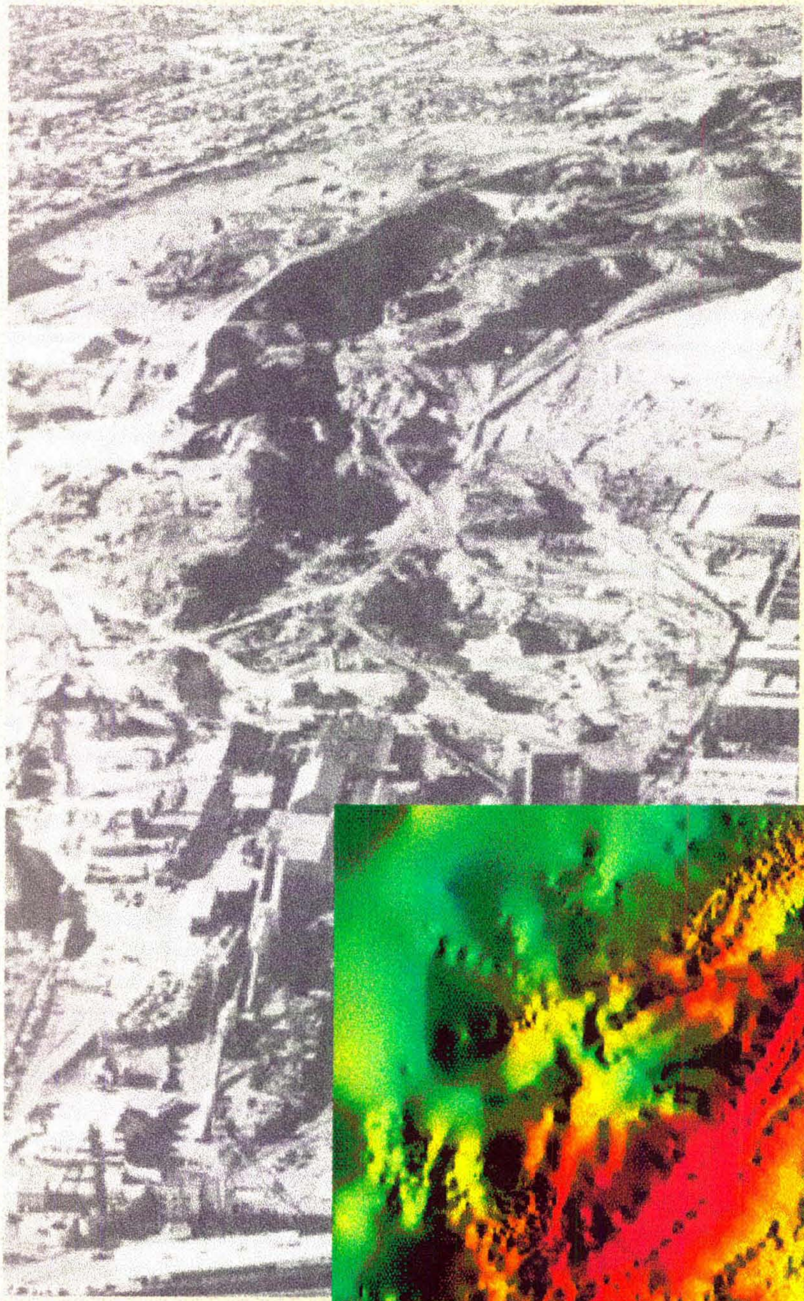
BROKEN HILL EXPLORATION INITIATIVE

Abstracts from 1997 Annual Meeting



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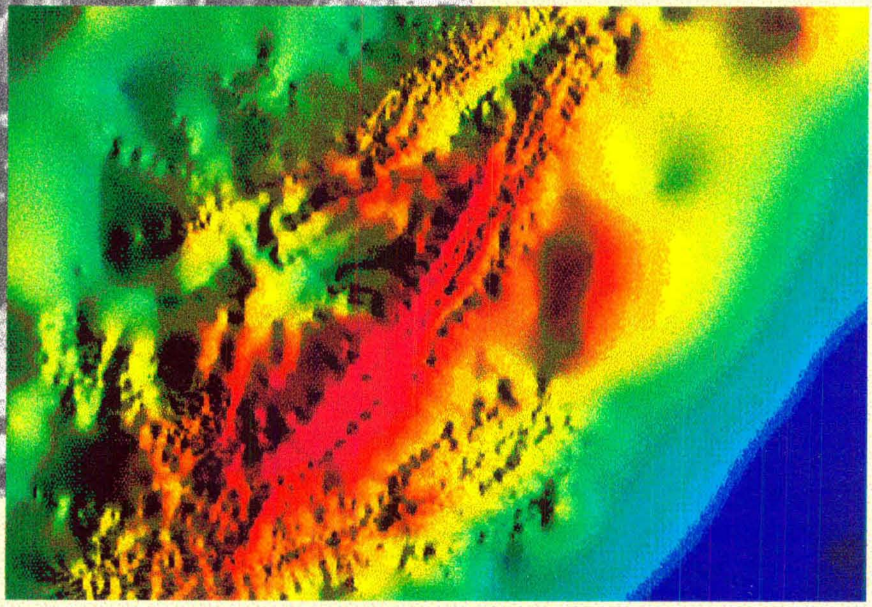

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BROKEN HILL EXPLORATION INITIATIVE:

ABSTRACTS FROM 1997 ANNUAL MEETING

Abstracts Volume

Record 1997/49

compiled by

David Denham

Australian Geological Survey Organisation

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources and Energy: Hon Warwick Parer
Secretary: Paul Barratt

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Neil Williams

ISSN 1039-0073
ISBN 0 642 27313 8

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Foreword

The third annual presentation of results from the Broken Hill Exploration Initiative (BHEI) was held in Broken Hill from 27-29 May 1997.

The BHEI is a joint Commonwealth/State program that aims to provide, through a multidisciplinary approach, a new generation of geoscientific information for the Broken Hill - Olary region in New South Wales and South Australia. This new information is seen as a basis for future development of the region, through increased exploration and subsequent discovery of new mines.

The program involves: -

- the Australian Geological Survey Organisation, the New South Wales Department of Mineral Resources, and the South Australian Department of Mines and Energy,
- the Cooperative Research Centres for Australian Geodynamics, Australian Mineral Exploration Technologies and Australian Landscape Evolution and Mineral Exploration,
- the Universities of La Trobe, Melbourne, Monash, New England and Tasmania, and,
- Mineral exploration and mining companies.

The first two days of the meeting were devoted to presentations on the following topics:

- Regolith Mapping, Geochronology, Structure, Stratigraphy
  Regional Geology, Geological Mapping, Gravity
  Interpretation, GIS packages, and Mineralisation

The third day was dedicated to a workshop on the results of the recently acquired deep seismic data, in the Broken Hill region.

This Record contains the Abstracts of most of the papers presented during the first two days of the meeting. They are reproduced in camera-ready copy provided by the authors, and hopefully contain a summary of the main results of the meeting.

David Denham
AGSO

SOLID GEOLOGY AND ECONOMIC POTENTIAL OF THE MULYUNGARIE 1:100 000 SHEET

WOLFGANG R. LEYH
(Eaglehawk Geological Consulting Pty Ltd)

Geological interpretation of the Willyama Supergroup on the Mulyungarie Sheet is based on detailed 1:25 000 scale mapping of an area with less than 1% outcrop, compilation of open file drill hole to basement logs and correlation with the recently completed BHEI aeromagnetics and gravity surveys.

Mapping in the Boolcoomata area shows the presence of Calc-silicate to Quartzofeldspathic suites and minor calc-silicate related Bimba gossan. Several poorly outcropping gossanous Cu Au bearing horizons with extensive strike potential under shallow alluvium have been located. Mineralization is associated with altered calc-albitite / calc-silicate, skarn and albitic gneiss +/- pyrite, magnetite rich sequences.

Metamorphic grade ranges from greenschist facies at Mooleulooloo to lower amphibolite facies (andalusite-sillimanite transition) at Boolcoomata. An evolving suite of anatectic 'S type' granitoids is present. These grade from weakly foliated often inclusion rich granodiorites in complexly disturbed migmatite / metasediment sequences to large homogeneous fractionated microcline rich weakly metamorphosed monzogranite intrusions at Mundearno Hill.

Structural data from the Mooleulooloo Hills indicates the presence of a large shallow south plunging dextral fold overprinted by a strong N-S vertical retrograde axial plane schistosity. Structural interpretation in the Boolcoomata area indicates the presence of tight reclined refolded E-W trending F1 or F2 folds cross-folded by regionally open NE trending F2 or F3 folds. This possibly leads to complex dome and basin interference structures. An interpreted refolded fold is located north of Boolcoomata Homestead.

The solid geology interpretation identifies several major structures including the crossfolded Yarramba Basin, the north plunging Mulyungarie Anticlinorial Fold, the major NW trending Mooleulooloo Fault corridor, and the NNW trending McBrides Dam Fault.

Aeromagnetic data outlines several major NE trending dome and basin interference structures in the eastern half of the map sheet. Similar structures have been targeted for basemetals and gold in the Mundi Mundi Area of NSW. Structural control of granite intrusions is inferred from their distribution along the Mooleulooloo Fault corridor and the presence of associated domal features and radial fracturing. Two types of related granite intrusives are indicated. These are the 'S type' monzogranite which is anatectic, gradational, semiconcordant and locally magnetic and the 'Honeymoon type' which is clearly intrusive, discordant and non-magnetic.

Solid geology interpretation, mainly based on magnetics and gravity data, is underpinned by data compilation from approximately 400 drill holes, correlation with outcrop and stratigraphic subdivision of Thackaringa and Broken Hill Group rocks plus associated mineralization. Stratigraphic correlation of mineralization beyond Kalkaroo, Boolcoomata, Hunters Dam and Polygonum Prospects is derived from geology, magnetics and gravity plus localized drilling data around major prospects. This reveals a minimum of 140km strike length which is prospective for stratiform to stratabound mineralization.

Obvious economic potential for large stratiform to stratabound deposits relates to three adjacent interpreted zones wrapping around the Mulyungarie and Yarramba structures.

These are:-

1. Poorly explored upper Broken Hill Group Pb Ag Zn +/- (Cu Au W) mineralization.
2. Partly explored lower Broken Hill Group Bimba-Ettlewood Member. Zn Pb Ag +/- (Cu Au Co Mo W).
3. Very poorly explored Thackaringa Group Upper Albite - Himalaya Formation.
   Cu Au +/- (Mo Co)
   Calc-silicate - Cues Formation and lower Cu Zn (Pb),
   Cu Au, Cu Co Mo?

Some potential also exists on the Mulyungarie Sheet area for distal sediment hosted base metal deposits in Sundown and Paragon Group equivalents, for a range of epigenetic Pb Ag Zn Cu Au U Th REE Nb Ta deposits and finally for regolith hosted / supergene U, Cu Au, Pb Zn deposits.

In conclusion, the Mulyungarie Sheet is considered highly prospective for a range of economic commodities with cover depths generally less than 120m.

MAPPING PROGRESS AND NEW INFORMATION ON THE KOONENBERRY REGION

Kingsley Mills and Michael Hicks (NSWDMR)

Approximately one third of the geological mapping area of 16,000 sq km covering the central and southern parts of the Koonenberry Belt has been prepared for map production at 1:100000 scale. The Bunda and Grasmere sheets are available and field work is progressing on the Kayrunnera sheet. A preliminary 1:250 000 map of the central and southern part of the Koonenberry Belt is currently being edited with cartography. The maps are being produced using a digital format so that editing and updating can be carried out as new information accrues. Field and structural information is being accumulated in an ACCESS database.

The foundation of the Koonenberry Belt is essentially a Late Precambrian to Cambrian sedimentary sequence that underwent tight to isoclinal upright folding as it was thrust onto the eastern margin of the Curnamona Craton at about 500 Ma during the Middle to Late Cambrian Mootwingee Phase of the Delamerian Orogeny. Rocks previously recorded as Wonominta Beds have been subdivided into three informal lithological sequences. The Kara beds, occupying the axial and western parts of the belt, are assumed to be distal shelf deposits equivalent to the Late Proterozoic Adelaidean sequence exposed in the Broken Hill region. The lower Kara beds consist of a thick sequence of carbonaceous shales and siltstones containing minor clean quartz sandstone sheets and rare dolomitic lenses. The upper Kara beds contain abundant laminated and cross-bedded silty sandstones and siltstones with dolomitic units towards the top. Separating the lower and upper Kara beds are the alkaline basaltic pillow lavas and tuffs of the Mt Arrowsmith Volcanics. An outcrop near Nundora suggests that the Kara beds are stratigraphically overlain by the Teltawongee beds, a monotonous sequence of graded-bedded turbidites and minor siltstone beds. Sequences correlated with the Teltawongee beds at Wonnaminta and in Cupala Creek have been shown to contain sparse brachiopods, sponges and sponge spicules. The Teltawongee beds are thought to be Early to Middle Cambrian in age and to correlate broadly with the Kanmantoo Group in South Australia. Although strongly deformed, both the Kara and Teltawongee beds are everywhere lower greenschist facies metamorphic rocks. The Ponto beds are generally better exposed and occupy fault-bounded segments in the axial parts of the belt. They consist of phyllites and fine-grained quartzofeldspathic arenites with lesser tholeiitic pillow lavas and tuffs, dolomitic siltstones and thin felsic tuff horizons. The sequence is multiply deformed and is metamorphosed to the upper greenschist and lower amphibolitie facies. The relationship of the Ponto beds to the other pre-Delamerian sequences is currently enigmatic. The Ponto beds are observed to be unconformably overlain by the Late Cambrian Scopes Range beds at Bilpa. Euhedral zircons in felsic tuffs from the Ponto beds yielded an age of 516 ± 11 Ma at Bilpa, but further north ages as young as 484 ± 6 Ma have been obtained. In the north the Ponto beds then appear to have a radiogenic age that overlaps the palaeontological age of the Kayrunnera Group, a post-Delamerian siliciclastic sequence that overlaps the folded Teltawongee beds east of the Koonenberry Fault. This anomaly has yet to be explained.

The older rocks are partially covered by post-Delamerian sequences. The Kayrunnera Group is a trilobite-bearing shale-dominated distal shelf sequence that commenced in the

Mindyallan and extended through the Late Cambrian. The Mootwingee Group and Scopes Range beds to the south are proximal shelf, estuarine and fluvial mature siliciclastic deposits of similar age derived from the south and southwest. Local Early Devonian intramontane basins are preserved in the Wertago-Daubeny area and on Churinga. These basins are filled with maroon lithic and siliciclastic rudites and arenites derived from the north. A thick basal conglomerate contains sections with boulders up to 1m and some large rafts of older consolidated rocks with Kayrunnera Group affinities. Andesitic flows and pyroclastics and both andesitic and rhyolitic intrusions are significant igneous components of the northern basin.

In the Late Devonian a thick sequence of quartz sandstones, also derived from the north, covered the region. These have been equated with the Mulga Downs Group, locally divided into the Snake Cave Sandstone and the Ravendale Sandstone. The Snake Cave Sandstone was mildly folded and eroded before the Ravendale Sandstone was deposited. Some unconsolidated deposits and evidence of glacial moulding of topography in the south have been attributed to the Permian. Much of the area was surrounded and partially covered by Cretaceous deposits at the edge of the Great Australian Basin. While some near vertical faults in the area relate to thrusting in the Delamerian Orogeny many of the better defined faults, such as the Koonenberry Fault, were active zones of movement and brecciation in post-Ravendale, presumably Carboniferous, time. Some faults in the Scopes Range - Menindee region were reactivated late in the Tertiary.

