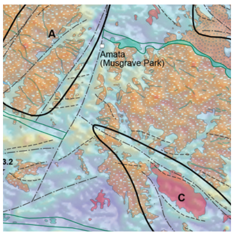
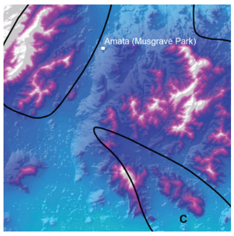
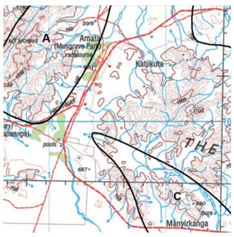
Investigating the potential for bedrock aquifers in the APY Lands

Mark J. Pawley and Carmen B.E. Krapf







Report Book
2016/00021

SOUTH AUSTRALIA
Government of South Australia
Department of State Development

Investigating the potential for bedrock aquifers in the APY Lands

Mark J. Pawley and Carmen B.E. Krapf

Geological Survey of South Australia, Resources and Energy Group, DSD

October 2016

Report Book 2016/00021

Resources and Energy
Department of State Development
Level 7, 101 Grenfell Street, Adelaide
GPO Box 320, Adelaide SA 5001
Phone +61 8 8463 3037
Email dsd.minerals@sa.gov.au
www.minerals.statedevelopment.sa.gov.au

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

Preferred way to cite this publication
Pawley M.J. and Krapf C.B.E. 2016. *Investigating the potential for bedrock aquifers in the APY Lands*, Report Book 2016/00021. Department of State Development, South Australia, Adelaide.

CONTENTS

FIGURES

Investigating the potential for bedrock aquifers in the APY Lands

Mark J. Pawley and Carmen B.E. Krapf

ABSTRACT

Water is a valuable commodity in the Anangu Pitjantjatjara Yankunytjatjara (APY) Lands, which has traditionally been sourced from palaeovalley sands, calcrete, and alluvial and aeolian sediments as well as from the onlapping sediments of the Officer Basin. A recent commissioned study has attempted to recognise features within the outcrop, or shallowly buried bedrock areas around some of the main communities in the APY Lands that may host groundwater aquifers. This work used a range of existing datasets, such as pre-existing geological data, aeromagnetics, orthoimages, digital elevation models, Landsat imagery, and earthquake data to find potential new targets. No new data was collected, nor was there any ground-truthing. The targets focus on areas that may have enhanced porosity and permeability. These include areas of fractured rock, recognisable on orthoimages, which could represent breccia zones or faults, and areas where several lineaments intersect. Also of interest are areas where breaks in outcrop coincided with aeromagnetic low lineaments, suggesting the presence of eroded faults covered by a veneer of Cenozoic sediments.

INTRODUCTION

This report book is the result of a request by the Department of Environment, Water and Natural Resources (DEWNR) to provide information and geological support about potential alternative water resources around the communities in the Anangu Pitjantjatjara Yankunytjatjara (APY) Lands. Traditionally, water is sourced from palaeovalley sands, calcrete, and alluvial and aeolian sediments as well as from the onlapping sediments of the Officer Basin in the south eastern part of the APY Lands. The Geological Survey of South Australia (GSSA) was asked to examine the geology in the vicinity of the main communities — Amata, Fregon, Indulkana, Mimili, Pukatja, Yunyarinyi — for bedrock structures that potentially can act as aquifers (Fig. 1). These include faults and breccia zones, where the fractured rock is permeable allowing water to flow and accumulate. As these types of aquifers have not been extensively exploited, they have potential to offer a valuable additional water resource for the region.

This report book is a compilation of the information that was provided to DEWNR in January 2015. It will start with a description of the approach used in this study, and a brief introduction to the regional geology of the South Australian part of the Musgrave Province. This will be followed by sections on each of the main communities outlining the geological events that occurred in these areas, the main structures and geological features that can be observed, and a list of possible sites where water could have flowed and accumulated. No fieldwork and ground-truthing has been carried out as part of this investigation.

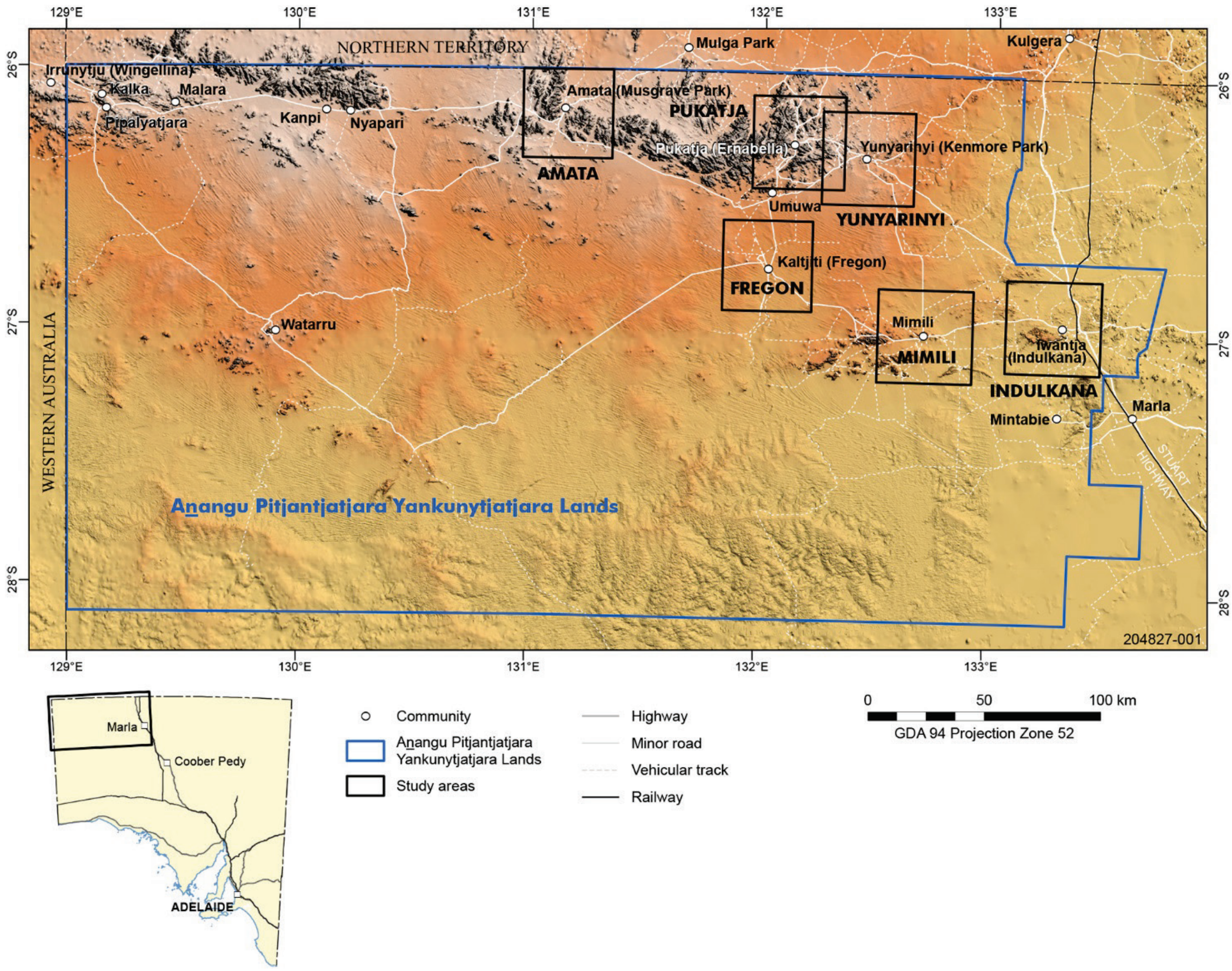


Figure 1. Map of northwest South Australia showing the boundary of the APY Lands and the main infrastructure. The base map is the digital elevation model. The small squares are the map areas presented in this report.

DATASETS AND APPROACH

The approach was to examine any available existing datasets in order to recognise faults, breccia zones and areas of fractured rock.

Several geological datasets were used, including previously mapped outcrop geology and structural elements that was acquired by GSSA (e.g. Conor, 2004; Krieg, 1972; Major et al., 1967; Sprigg et al., 1959), as well as previously interpreted structures (e.g. Aitken et al., 2009a; Major and Conor, 1993). The outcrop geology was used to recognised geological contacts that could have acted as rheological boundaries and focussed deformation, leading to localised deformation and fracturing. The structural elements allowed areas of foliated, jointed and fractured rocks to be recognised. This data has been digitally captured and is available in the South Australian Resources Information Geoserver (SARIG: www.statedevelopment.sa.gov.au/sarig).

Spatial and spectral data, such as orthoimages (including Google Earth imagery), Digital Elevation Models (e.g. 1 sec SRTM DEM), and Landsat imagery (e.g. TM5 and ETM7) were used. These images allowed areas of irregularly textured outcrop, which could represent brecciated and fractured rock, to be recognised.

Aeromagnetic images were used to highlight unexposed demagnetised linear features where fluid flow and alteration has destroyed the magnetic minerals. This likely occurred during faulting and fracturing of the rock. The aeromagnetic images, in conjunction with the orthoimages, made it possible to trace and correlate geographical features, such as linear valleys, with the extensions of mapped faults and fractures.

Other datasets included the Geoscience Australia Earthquake Database (http://www.ga.gov.au/earthquakes/searchQuake.do), which made it possible to recognise sites of recent activity or reactivation of structures and link them, where possible, to the interpreted structures.

The relevant data and interpretations of these datasets were then compiled in ArcGIS 10.3 into maps centred around several of the main communities (Fig. 1), which are included in each section. The maps show the main structures, such as mylonites, faults, and foliations, which were compiled based on the previous geology and aeromagnetic images (see above). The maps also include the simplified outcrop surface geology (as previously mapped) showing where there is outcrop, the main rock types, and exposed contacts. The outcrop layer, rather than the interpreted solid bedrock geology, was used as this allowed the relationship between the geology and geographical features on the surface to be recognised. This was particularly important where the unexposed structures could be traced along linear valleys. The 100K Geology layer in SARIG contains several generations of mapping that were compiled at various scales. This has often resulted in mismatches between adjoining map sheets, which have not been reconciled as part of this project. In the case of areas with little to no outcrop, e.g. Fregon, a basic new interpretation of the bedrock geology has been compiled.

Once the structures had been interpreted, a series of potential targets were recognised. These often focus on the main areas of structural complexity. In particular, areas of intersecting or anastomosing features have been selected as they would potentially have greater porosity and permeability and larger volume. Therefore, they potentially form a greater reservoir, with the larger areas of outcrop providing a greater catchment area. These targets are highlighted on the maps as polygons, but it is important to note that no priority or ranking was applied to these targets.

GEOLOGY OF THE MUSGRAVE PROVINCE

The study areas includes rocks from three distinct geological provinces and several palaeodrainage systems; the central and eastern part of the Proterozoic Musgrave Province, the Officer Basin, the north-western margin of the Mesozoic Eromanga Basin. The palaeodrainage systems include the Cainozoic Lindsay and Serpentine palaeodrainage systems and the north-western part of the Hamilton Basin (Fig. 2).

MUSGRAVE PROVINCE

The middle to late Mesoproterozoic Musgrave Province covers an area of c. 120 000 km^2, straddling the South Australia, Northern Territory and Western Australia borders (Fig. 2). The oldest exposed rocks belong to the Birksgate Complex, which comprise amphibolite to granulite facies, felsic and minor mafic gneisses with igneous, volcanic, volcaniclastic and, less commonly, sedimentary precursors (Edgoose et al., 2004; Major and Conor, 1993; Wade et al., 2006; Wade et al., 2008). SHRIMP U-Pb geochronology on zircons from these rocks indicate that the protoliths have ages between c. 1620 and 1550 Ma (Camacho and Fanning, 1995; Edgoose et al., 1993; Edgoose et al., 2004; Scrimgeour and Close, 1999). The Musgrave Province can be divided along the broadly east-trending Woodroffe Thrust into a northern Mulga Park Subdomain, which is composed of amphibolite-facies rocks, and a southern Fregon Subdomain comprising granulite-facies rocks. The difference in metamorphic grade is interpreted to represent the exposure of different crustal levels that were juxtaposed during the Petermann Orogeny (Camacho, 1989; Major and Conor, 1993).

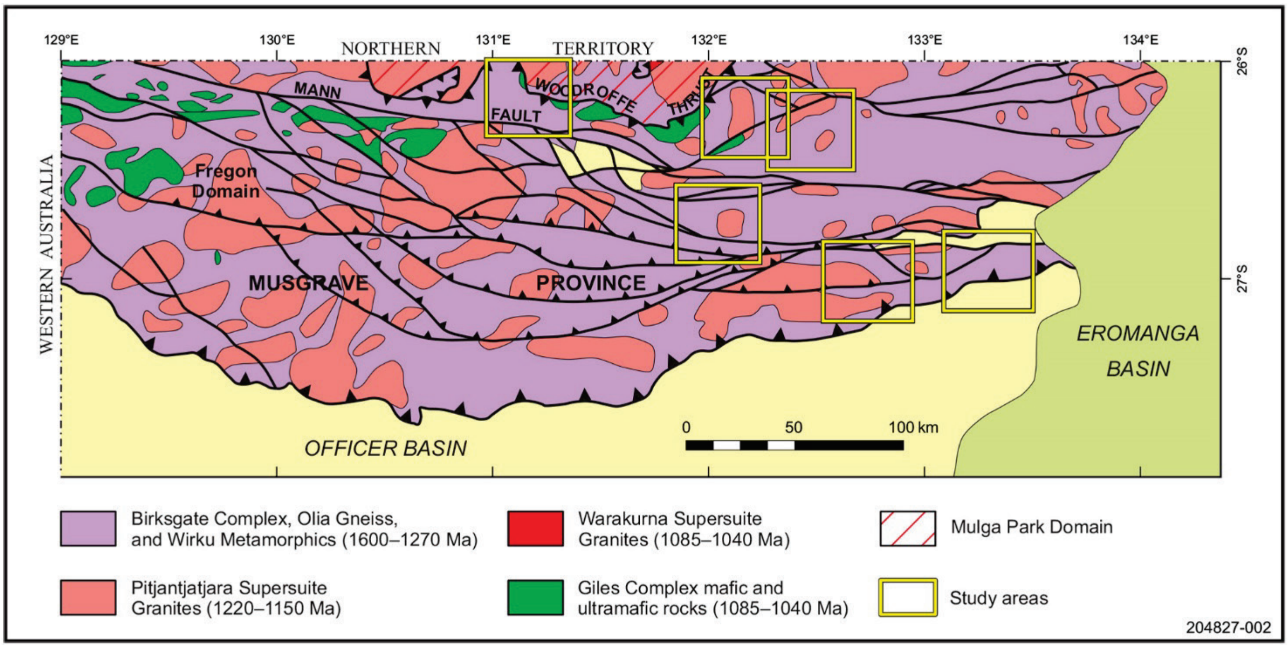


Figure 2. Geological map of the Musgrave Province showing the main geological units. The small squares are the map areas presented in this report (see Fig. 1 for labels).

There is also evidence for older crust in the Musgrave Province. A population of c. 2800 Ma zircons that were collected in a stream sediment sample from north of the Indulkana Range, has been interpreted to represent Archaean basement to the Musgrave Province (Gum and Belousova, 2006). The Hf isotopic data that was collected from zircons in the western Musgrave Province, suggests there was also a major period of crustal formation at c. 1900 Ma (Kirkland et al., 2013).

A metasedimentary cover sequence, with a maximum depositional age of c. 1.4 Ga, is interpreted to unconformably overlie the protoliths of the Birksgate Complex in the eastern Musgrave Province (Wade et al., 2008). The metasedimentary rocks are interlayered with felsic, mafic, and calc-silicate gneisses, and have been interpreted as a metavolcanic sequence (Conor, 2004). The extent is of this package is unknown.

The rocks of the Musgrave province were subsequently deformed and metamorphosed at amphibolite to granulite facies during the province-wide c. 1220–1120 Ma Musgravian Orogeny (Edgoose et al., 2004; Major and Conor, 1993; Smithies et al., 2010). Large volumes of predominantly felsic magma, which have been grouped into the Pitjantjatjara Supersuite, intruded during and immediately following the Musgravian Orogeny (Edgoose et al., 2004; Howard et al., 2011; Smithies et al., 2011).

The tectonic setting of the Musgravian Orogeny is unclear. Based on the long-lived, widespread nature of the event, and the high-temperature granites of the Pitjantjatjara Supersuite, it is considered to have been associated with extension and/or upwelling within an intracontinental setting (Smithies et al., 2010; Smithies et al., 2011). Alternatively, Aitken and Betts (2008) proposed that the Grenville-aged (i.e. c. 1300–1100 Ma) deformation in the Musgrave Province was the result of the clockwise rotation of the South Australian Craton, as it collided with the combined West and North Australian Cratons.

The Musgravian Orogeny was followed by the c. 1085–1040 Ma Giles Event. The igneous rocks of this event have been grouped into the Warakurna Supersuite, which includes the variably deformed, mafic-ultramafic layered intrusions of the Giles Complex, bimodal volcanic rocks and associated rift sediments of the Bentley Supergroup, the Tjauwata Group, the Alcurra Dolerite dyke suite, and minor granitic intrusions and felsic dykes (Close et al., 2003; Edgoose et al., 2004; Evins et al., 2010; Glikson et al., 1995; Glikson et al., 1996; Howard et al., 2011; Woodhouse and Gum, 2003). The Giles Event has been interpreted to form part of the Warakurna Large Igneous Province that affected much of central and western Australia (Wingate et al., 2004).

