late tectonic magmatism have occurred (Coompana & Nurrui Intrusives).



Basement-Involved Faults



All interpreted basement-involved faults in the Officer Basin are presented here in colours representing initiation age:

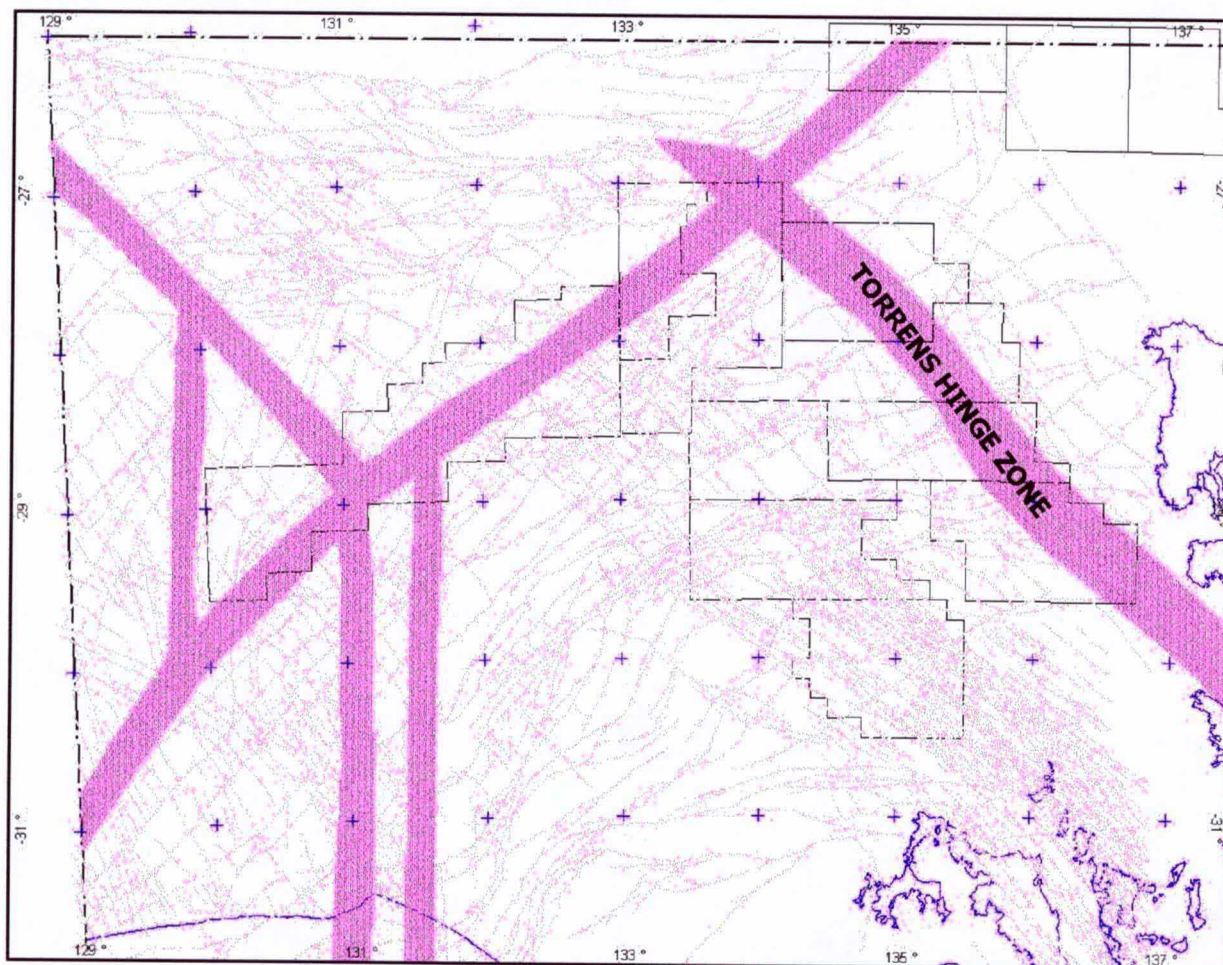
- Petermann Orogeny
- Neoproterozoic
- Mesoproterozoic

The line thickness is proportional to net displacement:

- 10m – 100m
- 100m – 1000m
- >1000m

All faults have been extensively attributed according to their reactivation history, source, displacement etc.

Deep Crustal Fracture Zones



Deep crustal fracture zones are seldom directly mappable in basins. They are deep seated (possibly mantle-derived), ancient zones of crustal weakness that directly or indirectly influence the subsequent development of structures and basins. They are often repeatedly reactivated. Often they coincide with terrane boundaries.

Deep crustal fracture zones in the Officer Basin form important boundaries between areas of high and low Neoproterozoic subsidence and subsequent inversion. The Torrens Hinge Zone is a well known but poorly understood deep crustal fracture zone that was very active during the Neoproterozoic and the Delamerian Orogeny. It was initiated during early Neoproterozoic extension (see p21), and crosscuts older Proterozoic terrane boundaries.

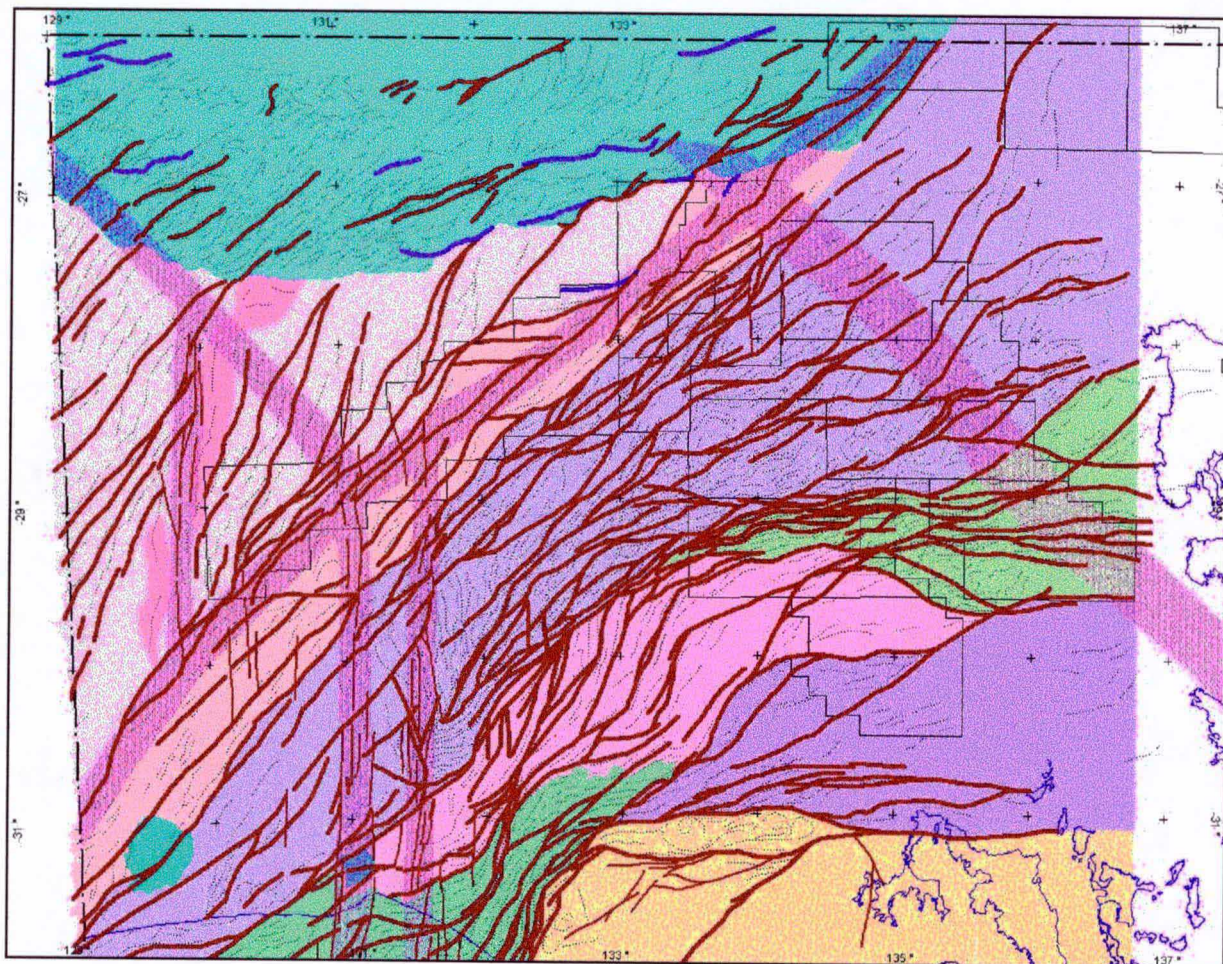


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Proterozoic Basement Deformation



Basement terranes of the Southern Australian Craton have undergone a complex history spanning the late Archaean to the late Mesoproterozoic. The final reworking and amalgamation of these basement terranes in the late Mesoproterozoic (~1450-1000Ma) was the most significant for the subsequent evolution of the Officer Basin. At this time many of the older structures were transposed and overprinted, and major ~NE trending, anastomosing, transpressional shear zone systems developed. These shear zones are shown in the map above. The geometry of the late shear zones was influenced by older structures, terrane boundaries and deep crustal fracture zones.

Localised basins formed during this shearing (e.g. Bangemall & Eraheedy Basins in WA), possibly as pull-apart or foreland basins which are filled with clastic sediments of latest Mesoproterozoic-early Neoproterozoic age. Several such basins have been identified in this study in the South Australian Officer (see Basin Architecture section).

Basin Evolution

The present-day geometry of the Officer Basin is the result of the superposition of 7 major tectonic "events" or basin phases spanning the Neoproterozoic to late Paleozoic. Unlike most basins, the architecture of the Officer is largely due to compressional deformation. Importantly, the Officer has evolved in an entirely intracratonic setting. The following chart details the tectonic history of the Officer Basin and its basement:

		BASIN PHASE	K'MATICS	DESCRIPTION
300	PERMIAN	LATE		
		EARLY		
	CARBONIFEROUS	LATE		
		EARLY		
	DEVONIAN	LATE		
		MIDDLE		
		EARLY		
	SILURIAN	LATE		
		EARLY		
	ORDOVICIAN	LATE		
		EARLY		
500	CAMBRIAN	LATE		
		MIDDLE		
		EARLY		
	NEOPROTEROZOIC	2		
		1		
1000	MESOPROTEROZOIC			
	PALEOPROTEROZOIC			
2500	ARCHEAN			

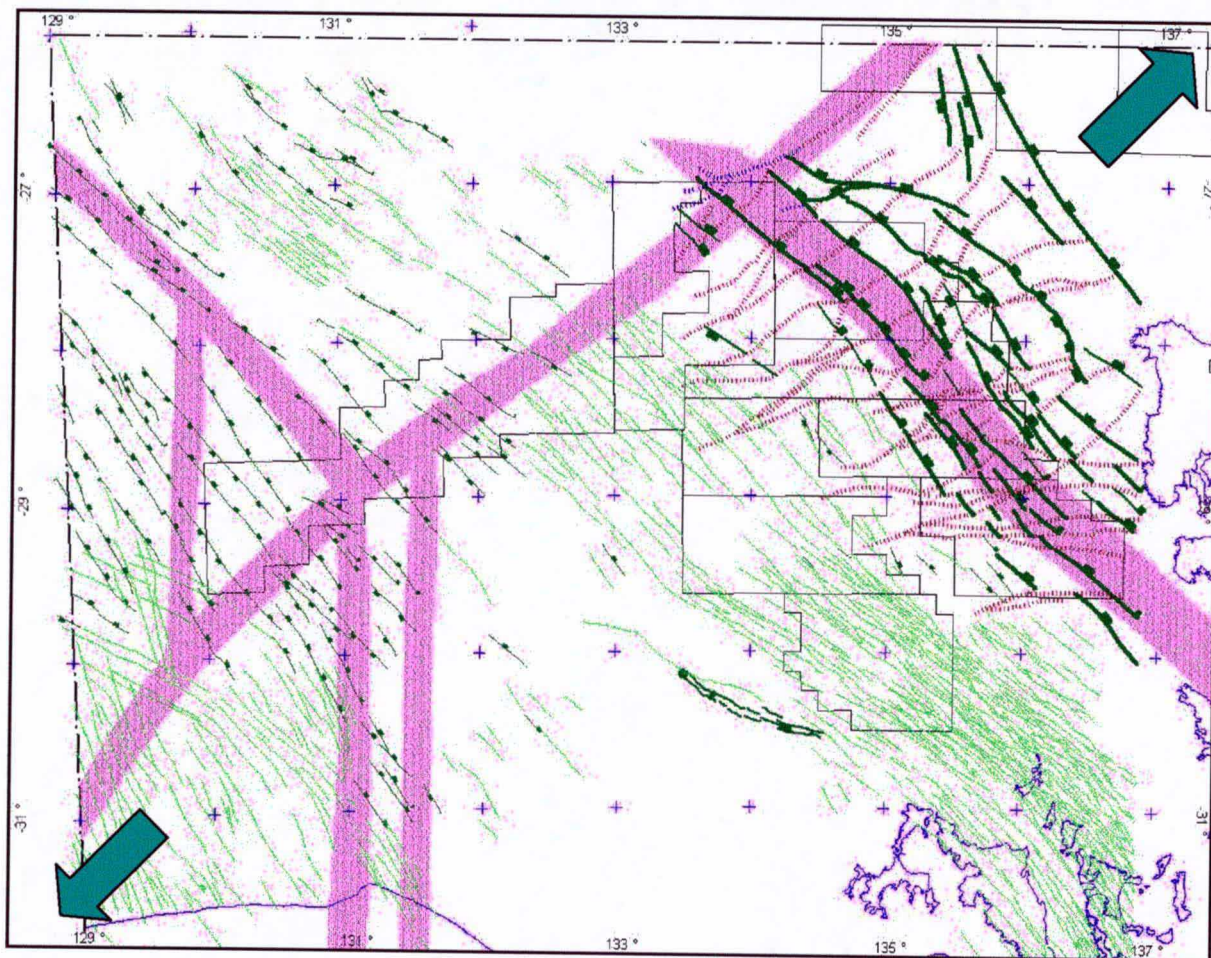
Stresses operating during each basin phase caused reactivation of basement structures and reactive fabrics, as well as the development of new structures. Understanding the kinematics of each tectonic event allows a predictive model for structural reactivation to be applied to the interpreted faults from fault history data calibrated with geological observations (e.g. seismic, maps), event maps for each basin phase have been constructed.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy
Steffen, Robertson & Krielen (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basin Phase 1: Neoproterozoic Extension



Minor, short-lived, NW-SE rifting occurred during the ~800Ma Gairdner Dyke "event" which marked the onset of Neoproterozoic sedimentation in the Officer. The Torrens Hinge Zone was formed at this time. This event also marked the onset of sedimentation in the Adelaide Geosyncline.

Neoproterozoic extensional structures formed at ~right angles to the Mesoproterozoic structural grain. All Neoproterozoic structures are interpreted to be "new", and do not appear to follow any pre-existing weaknesses. Although subtle in the Officer, NW trending Neoproterozoic structures have variably influenced its subsequent evolution.

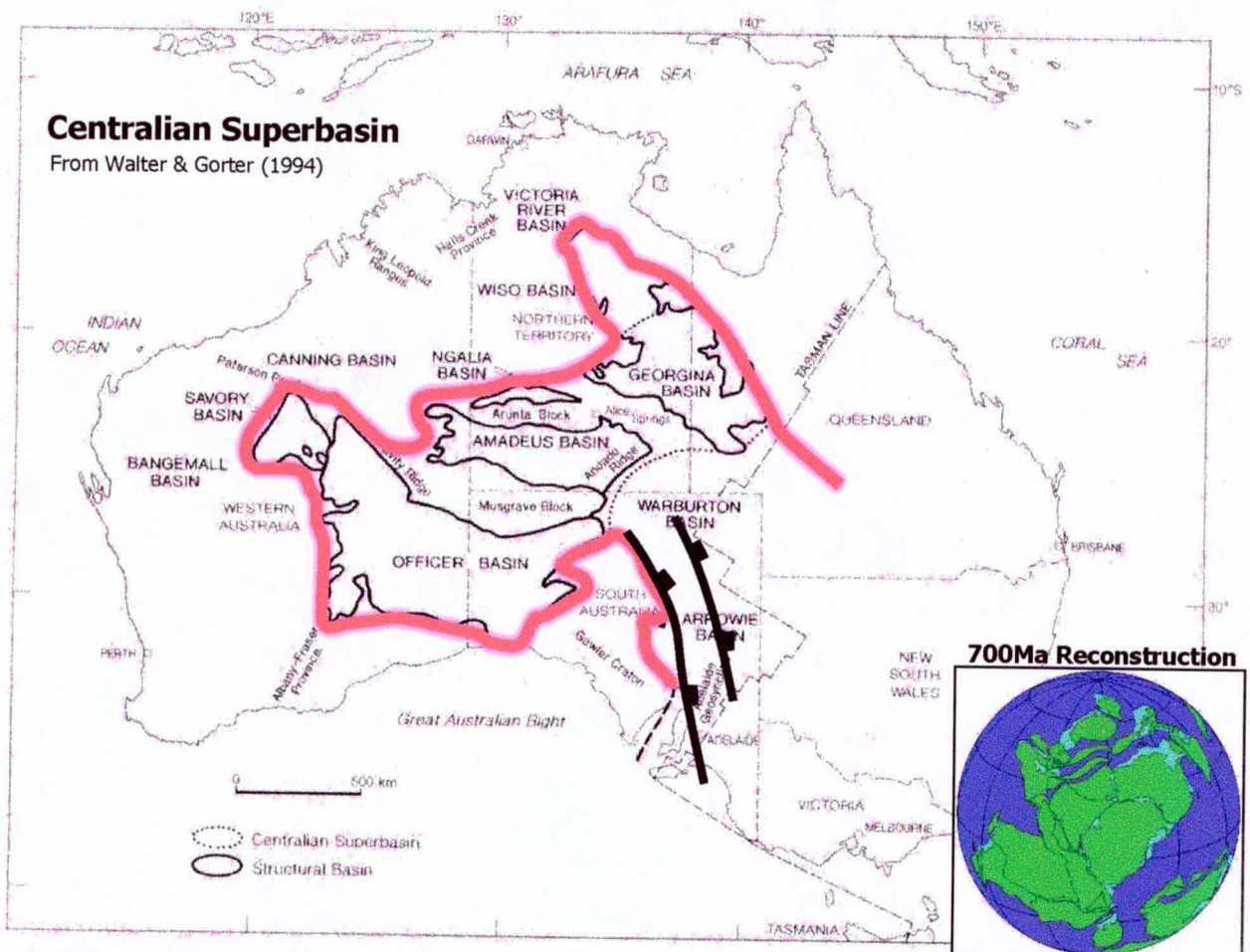
Basin Phase 2: Neoproterozoic Sag

Neoproterozoic sediments of the Officer Basin were originally deposited in a broad intracratonic sag basin termed the "Centralian Superbasin". The Centralian Superbasin spanned >2 million square km prior to the Petermann Orogeny at ~550Ma, and is notable for its lack of structuring. No major normal faults or syn-rift sequence has been identified; the basin comprises a thick (up to 10km) sequence of Neoproterozoic sediments which gently thin onto the basin margins. These sediments are now isolated in the Officer, Amadeus, Georgina and Ngalia Basins. The Adelaide Geosyncline formed during contemporaneous NNE-SSW rifting SE of the Centralian Superbasin.

Although the Centralian Superbasin was largely unstructured, subsidence geometry was significantly influenced by older basement structures and rheology. Notably, the older "hard" Archaean-Paleoproterozoic cratonic nuclei remained undisturbed, and sag was focussed into "softer" Mesoproterozoic mobile belts.

Internally, the sedimentary sequences in the Centralian Superbasin exhibit complex stacking patterns which reflect the interplay between stresses, flexure, sediment load & basement. At least two megasequences were deposited during Neoproterozoic sag.

The regional continuity of the Centralian Superbasin was terminated by the ~550Ma Petermann Orogeny, and further interrupted during the Paleozoic Delamerian and Alice Springs Orogenies. During these events the deepest parts of the basin underwent significant inversion.

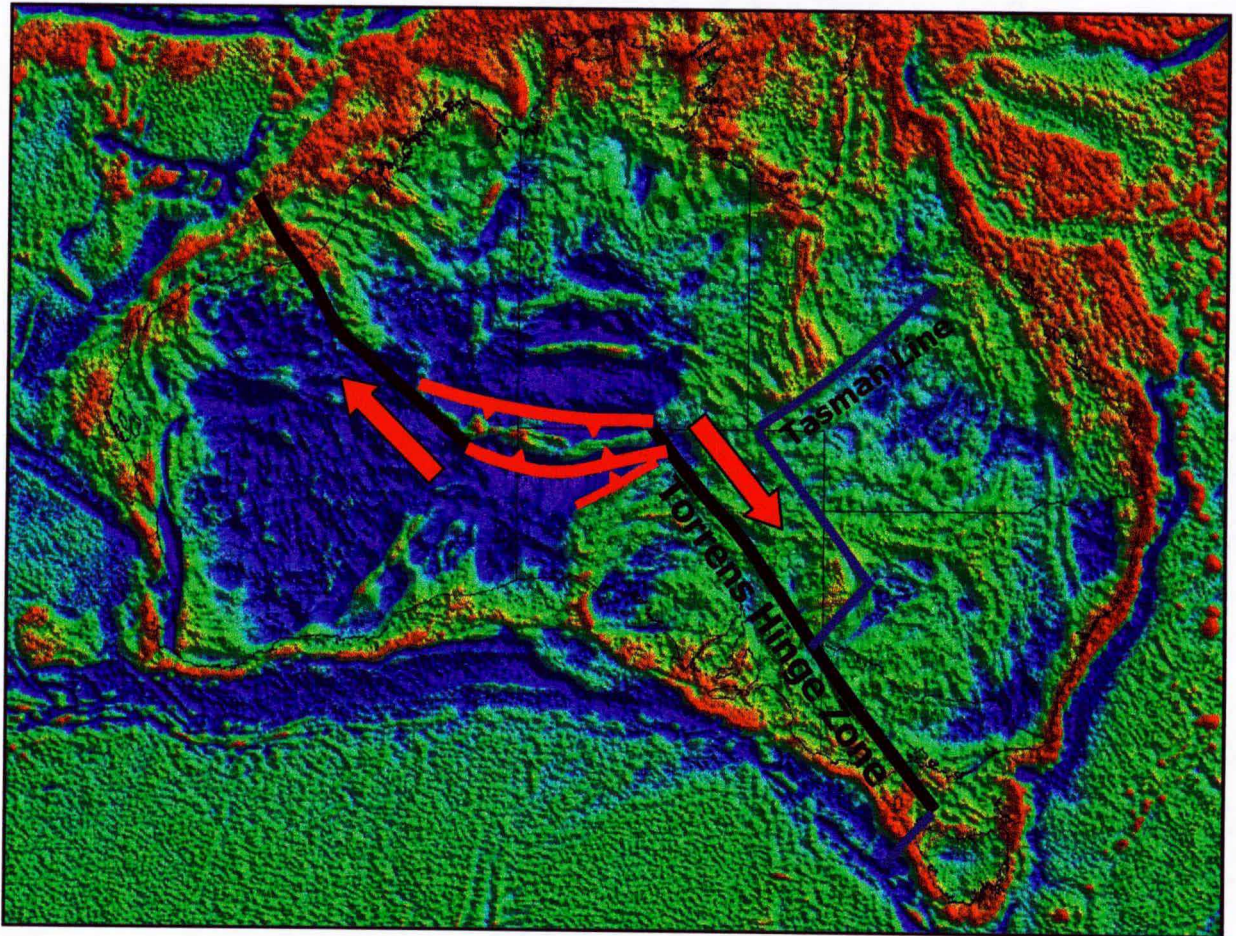


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

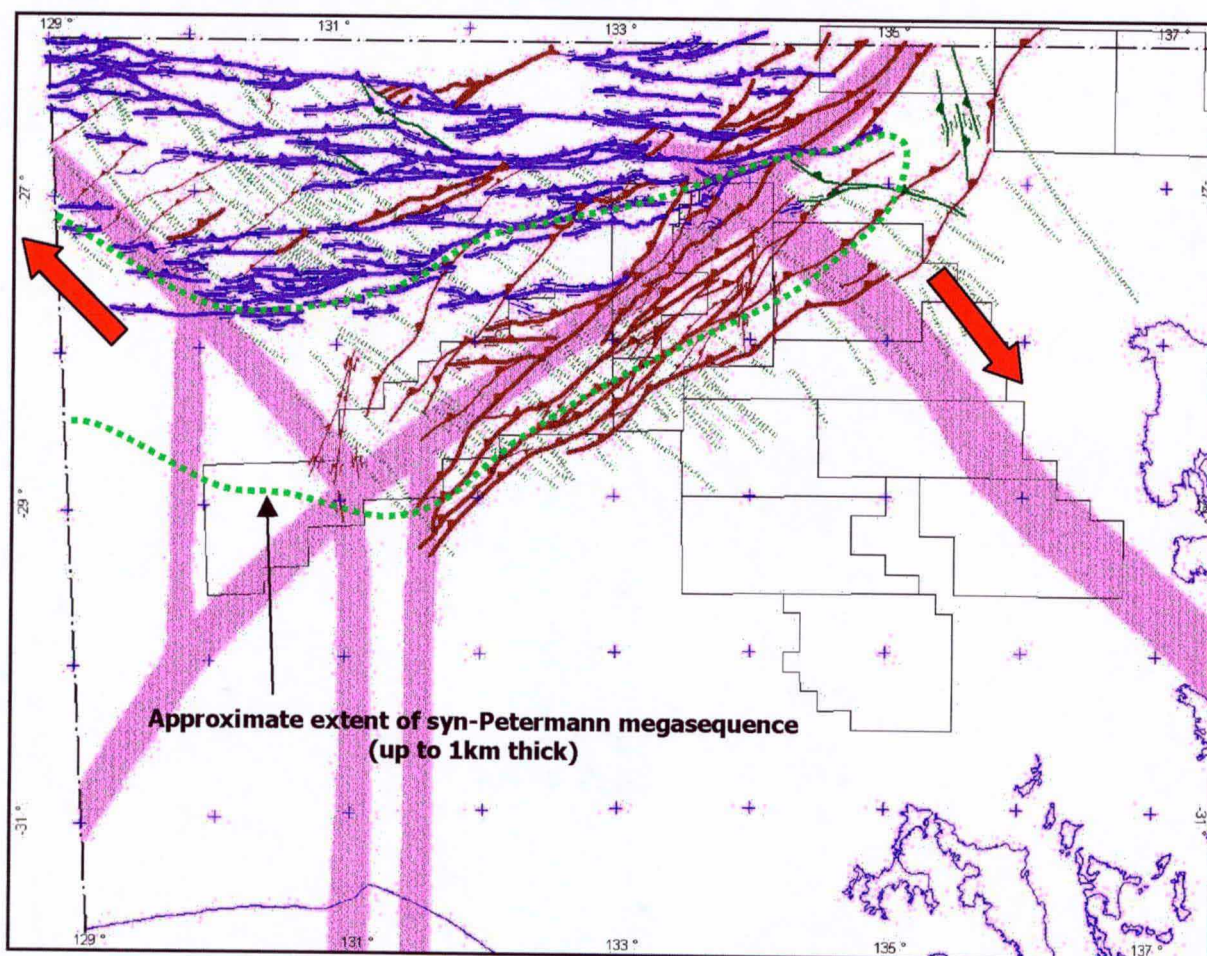
Basin Phase 3: Petermann Orogeny



During the late Pan African (~550-530Ma), dextral transpressional stresses in Gondwana caused strike slip movement along the Paterson Orogen-Torrens Hinge Zone, known as the Petermann Orogeny. At the stepover between these structures, a continent-scale “pop-up” occurred, exhuming and deforming what is now the Musgrave Block.

In Musgrave Block the Petermann Orogeny caused widespread tectonism, including regional eclogite facies metamorphism of basement, >40km of exhumation via a complex array of anastomosing ~E-W shear zones, and high pressure metamorphism of Neoproterozoic sediments. All of the Neoproterozoic Centralian Superbasin sediments were eroded into adjacent foreland basins (the Officer and Amadeus), and carried by major river systems to the continental margins. Isolated deep pull-apart basins formed at stepovers of major E-W transpressional structures (e.g. Levenger & Moorilyanna Grabens).

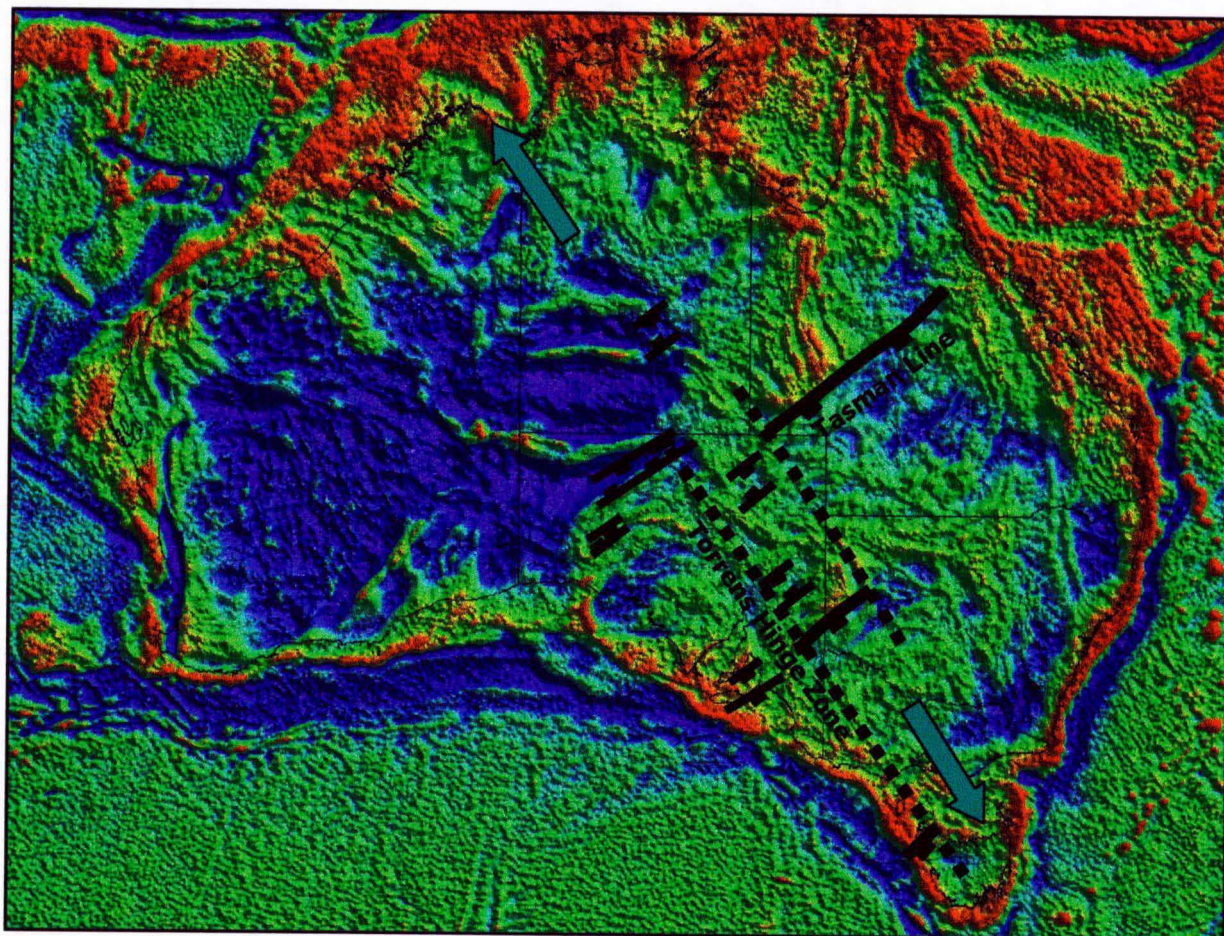
Basin Phase 3: Petermann Orogeny



The Petermann Orogeny caused the “breakup” of the Centralian Superbasin, and established the structural framework of the Officer Basin. Subsequent events have only caused relatively minor modification of the basin architecture.

In the Officer Basin, the Petermann Orogeny caused limited foreland basin sedimentation adjacent to the Musgrave Block, and reactivation and transposition of old NE trending basement structures. Up to 3.5km of basement-involved reverse movement occurred on major NE trending Mesoproterozoic structures (e.g. Ammaroodinna Ridge). NW trending Neoproterozoic dykes and faults acted as transfer zones during this deformation. Up to 1km of foreland basin sediments were deposited, which is surprisingly little given the magnitude of uplift in the Musgraves. This may reflect drainage patterns at the time – major river systems draining the mountains may have been structurally controlled and drained to the east, or possibly to the north along a major river system feeding the continental margin. This raises an important question regarding how much foreland accommodation was made in the Officer *but not filled* during the Petermann?