Small mineral deposits have been mined throughout the Koonenberry Belt and are mostly derived from or developed in the older basement rocks. The Kara beds contain interesting metal anomalies that have not been tested. The Teltawongee beds contain gold at Cawkers Well and Kayrunnera, and silver-lead at Wertago (Noonthorungie Silverfield). The Ponto beds contain copper, lead and silver at Bilpa, and copper at Grasmere, Wertago and Ponto. The Koonenberry Fault zone contains gold at Koonenberry and copper at Wertago. The silver-lead deposits on Wertago are found in undeformed siderite veins that may have been introduced in the late Palaeozoic. Some of the copper at Wertago appears to be spatially related to Early Devonian andesitic flows and intrusions but there is also evidence of later, perhaps Carboniferous, mobilisation into fault zones

The rotation of the vertical NW trending Delamerian axial plane cleavage clockwise through 90° into the Scopes Range trend seems to be brought about by a compound fault pattern of presumed late Palaeozoic age best expressed in the aeromagnetic maps of Grasmere and Bunda. The geology of this region is poorly exposed or covered in wind blown sand but the faulted structure provides numerous channelways for the movement of mineralising fluids. The Grasmere and Bunda sheets and the area extending southwest of Scopes Range should be a fertile area for exploration.

GEOLOGY OF THE BUNDA 1:100000 MAP SHEET, FAR WESTERN NSW:
PART OF THE DISCOVERY 2000 KOONENBERRY MAPPING PROGRAMME.

Michael Hicks and Kingsley Mills (NSWDMR)

Mapping of the Bunda 1:100000 geological sheet was completed in late 1996 and compiled in early 1997. The map is now available in both digital and hard copy format as part of the Discovery 2000 regional mapping programme for the Koonenberry Belt.

The Bunda sheet represents the southeastern portion of the Koonenberry Belt, an arcuate zone of Late Proterozoic to Palaeozoic sediments and volcanics that forms the eastern shell of the Curnamona Craton. The Bunda sheet is centred on Dolo Hill and is dissected by the Barrier Highway, approximately 130 km east of Broken Hill. Outcrop on Bunda is at best poorly exposed with up to half of the sheet covered by Quaternary sediment.

The oldest rocks mapped on the Bunda sheet are composed predominantly of slates, phyllites and turbiditic arenites. In the past these rocks were referred to as the Wonominta Beds, however more recently they have been informally subdivided into three distinct units, the Pre-Delamerian Kara, Ponto and Teltawongee Beds, which are believed to have been deposited in an outer shelf environment in the Early to Middle Cambrian.

The Kara Beds outcrop extremely poorly on the Bunda sheet, although they are thought to underlie the Scopes Range Beds over most of the NW corner of the sheet. Where encountered they outcrop as strongly weathered shales and minor volcanics. North of Bunda where outcrop is better, the Kara Beds comprise a thick sequence of black shales, slates and pure cross-bedded quartzites. The Ponto Beds comprise strongly cleaved phyllites, fine quartzofeldspathic arenites, trachybasalts and dacites as well as minor felsic tuffs and carbonates. These rocks are metamorphosed and multiply deformed. North of Bunda, the dominant cleavage within the Ponto Beds trends to the NW, however a major dextral shearing event has resulted in all structures including the Koonenberry Fault bending into the Scopes Range trend, and so throughout the Bunda sheet the dominant cleavage within Ponto Bed phyllites is near vertical and trends to the SW. Throughout the Bunda sheet, the Teltawongee Beds comprise a thick sequence of blue-grey turbiditic arenites, fine quartzofeldspathic sandstones and slates. Graded bedding is common in outcrop and suggests that locally some beds may be overturned as a result of steep isoclinal folding. No fossils have been found in any of the Pre-Delamerian units on the Bunda sheet.

After the Delamerian, the older units of the Koonenberry Belt were eroded down prior to deposition of the Mootwingee Group sediments. The Late Cambrian-Early Ordovician Scopes Range Beds unconformably overlie the Teltawongee Beds near Follies Tank on the Bunda sheet. They range from cross-bedded fluvial sandstones in the south to shallow marine quartzose sandstones and quartzites in the central and northern Bunda sheet area. The Scopes Range Beds are considered to be Mootwingee Group equivalents, the age of which is well documented with a range of trilobites, brachiopods and trace fossils. The Early Devonian saw a period of intermontane basin sedimentation depositing red bed conglomerates, sandstones and shales of the Mount Daubeny Formation. A remnant of these basins is preserved on the Bunda sheet in the form of strongly bedded arenites and minor conglomerates. The contact between the Mount Daubeny Formation and overlying Mulga Downs Group is thought to be an unconformity although the poor exposure made this contact impossible to locate. In the Middle to Late Devonian, fluvial quartzose sandstones of the Mulga Downs Group were deposited in large basins in the southern and central Koonenberry Belt. On the Bunda sheet, the Mulga Downs Group is subdivided into Snake Cave Sandstone dominated by thickly bedded and cross-bedded fluvial quartzose sandstones and quartzites, and Ravendale Formation comprising soft laminated sandstones. Assumed Permian glacial material, together with Tertiary and Quaternary regolith, cover the remainder of the sheet.

The dominant structural feature of the Bunda sheet is the Koonenberry Fault, a major structure which can be traced northwest to the Queensland border and southeast into South Australia and western Victoria. Within the Bunda sheet, the Koonenberry Fault occurs as a wide, brittle crush zone which was still active in the Carboniferous.

A number of mineral deposits have been mined on the Bunda sheet including the Cawkers Well Au-siderite-quartz reefs within metasediments of the Teltawongee Beds, Dolo Hill Au, associated with narrow quartz veins within quartzites, possibly associated with the faulted edge of the Devonian Mulga Downs Group, and west of Anderson Hill where at least 8 shafts have been dug into the Ponto Beds.

The completed first draft Bunda sheet is now available in digital and hard copy format together with field notes and rock descriptions. Shallow RAB drilling is planned to look beneath the cover in some important areas on the sheet. A GS report will also be available in the near future.

MINGARY 1:100 000 SHEET MAPPING: A PROGRESS REPORT

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The Mingary 1:100 000 sheet, in South Australia, adjoins the SA/NSW border sharing a common boundary with the Thackaringa 1:100 000 sheet in NSW. It occupies a position between the Olary, and Broken Hill Domains and shows some features in common with both.

Rocks which resemble those found in the Olary Domain, have been encountered during recent mapping, centred on the NE quadrant of the sheet. These include lithologies with possible "lower albite", 'calcsilicate suite' (including 'Bimba suite' gossans) and 'pelite suite' affinities. However the higher metamorphic grade, up to granulite facies in places, and the presence of abundant, ?1670 Ma amphibolite dykes, gives the area a more Broken Hill Domain than Olary Domain character.

Gross similarities between the lithologies observed on the Mingary 1:100 000 sheet and those in the Thackaringa and Broken Hill Groups from the Broken Hill Domain were also noted but there is insufficient difference between observed textures and strain history to allow correlation at formation level. In addition, it should be pointed out that pre-peak metamorphism alteration effects often mask any original genetic indicators. Therefore correlations based on similarities in alteration style may not be valid.

A major extensive migmatisation event gave rise to local in-situ partial melts. In places this event preserved enclaves of folded metasediments, including calcsilicates. Migmatisation affected a variety of rock units and post dated at least some of the major deformation events. The use of migmatite as an indicator of the base of the Willyama Supergroup, implicit in any subdivision which separates-out the Clevedale Migmatite as a distinct stratigraphic entity, is not valid on the Mingary sheet..

The Mingary area is traversed by a number of shear zones which can be characterised by orientation, mineralogy and magnetic response. Several NNE-trending, non-magnetic, "mylonitic" zones have been identified and sub-horizontal mineral lineations observed. Parallel to these shears is another distinctive shear style involving kyanite crystal growth, again with an apparent subhorizontal mineral lineation orientation. The NNE trend of the "lines of lode" at the Mutooroo and Mutooroo West mining-fields suggest this latter shear set could have controlled the emplacement of copper mineralisation.

Airborne magnetics highlight a later shearing event, identified in previous geological investigations as a number of cross cutting W-E to NW-trending features. These are believed to affect the earliest Neoproterozoic Cutana Beds, and therefore are, at least in part, post-Olarian in age. The shears include a variety of mineral assemblages, e.g. biotite + muscovite + garnet, biotite + muscovite + staurolite and chlorite + garnet. Sulphide mineralisation (pyrite + chalcopyrite) is associated with one of these shear zones particularly at the Trinity Mine, but numerous prospecting pits extending to Kings Dam and Quartz Hill in the west all show malachite and anomalous gold in the spoil. Current mapping has identified abundant pseudomorphs after pyrite associated with many other shears of this type indicating that sulphides are more widespread than previously thought. These shears then are also prospective for copper - gold mineralisation.

Geological mapping of the Mingary 1:100 000 map sheet area continues. The lithological maps of the two NE 1:25 000 sheets are currently being drafted by MESA. The field work for the two SE 1:25 000 map sheets is being compiled. Regolith maps and solid geology maps are also being compiled.

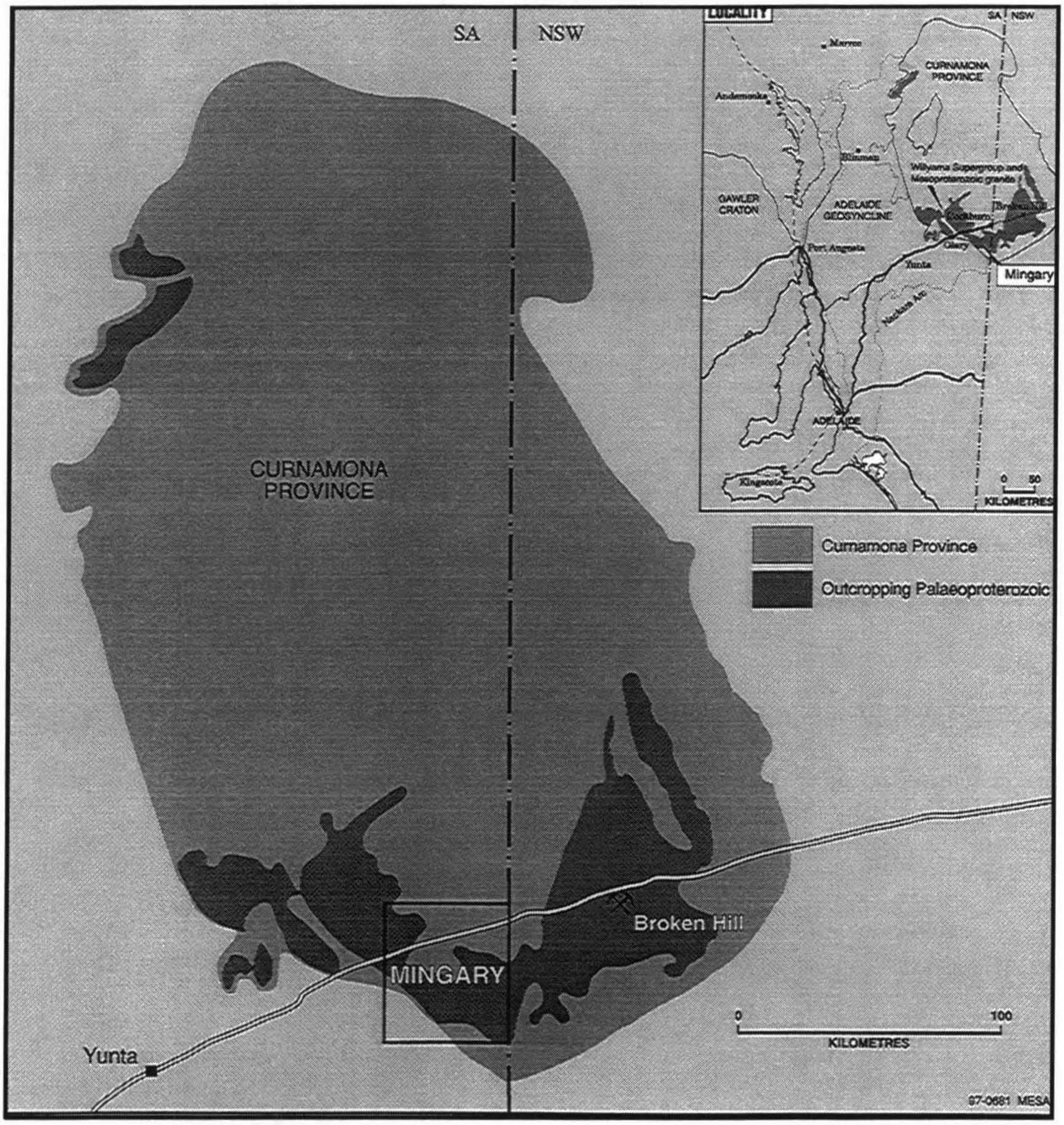

Fig 1. *Mingary 1:100 000 Sheet – Location.*

GEOPHYSICAL INVESTIGATIONS OF THE KOONENBERRY BELT, WESTERN NSW

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Upon consideration of the latest geophysical datasets and recent mapping, the Koonenberry belt can be shown to be a Mid Palaeozoic fold and thrust belt. To date, studies of the belt have been hampered by poor outcrop conditions which limit the possibilities of retrieving comprehensive structural data from surface mapping programs. This study presents the results of geologically controlled two-dimensional modelling of gravity and magnetic data that permit a new tectonic interpretation to be made.

The Koonenberry belt comprises three distinct tectonostratigraphic packages. The *Mulga Downs Group* is a package of fossil-dated Late Devonian and Carboniferous siliciclastics, which are generally flat-lying and contain open folds. Beds may be locally overturned in major fault zones such as the Koonenberry Fault.

The *Mootwingee Group* and its correlates (Cupala Ck Fm, Kayrunnera Gp, Kandie Tank Limestone) are a package of fluvial to shallow marine siliciclastics and carbonates of Late Cambrian to Early Ordovician age. These contain an abundant trilobite fauna. They are tightly folded with a weakly developed axial planar cleavage, due to their competence. Seismic reflection at the margins of the Bancannia Trough has identified low-angle thrusts in this package. The metamorphic grade of these units is lowest greenschist facies.

The final tectonostratigraphic package is composed of four distinctive groups of rocks informally termed the *Ponto Beds, Teltawongee Beds, Kara Beds,* and *Mt Arrowsmith Volcanics*. This package has traditionally been termed the "Wonominta Complex" .The *Ponto Beds* are a series of deformed siliciclastics, containing probable exhalites, tuffs and tholeiitic basaltic volcanics. They have been dated as Upper Cambrian to Early Ordovician using SHRIMP Zr methods. They contain isoclinal folds with 2 or 3 cleavages. They are bimodal in their magnetic susceptibility, and trimodal in density. Changes in density reflect elevation of metamorphic grade near major faults, from lower greenschist to amphibolite facies. The *Teltawongee Beds* are lower greenschist turbidites, with isoclinal folds and two cleavages. They are the most extensive lithology in the Koonenberry belt, and may be correlated with the Cambrian Kanmantoo Group of South Australia. Unconformable relationships with the package above demonstrate that isoclinal folding occurred prior to the Late Cambrian, and that the following deformation was coaxial. The *Kara Beds* are an undated sequence of shales, sands and dolomites lying stratigraphically beneath the Teltawongee Beds. They are also affected by two deformations. They are host to the *Mt Arrowsmith Volcanics*, a package of strongly magnetic alkaline basalts that outcrop in two locations next to major faults. These have recently been SHRIMP dated as Late Neoproterozoic.

Analysis and modelling of geophysical data, in particular aeromagnetics acquired under the Broken Hill Exploration Initiative, show several interesting features. These include:

- apparent across-strike repetitions of the strongly magnetic Mt Arrowsmith Volcanics at several different structural positions;
- high spatial frequency linear features that require steep surface dips but easterly dips at depths of between 4 and 10 km;
- and broad spatial wavelength features that require sub-horizontal bodies between 4 and 10 km.

In addition, detailed sub-kilometre gravity shows anomalies are skewed to the east near the positions of suspected faults. This arises from an elevation of density immediately to the east of the fault, probably corresponding to an increase in metamorphic grade. This relationship is observed in the Ponto Beds near the Mt Wright Fault.

These features strongly suggest that the Koonenberry belt is an easterly dipping thrust package that detaches in the mid-crust at c.10 km.

Forward modelling of gravity and magnetic data with mapping control (Figure 2) indicates that both the Mootwingee Group and Wonominta Complex are involved in thrusting, whereas the Mulga Downs

Group is unaffected by this style of deformation. This limits the timing of deformation to either the Silurian or Devonian, probably corresponding to either the Benambran or Tabberabberan events in the Lachlan Fold Belt. This deformation coaxially overprints an earlier pre-Late Cambrian event that has deformed only the Wonominta Complex. Conversely it is weakly overprinted by a probable Carboniferous event that has buckled the Mulga Downs Group without cleavage formation.