Following the Giles Event, the Musgrave Province was intruded by a number of dolerite suites. These include the c. 1000 Ma Kullal Dyke Suite (Glikson et al., 1996; Howard et al., 2011), the c. 825 Ma Amata Dolerite, a correlative of the Gairdner Dolerite that intrudes the Gawler Craton (Glikson et al., 1996; Wingate et al., 1998; Zhao and McCulloch, 1993; Zhao et al., 1994). Recently, an east-trending dolerite dyke from the eastern part of the province was found to have an Sm-Nd crystallisation age of c. 760 Ma and an εNd isotopic composition that is more juvenile than the c. 1085–1040 Ma Alcurra Dolerites (Dutch et al., 2013). The dolerite was interpreted to belong to a new suite of dolerite dykes that are younger than the Amata/Gairdner Dolerite (Werner et al., 2014), and which may be associated with rifting and the development of the Neoproterozoic Adelaidean Basin (Preiss, 2000).

The 570–530 Ma Petermann Orogeny was a major intracratonic event that resulted in the reactivation of several crustal scale, east-west trending shears, faults and thrusts and the development of widespread mylonitic shear fabrics, and the final exhumation of the Musgrave Province from beneath the Centralian Superbasin (Camacho et al., 1997; Camacho and McDougall, 2000; Edgoose et al., 2004; Howard et al., 2011; Pawley et al., 2014; Raimondo et al., 2009; Scrimgeour and Close, 1999). These structures, particularly the north-dipping Wintinna Hill Seismic Subdomain to the south, and the south-dipping Woodroffe Thrust to the north, are interpreted to have accommodated the exhumation of the Fregon Domain (Korsch and Kositcin, 2010), although the steeper Wintiginna Fault and Mann-Ferdinand-Marryat fault system were also interpreted to have been important for exhumation (Aitken et al., 2009a; Aitken et al., 2009b). Coeval with the Petermann Orogeny was the development of the Levenger and Moorliyanna grabens, which are strike-slip basins that were infilled with clastic sediments derived from the locally exposed Musgrave Province basement (Coats, 1962).

The c. 400–300 Ma Alice Springs Orogeny is a significant event which is best recorded in the Arunta Province (Northern Territory), where it is associated with the uplift of the Arunta Block from beneath the Centralian Superbasin and the deposition of early Devonian syn-orogenic sediments into the Amadeus Basin (Edgoose et al., 2002; Haines et al., 2001; Hand and Sandiford, 1999). This event has also been observed in the eastern Musgrave Province, with apatite fission track dating indicating that the Ayers Range Granite underwent uplifting and cooling during the Alice Springs Orogeny (Tingate, 1990). A recent low-T thermochronological study found that deformation was more widespread during the Alice Springs Orogeny, with exhumation of an inverted graben occurring along the Marryatt Fault and the Coglin lineament (Agostino, 2015).

OFFICER BASIN

Sediments of the intracratonic Officer Basin have been deposited during the Neoproterozoic to Late Devonian and crop out in a linear belt south of the Musgrave Block, marking the northern limit of the basin (Fig. 2). The two major depocentres in South Australia, the Birksgate Sub-basin and Munyarai Trough, are separated by a structural rise, and contain 5–10 km of sediment respectively. The succession contains shallow marine, aeolian, fluvial, lacustrine and glacial deposits. The basin developed under compressional and extensional tectonic regimes punctuated by deformational and erosional events.

Following a period of minor, short-lived rifting, thermal sag allowed deposition of predominantly fluvial and marine siliciclastic and carbonate sediments and evaporates. This succession is terminated by minor erosion at 780–760 Ma (Jackson and van de Graaff, 1981; Tingate and McKirdy, 2003). The resultant erosional surface is overlain by fluvial and glacigene sediments associated with the Sturtian and/or Marinoan glaciations.

Depositional patterns were changed abruptly by the Petermann Ranges Orogeny in the late Neoproterozoic with significant north-south-directed shortening resulting in folding and thrusting. Renewed extensive uplift along the northern margin of the basin resulted in deposition of widespread fluvial and marine siliciclastics and carbonates during the latest Proterozoic-Late Cambrian. Cambrian sedimentation ceased with the onset of the Delamerian Orogeny, which was accompanied by extensive basaltic volcanism in the central and western parts of the basin. At this time also further thrusting occurred and reactivated Stage 2 structures (Tingate and McKirdy, 2003).

A period of extension during the Ordovician led to deposition of shallow marine to fluvio-deltaic siliciclastics in the northeastern part of the basin. Uplift associated with the Alice Springs Orogeny terminated sedimentation in the latest Ordovician or Silurian (Edgoose et al., 2002; Haines et al., 2001; Hand and Sandiford, 1999). A suspected extensional event during the Late Devonian provided accommodation space for the deposition of fluvial siliciclastics also in the northeastern part of the basin (Jackson and van de Graaff, 1981).

During the Alice Springs Orogen basement of the Musgrave Block was thrust up over the Officer Basin succession along a north-dipping fault plane oriented approximately east-west (Milton and Parker, 1973). During this period the basin sediments were deformed into gentle, open folds, which were subsequently uplifted forming amongst others the Indulkana Ranges.

Deposits of the Permian Arckaringa Basin occur along the southeast margin of the APY Lands and have only been encountered in the subsurface.

MESOZOIC, CENOZOIC AND PALAEOVALLEYS

Following the Alice Springs Orogeny the Musgrave Province has undergone at least one phase of intensive deep weathering and erosion prior to the deposition of clastic sediments of the Mesozoic Eromanga Basin along its eastern margin (Fig. 2: Cotton et al., 2006; Krieg and Rogers, 1995).

Sediments of the Eromanga Basin, which is part of the Great Artesian Basin, occur on the southeast margin of the APY Lands. They were deposited between ~150–100 Ma and include important aquifers.

Intense chemical weathering of the Mesozoic sedimentary rocks as well as basement rocks occurred at several periods during the late Cretaceous and Tertiary and resulted in deep weathering profiles that can reach up to 90 m below the present day land surface. The typically composite weathering profiles are characterised by kaolinisation and mottled or varicoloured, pallid, ferruginous or siliceous zones. Multiple phases of post-Mesozoic, dominantly siliceous and ferruginous induration, led to the formation of widespread silcrete and ferruginous duricrust.

During the Neogene, rivers, that had their headwaters in the ranges and drained southwards into the Eucla Basin, incised up to 70 m into the underlying weathered rocks. The channels were subsequently filled with clastic sediments during a warm and wet subtropical to tropical climate forming the infill of the Lindsay and Serpentine palaeodrainage systems as well as the Hamilton Basin (Fig. 3: Lewis et al., 2010; Magee, 2009; Rogers, 1995). The lacustrine Mangatitja Formation, which crops out extensively throughout the Musgrave Province, is a remnant of this event (Rogers, 1995). The clastic sediments are mostly composed of clay, sandy clay and minor lenses of coarse sand and gravel and are commonly associated with near surface calcrete deposits. Lewis et al. (2010) considered the palaeovalleys to be the best targets for groundwater supply, however their internal lithological heterogeneity could affect groundwater flow and hence make them a less prospective groundwater target. Also the groundwater salinity in the palaeochannels is high with an average of 4500 mg/L (Varma, 2012).

In the Quaternary, the onset of aridity, with episodes of alluvial and aeolian activity, resulted in today's landscape with the formation of alluvial plains, sand plains and aeolian dunes and dunefields. The modern sand dunes and sand spreads of the Great Victoria Desert mantle the lowlands and the southern region of the APY Lands.

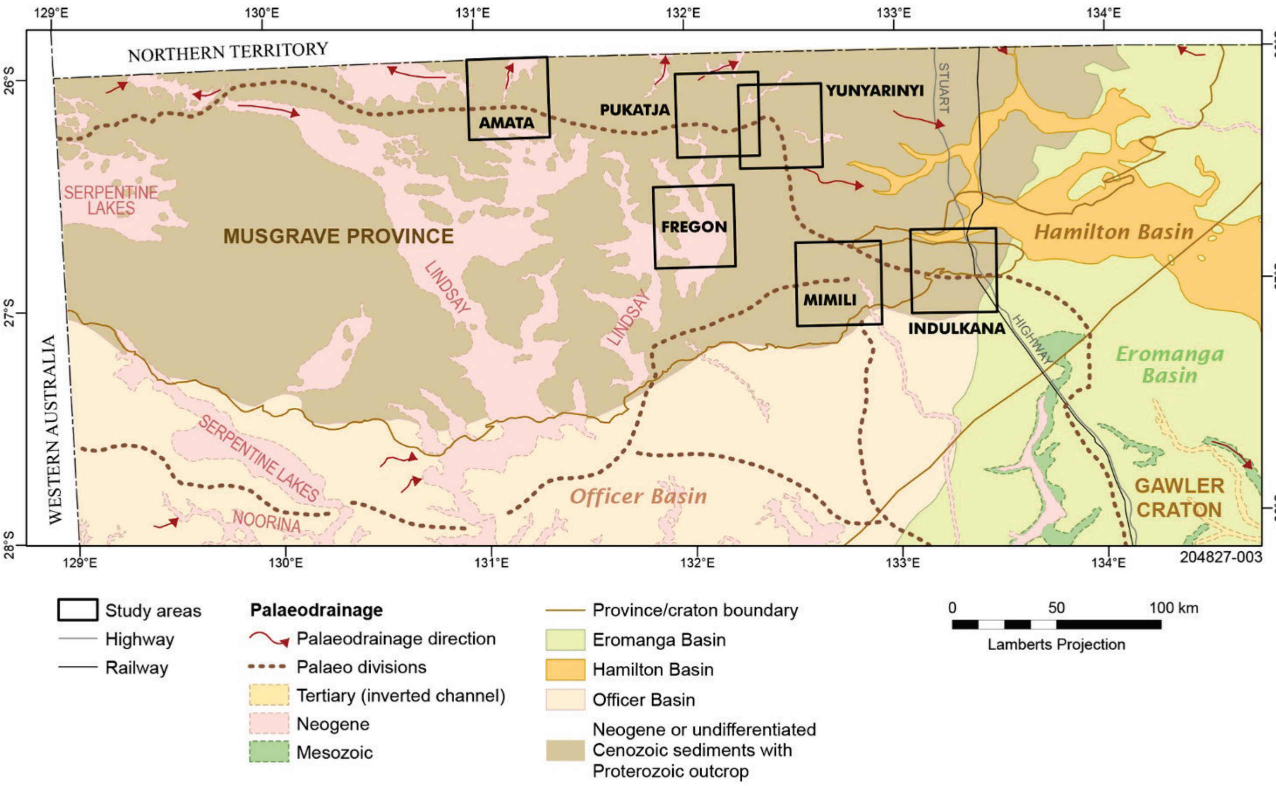


Figure 3. Palaeodrainage map of the Musgrave Province, showing the main palaeochannel systems mentioned in this report. Modified from Hou et al. (2012). The small squares are the map areas presented in this report.

The Musgrave Province is still tectonically active with a number of significant earthquakes occurring in the region in the past 40 years (Fig. 4). In 1986 a 6.0 magnitude earthquake produced a 13 km long fault scarp with a maximum throw of 0.6 m along the Marryat Fault zone. More recently, the community of Pukatja (Ernabella) recorded two magnitude 5.7 earthquakes in both 2012 and 2013 (http://www.ga.gov.au/earthquakes/searchQuake.do).

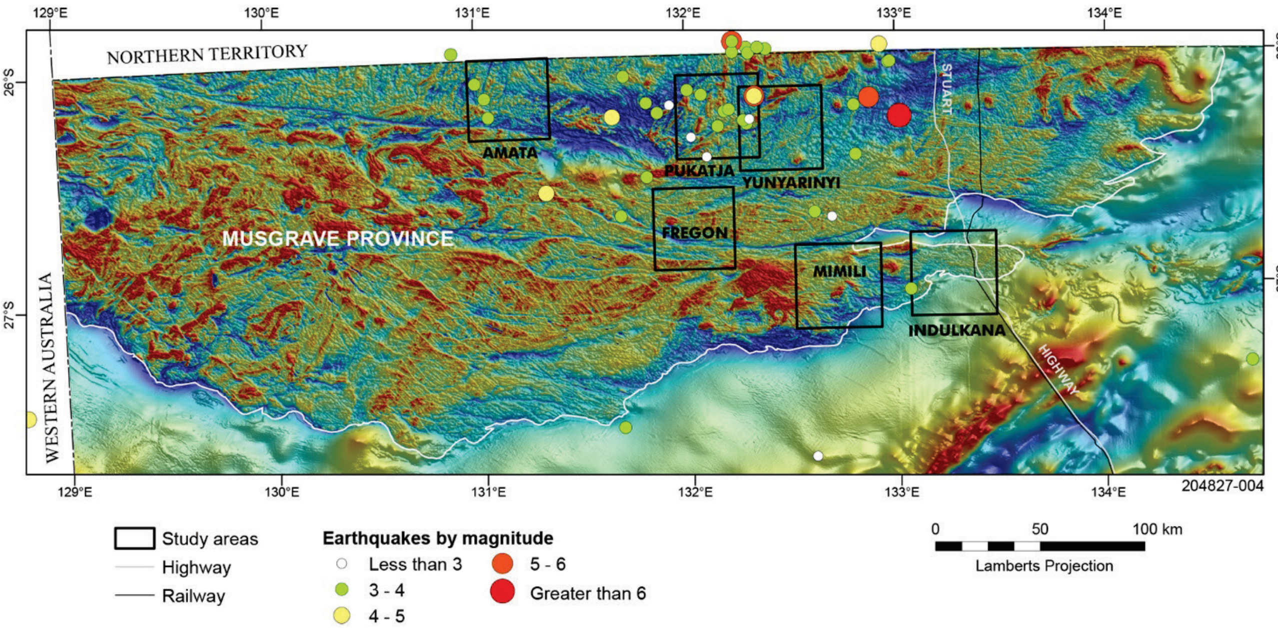


Figure 4. Total magnetic intensity image of the study area showing the distribution of earthquakes in the GA Earthquake Database. The small squares are the map areas presented in this report.

AMATA AREA

The geology of the Amata area can be broken down into seven main stages of development.

c. 1620–1550 Ma: Formation of the protoliths to the Birksgate Complex. The protoliths included felsic and minor mafic intrusive, volcanic, and volcaniclastic rocks, with less common sedimentary rocks (Edgoose et al., 2004; Major and Conor, 1993; Wade et al., 2006; Wade et al., 2008).

c. 1220–1120 Ma: The Musgravian Orogeny resulted in granulite and amphibolite facies metamorphism to produce the gneisses of the Birksgate Complex and the Olia Gneiss (Edgoose et al., 2004; Major and Conor, 1993; Smithies et al., 2010). Thrusting during the Petermann Orogeny resulted in the juxtaposition of the granulite facies Olia Gneiss to the north with the amphibolite facies Birksgate Complex to the south of the Woodroffe Thrust (Major and Conor, 1993). Granites of the Pitjantjatjara Supersuite intruded during, and immediately following, the Musgravian Orogeny (Edgoose et al., 2004; Howard et al., 2011; Smithies et al., 2011).

c. 1085–1040 Ma: Intrusion of mafic magmas of the Giles Complex. The magmas formed large, often layered bodies, and thin dykes that cross-cut all of the earlier phases (Close et al., 2003; Edgoose et al., 2004; Evins et al., 2010; Glikson et al., 1995; Glikson et al., 1996; Howard et al., 2011; Woodhouse and Gum, 2003).

c. 570–530 Ma: The Petermann Orogeny was a dextral transpressional event that resulted in the exhumation of the core of the Musgrave Province along an east-trending flower structure. Uplift was accommodated by thrusts near the margins of the province, i.e. the Woodroffe Thrust that can be traced across the Amata area, and steeper structures closer to the core of the province, i.e. the Mann Fault that occurs south of Amata (Camacho et al., 1997; Camacho and McDougall, 2000; Edgoose et al., 2004; Howard et al., 2011; Pawley et al., 2014; Raimondo et al., 2009; Scrimgeour and Close, 1999).

Ordovician: The Alice Springs Orogeny resulted in the reactivation of some of the Petermann-aged structures. It was associated with fluid flow that caused localised epidote and silica alteration (e.g. Conor, 2004).

Tertiary: Development of palaeochannels, such as the Neogene Lindsay Palaeochannel, which formed a series of connected basins that are associated with wider drainages (Fig. 3: Hou et al., 2012; Lewis et al., 2010; Magee, 2009; Rogers, 1995). The palaeochannels are relatively deep (>20–25 metres below surface), and may contain groundwater-bearing fluvial sediments within valley profiles that are not evident on the surface.

Quaternary: Alluvial/fluvial sediments were deposited within channels, and across broader floodplain areas. There was also deposition of aeolian sediments. Earthquakes have been recorded in the area, indicating neotectonic activity (http://www.ga.gov.au/earthquakes/searchQuake.do).

STRUCTURES IN THE VICINITY OF AMATA

Based on a review of the existing geological and geophysical datasets, several observations can be made about the faults and structures around Amata (Fig. 5):

- The broad, shallowly south-dipping Woodroffe Thrust outcrops near Amata. The thrust is generally east- to east-southeast-striking, although north-striking mylonites have also been mapped, most notably to the north and west of Amata;
- The east-southeast-striking Mann Fault outcrops about 16 km south of Amata;
- There are relatively narrow faults that form low aeromagnetic lineaments, which often correspond with curviplanar valleys, and appear to truncate and deflect the gneissosity. These narrow structures appear to occur in two main orientations;
    - Those to the west of Amata (i.e. near Mount Morris) are north-northeast-striking and are at a low angle to a north-trending segment of the Woodroffe Thrust,

- Those to the east of Amata (i.e. near Weelo Soak) are east-southeast- to southeast-striking and sub-parallel to an east-trending segment of the Woodroffe Thrust,
    - Both of these orientations may represent splays off the larger mylonite zones;
- There appears to be some unexposed curviplanar faults to the southeast of Amata (i.e. near Manyirkanga) that are defined by aeromagnetic lineaments that correspond to breaks in the outcrop; and
- Some basement rocks adjacent to the faults have experienced epidote and silica alteration, indicating fluid flow within the structures.