Basin Phase 4: Early Cambrian Rifting

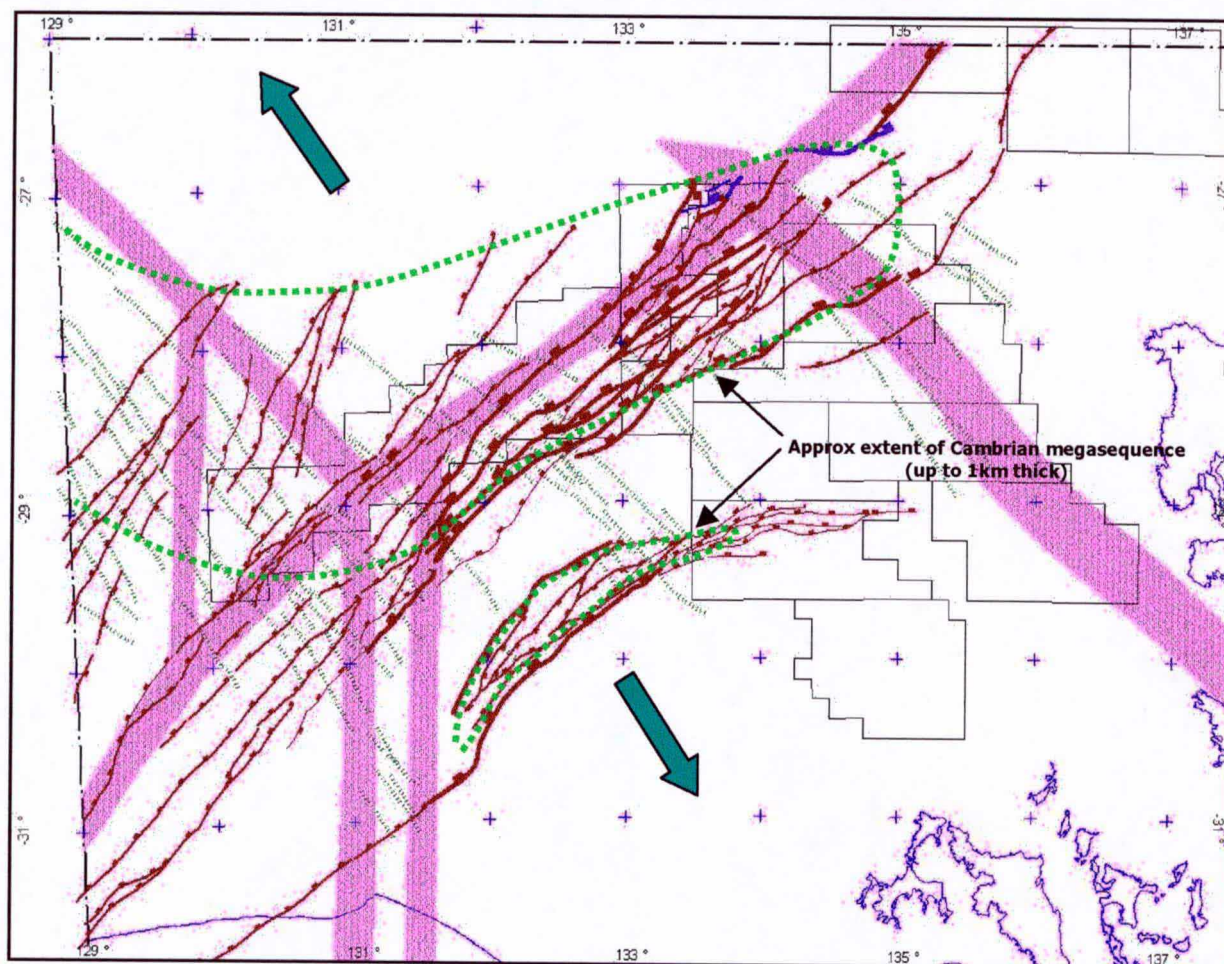


Early Cambrian extension in South Australia was caused by the final rifting & breakup between Australia & North America along the Tasman Line. In the early Cambrian this extension was oriented ~NW-SE. Most of the extension was accommodated to the SE of the Tasman Line on structures in the present-day Tasman Fold Belt.

Limited early Cambrian intracratonic rifting occurred to the NE in the Georgina, Officer, Stansbury, Arrowie and Warburton basins. These localised early Cambrian depocentres may contain good source rocks (as discovered in the Georgina Basin).

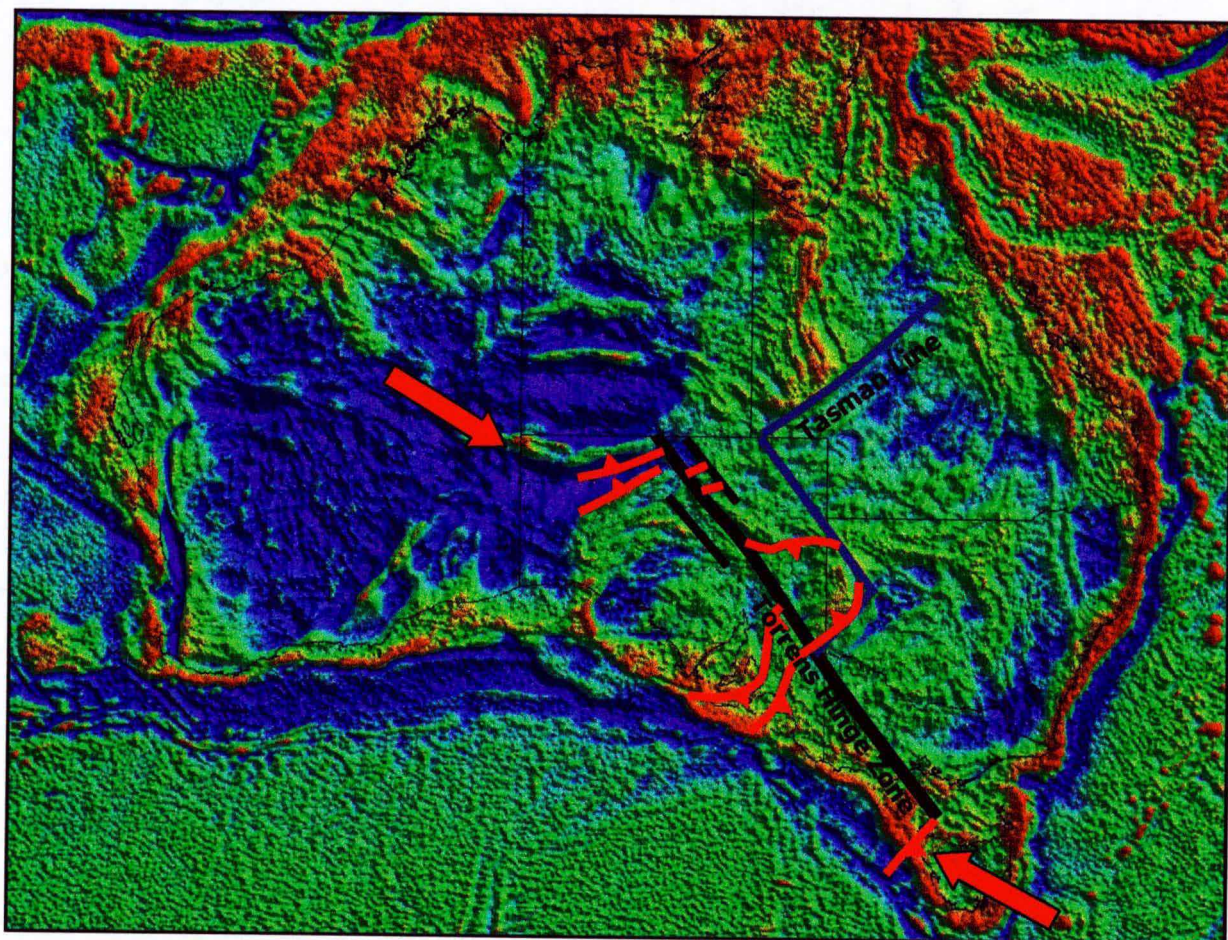
Mid-late Cambrian extension in the Lachlan Fold Belt of eastern Australia was oriented ~NNE-SSW, however no evidence for such rifting was observed in this project in South Australia.

Basin Phase 4: Early Cambrian Rifting



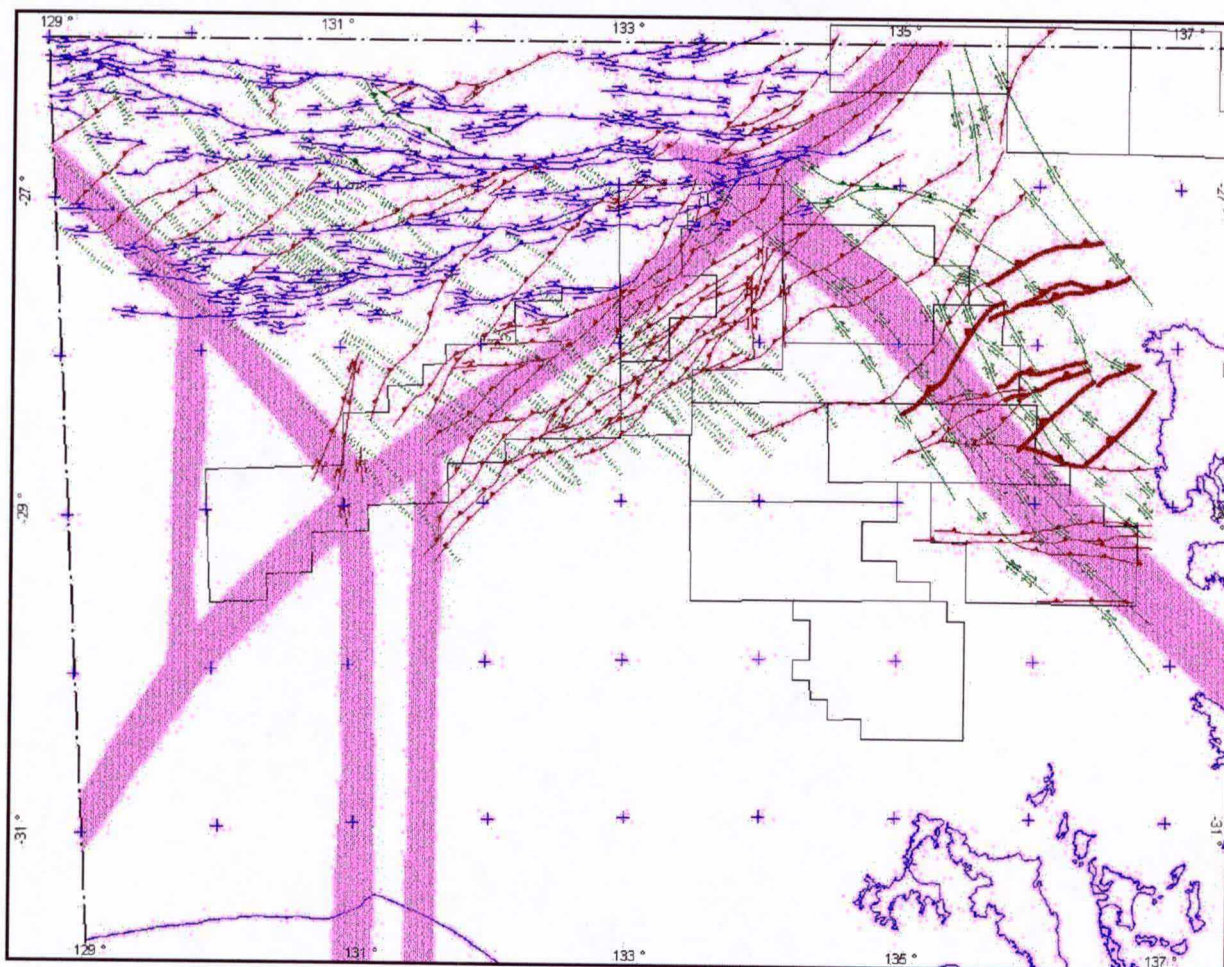
In the Officer Basin, NW-SE extension in the early Cambrian caused normal reactivation of some NE trending basement structures. NW trending Neoproterozoic dykes and faults acted as transfer/accommodation zones during this extension. Ongoing foreland sedimentation from Petermann Orogen filled some of these graben, however more distal early Cambrian graben (e.g. Tallaringa Trough) were filled with up to 1km of organic-rich lacustrine sediments.

Basin Phase 5: Delamerian Orogeny



The Delamerian Orogeny was a kinematically complex series of compressional events marking the terminal stages of the Gondwana-wide Pan African "event" during the time interval ~520-460Ma (late Cambrian to early Ordovician). In South Australia it caused the deformation of a series of fold-thrust belts including the Adelaide Fold Belt, Flinders Ranges and Olary-Broken Hill Province. The main phase of compression was probably oriented NNW-SSE. Sinistral transpressional movement took place along the Torrens Hinge Zone during the Delamerian.

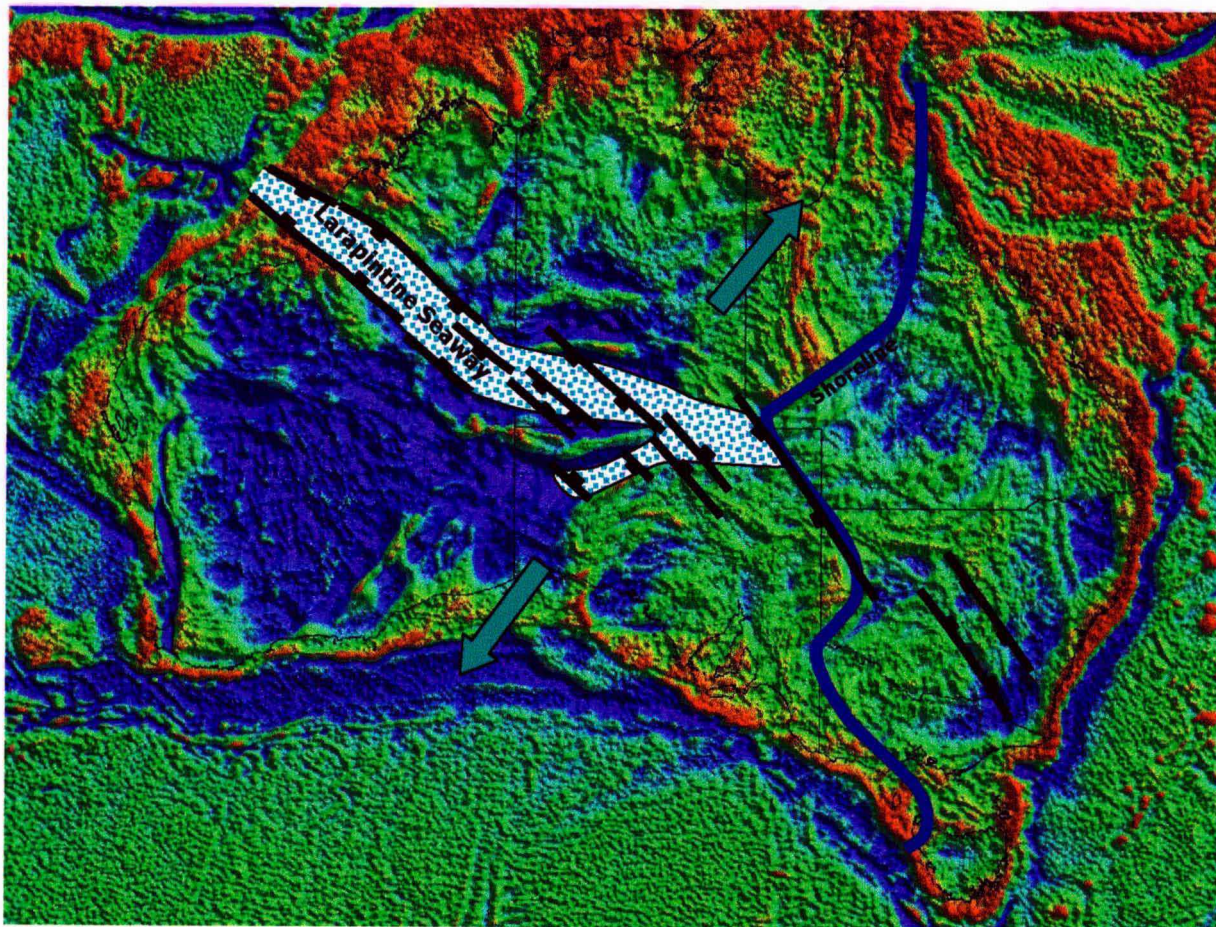
Basin Phase 5: Delamerian Orogeny



The effects of the Delamerian Orogeny in the Officer Basin are minor and require confirmation with seismic data. Possibly minor inversion of NE trending basement structures occurred in the NE Officer Basin. However, transpressional deformation along the Torrens Hinge Zone caused folding and faulting of Neoproterozoic strata, and exhumation of basement inliers in popup structures (e.g. Mt Woods Inlier).

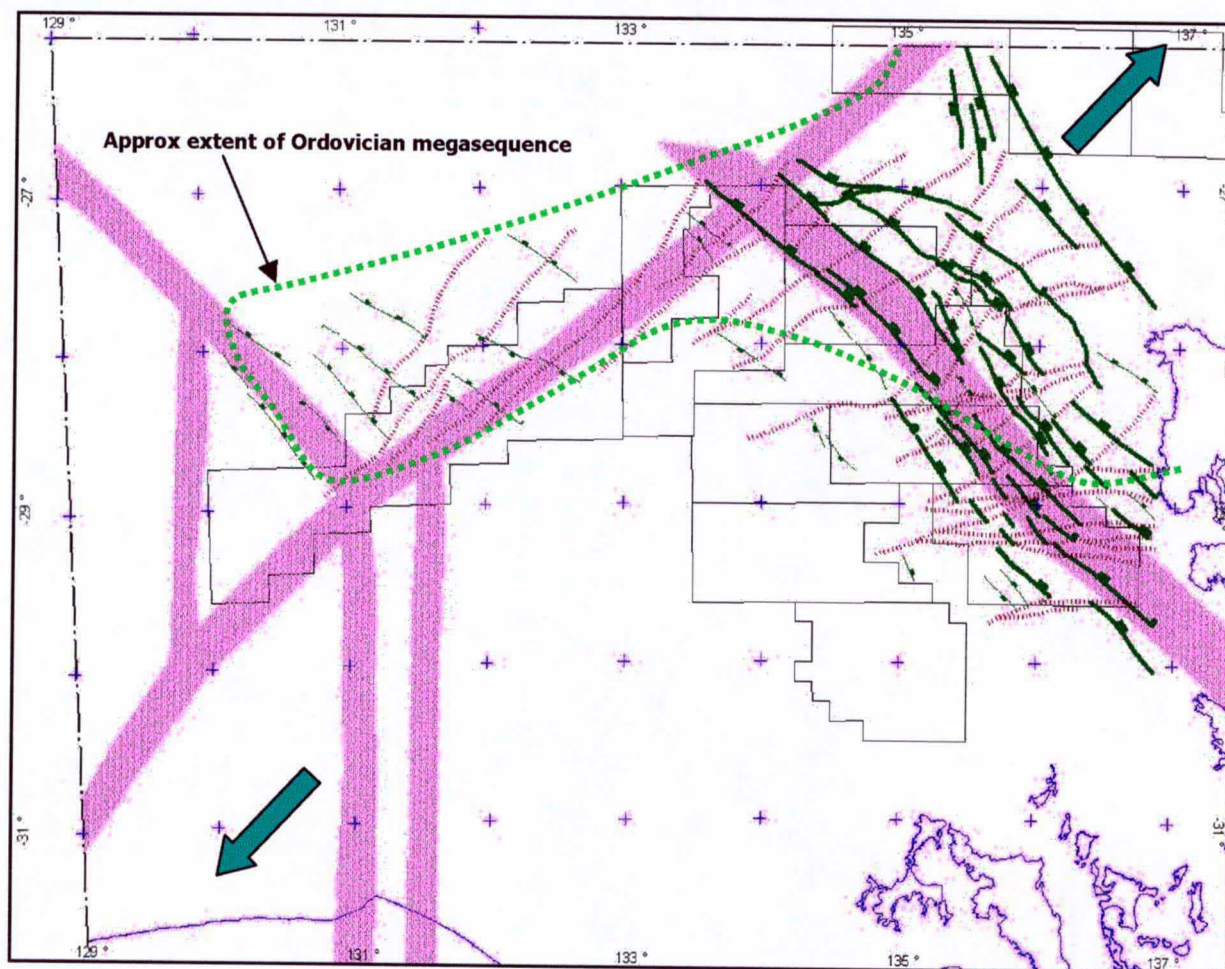
There are no recognised Delamerian-aged depocentres in the Officer Basin.

Basin Phase 6: Ordovician Extension



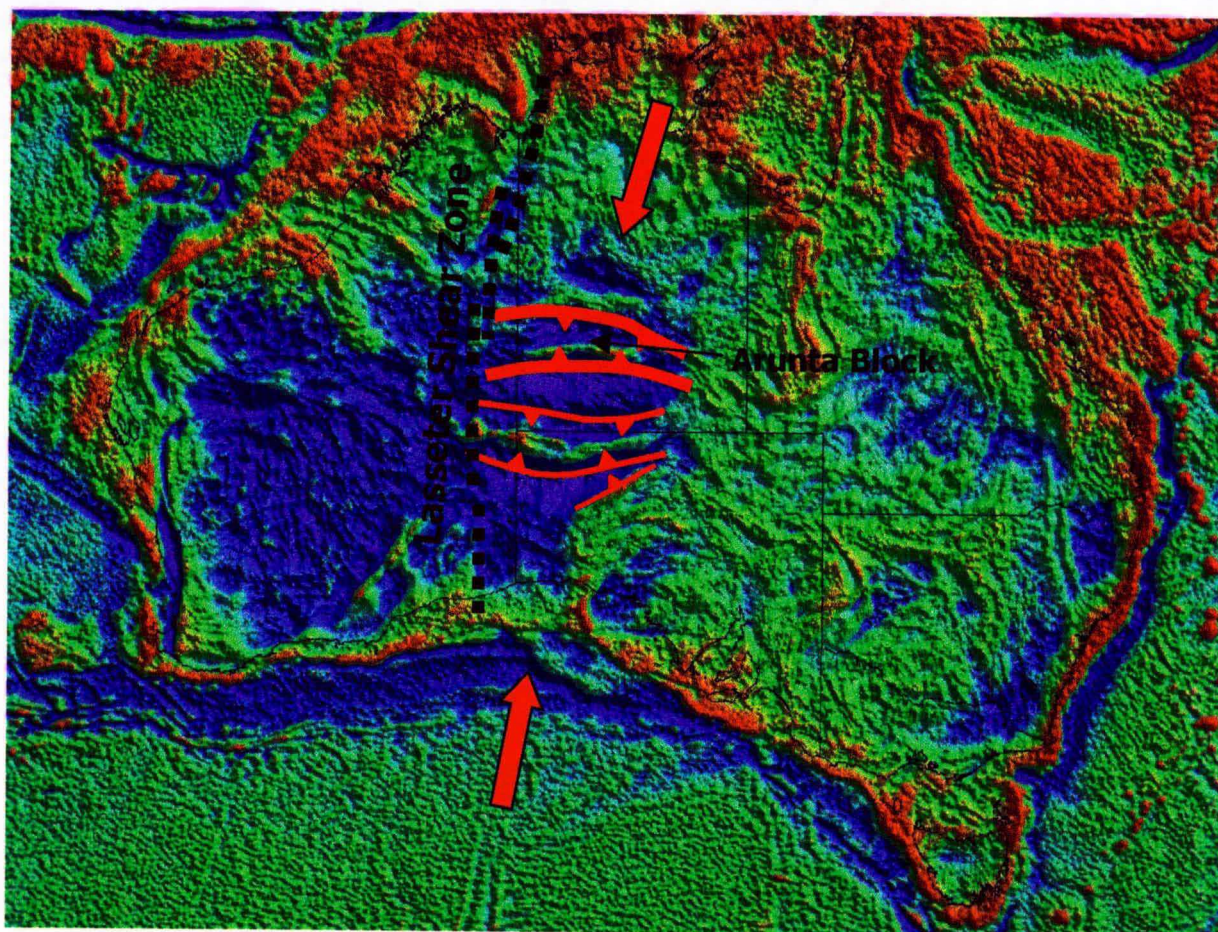
During the mid-late Ordovician, NE-SW intracratonic extension opened a broad rift basin which transected the Australian part of Gondwana, connecting the Canning, Amadeus and Warburton basins to the proto-Pacific Ocean, forming the Larapintine Seaway. Marine sediments were deposited in this narrow seaway, which was connected to the ocean to the NW and SE. Source rocks were deposited in the Canning and Amadeus Basins at this time.

Basin Phase 6: Ordovician Extension



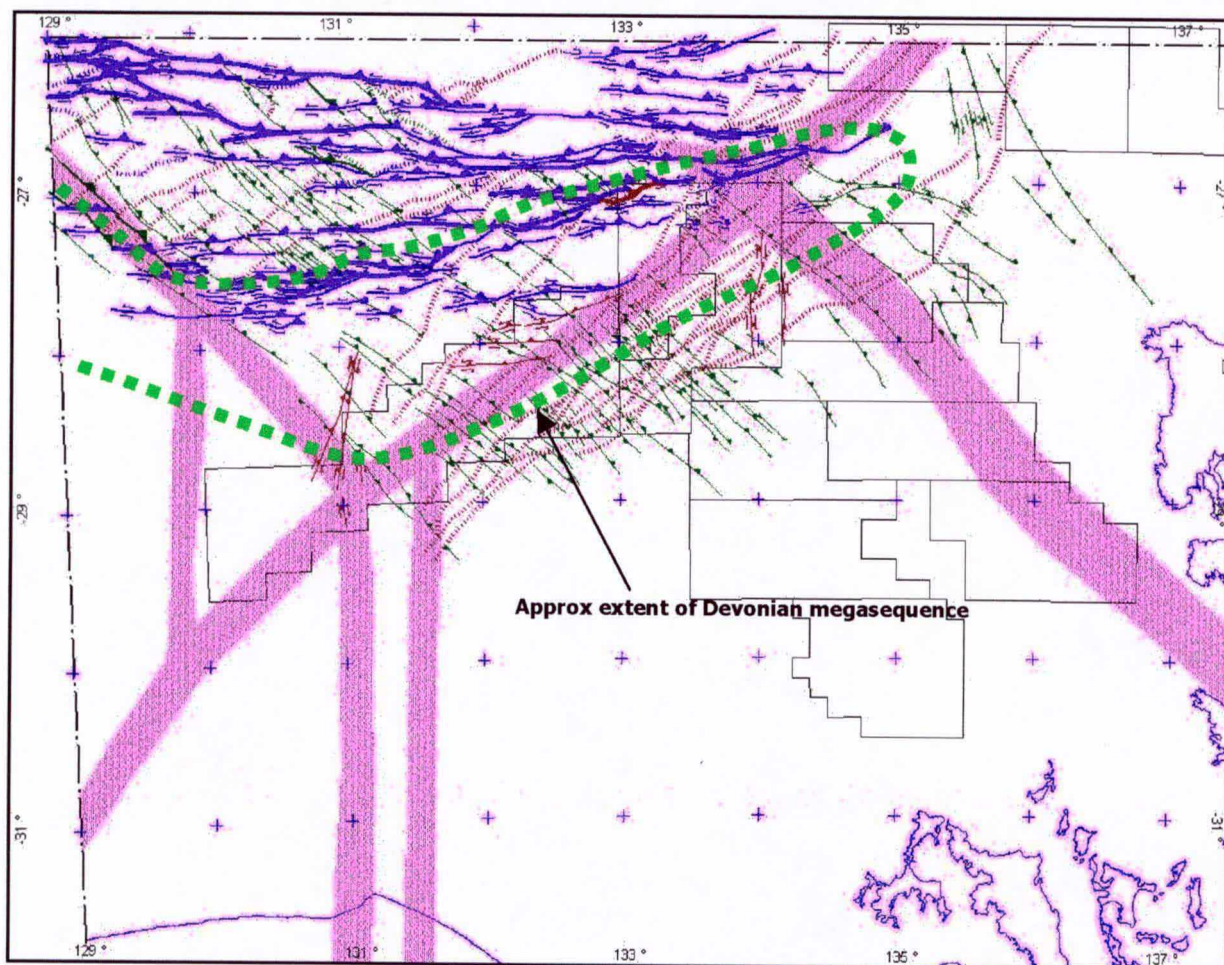
Ordovician sediments in the Officer were deposited in a narrow offshoot of the Larapintine Seaway. Up to 1km of sediment was deposited. Basin formation was probably controlled by NW trending normal faults (reactivated Neoproterozoic structures and/or dykes). More extensive normal faulting probably occurred further to the east in the Torrens Hinge Zone and Warburton Basin.

Basin Phase 7: Alice Springs Orogeny



The term "Alice Springs Orogeny" is used here to describe a series of at least 7 intraplate compressional and extensional events or "movements" ranging from the Rodingan Movement in the early Silurian to the early Triassic – an ~180Ma timespan. During this time various pulses of deformation variably effected the Amadeus and Canning Basins, with significant decoupling of stress and strain across the Lasseter Shear Zone. The average compression direction was approximately NNE-SSW. The most significant deformation occurred in the Arunta Block, including high grade metamorphism, ductile deformation, and exhumation of lower crustal rocks. Limited uplift and reactivation of Petermann structures occurred in the Musgrave Block, including popup inversion of Petermann-age pull-apart basins (e.g. Levenger & Moorilyanna Grabens).

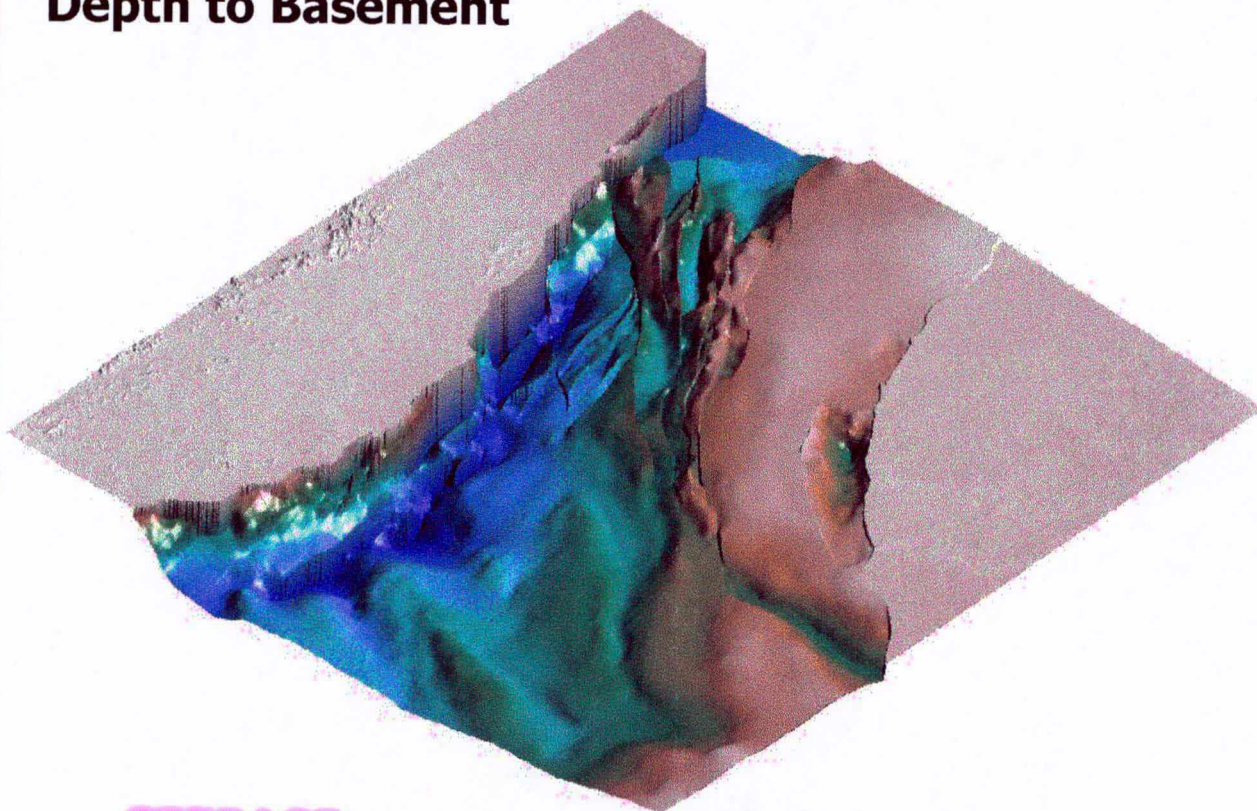
Basin Phase 7: Alice Springs Orogeny



In the Officer Basin, minor reactivation of some basement structures probably occurred. This deformation is poorly understood and needs confirmation using seismic.