These conclusions indicate that the Koonenberry belt is a zone of overlap between the Lachlan and Adelaide Fold Thrust Belts.

Acknowledgements: Magnetic data are published with the permission of the Director of the Geological Survey of NSW; Mineral Resources NSW, the Australian Geological Survey Organisation, Aberfoyle Resources and BHP Minerals Exploration are thanked for financial assistance; staff and students of the University of Tasmania Geology Department are thanked for assistance with field work.

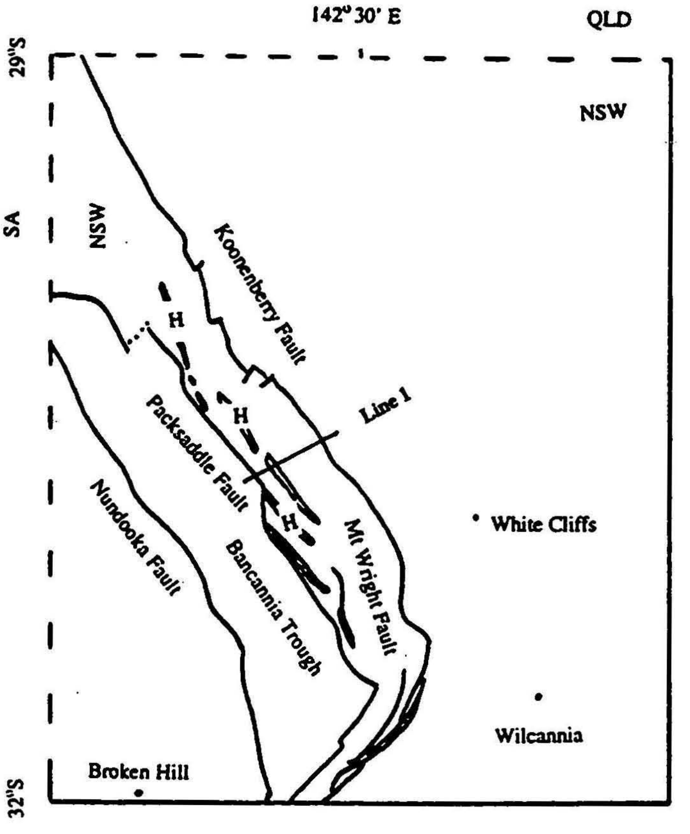

Figure 1: Location Diagram (Schematic). Aeromagnetic highs corresponding to positions of Mt Arrowsmith Volcanics shown as "H".

2D GRAVITY AND MAGNETICS MODEL

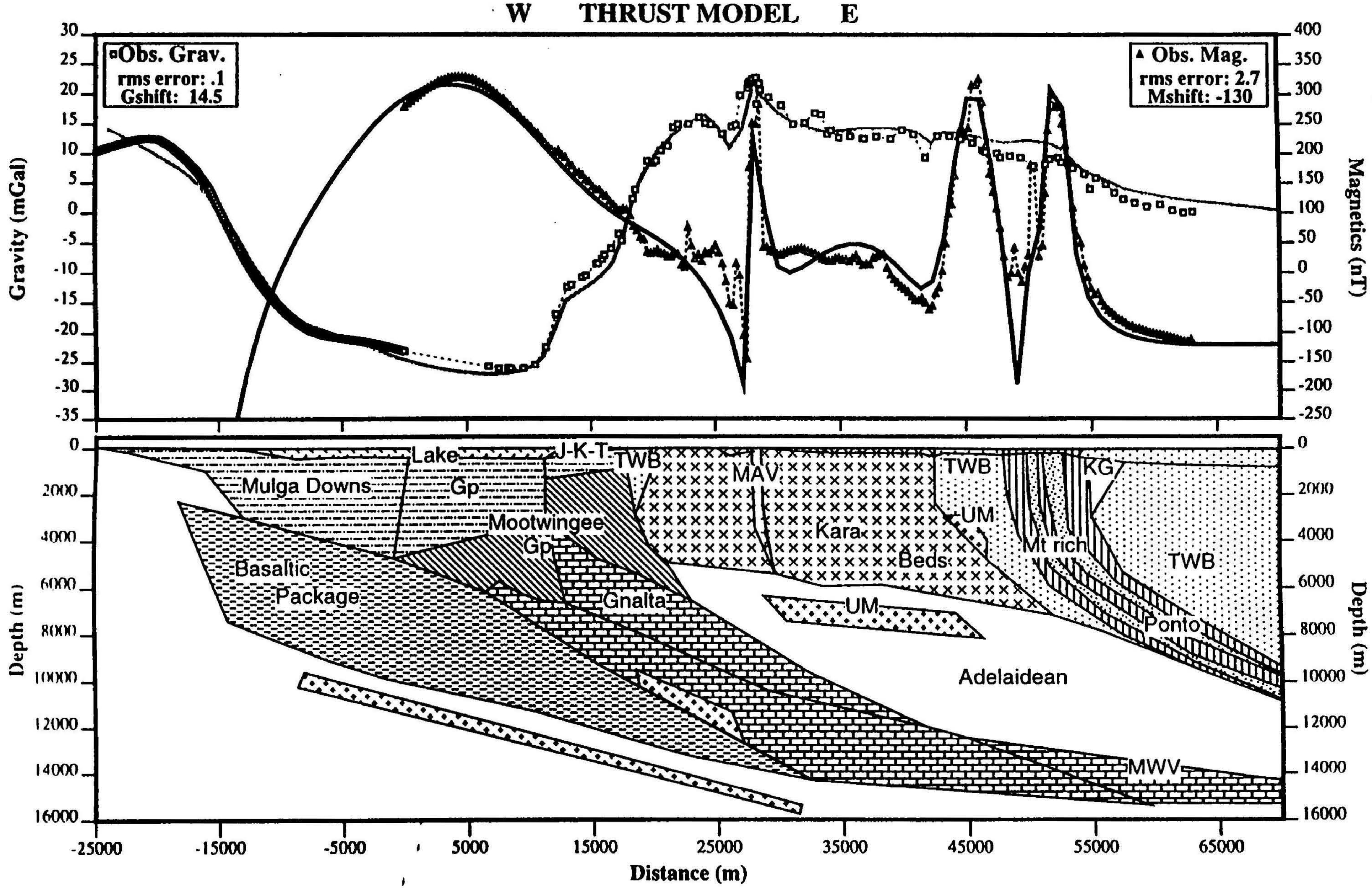

Figure 2a: Two-dimensional forward model of gravity and magnetic data along the section shown in Fig. 1.
KEY: J-K-T = Murray Basin sediments. TWB = Teltawongee Beds. MAV - Mt Arrowsmith Volcanics. UM - serpentinised ultramafic complex.
KG - Kayrunnera Gp. MWV = Mt Wright Volcanics.

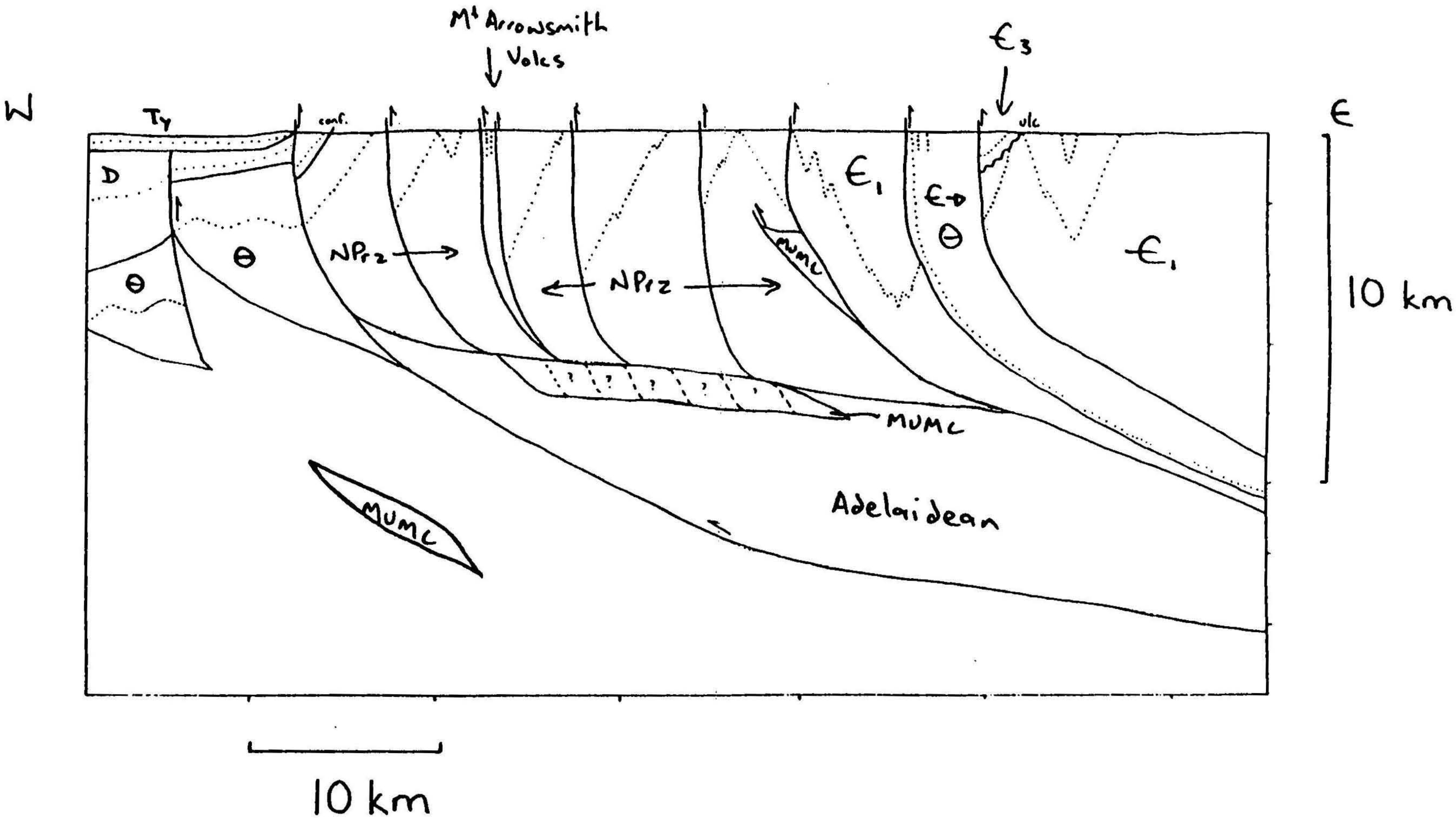

Figure 2b: Structural interpretation of geophysical model in Fig. 2a.
KEY: Ty = Tertiary unconsolidated sediments. D = Mulga Downs Gp. θ = Mootwingee Gp. NPrz = Kara Beds.
MUMC = Serpentinised Mafic-Ultramafic Complexes. ε1 = Teltawongee Beds. ε - θ = Ponto Beds. ε3 = Kayrunnera Gp.
Bedding form surface shown dotted.

Preliminary Gravity Interpretation of the Olary Domain

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During 1995 and 1996 Mines and Energy Resources South Australia (MESA) conducted two extensive regional gravity surveys within the BHEI area. The net result of these surveys and associated company joint ventures was the acquisition of approximately 8,000 high quality gravity stations.

Initial investigations have focussed on the Mulyungarie 1:100,000 map sheet and in particular the large 'U" shaped structure that occupies a majority of the map sheet. A transect of gravity values were determined along a line trending from the northwest to the southeast within the central portion of the map sheet, totaling a distance of almost 50 kilometres. The transect was located at this point so as to best utilise drill hole and outcrop information available.

The two main gravity features to be observed in the region were firstly, the structurally controlled anomalous high and, secondly, the sharply contrasting gravity lows. The relatively thin band of anomalous high Bouguer Gravity that appears to be continuous throughout the region could be due to mineralogical variations at the contact between the Broken Hill Group and the overlying Sundown/Paragon Groups. The high values were investigated to remove any doubts that they were not the result of terrain influences.

The contact between these two rock groups, based on the gravity signature, can be extrapolated outside of the area recently surveyed into areas covered by pre-existing regional stations, with varying degrees of confidence. It is possible to see that the anomalous zone stretches over into NSW within the region of the Polygonum prospect and also to the north west before becoming obscured due to poor resolution.

The second prominent gravity feature within the map sheet is the presence of several sharply contrasting gravity lows, which have been interpreted as intrusive granitoids. By observing the associated magnetic image of the area it is possible to see that these granites are also magnetic destructive especially in the case of the granite in the south central portion of the area, which is sharply discordant with the surrounding magnetic horizon.

Before modelling was conducted the regional or long wavelength response was removed from the Bouguer gravity thus enhancing localised affects. A background density of 2.73 t/m^3 was assumed based on results as published by Tucker, 1983. Structural control was available from observations taken at Moolooloo Hills and drill hole information from the Hunters Dam Prospect. Although the magnetic response was not incorporated it was referred to as a generalised guide.

The major problem associated with this exercise was determining rock densities. As with any gravity modeling it is necessary to resolve density values for the underlying rock types. An initial estimate based on the average of samples gathered from outcrops proved to be unreliable as the samples were highly weathered. For future work, densities could be measured from freshly obtained drill samples. However, as the scope of this study is on a regional scale rather than on a prospect scale, a system of weighted averages should be used. This would entail determining the relative percentages of each rock type present in a formation and its associated density then determining the overall rock density based on the abundance of the constituent rock types.

From the resultant model it is possible to observe a dominant basinal structure in the centre of the profile, with Paragon/Sundown Groups occupying the core of the syncline. Although it is possible to observe the Broken Hill Group on the eastern and western limbs of the syncline it is not possible at present to determine the nature of the fold at depth. Debate exists as to whether the limbs are continuous at their present dip or whether the Broken Hill Group rises towards the surface, forming a subsidiary antiform at the hinge position of the proposed synclinal structure. The resultant gravity-high response would be then negated by the presence of a large granitoid body at depth.

The Bouguer Gravity anomalies on the western portion of the transect can be explained by extrapolating the plunging structure to the north west back onto the transect, resulting in a series of folds within the Broken Hill Group. However, it should be pointed out that there is no conclusive evidence for this and there is no drill hole information available in this area at present.

At present this work represents a first pass study, with future work to incorporate other geophysical methods such as radiometrics and magnetics in order to facilitate a greater knowledge of the geology within the Olary Domain.

Reference

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A RE-EVALUATION OF SOME REGIONAL REGOLITH-LANDFORM PARADIGMS AS A BASIS FOR IMPROVED MINERAL EXPLORATION MODELS IN THE BROKEN HILL REGION

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Many of the early regolith and landscape studies in central and south eastern Australia initiated or subscribed to a number of regionally significant research paradigms. Some of these paradigms remain entrenched in recent studies despite further evidence often indicating their simplicity and inappropriateness. A current study initiated by the Centre for Australian Regolith Studies (CARS) and continued through the Co-operative Research Centre for Landscape Evolution and Mineral Exploration (CRC LEME) enables a re-evaluation of several of these paradigms as a basis for landscape evolution and mineral exploration models in the area. The evaluation of these paradigms is fundamental to the development of mineral exploration models, particularly within regolith dominated terrains in the Broken Hill region. This provides a framework for understanding the physical and geochemical dispersion associated with mineral exploration sampling media, and the development of efficient and effective exploration models for regolith dominated terrains. Interestingly, even by conservative estimates, greater than two thirds of the prospective ground around Broken Hill is regolith dominated. Bedrock-based exploration techniques and models, however, have dominated previous exploration efforts. The development of regolith and landscape based mineral exploration models for this region is one of the next exploration frontiers.

Australian regolith and landscape studies have frequently invoked research paradigms associated with the following aspects of the regolith and landscape evolution:

i) TECTONISM

The last twenty or more years have seen widespread acceptance that much of Australia (in particular cratonic areas) has experienced long-term tectonic stability. Support for this has largely come from: (i) Australia's position away from present plate boundaries; (ii) the low relief of Australian landscapes; (iii) the antiquity of many facets of Australian landscapes; and, (iv) its appeal as a response to the failings of an even earlier landscape paradigm advocating widespread late Tertiary uplift (e.g. the Kosciusko Orogeny).