These structures are generally interpreted to have formed during the Petermann Orogeny, with the spatially associated alteration possibly occurring during younger reactivation.

Significantly, the Amata area has experienced five earthquake events in the past 50 years that were larger than magnitude 2.3, many of which resulted in surface ruptures (http://www.ga.gov.au/earthquakes/searchQuake.do). This suggests that reactivation of the older structures is still occurring, which may increase porosity and permeability along these features.

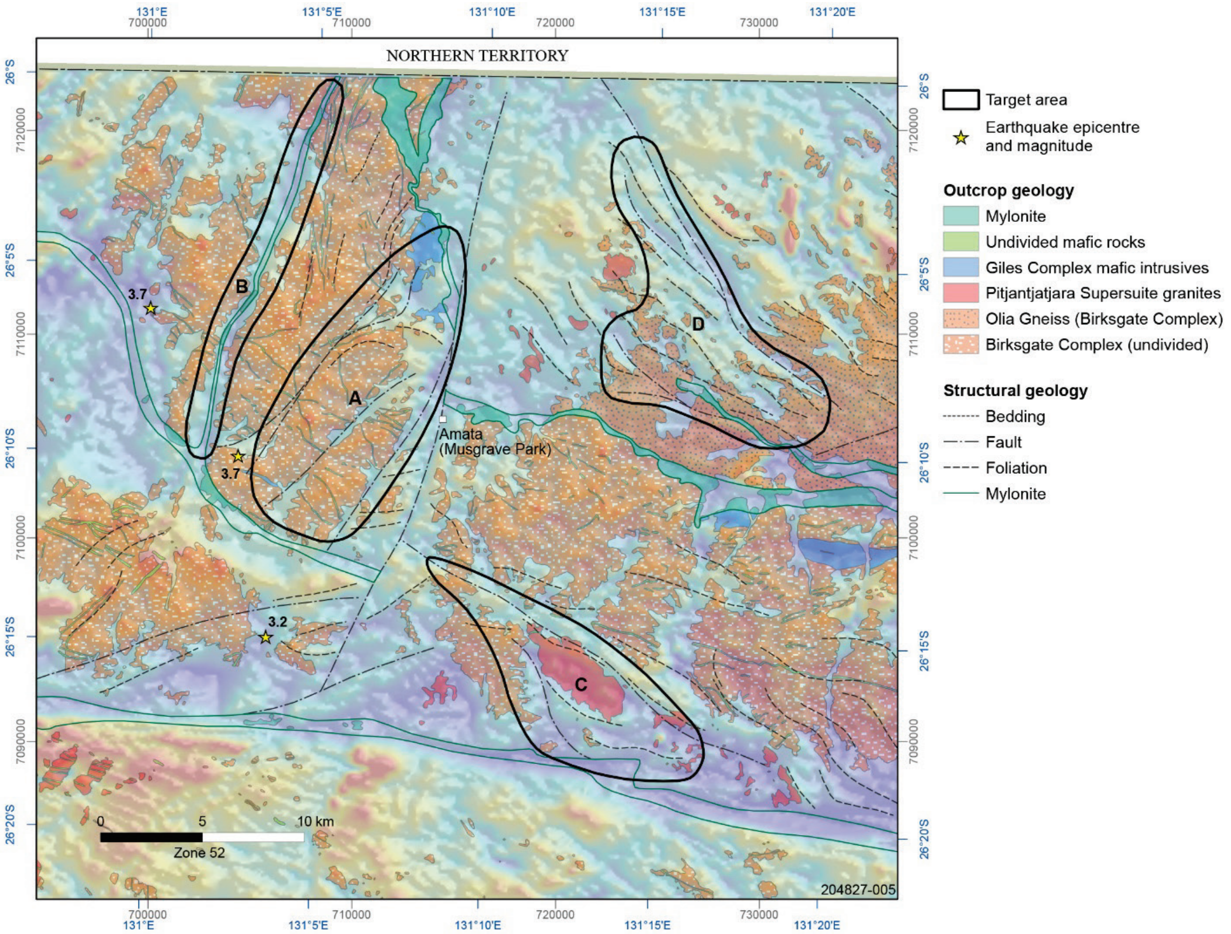
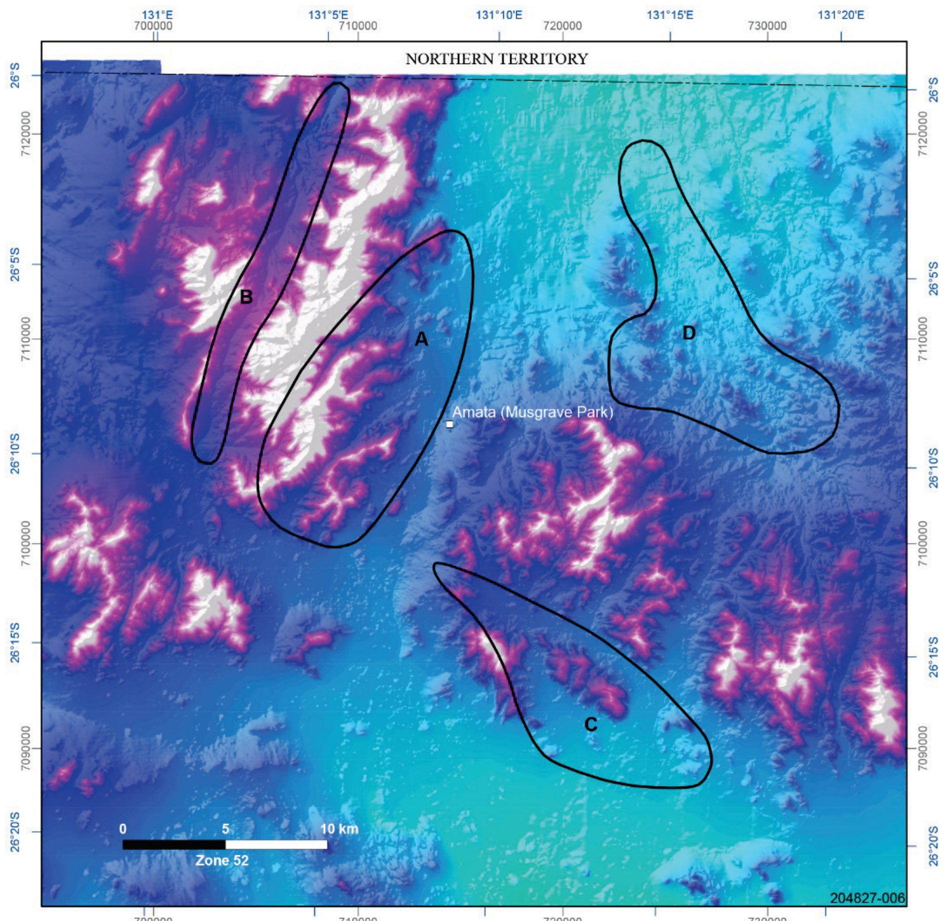


Figure 5. Maps and datasets of the Amata area. a) shows the preexisting simplified outcrop geology polygons and interpreted structural geology linework over the total magnetic intensity (TMI). The yellow stars are the earthquakes from the GA Earthquake Database. The polygons with thick black lines are the target areas. **b; next page)** shows the target areas over the digital terrane model (DTM), which has been stretched to the whole dataset and has northwest hill-shading. **c)** shows the target areas over the topographic map.



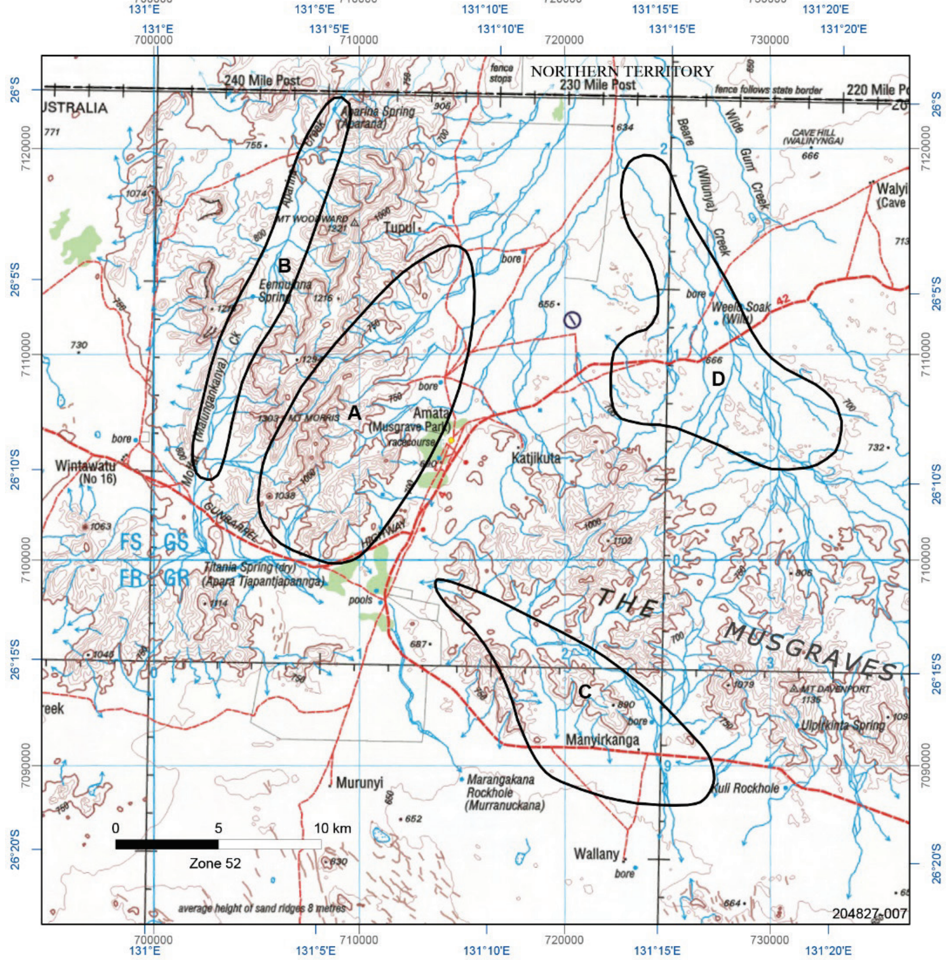


Figure 5 b and c.

POSSIBLE TARGETS IN THE AMATA AREA

The geophysical datasets of the area were examined for zones of faulted, fractured and weathered basement rocks that may represent aquifers. These are represented in the datasets by low aeromagnetic lineaments, which are often parallel to linear to curvilinear valleys, and are interpreted as faults. Networks of faults, rather than single isolated structures, were preferred since the intersecting structures may have greater permeability and porosity. There are several areas that meet the criteria, and would be worth a closer examination (Fig. 5). These are not listed in any particular order and include:

A. One target area is located just to the west of Amata, extending in a south-southwest direction for about 16 km. The southern part of this area contains a series of sub-parallel, north-northeast-striking structures that are apparent as lows on the aeromagnetic images. These structures are locally at a high angle to measured gneissosity, and follow linear drainage systems. In the northern part, there appears to be a series of structures that wrap along the contacts between the different phases in the bedrock, before linking up with the Woodroffe Thrust;
B. About 10 km to the west of Amata is a north-northeast-striking drainage system that can be traced for about 18 km, and comprises the southern Malungankanya and northern Aparina Creek. Two springs have been recorded in the north-flowing Aparina Creek, including Eennuinna Spring in the middle of the target, and Aparina Spring at the northern end of the target near the border with the Northern Territory. This system overlies a low aeromagnetic feature, and also contains several outcrops of mylonitic rocks;
C. About 15 km to the south-southeast of Amata, altered gneisses and gneissic granite are cut by a series of southeast-striking features that correspond to low aeromagnetic lineaments and drainage systems. These features appear to wrap into the Mann Fault to the south; and
D. About 15 km to the east-northeast of Amata, the foliation in the gneisses is southeast-striking and broadly anastomosing, with numerous low-angle truncations representing shearing. The shears correspond to low aeromagnetic lineaments and breaks in the drainage systems. This area comprises a broad anastomosing drainage system with documented soaks, e.g. Weelo Soak.

Although they are prominent features, it is unclear whether the Mann Fault that forms a broad east-striking mylonite zone to the south of Amata, and the Woodroffe Thrust to the north would be suitable aquifers. This is because recrystallisation and grainsize reduction during deformation may have reduced porosity and permeability.

However, target B contains several outcrops described as mylonites, yet this zone contains several springs suggesting that they may form suitable aquifers. It is interesting to note that target B is at a high angle to the other mylonite zones, and this orientation may be the reason for the springs as it could have been at a favourable orientation for reactivation during subsequent deformations.

FREGON AREA

The geology of the Fregon area can be broken down into eight main stages of development.

c. 1620–1550 Ma: Formation of the protoliths to the Birksgate Complex. The protoliths included felsic and minor mafic intrusive, volcanic, and volcaniclastic rocks, with less common sedimentary rocks (Edgoose et al., 2004; Major and Conor, 1993; Wade et al., 2006; Wade et al., 2008).

c. 1220–1120 Ma: The Musgravian Orogeny resulted in granulite and amphibolite facies metamorphism to produce the gneisses of the Birksgate Complex (Edgoose et al., 2004; Major and Conor, 1993; Smithies et al., 2010). Granites of the Pitjantjatjara Supersuite intruded during, and immediately following, the Musgravian Orogeny (Edgoose et al., 2004; Howard et al., 2011; Smithies et al., 2011).

c. 1085–1040 Ma: Intrusion of mafic magmas of the Giles Complex. The magmas formed large, often layered bodies, and thin dykes that cross-cut all of the earlier phases (Close et al., 2003; Edgoose et al., 2004; Evins et al., 2010; Glikson et al., 1995; Glikson et al., 1996; Howard et al., 2011; Woodhouse and Gum, 2003).

c. 825–760 Ma: Intrusion of the Amata Dolerite, which is a correlative of the Gairdner Dolerite that intrudes the Gawler Craton (Werner et al., 2014).

c. 570–530 Ma: The Petermann Orogeny was a dextral transpressional event that resulted in the exhumation of the core of the Musgrave Province along an east-trending flower structure (Korsch and Kositcin, 2010; Lambeck and Burgess, 1992). Uplift was accommodated by thrusts near the margins of the province (e.g. the Everard Thrust), and steeper structures in the core of the province (e.g. the Wintiginna and Poorara faults: Camacho et al., 1997; Camacho and McDougall, 2000; Edgoose et al., 2004; Howard et al., 2011; Pawley et al., 2014; Raimondo et al., 2009; Scrimgeour and Close, 1999). Strike-slip movement resulted in basins, such as the Moorilyanna Graben to the east (Coats, 1962).

Ordovician: The Alice Springs Orogeny resulted in reactivation of some Petermann-aged structures. The orogeny was also associated with fluid flow that caused localised epidote and silica alteration (e.g. Conor, 2004).

Tertiary: Development of palaeochannels, such as the Neogene Lindsay Palaeochannel, form a series of connected basins that are associated with wider drainages (Fig. 3: Hou et al., 2012; Lewis et al., 2010; Magee, 2009; Rogers, 1995). The Lindsay Palaeochannel covers a significant part of the Fregon area. The palaeochannels are relatively deep (>20–25 metres below surface), and may contain groundwater-bearing fluvial sediments within valley profiles that are not evident at the surface.

Quaternary: Alluvial/fluvial sediments that form within channels with current bedload, and across broader floodplain areas, and aeolian sediments. Earthquakes have been recorded just outside the map area, indicating neotectonic activity (http://www.ga.gov.au/earthquakes/searchQuake.do).

STRUCTURES IN THE VICINITY OF FREGON

Based on a review of the existing geological and geophysical datasets, several observations can be made about that the faults around Fregon (Fig. 6). Note that due to the sparse outcrop around Fregon, the interpretation is primarily based on the geophysical datasets with all structures unexposed:

- The area around Fregon is dominated by a series of unexposed, east-striking, laterally extensive faults that can be traced as low aeromagnetic lineaments across the map area. These faults appear to truncate the boundaries of granite plutons and locally dextrally deflect the gneissosity (i.e. about 15 km south of Fregon). The faults can be subdivided into two main sets;
    - Between 5 and 19 km south of Fregon is a series of anastomosing, east-striking faults that form a zone bounded by the Wintiginna Fault to the south. The bounding faults of this zone also form the marginal structures of the western extent of the Moorilyanna Graben, which is located to the east, indicating they were active during the 600–530 Ma Petermann Orogeny. The core of this zone is characterised by a

lower magnetic response than the surrounding areas, suggesting it may have a history of relatively pervasive fluid flow and alteration. Overall, this zone appears to form a mylonite with widespread deformation; and

- Between 7 and 17 km north of Fregon is a series of curviplanar faults that are generally parallel and form discrete structures (c.f. the zone to the south of Fregon). This series of faults includes the Echo Fault, which along with the De Rose Fault, forms the northern margin of the Moorilyanna Graben. The Echo Fault is interpreted to be a long-lived structure with several stages of reactivation (Pawley et al., 2014). An exception is an east-southeast-striking zone that extends from 8 km north to 29 km northeast of Fregon. This zone is characterised by lower magnetic response, and may represent demagnetised or altered rocks where fluid flow has occurred adjacent to major structures or Giles Complex intrusives.