A thick sequence of late Devonian clastic sediments dominates the NE Officer Basin (up to 3km of sediment). Since cooling ages in the Musgrave Block are all late Neoproterozoic (ie Petermann Orogeny), uplift in the Musgrave Block during the Alice Springs Orogeny was minimal, hence it is unlikely that these sediments are active foreland basin sediments to the Musgraves. Therefore the origin of accommodation space for Late Devonian sediments is enigmatic. The most likely scenario is that it evolved during extension, possibly in a pull-apart setting. The short timespan of deposition also supports this model, possibly indicating a short pulse/event of extension during the Alice Springs Orogeny.

Depth to Basement



SEEBASE (Structurally Enhanced View of Economic Basement)

What is SEEBASE?

SEEBASE is much more than just another magnetic depth-to-basement model. It is the culmination of a number of calibration and integration steps:

- Integrated structural/kinematic interpretation
- Geophysical modeling
- Seismic & well calibration
- Integration of tectonic events & responses

SEEBASE is a qualitative model of economic basement topography that is consistent with the structural evolution of the basin. SEEBASE defines basin architecture, and is a predictive model for exploration. It is a key base for understanding basin phase geometry/distribution and petroleum systems. As new data is acquired which allows more precise calibration, SEEBASE can be updated to reflect all new information.

SEEBASE provides a foundation for petroleum systems evaluation, including play element distribution (source/reservoir/seal), migration pathways, zones of structural complexity, trap distribution, trap type & integrity, paleogeography, oil vs. gas distribution etc.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

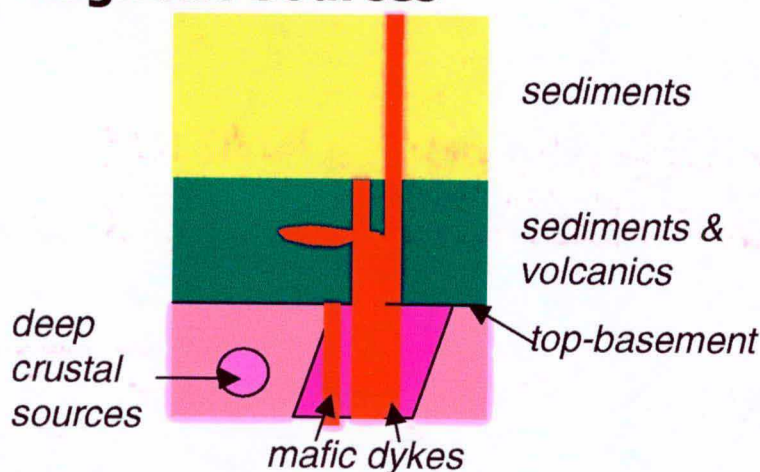
SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kisten (Australia) Pty Ltd, ABN 56 074 271 720, trading as SRK Consulting

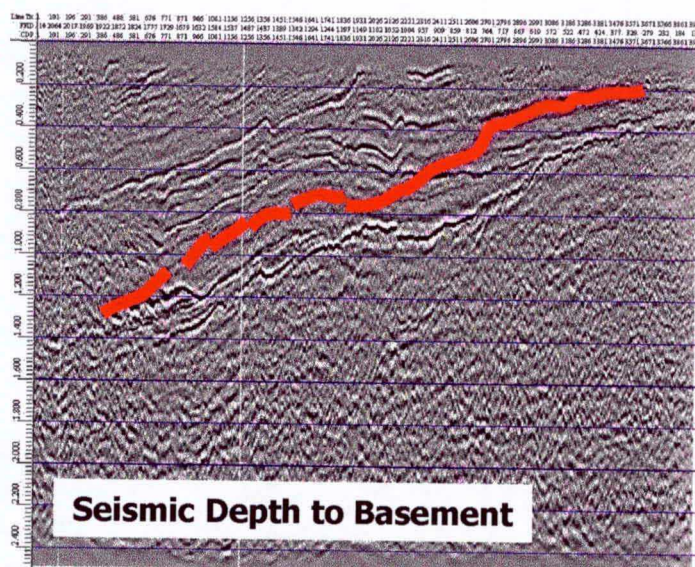
SEEBASE Methodology

- Depth models to magnetic basement sources, obtained from profiles across selected anomalies
- Attribution of source type to depth estimates (require top-basement sources)
- Identification of major basement-involved faults
- Integration of event/response history
- Integration of gravity modeling & interp (if available)
- Incorporation of refraction/seismic/well data (if available)
- Intelligent contouring of "top basement" depth estimates
- Grid construction using CPS-3
- 2D and 3D image processing in ERMapper

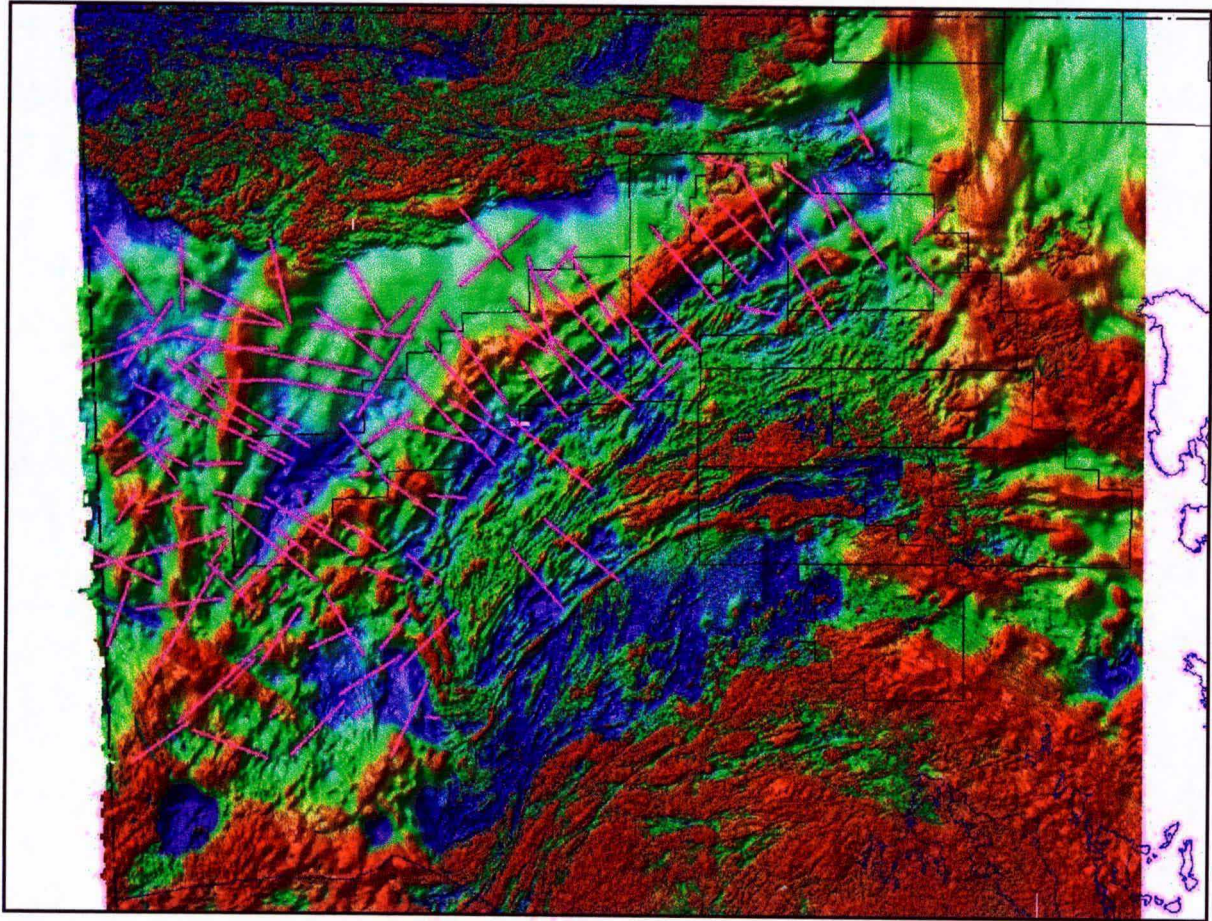
Magnetic Sources



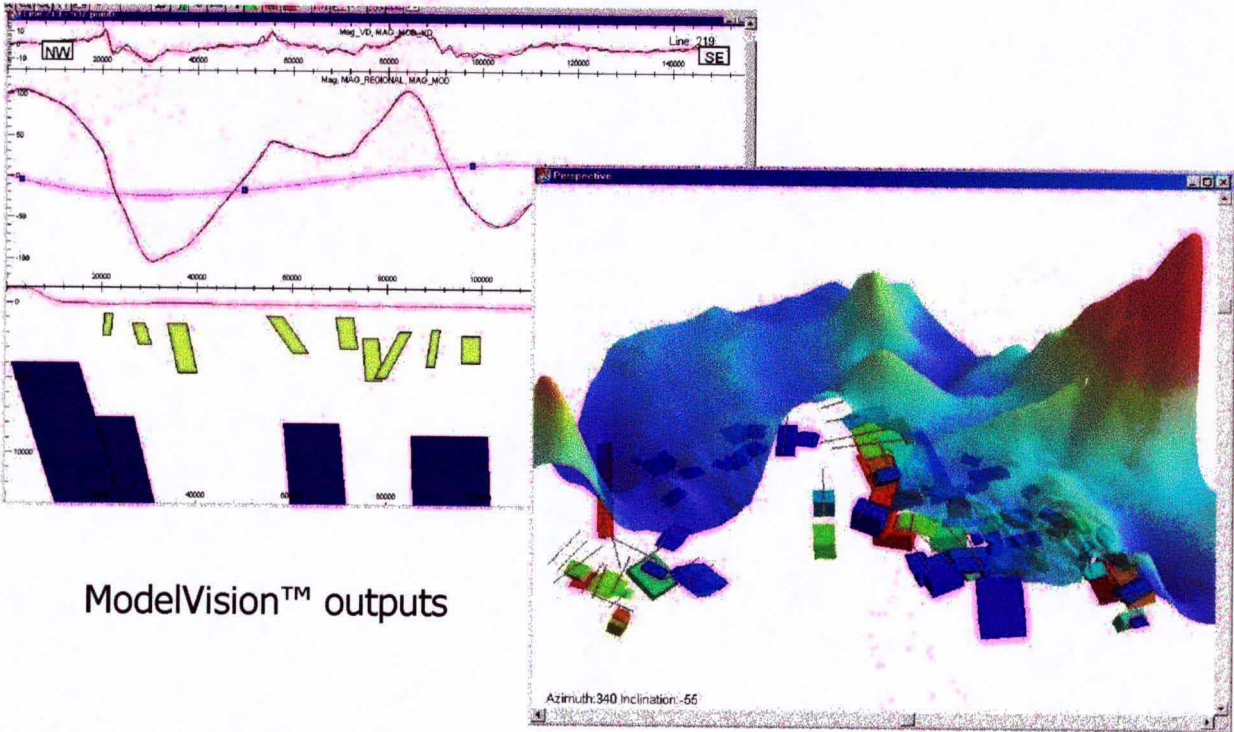
Calibration Example



Magnetic Profiles



Modeled Profiles & Modeled Bodies

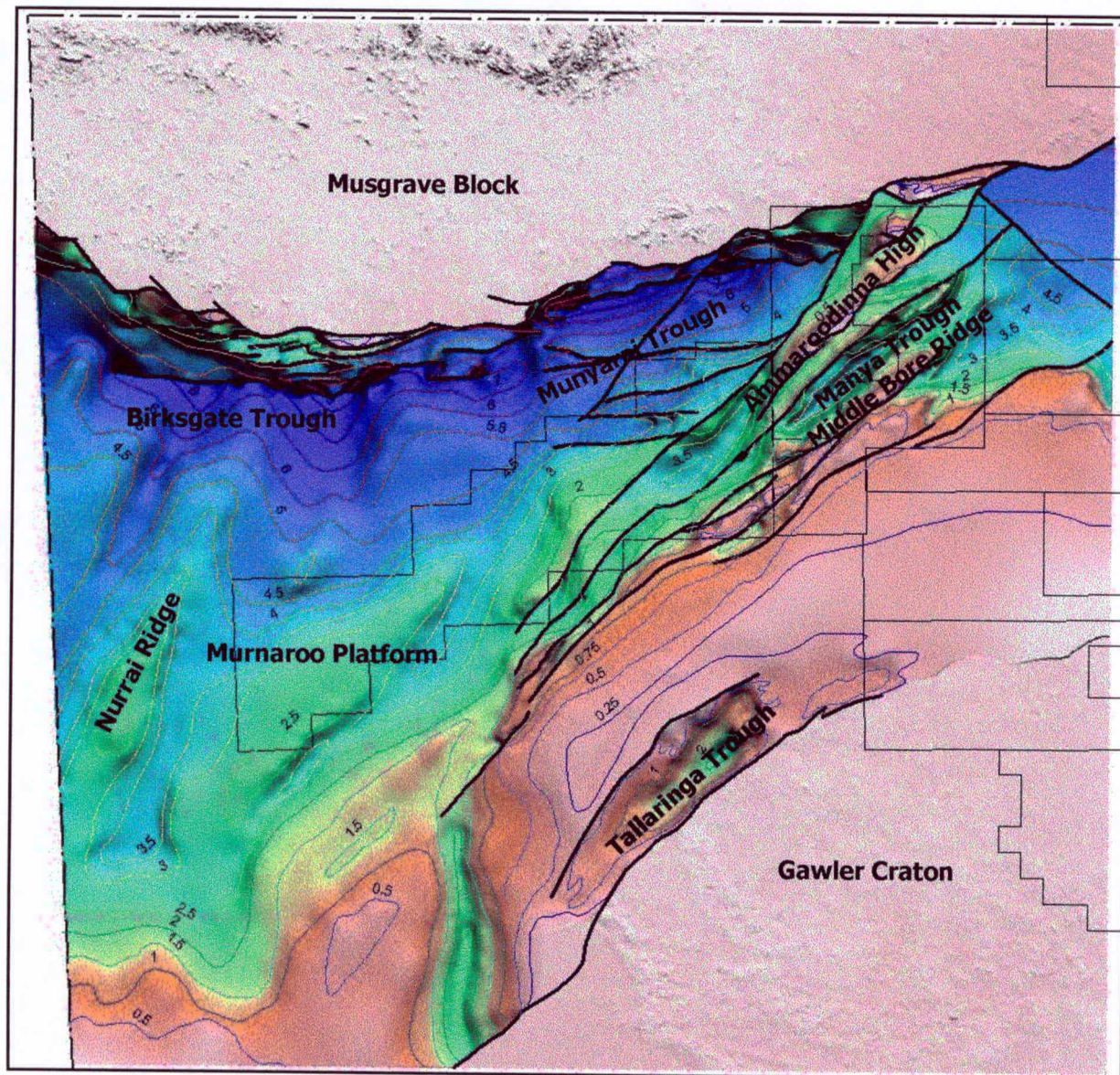


**PRIMARY INDUSTRIES
AND RESOURCES SA**

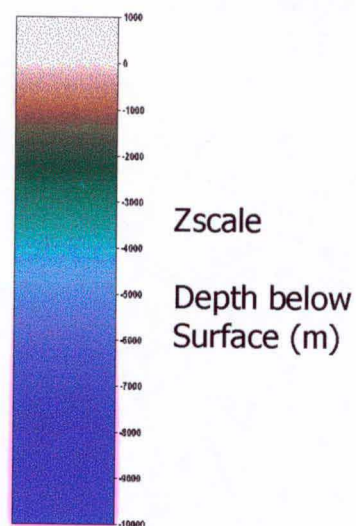
SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Officer Basin SEEBASE



- Principal Basement-Involved Faults
- SA Petroleum Permits



PRIMARY INDUSTRIES
AND RESOURCES SA

SRK Consulting
Integrated Science and Engineering Consultancy

Staffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

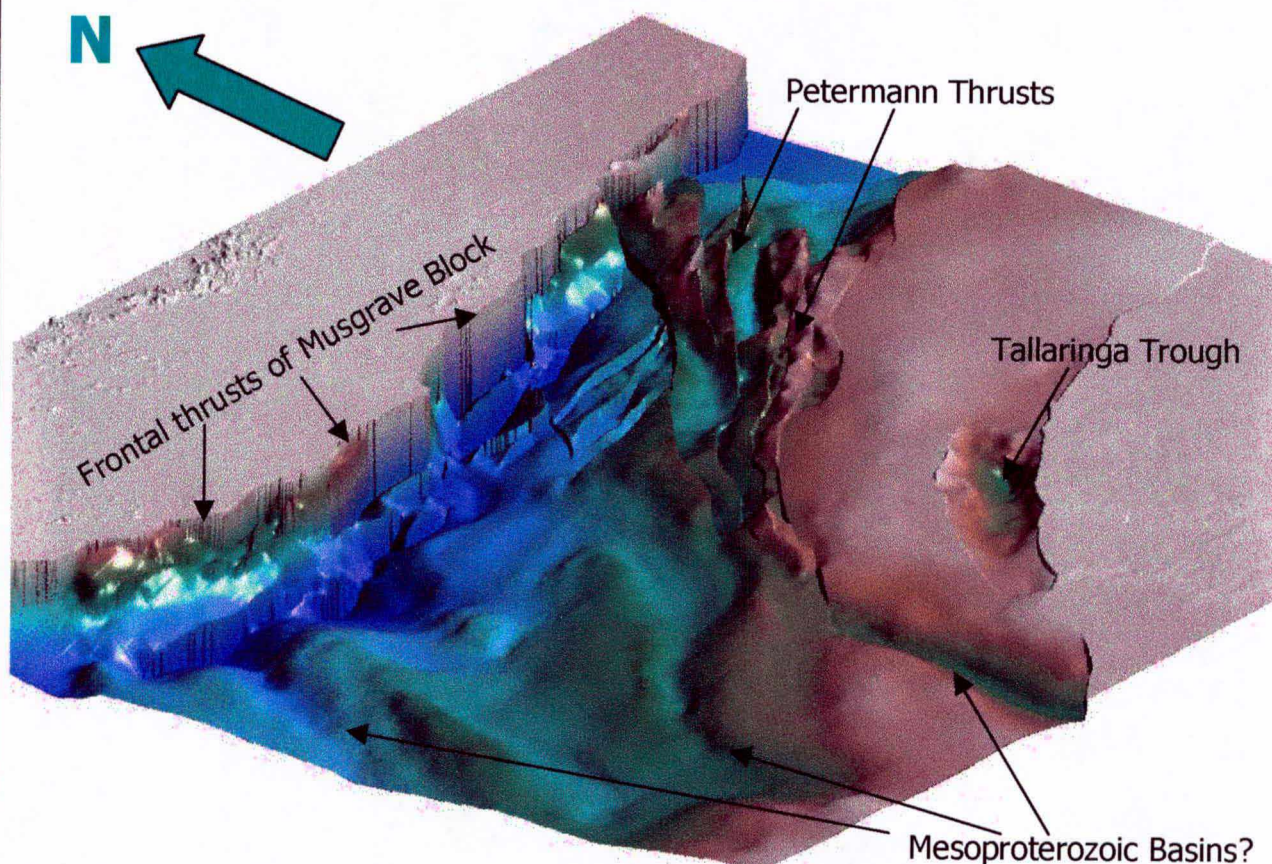
Officer Basin SEEBASE

Magnetic depth to basement modelling was very successful in the Officer due to dyke-like source geometries of linear terranes and Gairdner Dykes, and good data quality. As a result, this SEEBASE dataset is probably accurate to $\pm 10\%$ in areas where magnetic data quality is good.

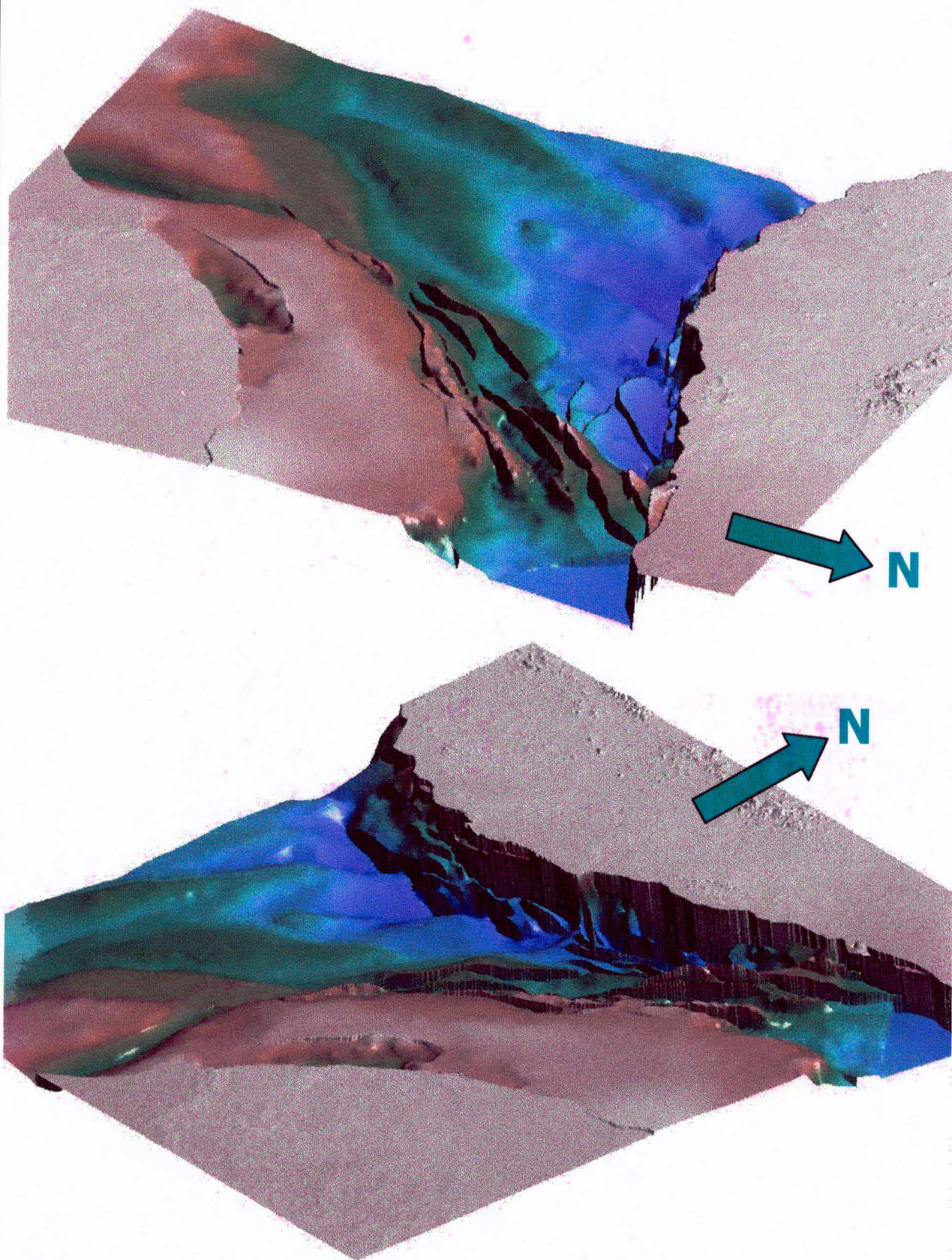
SEEBASE images of the Officer Basin show basin architecture, and can be used to analyse petroleum systems and basin phases.

Significant features evident in the Officer Basin SEEBASE include:

- Potential late Mesoproterozoic basins (analogous to Bangemall Basin in WA), often ~N-S trending ?pull-aparts.
- NE Officer dominated by Petermann Orogeny inversion structures
- Thickest parts of basin adjacent to frontal thrusts S of Musgrave Block (up to 9km)
- SEEBASE depth estimates often deeper than current seismic interpretations (which just pick the lower-most horizontal reflector in poor quality data)
- Tallaringa Trough ~2.5km deep (probably contains Mesoproterozoic sediments beneath the Cambrian).



3D Views of Basin Architecture

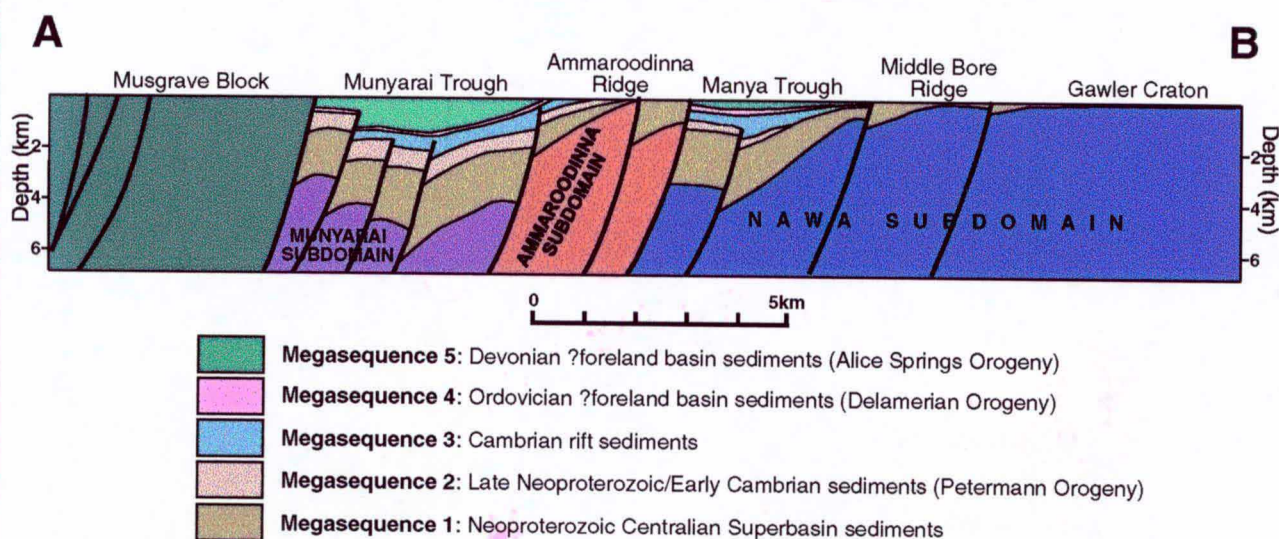
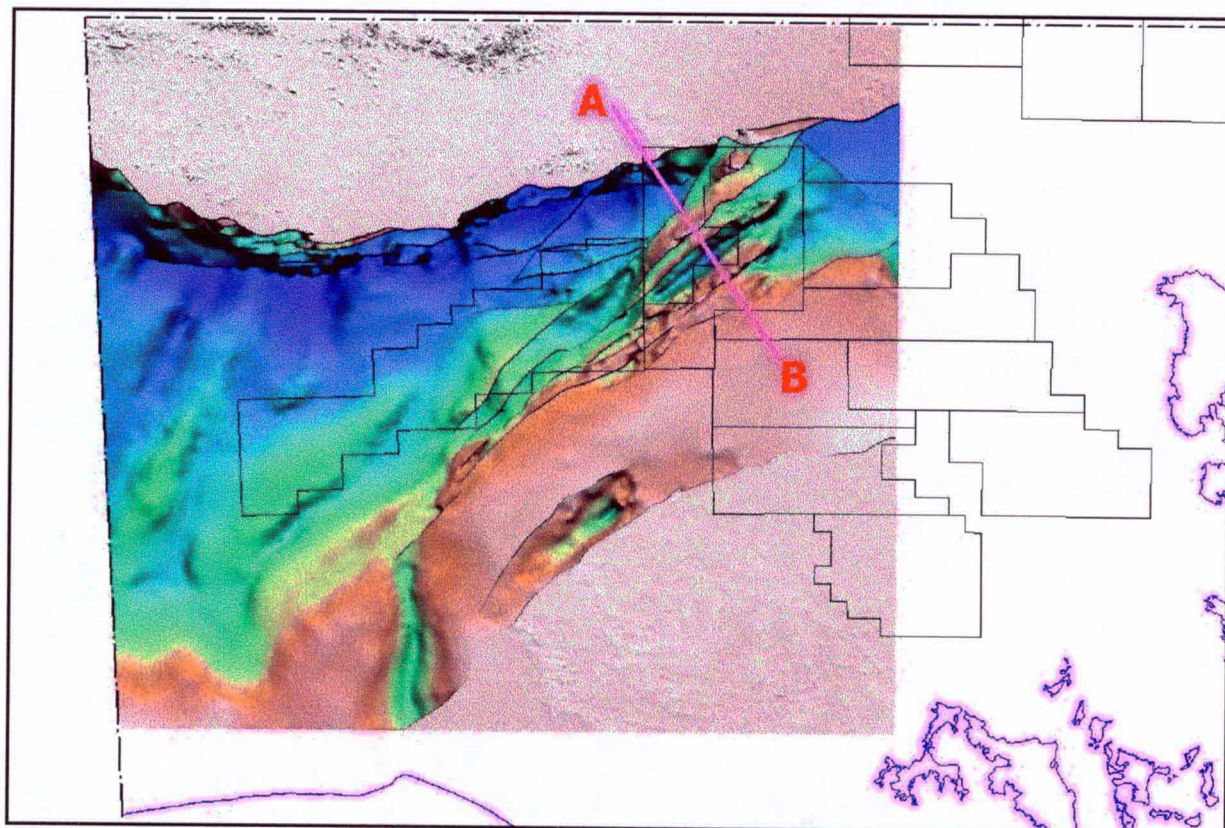


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd. ABN 56 074 271 720, trading as SRK Consulting

Basement Controls on Basin Architecture



This schematic cross section shows the architecture of the Officer Basin is dominated by compressional structures, and how the basement terrane boundaries exerted a first-order control on basin formation. The Ammaroodinna Subdomain has undergone more Petermann & Alice Springs Orogeny uplift than the adjacent Munyarai and Nawa Subdomains.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

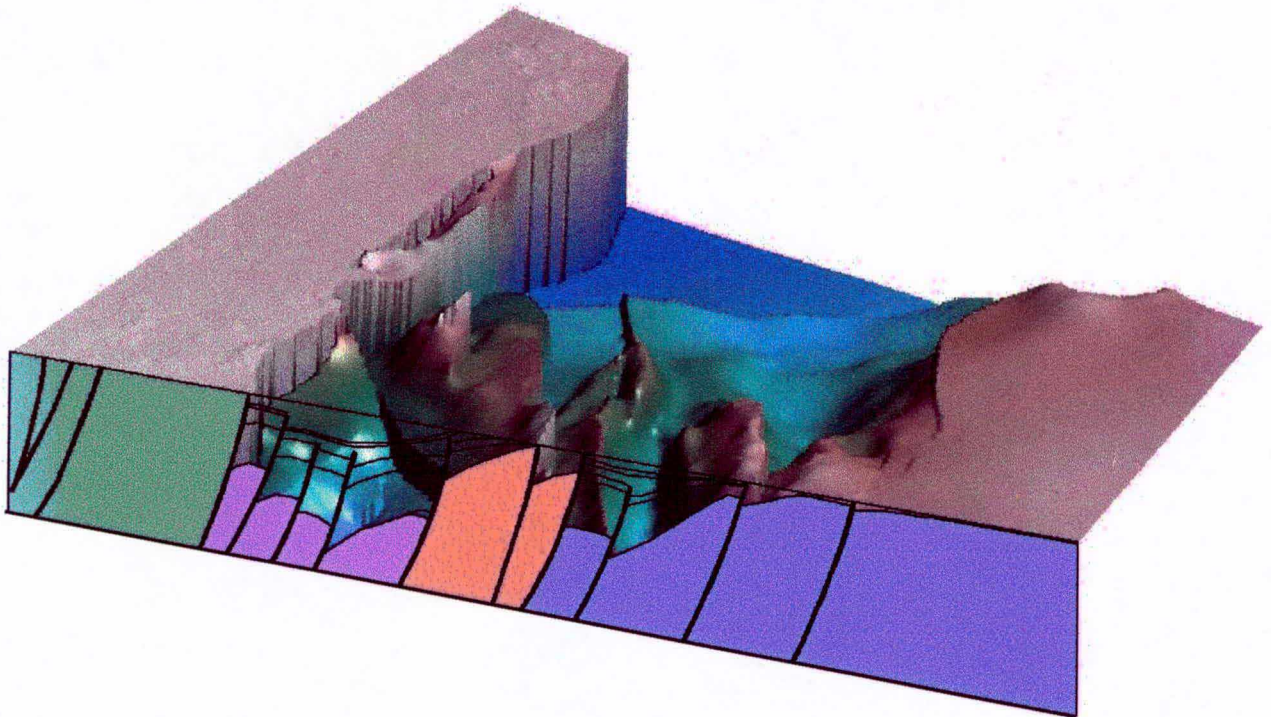
Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basement Controls on Basin Architecture (cont'd)

The architecture of the Officer Basin is largely controlled by pre-existing basement structures, as outlined below:

- The basement geology of the Officer is dominated by NE trending, contrasting terranes which amalgamated during the Mesoproterozoic along a network of major NE trending shear zones.
- The present-day geometry of the Officer Basin was established in the late Cambrian-early Neoproterozoic Petermann Orogeny
- Basin architecture is largely controlled by basement structures, composition, fabric and rheology.
- NE trending Mesoproterozoic shear zones/terranes boundaries were a first-order control on basin evolution during the Paleozoic.
- NW trending Neoproterozoic fractures were a second-order control on basin evolution during the Paleozoic.
- The Officer Basin has largely evolved during compression, and has been significantly influenced by intracratonic processes operating in the Musgrave and Arunta Blocks to the north.