In the Broken Hill region there is strong evidence that parts of the landscape have recently been tectonically active. Well-defined fault-line escarpments (such as along the Mundi Mundi, Kantappa and Mulculca Faults) often feature deep incision and associated large alluvial fans with folding and offset of many Cainozoic units. Approximately NE-SW and NW-SE trending faults define a series of tilted fault blocks. Much of the recent tectonism has been restricted to the reactivation of older structures (such as shear zones) accommodating movement throughout the Mesozoic and Cainozoic, in close association with sedimentary basin development adjacent to the Broken Hill Block (particularly associated with the Murray Basin and Callabonna Sub-basin). This had lead to the erosion of weathered materials from uplifted areas and related pulses of sedimentation (both fluvial and lacustrine) in adjacent down faulted areas. As a result, tectonism is a major driving force behind the development, distribution and associated physical and geochemical dispersion characteristics of transported regolith and the preservation or erosion of *in situ* regolith.

(ii) PALAEOSURFACES

Early Australian landscape studies considered much of inland Australia to be part of an extensive erosion surface of Miocene age (e.g. "The Great Peneplain" or "Great Australian Peneplain" of authors such as Woolnough, Jutson, Andrews). A legacy of this paradigm can be see in many recent studies using landsurfaces as morphostratigraphic markers. Recent studies in areas such as the Yilgarn of Western Australia, have highlighted some of these palaeosurface remnants as significant landscape facets in regolith-based mineral exploration models (e.g. so-called "relict regimes").

Although descriptions of the landscape in the Broken Hill region usually contain reference to remnants of a single palaeosurface (or peneplain), there are many different landscape features related to a wide range of palaeosurfaces. These are a range of ages, possibly dating from the Permian, and through the Mesozoic and Cainozoic. They feature a wide range of different regolith materials and origins, with preservation enhanced by sedimentary burial, protective duricrust cappings, local lithological influences on stream baselevels and within down-tilted areas. Palaeosurfaces also tend to be diachronous and polygenetic, with continual histories of burial, exhumation, and overprinting by later processes. Many palaeosurafce related features in bedrock dominated terrains reflect the exposure of weathering fronts associated with ancient weathering profiles (etchsurfaces) rather than an ancient landsurface in the strict sense. Rather than the wholesale acceptance of the presence of a regionally significant palaeosurface of a given age, extreme caution is advisable when using wide extrapolations of a palaeosurface and associated features (e.g. "Cordillo Silcrete", "Lateritic Residuum" or "Relict Regimes") as the basis for landscape evolution and mineral exploration models.

(iii) DURICRUSTS

Previous studies have related a number of assumptions to the regional significance of duricrusts, including:

a) duricrusts reflect monogentic events (e.g. a specific climate or palaeoenvironment);
b) duricrusts form on laterally continuous, "flat" or extremely low relief landsurfaces
c) duricrust morphology reflects age and stratigraphic equivalence;
d) duricrusts form very quickly and having done so undergo little modification; and,
e) duricrusts are genetically associated with deep weathering profiles and are therefore syngenetic (e.g. a "complete lateritic profile")

One of the appeals of these assumptions has largely been due to their ability to implicitly combine aspects of various paradigms such as, climatic geomorphology, peneplains and Davisian landscape theory, the concept of duricrust profiles, and static landscape relicts.

In the Broken Hill region the above assumptions are not universally valid. The duricrusts reflect past and present, local environmental conditions and are therefore not a reliable morphostratigraphic marker. The wide range of stratigraphic settings of the duricrusts shows that their age is best considered within the context of a model of continual change over the course of landscape development. The rates of these continual changes, and therefore the balance between duricrust formation and destruction, will not only vary over time but also spatially as landscapes are composed of a locally variable mosaic of environmental conditions. This results in the development and preservation of duricrusts at particular time periods in one part of a landscape, and their destruction at particular time periods in other landscape settings. As well as an association with low-relief, deeply weathered landsurfaces, they may also be found in a wide variety of landscape settings, including transported regolith materials, directly overlying fresh bedrock, and over parts of landsurfaces of high to moderate relief (e.g. within palaeo-valley systems).

Associated Products

Some of the products resulting from this study include:

* A 1:100,000 regolith-landfrom map of the Broken Hill Block and adjacent area (covering the same area as the 1:100,000 Broken Hill Stratigraphic map)
* A range of 1:25,000 regolith materials and landform facet based maps.
* Characterisation (geochemical, mineralogical, morphological and geomorphological), correlation and genetic models developed for major regolith materials
* Development of regional regolith and landscape evolution models
* Provision of the framework for mineral exploration models for regolith dominated terrains in the region.

LANDFORM EVOLUTION, POST-CRETACEOUS TECTONICS AND REGOLITH IN THE BROKEN HILL REGION

D.L. Gibson, CRC LEME, AGSO

The Broken Hill region is host to a wide variety of landforms and regolith. Post-Early Cretaceous tectonics have helped shape the landform of the region and have influenced the preservation of in situ regolith and deposition of transported regolith. Uplifted and tilted areas are dominated by erosion, and there is little preserved regolith. Low-lying and downwarped areas received sediment derived from the raised uplands, resulting in thick transported regolith. Intermediate in setting between these are areas which have been covered by thin, poorly-cemented Eromanga Basin and possibly younger rocks, and where the pre-Cretaceous topography has been only slightly modified since being exhumed by stripping of the cover sediment.

The identification of tectonic landscapes depends not only on recognising recent fault scarps, but also on the elevation and deformation of post Palaeozoic sedimentary rocks. These have been poorly mapped and dated in the past because of poor outcrop, difficulty in recognition, degree of weathering, and perceived economic insignificance. There is also a tendency to label thin cover rocks away from the known thick Eromanga Basin sequence as 'Tertiary', when there is no age evidence. Some so called 'Tertiary' rocks in the Fowlers Gap area have been shown by recently discovered plant macro- and microfossils to be of Early Cretaceous age.

Thrust movement on the generally N to NNE trending, east-dipping Mundi Mundi Fault has had the greatest effect on the local Broken Hill landscape. Uplift of up to 400 m is postulated. Erosion of the upthrust area by new streams flowing to the west has resulted in the rugged topography near Silverton. The material eroded from this area has been deposited as reddish-brown fine to coarse alluvium on the Mundi Mundi Plain to the west. AGSO seismic refraction data indicate that this reaches 90 m thick adjacent to the fault line scarp, thinning to 60 m at the SA border. It is interpreted that the Broken Hill area has been tilted to the southeast, with new and rejuvenated southeast-flowing streams eroding a low relief, regolith-dominated landscape. This eroded material was deposited as alluvium up to 40 m thick at the margin of the Murray Basin. The post-tectonic alluvium on the Mundi Mundi Plain overlies probable Miocene Namba Formation (silt and smectitic clay deposited in a lacustrine to stagnant alluvial environment), and thus a post-Miocene age for movement is suggested.

The low Kantappa Fault line scarp branches NW from the Mundi Mundi Fault line scarp at about 31°30' S, separating rises underlain mostly by weathered bedrock capped with a discontinuous veneer of previously unmapped probable Cretaceous rocks (a microfossil dating program is currently under way) from alluvium and aeolian sand on the Mundi Mundi Plain. Much of the scarp is formed in poorly consolidated and highly weathered material, suggesting that it is a recent feature. The Mundi Mundi Fault line scarp is less well defined in this area, and it is interpreted that most recent movements in the area have been taken up by the Kantappa Fault, which is interpreted as a splay from the Mundi Mundi Fault.

The Scopes Range is a fault-bounded, northeasterly trending range of deformed Palaeozoic sedimentary rocks about 90 km E of Broken Hill. Previously undescribed flat-lying pebbly sandstone and conglomerate up to 15 m thick is locally present near the crest of the range. Possible equivalent rocks are present in rises on the plain to the southeast. The AGSO seismic line shows that the base of the Murray Basin has been upfaulted and where it crosses the area along structural strike to the southwest of the range. It is interpreted that the range had little relief when the flat-lying rocks were deposited, and that relative uplift of at least 50 m has occurred. The range is most likely the surface expression of a horst.

Interpreted post-Palaeozoic rocks have also been identified in the Dolo Hills further to the E. These remain undated despite attempts to isolate plant microfossils from bioturbated mudstones. However, a drilling program to sample these rocks is currently planned by the Geological Survey of NSW. These rocks appear to be present at varying elevations, and a tectonic origin is considered possible for the hills.

Devonian sandstone, forming ranges north of Fowlers Gap 120 km N of Broken Hill is unconformably overlain by east-dipping Early Cretaceous fluvial to paralic sediments at the western margin of the Bancannia Trough. The previously unmapped surface trace of the unconformity generally occurs at the break of slope at the eastern margin of the ranges. Small outliers of the Cretaceous rocks are locally present on and to the west of the ranges. Analysis of the pattern of dips in the Devonian rocks, and the elevation and attitude of the Cretaceous, indicates that the ranges result from monoclinal flexing of uniformly east-dipping Devonian rocks unconformably overlain by horizontal Cretaceous sediments. Post-deformation erosion has removed most of the poorly consolidated Cretaceous sediment to near local base level, and etched the Devonian rocks, giving the ranges their current morphology. The deformation probably results from thrusting at depth on a west-dipping fault system, which includes the previously mapped Nundooka Fault, which also has Palaeozoic displacement. The interpreted fault system may constitute a flower structure, formed by the interaction of sinistral wrenching and a northward deflection in the NNW-trend of the Nundooka Fault.

Overall, an E to SE shortening direction for the region is inferred, in contrast with the present day E to NE principal stress orientation. A time of high stress is indicated during the late Cainozoic, with the changing configuration of the northern margin of the Indo-Australian Plate as it migrated northward and interacted with the Pacific, Philippine, and Eurasian Plates providing a mechanism for changes in stress direction and intensity.

The uplifted and tilted erosional areas have only a veneer of young transported regolith, mostly local alluvium/colluvium of mixed parna- and bedrock-derived material up to 6 m thick along drainage lines. The underlying bedrock is mostly only slightly weathered, depending on lithology. These areas encompass virtually all known mineral occurrences in the Broken Hill region, most of these discovered by gossans and outcrop prospecting. Depositional areas have a range of sediment cover, ranging in age from Mesozoic to recent, and the underlying bedrock is deeply weathered in many areas. Exploration of these areas requires remote techniques and drilling to possible targets. Several exploration targets have recently been identified in these areas, beneath thick transported overburden.

Areas which have experienced little net erosion or deposition since the Cretaceous are characterised by poor outcrop, deep weathering profiles, probably well established by the Cretaceous, and a discontinuous veneer of cover sediment of various ages. Much of the Koonenberry Belt, and areas to the south and east of Broken Hill belong to this category. Different exploration techniques are required, as in situ bedrock, although close to the surface, is in many places highly weathered and largely hidden by a transported veneer, which may be quite old. Slow geomorphic processes mean that chemical dispersion has occurred over long time periods, and exploration methods similar to those being used in the Cobar area may be applicable to these areas.

Regolith of the Curnamona Province for Geochemists

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Base metal and gold exploration in the Olary Domain (OD) is necessarily becoming directed towards areas in northern parts of the Domain where at least 70% of the Willyama Supergroup is concealed by regolith comprising weathered basement and Cretaceous, Tertiary and Quaternary sedimentary sequences. Exploration in such terrain requires an appreciation of iron-rich regolith geochemistry for the evaluation of grab samples and rock chips of ferruginous material obtained by drilling under cover.

Ferruginous Weathering Products

Ferruginous weathering products have been subdivided into groups based on field occurrence, texture (both hand lens and microscopy) and geochemistry. Groups include;

(1) Sulphide-Derived Gossans. Surface expressions of sulphide mineralisation in the OD have three major geochemical signatures in gossanous ironstones. These types are: (1) Mn-Zn-Pb-Ba-As (Bimba syndepositional mineralisation), (2) Cu-Fe-As-Co-Mo-Ni-Au (epigenetic mineralisation) and (3) low base metal ironstones (derived from the weathering of iron sulphide- and calcsilicate-rich rocks). The Bimba Suite is a prominent gossan-forming unit widely distributed in northern areas of the OD. The group may be identified based on field occurrence and texture, however subdivision into the three sub-types is unreliable without geochemistry.

(2) Ferruginous Lags. Extensive surface pavements, or veneer lags occur near northern parts of Ranges. Veneer lags consist mainly of ferruginised rock fragments which preserve primary rock fabrics, together with minor pisoliths and nodules. Variants include lags derived from mottles and manganiferous weathered basement rocks. Most of the veneer lags are sourced from pelitic rocks, and furthermore, represent the dismantling of a weathering front from the *base* of a pre-existing weathering profile. In equivalent regolith situations underlain by quartzo-feldspathic rocks, pegmatites and quartz veins, an angular quartz lag is developed.

(3) Ferruginised Basement Rocks. Ferruginised basement includes a mixture of both Adelaidean and Willyama rocks. Primary rock textures are preserved.

(4) Ferricretes. Ferricretes include massive and pisolitic varieties. Massive ferricretes may be associated with 'laterite' profiles, and are texturally and mineralogically linked to the underlying weathered basement rock. A single occurrence of pisolitic ferricrete appears to have developed *in-situ*. The internal texture of the rock also indicates the pisolitic ferricrete did not develop in basement rocks, but rather in transported overburden. The ferricrete is most likely a 'lateralite' ie, has derived its iron from lateral sources.

(5) Mottles. Hematitic mottles are present is some areas and occur in a matrix of kaolinised basement rock.

Regolith and Cover Sequence

Over southern parts of the Curnamona Sheet, depth to basement is thin and basement has much expression at the surface, even though covered by a thin veneer of Quaternary sediments. Where the depth to basement increases, the cover sequence becomes more complex and may comprise Tertiary rocks of the Eyre and Namba Formations and in the northeastern and northwestern corners, the Cretaceous Marree Subgroup.

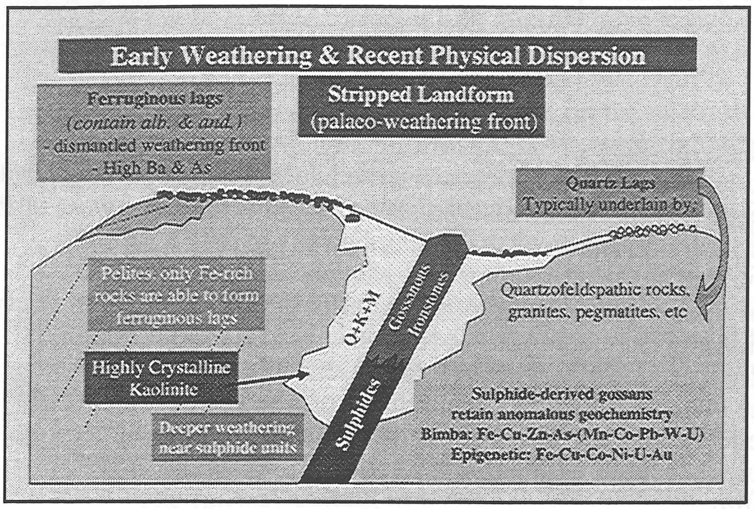
Tertiary Eyre Formation - The Late Eocene to Late Paleocene Eyre Formation comprises carbonaceous sand with minor clay lenses. The sands vary from fine to coarse, are moderately sorted and subrounded to subangular. Over southern parts of the sheet area, the Eyre comprises channelled facies that are sourced from the erosion of weathered basement rocks in the Olary region, and as a result the clay mineralogy is dominated by kaolinite.

Tertiary Namba Formation - The Miocene Namba Formation consists of fine clastics, olive to grey coloured clay, sandy clay and silts. Deposition was in a low energy environment on the Eyre Formation over large parts of Curnamona, except over the Benagerie Ridge, where the Namba in places sits directly on, and buries, basement rocks. In contrast to the Eyre Formation, the clay mineralogy of the Namba is dominated by smectites.