These structures have generally been interpreted to have formed, or been reactivated during the Petermann Orogeny.

Earthquakes have not been recorded in the vicinity of Fregon, however earthquakes with magnitude between 3.1 and 3.5 have been recorded along the Poorara Fault, about 60 km to the east and 30 km to the west of Fregon (Fig. 4; http://www.ga.gov.au/earthquakes/searchQuake.do). Two earthquakes with magnitudes of 2.4 and 2.8 were recorded about 24 km to the northwest of Fregon. This suggests that reactivation is still occurring, which may increase porosity and permeability along these features.

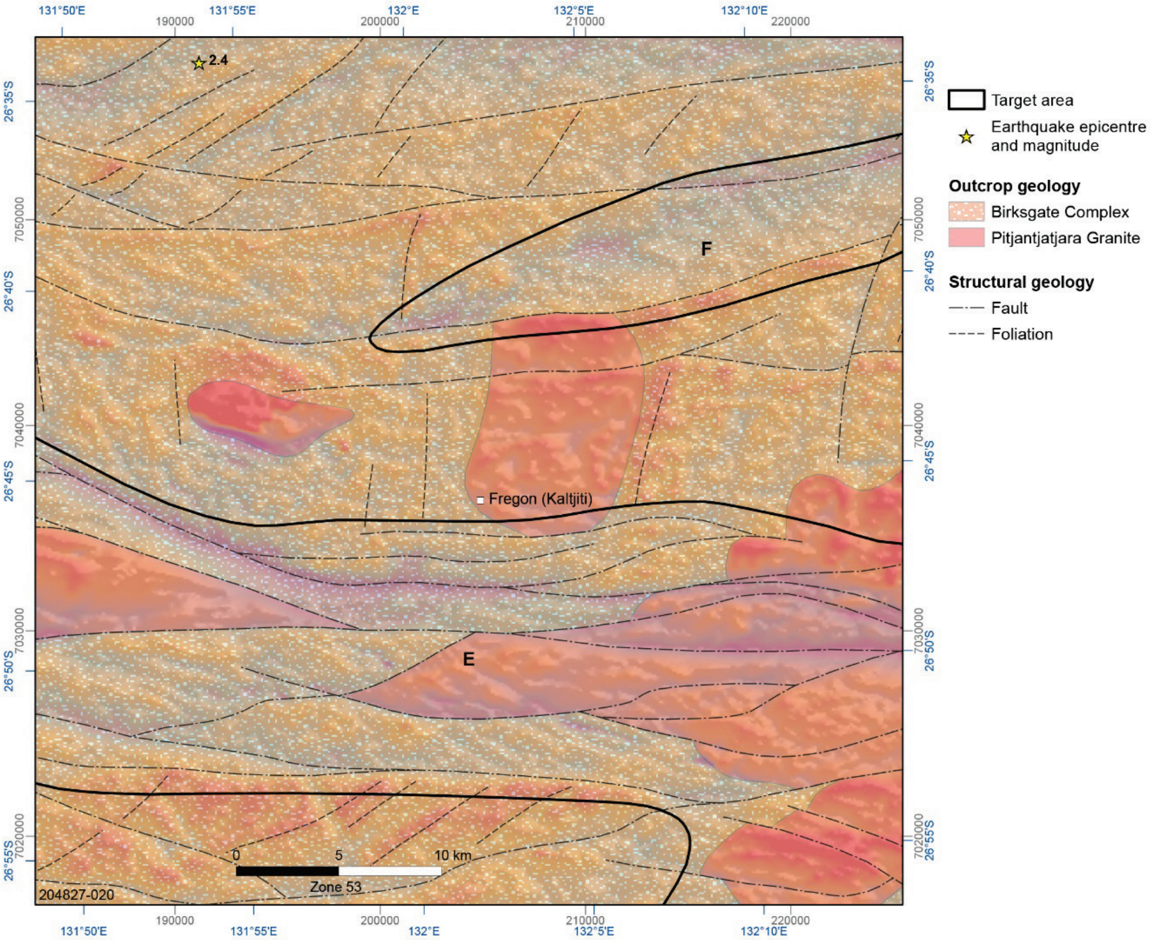


Figure 6. Maps and datasets of the Fregon area. a) shows the simplified interpreted bedrock geology polygons and structural geology linework over the TMI. The polygons with thick black lines are the target areas. **b; next page)** shows the target areas over the topographic map. The transparent yellow area is the distribution of the Lindsay Palaeochannel (Hou et al., 2012).

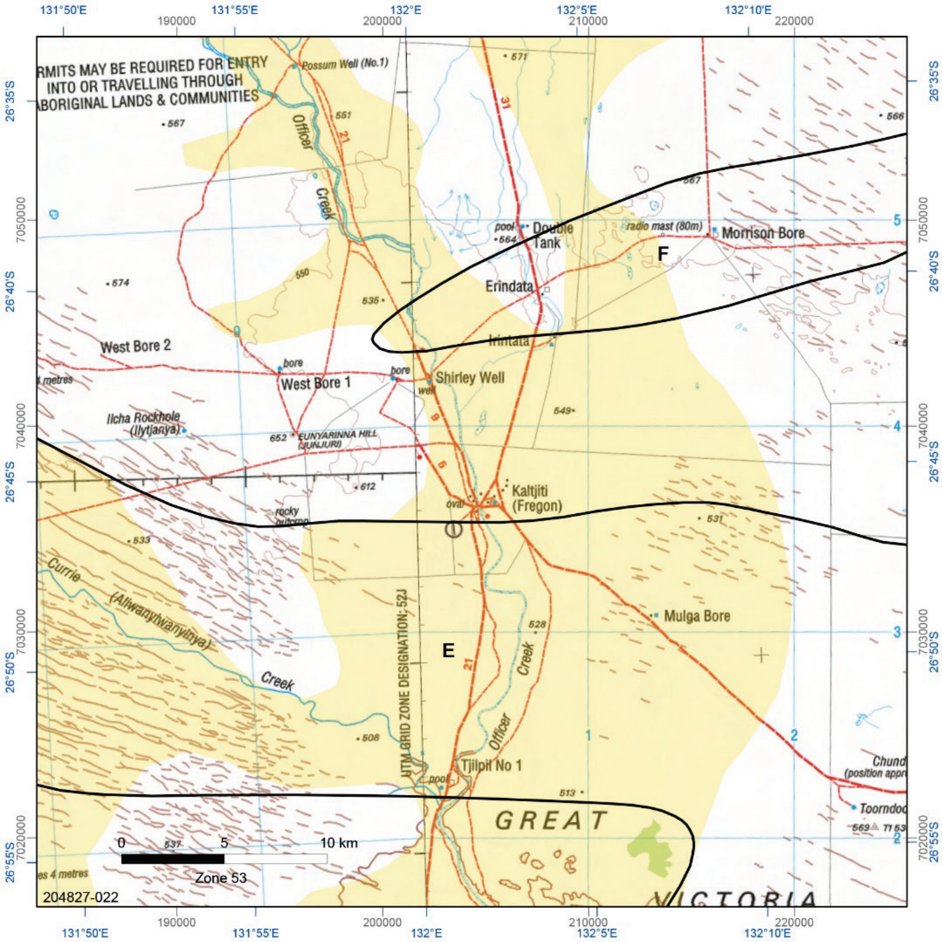


Figure 6 b.

POSSIBLE TARGETS IN THE VICINITY OF FREGON

The geophysical and geological datasets of the area were examined, looking for zones of faulted, fractured and weathered basement rocks that may represent aquifers. These were represented on the datasets by low aeromagnetic lineaments. Networks of faults, rather than single isolated structures, were preferred since the intersecting structures may have greater permeability and porosity. There are several areas that meet the criteria, and would be worth closer examination (Fig. 6). These include:

E. One possible target area is the laterally extensive zone of east-striking, anastomosing faults located south of Fregon. The demagnetisation in this area suggests fluid flow and alteration in this zone, with the anastomosing, intersecting structures providing pathways for fluid flow. The presence of earthquakes along strike of these structures suggests ongoing tectonic activity. Unfortunately, there is no outcrop in this area, which would help to narrow the target area; and

F. Another possible target is the fault-bounded demagnetised area northeast of Fregon, which appears to have focussed fluid flow in the past. However, the lack of outcrop also makes it difficult to precisely define targets in this area.

INDULKANA AREA

The geology of the Indulkana area can be broken down into nine main stages of development.

c. 1620–1550 Ma: Formation of the protoliths to the Birksgate Complex. The protoliths included felsic and minor mafic intrusive, volcanic, and volcaniclastic rocks, with less common sedimentary rocks (Edgoose et al., 2004; Major and Conor, 1993; Wade et al., 2006; Wade et al., 2008).

c. 1220–1120 Ma: The Musgravian Orogeny resulted in granulite and amphibolite facies metamorphism to produce the gneisses of the Birksgate Complex (Edgoose et al., 2004; Major and Conor, 1993; Smithies et al., 2010). Granites of the Pitjantjatjara Supersuite intruded during, and immediately following, the Musgravian Orogeny (Edgoose et al., 2004; Howard et al., 2011; Smithies et al., 2011).

c. 1085–1040 Ma: Intrusion of mafic magmas of the Giles Complex. The magmas formed large, often layered bodies, and thin dykes that cross-cut all of the earlier phases (Close et al., 2003; Edgoose et al., 2004; Evins et al., 2010; Glikson et al., 1995; Glikson et al., 1996; Howard et al., 2011; Woodhouse and Gum, 2003).

c. 825–760 Ma: Intrusion of the Amata Dolerite, which is a correlative of the Gairdner Dolerite that intrudes the Gawler Craton (Werner et al., 2014).

Neoproterozoic to late Palaeozoic: Deposition of the sedimentary rocks of the intracratonic Officer Basin, which occur at the base of the Indulkana Range.

c. 570–530 Ma: The Petermann Orogeny was a dextral transpressional event that resulted in the exhumation of the core of the Musgrave Province along an east-trending flower structure (Korsch and Kositcin, 2010; Lambeck and Burgess, 1992). Uplift was accommodated by thrusts near the margins of the province (e.g. the Everard Thrust), and steeper structures in the core of the province (e.g. the Wintiginna Fault: Camacho et al., 1997; Camacho and McDougall, 2000; Edgoose et al., 2004; Howard et al., 2011; Pawley et al., 2014; Raimondo et al., 2009; Scrimgeour and Close, 1999). Strike-slip movement along some of these structures (e.g. the Wintiginna Fault) resulted in basins, such as the Moorilyanna Graben (Coats, 1962).

Ordovician: Continued deposition in the Officer Basin resulted in the sedimentary rocks that form the Indulkana Range. This phase of deposition was terminated during the Alice Springs Orogeny (Edgoose et al., 2002; Haines et al., 2001; Hand and Sandiford, 1999), which resulted in the reactivation of some of the Petermann-aged structures. The orogeny was also associated with fluid flow that caused localised epidote and silica alteration (e.g. Conor, 2004).

Tertiary: Development of palaeochannels, such as the Neogene Lindsay Palaeochannel, which form a series of connected basins that are associated with wider drainages (Fig. 3: Hou et al., 2012; Lewis et al., 2010; Magee, 2009; Rogers, 1995). The palaeochannels are relatively deep (>20–25 metres below surface), and may contain groundwater-bearing fluvial sediments within valley profiles that are not evident at the surface.

Quaternary: Alluvial/fluvial sediments that form within channels with current bedload, and across broader floodplain areas, and aeolian sediments. Earthquakes have been recorded in the area, indicating neotectonic activity (http://www.ga.gov.au/earthquakes/searchQuake.do).

STRUCTURES IN THE VICINITY OF INDULKANA

Based on a review of the existing geological and geophysical datasets, several observations can be made about that the faults around Indulkana (Fig. 7):

- There is the unexposed, east-striking, curvilinear, north-dipping Everard Thrust to the south of Indulkana, which is concealed by the Palaeozoic sedimentary rocks of the Indulkana Range;

- The east-striking Wintiginna Fault is located about 11 km north of Indulkana where it forms the southern margin of the Moorilyanna Graben;
- There are a series of northwest-striking low aeromagnetic lineaments, about 12–25 km to the west-northwest of Indulkana (in the vicinity of Allan Well), which may represent faults as they are at a moderate angle to the gneissic trends. These lineaments also correspond to breaks in the outcrop and narrow valleys;
- NE-striking faults have been mapped to the west and southwest of the Indulkana Range (in the area around Chambers Bluff), where they are sub-parallel to the Everard Thrust. It is possible that these faults continue across the Indulkana Range, as prominent valleys in the range are parallel to aeromagnetic low lineaments; and
- There are several east-trending, often anastomosing, low aeromagnetic lineaments underneath Indulkana community that extend to the northeast and east for about 15 km. These lineaments can be traced through gaps in the outcrop, and may represent faults as they are at a moderate angle to the gneissic trends.

These structures have generally been interpreted to have formed, or been reactivated during the Petermann Orogeny.

On the 6th January 2015, an earthquake with a magnitude of 3.4 was recorded to have a hypocentre about 25 km northwest of Indulkana (near Allan Well and the Wintiginna Fault) at about 4km depth (http://www.ga.gov.au/earthquakes/searchQuake.do). This suggests that reactivation is still occurring along these features, which may increase porosity and permeability.

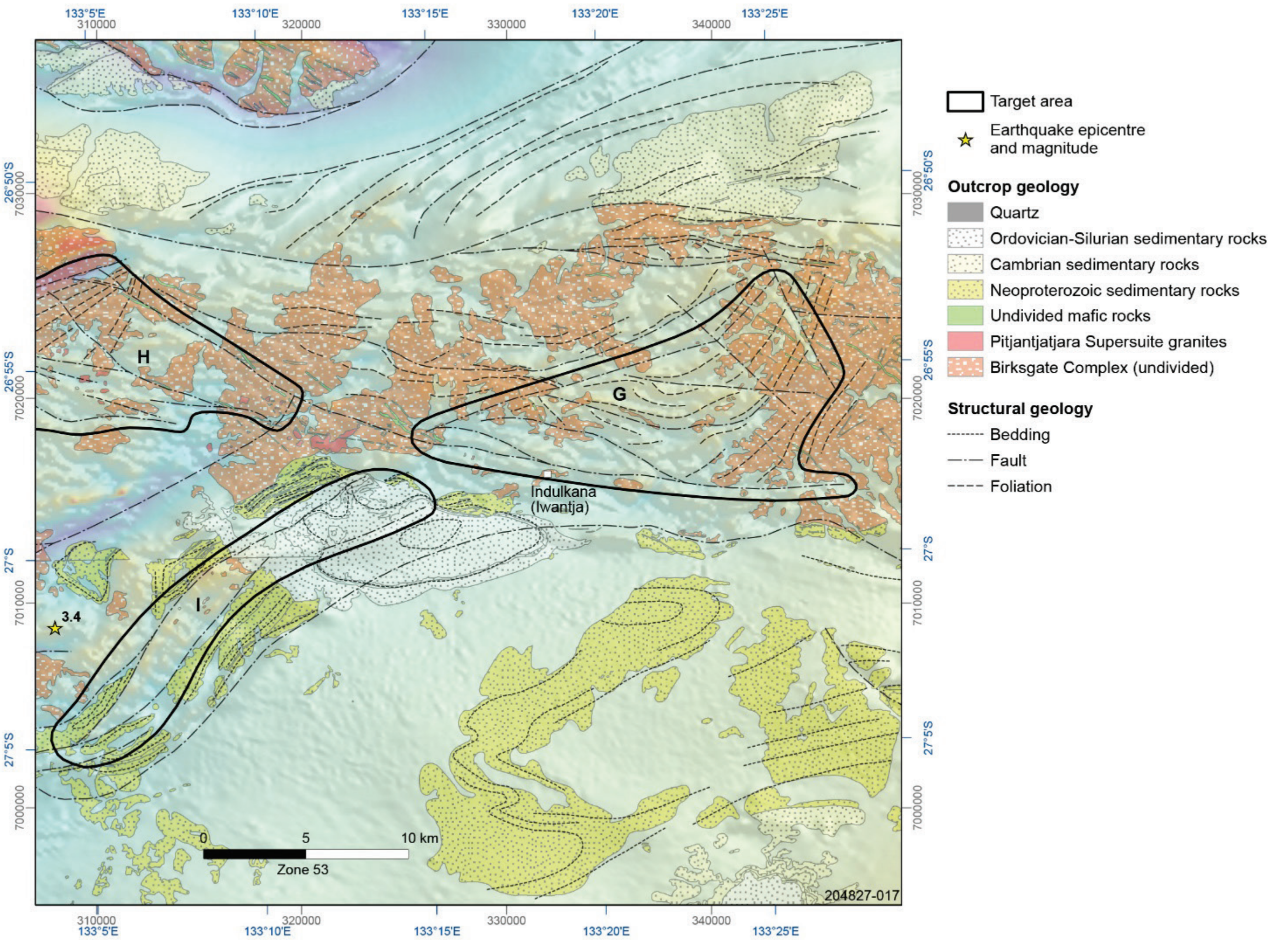


Figure 7. Maps and datasets of the Indulkana area. a) shows the preexisting simplified outcrop geology polygons and interpreted structural geology linework over the TMI. The yellow stars are the earthquakes from the GA Earthquake Database. The polygons with thick black lines are the target areas. **b; next page)** shows the target areas over the DTM, which has been stretched to the map area and has northwest hill-shading. **c)** shows the target areas over the topographic map.