This 3D block diagram below illustrates how mainly N-dipping basement-involved thrust faults/terranes boundaries control the architecture of the Officer Basin.



References

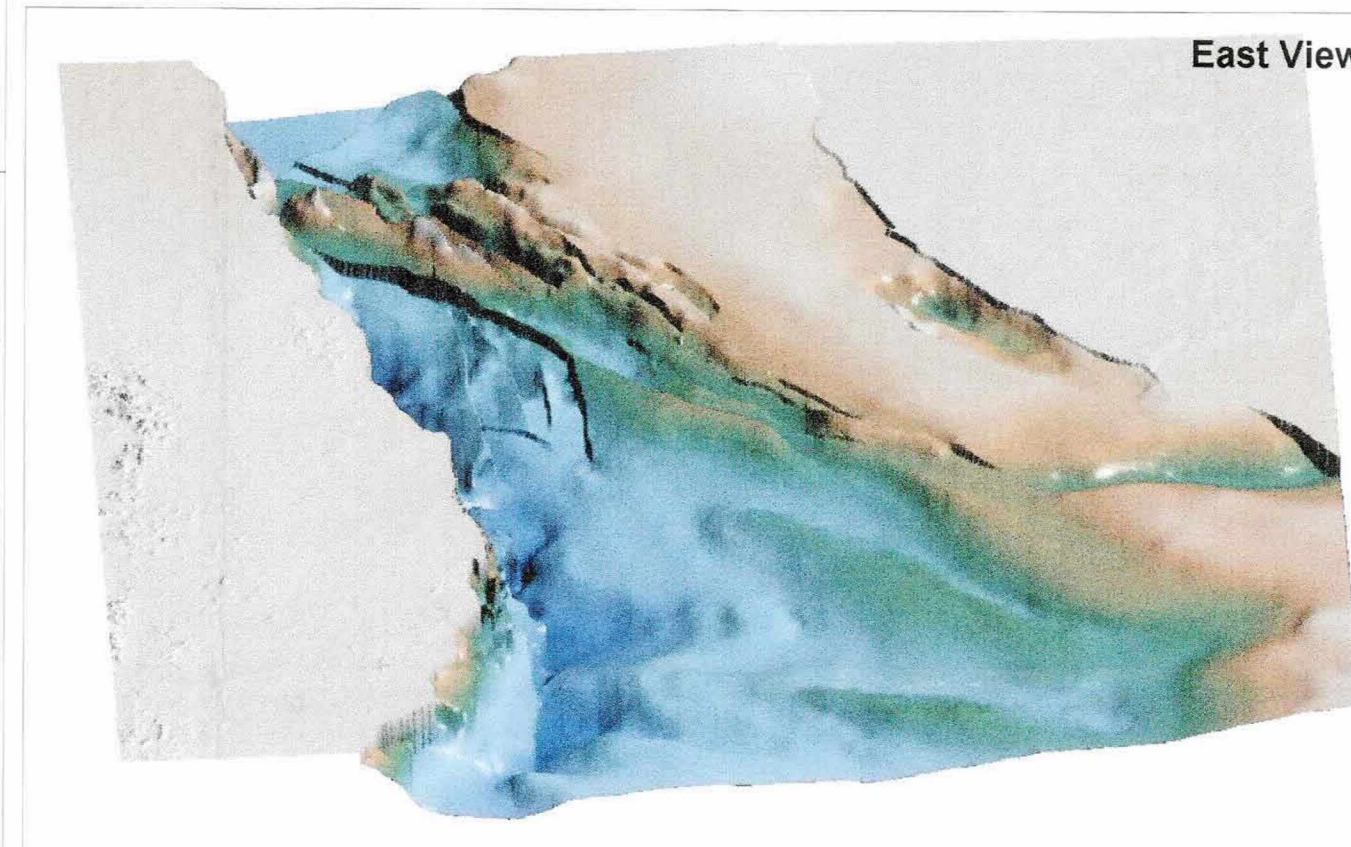
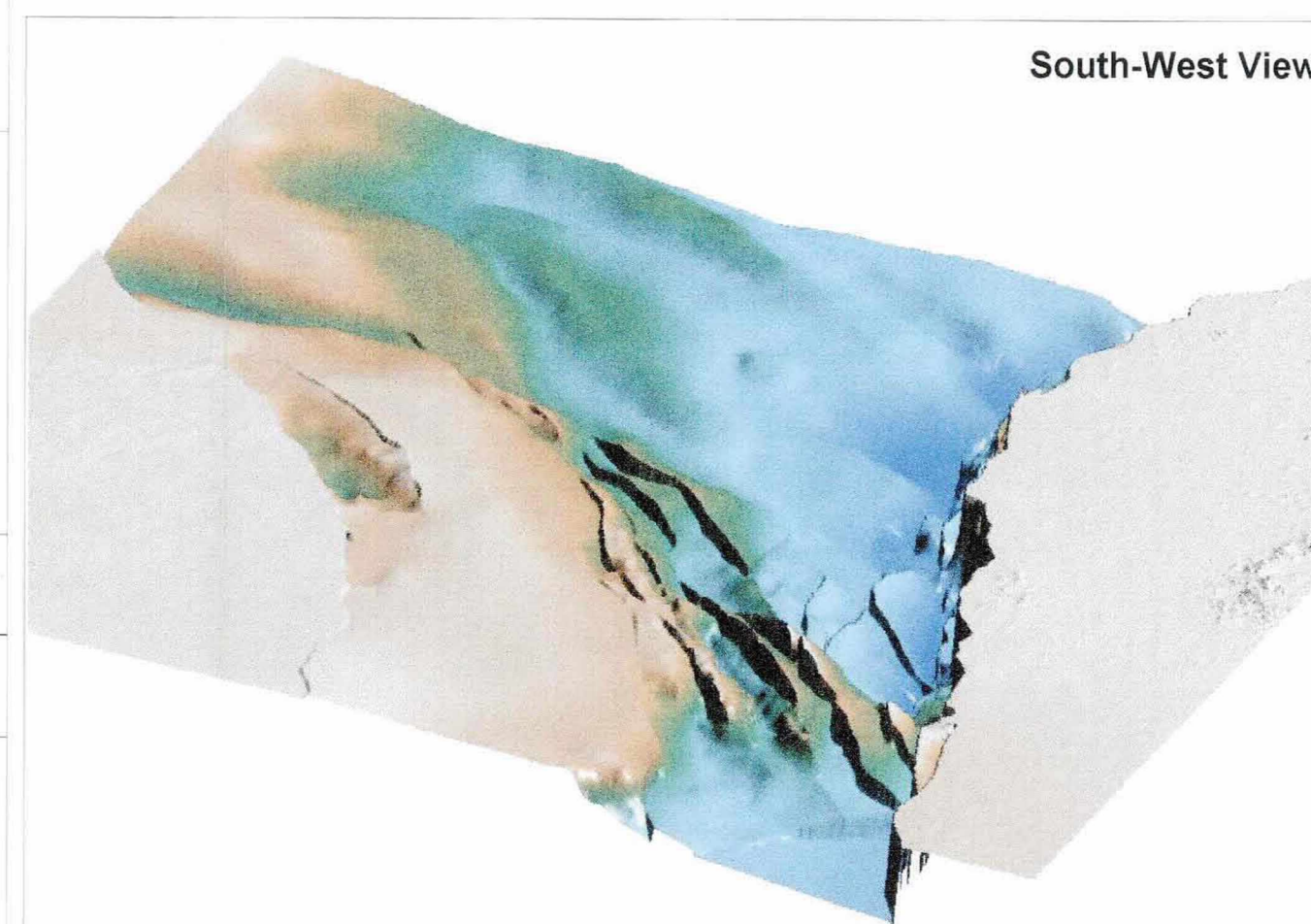
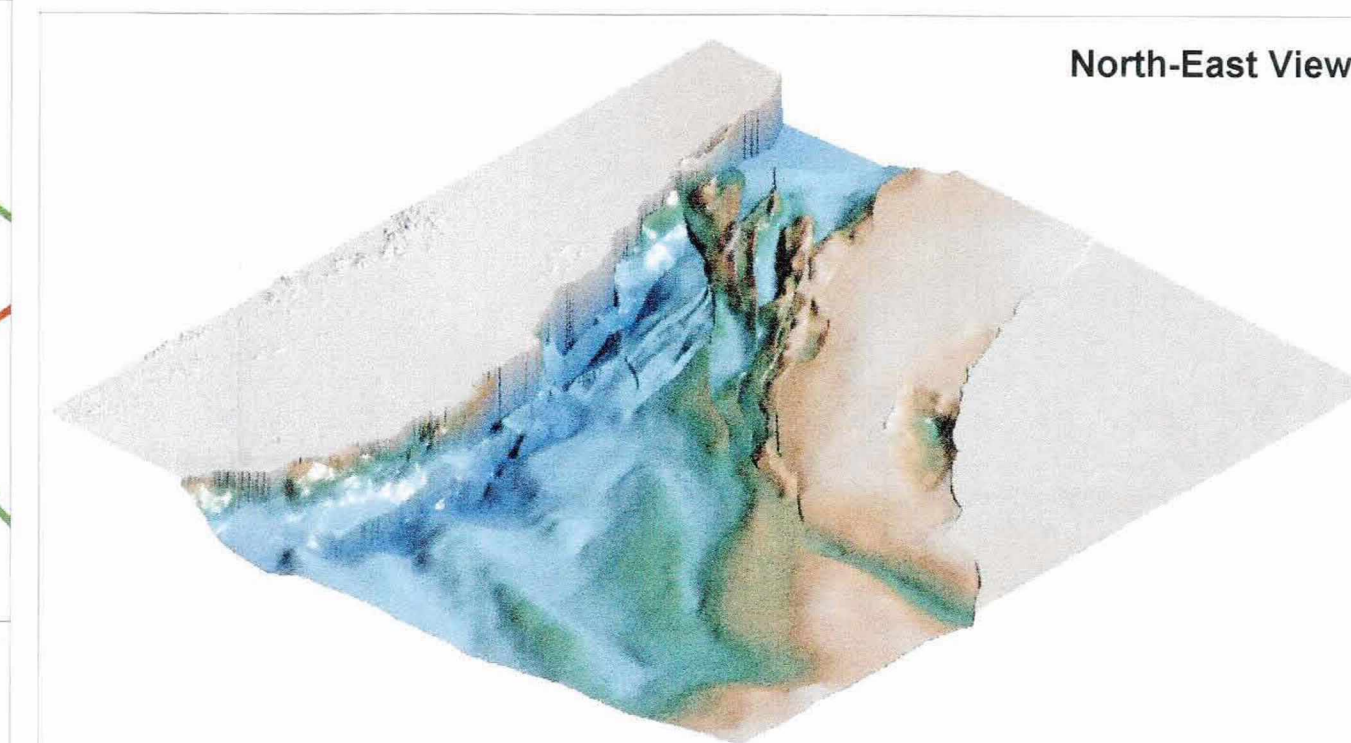
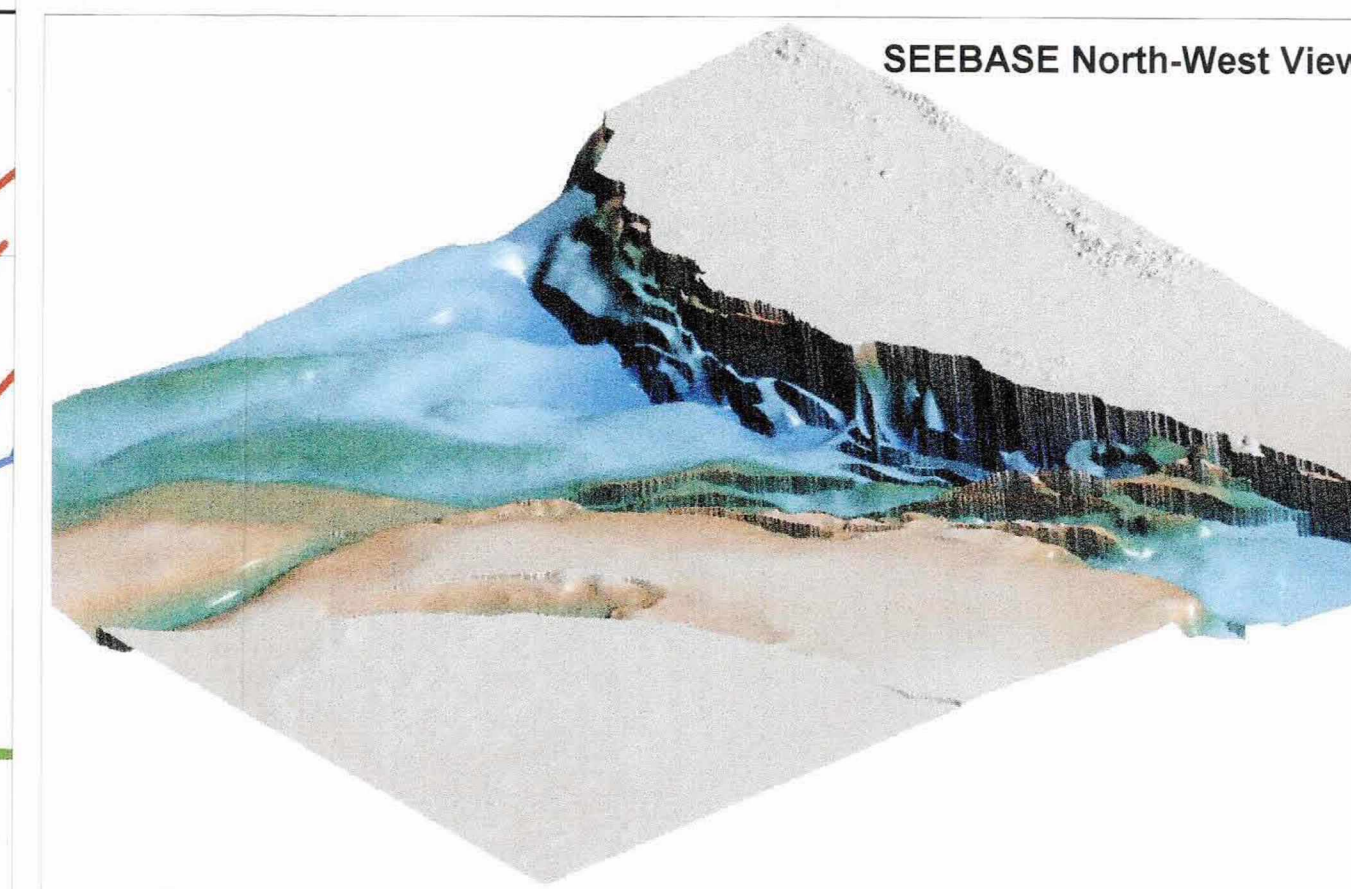
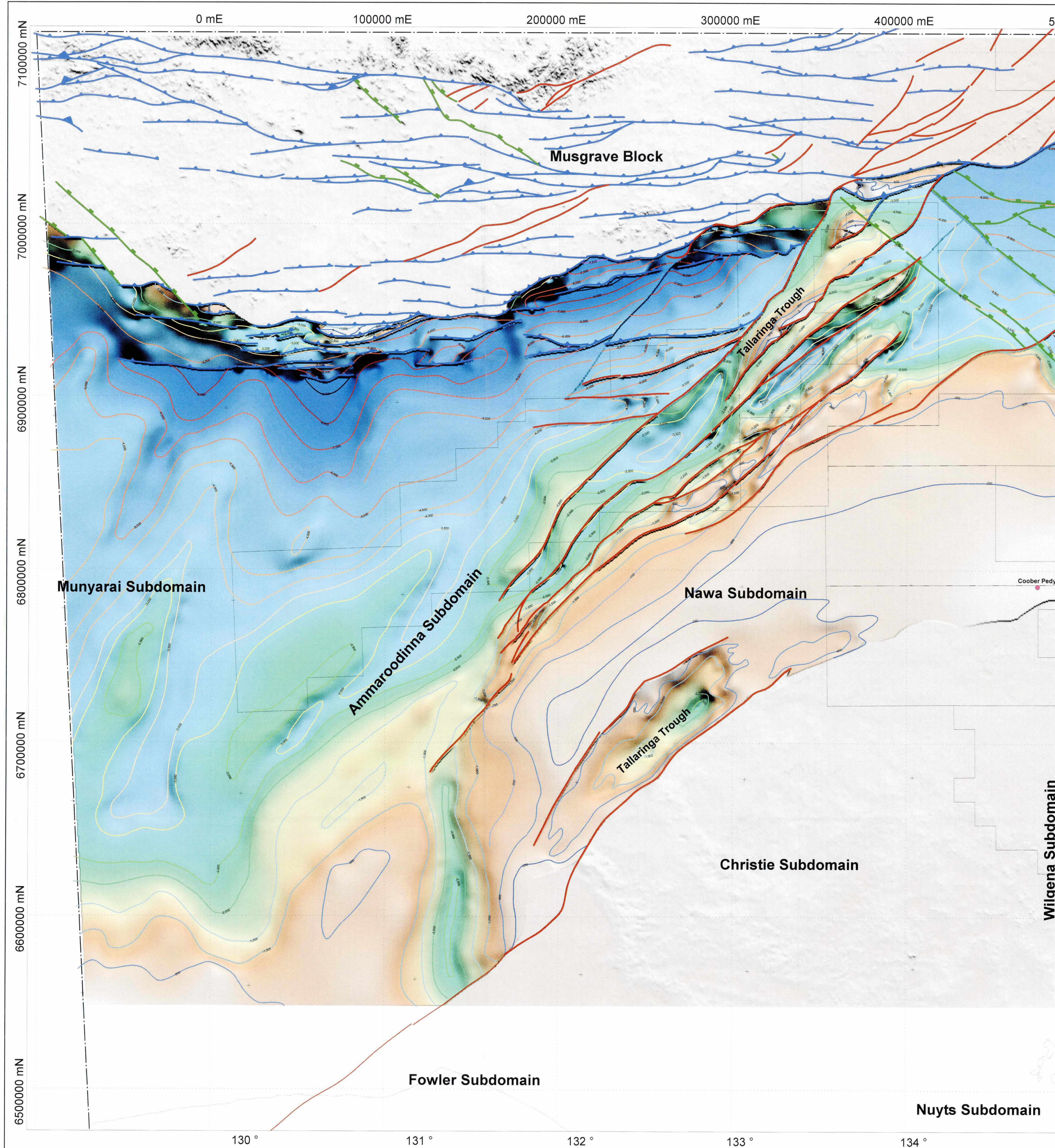
- Benbow, M.C., 1993, *Tallaringa*, Department of Mines and Energy, South Australia, 1:250,000 Geological Series, Map & Explanatory Notes.
- Braun, J., McQueen, H. & Etheridge, M.A., 1991, A fresh look at the late Palaeozoic tectonic history of western-central Australia. In *Exploration Geophysics*, 22, p49-54.
- Drexel, J.F., Preiss, W.V. & Parker, A.J., 1993, *The Geology of South Australia, Volume 1: The Precambrian*, Mines and Energy South Australia, Bulletin 54.
- Drexel, J.F. & Preiss, W.V., 1995, *The Geology of South Australia, Volume 2: The Phanerozoic*, Mines and Energy South Australia, Bulletin 54.
- Gravestock, D.I. & Lindsay, J.F., 1994, Summary of 1993 seismic exploration in the Officer Basin, South Australia. In *PESA Journal*, 22, p65-75.
- Hoskins, D. & Lemon, N., 1995, Tectonic development of the Eastern Officer Basin, Central Australia. In *Exploration Geophysics*, 26, p395-402.
- Iasky, R.P., 1990, Officer Basin. Chapter in *Geological and Mineral Resources of Western Australia*, Western Australian Geological Survey, Memoir 3, p362-380.
- Korsch, R.J., Goleby, B.R., Leven, J.H. & Drummond, B.J., 1998, Crustal architecture of central Australia based on deep seismic reflection profiling. In *Tectonophysics*, 288, p57-69.
- Lambeck, K., 1984, Structure and evolution of the Amadeus, Officer and Ngalia Basins of Central Australia. In *Australian Journal of Earth Sciences*, 31, p25-48.
- Leven, J.H. & Lindsay, J.F., 1992, Morphology of the Late Proterozoic to Early Paleozoic Officer Basin, South Australia. In *Exploration Geophysics*, 23, p191-196.
- Lindsay, J.F., 1995, *Geological Atlas of the Officer Basin, South Australia*. Australian Geological Survey Organisation and Department of Mines and Energy, South Australia.
- Lindsay, J.F. & Leven, J.H., 1996, Evolution of a Neoproterozoic to Palaeozoic intracratonic setting, Officer Basin, South Australia. In *Basin Research*, 8, p403-424.
- Morton, J.G.G. & Drexel, J.F., 1997, *The Petroleum Geology of South Australia, Volume 3: Officer Basin*, Mines and Energy Resources, South Australia, Report Book 97/19.
- Moussavi-Harami, R. & Gravestock, D.I., 1995, Burial history of the eastern Officer Basin, South Australia. In *APEA Journal*, 35(1), p307-320.
- Perincek, D., 1996, The stratigraphic and structural development of the Officer Basin, Western Australia: a review. In *Geological Survey of Western Australia: 1995-96 Annual Review*, p135-148.
- Phillips, B.J., James, A.W. & Philip, G.M., 1985, The geology and hydrocarbon potential of the north-western Officer Basin. In *APEA Journal*, 25(1), p52-61.
- Shaw, R.D., Etheridge, M.A. & Lambeck, K., 1991, Development of the late Proterozoic to mid-Paleozoic intracratonic Amadeus Basin in central Australia: A key to understanding tectonic forces in plate interiors. In *Tectonics*, 10(4), p688-721.
- Struckmeyer, H.I.M. & Totterdell, J.M., 1992, *Australia: Evolution of a Continent*. BMR Publication, Canberra.
- Teasdale, J.P., 1997, *Understanding Poorly Exposed Terranes: The Interpretive Geology and Tectonothermal Evolution of the Western Gawler Craton, South Australia*. Unpublished PhD Thesis, University of Adelaide.
- Townson, W.G., 1985, The subsurface geology of the western Officer Basin – Results of Shell's 1980-1984 petroleum exploration campaign. In *The APEA Journal*, 25(1), p34-51.
- Veevers, J.J. (ed.), 2000, *Billion Year Earth History of Australia and Neighbours in Gondwanaland*. GEMOC Press, Sydney.
- Walter, M.R. & Gorter, J.D., 1994, The Neoproterozoic Centralian Superbasin in Western Australia: the Savory and Officer Basins. In Purcell, P.G. & Purcell, R.R., *The Sedimentary Basins of Western Australia*, Proceedings of the Western



**PRIMARY INDUSTRIES
AND RESOURCES SA**

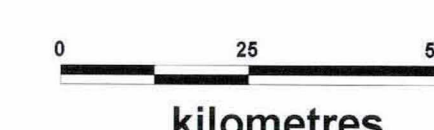
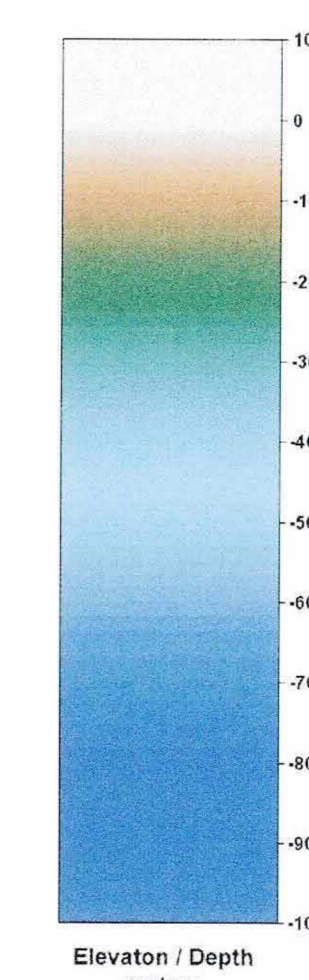
SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kieren (Australia) Pty. Ltd, ABN 66 074 271 720, trading as SRK Consulting



Synthesis Faults

- Mesoproterozoic
- Neoproterozoic
- Petermann

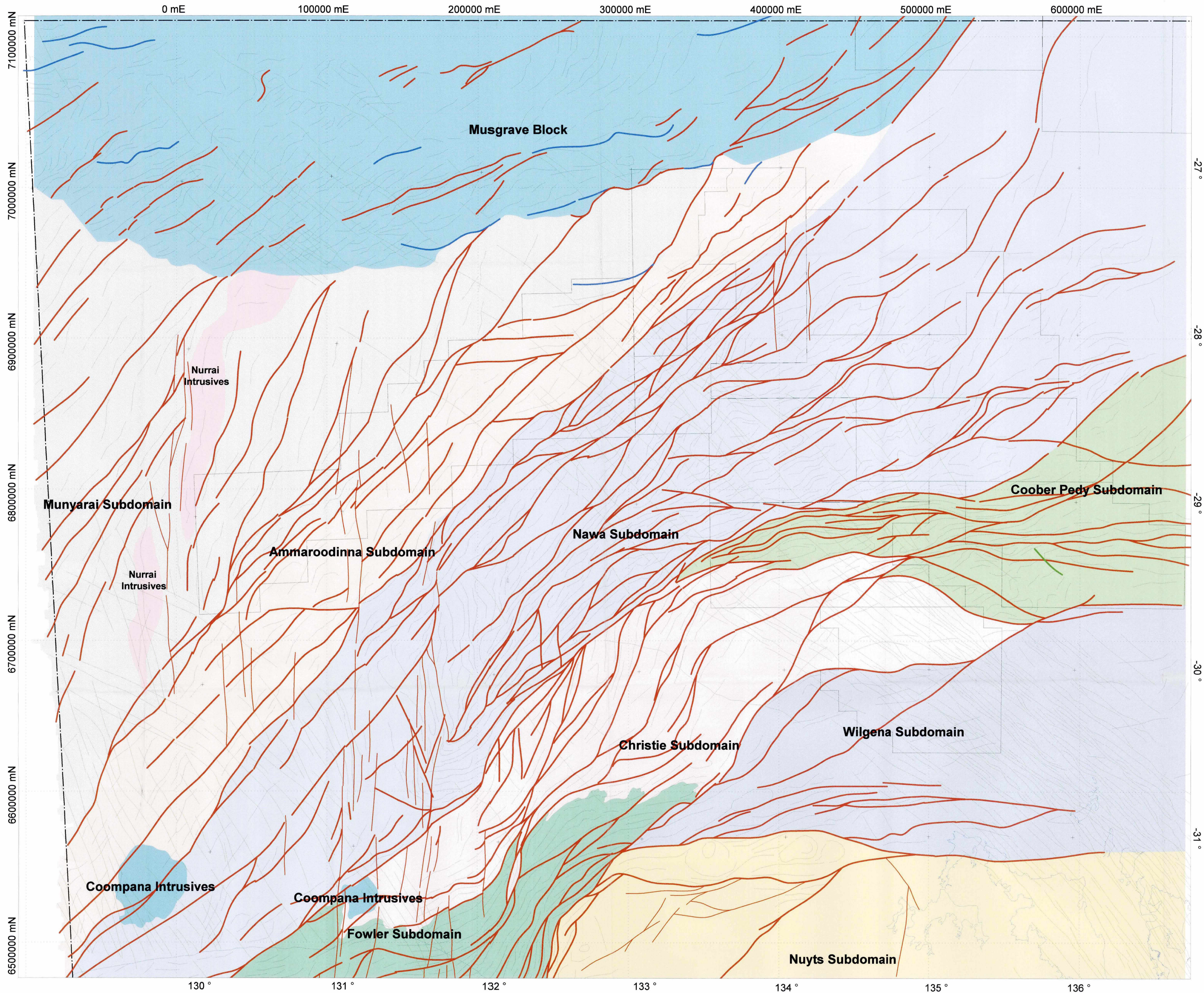


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Energy Services
6/50 Geils Court
Deakin ACT 2600
Canberra, Australia
Tel: +61 2 6283 4800
Fax: +61 2 6283 4801
URL: www.srk.com.au

Source: Robinson and Kinder (Robinson, Pp. 445-458, 211-222, 223, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000)

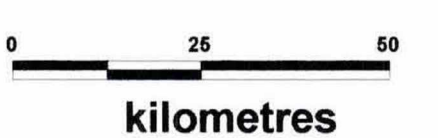


Basement Terranes

- Nawa Subdomain**
Archaean to Mesoproterozoic
Complex high grade gneiss terrane with abundant intrusives
- Coober Pedy Subdomain**
Palaeo-Mesoproterozoic
High grade gneiss terrane
- Fowler Subdomain**
Palaeo-Mesoproterozoic
High grade multi-intermediate gneiss terrane
- Nuyts Subdomain**
Mesoproterozoic
Upper crustal felsic intrusives and volcanics
- Christie Subdomain**
Archaean to Mesoproterozoic
High grade Archaean gneiss terrane intruded by Palaeo-Mesoproterozoic granitoids
- Munyarai Subdomain**
Palaeo-Mesoproterozoic
High grade, low TM gneiss terrane
- Wilgena Subdomain**
Archaean to Mesoproterozoic
Complex upper crustal terrane with Archaean basement
- Ammaroodinna Subdomain**
Palaeo-Mesoproterozoic
High grade, high TM gneiss terrane
- Musgrave Block**
Mesoproterozoic to Early Palaeozoic
High grade Mesoproterozoic gneiss terrane reworked in the Palaeozoic and Alsea Springs Orogenies
- Coompana Intrusives**
Mesoproterozoic
Mafic plutons with strong remnant magnetisation
- Nurrui Intrusives**
Mesoproterozoic
Highly magnetic, mafic intrusives

Basement Structures

- Mesoproterozoic Shear Zones
- Palaeozoic Orogeny Structures
- Neoproterozoic Dikes
- Trends



**PRIMARY INDUSTRIES
AND RESOURCES SA**



Energy Services
6/50 Gills Court
Deakin ACT 2600
Canberra, Australia
Tel: +61 2 6283 4800
Fax: +61 2 6283 4801
URL: www.srk.com.au

PIRSA - Officer Basin

May, 2001

SRK Job Code: P111

Scale: 1: 1,000,000

Projection: Australian Map Grid (AGD 66), Zone 53

Basement Geology



SRK Consulting

Integrated Science and Engineering Consultancy



**PRIMARY INDUSTRIES
AND RESOURCES SA**



SRK Consulting

Integrated Science and Engineering Consultancy

Eastern Arrowie Basin SEEBASE Project

SRK Project Code: PI12

May 2001



**PRIMARY INDUSTRIES
AND RESOURCES SA**



Suite 7, Deakin House
50 Geills Court
PO Box 250
Deakin West ACT 2600
Australia

email: canberra@srk.com.au
URL: <http://www.srk.com.au>
Tel: +61 2 6283 4800
Fax: +61 2 6283 4801

Eastern Arrowie Basin SEEBASE* Project

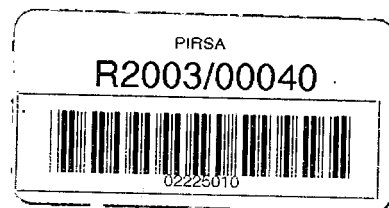
SRK Project Code: PI12

April - May 2001

Authors:

Jon Teasdale
Lynn Pryer
Mike Etheridge
Karen Romine
Peter Stuart-Smith
Jun Cowan
Tom Loutit
John Vizey
Phil Henley

Jon Teasdale
Consultant Geologist



Tom Loutit
Technical Director

***SEEBASE = Structurally Enhanced view of Economic Basement**

The conclusions and recommendations expressed in this material represent the opinions of the authors based on the data available to them. The opinions and recommendations provided from this information are in response to a request from the client and no liability is accepted for commercial decisions or actions resulting from them.