Weathering Effects - The basement, including Willyama and Adelaidean aged rocks, is variably weathered and contains kaolinite development and iron staining. The degree of kaolinite development is controlled by the mineralogy of the pre-existing rocks. Zones rich in sulphides and calcsilicate minerals show the most intense weathering. Conversely, either side of these zones, fresh rock may occur. The presence of these zones, together with the presence of a now dismantled weathering front, would indicate the area has had a pre-existing weathering profile stripped from it, and this material most likely provided detritus for the Eyre Formation. Identification of the unconformity between the Tertiary and basement on the Benagerie Ridge can pose problems where both are kaolinitic. Fortunately, the primary rock fabrics are usually preserved (eg., laminations, boxworks, cleavage and veining). However, the weathered basement may be massive in which case the correct location of the unconformity is difficult.

Exploration

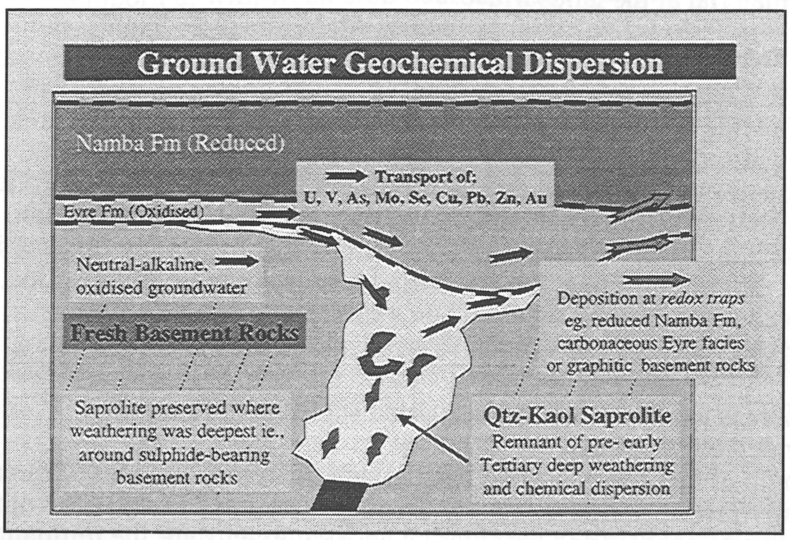
Exploration geochemistry has the potential to play an important role in the discovery of new orebodies in the Olary Domain. In regions where basement is outcropping, ferruginous materials may be identified using field occurrence, texture and geochemistry. Further to the north it is encouraging that basement is near, or at least within 100m of the surface over most of the Curnamona Sheet.



At least three major periods of secondary geochemical dispersion are recognised.

(1) Pre-Early Tertiary chemical dispersion during deep weathering. Preserved examples of this event include weathered basement rocks exposed both near to the ranges and further to the north beneath Tertiary sediments. Ferruginous products of deep weathering include, gossans, ferruginised basement rocks and some massive ferricretes. Fluid conditions for element mobilisation and transport were probably acid to neutral and oxidising.

(2) Middle Tertiary to ? element mobilisation and redistribution within Tertiary rocks and weathered basement by groundwater. Evidence for extensive further and later geochemical dispersion within groundwater is provided by the development of roll-front U mineralisation in the Eyre Formation peripheral to the Benagerie Ridge. The groundwater was/is probably neutral to alkaline and mildly oxidised. Apart from U, roll-fronts are enriched in Zn, Cu and Pb. These fluids could be further expected to mobilise other elements such as Mo, Se, V and Au. These fluids have the potential to enlarge pre-existing type 1 dispersion haloes, mobilise primary mineralisation and form mineral deposits in their own right, especially where they interact with reduced rocks (either Tertiary or basement rocks) where apart from U, other soluble species of, for example Au, could be destabilised and precipitated.



(3) Recent physical dispersion of pre-weathered regolith materials, especially where regolith is thin. Physical dispersion also serves to enlarge geochemical targets. The timing of this event is constrained by a lack of evidence for similar processes preserved under Tertiary cover. Examples from the field area include lags of ferruginised pelites, gossans and lags of angular qtz from pegmatites, quartz veins and quartzo- feldspathic rocks.

If the dispersion processes are understood, exploration geochemical data can help to determine the source of the metals, style of mineralisation (if derived from sulphides), regolith type and genesis. Thin cover over large parts of Curnamona means that surface prospecting, eg gossan search is possible, as is the application of remote-sensing techniques (Landsat TM, radiometrics and air-photos). "See-through" approaches to exploration geochemistry may work where basement is mantled by a thin oxidised regolith, however areas overlain by the Namba Formation are more difficult to prospect geochemically from the surface as the Namba is a reduced, smectitic unit, and often contains more Zn than the underlying basement rocks.

Acknowledgments: North Ltd., Pasminco Exploration, MESA and AGSO.

BROKEN HILL REGOLITH FIELD EXCURSION

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This field excursion visits sites that represent a transect from southeast to northwest across the regionally tilted fault blocks in the Broken Hill region. As a result we will see a variety of regolith materials in a range of landscape and morphotectonic settings.

STOP 1: Redan Fault (Redan GR 780455)

The Redan Fault is considered the boundary between the Murray Basin and the Broken Hill Block, however, Murray Basin sediments are also present as valley fills northwest of this boundary. It appears that the surface expression of the Redan Fault is in fact a partially dissected fault-line escarpment which has been onlapped by Murray Basin sediments.

Immediately southeast of the fault line escarpment, red alluvium up to 40 m thick covers the Murray Basin sediments. This alluvium comprises both detrital bedrock-derived and reworked parna material. Patterned ground is well developed in this alluvium with linear gilgai aligned normal to the slope. The gilgai result from development of a stepped slope profile with stoney rises separating flatter vegetated areas. Throughout the Broken Hill area linear gilgai appears to reflect the presence of a substrate with parna-rich soil and pebble lag, often developed on alluvium / colluvium.

To the northwest of the Redan Fault line, a thin veneer of transported regolith overlies highly to slightly weathered bedrock. Outcrop is poor, but radiometric data indicate a large proportion of bedrock derived material at the landsurface.

STOP 2: Farmcote (Redan GR 700535)

At this site we will see a wide range of regolith materials in a relatively confined area. The dominant bedrock here is quartzofeldspathic gneiss. This rock has been very highly weathered and we can see exposures of both pallid and mottled saprolite. Ferricreted saprolite mottles are concentrated at the landsurface after the removal of the softer kaolinitic saprolite. The exhumed ferricreted saprolite may then be transported and accumulate as valley fills and in some cases recemented to form detrital ferricrete. These detrital ferricretes are often pisolitic, with well developed goethitic and hematitic cutans.

A small escarpment on this rise with carvernous weathering features is composed of silicified saprolite.

At the top of the rise there is a transition from ferricreted saprolite to ferricreted sediments with angular to rounded quartz clasts.

The small hill to the south of this rise is capped by silcreted quartzose fluvial sediments which have been topographically inverted. These are angular to sub-rounded fine sands with rounded to well-rounded vein quartz pebbles and granules. These sediments are the remnants of a channel system that can be followed to the southeast towards the Murray Basin. Similar silcreted, quartzose sediments are common along the southeastern and southern margins of the Broken Hill Block.

STOP 3: Seventeen Mile Creek (Redan GR 610525)

The low, flat area to the west of Stop 2 is underlain by grey, mottled sandy silt beneath a thin veneer of red-brown alluvium. This sandy silt is lithologically similar to sediments described as the lacustrine, Pliocene-Pleistocene, Blanchtown Clay of the Murray Basin in the Menindee region.

Exposures of this clay can be seen along Seventeen Mile Creek near the Menindee Road. The sandy silt in the area contains irregular, goethite-hematite nodules and polycrystalline gypsum aggregates. Shot-hole drilling associated with the nearby AGSO

Seismic Traverse shows the sediments extend to up to 17 m deep and are underlain by bleached, highly weathered, kaolinised bedrock. It is not known whether the overlying sediment influenced the groundwater conditions to enhance this weathering, or rather the sediments were deposited in a valley preferentially erodoed in the least competent, most highly weathered bedrock.

STOP 4: Limestone Station Carbocretes (Broken Hill GR 310700)

A series of pits to the north of the Silverton Road provide sections through carbocretes developed in alluvial sediments and the underlying bedrock. Two main types of carbocretes can be seen in these pits. The upper part of the profile features pedogenic calcrete which includes nodular, laminated and friable facies. The lower part of the profile, and the material that has been intersected by the groundwater bore on the north side of Umberumberka Creek is a groundwater calcrete which forms massive, well crystalline sheets resulting from subsurface carbonate precipitation below the water table.

It is important to note that the dominant mineralogy in this profile varies from being calcite-rich near the surface, to dolomite-rich at depth. This is typical of carbocretes in the Broken Hill region that include accumulations rich in calcite (calcretes), dolomite (dolocretes) and magnesite (magcretes). Preliminary studies of the carbocrete geochemistry in this region suggest that the recognition of the carbocrete morphological and compositional facies are important considerations for mineral exploration sampling media.

STOP 5: Silverton Railway Cutting (Broken Hill GR 180735)

The railway cutting in this area coincides with the Umberumberka Shear Zone. Most of the cutting contains weathered bedrock, however, the southern face shows a section through over ten metres of debris flow sediments. These sediments are very poorly sorted, matrix supported, with weathered bedrock clasts (largely the locally derived pegmatite clasts). The minimal exposure of the sediments on the north face indicates these sediments were deposited on a very steep palaeoslope. A possible cause of this is reactivation of the shear zone in relatively recent times. Without the three dimensional exposure provided by this cutting, it would be difficult to detect these sediments from surface features alone.

STOP 6: Mundi Mundi Lookout and Fault (Broken Hill GR 190765)

A fault line escarpment separates the Barrier Ranges from the Mundi Mundi Plain. The plain has an extensive depositional regolith consisting of up to 90 m of red-brown alluvium overlying possible Tertiary and Cretaceous sediments. The fault scarp is interpreted to be largely the product of a long history of tectonic reactivation, including significant post-Miocene displacement of about 300m. The Mundi Mundi Fault defines the western edge of the major regional tilted block that extends across the Broken Hill region.

STOP 7: Umberumberka Creek and alluvial fans (Broken Hill GR 180820)

This site shows a section through the proximal part of a high level alluvial fan deposited on the Mundi Mundi Plain. The fans in this area show a complex history of reworking and several series of depositional lobes, reflecting the interaction between climatic change and tectonism on regolith development.

STOP 8: Silverton Hotel (Broken Hill GR 210725)

Cheers!!!!!

ACKNOWLEDGMENTS

We gratefully acknowledge the support provided by CRA Exploration (for the PhD research by SMH) the Broken Hill Exploration Initiative, and NSW Discovery 2000.

Ion microprobe U-Pb ages for Neoproterozoic rift-related basaltic magmatism in south-central Australia

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Ion microprobe U-Th-Pb analyses of baddeleyite and zircon yield precise estimates of the age of Neoproterozoic mafic magmatism that accompanied initial rifting in the Adelaide Geosyncline and adjacent platforms in southern and central Australia. An age of 827 ± 6 Ma is inferred for emplacement of the Gairdner Dyke Swarm (GDS), based on 137 207Pb/206Pb analyses of 66 baddeleyite crystals from a drill-core sample of GDS dolerite. Analyses of zircon and baddeleyite indicate that a uralitised gabbro pluton of the eastern Willyama Inlier (Little Broken Hill gabbro) crystallised at 827 ± 9 Ma, identical to the age inferred for the GDS. Breakdown of baddeleyite to form overgrowths of polycrystalline zircon occurred at 500 ± 7 Ma, thereby providing a precise estimate of the age of the thermal event associated with the Delamerian Orogeny in the Broken Hill region.

These data, in conjunction with previous isotopic, geochemical, and stratigraphic information, confirm the synchronous nature of Willouran magmatism over most of south-central Australia. Our best estimate of the age of this event, and of initial rifting in the Adelaide Geosyncline and environs, is 827 ± 6 Ma. It has been proposed that the GDS, together with ~780 Ma mafic intrusive suites in three widely-separated areas of western North America, represent sectors of a giant radiating dyke swarm fragmented by the separation of Australia and Laurentia during breakup of Rodinia. Our results show that the GDS is at least 40 Ma older than the intrusions of North America, and therefore cannot have been emplaced during the same event. It has been proposed elsewhere that separation between Australia and Laurentia occurred at ~700 Ma. If so, then neither of these magmatic episodes is likely to be related directly to breakup, in which case breakup is likely to have been driven by plate-scale, rather than plume-related, processes. If the Little Broken Hill gabbro and associated dykes in the Willyama Inlier are breakup-related, then breakup followed soon after eruption of the Willouran CFB at 827 Ma, and the Willouran mantle plume is likely to have played an active role in triggering the process. Our results show the GDS and related rocks in Australia to be roughly coeval with mafic igneous rocks in similar stratigraphic position in the Lower Sinian System, and may lend support to the hypothesis that parts of South China were situated between Australia and Laurentia prior to the breakup of Rodinia.

Re-evaluation of the tectonic and thermal history of the Mount Robe region, Broken Hill

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The rocks in the northwest region of the Broken Hill Inlier preserve evidence for at least three thermal events, in addition to four episodes of metamorphism. As a response to heightened thermal conditions, two major episodes of mafic and granitic magmatism occurred at 1673 ±23 Ma and 1613 ±4 Ma, and were followed by partial melting and granitisation during the Grenvillian (~1270 Ma). Although other regions within the Australian continent record the Grenvillian event (e.g. Albany-Fraser province, Musgrave Block), the extent and the effects of this event on the Broken Hill Inlier have not been fully realised.

Prior to 1200 Ma, the northwest region of the Inlier underwent intense deformation, producing complex fold interference patterns with kilometre scale sheath fold geometries. These fold geometries are detectable by surface meso-scale mapping and magnetic images and are distinctly different to surrounding regions within the Broken Hill Inlier. Heterogeneities in structural style across the Broken Hill Inlier are becoming more apparent and new results show that specific regions record distinct episodes of the tectono-thermal evolution of the Inlier. In particular, the Thackaringa and Redan regions to the south selectively preserve pre-1690 Ma tectonism and thermal activity (Nutman and Ehlers in press) and appear to have been affected by the 1200 Ma event to a lesser degree than the Mount Robe region. With these new results in mind, it seems improbable that a simple three phase deformational scheme can apply to the entire Broken Hill Inlier, as previous workers have suggested (e.g. Marjoribanks *et al* 1980, Hobbs *et al* 1984).

An integrated study of structure, metamorphism and geochronology has resulted in a new structural model for the Mount Robe region. This model does not support the established and widely accepted Willyama Supergroup stratigraphy which has profoundly influenced structural models and exploration strategy across the entire Broken Hill Inlier.

The Mount Robe region, located approximately thirty-five kilometres northwest of Broken Hill, consists of a diverse array of biotite+sillimanite+garnet+andalusite schists, meta-quartzites, amphibolites, pegmatites and granites. U-Pb zircon geochronology on a meta-quartzite yielded a maximum deposition age of 1740 Ma. Previous interpretations (Hobbs *et al* 1984, Willis 1989) imply a continuous stratigraphic sequence which has been deformed into a major south plunging synformal anticline. According to this stratigraphy, the stratigraphically lower Thackaringa Group, occupies the core of the synform and is underlain by younger Broken Hill Group rocks. Amphibolites are interpreted to be volcanic in origin (Reynolds 1975, Often 1983), and represent a distinct stratigraphic horizon in the upper part of the Broken Hill Group. However, the amphibolites locally cross cut sediments, preserve relict meta-gabbroic and meta-doleritic igneous textures and yield igneous zircons which give a SHRIMP $^{207}Pb/^{206}Pb$ age of 1673 ±23 Ma. This is interpreted as the magmatic intrusion age of the amphibolite. These observations suggest that the amphibolite unit is a highly deformed intrusive rock, rather than a stratigraphic horizon (see also Donaghy, this volume).