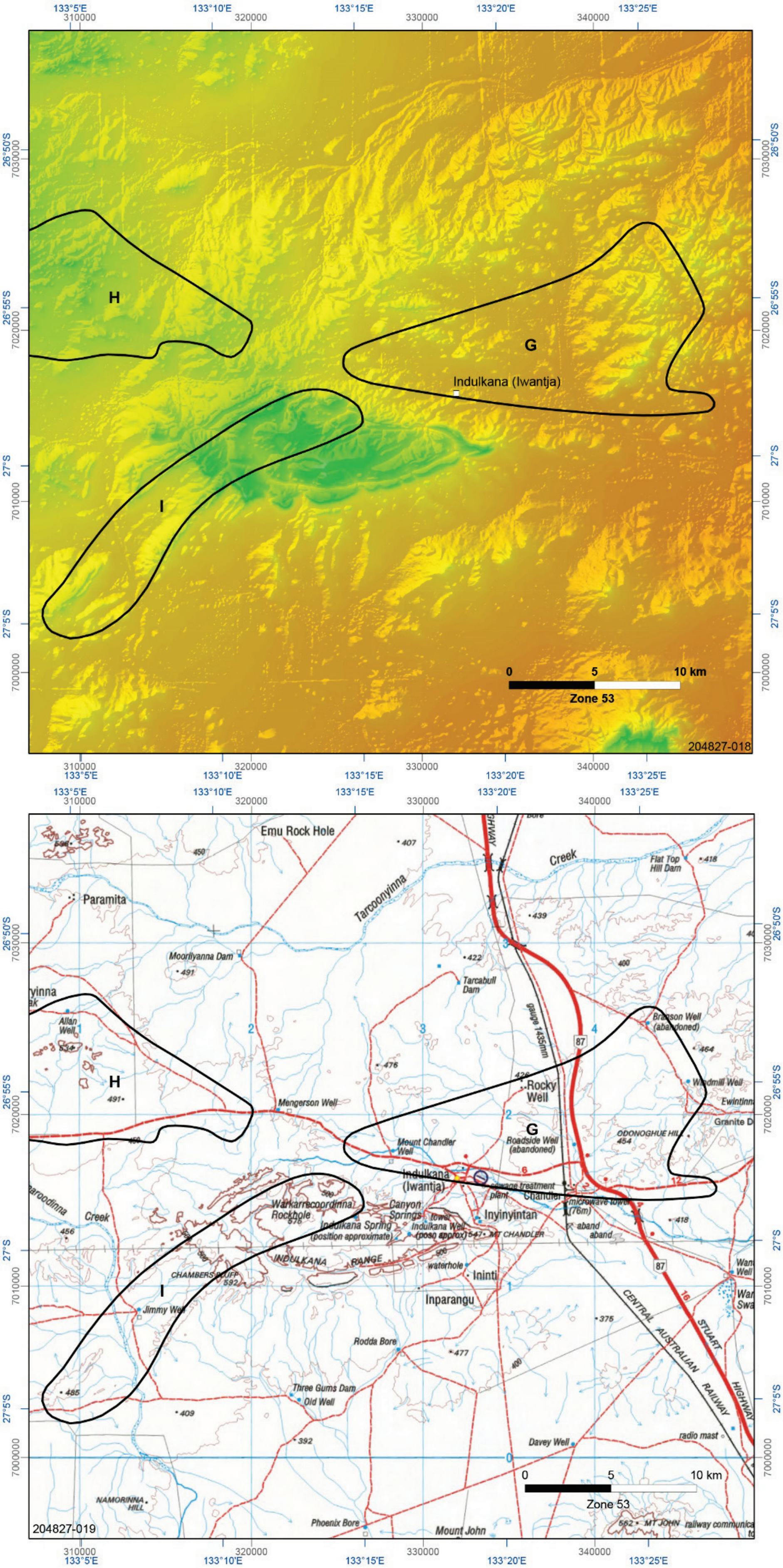


Figure 7 b and c.

POSSIBLE TARGETS IN THE VICINITY OF INDULKANA

The geophysical datasets of the area were examined, looking for zones of faulted, fractured and weathered basement rocks that may represent aquifers. These were represented on the datasets by low aeromagnetic lineaments, which are often parallel to straight to curviplanar valleys, and are interpreted as faults. Networks of faults, rather than single isolated structures, were preferred since the intersecting structures may have greater permeability and porosity. There are several areas that meet the criteria, and would be worth a closer examination (Fig. 7). These include:

G. One target area is located around the Indulkana community, and extends to the east and northeast for about 15 km. This zone contains east-striking low aeromagnetic lineaments that correspond to gaps in the outcrop, as well as a series of discontinuous northwest-striking magnetic lows. This area already contains several wells.

H. One possible target starts about 10 km to the west of Indulkana, and extends to the northwest for about 15 km. This zone is characterised by northwest-striking features to the south, and east-northeast-striking features at the northern end of the zone. These features correspond to low aeromagnetic lineaments and poorly developed linear drainage systems. There is a well, i.e. Allan Well, in the northern part of this target.

I. Another target comprises a series of northeast-striking structures near Chambers Bluff, which start about 7 km to the west of the Indulkana community, and continues to the southwest for almost 20 km. This system corresponds to low aeromagnetic features, and parallel topographic lows and drainage channels. There is a documented spring near the northern end of this target, i.e. Indulkana Spring, which is located on top of the range, and a well, i.e. Jimmy Well, to the southwest.

MIMILI AREA

The geology of the Mimili area can be broken down into nine main stages of development.

c. 1620–1550 Ma: Formation of the protoliths to the Birksgate Complex. The protoliths included felsic and minor mafic intrusive, volcanic, and volcaniclastic rocks, with less common sedimentary rocks (Edgoose et al., 2004; Major and Conor, 1993; Wade et al., 2006; Wade et al., 2008).

c. 1220–1120 Ma: The Musgravian Orogeny resulted in granulite and amphibolite facies metamorphism to produce the gneisses of the Birksgate Complex (Edgoose et al., 2004; Major and Conor, 1993; Smithies et al., 2010). Granites of the Pitjantjatjara Supersuite intruded during, and immediately following, the Musgravian Orogeny (Edgoose et al., 2004; Howard et al., 2011; Smithies et al., 2011).

c. 1085–1040 Ma: Intrusion of mafic magmas of the Giles Complex. The magmas formed large, often layered bodies, and thin dykes that cross-cut all of the earlier phases (Close et al., 2003; Edgoose et al., 2004; Evins et al., 2010; Glikson et al., 1995; Glikson et al., 1996; Howard et al., 2011; Woodhouse and Gum, 2003).

c. 825–760 Ma: Intrusion of the Amata Dolerite, which is a correlative of the Gairdner Dolerite that intrudes the Gawler Craton (Werner et al., 2014).

Neoproterozoic to late Palaeozoic: Deposition of the sedimentary rocks of the intracratonic Officer Basin, which occur in the footwall of the Everard Thrust near the Blue Hills.

c. 570–530 Ma: The Petermann Orogeny was a dextral transpressional event that resulted in the exhumation of the core of the Musgrave Province along an east-trending flower structure (Korsch and Kositcin, 2010; Lambeck and Burgess, 1992). Uplift was accommodated by thrusts near the margins of the province (e.g. the Everard Thrust), and steeper structures in the core of the province (e.g. the Wintiginna and Poorara faults: Camacho et al., 1997; Camacho and McDougall, 2000; Edgoose et al., 2004; Howard et al., 2011; Pawley et al., 2014; Raimondo et al., 2009; Scrimgeour and Close, 1999). Strike-slip movement resulted in basins, such as the Moorilyanna Graben to the east (Coats, 1962), which occurs undercover on the northeast corner of the map.

Ordovician: Deposition continued in the Officer Basin, resulting in the sedimentary rocks of the Blue Hills. This phase of deposition terminated during the Alice Springs Orogeny (Edgoose et al., 2002; Haines et al., 2001; Hand and Sandiford, 1999). The Ordovician Alice Springs Orogeny resulted in reactivation of some Petermann-aged structures. The orogeny was also associated with fluid flow that caused localised epidote and silica alteration (e.g. Conor, 2004).

Tertiary: Development of palaeochannels, such as the Neogene Lindsay Palaeochannel, which forms a series of connected basins that are associated with wider drainages (Fig. 3: Hou et al., 2012; Lewis et al., 2010; Magee, 2009; Rogers, 1995). The palaeochannels are relatively deep (>20–25 metres below surface), and may contain groundwater-bearing fluvial sediments within valley profiles that are not evident at the surface.

Quaternary: Deposition of alluvial/fluvial sediments within channels with current bedload, and across broader floodplain areas, and aeolian sediments. Earthquakes have been recorded outside the map area, indicating neotectonic activity (http://www.ga.gov.au/earthquakes/searchQuake.do).

STRUCTURES IN THE VICINITY OF MIMILI

Based on a review of the existing geological and geophysical datasets, several observations can be made about the faults around Mimili (Fig. 8):

- There is the unexposed, north-dipping Everard Thrust to the south of Mimili. The thrust is northeast-striking in this area, and there are several parallel structures in the Proterozoic Rocks to the north of the thrust;
- The east-striking Wintiginna Fault that is located about 13.5 km north of Mimili where it forms the southern margin of the Moorilyanna Graben;
- There are a series of east-striking, laterally extensive, anastamosing faults that form a zone up to 13 km wide, between about 3 km north of Mimili and about 10 km south of the community. The faults, which are variably exposed and can be traced as low aeromagnetic

lineaments, locally deflect the gneissosity, dextrally offset the boundary of a pluton, and correspond to breaks in the outcrop and drainage systems;

- There are a series of northwest-trending, low aeromagnetic lineaments in the Everard Ranges that extend from about 16 km south of Mimili to about 18 km southwest of the community. These lineaments can be traced through gaps in the outcrop and drainage systems, and may represent faults as they are at a high angle to the gneissic trends. These features are sub-parallel to the margin of the Illbillie Adamellite, suggesting there may be a rheological contrast in this area. A set of dolerite dykes are also parallel to this trend; and
- There are a series of unexposed, northwest-striking, low aeromagnetic lineaments between the east-trending faults at Mimili and the Wintiginna Fault to the north. The northwest-striking structures which may be step overs linking the east-striking structures.

These structures have generally been interpreted to have formed, or been reactivated during the Petermann Orogeny.

No earthquakes have been recorded in the near vicinity of Mimili, however an earthquake with a magnitude of 3.2 was recorded to have a hypocenter about 23 km to the north-northwest of Mimili (near the Poorara Fault) and about 9 km deep (http://www.ga.gov.au/earthquakes/searchQuake.do). This suggests that reactivation is still occurring, which may increase porosity and permeability along these features.

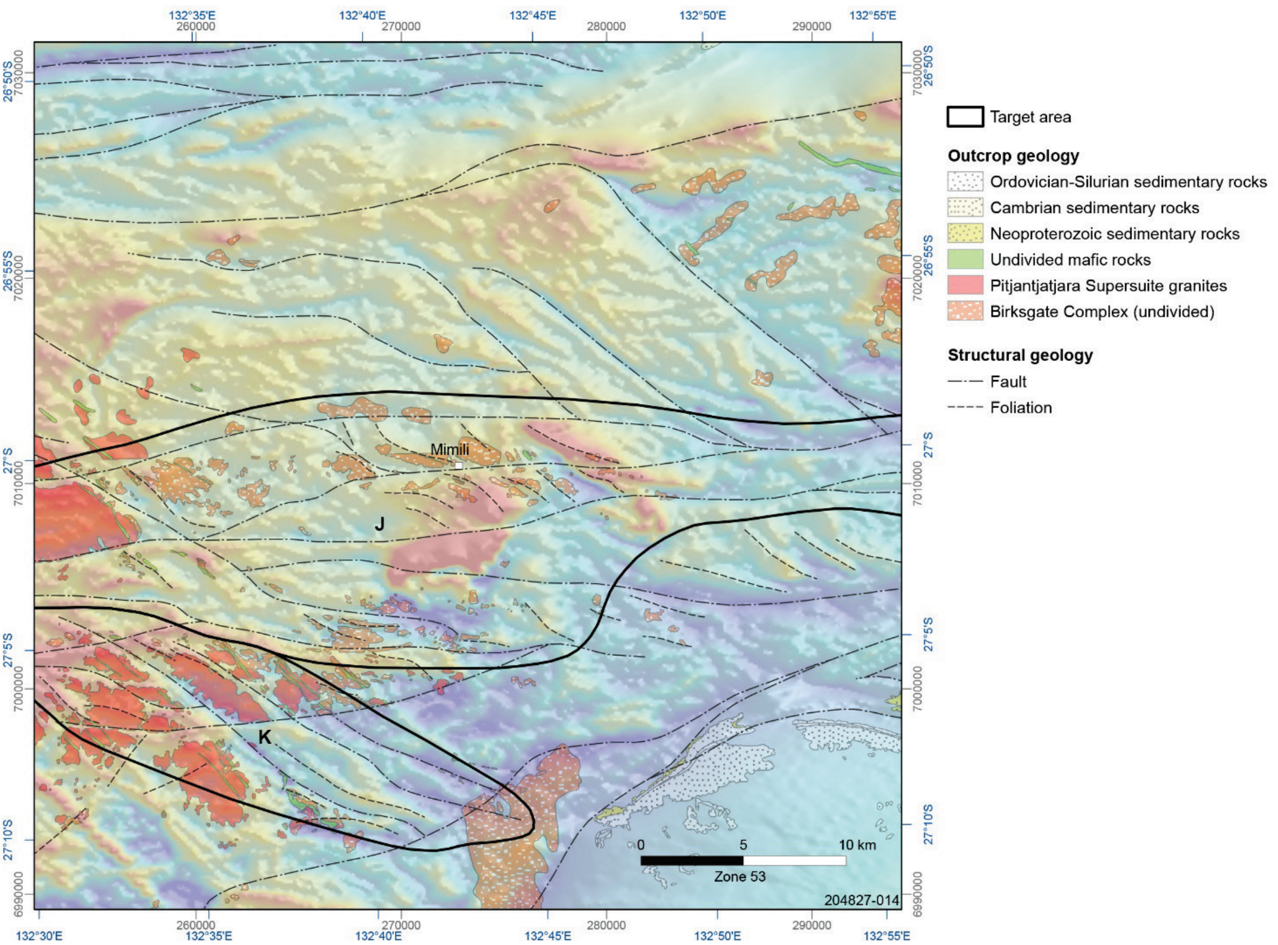
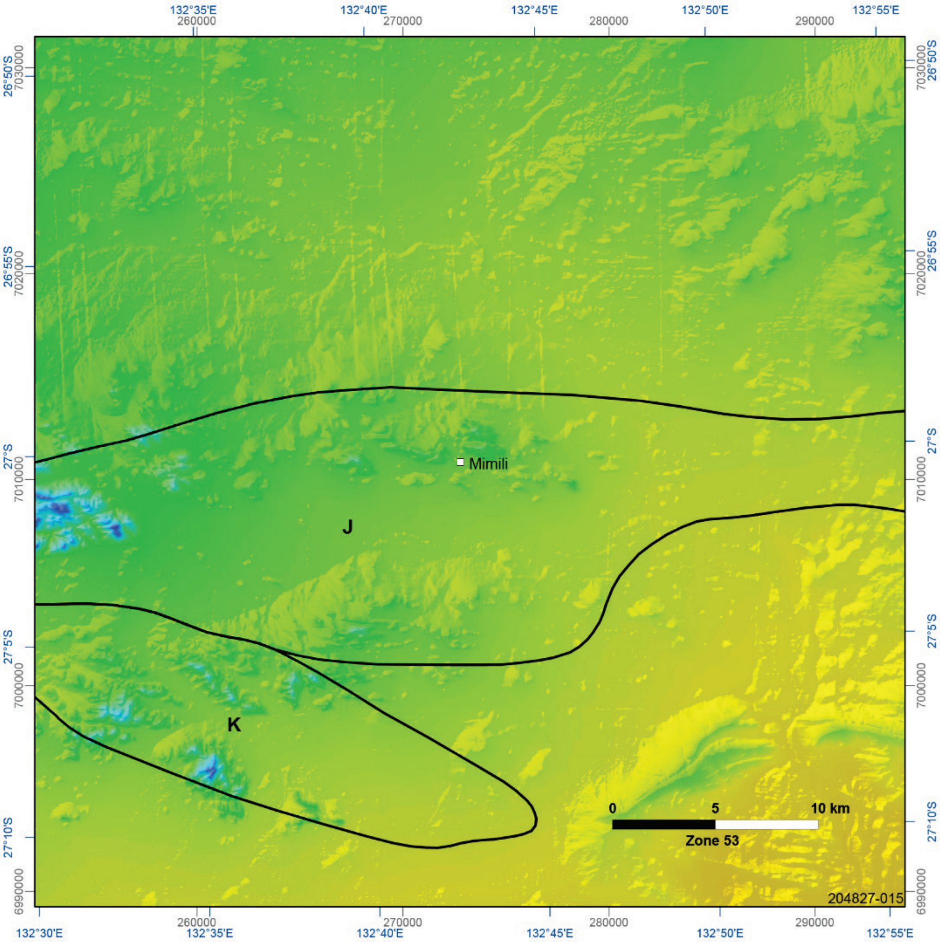


Figure 8. Maps and datasets of the Mimili area. a) shows the preexisting simplified outcrop geology polygons and interpreted structural geology linework over the TMI. The polygons with thick black lines are the target areas. **b; next page)** shows the target areas over the DTM, which has been stretched to the map area and has northwest hill-shading. **c)** shows the target areas over the topographic map.