**PRIMARY INDUSTRIES
AND RESOURCES SA**



Steffen, Robertson & Kirsan (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Table of Contents

Introduction

Executive Summary	4
Recommendations	5
Project Background, Aims, Why SRK?	6

Data Compilation & Processing

Datasets, Project Area	7
Aeromagnetics	8
Bouguer Gravity	9
Digital Elevation Model	10
Seismic Coverage, Wells Coverage	11

Calibration & Methodology

Calibration of Potential Field Data, Why Basement?	12
SABRE, Basement Character & Petroleum Systems	13

Basement Geology of the Arrowie Basin

Basement Terranes	14
Basement Composition	15
Basement Structure – Overview	16
Basement-Involved Faults	17
Deep Crustal Fracture Zones	18
Proterozoic Basement Deformation	19

Geological Evolution of the Arrowie Basin

Basin Phase 1: Neoproterozoic Extension	20
Basin Phase 2: Early Cambrian Rifting	21
Basin Phase 3: Delamerian Orogeny	23
Basin Phase 4: Tertiary Uplift	25
	27

SEEBASE Depth to Basement

SEEBASE Methodology	29
Model Magnetic Profiles	30
Arrowie Basin SEEBASE	31
3D Views of Arrowie Basin Architecture	32
	34

Basement Controls on Basin Architecture

References	35
	36



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kieren (Australasia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Executive Summary

This project was initiated by PIRSA to augment their marketing campaign to attract new hydrocarbon explorers to the Arrowie by providing new insights into its geology and hence reduce exploration risk. SRK was contracted in March 2001 to provide an integrated regional interpretation of basement composition, structure and depth in the eastern Arrowie Basin, and investigate the effect of basement geology on basin evolution and petroleum systems.

SRK's approach primarily relies on the interpretation of magnetic and gravity data, calibrated with many other datasets including mapped geology, topography, event histories, wells and seismic. SRK utilizes a "bottom-up" approach to basin analysis, starting with a rigorous understanding of basement geology. By integrating the plate-scale kinematic event history for the area of interest, a interpretation of the basin's structural evolution through time can be mapped. Combined with a SEEBASE* map of depth to basement, this data can be used to understand basin phase distribution and petroleum systems.

The key findings of this project are as follows:

- The eastern Arrowie Basin overlies the Curnamona "Craton", a ~circular crustal block which was not deformed during the Delamerian Orogeny and is surrounded by Delamerian mobile belts.
- The Curnamona "Craton" was not significantly deformed in the Delamerian due to the presence of a large, strong mid-upper crustal Mesoproterozoic pluton.
- Basin architecture is controlled by new Neoproterozoic/Cambrian rift structures and reactivated basement structures.
- Four basin phases/tectonic events have shaped the Arrowie during the Neoproterozoic, early Paleozoic and Tertiary.
- A SEEBASE* model for the eastern Arrowie Basin shows basement topography, and can be used to map basin phase distribution, migration pathways and trap type/distribution.
- The geometry of the eastern Arrowie is dominated by a central basement ridge which separates two thick Neoproterozoic to Cambrian depocentres.
- Up to 4km of Neoproterozoic sediment fills the deeper parts of the eastern Arrowie.

**SEEBASE = Structurally Enhanced view of Economic Basement*



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirwan (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Recommendations

- This project provides new base to investigate the stratigraphic evolution of the eastern Arrowie Basin. A sequence stratigraphic study based on the structural framework and SEEBASE model presented here would provide new insights into its evolution and petroleum potential.
- More detailed SEEBASE study of prospective areas/permits integrating all available seismic data. The existing magnetic dataset can support more detailed work than done in this project, and a full seismic calibration would provide additional constraints on structural geometries at depth and reactivation histories.
- Acquire new seismic in the deeper parts of the Arrowie aimed at resolving basement and the thickness/geometry of the Adelaidean section.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

 **SRK Consulting**
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australasia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Project Background

- The 1996 & 1999 PIRSA Petroleum Industry Surveys demonstrated that a perceived lack of knowledge and largely unfounded geological biases (e.g. poor source/reservoir quality, poor migration timing etc) were preventing petroleum companies from exploring in the Arrowie Basin.
- This project was initiated by PIRSA to augment their marketing campaign to attract new explorers to the Arrowie by providing new insights into its geology and hence reduce exploration risk. SRK Consulting was contracted by PIRSA in March 2001.
- This project was completed in 2 weeks' work by the SRK Energy Services team.

Project Aims

- To provide an integrated regional interpretation of basement composition, structure and depth in the Arrowie Basin, utilizing available gravity, magnetic, seismic and other data.
- To investigate the effects of basement geology on basin evolution and petroleum systems in the Arrowie Basin, focusing on structural evolution/reactivation, basin architecture and tectonic history.

Why SRK?

- SRK Consulting is one of the world's largest natural resource consultancies, with 22 offices in 5 continents.
- The SRK Energy Services group is based in Canberra, Australia. We are leaders in innovative, integrated *geological* interpretation of non-seismic and seismic data, principally magnetic and gravity data. We have worldwide experience in the petroleum, minerals and coal sectors.
- SRK Energy Services has worldwide experience in basin analysis, and has pioneered many new techniques for rapidly evaluating the structural framework and tectonic evolution of all types of basins, based largely on geopotential field data. SRK utilizes a "bottom-up" approach to basin analysis, starting with a rigorous understanding of basement geology. By integrating the plate-scale kinematic event history for the area of interest, a interpretation of the basin's structural evolution through time can be mapped. Combined with a SEEBASE* map of depth to basement, this data can be used to understand basin phase distribution and petroleum systems. (*SEEBASE = Structurally Enhanced view of Economic Basement)

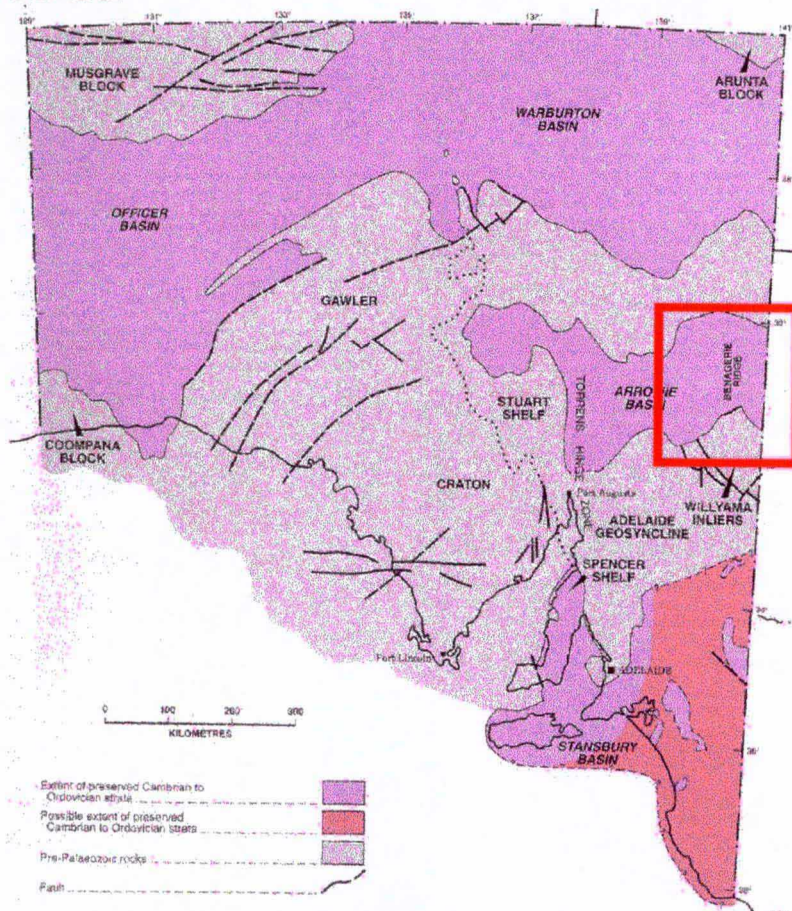


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kitzan (Australia) Pty. Ltd., ABN 66 074 271 720, trading as SRK Consulting

Project Area



The project area is shown in the above map of the Cambrian of South Australia (from Drexel & Preiss, 1995). By definition, the Arrowie Basin includes all Cambrian sediment in the southern Adelaide Fold Belt. This study focusses on the relatively undeformed and unmetamorphosed part of the eastern Arrowie which overlies the Curnamona Craton.

Datasets

The following datasets were provided by PIRSA for the Arrowie SEEBASE project:

- Bouguer Gravity (state 500m grid)
- Magnetics (state 100m grid)
- DEM (Auslig 9 sec)
- Seismic (mainly 1993 AGSO data)
- Wells (completion reports, summary logs)
- PIRSA Minerals GIS's (SA_GIS, Western Gawler Craton, Northern Gawler Craton)

In addition, SRK integrated its extensive in-house knowledge of Australian geology, published literature, and plate tectonic reconstructions.

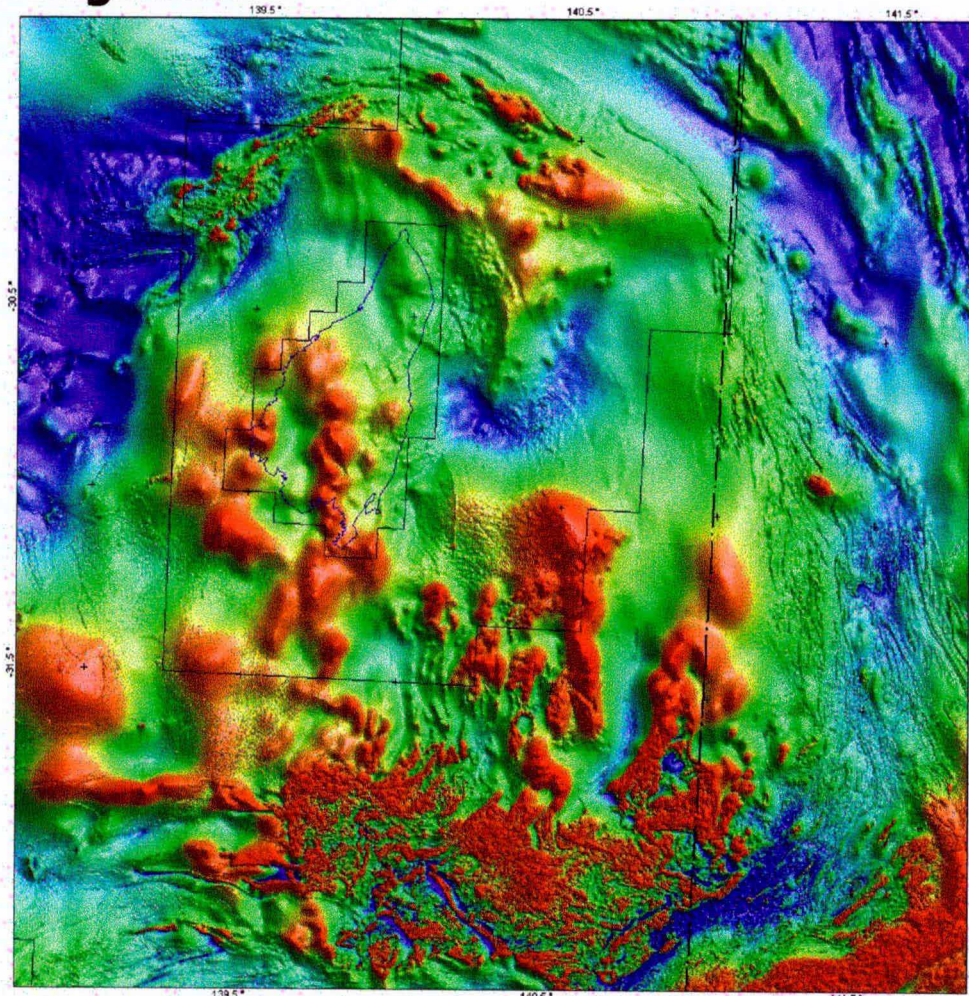


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Aeromagnetics



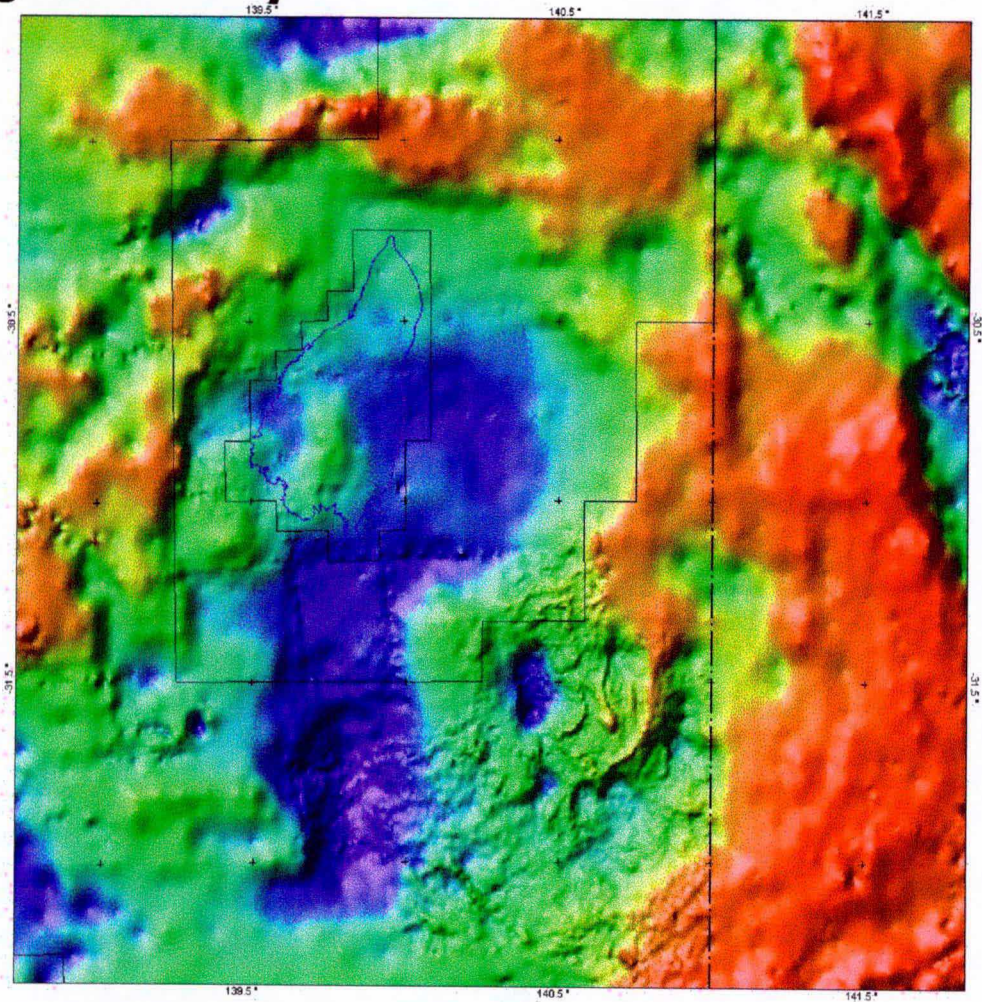
HSI image of Total Magnetic Intensity Reduced to the Pole (RTP)

Aeromagnetic data measures variations in the Earth's magnetic field caused by variations in the magnetic susceptibility of the underlying rocks. It provides information on the structure and composition of the magnetic basement. Most bodies within the basement have a distinctive magnetic signature which is characterised by the magnitude, heterogeneity and fabric of the magnetic signal. When calibrated with known geology, terranes can be mapped under a cover of sedimentary rock and/or water.

The most important and accurate information provided by magnetic data is the structural fabric of the basement. Major basement structures can be interpreted from consistent discontinuities and/or pattern breaks in the magnetic fabric. Once the structures have been evaluated and combined with those interpreted from the gravity data, a model for the evolution of the basement and overlying basins can be developed.

For the Arrowie Basin project, the SA state 100m stitched magnetic grid was reduced to the pole and imaged in ERMMapper using a Hue-Saturation-Intensity colour model. Various enhancement filters were applied to resolve the geometry and structure of the basement at depth (e.g. 1st vertical derivative, automatic gain control).

Bouguer Gravity



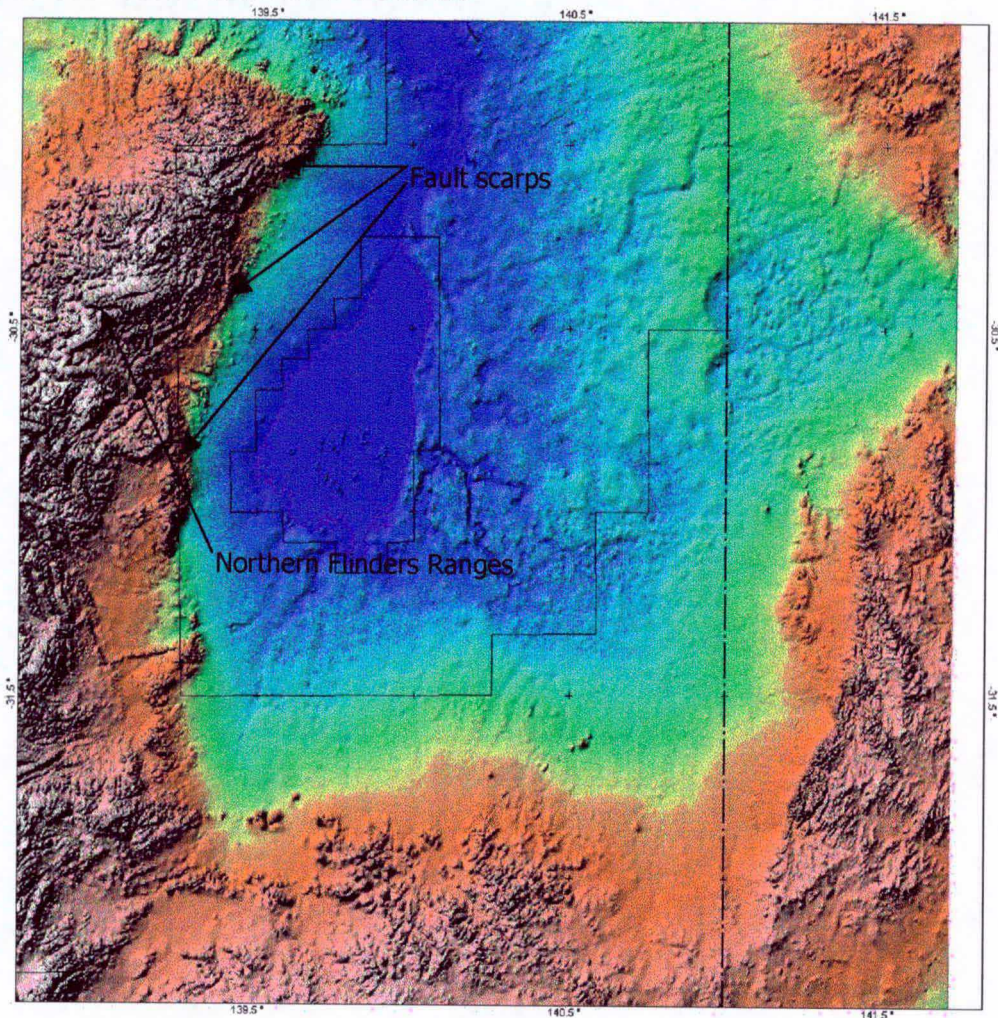
HSI image of Bouguer Gravity

Gravity data is a very important tool for interpreting basins. It maps subtle changes in the Earth's gravitational field caused by variations in the density of the underlying rocks. Although the resolution of this dataset is low (7km spacing), it provides valuable information on the nature of the deeper parts of the crust and mantle beneath the basins. Important intra-basin structures often have an associated gravity signature indicating that each element is related to a deep basement structure.

In order to evaluate the source of the gravity signature, the data must be calibrated with known geology and/or geophysical models. Gravity images show density contrasts within the crust and upper mantle but the source of the contrast is not unique. Thus the origin of each anomaly must be distinguished in this calibration process.

For the Arrowie Basin study, the SA state 500m stitched gravity grid was imaged in ERMMapper using a HSI colour model. Note the new high resolution PIRSA gravity data in the Olary Inlier and Benagerie Ridge.

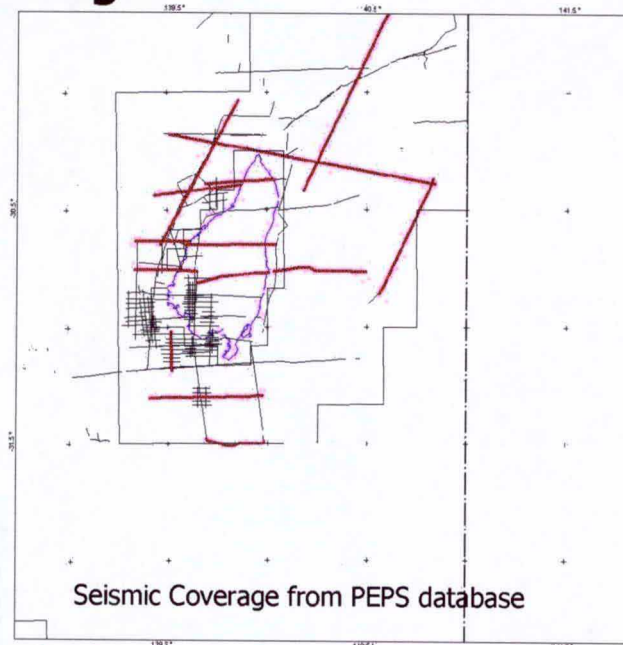
Digital Elevation Model



Digital Elevation Models (DEM's) often show the youngest structures, and any active geological structures. They are widely used for neotectonic analysis. The composition of eroding terrain controls its resistance to weathering, hence DEM's can be used to distinguish different compositional domains.

The Digital Elevation Model (DEM) for the project area shows the Tertiary topography of the Northern Flinders Ranges, defined by major faults scarps.

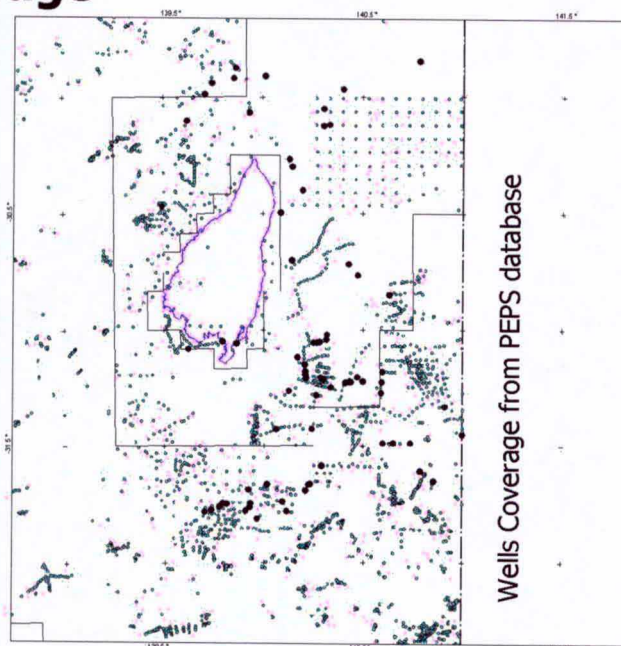
Seismic Coverage



Seismic coverage in the Arrowie Basin is very limited and generally poor quality. The top-basement unconformity is generally not clearly imaged.

In this study, limited seismic data has been used as a calibration tool for the depth to basement modeling and the structural interpretation (particularly timing of structural reactivation). Lines used are shown as bold in the above map.

Wells Coverage



Well coverage from the deeper parts of the Arrowie is very limited, with only a few basement penetrations in the shallower parts of the basin. Solid black dots represent wells used to calibrate this study.

Calibration of Potential Field Data

Calibration is a critical process in any potential field interpretation.

In order to extract as much reliable geological information as possible from potential field data, it is critical to calibrate the data. This is done initially using mapped geology or basement well intersections combined with rock property data (e.g. magnetic susceptibility, density). Once identified, mapped geological units can be traced offshore or under sedimentary cover. Knowing the particular geological units provides information about basement composition and allows for much better constrained depth models from magnetic data.

Away from outcrop control, seismic data are integrated (when available) to further constrain the development of a geological model. Basement penetration by wells and deep seismic data are particularly useful in constraining depth-to-basement estimates from the aeromagnetic data.

Why Basement?

The basement of any basin provides the foundation onto which the sediments are deposited. The rheology and mechanical behaviour of the basement controls the geometry and rate of subsidence of the evolving basin. Basement rheology and mechanical behaviour are determined by its composition and structural fabric. Thus it is important to understand basement evolution prior to basin development.

Understanding basement structures allows models to be developed that can predict which structures will reactivate, and how they will move under an applied stress. Using plate tectonic reconstructions, the far-field stress state during past events can be estimated and a kinematic reconstruction produced for each event. Basin sediments deform in response to movements in the basement and to gravity. Knowing how and when the basement moves provides a basis for predicting the most likely locations of depocentres and structures in the sediments.

Hence basement influences:

- basin phase architecture
- source-rock quality and distribution
- heat flow
- migration focusing, pathways and timing
- trap timing, distribution, type, integrity & size
- sediment supply and stratal geometry
- reservoir, seal quality & distribution



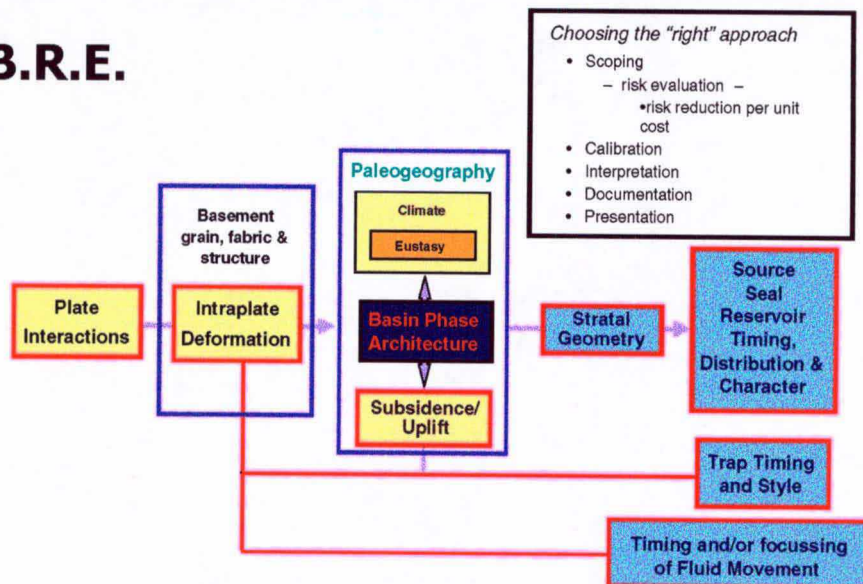
**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsan (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Systematic Approach to Basin Resource Evaluation

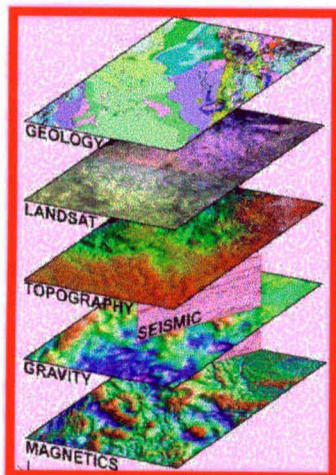
S.A.B.R.E.



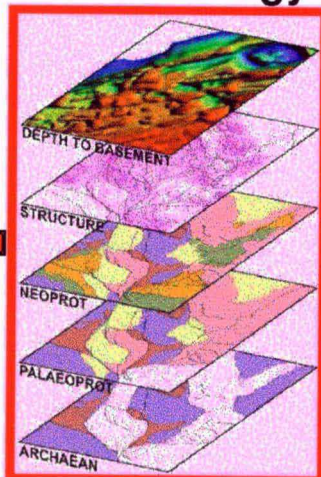
The methodology used to develop a comprehensive structural model relies on the integration of all available geological information. Individual datasets alone can be ambiguous and when isolated often produce poorly constrained interpretations. Through integration, the model can be tightly constrained. Integration provides the means with which to calibrate each dataset to the other.

Basement Character and Petroleum Systems

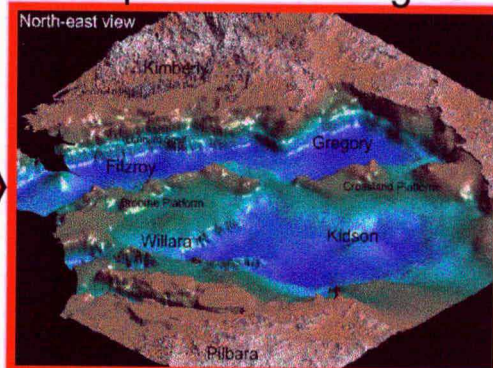
Old Data



Good Geology



New Exploration and Acquisition Strategies



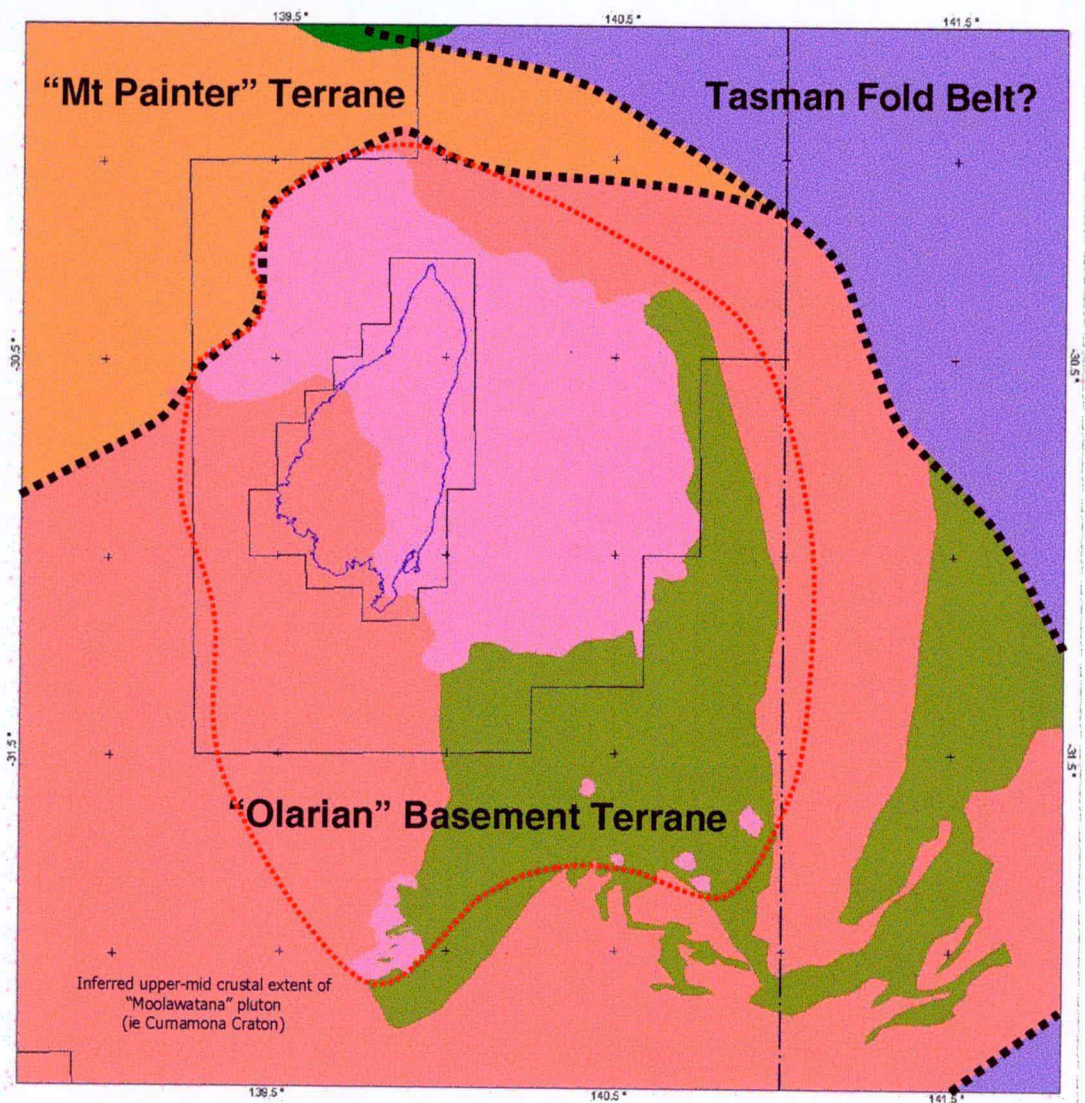
New Technology

Bottom-up

New Views in Old Basins

*Efficient and Effective
Exploration*

Basement Terranes



Three Paleo-Mesoproterozoic basement terranes occur in the project area: the "Olarian" Basement Terrane, the "Mt Painter" Terrane, and the western-most parts of the Tasman Fold Belt.