The region has undergone at least four metamorphic events (M1-M4) which have each been followed by or are synchronous with four episodes of intense deformation (D1-D4). This observation already differs considerably from the work of Binns (1964) and Phillips (1978), both of whom interpreted a peak prograde assemblage followed by a retrograde overprint. Their study concluded that metamorphic grade decreased to the northwest, from granulite facies in the southeast of the inlier to lower amphibolite facies in the northwest. It was thought that this decrease was the effect of a single event across the entire inlier. This study however, recognises two metamorphic assemblages prior to the prograde metamorphic event identified by Binns (1964) and Phillips (1978).

An early sillimanite stable assemblage is identified as M1, and was overprinted by an andalusite stable assemblage, M2. These early episodes of metamorphism are also associated with biotite, cordierite, garnet, quartz and muscovite and are either aligned in the S1 fabric or grew prior to the S2 fabric. M1 has been relatively timed as syn-post 1673 Ma and is thought to have formed at slightly higher pressures than M2, but at similar temperatures of approximately 650°C (possibly in excess of 700°C). M2 has been relatively timed to have taken place between 1673 Ma and 1613 Ma.

Intense, post M2 deformation (D2), produced the dominant fabric throughout the region (S2), which is characterised by a high temperature (M3) mylonite fabric defined by biotite and coarse blades of sillimanite. M3 can be correlated with the peak prograde metamorphic event identified by Binns (1964) and Phillips (1978) and has been dated at approximately 1600 Ma (Page and Laing, 1992). D2 transposed lithological layering and melt veins so that they are parallel and subparallel with S2. The melt veins are thought to post-date D1 and are pre-syn D2, *ie.* they are possibly associated with M3 metamorphism. The rock package was then tightly folded into recumbent folds which characterise D3.

M3 was followed by retrograde metamorphism M4, characterised by an overprint of chlorite, chloritoid, garnet and muscovite. Pressure-temperature estimates for M4 have been calculated using Thermocalc V2.2b4 and are estimated to be between 5-6 kbar and 520°C.

Regional pegmatite sheets now located within the cores of regional F4 folds, were intruded between M2 and M3. Monazite separates from a pegmatite yield a single SHRIMP U-Pb age population with a maximum age of 1615±4 Ma and a minimum age of 1613±4 Ma. This is interpreted as the intrusion age of the pegmatite. Zircon ages from the same sample reveal a spectrum of ages, with a concordant cluster at approximately 1270 Ma.

In outcrop, the pegmatite preserves regions of coarsely recrystallised feldspar, quartz and mica, while the enclosing sediments are granitised and recrystallised. Micas form decussate grains while quartz, opaque minerals, tourmaline and garnet exhibit foam textures with easily recognisable triple points. These textures are interpreted as re-melting textures, resulting from the re-melting of the pegmatite and some sediments at ~1270 Ma, during Grenville time. Finally, the region was folded into open, upright folds which form the gross geometry of the present outcrop pattern.

This study does not support the previous interpretations of an overturned, continuous stratigraphy from upper Thackaringa Group to Broken Hill Group, but suggests that the rock package has been grossly modified from its original state due to attenuation, reorientation, metamorphism and partial melting. Three discrete thermal events have been identified at 1673 ±23 Ma, 1613 ±4 Ma and ~1270 Ma respectively, and as a result, major constraints have been forced on the timing of deformation and metamorphism throughout the region.

Providing absolute age constraints on the initiation of thermal activity and understanding the evolution of the Mount Robe region has already proved to be invaluable in unravelling the tectono-thermal history of part of the Broken Hill Inlier. In addition, this detailed study can also be related to specific time events which have proved to be cornerstones in the evolution of the Australian continent.

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The Significance of Younger Thermal Events in the Willyama Inliers: Using ^{40}Ar-^{39}Ar Thermochronology

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The Broken Hill, Olary and Mount Painter Block (Willyama Inliers) are the main Precambrian basement inliers that outcrop extensively in western New South Wales and South Australia, and form part of the north/northeastern margin of the Adelaide Fold Belt. These terrains, comprised of Palaeo to Mesoproterozoic metasedimentary and metaigneous rocks (Willyama Group), have experienced several orogenic events that have resulted in a complex structural and metamorphic history. The presence of younger tectonic events in the Broken Hill Block have been recognised from $^{40}Ar/^{39}Ar$ thermochronology. Apparent muscovite ages constrain a pattern of broadly Grenvillian (Musgravian) resetting of the basement in the northern part of the Broken Hill Block (Poolamacca Inlier) with temperatures reaching the order of ~350°C. The samples, although limited, begin to show the tectonic influences of younger thermal overprints, the effects of which may be spread over the entire inlier.

Willyama Group rocks of the Broken Hill, Olary and Mount Painter Block exhibit some similarities that enable them to be correlated, lithologically, structurally and metamorphically. These terrains underwent peak metamorphism between ~1700 and 1600Ma and reached metamorphic grades of upper amphibolite to granulite facies (Willis et al, 1983). Collectively, the Willyama inliers form part of an extensive intracratonic basin complex that remained active until the late Proterozoic (Grenvillian), triggering the commencement of deposition of an unconformably overlying thick succession of terrestrial and shallow marine rocks known as the Adelaidean Supergroup. Believed to be part of a single intracratonic basin, significant variation in relief of fault blocks was sufficient enough to produce isolated regions of outstanding relief (Broken Hill, Olary and Mount Painter Blocks) which were the primary sources for localised Adelaidean sedimentation from ~1100Ma (Preiss, 1981; Stevens, 1986).

Following basin infill, the Adelaidean cover underwent widespread deformation at low grade (sub-greenschist facies) during the Delamerian Orogeny (~500Ma).

Although not pervasive throughout the cover sequence, zones of polydeformation are prevalent along and proximal to basement/cover interfaces (for example, Poolamacca Inlier). The preservation of polydeformation within the Adelaidean implies that the Delamerian Orogeny may not be confined to a single phase tectonic event as previously thought for this area. Apparently restricted to the Adelaidean cover sequence, the Delamerian Orogeny also affected Willyama basement rocks. Folding of pegmatites and the development of an overprinting (latest?) fabric within the basement show very similar orientations to the north-south folds of the cover sequence, suggesting that the cover and basement structures developed synchronously, during the Delamerian. One hypothesis may imply that initial Delamerian deformation was most likely confined to displacement along zones of weakness (for example basement/cover contacts and/or shears) until attainment of sufficient shortening achieved gentle buckling and minor reverse faulting of the Adelaidean cover. However, results suggest that folding of the basement preceded the shearing event. Final cooling of the basement due to early Delamerian(?) folding is recorded at ~550Ma at ~350°C with shearing occurring at ~500Ma with an estimated temperature of ~280°C. Further reactivation of the shear zones occurred at 280Ma coinciding with the Alice Springs Orogeny. Furthermore, folding of the thin Adelaidean strata over the Willyama Inliers is also believed to be attributed to the renewed movement of ancient shear zones within the Willyama Complex (Marjoribanks et al, 1980).

The main aim of this study is to analyse muscovite, K-feldspar and whole rock chips by the $^{40}Ar/^{39}Ar$ dating method (in progress) to elucidate the *late* temperature-time history and tectonics of the Broken Hill, Olary and Mount Painter Blocks by targeting shear zones and the geology that abounds them. Previous results, in particularly around the central to southern portion of the Broken Hill Block, revealed through $^{40}Ar/^{39}Ar$ thermochronology, have shown that the basement was effected by a single tectonic "pulse" at 520±40Ma with temperatures in the order of ~350°C (Harrison and McDougall, 1981), after the high grade metamorphic event at 1590±10Ma. Contrary to previous results, current results show that at least the northern part of the Broken Hill (i.e. Poolamacca Inlier) terrain has recorded several events post-dating the high grade metamorphism.

Unlike previous work, where sample coverage was limited, this project has focused on systematically sampling along 3 separate traverses in the Broken Hill region, which include the 1996 AGSO seismic traverse, Wendelpa traverse (north-central portion of the inlier) and the Poolamacca Inlier traverse (northern most part of the block "proper"), an area which shows interesting basement/cover relationships. Similar sampling strategies have also been accomplished in the Olary and Mount Painter Blocks in an attempt to determine the extent of the younger thermal events affecting the basement. The new results will be integrated with previous geochronological and thermochronological data to focus on the nature, origin and significance of the younger tectonothermal events active in the Broken Hill, Olary and Mount Painter Blocks. Constraints on the timing and patterns of deformation may have implications for metallogenesis in the Willyama Inliers and contribute to a broader understanding of the Adelaide Fold Belt.

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Structure and Geochronology of the Thackaringa Region : Implications for Stratigraphic Interpretation

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Summary

The Thackaringa region of Broken Hill preserves clear evidence that;

(1) The quartz-albite rocks are metasediments of complex provenance with a ~1710 Ma Olary volcanic component. They are not part of a 1690 Ma volcanic pile.
(2) The Alma Gneiss is a granite intrusion at ~ 1690 Ma.
(3) There has been mafic intrusion at ~1675 Ma.
(4) There has been deformation and partial melting pre-1675 Ma.
(5) That regionally extensive, high-metamorphic grade S_2 and S_3 mylonites and isoclinal F_1, F_2 and F_3 and regional scale F_4 folds transpose, attenuate and reorient lithologies on all scales.

These observations combined with field tracing of S_2 and S_3 fabrics strongly suggest that stratigraphic units with similar lithogical associations, such as the Lady Brassey and Himalaya Formations and the Cues and Parnell Formations, are structural repetitions of the same units. Furthermore, since such repetition occurs at the type localities for the units ascribed to the Thackaringa Group, a complete reassessment of the Thackaringa Group stratigraphy needs to be conducted.

Introduction and Background

This thesis is a study of the structural evolution of the Thackaringa region of Broken Hill, NSW, Australia. While detailed lithological mapping and a complex stratigraphic interpretation has been conducted in the area by the NSW Department of Mineral Resources, this study represents the first detailed structural mapping of the entire region. The primary aim of the thesis is to integrate geochronology with detailed structural mapping to test the models of protolith formation and subsequent structural and stratigraphic interpretation erected by previous workers. Work carried out to date suggests that many criteria used to separate units with similar lithological associations into different stratigraphic horizons are based on invalid assumptions of protolith formation, post-depositional features - such as partial melting and metasomatism, and an over-simplistic structural interpretation.

The Thackaringa region, located 35km to the south-west of Broken Hill, contains lithologies currently assigned to the central and lower portion of the Willyama Supergroup stratigraphy. Stratigraphic units represented in the Thackaringa region are the Thackaringa Group, including all of the type localities and type sections (except for the Rasp Ridge and Alma Gneisses); the Broken Hill Group; and the Sundown Group. Outcrop in the region is dominated by lithologies of the Thackaringa Group, previously interpreted as a 1-3 km thick sequence of felsic volcanics/volcanosedimentary facies with intercalated feldspar-rich sediments and minor mafic tholeiitic lavas (summarised in Table 1). The stratigraphy is based on association of key marker lithologies, particularly mafic and quartzo-feldspathic gneisses. This is due to the absence of reliable sedimentary structures and younging criteria, and the intense nature of strain and partial melting in the region (Willis 1984b).

Table 1. Stratigraphic column for the Thackaringa Group. (After Willis *et al.* 1983)

Thackaringa Group Stratigraphic Unit	Metamorphic Lithology	Previous Interpretation of Protoliths
Himalaya Formation	Thin-layered albite-quartz rocks; minor basic gneiss;	Thin-bedded, possibly reworked, sodic felsic analcitised air fall tuffs; minor tholeiitic volcanics;
Rasp Ridge Gneiss	Quartz-feldspar-biotite gneiss; minor basic gneiss.	Rhyolitic to dacitic volcanics; minor tholeiitic volcanics; possible subvolcanic intrusives.
Cues Formation	Psammite to psammopelite & composite gneiss; with interbedded basic gneiss; quartz-feldspar-biotite-garnet gneiss, leucogneiss.	Thin-bedded feldspathic sands, silts; with interbedded tholeiitic, rhyodacitic volcanics; rhyolitic air fall tuffs.
Alders Tank Formation	Albitic quartzo-feldspathic composite gneiss.	Bedded feldspathic sediments/volcaniclastics.
Lady Brassey Formation	Layered leucocratic albite-quartz rocks; massive basic gneiss.	Thin-bedded sodic rhyolitic or altered air fall tuffs and volcaniclastics; interbedded tholeiitic volcanics.
Alma Gneiss	K-feldspar megacrystic quartz-feldspar-biotite gneiss; minor basic gneiss.	Rhyolitic-dacitic porphyritic volcanics; and interbedded tholeiitic volcanics.

Previous workers in the Thackaringa region (e.g. Funnell 1983; Willis 1984a) invoked a complicated set of fold interference patterns to explain perceived repetitions in the interpreted stratigraphy. The interpretation is dominated by regional scale, east-northeast trending F2 folds with minor mesoscopic scale north-trending F3, and easterly trending F4 folds, all with upright to steep-inclined axial surfaces (Funnell 1983; Willis 1981, 1984a, b, 1985). However, these studies rely heavily on the lithological form lines of the key stratigraphic markers, particularly the mafic and quartzofeldspathic gneisses, and detailed structural fabric mapping was not carried out.

New Structural Observation

To date, structural fabric mapping conducted as part of this study is difficult to reconcile with the previous structural interpretation of Willis (1984a). The identification of four deformations, including two early mylonite shear fabrics, offer an alternate explanation for the present distribution of lithologies within the Thackaringa region. The two mylonite fabrics are sufficiently intense to make the identification of the protolith locally difficult. Gross attenuation, reorientation and transposition of lithological layering on all scales have further complicated the recognition of original lithologies.

S_1 is best preserved within large quartzofeldspathic masses, particularly kilometre scale bodies of quartz-albite rock of the Thackaringa Group, bounded by S_2 and S_3 mylonites. S_1 within the quartz-albites is defined by a biotite foliation axial planar to rare small upright isoclinal folds (F_1) and layer parallel along the F_1 limbs. Many internal fabrics within the quartz-albite rocks, previously thought to be well developed sedimentary bedding, are better interpreted as a syn-S_1 transposition of layering which post dates insitu partial melting.

The first mylonite fabric (S_2) is of high metamorphic grade - containing garnet porphyroblasts and a prominent L_2 sillimanite mineral lineation within pelitic lithologies. S_2 is best preserved within large quartzofeldspathic and mafic gneiss packages boudinaged by the S_3 fabric. Within the S_2 fabric are numerous quartzofeldspathic melt segregations and rootless isoclinal folds hinges (F_1?) boudinaged along the L_2 sillimanite lineation. S_2 and L_2 fabric formation are regionally extensive and strongly partitioned into pelite dominated lithologies.

The S_3 mylonites are best developed on the limbs of regional scale isoclinal folds (F_3) of the S_2 fabric, producing a composite S_2/S_3 fabric. The associated S_3 mylonite fabric is lower grade than, and overgrows S_2, with retrogression of the K-feldspar in melt segregations and S_2 sillimanite to sericite and muscovite, and of garnet to biotite. The axes of the F_3 folds plunge parallel to the L_2 lineation. The principal extension direction within the S_3 fabric is perpendicular to the L_2 lineation and leads to extreme attenuation and transposition of competent lithologies along the F_3 fold limbs.

S_2 and S_3 are overprinted by upright mesoscopic asymmetric folds (F_4) with a localised axial planar fabric (S_4), consisting of a chevron-style crenulation. Preliminary study suggests a regional scale syn- to post-F_4 fold generation in the southern part of the Thackaringa area. Folds of this generation have been interpreted as east-northeast trending regional scale F_2 folds by Willis (1981, 1984a). However, they fold F_3 folds and the S_2/S_3 fabric. Axial zones of these folds trend parallel to the Thackaringa-Pinnacles Shear and are probably genetically related.

SHRIMP Geochronology

SHRIMP zircon geochronology places constraints on the formation of the protolith and subsequent deformation history. Key marker horizons dated were:

(1) Two quartz-albite rocks, one each from the Himalaya and Lady Brassey Formations, up to 50% of which consists of leucocratic partial melt rocks lying within the dominant transposed tectonic layering (S_1?) previously described as well developed bedding.

(2) Two mafic gneisses, one clearly transgressive to the tectonic layering and partial melts within the Himalaya Formation and previously ascribed to a much younger (ca 500-800 Ma) generation of mafic dykes and plugs; the other from within the Lady Brassey Formation and also locally transgressive to layering.