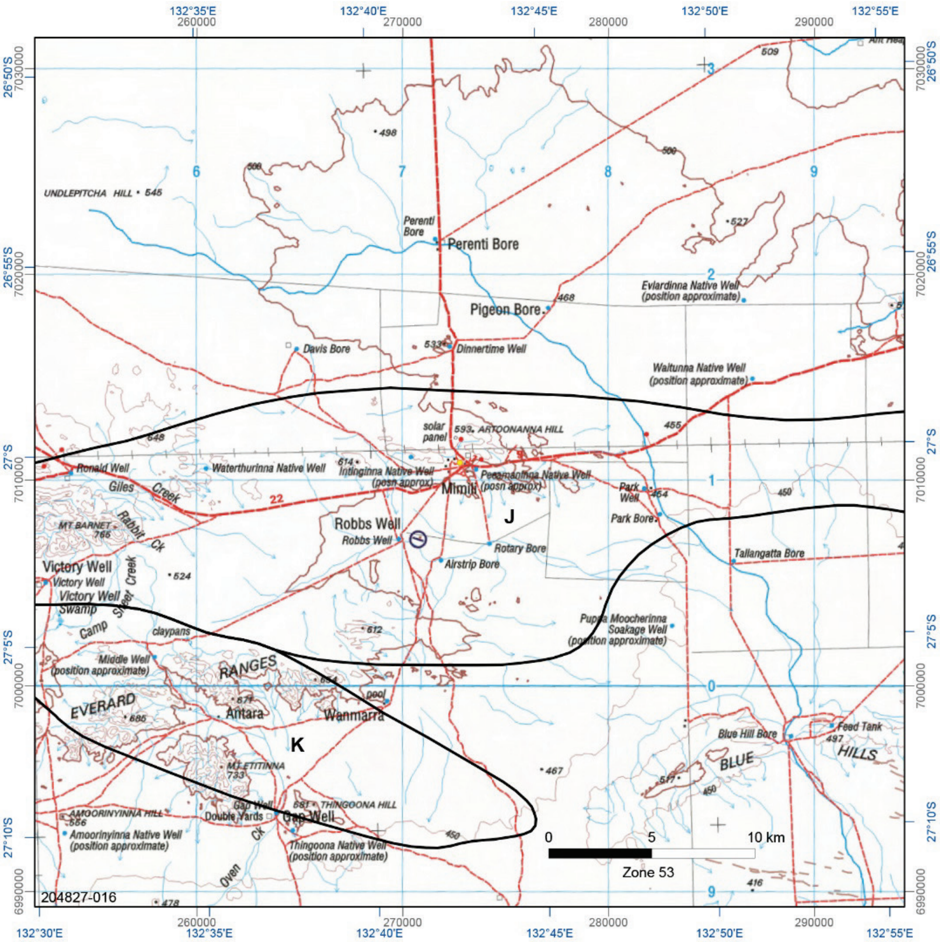


Figure 8 b and c.

POSSIBLE TARGETS IN THE VICINITY OF MIMILI

The geophysical datasets of the area were examined, looking for zones of faulted, fractured and weathered basement rocks that may represent aquifers. These were represented on the datasets by low aeromagnetic lineaments, which are often parallel to straight to curviplanar valleys, and are interpreted as faults. Networks of faults, rather than single isolated structures, were preferred since the intersecting structures may have greater permeability and porosity. There are several areas that meet the criteria, and would be worth a closer examination (Fig. 8). These include:

J. One possible target area is the laterally extensive zone of east-striking, anastomosing faults that underlie Mimili. This zone is unexposed to the east of Mimili. In the vicinity of Mimili, and to the west, there are drainage systems and gaps in the outcrop that are parallel to the low aeromagnetic lineaments. There are several wells and bores in this target, which are mostly along the drainage systems on the plains. In contrast, several “native wells” have been documented in the hills around Mimili (e.g. Intinginna Native Well) and these features would warrant a closer look.

K. Another possible target is the area about 15 km to the southwest of Mimili in the Everard Ranges, where a series of northwest-striking structures are aligned parallel to a pluton margin, suggesting there may be a local rheological control on their orientation. Furthermore, these features intersect with the east-striking faults to form a local fault/fracture network. The low aeromagnetic lineaments in this area correspond to gaps in the outcrop and associated drainage systems. Several wells have been documented in this area, including Middle Well and Gap Well.

PUKATJA AREA

The geology of the Pukatja area can be broken down into seven main stages of development.

c. 1620–1550 Ma: Formation of the protoliths to the Birksgate Complex. The protoliths included felsic and minor mafic intrusive, volcanic and volcaniclastic rocks, with less common sedimentary rocks (Edgoose et al., 2004; Major and Conor, 1993; Wade et al., 2006; Wade et al., 2008).

c. 1220–1120 Ma: The Musgravian Orogeny resulted in granulite and amphibolite facies metamorphism producing gneisses of the Birksgate Complex (Edgoose et al., 2004; Major and Conor, 1993; Smithies et al., 2010). Granites of the Pitjantjatjara Supersuite, such as the Ernabella Adamellite, intruded during, and immediately following, the Musgravian Orogeny (Edgoose et al., 2004; Howard et al., 2011; Smithies et al., 2011).

c. 1085–1040 Ma: Intrusion of mafic magmas of the Giles Complex. The magmas formed large, often layered bodies, and thin dykes that cross-cut rocks of all of the earlier phases (Close et al., 2003; Edgoose et al., 2004; Evins et al., 2010; Glikson et al., 1995; Glikson et al., 1996; Howard et al., 2011; Woodhouse and Gum, 2003).

c. 570–530 Ma: The Petermann Orogeny was a dextral transpressional event that resulted in the exhumation of the core of the Musgrave Province along an east-trending flower structure (Korsch and Kositcin, 2010; Lambeck and Burgess, 1992). Uplift was accommodated by thrusts near the margins of the province, and steeper structures in the core (Camacho et al., 1997; Camacho and McDougall, 2000; Edgoose et al., 2004; Howard et al., 2011; Pawley et al., 2014; Raimondo et al., 2009; Scrimgeour and Close, 1999). These structures are typically represented in the map area by broad mylonite zones, such as the Woodroffe Thrust and the Ferdinand Fault.

Ordovician: The Alice Springs Orogeny resulted in the reactivation of some of the Petermann-aged structures. It was also associated with fluid flow that caused localised epidote and silica alteration (e.g. Conor, 2004).

Tertiary: Development of palaeochannels, such as the Neogene Lindsay Palaeochannel to the west of Ernabella, form a series of connected basins that are associated with wider drainages (Fig. 3: Hou et al., 2012; Lewis et al., 2010; Magee, 2009; Rogers, 1995). The palaeochannels are relatively deep (>20–25 metres below surface), and may contain groundwater-bearing fluvial sediments within valley profiles that are not evident at the surface.

Quaternary: Alluvial/fluvial sediments were deposited within channels with current bedload, and also across broader floodplain areas. Numerous earthquakes, with magnitudes ranging from 2.8 to 5.7 have been recorded in the area, indicating neotectonic activity (http://www.ga.gov.au/earthquakes/searchQuake.do).

STRUCTURES IN THE VICINITY OF PUKATJA

Based on a review of the existing geological and geophysical datasets, several observations can be made about that the faults around Pukatja (Fig. 9):

- There are broad northeast-striking mylonite zones, such as the upright Ferdinand Fault that is about 5 km south of Pukatja, and the northwest-dipping Woodroffe Thrust located about 20 km to the northwest of the community;
- There are a series of relatively narrow faults along the northern side of the Ferdinand Fault that form low aeromagnetic lineaments, often correspond with curviplanar valleys, and appear to truncate and deflect the gneissosity. These structures are generally east-northeast- to north-striking (although they vary), and may represent splays off the larger mylonite zone. They are best developed in the vicinity of Turkey Bore in the southwestern part of the map area;
- About 15 km to the west-southwest of Pukatja, just to the southeast of Mount Spec, there are a series of anastomosing faults that appear to form breccia zones along northeast-striking valleys;
- The area around Itjinpiri, about 9 km north of Pukatja, contains a series of intersecting faults with variable orientations that range from east-, northeast, north-northeast- to north-

northwest-striking. These faults are often within the Ernabella Adamellite. The structures often correspond to gaps in the outcrops and linear valleys;
- About 18 km to the northeast of Pukatja is a thin, northwest-striking aeromagnetic low that can be traced from the Ferdinand Fault to the northwest across the Woodroffe Thrust for about 35 km. This feature appears to be dextrally offset by the Woodroffe Thrust. This feature is interpreted as a fault that offsets the Ernabella Adamellite, possibly with a northeast-side-up sense of movement. This fault corresponds to a break in outcrop and a topographic low along the northwestern end of the feature. This fault underlies Womikata and will be referred to as the Womikata Fault in this report;
- There a series of southeast-striking, curvilinear low magnetic features on the southeastern side of the Ferdinand Fault, about 12 km to the east-southeast of Pukatja. These features correspond to narrow valleys and discontinuous gaps in the outcrop. and
- Some basement rocks adjacent to the faults have experienced epidote and silica alteration, indicating fluid flow (Conor, 2004).

These structures have generally been interpreted to have formed during the Petermann Orogeny, with the spatially associated alteration occurring during younger reactivation.

Significantly, Pukatja has experienced nine earthquake events in the past 30 years, with two of magnitude 5.7 (Fig. 9a; http://www.ga.gov.au/earthquakes/searchQuake.do). This suggests that reactivation of the older structures is still occurring, which may increase porosity and permeability along these features.

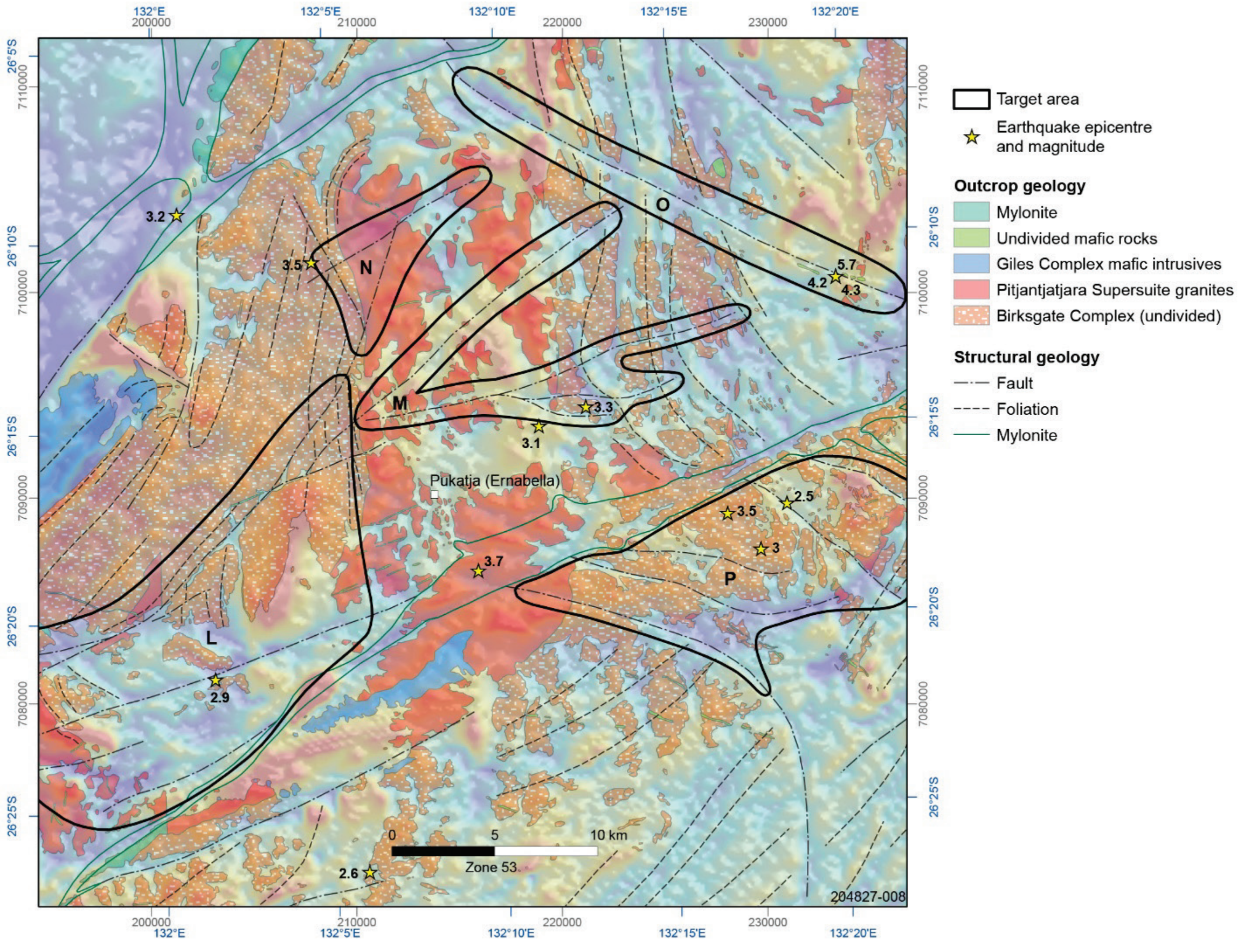


Figure 9. Maps and datasets of the Pukatja area. a) shows the preexisting simplified outcrop geology polygons and interpreted structural geology linework over the TMI. The yellow stars are the earthquakes from the GA Earthquake Database. The polygons with thick black lines are the target areas. **b; next page)** shows the target areas over the DTM, stretched to the whole dataset with northwest hill-shading. **c)** shows the target areas over the topographic map.

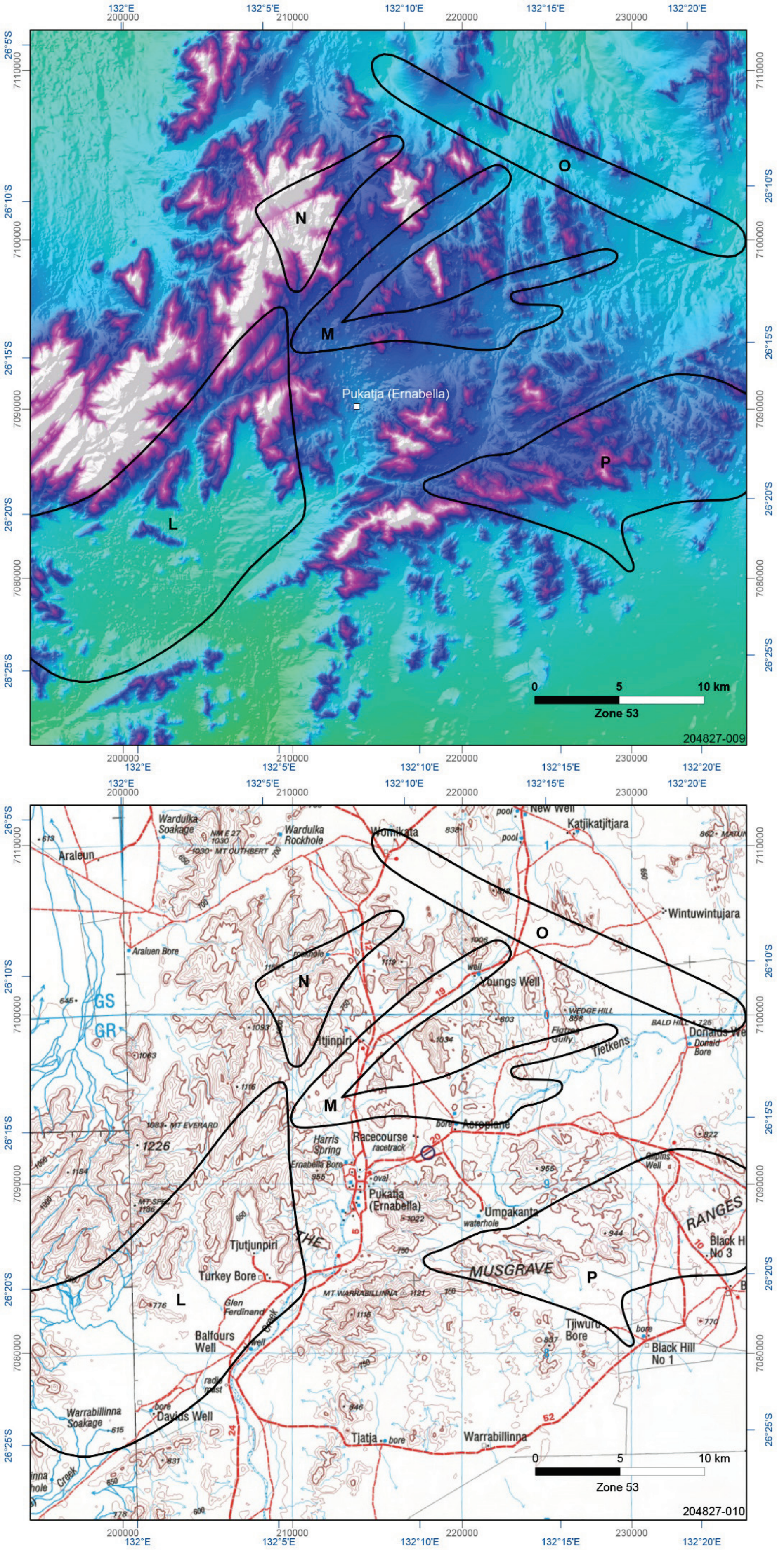


Figure 9 b and c.