The "Olarian" Basement Terrane is defined based on its Proterozoic geological history. It contains a high grade, early Paleoproterozoic felsic gneiss suite (the Lower Broken Hill Group) unconformably overlain by a Paleoproterozoic metasedimentary sequence (the Upper Broken Hill Group). The entire Broken Hill Group was extensively deformed and variably metamorphosed during the ~1700-1600Ma Olarian Orogeny. It has been intruded by anorogenic, Mesoproterozoic, high level granitoids and felsic volcanics of the Moolawatana Suite. Importantly, Neoproterozoic-Cambrian basin evolution (and the resultant Curnamona "Craton") has been controlled by structures and compositional domains within the Olarian Terrane (principally the Moolawatana Pluton whose below-surface extent defines the Curnamona Craton). This study is the first time this pluton has been recognised.

The "Mt Painter" Terrane contains very high heat-producing Mesoproterozoic gneisses which are currently exposed in the Mt Painter Inlier. Heat production has been sufficient to metamorphose overlying Neoproterozoic sediments to upper amphibolite facies, and cause large-scale diapirism of lower Adelaidean carbonates. This basement terrane is rheologically "soft" due to its high heat flow hence has been multiply deformed since the Mesoproterozoic.

(cont'd overleaf)

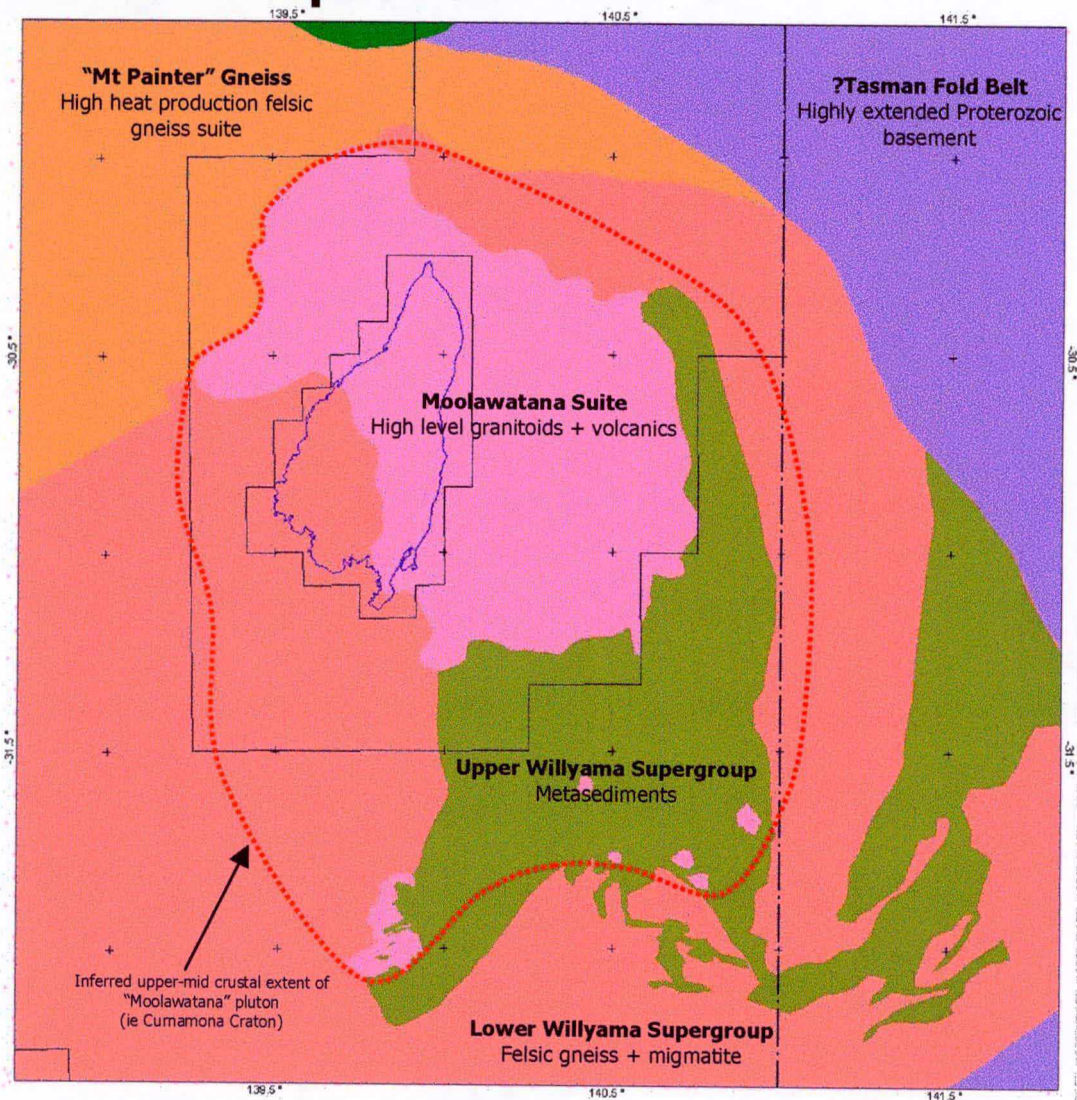


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basement Composition



(...cont'd from previous page)

The Tasman Fold Belt basement contains highly extended Proterozoic basement of unknown origin. This basement terrane probably has a significantly different composition due to the contrast in Neoproterozoic-Paleozoic extension between it and the Olarian Terrane.

The contrasts between the three basement terranes and the structures and compositional domains within and between them were a first-order control on the evolution of the Arrowie Basin. The terrane boundaries have acted as key reactivation zones and the terranes have behaved very differently under the stresses responsible for the basin formation due to their contrasting rheology and reactive fabrics.

All 3 basement terranes, *apart from the Moolawatana Pluton*, have been extensively reworked during the Delamerian Orogeny. The eastern Arrowie Basin was not deformed at this time due to the underlying Moolawatana Pluton.

Basement Structure - Overview

Basement structures are key reactivation zones during basin formation. The following basement structures have been interpreted during this project:

- Faults/shear zones
- Fabric/grain/foliation
- Deep crustal fracture zones
- Transfer/accommodation zones

These structures have been interpreted using the following data sources:

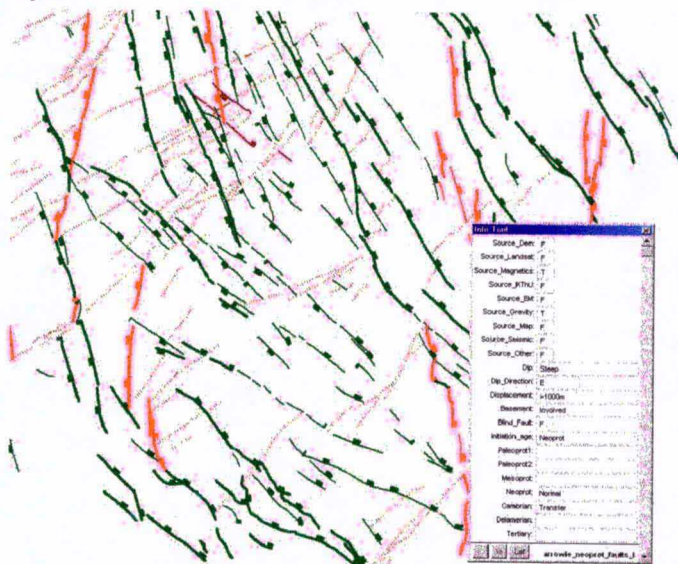
- Mapped faults
- Magnetic anomalies & discontinuities
- Gravity anomalies & discontinuities
- DEM trends & breaks
- Seismic basement-involved faults

The history of the structures is quantified using the following criteria and calibration:

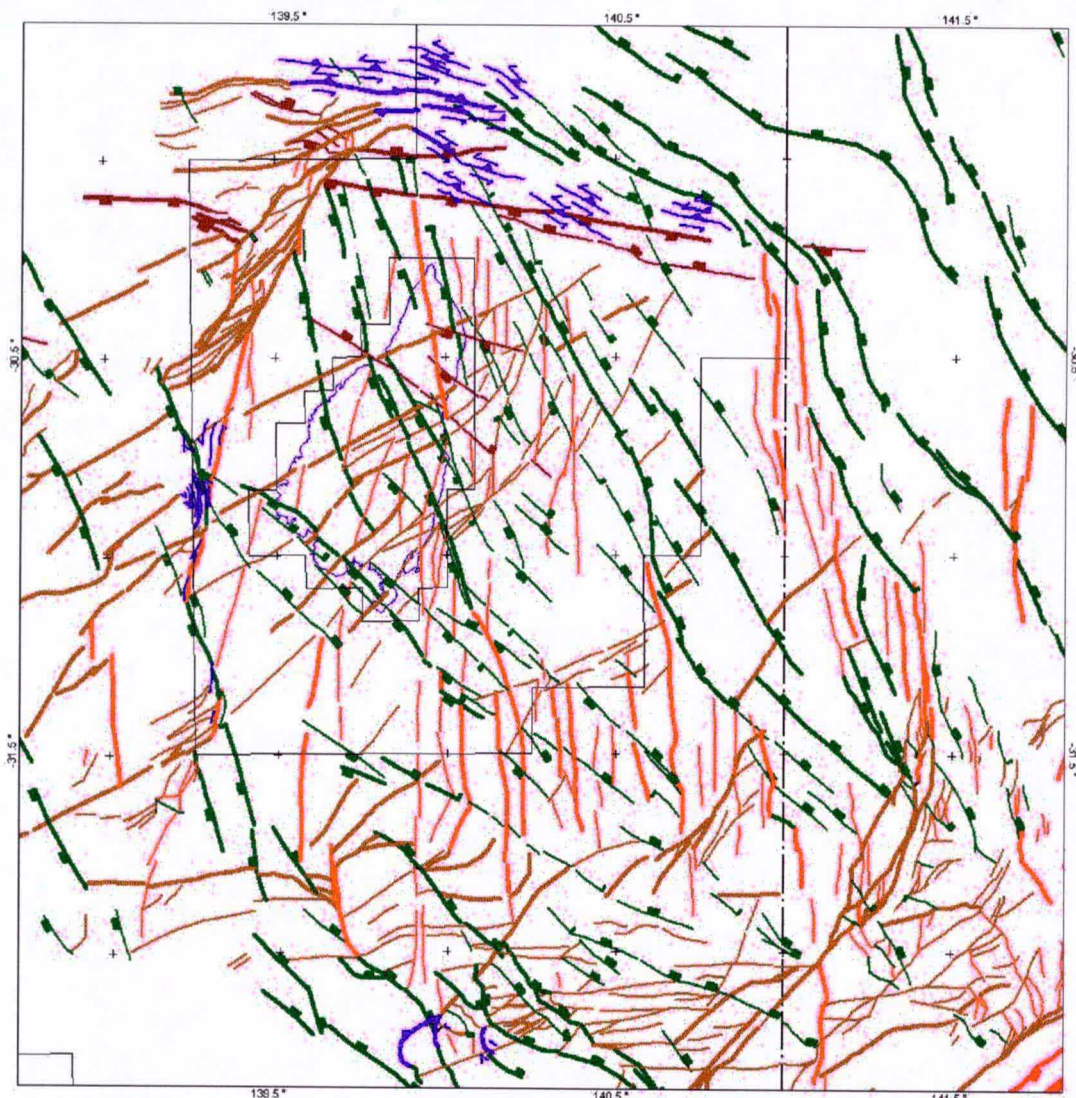
- Structural superposition
- Age of strata displaced
- Relationship to intrusive bodies
- Consistency of fault kinematics to regional paleo-stress regimes and plate movements
- Correspondence to: mapped structures, known movement history

In the GIS, the faults are all attributed by:

- Source (magnetics, gravity, DEM, map etc)
- Orientation
- Displacement
- Basement character (involved or detached)
- Dyke
- Initiation age
- Reactivation history



Basement-Involved Faults



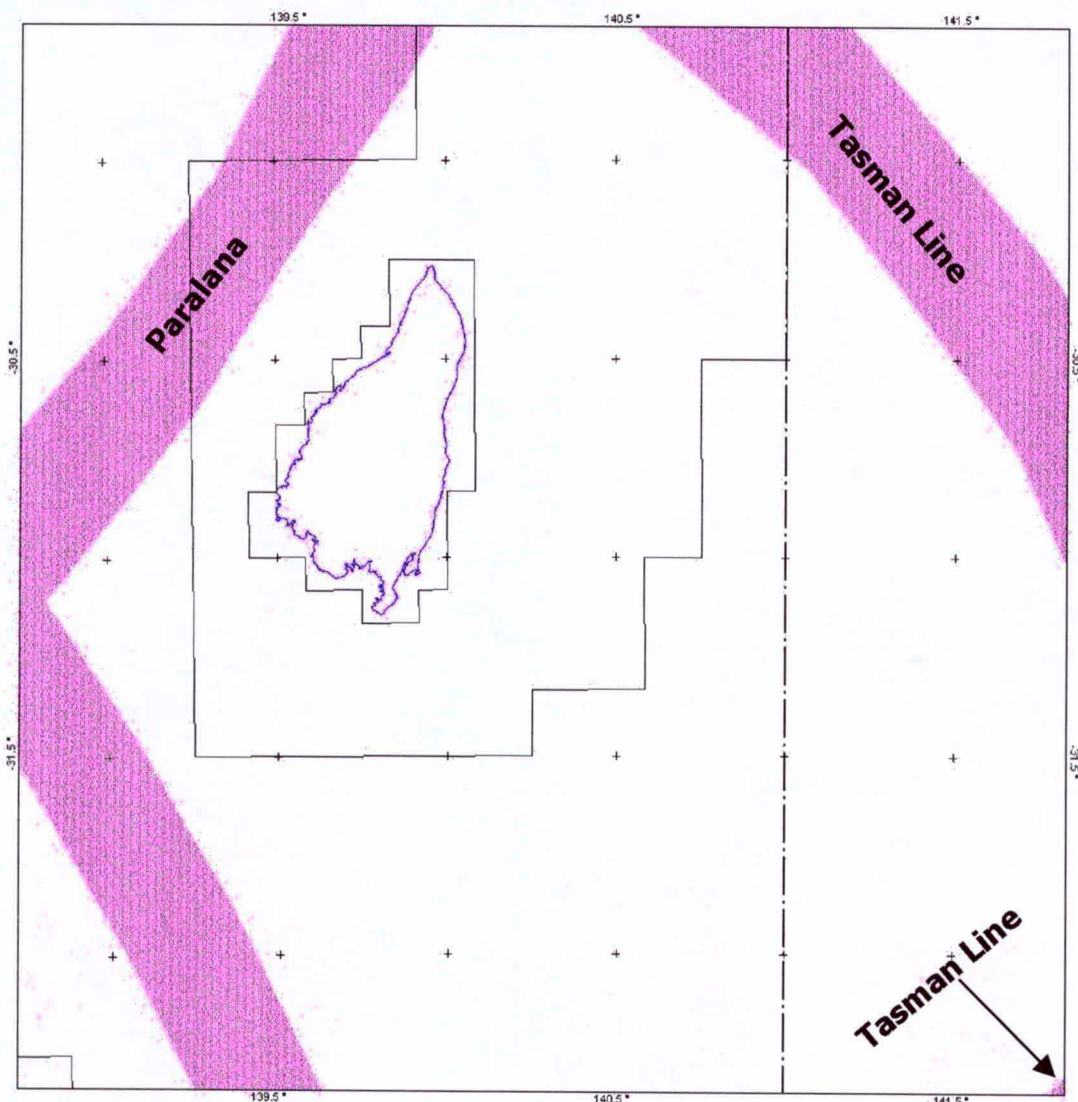
All interpreted basement-involved faults in the eastern Arrowie Basin are shown in the above map, where colour represents initiation age:

- Early Olarian
- Late Olarian
- Mesoproterozoic
- Neoproterozoic (Adelaidean)

Dashed fine lines represent the trend/fabric of basement lithologies.

Outside the Curnamona "Craton"/eastern Arrowie basement has been extensively reworked during Neoproterozoic rifting and the Delamerian Orogeny.

Deep Crustal Fracture Zones



Deep crustal fracture zones are seldom directly mappable in basins. They are deep seated (possibly mantle-derived), ancient zones of crustal weakness that directly or indirectly influence the subsequent development of structures and basins. They are often repeatedly reactivated. Often they coincide with terrane boundaries.

Deep crustal fracture zones in the Arrowie Basin form important boundaries between contrasting basement terranes. They were a first order control on basin evolution, especially during the Neoproterozoic. The Tasman Line is one of the most significant structures in the Australian continent. It marks the western edge of "Proterozoic" Australia, and the eastern edge of the Paleozoic Tasman Fold Belt.

Proterozoic Basement Deformation



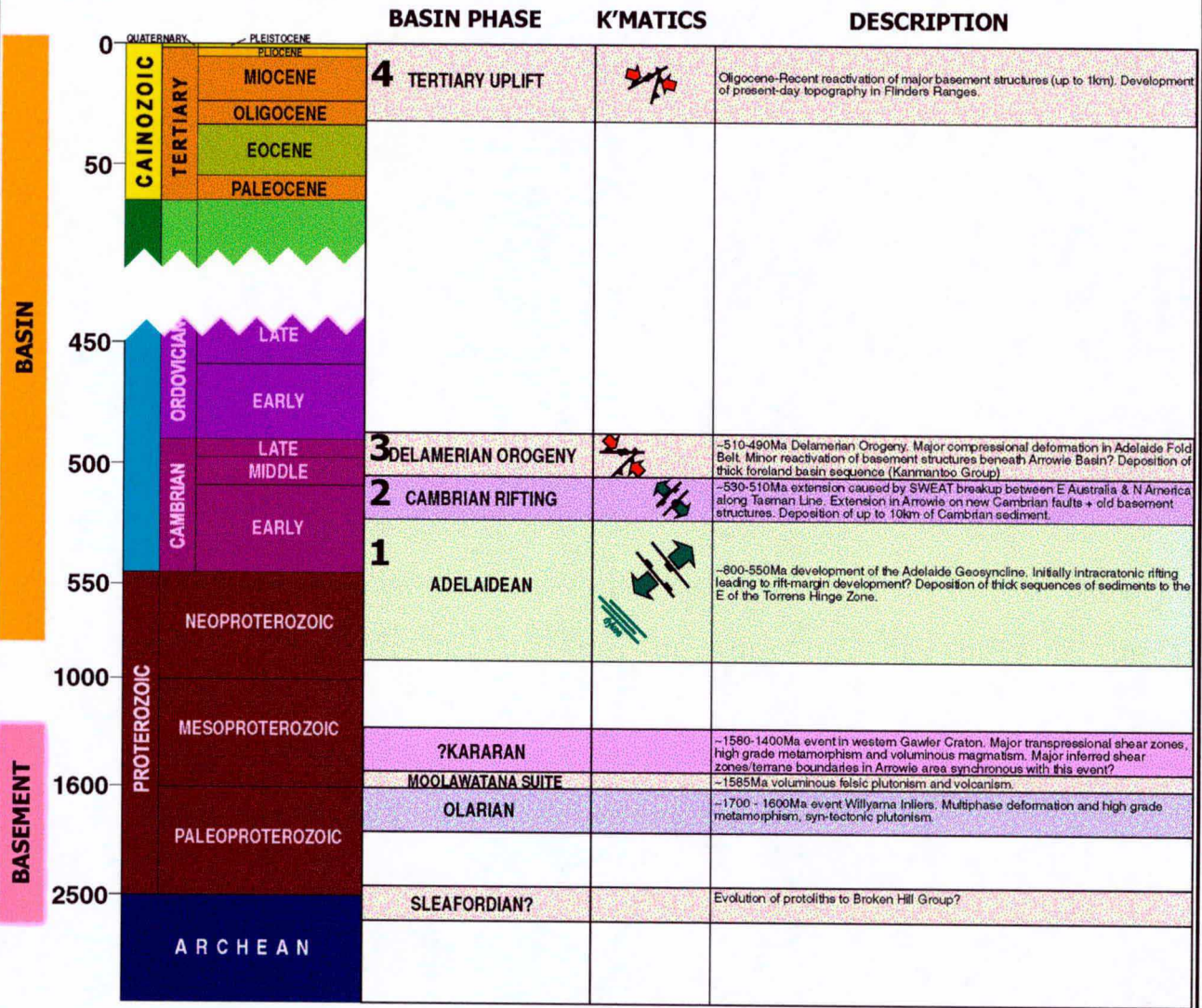
Basement terranes surrounding the eastern Arrowie have undergone a complex Proterozoic structural history, largely during the late Paleoproterozoic Olarian Orogeny. Three main sets of basement structures have been interpreted:

- (i) ~N-S trending early Olarian shear zones/compositional domain boundaries;
- (ii) ~ENE to E-W trending late Olarian ductile structures (shear zones, fold axes), including the Olarian-Mt Painter terrane boundary;
- (iii) WNW trending Mesoproterozoic faults (synchronous with Moolawatana Granite?).

Although the N-S and ENE structures pre-date the Moolawatana pluton, they have been reactivated during subsequent basin formation.

Basin Evolution

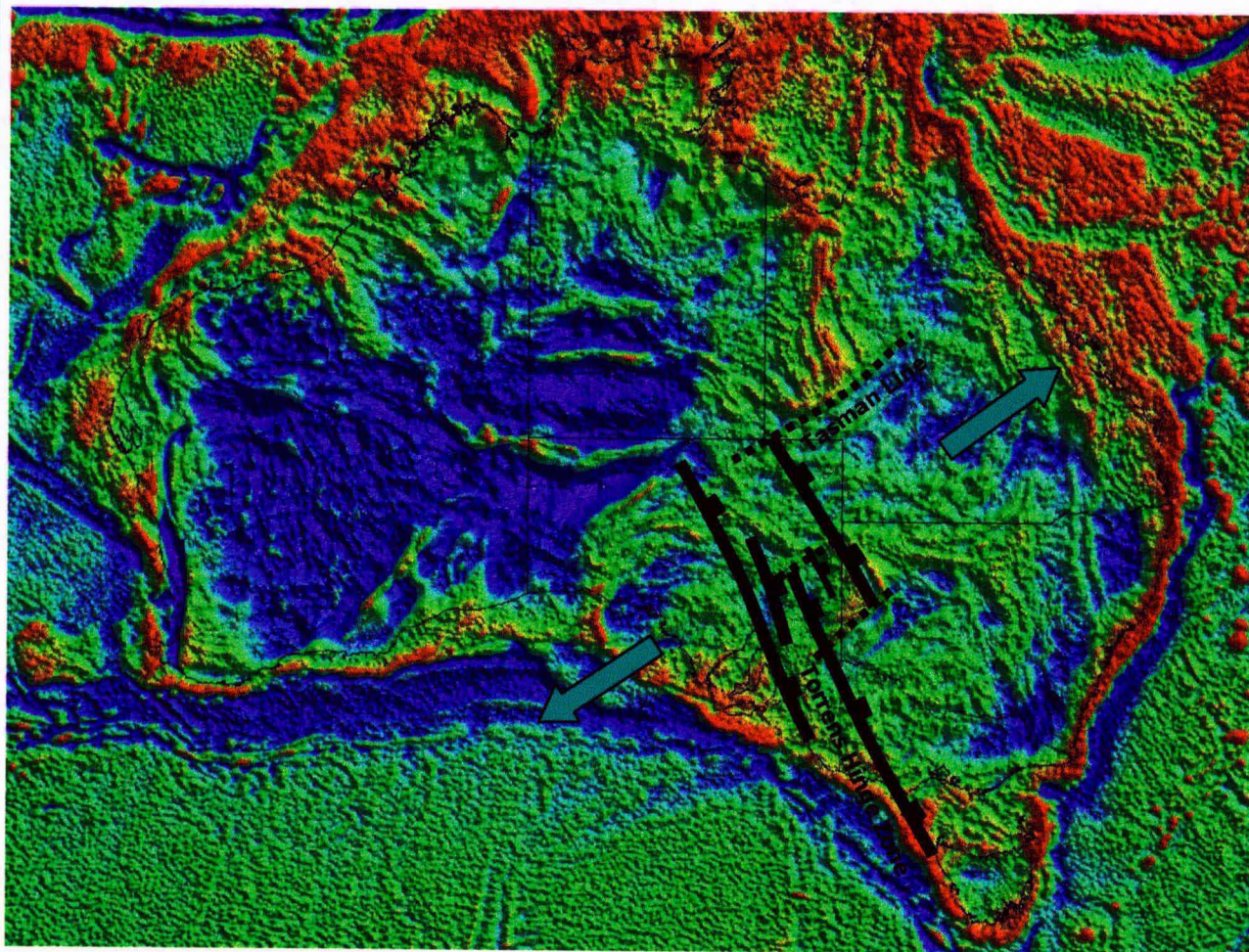
The present-day geometry of the Arrowie Basin is the result of the superposition of 4 major tectonic “events” or basin phases spanning the late Neoproterozoic to Recent. The following chart details the tectonic history of the Arrowie Basin and its basement:



Stresses operating during these basin phases caused reactivation of basement structures and reactive fabrics, as well as the development of new structures. By understanding the kinematics of each tectonic event, a predictive model for structural reactivation can be applied to the interpreted faults. When calibrated with fault history data from geological observations (e.g. seismic, maps), event maps for each basin phase can be constructed.



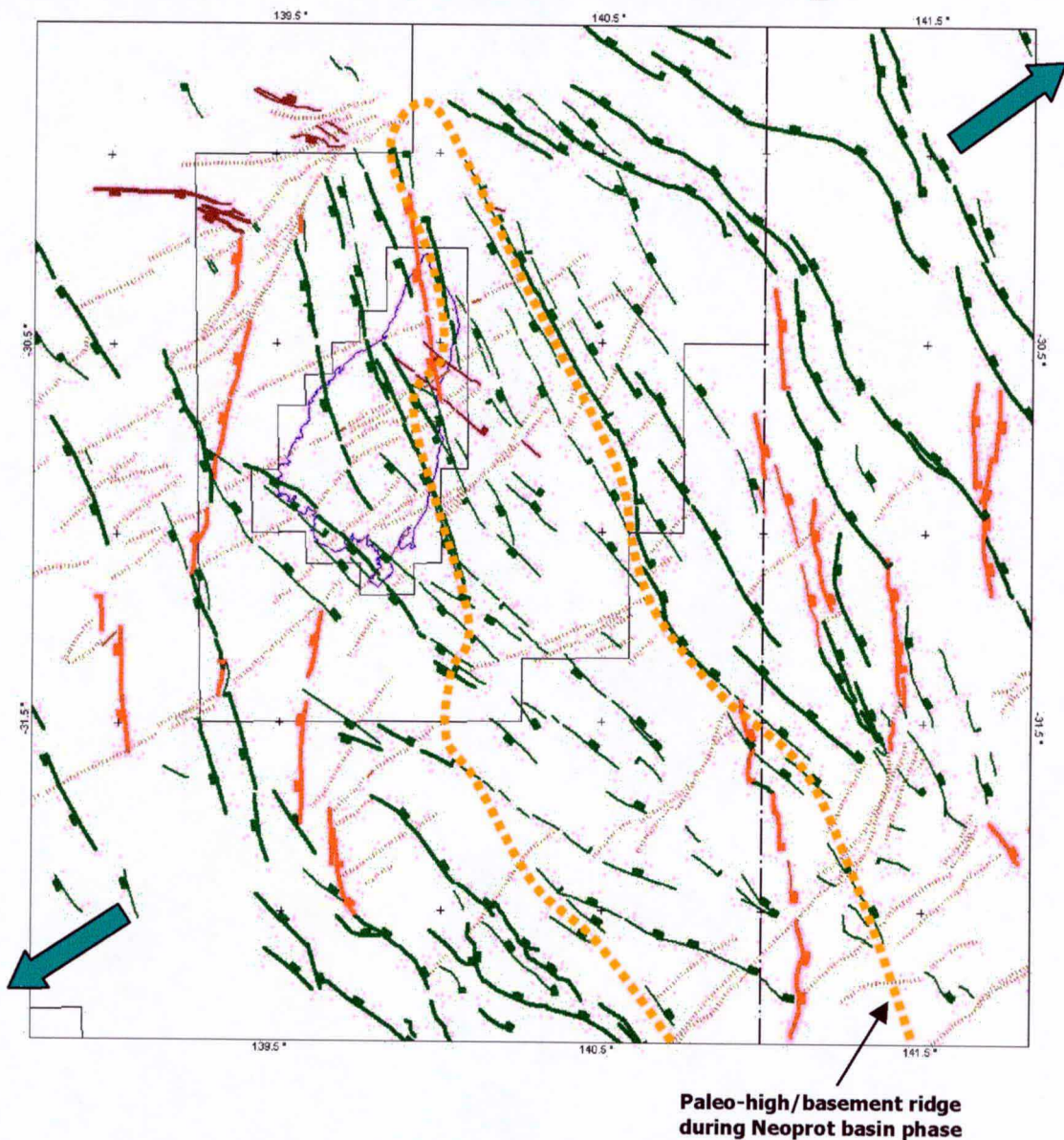
Basin Phase 1: Neoproterozoic Rifting



Intracratonic rifting between Proterozoic Australia and North America began during the Gairdner Dyke event at ~800Ma. Ongoing series of rift events through the Neoproterozoic led to the eventual SWEAT breakup in the early Cambrian. This rifting was synchronous with the flexural evolution of the Centralian Superbasin.

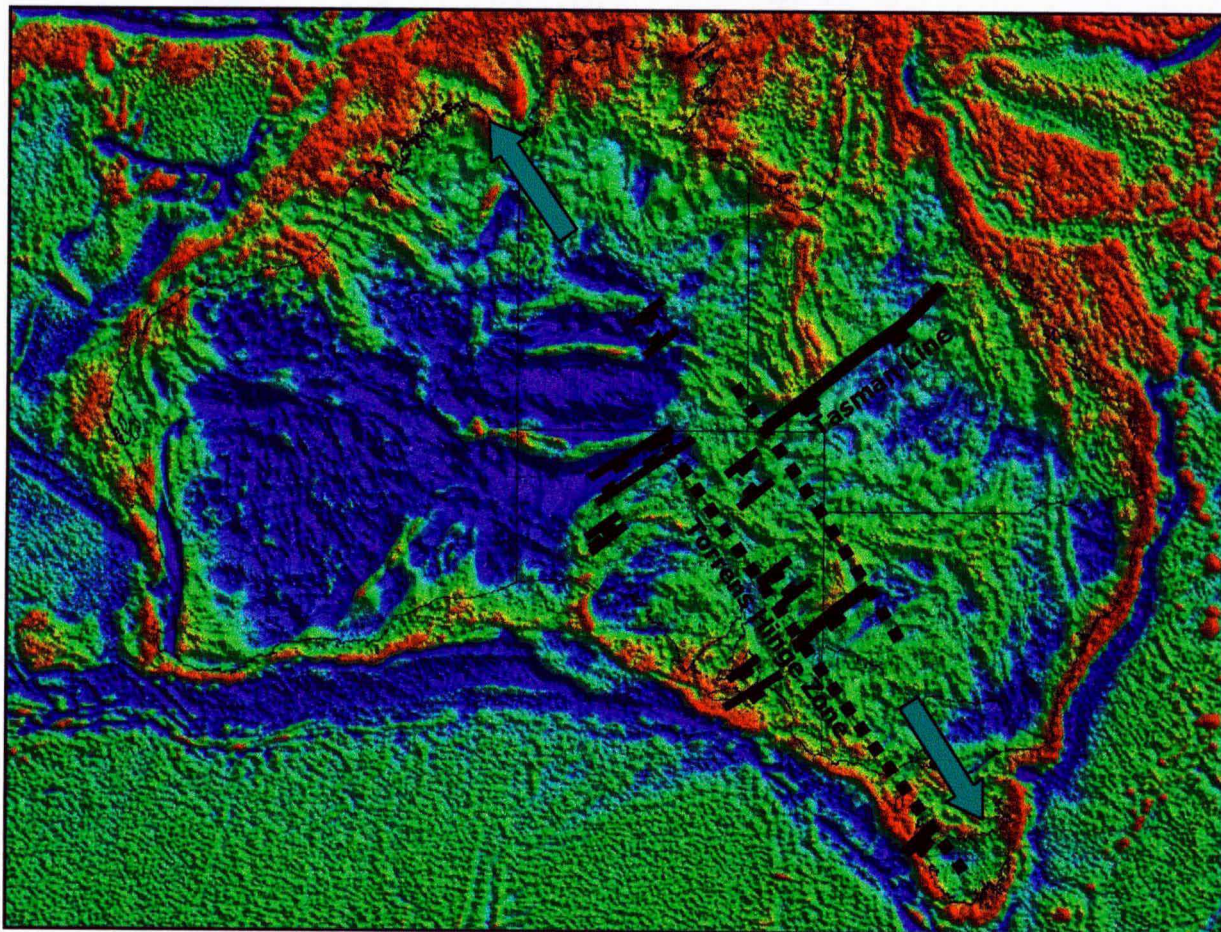
During this time the thick (up to 15km) sedimentary sequence of the Adelaide Geosyncline was deposited in ~ENE-WSW rift basins. At least 4 rift cycles have been recognised. (Preiss, 2000)

Basin Phase 1: Neoproterozoic Rifting



In the eastern Arrowie Basin, up to 4km of Neoproterozoic sediment was deposited in NNW trending graben and half graben to the east and west of the Benagerie Ridge. These graben are well defined by NNW trending normal faults and ENE transfers. The thick Neoproterozoic sequence is inferred from the difference between the Delhi Petroleum (1987) base-Cambrian map and the SEEBASE model presented here.