(3) The Alma Gneiss from the type locality used to demonstrate stratigraphic equivalence with the Lady Brassey Formation, although intrusive relationships with the surrounding quartz-albite rocks can be clearly demonstrated. The Alma Gneiss is also used as an "anchor" at the base of the interpreted stratigraphic section immediately adjacent to the type localities for the Cues and Alders Tank Formations.

(4) A mafic gneiss and "Potosi-type" gneiss assigned to the Parnell Fm (Broken Hill Group), although taken from different localities, within intensely developed S_2 mylonite shear fabric.

Although interpreted to be at the top and bottom of the Thackaringa Group stratigraphy respectively, the Himalaya Formation and Lady Brassey Formation quartz-albite rocks cannot be distinguished based on field observations and their zircon populations. They reveal near-identical complex sedimentary detrital patterns, with ages ranging from the Archaean through to significant populations at ~1710 Ma. A-type volcanics from Olary have been SHRIMP dated at ~1710 Ma (Paul Ashley and Ian Plimer pers. comm. 1997).

The transgressive mafic gneiss within the Himalaya Fm yields an intrusion age of 1676 ± 7 (2σ) Ma; a comparable age of 1673 ± 13 Ma was obtained from the Lady Brassey Fm mafic gneiss. As these are transgressive to layering in the quartz-albite lithologies, it is inferred that partial melting and D_1 occured prior to 1675 Ma.

The Alma Gneiss has a magmatic zircon population of 1693 ± 10 Ma. This is an intrusive age and suggests that the surrounding quartz-albite lithologies are significantly older than the deposition age of ~1690 Ma for the Broken Hill Group proposed by Page and Laing (1992). The Alma Gneiss cannot be used as a stratigraphic marker.

Zircons from the Parnell Formation gneisses within the S_2 mylonites are extremely isotopically disturbed and have been totally reset by thermal activity at ~1590 Ma. It is inferred that this places an indirect age on the formation of the S_2 mylonites.

Implications

The Thackaringa region is important for the understanding of the Broken Hill region as a whole as it contains the type localities for the Thackaringa Group, the basal sequence of the Willyama Supergroup stratigraphy. Potential exists for gross simplification of the Willyama Supergroup stratigraphy within the Thackaringa region by removal of units with similar lithological associations that are structurally, rather than stratigraphically repeated within the sequence. It also has important ramifications for mineral exploration in Broken Hill as the Broken Hill Pb-Zn-Ag style of mineralisation is believed to occupy a discrete stratigraphic location.

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GEOLOGY AND METALLOGENY OF THE CORONA 1:25 000 SHEET AREA, NORTHERN EURIOWIE BLOCK

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GEOLOGICAL SURVEY OF NEW SOUTH WALES

The Corona 1:25 000 sheet is located at the northern end of the Euriowie Block, approximately 100 km north of Broken Hill. It is the final sheet in the Geological Survey of New South Wales' 1:25 000 series of the Broken Hill and Euriowie Blocks. The completion of the Corona sheet marks the end of the mapping program which was begun in the mid-1970s.

The Willyama Supergroup in the Corona area consists of three distinct rock packages. In stratigraphic succession these are - the Broken Hill Group, comprising mainly composite gneiss and migmatite with numerous amphibolite pods, minor quartzo-feldspathic gneiss (including Potosi gneiss), various types of calc-silicate rock, rare BIF and calc-silicate ellipsoids; the Sundown Group, comprising metasediments with minor calc-silicate ellipsoids; and the Paragon Group, comprising mainly graphitic metasediments, albitic psammites and a laminated calc-silicate horizon (the King Gunnia Calc-Silicate Member). The sequence has been intruded by granitoids and pegmatites.

Potosi gneiss in the area grades into a fine-grained rock comprising quartz, chlorite and clinozoisite +/- garnet porphyroblasts. Dark, elongate inclusions up to several centimetres long within the rock may be relict lapilli. This rock in turn grades into amphibolite. This evidence suggests that the Potosi gneiss progenitor was a volcaniclastic rock rather than an intrusion or lava flow. Samples of Potosi gneiss have been submitted for zircon age dating.

The lowest prograde metamorphic rocks in the area are andalusite-bearing and occur within the Paragon Group. Sillimanite-bearing rocks without partial melt occur within the Sundown Group. A poorly defined intermediate zone within the Sundown Group in the southeastern part of the area contains suspect chiastolite, possibly replaced by sillimanite, but is obscured by retrogression. Rocks containing significant partial melt are confined mainly to the Broken Hill Group.

Wherever bedding (S_0) has been observed it is considered to be right way up. S_1 is the first tectonic fabric recognisable and is parallel to bedding in metasediments and is also present within other rocks. S_2 is a north-trending foliation axial planar to F_2 folds. F_2 folds are upright, northerly plunging folds. No F_1 folds are recognised in the area. A pervasive retrograde fabric overprints most of the high grade textures.

A north to northwest trending, east-dipping thrust fault comprising a breccia about 1m wide occurs along the western margin of the Euriowie Block. At its northern end the breccia zone underlies masses of Adelaidean dolomite (with minor diamictite) which have been thrust into the Willyama Supergroup. The fault geometry indicates northeasterly to easterly directed compression at some stage, probably during the Delamerian. In places the breccia texture is distinctly hydrothermal indicating that the fault has been a pathway for fluids. Samples have been submitted for gold assay. A siliceous fault zone runs northeasterly through the Willyama Supergroup in the northeastern part of the area and may have acted as a strike-slip fault, accommodating northeasterly directed compression associated with the thrust fault. A chloritoid-rich retrograde schist in the southeastern corner of the map is coincident with a displacement in the unconformity. It is probable that this is a pre-Delamerian fault reactivated during the Delamerian.

Mineral deposits on the Corona sheet comprise tin-bearing pegmatites, Cu +/- Au - bearing quartz veins, the Corona Ironstone and amethyst veins.

Tin-bearing pegmatites are tabular bodies of the order of several metres wide and up to several hundred metres long. They comprise chiefly quartz, K-feldspar, albite and muscovite with tourmaline, apatite, garnet, cassiterite, beryl, amblygonite and fluorite with rare columbite-tantalite at one locality. The pegmatites are commonly zoned and the wallrocks are commonly altered to greisen comprising quartz, muscovite and tourmaline. The pegmatites occur chiefly within Paragon Group with a few in Sundown Group, stratigraphically above granitoid intrusions. They are both parallel to and discordant to bedding and the strong influence of bedding is taken as evidence that the pegmatites were emplaced while the rocks were still approximately horizontal. Buoyancy was probably the main control on their stratigraphic localisation. Many of the bodies contain both the S_1 and S_2 foliations, are folded in F_2 and exhibit other deformation features such as boudinage and en echelon pinch and swell. They clearly predate D_1 deformation or must have formed very early in D_1.

It is considered that the tin-bearing pegmatites were derived from the numerous granitoid intrusions stratigraphically beneath them. The granitoids comprise quartz, K-feldspar, plagioclase, biotite and muscovite. They range in composition from "true" granite (represented by typical "Granite" gneiss) to alkali feldspar granite (represented by leucocratic quartzo-feldspathic gneiss (Lf rock) and undeformed leucocratic granite). Deformed granite (containing S_1 folded in F_2) grades directly into undeformed granite and pegmatite. The granitoids must be either syn- or early D_1 in age, consistent with the age of the tin pegmatites. Samples of granitoid have been submitted for zircon age dating.

On the eastern side of the Euriowie Block amphibolite masses up to several tens of metres across lie wholly within granitoid. It is speculated that those particular amphibolites may be coeval with the granitoids. However, metasediment masses also occur within granitoids and are no doubt wallrock pendants or inclusions. It is hoped that zircon age dating of the amphibolites will shed light on their origin.

The abundance of disseminated tourmaline and quartz-tourmaline pods within metasedimentary rocks increases towards the granitoids and some of the leucocratic granites contain tourmaline clots. It appears that abundant B-rich fluids have been expelled from the granitoids and it is considered that this observation may have bearing on the interpretation of some other tourmaline-bearing rocks elsewhere in the Willyama Supergroup.

The granitoids are chiefly but not entirely concentrated at and above the boundary between the Sundown and Broken Hill Groups, which is also the boundary between metasediments and partially melted rocks. This localisation of the granitoids may be either a buoyancy effect or perhaps the "stratigraphic" boundary may actually be a structural boundary, at least in part, along which the granitoids have been intruded. Some granitoids occur within retrograde schist zones which may either be reactivated high grade shear zones or the shear zones may have formed preferentially around the granitoids after their emplacement.

Harker plots of various elements versus SiO_2 from granitoid samples show linear correlations which are interpreted as fractionation trends. Total Fe, TiO_2, Y and F decrease with increasing SiO_2 and have probably fractionated out with biotite. Zirconium, U and Th also decrease with increasing SiO_2 and have precipitated out with zircon. Rubidium decreases with increasing SiO_2 and has probably substituted for K in biotite. Fractionation is one prerequisite for a tin-mineralising granite system.

A plot of Fe_2O_3/FeO vs SiO_2 demonstrates that the granitoids all plot in the magnetite series field indicating that they are relatively oxidised. They also show an increase in oxidation with fractionation. Tin-associated granites are normally reduced. The conclusion is either that the granitoids were not the source for the tin, or, more likely, they were the source but other factors, particularly the abundance of F and B have allowed Sn to stay in the melt despite the oxidation state.

A REE plot of the granitoids shows that they have a relative depletion in HREE with a weak to moderate Eu depletion. This could indicate that feldspars were fractionating from the melt, as might be expected, however, the pattern is identical to that of Willyama Supergroup metasediments and it could be that the granitoids have been derived from the partial melting of metasediments.

Copper+/-gold-bearing quartz veins are clustered in the northern part of the Euriowie Block. They are generally several centimetres wide and several metres long and occur within and parallel to narrow, northeast trending retrograde schist zones. The age of the veins is not known but is considered to be Delamerian.

Amethyst veins cluster in the northern part of the Euriowie Block. As with the Cu+/-Au veins they also occur within northeast trending retrograde shear zones and are generally parallel to the shears though some are oriented easterly to southeasterly, oblique to the retrograde schistosity. The veins are several centimetres wide with systems of veins being up to several hundred metres long. A few contain disseminated pyrite and samples have been submitted for gold analysis. They are probably late Delamerian in age, being undeformed.

The Corona Ironstone comprises ferruginous masses developed mainly within Adelaidean dolomite. It is probably some kind of surficial weathering deposit and its age is unknown. While it has scavenged minor amounts of Zn, Cu and U the ironstone is not considered prospective.

OLARY DOMAIN GEOLOGY AND MINERALISATION

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The geology and mineralisation of the Palaeoproterozoic Willyama Supergroup in the Olary Domain in South Australia has been investigated as part of the collaborative "Olary Mapping Project" and has involved 35 Honours mapping projects and several integrated research projects, including 3 PhD theses.

The Olary Domain (OD) sequence (Fig. 1) displays significant regional correlations with the Willyama Supergroup (WS) in the adjacent Broken Hill Block, although there are numerous differences in detail. The WS contain metamorphosed sedimentary, volcanic and intrusive rocks, interpreted to have been developed in an intracontinental rift, with initial intercalated terrestrial, lacustrine/sabhka and marine sequences being succeeded by deeper marine/lacustrine sequences. The lower part of the OD sequence is dominated by quartzofeldspathic and psammopelitic composite gneiss and migmatite and may be partly intrusive (Composite Gneiss Suite). It grades into, and may simply be a more melted equivalent of the overlying Quartzofeldspathic Suite. The latter contains the "Lower Albite" unit, dominated by ~1710-1700 Ma A-type metagranitoids and co-magmatic felsic metavolcanic rocks, the "Middle Schist", dominated by psammopelitic schist and composite gneiss, and the "Upper Albite", dominated by finely laminated albitite, as well as minor amounts of iron formation. The Quartzofeldspathic Suite grades up-sequence into the Calcsilicate Suite, dominated by laminated calc-albitites and minor calcsilicate and Mn-rich rocks. In turn, there is an up-sequence transition into the Bimba Suite, dominated by calcsilicate rocks and marble, locally with abundant Fe(CuZn) sulphides, and minor pelite and albitite. The Bimba Suite is overlain by a regionally sharp contact with the Pelite Suite, composed of pelite and psammopelite, with local graphitic facies, psammite, tourmalinite and manganiferous iron formation. It is interpreted that the WS sequence was largely deposited at ~1710-1690 Ma; the younger age limit is not well-constrained but the Pelite Suite may have been intruded by ~1640-1630 Ma granitoids.

Several intrusive suites occur in the OD (Fig. 1) and there have been at least five deformation and metamorphic events. Temporal relationships have been investigated by zircon U-Pb and muscovite Ar-Ar geochronology. A-type granitoids were emplaced at ~1710-1700 Ma and co-magmatic rhyolitic volcanic rocks were erupted. The WS sequence may have been deformed prior to intrusion of mafic igneous masses at ?~1670 Ma. Several small I-type granitoid bodies were emplaced into the central part of the OD at ~1640-1630 Ma. A major episode of deformation and amphibolite grade metamorphism occurred in the Olarian Orogeny at ~1600 ± 20 Ma, with subsequent emplacement of voluminous S-type granitoids and associated pegmatite bodies. Regional-scale retrograde metamorphism and alteration may have followed episodically between ~1580 Ma and ~1500 Ma, and there were further thermal perturbations during the Musgravian Orogeny at ~1200-1100 Ma. Mafic dyke emplacement at ~820 Ma was a precursor to development of the Adelaide Geosyncline in the region and at least two episodes of low grade metamorphism and deformation occurred between ~500-450 Ma during the Delamerian Orogeny.

Regional-scale hydrothermal alteration has affected much of the sequence, as well as some intrusives, within the OD. Fluids have been high-temperature (~450-600°C), oxidising and saline, and may have been largely metamorphically derived, with significant influence from precursor evaporitic and oxidised sedimentary sequences. Widespread Na(-Fe) metasomatism of quartzofeldspathic rocks has occurred (mainly albite ± Fe oxides, pyrite), with local strong Fe-metasomatism of iron formations and albitites and CaFe-metasomatism of calcsilicate rocks (commonly in association with spectacular breccias), marble and quartzofeldspathic rocks.

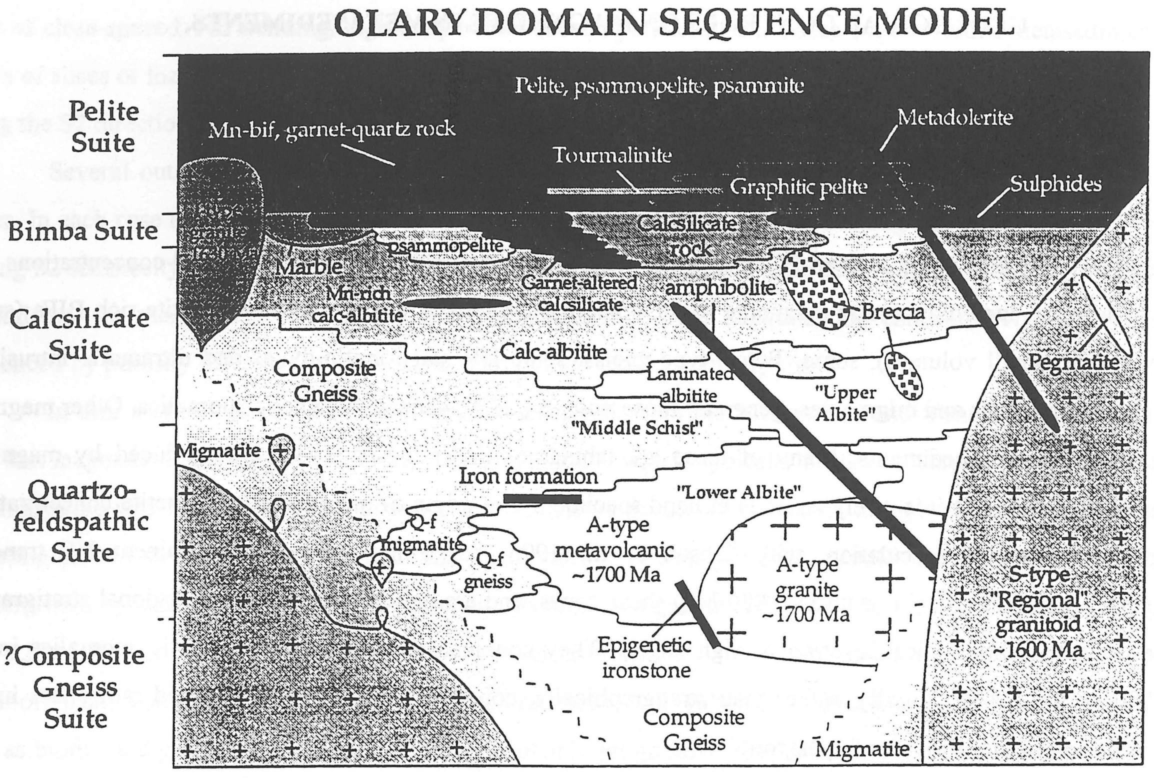

Fig. 1. Interpretive cartoon of rock relationships in the Willyama Supergroup sequence in the Olary Domain, and the position of intrusives.