POSSIBLE TARGETS IN THE PUKATJA AREA

The geophysical datasets of the area were examined, looking for zones of faulted, fractured and weathered basement rocks that may represent aquifers. These were represented on the datasets by low aeromagnetic lineaments, which are often parallel to curviplanar valleys, which are interpreted as faults. Networks of faults, rather than single isolated structures, were preferred since the intersecting structures may have greater permeability and porosity. There are several areas that meet the criteria, and would be worth a closer examination (Fig. 9). These include:

L. One target that extends from the western edge of the Ernabella Adamellite (about 5 km to the west of Pukatja) to the southwest for about 25 km. This area contains a series of sub-parallel, east-northeast-striking structures that locally truncate the gneissosity at a high angle, locally wrap along the contacts between the different phases in the bedrock, and follow linear drainage systems. There are several wells and bores in this target, as well as one soak near the southwestern corner (i.e. Warrabillinna Soakage);

M. Some of the structures in the target described above can be traced into, and across the Ernabella Adamellite, about 4-5 km to the north of the community. These structures correspond to gaps in the outcrop and narrow linear valleys. One well, i.e. Youngs Well, occurs in this area, and two earthquakes have been recorded in this area, with magnitudes of 2.8 and 3.6 (http://www.ga.gov.au/earthquakes/searchQuake.do);

N. Three faults, represented by magnetically low lineaments at a moderate angle to the penetrative foliation, intersect in an area about 4.5 km to the northwest of Itjinpiri (about 12 km to the north-northwest of Pukatja). This target corresponds to an extensive area of outcrop, but the faults coincide with narrow valleys that often have an irregular texture on the orthoimages, suggesting that the rock has been broken up and brecciated. Two faults have been documented in this area, with magnitudes of 3.0 and 3.3 (http://www.ga.gov.au/earthquakes/searchQuake.do);

O. There is a northwest-striking feature about 17 km to the northeast of Pukatja that forms a prominent low aeromagnetic lineament that can be traced along strike for about 30 km. This feature, called the Womikata Fault, corresponds to a linear gap in the outcrop, and a broad valley. An earthquake with a magnitude of 3.8 has been recorded just to the northeast of the fault, and an earthquake with a magnitude of 5.7 is near the northwestern end. A well, i.e. Donalds Well, is located near the southeastern end of the target. This target occurs in an area that overlaps with the Yunyarinyi map (see Fig. 10), and would also be a target for that area; and

P. To the southeast of the Ferdinand Fault is a series of southeast-striking faults that locally correspond to breaks in the outcrop and narrow valleys. Several bores are located on the plains near the southeastern margin of this target, and one well (i.e. Gilpins Well) is located in the northeast corner. This target occurs in an area that also overlaps with the Yunyarinyi map (see Fig. 10), and would also be a target for that area.

Although they form prominent features, it is unclear whether the Ferdinand Fault that forms a broad east-northeast-striking mylonite zone to the south of Pukatja, and the Woodroffe Thrust to the north would be suitable aquifers. This is because recrystallisation and grainsize reduction during deformation may have reduced porosity and permeability. However, bores have been established along these structures, suggesting that they may also form suitable targets.

YUNYARINYI AREA

The geology of the Yunyarinyi area can be broken down into eight main stages of development.

c. 1620–1550 Ma: Formation of the protoliths to the Birksgate Complex. The protoliths included felsic and minor mafic intrusive, volcanic, and volcaniclastic rocks, with less common sedimentary rocks (Edgoose et al., 2004; Major and Conor, 1993; Wade et al., 2006; Wade et al., 2008).

c. 1220–1120 Ma: The Musgravian Orogeny resulted in granulite and amphibolite facies metamorphism to produce the gneisses of the Birksgate Complex (Edgoose et al., 2004; Major and Conor, 1993; Smithies et al., 2010). Granites of the Pitjantjatjara Supersuite, such as the Ernabella Adamellite to the northwest of Yunyarinyi, intruded during, and immediately following, the Musgravian Orogeny (Edgoose et al., 2004; Howard et al., 2011; Smithies et al., 2011).

c. 1085–1040 Ma: Intrusion of mafic magmas of the Giles Complex. The magmas formed large, often layered bodies, and thin dykes that cross-cut all of the earlier phases (Close et al., 2003; Edgoose et al., 2004; Evins et al., 2010; Glikson et al., 1995; Glikson et al., 1996; Howard et al., 2011; Woodhouse and Gum, 2003).

c. 825–760 Ma: Intrusion of the Amata Dolerite, which is a correlative of the Gairdner Dolerite that intrudes the Gawler Craton (Werner et al., 2014).

c. 570–530 Ma: The Petermann Orogeny was a dextral transpressional event that resulted in the exhumation of the core of the Musgrave Province along an east-trending flower structure (Korsch and Kositcin, 2010; Lambeck and Burgess, 1992). Uplift was accommodated by thrusts near the margins of the province, and steeper structures in the core (Camacho et al., 1997; Camacho and McDougall, 2000; Edgoose et al., 2004; Howard et al., 2011; Pawley et al., 2014; Raimondo et al., 2009; Scrimgeour and Close, 1999). These structures are represented in the map area by broad mylonite zones, such as the Ferdinand Fault.

Ordovician: The Alice Springs Orogeny resulted in the reactivation of some of the Petermann-aged structures. It was associated with fluid flow that caused localised epidote and silica alteration (e.g. Conor, 2004).

Tertiary: Development of palaeochannels, such as the Neogene Lindsay Palaeochannel to the west of Yunyarinyi, which form a series of connected basins that are associated with wider drainages (Fig. 3: Hou et al., 2012; Lewis et al., 2010; Magee, 2009; Rogers, 1995). The palaeochannels are relatively deep (>20–25 metres below surface), and may contain groundwater-bearing fluvial sediments within valley profiles that are not evident at the surface.

Quaternary: Alluvial/fluvial sediments were deposited within channels with current bedload, and also across broader floodplain areas. Several earthquakes, with magnitudes ranging from 3.0 to 6.0 have been recorded in the area, indicating neotectonic activity (http://www.ga.gov.au/earthquakes/searchQuake.do).

STRUCTURES IN THE VICINITY OF YUNYARINYI

Based on a review of the existing geological and geophysical datasets, several observations can be made about the faults around Yunyarinyi (Fig. 10):

- The Ferdinand Fault is a broad east-northeast-striking mylonite zone located about 12 km to the northwest of Yunyarinyi. In outcrop, the Ferdinand Fault often forms a prominent ridge that suggests it is relatively competent, and may not be permeable and porous;
- A series of east-southeast-striking, curvilinear structures splay off the southeastern side of the Ferdinand Fault. These structures are defined by aeromagnetic lows, and correspond to gaps in the outcrop and the drainage systems. These features overlap with the Pukatja map area (see Fig. 9);
- The Marryat Fault, located about 20 km to the north-northeast of Yunyarinyi, is a curvilinear structure that splays off the Ferdinand Fault and continues eastwards for over 170 km to the edge of the province;
- There is extensive outcrop to the northeast of Yunyarinyi where a series of shears and faults are exposed (e.g. the Herringbone Fault; Conor, 2004). In this area, the gneisses are cut by abundant, broadly northeast-striking shears that form topographic highs up to 30 m-

wide, that appear as dark features on the orthophotos. There are few geological observations from this area, and it is unclear whether these represent mylonites (texturally similar to the Ferdinand Fault), structures that have been intruded by mafic magmas, or something else. However, the observation that features form topographic highs suggests they are composed of relatively competent material. These features form magnetically low lineaments on the aeromagnetic images; and

- About 5 km east of Yunyarinyi is a northeast-striking fault that was recognised by Conor (Conor, 2004), and described as "late" as it appears to overprint all of the other structures including the prominent layering and mafic dykes with a component of sinstral movement. This fault can be traced to the northeast for about 15 km, corresponding to a weak magnetic low, breaks in the outcrop, as well as in the drainage pattern. This structure has herein been called the Yunyarinyi Fault.

The Yunyarinyi area has experienced several earthquake events in the past 32 years, ranging from magnitude 3.0 to 6.0 (http://www.ga.gov.au/earthquakes/searchQuake.do). These events occurred within about 3 km of the Yunyarinyi Fault. However, there appears to be some discrepancies about the location of the magnitude 6.0 event, with the GA Earthquake Database placing it about 6.5 km to the east of the community, whereas published reports place the epicenter about 40 km to the east-northeast of Yunyarinyi, near Gosse Bore (Machette et al., 1993). The study by Machette et al. (1993) also found evidence for prehistoric reactivation of the faults in this area. A magnitude 4.1 event occurred near the Marryat Fault, about 20 km to the northeast of Yunyarinyi and just outside the map area. Overall, there appears to have been recent reactivation of the older structures in this area, particularly in the vicinity of the Yunyarinyi Fault, which may increase porosity and permeability along these features.

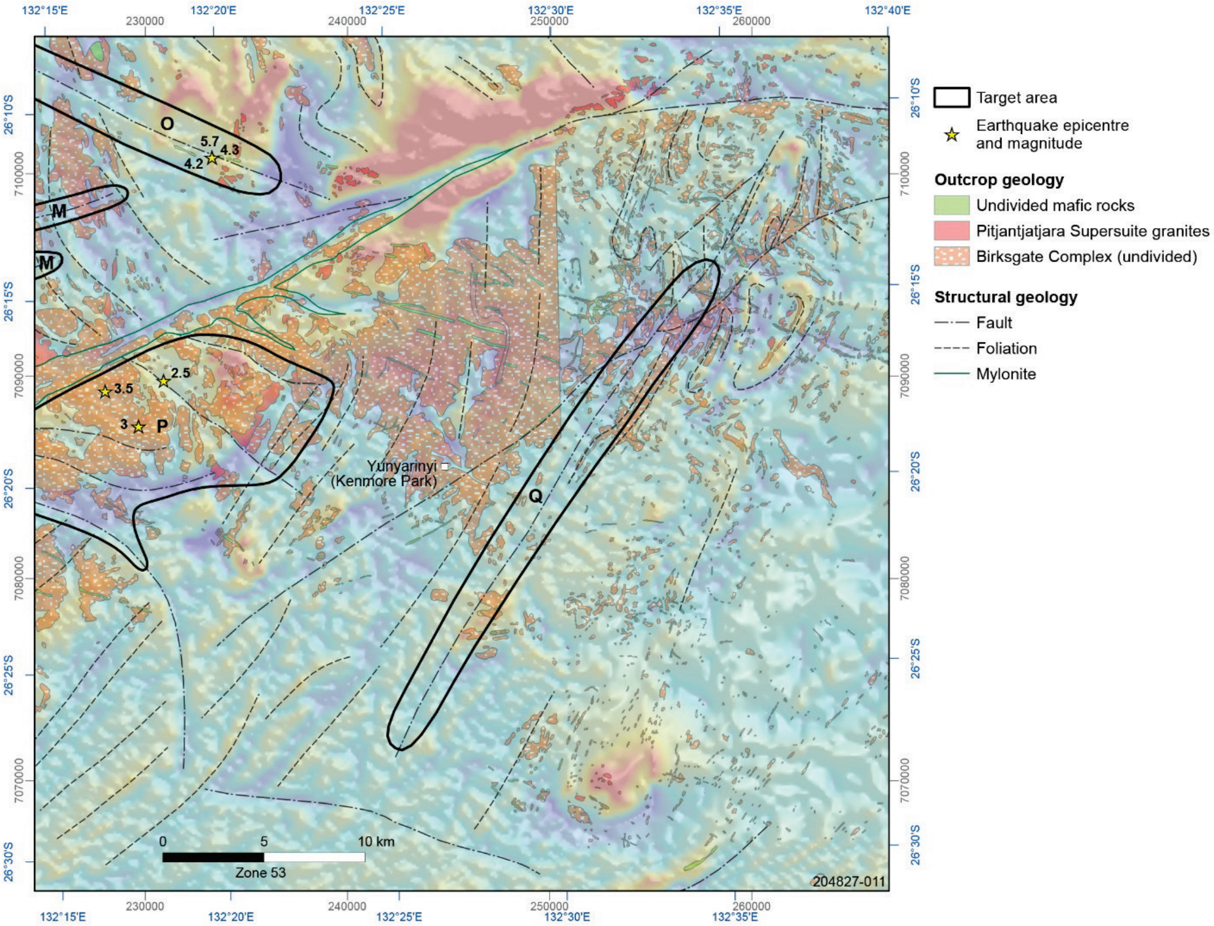
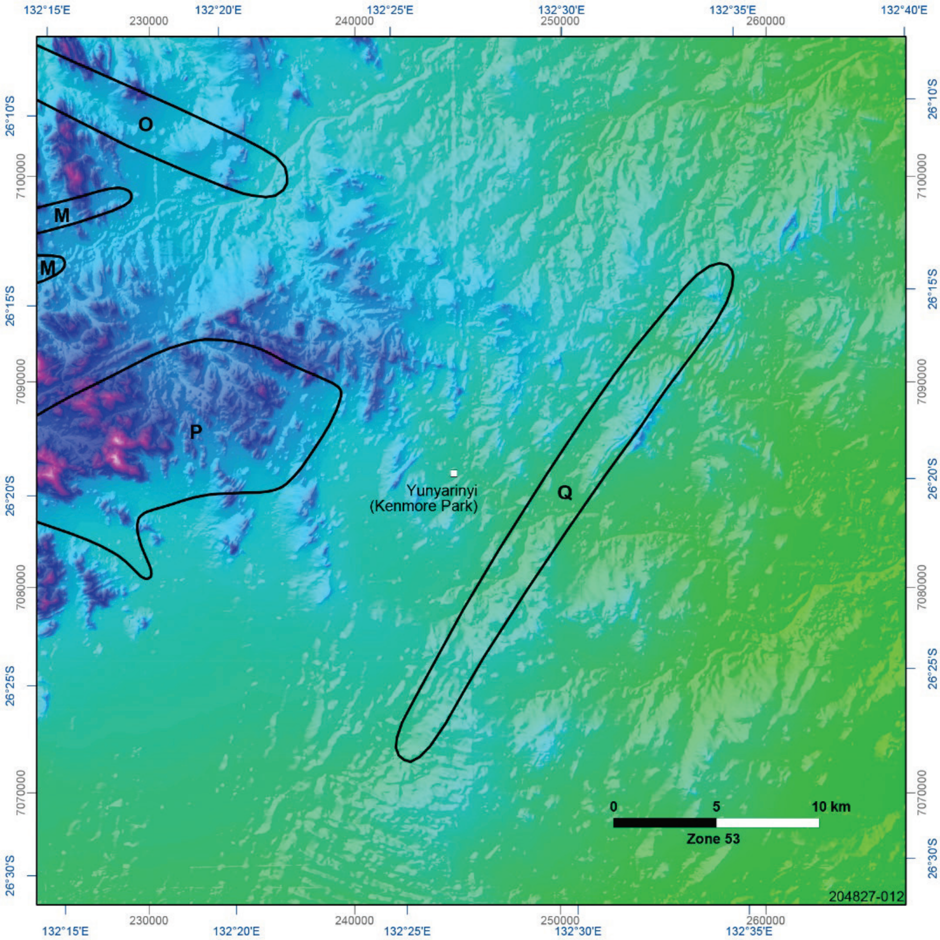


Figure 10. Maps and datasets of the Yunyarinyi area. a) shows the preexisting simplified outcrop geology polygons and interpreted structural geology linework over the TMI. The yellow stars are the earthquakes from the GA Earthquake Database. The polygons with thick black lines are the target areas. **b; next page)** shows the target areas over the DTM, stretched to the whole dataset with northwest hill-shading. **c)** shows the target areas over the topographic map.



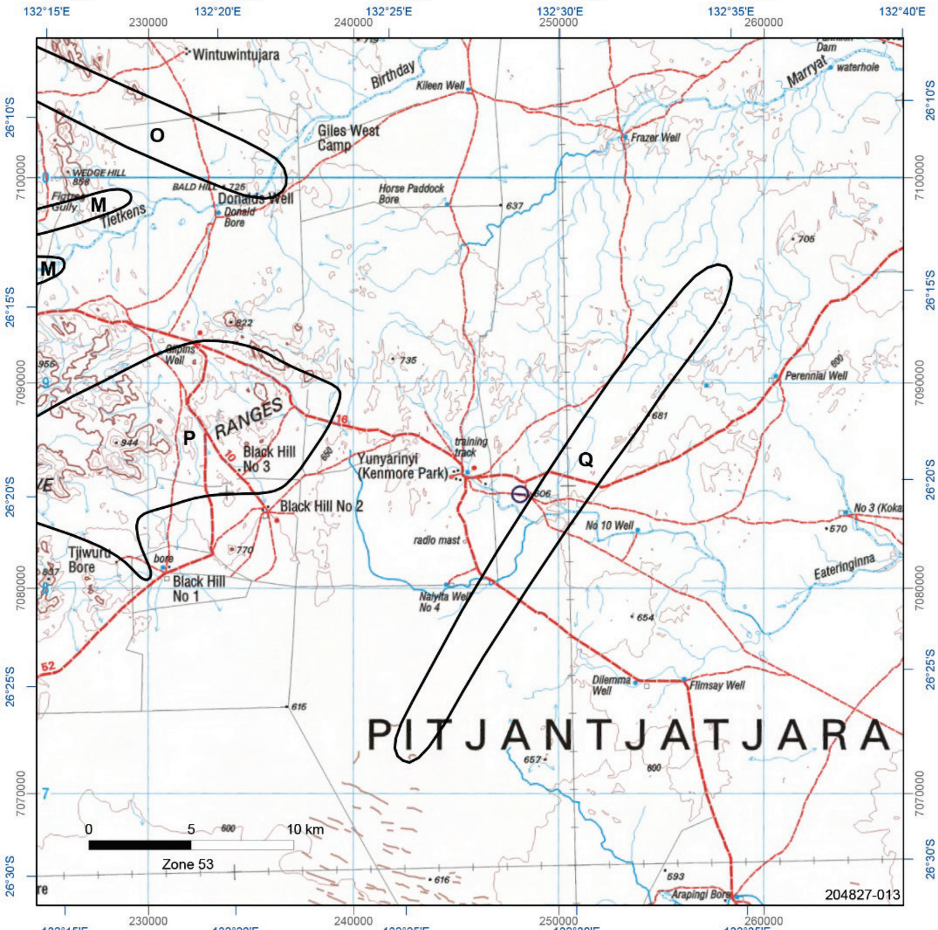


Figure 10 b and c.