Basin Phase 2: Early Cambrian Extension

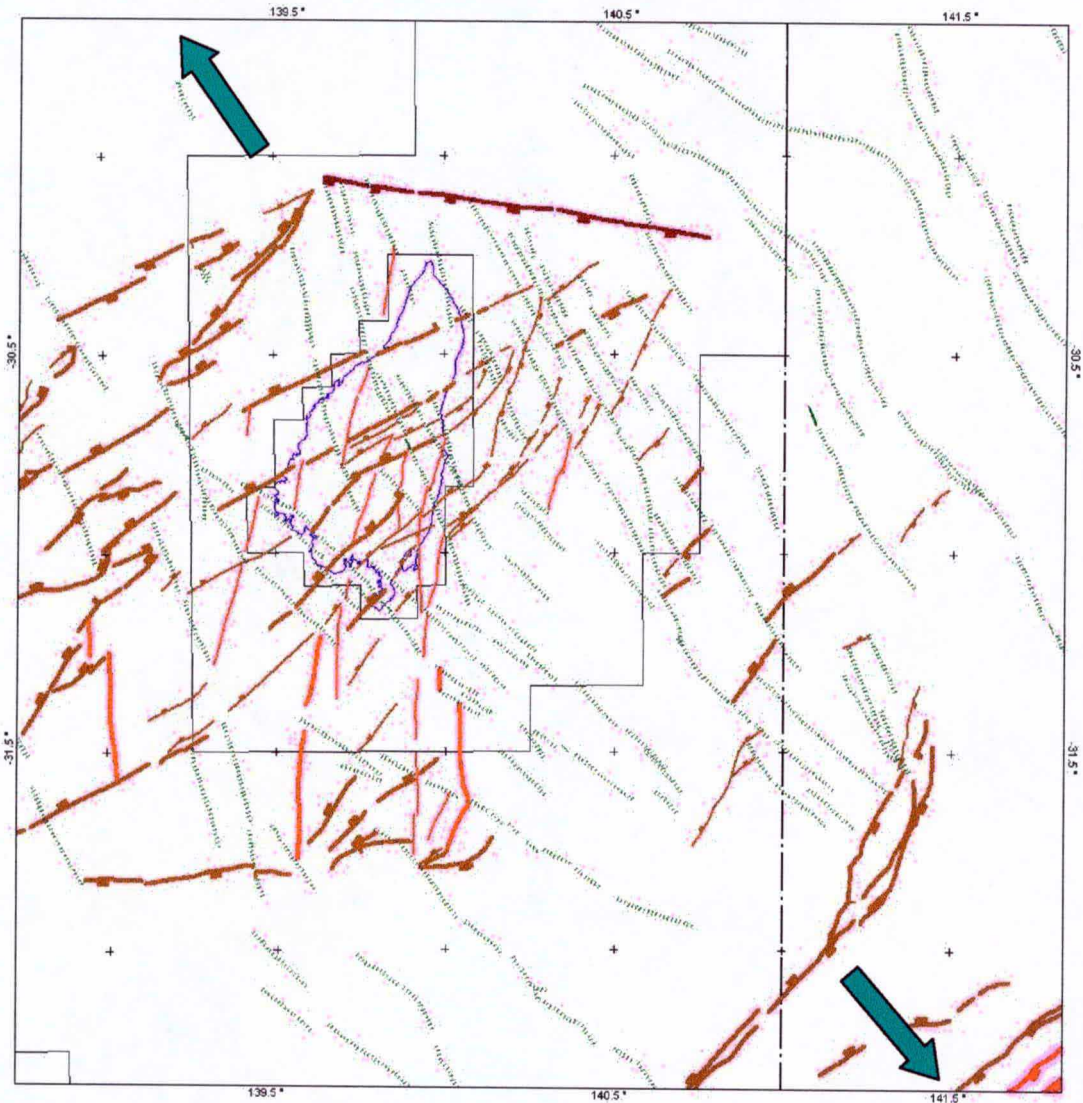


Early Cambrian extension in South Australia was caused by the final SWEAT rifting & breakup between Australia & North America along the Tasman Line. In the early Cambrian this extension was oriented ~NW-SE. Most of the extension was accommodated to the SE of the Tasman Line on structures in the present-day Tasman Fold Belt.

Limited early Cambrian intracratonic rifting occurred to the NE in the Georgina, Officer, Stansbury, Arrowie and Warburton basins. These localised early ?pull-apart Cambrian depocentres may contain good source rocks (as discovered in the Georgina Basin).

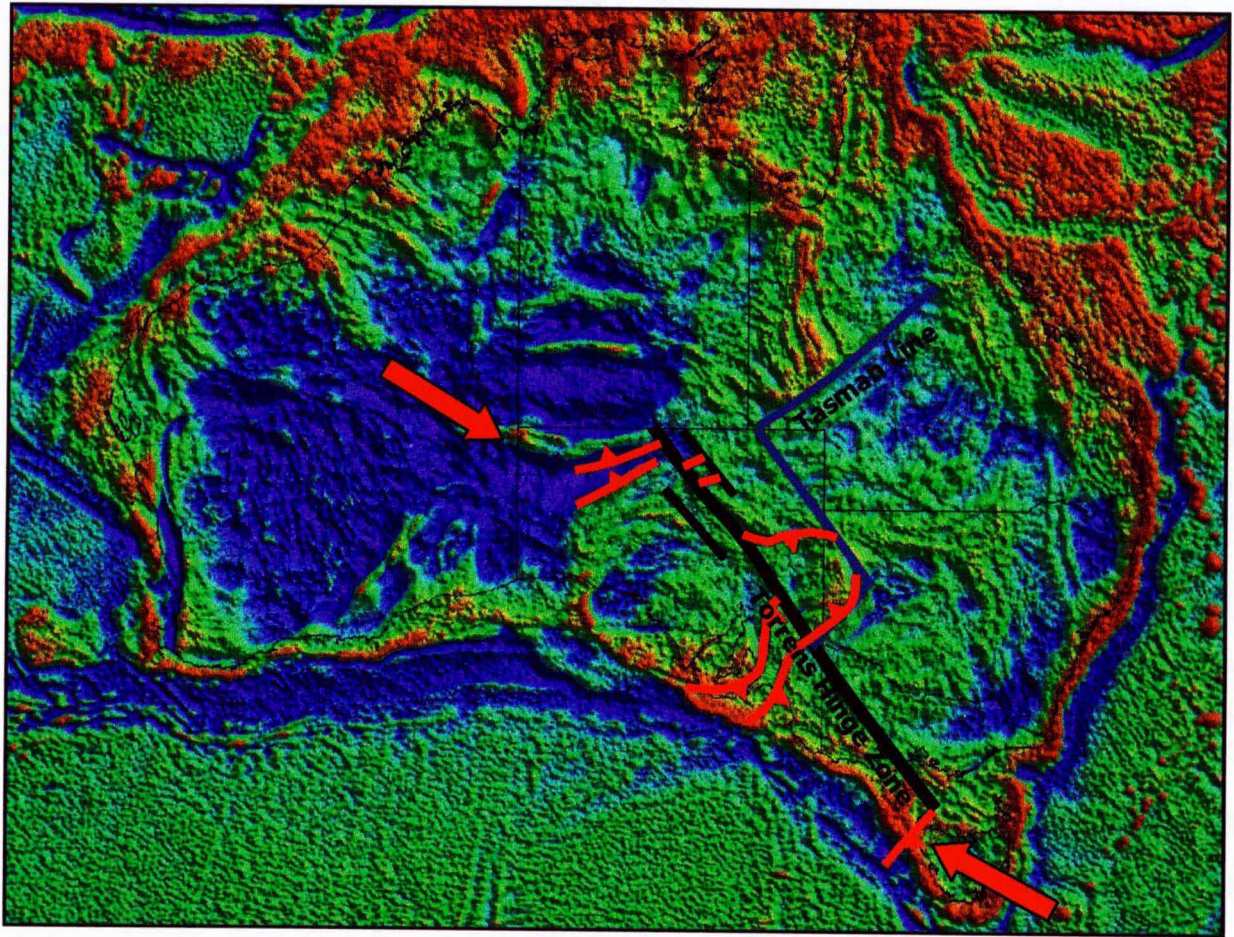
Mid-late Cambrian extension in the Lachlan Fold Belt of eastern Australia was oriented ~NNE-SSW, however no evidence for such rifting was observed in this project in South Australia.

Basin Phase 2: Early Cambrian Faults



In the Arrowie Basin, NW-SE extension in the early Cambrian caused normal reactivation of old NE trending basement structures. Up to 3km of sediment was deposited in NE trending graben and half graben. NNW trending Neoproterozoic normal faults acted as transfer zones. Older Paleoproterozoic N-S structures were also reactivated during this extension.

Basin Phase 3: Delamerian Orogeny



The Delamerian Orogeny was a kinematically complex compressional event marking the terminal stages of the Gondwana-wide Pan African "event" during the time interval ~520-460Ma (late Cambrian to early Ordovician). In South Australia it caused the deformation of a series of fold-thrust belts including the Adelaide Fold Belt, Flinders Ranges and Olary-Broken Hill Province. The main phase of compression was probably oriented NNW-SSE. Sinistral transpressional movement along the Torrens Hinge Zone during the Delamerian caused popup structures to form (e.g. Mt Woods Inlier).

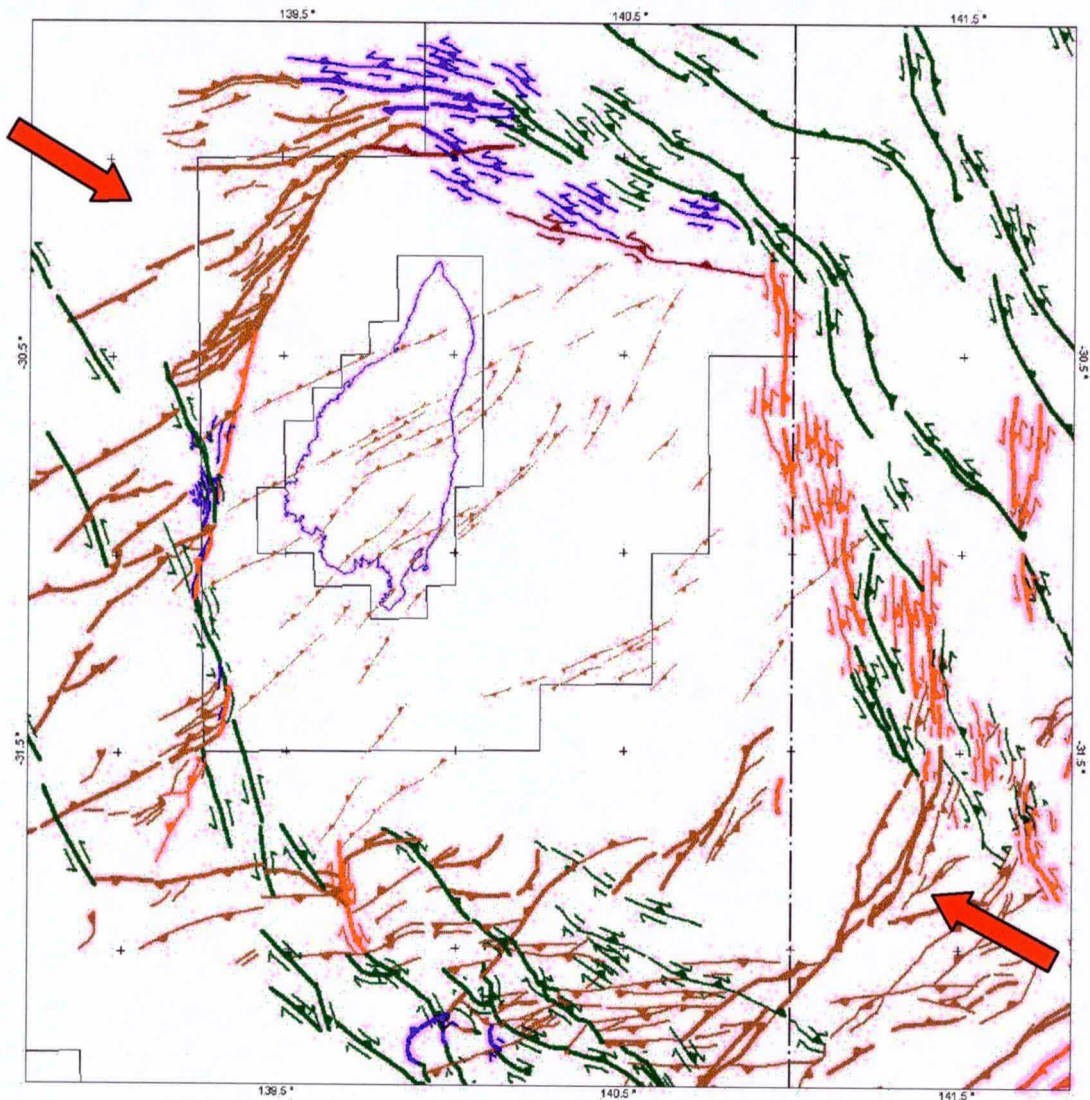


**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kirsten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Basin Phase 3: Delamerian Orogeny

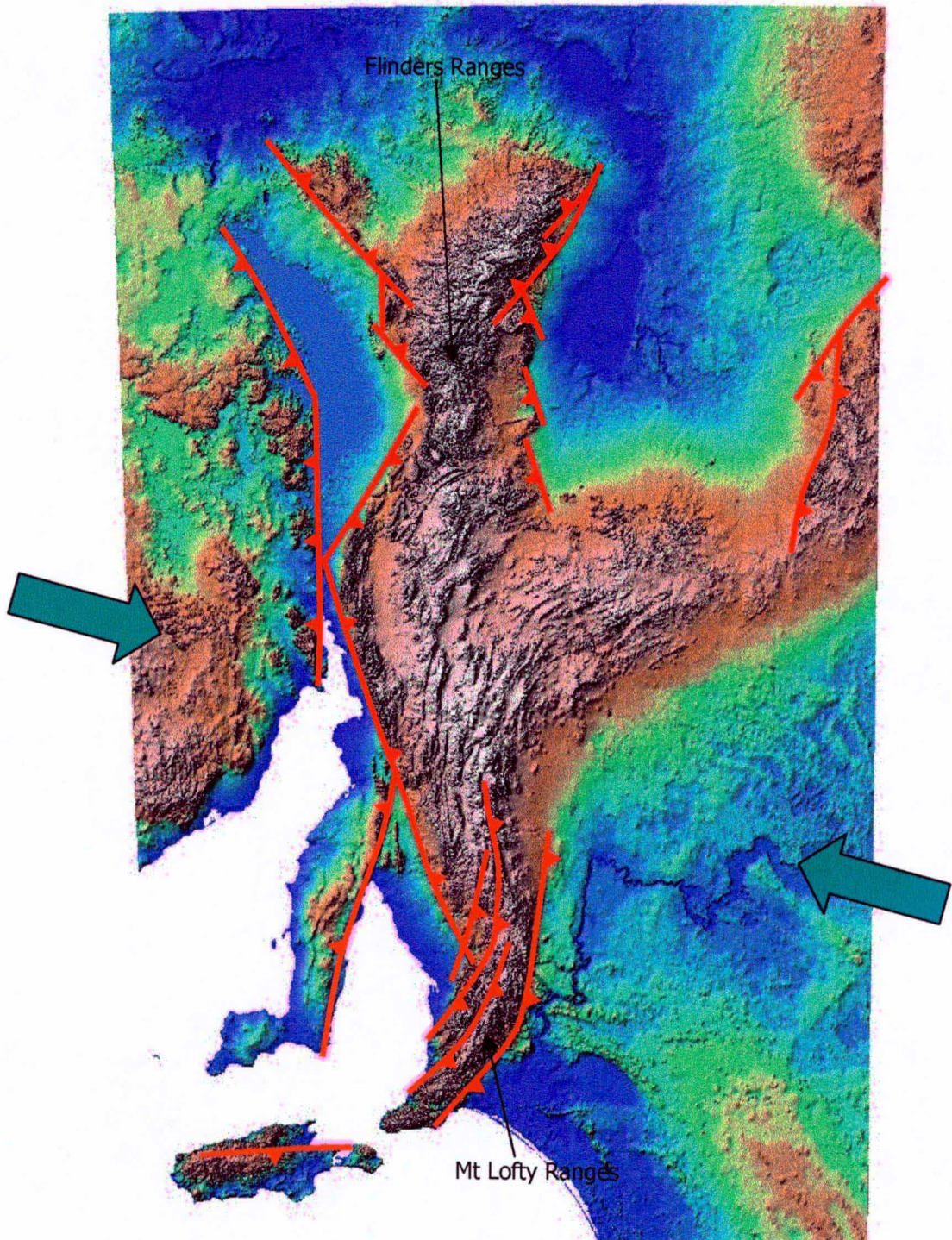


Extensive, kinematically complex deformation occurred in Delamerian mobile belts surrounding the eastern Arrowie Basin. Internally the eastern Arrowie only underwent very minor deformation via inversion of some Cambrian normal faults (potentially an important trap-forming event). In the absence of significant Delamerian deformation in this crustal block, it has been termed the "Curnamona Craton". The inferred reason for the lack of deformation is the presence of a large, rheologically strong, Mesoproterozoic, upper crustal pluton (the Moolawatana Pluton).

Foreland flexure has occurred in eastern Arrowie due to the loading of the Delamerian mobile belts. A thin sequence of foreland basin sediments (Kamantoo Group equivalent) has been deposited.

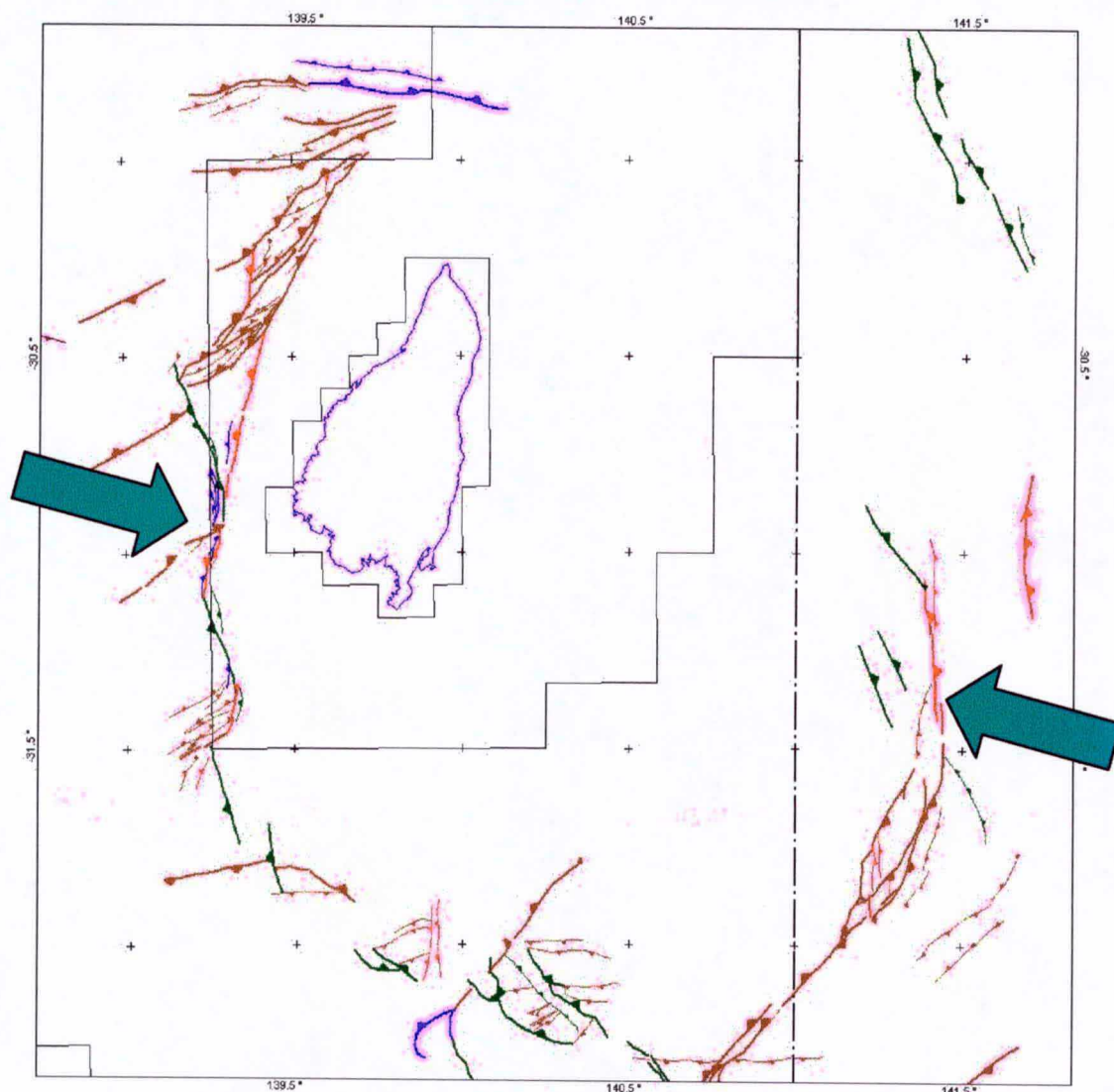
In the Adelaide Fold Belt, early Cambrian Arrowie Basin sediments were folded and faulted during the Delamerian.

Basin Phase 4: Tertiary Uplift



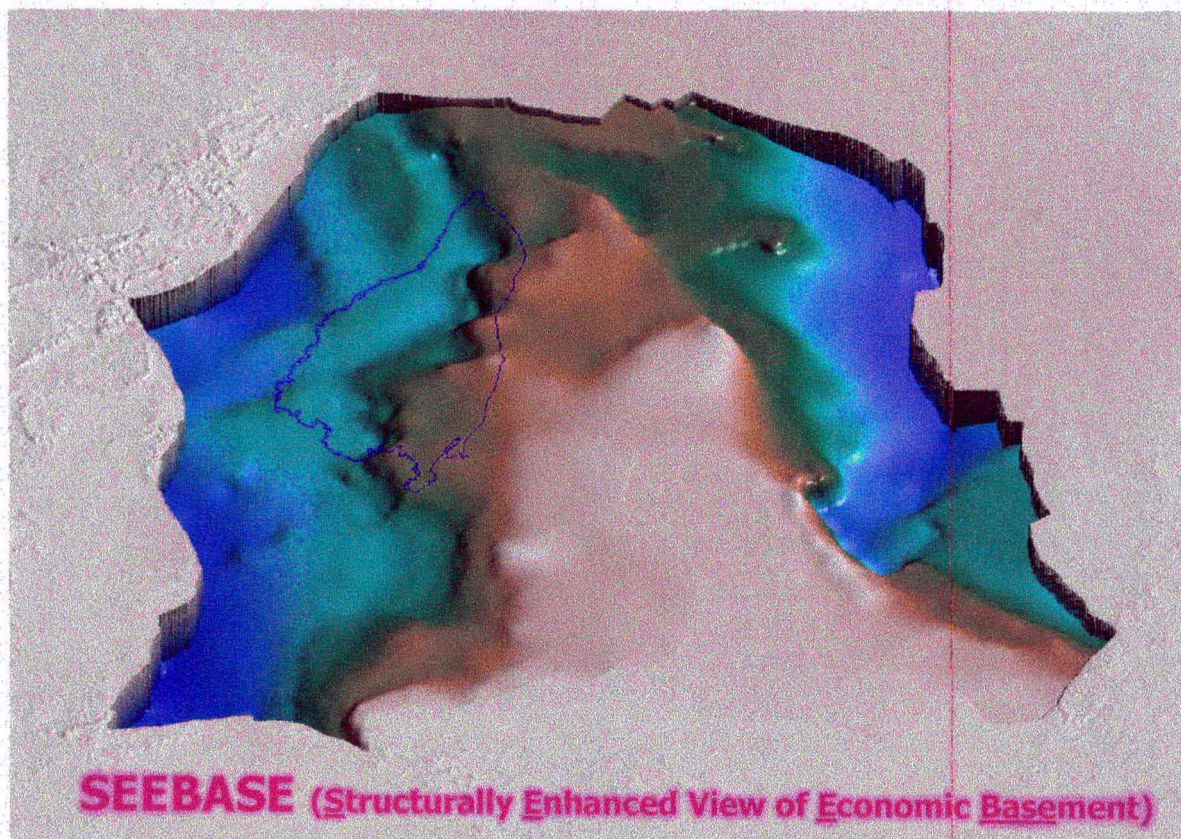
During the Miocene-Recent, ~ENE directed intraplate stresses have reactivated “weak” basement structures in the Adelaide Fold Belt. This compression led to uplift which formed the present-day topography of the Mt Lofty and Flinders Ranges. Uplift continues today, as evidenced by recent seismicity. Up to 1km of uplift has occurred on major structures.

Basin Phase 4: Tertiary Uplift Faults



Tertiary compression (Miocene to Recent) has caused reactivation of major faults surrounding the eastern Arrowie Basin, most notably in the northern Flinders Ranges. This uplift has caused minor foreland flexure in the eastern Arrowie/Curnamona Craton. Up to 800m of clastic sediment has been deposited in the resulting basin, derived from the surrounding uplands.

Depth to Basement



What is SEEBASE?

SEEBASE is much more than just another magnetic depth-to-basement model. It is the culmination of a number of calibration and integration steps:

- Integrated structural/kinematic interpretation
- Geophysical modeling
- Seismic & well calibration
- Integration of tectonic events & responses

SEEBASE is a qualitative model of economic basement topography that is consistent with the structural evolution of the basin. SEEBASE defines basin architecture, and is a predictive model for exploration. It is a key base for understanding basin phase geometry/distribution and petroleum systems. As new data is acquired which allows more precise calibration, SEEBASE can be updated to reflect all new information.

SEEBASE provides a foundation for petroleum systems evaluation, including play element distribution (source/reservoir/seal), migration pathways, zones of structural complexity, trap distribution, trap type & integrity, paleogeography, oil vs. gas distribution etc.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

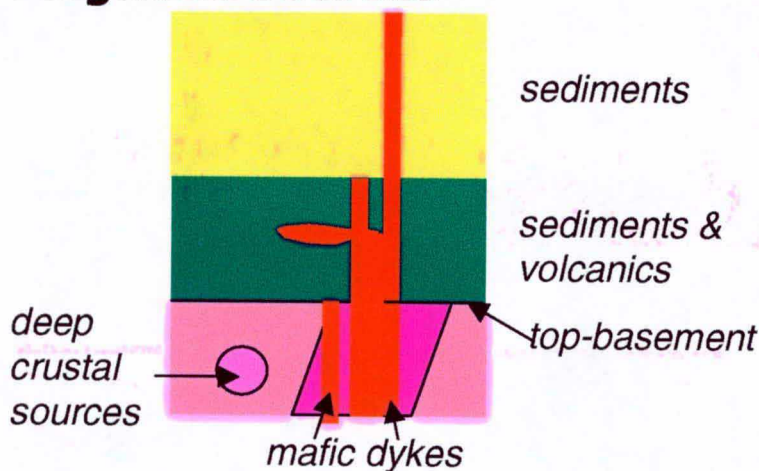
SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Krieten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

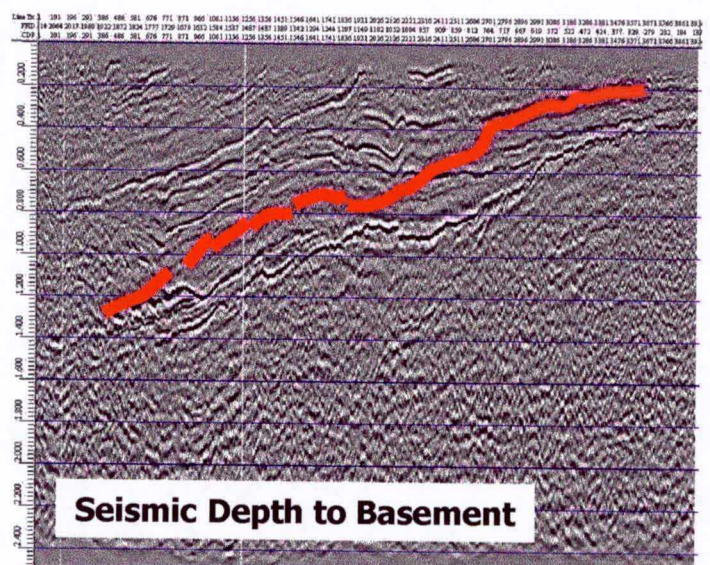
SEEBASE Methodology

- Depth models to magnetic basement sources, obtained from profiles across selected anomalies
- Attribution of source type to depth estimates (require top-basement sources)
- Identification of major basement-involved faults
- Integration of event/response history
- Integration of gravity modeling & interp (if available)
- Incorporation of refraction/seismic/well data (if available)
- Intelligent contouring of "top basement" depth estimates
- Grid construction using CPS-3
- 2D and 3D image processing in ERMapper