POSSIBLE TARGETS IN THE VICINITY OF YUNYARINYI

The geophysical datasets of the area were examined, looking for zones of faulted, fractured and weathered basement rocks that may represent aquifers. These were represented on the datasets by low aeromagnetic lineaments, which are often parallel to curviplanar valleys, which were interpreted as faults. Networks of faults, rather than single isolated structures, were preferred since the intersecting structures may have greater permeability and porosity. There are several areas that meet the criteria, and would be worth a closer examination (Fig. 10). These include:

M. This target is part of an east-northeast-striking structure near Figtree Gully that can be traced onto the Pukatja map area (Fig. 9), where it crosses the Ernabella Adamellite, about 4–5 km to the north of the community. This structure corresponds to a gap in the outcrop and narrow linear valleys. Two earthquakes have been recorded in this area, with magnitudes of 2.8 and 3.6 (http://www.ga.gov.au/earthquakes/searchQuake.do);

O. This target includes the Womikata Fault in the northeastern part of the Pukatja map. This is a northwest-striking feature about 17 km to the northwest of Yunyarinyi that forms a prominent low aeromagnetic lineament that can be traced along strike for about 30 km. This feature corresponds to a linear gap in the outcrop, and a broad valley. An earthquake with a magnitude of 3.8 has been recorded just to the northeast of the fault. A well, i.e. Donalds Well, is located near the southeastern end of the target;

P. Another target in this area is located about 15 km to the west of Yunyarinyi and includes the southeast-striking faults that occur to the southeast of the Ferdinand Fault. This target also occurs on the Pukatja map area (see Fig. 9). These faults locally correspond to breaks in the outcrop and narrow valleys. Several bores are located near the southeast margin of this target, near the edge of the outcrop, and one well (i.e. Gilpins Well) is located in the northeast corner; and

Q. The Yunyarinyi Fault is another target. Of particular interest is the broad, northeast-striking drainage area that overlies the aeromagnetic low, extending from about 5 km to the east of the community to the northeast for about 8 km. Three earthquakes, with magnitudes ranging from 3.0 to 6.0 have been recognised near this structure (http://www.ga.gov.au/earthquakes/searchQuake.do). Two wells are located within 2.5 km of the fault (i.e. No. 10 Well and Nalylta Well No. 4).

SUMMARY

Seventeen possible target areas worth a closer examination have been identified in this report. The targets are not listed in any particular order of priority.

Amata (Fig. 5):

A. A series of sub-parallel, north-northeast-striking structures that are apparent as lows on the aeromagnetic images, located just to the west of Amata, extending in a south-southwest direction for about 16 km;
B. About 10 km west of Amata a north-northeast-striking drainage system, which overlies a low aeromagnetic feature and also contains several outcrops of mylonitic rocks, can be traced for about 18 km, and comprises the southern Malungankanya and northern Aparina Creek;
C. About 15 km to the south-southeast of Amata, altered gneisses and gneissic granite are cut by a series of southeast-striking features that correspond to low aeromagnetic lineaments and drainage systems;
D. About 15 km to the east-northeast of Amata shears in gneisses correspond to low aeromagnetic lineaments and breaks in the drainage systems.

Fregon (Fig. 6):

E. A laterally extensive demagnetised zone of east-striking, anastomosing faults located south of Fregon;
F. A fault-bounded demagnetised area northeast of Fregon.

Indulkana (Fig. 7):

G. East-striking low aeromagnetic lineaments around the Indulkana community extending to the east and northeast for about 15 km;
H. Low aeromagnetic lineaments and poorly developed linear drainage systems about 10 km to the west of Indulkana, extending to the northwest for about 15 km;
I. A series of NE-striking structures corresponding to low aeromagnetic features near Chambers Bluff, which start about 7 km to the west of the Indulkana community continuing to the southwest for almost 20 km.

Mimili (Fig. 8):

J. A laterally extensive zone of E-striking, anastomosing faults that underlie Mimili;
K. A series of NW-striking structures are aligned parallel to a pluton margin about 15 km to the SW of Mimili in the Everard Ranges.

Pukatja (Fig. 9):

L. A series of sub-parallel, east-northeast-striking structures that extend from the western edge of the Ernabella Adamellite (about 5 km to the west of Pukatja) to the southwest for about 25 km;
N. Three faults, represented by magnetically low lineaments, intersect in an area about 4.5 km to the northwest of Itjinpiri (about 12 km to the north-northwest of Pukatja).

Pukatja and **Yunyarinyi** (Figs 9 and 10):

M. Some of the structures in target (L) can be traced into, and across the Ernabella Adamellite, about 4-5 km to the north of the community. These structures appear to continue onto the Yunyarinyi map area;
O. The Womikata Fault, a northwest-striking feature about 17 km to the northeast of Pukatja forming a prominent low aeromagnetic lineament that can be traced along strike for about 30 km;
P. A series of southeast-striking faults to the southeast of the Ferdinand Fault.

Yunyarinyi (Fig. 10):

Q. Part of the Yunyarinyi Fault where a broad, northeast-striking drainage area overlies an aeromagnetic low, extending from about 5 km to the east of Yunyarinyi to the northeast for about 8 km.

ACKNOWLEDGEMENTS

We'd like to thank Michael Gogoll (DEWNR) for setting up the project and ongoing discussion of the geology of the Musgrave Province. Michael Gogoll is also thanked for his review of the manuscript. Mario Werner, Rian Dutch and Wolfgang Preiss (GSSA) are thanked for many in-house discussions on the geology of the Musgrave Province and the Officer Basin.

REFERENCES

Agostino, K.N., 2015. A low-temperature thermochronologic insight into the thermal and exhumation history of the eastern Musgrave Province, South Australia. Honours Thesis, University of Adelaide, 85 pp.

Aitken, A.R.A., Betts, P.G., 2008. High-resolution aeromagnetic data over central Australia assist Grenville-era (1300–1100 Ma) Rodinia reconstructions. Geophysical Research Letters, 35.

Aitken, A.R.A., Betts, P.G., Ailleres, L., 2009a. The architecture, kinematics, and lithospheric processes of a compressional intraplate orogen occurring under Gondwana assembly: The Petermann Orogeny, central Australia. Lithosphere, 1(6): 343-357.

Aitken, A.R.A., Betts, P.G., Weinberg, R.F., Gray, D., 2009b. Constrained potential field modeling of the crustal architecture of the Musgrave Province in central Australia: Evidence for lithospheric strengthening due to crust-mantle boundary uplift. Journal of Geophysical Research, 114.

Camacho, A., 1989. The Woodroffe Thrust, eastern Musgrave Block, NT: a problem of large-scale melting during thrusting, Specialist Group in Tectonics and Structural Geology, Kangaroo Island. Geological Society of Australia, pp. 14-15.

Camacho, A., Compston, W., McCulloch, M.T., McDougall, I., 1997. Timing and exhumation of eclogite facies shear zones, Musgrave Block, central Australia. Journal of Metamorphic Geology, 15: 735-751.

Camacho, A., Fanning, C.M., 1995. Some isotopic constraints on the evolution of the granulite and upper amphibolite facies terranes in the eastern Musgrave Block, central Australia. Precambrian Research, 71(1–4): 155-181.

Camacho, A., McDougall, I., 2000. Intracratonic, strike-slip partitioned transpression and the formation and exhumation of eclogite facies rocks: An example from the Musgrave Block, central Australia. Tectonics, 19: 978-996.

Close, D.F., Edgoose, C.J., Scrimgeour, I.R., 2003. Hull and Bloods Range Special, Northern Territory. 1:100 000 geological map series explanatory notes, 4748, 4848. Northern Territory Geological Survey, Darwin.

Coats, R.P., 1962. The geology of the Alberga 4-Mile Military Sheet, Report of Investigations 22. Geological Survey of South Australia, 22 pp.

Conor, C.H.H., 2004. The geology of the Eateringinna 1:100 000 sheet area, eastern Musgrave Block, South Australia, Report Book 2003/16. Department of Primary Industry and Resources, South Australia, 603 pp.

Cotton, T.B., Scardigno, M.F., Hibburt, J.E., 2006. The petroleum geology of South Australia. Vol. 2: Eromanga Basin. Petroleum Geology of South Australia Series. Department of Primary Industries and Resources, South Australia.

Dutch, R.A., Payne, J.L., Woodhouse, A., 2013. Sm-Nd and Hf isotopic data of the Tieyon (5645) 1:100 000 mapsheet. Department for Manufacturing, Innovation, Trade, Resources and Energy, South Australia, Report Book 2013/10. Department for Manufacturing, Innovation, Trade, Resources and Energy, South Australia.

Edgoose, C.J., Camacho, A., Wakelin-King, G.W., Simons, B., 1993. Kulgera SG53-5, 1:250000 Geological Map Series Explanatory Notes. Northern Territory Geological Survey, 46 pp.

Edgoose, C.J., Close, D.F., Stewart, A.J., Duncan, N., 2002. UMBEARA, Northern Territory. 1:100 000 geological map series explanatory notes, 5646. Northern Territory Geological Survey, Darwin and Geoscience Australia, Canberra (National Geoscience Mapping Accord).

Edgoose, C.J., Scrimgeour, I.R., Close, D.F., 2004. Geology of the Musgrave Block, Northern Territory, Report 15. Northern Territory Geological Survey, 44 pp.

Evins, P.M. et al., 2010. Devil in the detail; The 1150–1000 Ma magmatic and structural evolution of the Ngaanyatjarra Rift, west Musgrave Province, Central Australia. Precambrian Research, 183(3): 572-588.

Glikson, A.Y. et al., 1995. Geological framework and crustal evolution of the Giles mafic-ultramafic complex and environs, western Musgrave Block, central Australia. AGSO Journal of Australian Geology and Geophysics, 16: 41-67.

Glikson, A.Y. et al., 1996. Geology of the western Musgrave Block, central Australia, with particular reference to the mafic-ultramafic Giles Complex, Bulletin 239. Australian Geological Survey Organisation, 206 pp.

Gum, J.C., Belousova, E.A., 2006. Musgrave Province reconnaissance using TerraneChron™, Australian Earth Sciences Convention, Melbourne, 2006. Geological Society of Australia, pp. 68.
Haines, P.W., Hand, M., Sandiford, M., 2001. Palaeozoic synorogenic sedimentation in central and northern Australia: a review of distribution and timing with implications for the evolution of intracontinental orogens. Australian Journal of Earth Sciences, 48(6): 911-928.
Hand, M., Sandiford, M., 1999. Intraplate deformation in central Australia, the link between subsidence and fault reactivation. Tectonophysics, 305: 121-140.
Hou, B. et al., 2012. Palaeodrainage and Tertiary Coastal Barrier of South Australia. Digital Geological Map of South Australia, 1:2 000 000 Series. Geological Survey of South Australia, Department for Manufacturing, Innovation, Trade, Resources and Energy, South Australia, Adelaide.
Howard, H.M. et al., 2011. The geology of the west Musgrave Province and the Bentley Supergroup – a field guide, Record 2011/4. Geological Survey of Western Australia, Perth, Western Australia, 116 pp.
Jackson, M.J., van de Graaff, W.J.E., 1981. Geology of the Officer Basin, Bulletin 206. Geology of the Officer Basin. Bureau of Mineral Resources, Australia.
Kirkland, C.L. et al., 2013. Constraints and deception in the isotopic record; the crustal evolution of the west Musgrave Province, central Australia. Gondwana Research, 23(2): 759-781.
Korsch, R.J., Kositcin, N. (Eds.), 2010. GOMA (Gawler Craton-Officer Basin-Musgrave Province-Amadeus Basin) Seismic and MT Workshop 2010, Record 2010/39. Geoscience Australia, 162 pp.
Krieg, G.W., 1972. EVERARD SG 53-13 1:250 000 geological map. Geological Survey of South Australia.
Krieg, G.W., Rogers, P.A., 1995. Eromanga Basin: stratigraphy – marine succession. In: Drexel, J.F., Preiss, V.P. (Eds.), The geology of South Australia. Vol. 2, The Phanerozoic. Geological Survey of South Australia, Bulletin, 54, pp. 112-123.
Lambeck, K., Burgess, G., 1992. Deep crustal structure of the Musgrave Block, central Australia: Results from teleseismic travel-time anomalies. Australian Journal of Earth Sciences, 39: 1-19.
Lewis, S.J. et al., 2010. The Palaeovalley Groundwater Project: Operational Update on Demonstration Study Sites. Geoscience Australia Report, 303 pp.
Machette, M.N., Crone, A.J., Bowman, J.R., 1993. Geologic investigations of the 1986 Marryat Creek, Australia, earthquake; implications for paleoseismicity in stable continental regions. 2032B.
Magee, J.W., 2009. Palaeovalley Groundwater Resources in Arid and Semi-Arid Australia – A Literature Review, Record 2009/03. Geoscience Australia, 224 pp.
Major, R.B., Conor, C.H.H., 1993. The Musgrave Block. In: Drexel, J.F., Preiss, W.V., Parker, A.J. (Eds.), The Geology of South Australia, Vol.1. The Precambrian. Geological Survey of South Australia. , Adelaide, South Australia, pp. 156-167.
Major, R.B., Johnson, J.E., Leeson, B., Mirams, R.C., 1967. Woodroffe SG 52-12 1:250 000 geological map. Geological Survey of South Australia.
Milton, B.E., Parker, A.J., 1973. An interpretation of geophysical observations on the northern margin of the eastern Officer Basin. South Australia. Geological Survey. Quarterly Geological Notes, 46: 10-14.
Pawley, M.J., Dutch, R.A., Werner, M., Krapf, C.B.E., 2014. Repeated failure: long-lived faults in the eastern Musgrave Province. MESA Journal, 75(4): 45–55.
Preiss, W.V., 2000. The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction. Precambrian Research, 100(1-3): 21-63.
Raimondo, T. et al., 2009. Ediacaran intracontinental channel flow. Geology, 37(4): 291-294.
Rogers, P.A., 1995. Hamilton Basin. In: Drexel, J.F., Preiss, W.V. (Eds.), The geology of South Australia. Vol. 2, The Phanerozoic. Geological Survey of South Australia, pp. 198.
Scrimgeour, I.R., Close, D.F., 1999. Regional high-pressure metamorphism during intracratonic deformation: the Petermann Orogeny, central Australia. Journal of Metamorphic Geology, 17(5): 557-572.
Smithies, R.H. et al., 2010. Geochemistry, geochronology and petrogenesis of Mesoproterozoic felsic rocks in the western Musgrave Province of central Australia, and implication for the

Mesoproterozoic tectonic evolution of the region, Report 106. Geological Survey of Western Australia, Perth, Western Australia, 73 pp.
Smithies, R.H. et al., 2011. High-temperature granite magmatism, crust–mantle interaction and the Mesoproterozoic intracontinental evolution of the Musgrave Province, Central Australia. Journal of Petrology, 52(5): 931-958.
Sprigg, R.C., Wilson, B., Coats, R.P., 1959. ALBERGA 1:253 440 geological map. Geological Survey of South Australia.
Tingate, P.R., 1990. Apatite fission track studies from the Amadeus Basin, central Australia. PhD Thesis, University of Melbourne.
Tingate, P.R., McKirdy, D.M., 2003. Exploration opportunities in the Officer Basin, South Australia. Revised (July) edition, Report Book, 2003/00001. South Australia. Department of Primary Industries and Resources.
Varma, S., 2012. Hydrogeological review of the Musgrave Province, South Australia. Goyder Institute for Water Research Technical Report Series No. 12/8.
Wade, B.P., Barovich, K.M., Hand, M., Scrimgeour, I.R., Close, D.F., 2006. Evidence for early Mesoproterozoic arc magmatism in the Musgrave Block, Central Australia: implications for Proterozoic crustal growth and tectonic reconstructions of Australia. The Journal of Geology, 114(1): 43-63.
Wade, B.P., Kelsey, D.E., Hand, M., Barovich, K.M., 2008. The Musgrave Province: Stitching north, west and south Australia. Precambrian Research, 166(1–4): 370-386.
Werner, M., Dutch, R.A., Pawley, M.J., Krapf, C.B.E., 2014. Mafic intrusions in the East Musgraves: new geochemical data set available now!, Unlocking SA's Mineral Wealth Technical Forum. Department for Manufacturing, Innovation, Trade, Resources and Energy, Adelaide, South Australia, pp. 37-40.
Wingate, M.T.D., Campbell, I.H., Compston, W., Gibson, G.M., 1998. Ion microprobe U–Pb ages for Neoproterozoic basaltic magmatism in south-central Australia and implications for the breakup of Rodinia. Precambrian Research, 87(3–4): 135-159.
Wingate, M.T.D., Pirajno, F., Morris, P.A., 2004. Warakurna large igneous province: A new Mesoproterozoic large igneous province in west-central Australia. Geology, 32(2): 105-108.
Woodhouse, A.J., Gum, J.C., 2003. Musgrave Province — geological summary and exploration history, Report Book, 2003/21. Department of Primary Industries and Resources South Australia, South Australia, 105 pp.
Zhao, J.-X., McCulloch, M.T., 1993. Sm-Nd mineral isochron ages of Late Proterozoic dyke swarms in Australia: evidence for two distinctive events of mafic magmatism and crustal extension. Chemical Geology, 109: 341-354.
Zhao, J.-X., McCulloch, M.T., Korsch, R.J., 1994. Characterisation of a plume-related approximately 800 Ma magmatic event and its implications for basin formation in central-southern Australia. Earth and Planetary Science Letters, 121(3-4): 349-367.