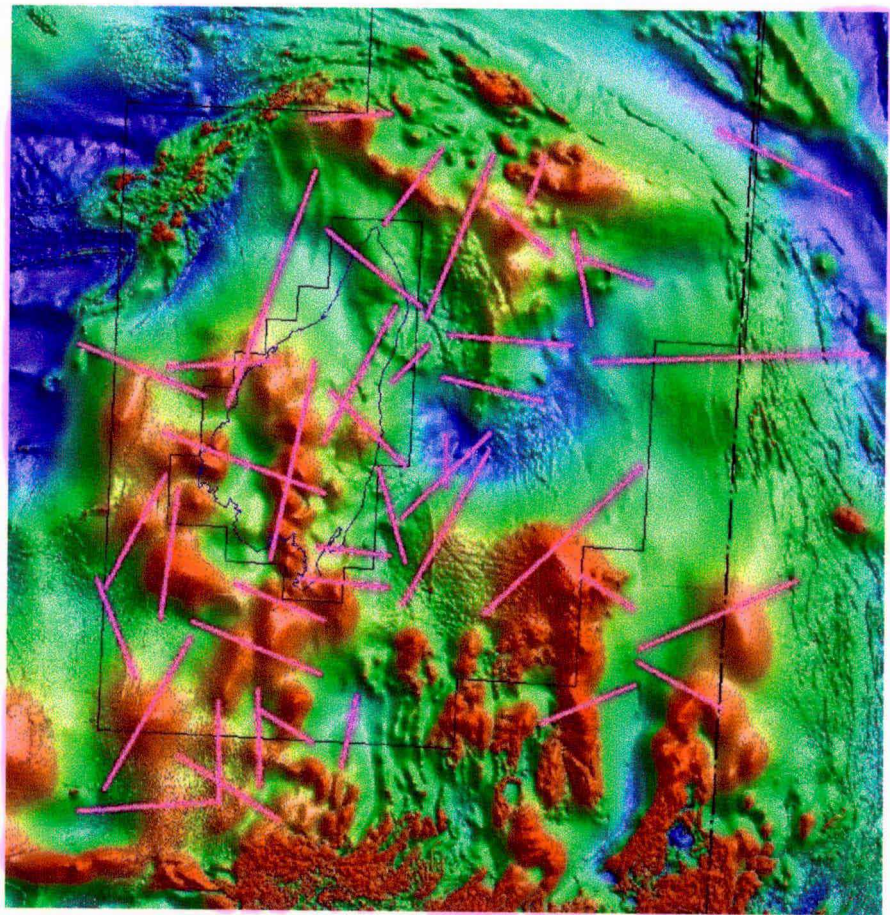
Magnetic Sources



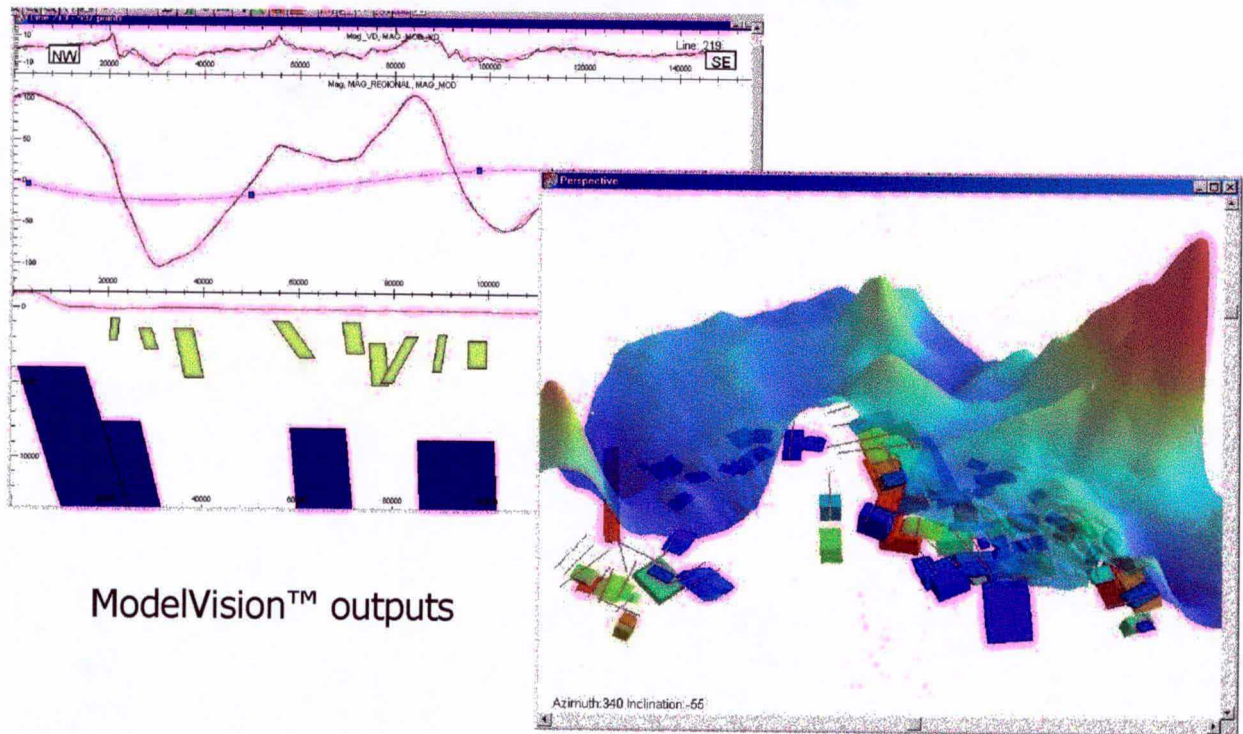
Calibration Example



Magnetic Profiles



Modeled Profiles & Modeled Bodies



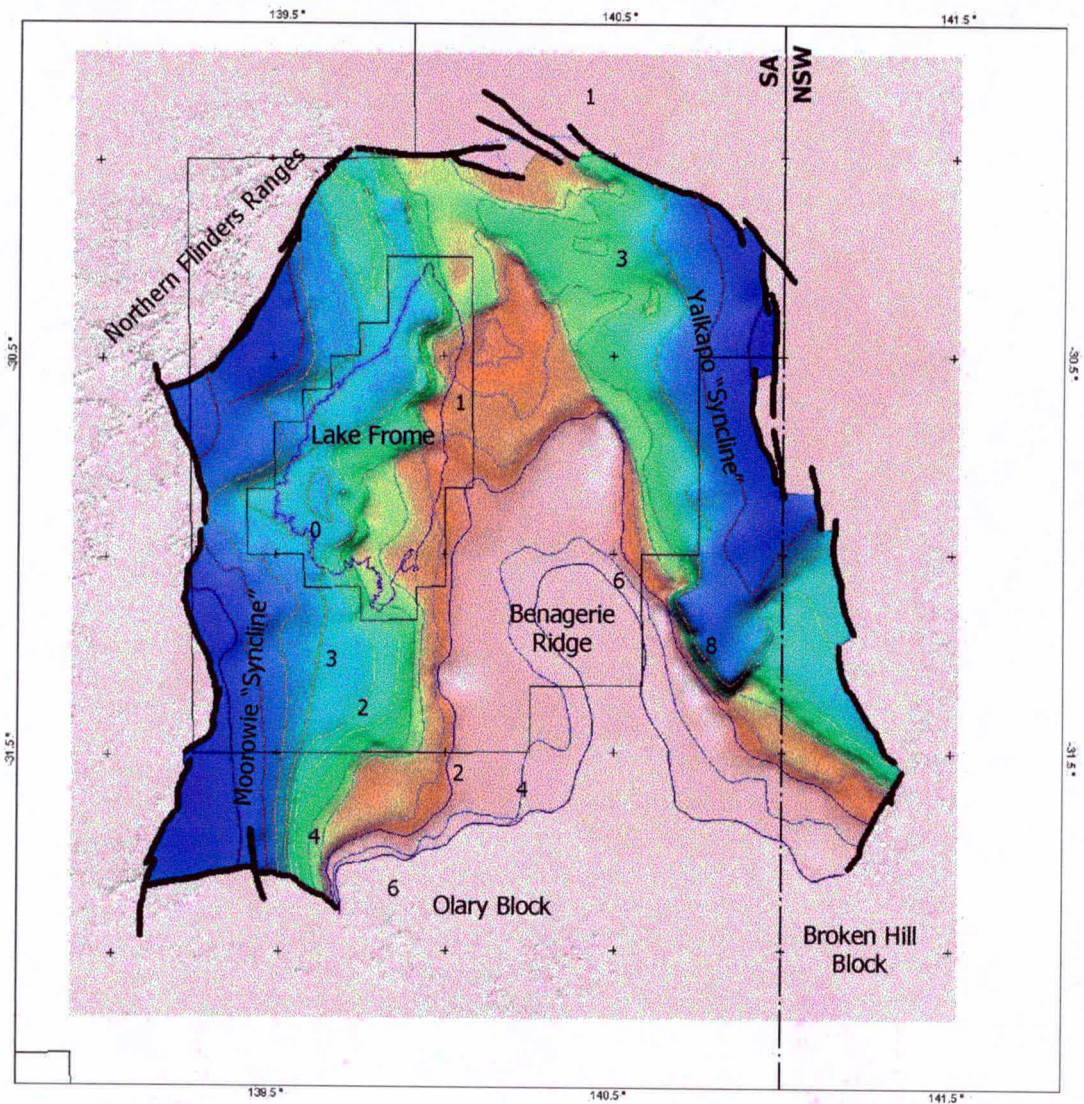
ModelVision™ outputs



**PRIMARY INDUSTRIES
AND RESOURCES SA**

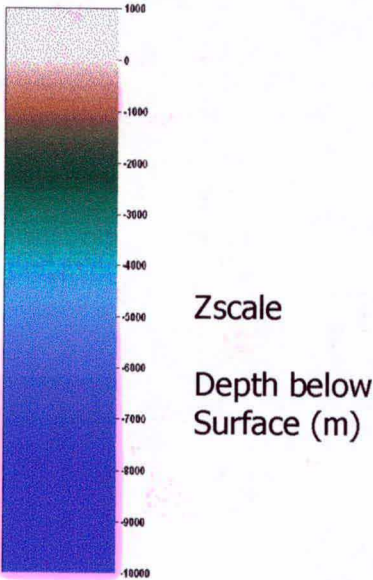
SRK Consulting
Integrated Science and Engineering Consultancy
Steffen, Robertson & Kieren (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

Arrowie Basin SEEBASE



Numbers represent contour values in km

- Principal Basement-Involved Faults
- SA Petroleum Permits



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Steffen, Robertson & Kireten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

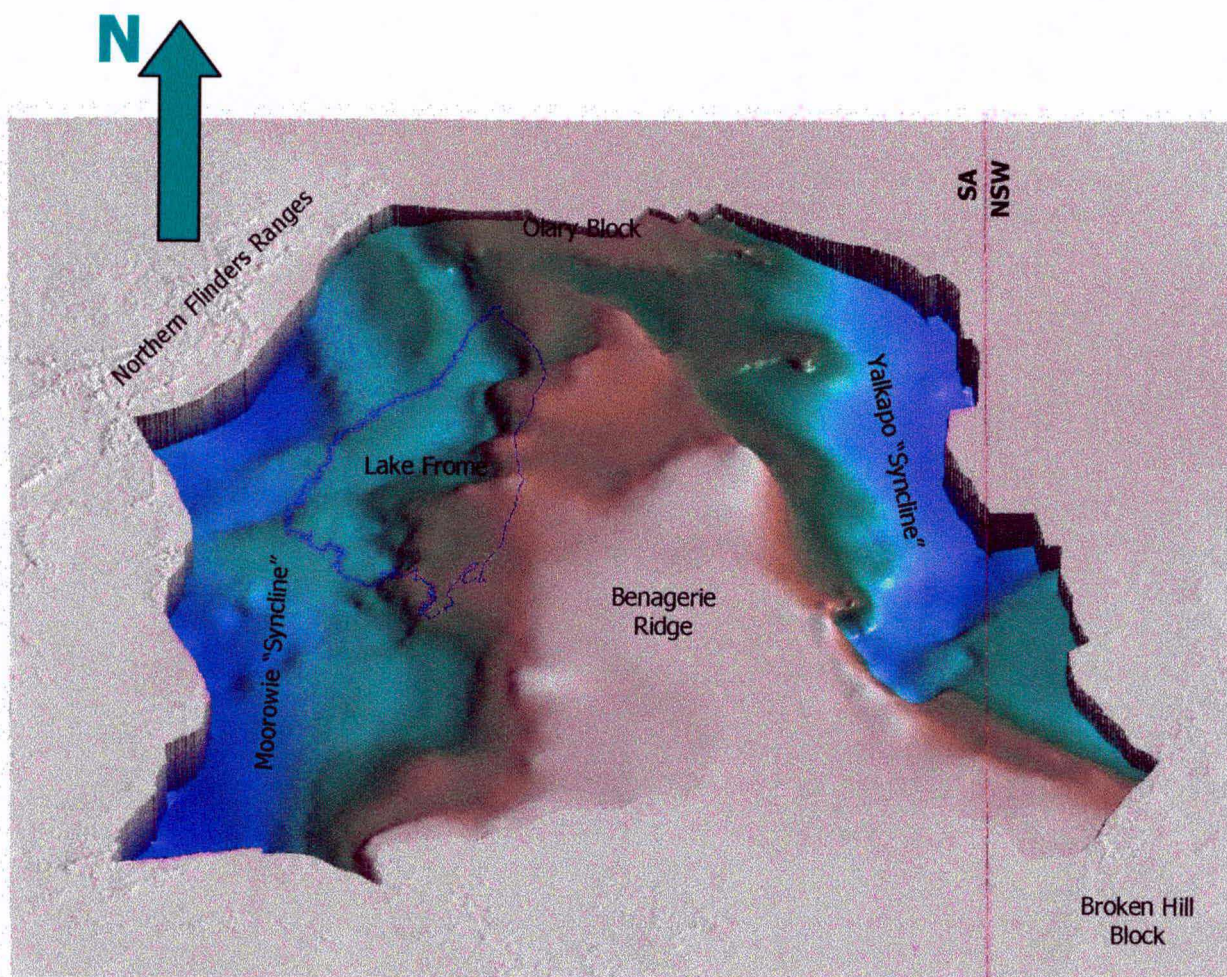
Arrowie Basin SEEBASE

Magnetic depth to basement modelling was successful in the eastern Arrowie due to good data quality. As a result, this SEEBASE dataset is probably accurate to $\pm 10\%$ in areas of shallower basement ($< 4\text{km}$).

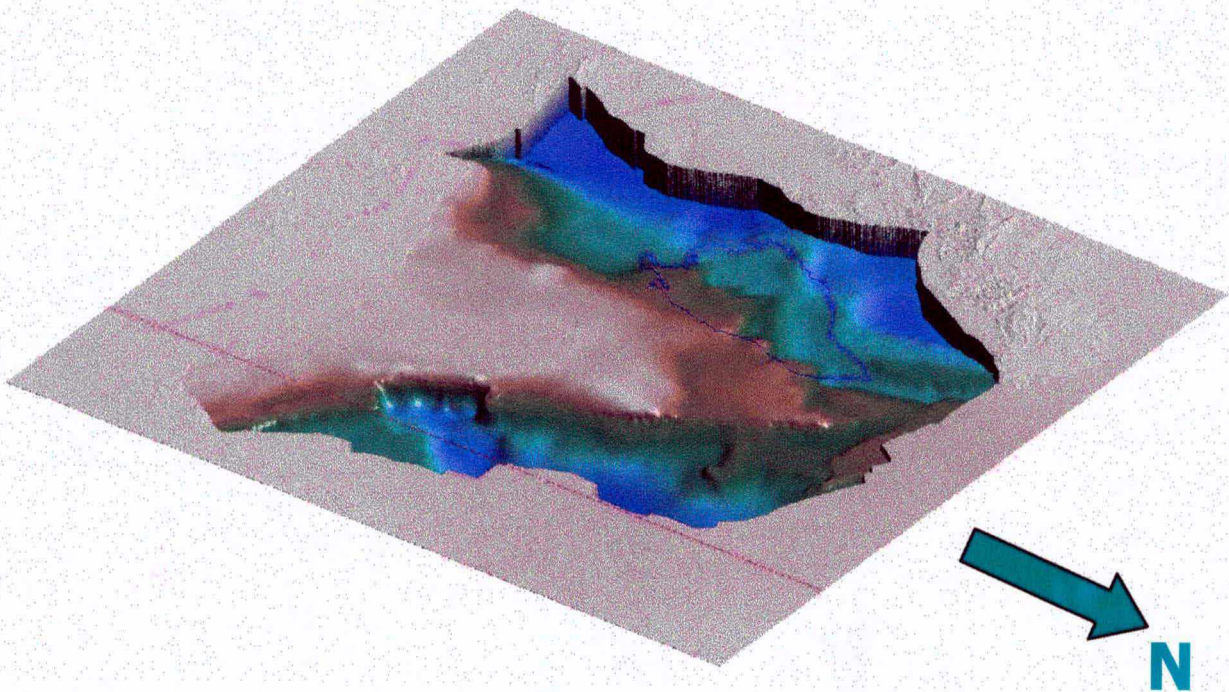
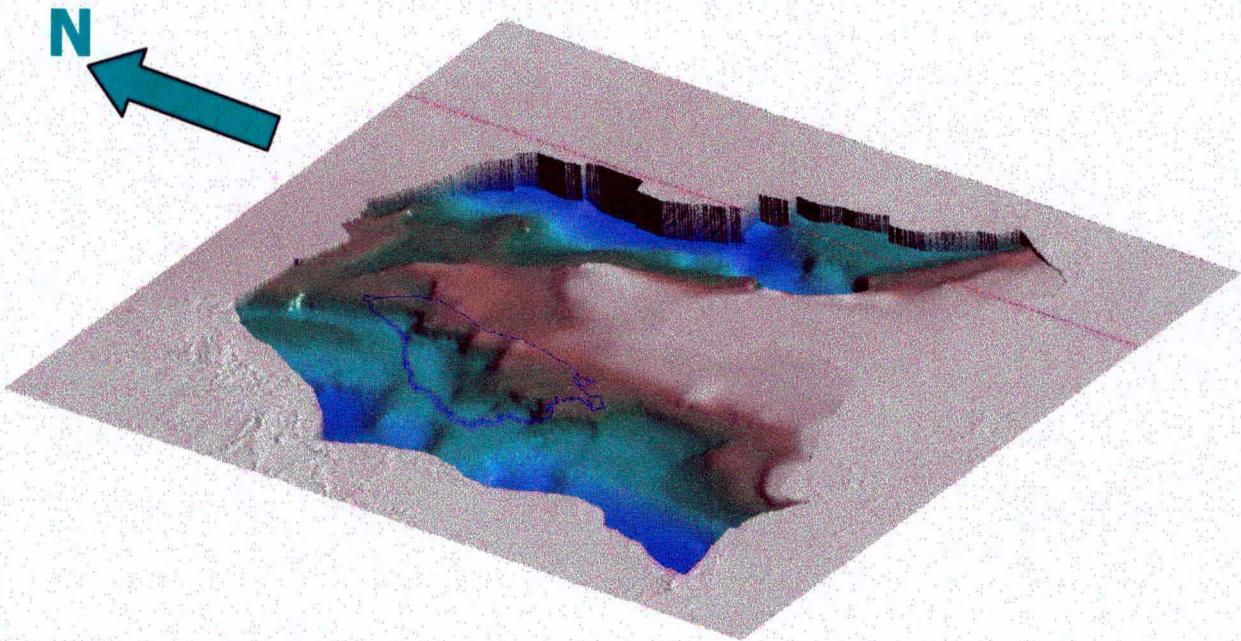
SEEBASE images of the Arrowie Basin show basin architecture, and can be used to analyse petroleum systems and basin phases.

Significant features evident in the Arrowie Basin SEEBASE include:

- Central basement high (the Benagerie Ridge)
- Thick Neoproterozoic-Cambrian depocentres either side of the Benagerie Ridge (the Moorowie and Yalkapo "Synclines")
- SEEBASE depth estimates often deeper than current seismic interpretations (which just pick the lower-most horizontal reflector in poor quality data)



3D Views of Basin Architecture



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy
Steffen, Roberson & Krieten (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting

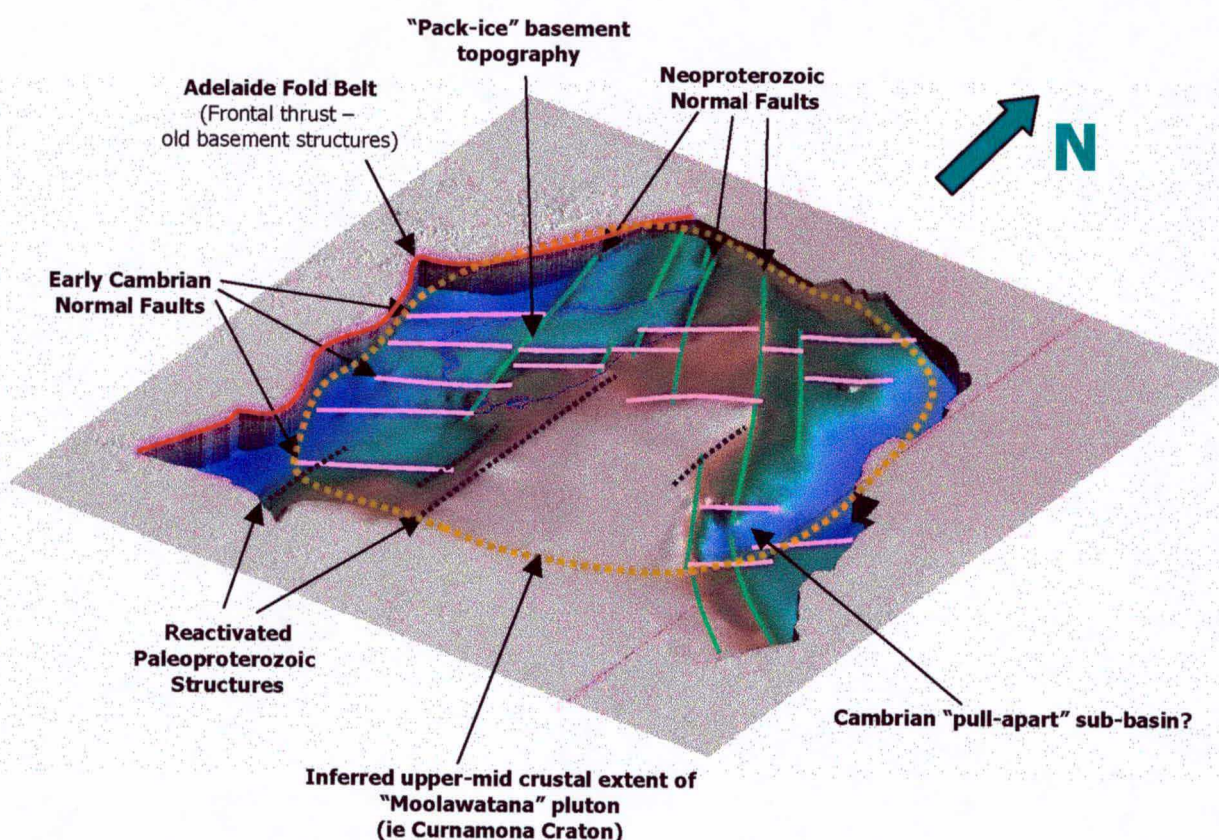
Basement Controls on Basin Architecture

This project emphasises the fact that the architecture of the Arrowie Basin is controlled by pre-existing basement structures and compositional contrasts. Key factors include:

- Rheologically strong Mid-upper crustal Moolawatana Pluton has "shielded" the eastern Arrowie from Delamerian and Tertiary deformation.
- NE and N-S trending basement structures have been reactivated during the Early Cambrian

The superposition of NE & NNW trending basin-forming faults during the Neoproterozoic and early Cambrian basin phases has resulted in a "pack ice" geometry for basement topography. Such geometries are strain-hardening since cross-cutting structures are rarely continuous, and probably further shielded the eastern Arrowie basement from Delamerian deformation.

This 3D block diagram below illustrates the influence of basement geology on basin architecture in the eastern Arrowie Basin.



References

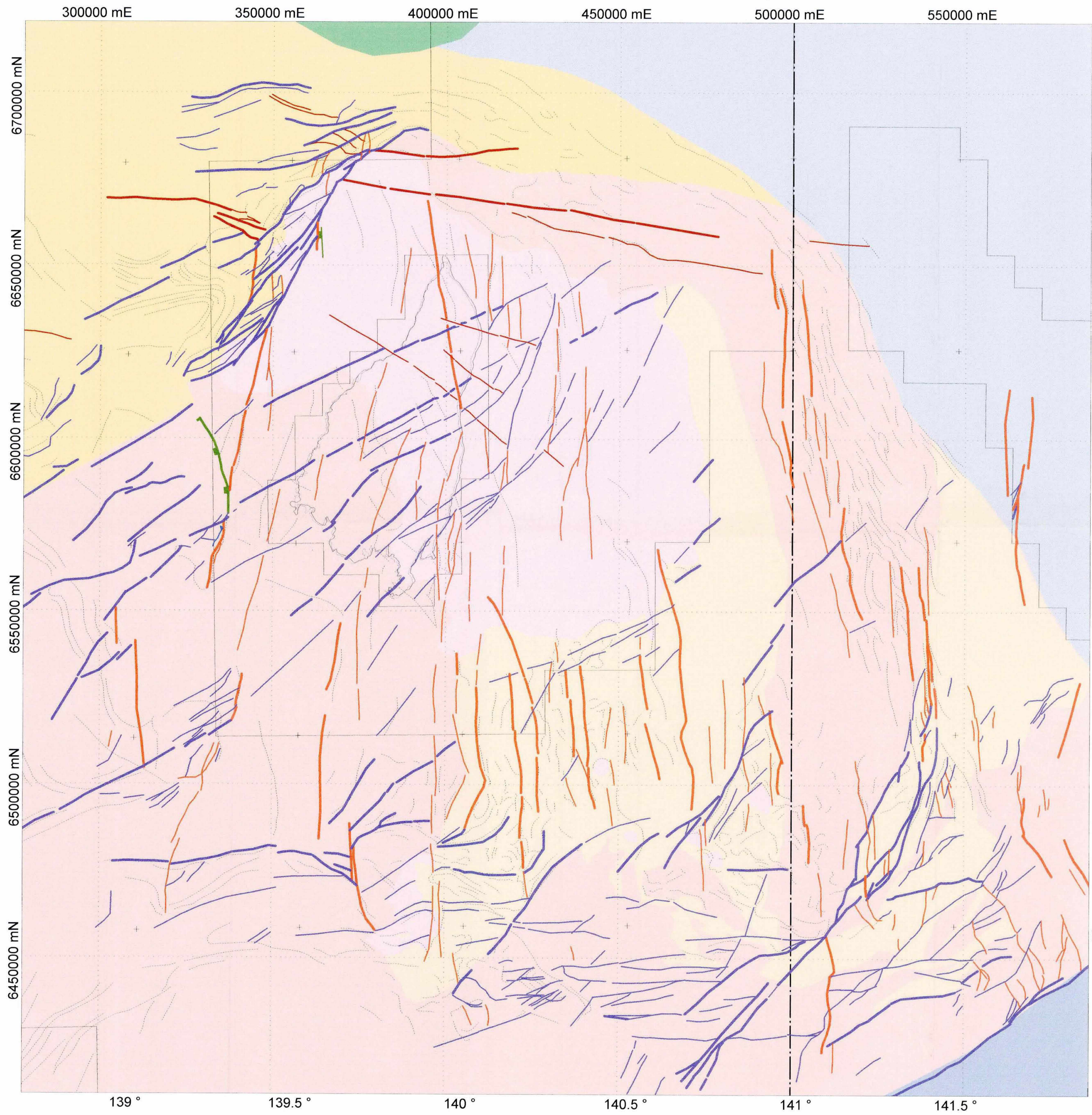
- Delhi Petroleum Pty Ltd, 1987, *PEL's 5 and 6: 1984 Hogarth Seismic Survey Reports*, South Australia Department of Mines and Energy, Open File Envelope 5561.
- Drexel, J.F., Preiss, W.V. & Parker, A.J., 1993, *The Geology of South Australia, Volume 1: The Precambrian*, Mines and Energy South Australia, Bulletin 54.
- Drexel, J.F. & Preiss, W.V., 1995, *The Geology of South Australia, Volume 2: The Phanerozoic*, Mines and Energy South Australia, Bulletin 54.
- Flottmann, T. & Cockshell, C.D., 1996, Paleozoic basins of southern South Australia: new insights into their structural history from regional seismic data. *Australian Journal of Earth Sciences*, 43, p45-55.
- Flottmann, T. & James, P., 1997, Influence of basin architecture on the style of inversion and fold-thrust belt tectonics – the southern Adelaide Fold-Thrust Belt, South Australia. *Journal of Structural Geology*, 19(8), p1093-1110.
- Gravestock, D.I. & Hibburt, J.E., 1991, Sequence stratigraphy of the eastern Officer and Arrowie Basins: a framework for Cambrian oil search. *APEA Journal*, p177-190.
- Haines, P.W. & Flottman, T., 1998, Delamerian Orogeny and potential foreland sedimentation: a review of age and stratigraphic constraints. *Australian Journal of Earth Sciences*, 45, p559-570.
- James, N.P. & Gravestock, D.I., 1990, Lower Cambrian shelf and shelf margin buildups, Flinders Ranges, South Australia. *Sedimentology*, 37, p455-480.
- Marshak, S. & Flottmann, T., 1996, Structure and origin of the Fleurieu and Nackara Arcs in the Adelaide fold-thrust belt, South Australia: salient and recess development in the Delamerian Orogen. *Journal of Structural Geology*, 18(7), p891-908.
- Paul, E., Flottmann, T. & Sandiford, M., 1999, Structural geometry and controls on basement-involved deformation in the northern Flinders Ranges, Adelaide Fold Belt, South Australia. *Australian Journal of Earth Sciences*, 46, p343-354.
- Preiss, W.V., 2000, The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction. *Precambrian Research*, 100, p21-63.
- Struckmeyer, H.I.M. & Totterdell, J.M., 1992, *Australia: Evolution of a Continent*. BMR Publication, Canberra.
- Veevers, J.J. (ed.), 2000, *Billion Year Earth History of Australia and Neighbours in Gondwanaland*. GEMOC Press, Sydney.
- Youngs, B.C. & Moorcroft, E., 1982, The petroleum potential of the eastern Arrowie Basin and Frome Embayment. *APEA Journal*, 22, p82-101.



**PRIMARY INDUSTRIES
AND RESOURCES SA**

SRK Consulting
Integrated Science and Engineering Consultancy

Stallen, Robertson & Kriden (Australia) Pty. Ltd., ABN 56 074 271 720, trading as SRK Consulting



Basement Composition

- Tasman Fold Belt**
Highly extended Proterozoic basement beneath Tasman Fold Belt
- Delamerian Granitoids**
Low gravity granitoid pluton, post orogenic
- Moolawatana Suite + unnamed volcanic equivalents**
High level felsic-intermediate granitoids & subaerial volcanics, ~1550Ma (Hiltaba Suite/GRV equivalents)
- Mt Painter Gneiss**
Undifferentiated Mesoproterozoic gneisses beneath northern Adelaide Fold Belt (e.g. Mt Painter basement gneisses), very high heat production
- Upper Willyama Supergroup**
Metasedimentary units of the Willyama Inliers - metapelites, amphibolites & calc-silicates
- Lower Willyama Supergroup**
Basal gneiss suites of the Willyama Inliers - multiply deformed migmatites & granitoids

Basement Structures

- Paleoproterozoic D1 (Olarian Orogeny)**
- Paleoproterozoic D2 (Olarian Orogeny)**
- Mesoproterozoic**
- Neoproterozoic**
- Delamerian Orogeny**
- Trends/Fabric**



**PRIMARY INDUSTRIES
AND RESOURCES SA**



Energy Services

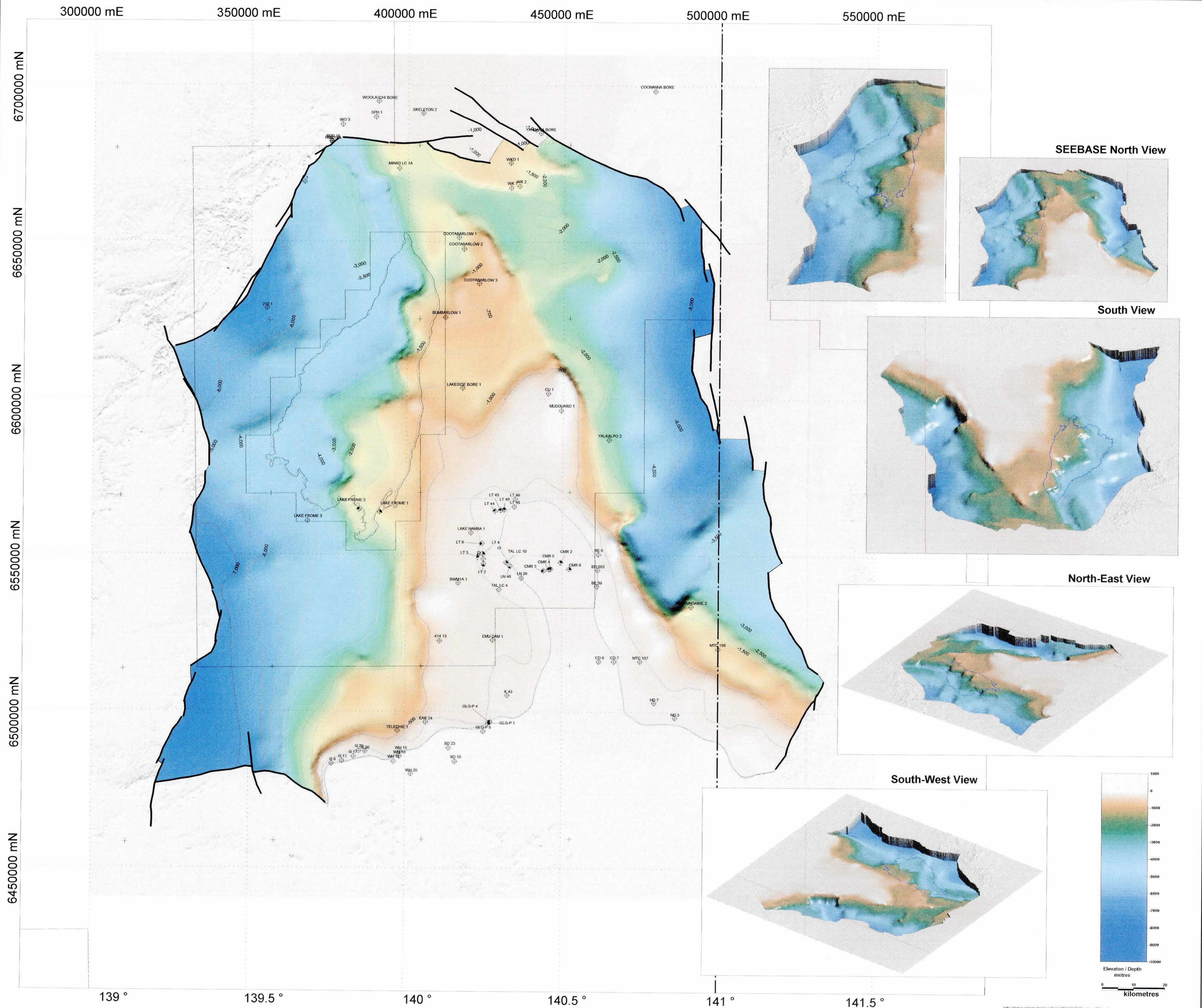
6/50 Gellie Court
Deakin ACT 2600
Canberra, Australia
Tel: +61 2 6283 4800
Fax: +61 2 6283 4801
URL: www.srk.com.au

PIRSA - Arrowie Basin

June, 2001
SRK Job Code: P112
Scale: 1: 700,000

Basement Geology

Projection: Australian Map Grid (AGD 66), Zone 54





SRK Consulting

Integrated Science and Engineering Consultancy



**PRIMARY INDUSTRIES
AND RESOURCES SA**