Several styles of mineral deposits are recognised in the OD, including early, syn-sedimentary or diagenetic types, various hydrothermal deposits related to intrusives and metamorphic/alteration events, and late, weathering-related types. Syngenetic and/or diagenetic deposit styles are represented by Fe (Zn) sulphides in the Bimba Suite, iron formations (including baritic types in the Quartzofeldspathic Suite) and Mn-enrichments in the Calcsilicate and Pelite Suites. Manganiferous iron formations in the Pelite Suite are closely analogous to iron formations associated with the Broken Hill ore bodies. In the Bimba Suite, stratiform laminated to massive and disseminated sulphides are common in calcsilicate, marble and pelitic rocks and have given rise, in part, to extensive, base metal-anomalous gossans. Epigenetic mineral deposits are represented by various types of replacements in calcsilicates, marble and iron formation, and vein/stockwork systems, generally with a Cu(AuCoZnMo) signature, and rare metal pegmatites and UThREE deposits related to the ~1600 Ma S-type granitoids. The vein/stockwork and replacement deposits are interpreted to have formed during prograde and retrograde metamorphic and deformation events, and cannot be directly linked to intrusives. They include several "stratabound skarn" systems associated with the Bimba Suite, Fe oxide-rich replacements of iron formations and vein/stockwork systems in brittle rocks of the "Upper Albite" unit. Supergene oxidation and diagenetic processes from the Mesozoic to Recent has led to Cu(CoAu) enrichment deposits and redox-controlled U and Au deposits, especially to the north of the outcropping OD.

Exploration potential for stratiform/stratabound, sediment-hosted base metal deposits (Broken Hill and Mt Isa types), epigenetic CuAu in lithologically and structurally favourable sites is considered high. It is manifest by recent discoveries of Cu and Au prospects under cover, and by blanket coverage of the region by exploration tenements.

Acknowledgements: The Olary Mapping Project has been generously funded over several years by a consortium of Australian mineral exploration companies, Mines and Energy South Australia and AGSO. The input of many colleagues, including Frank Bierlein, Peter Black, Nick Cook, Mark Fanning, Adam Kent, Dave Lawie, Bernd Lottermoser and Jiangchun Lu, is much appreciated.

GEOLOGICAL CONTROLS ON MAGNETITE IN METASEDIMENTS, BROKEN HILL

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Most magnetic anomalies in the Broken Hill Block are generated by magnetite disseminations and concentrations in a range of rock types, including quartz-magnetite rocks, some basic gneisses, garnet-magnetite-apatite-rich BIFs (small anomalies due to small volumes), some 'Potosi-type gneiss, some late stage mafic dykes and ultramafic intrusions. Some composite gneisses and migmatites, generally those poor in garnet, generate magnetic anomalies. Other magnetic anomalies occur in metasediments. Many of these are tabular or linear in shape and are produced by magnetite disseminated so finely that it is rarely obvious in hand specimen. The origin of these tabular magnetite concentrations has been the subject of speculation, with Gibson et al. (1996) suggesting that many prominent NE trending aeromagnetic anomalies coincide with D4 (800 Ma) shear zones, and are not only discordant to regional stratigraphy, but some cut across lithological layering at high angles. They conclude that 'many aeromagnetic anomalies in the Broken Hill region are structurally, rather than stratigraphically, controlled, and evidently formed rather late in the tectonic evolution of the Willyama Supergroup'.

I chose two anomalies entirely in metasediment for detailed study: the 'Monuments' area in Sundown Group metasediments east of the Nine Mile mine, and an area of Sundown Group or Broken Hill Group metasediments 4 km SSE of Yanco Glen.

YANCO GLEN SE MAGNETIC ANOMALY

The area studied SSE of Yanco Glen contains about 0.5 km strike length of the northernmost part of a prominent tabular anomaly which continues with irregularities for about 17 km SSW to the Stephens Creek Shear Zone. The NE trend of the magnetic anomaly here is transgressive to N trends of 'probable bedding' (Stephens Creek 1:25,000 sheet, Stroud 1989). Geological mapping at 1:2500 showed that the northerly trends represent fault slices, many of which are parallel to a prominent, probably D3 schistosity and that bedding predominantly strikes ESE. A ground magnetic survey and magnetic susceptibility mapping showed that the aeromagnetic anomaly was produced by a massive magnetic pelite, sliced into a series of en echelon blocks by northerly trending D3 shears, reactivated during retrograde deformation. The NE trending aeromagnetic anomaly is parallel to neither the predominant bedding trends nor to the dominant schistosity, but represents an enveloping surface around the numerous off-set fault blocks. There is no indication that this magnetic pelite represents a shear zone. Examination of the whole 17 km-long anomaly shows that it parallels mapped stratigraphic units, including the folded margin of the Stephens Creek quartzo-feldspathic gneiss (Rasp Ridge Gneiss), and that the anomaly shows evidence of off-sets and folding. Its characteristics are that of a stratiform rock unit, and not of a shear zone.

MAGNETIC ANOMALIES IN THE MONUMENTS AREA

The Monuments anomalies are situated in Sundown Group metasediments between two limbs of Hores Gneiss. The overall structure is interpreted as a NE trending D2 syncline, closing to the south and cut off by the Stephens Creek Shear to the north. The eastern limb is partly sheared off by the Nine Mile Discontinuity. Within the magnetically anomalous metasediments, some bedding trends are transgressive to the overall NE trend of the anomaly. But the zones of magnetic metasediment are 50-75m wide whereas beds can rarely be traced for more than 10m. Detailed lithological mapping shows that bedding is only a minor control on the trends and shapes of lithological units. The main control is a set of close-spaced, NE trending, high temperature shears, parallel to S2. These cut the folded metasediments into a series of slices or lozenges. The magnetic anomalies represent a sequence of magnetic pelites and psammites strung out along the S2 direction.

Several outcrops of magnetic metasediment were mapped on a 10 cm grid, using a magnetic susceptibility meter. In each case the distribution of magnetite was found to be controlled by bedding and independent of the cross-cutting S2 schistosity. In one outcrop magnetite following bedding appears to be destroyed in the vicinity of a D2 shear. A tendency for magnetite to be concencentrated in psammite beds suggests that concentration of magnetite was influenced by porosity diferences which existed before high grade metamorphism.

In thin sections of magnetite-bearing metasediments from the Monuments and Yanco Glen areas, it can be seen that magnetite is disseminated, unlike detrital magnetite, which typically occurs as heavy mineral concentrations. The magnetite was formed by a chemical process. Magnetite occurs as inclusions in high grade metamorphic quartz, predating the coarse growth of quartz, and interstitially between quartz grains, recrystallising with the quartz. Magnetite is overgrown by coarse, retrograde muscovite, and in places magnetite is flattened in the S2 schistosity and predates that schistosity. Introduction of magnetite along shear zones or along schistosity during or after high grade metamorphism, would require an oxidising fluid to pass through the relatively reduced metasediment. Ferrous minerals such as biotite and garnet, would be oxidised and probably progressively replaced by magnetite. There is no obvious replacement of this biotite or garnet by magnetite. All three minerals were present during the high grade metamorphism.

THE SUNDOWN AREA

In the area between Broken Hill City and the Nine Mile mine, including Sundown Trig, there is a series of magnetic anomalies within the Sundown Group. A number of geologists have decided that these represent a set of shears, forming a shear duplex. The mapped retrograde shears and their extensions are non-magnetic and have sliced up the magnetic rocks. Lithological data from the Broken Hill 1:25,000 sheet (Brown 1983) shows that almost all of the anomalies are in a mixed psammitic/pelitic sequence, and that the pelitic sequences on either side of it are virtually non-magnetic. Where the rocks young predominantly NW there is a relatively simple anomaly pattern. Where there are younging reversals there are multiple anomalies. It is quite likely that the magnetic anomalies represent a single stratigraphic package, tens of metres thick, within the central psammitic part of the Sundown Group, deformed by folding, and sliced up by retrograde shear zones.

So far I have not found any major anomalies in the Broken Hill Block, which are actually transgressive and where magnetite has been emplaced in a shear zone, rather than predating the shear and dragged into it. Such features may exist, but the closer you look, the less evidence there is. What is needed now is understanding of the sedimentary or diagenetic processes which produced the magnetite, and an evaluation of the usefulness of magnetic anomalies as stratigraphic markers.

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A REVIEW AND RE-EVALUATION OF THE STRATIGRAPHY AND STRUCTURE OF THE EASTERN WEEKEROO INLIER. OLARY DOMAIN, SOUTH AUSTRALIA: JUSTIFICATION FOR CONTINUED MAPPING

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The extraction of critical geological information from complex terrains requires careful examination, thus the inception of a mapping program demands the decision as to whether to generalise or differentiate the geology; if the latter is chosen then the scale of mapping should be commensurate with the complexity of the geology. Cost, and hence mapping time, is important; the difficulty therefore is to achieve a cost-effective compromise which will unearth all the critical components without being side-tracked by detail. The justification for mapping, rather than prospecting, is the gain of understanding of both the geometry and geological processes which formed the rocks and hence the enclosed mineral deposits. Geological mapping is not a one stage process, but is iterative; the successive application of new techniques and ways of thought are essential to improved understanding.

The Walparuta Cu-Au Mine area (eastern Weekeroo inlier; Olary Domain (Figs.1 & 2)) provides a good example of improved understanding stemming from successive studies over the past 40 years. The following list illustrates some of the important stages:

- Campana and King (1958); regional mapping defining the Willyama Supergroup inliers (Fig.1),

- Talbot (1967); an informal stratigraphy proposed for the Willyama Supergroup within the central Weekeroo inlier, including a thick quartzofeldspathic (albitite-rich) unit overlain by a major pelitic unit,

- Dickinson (1974, possibly in conjunction with Pitt - 1979); 1:50 000 scale mapping, the stratigraphy of Talbot applied to all three Weekeroo inliers, a further two units (including a lowest 'quartzite') added to the base of the sequence, the recognition of a major NE trending antiform (F3) in the eastern inlier and the interpreted connection of the Walparuta Barite Mine and the Walparuta Cu-Au Mine across the fold (Fig.2).

- Pitt (1979); 1:50 000 scale mapping, recognition of structural repeats across a NW-trending fold set (i.e. F2).

- Cotton (1980); 1:10 000 scale mapping (by G.L. Clarke), recognition that the pelitic unit cores a slightly overturned (pre-F3), shallowly NE-plunging synform (the 'Dead Horse syncline') and that a sulphidic unit (the 'Bimba formation') repeats across the structure (Fig. 2).

- Clarke et al. (1986); regional interpretation showing the 'Dead Horse syncline', and a similar syncline to the north (the 'Walter-Outalpa syncline'), to be parts of a southerly verging nappe (this interpretation did not take the NE trending F3 fold into account). A broad stratigraphic scheme was proposed younging upwards as follows: 'composite gneiss suite', 'quartzofeldspathic suite', 'calcsilicate suite', 'Bimba suite', 'pelite suite'.

Curtis (1996 pers. com.); re-interpretation of the 'Dead Horse nappe', incorporating the F3 structure and proposing northerly transport.

Subsequent mapping by the present author has shown the following (Fig. 2):

- the 'Dead Horse' and 'Walter-Outalpa' synclines are structurally not similar, and therefore the 'Dead Horse nappe' hypothesis, at least in its present form, difficult to support.

- There are possibly two, calcsilicate associated, stratigraphic mineralised horizons, i.e. the upper 'Bimba suite' and the lower 'Walparuta Cu-Au Mine horizon'.

- Felsic volcanic (?pyroclastic) lenses (~1710 Ma, Conor 1996) are common lower in the 'quartzofeldspathic suite' (Fig. 2). These are prospective being iron-rich and sulphidic (magnetite, pyrite), and are commonly accompanied by stratiform iron formations. The volcanic lenses constitute local marker horizons and characterise a possible volcanogenic stratigraphic horizon equivalent to the lower 'quartzite' of Dickinson (1974).

One objective of the current mapping program is 'ground truthing' of the MESA 1:25 000 compilation (Laing, 1995); the mapping clearly demonstrates that the geological and metallogenic understanding of the region still lies well within the steep portion of the 'learning curve'. Continued detailed mapping will increase our knowledge dramatically, and thus will potentially contribute to the discovery of new metal deposits in the Curnamona Province.

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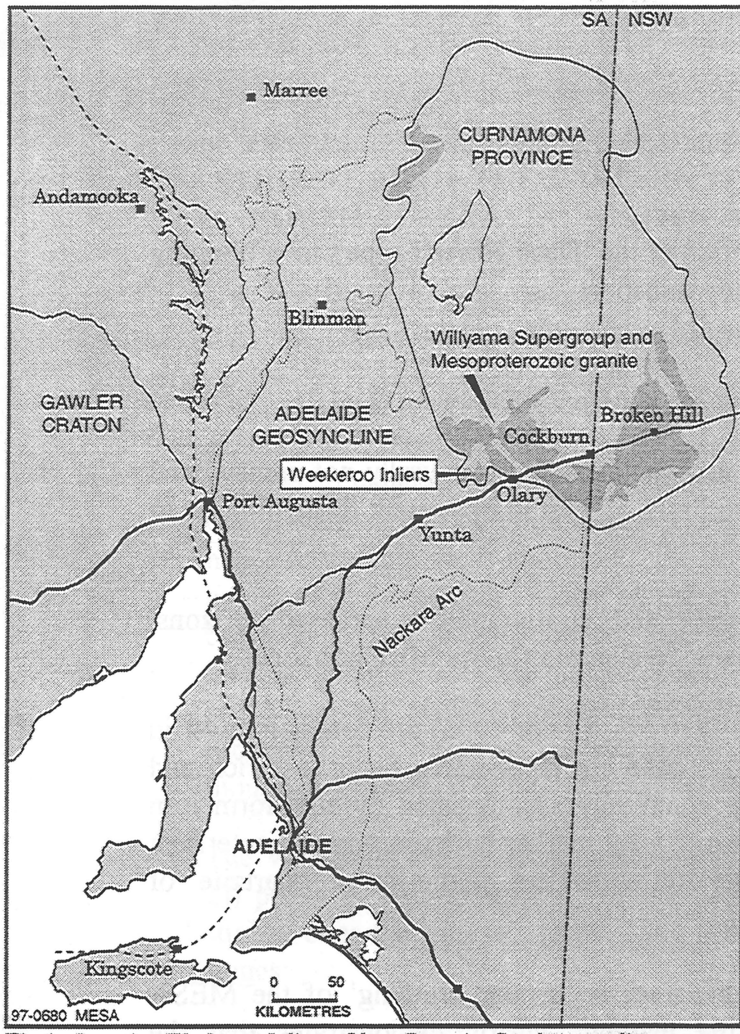
A REVIEW AND RE-EVALUATION OF THE STRATIGRAPHY AND STRUCTURE OF THE EASTERN WEEKEROO INLIER, OLARY DOMAIN, SOUTH AUSTRALIA: JUSTIFICATION FOR CONTINUED MAPPING

C.H.H. CONOR



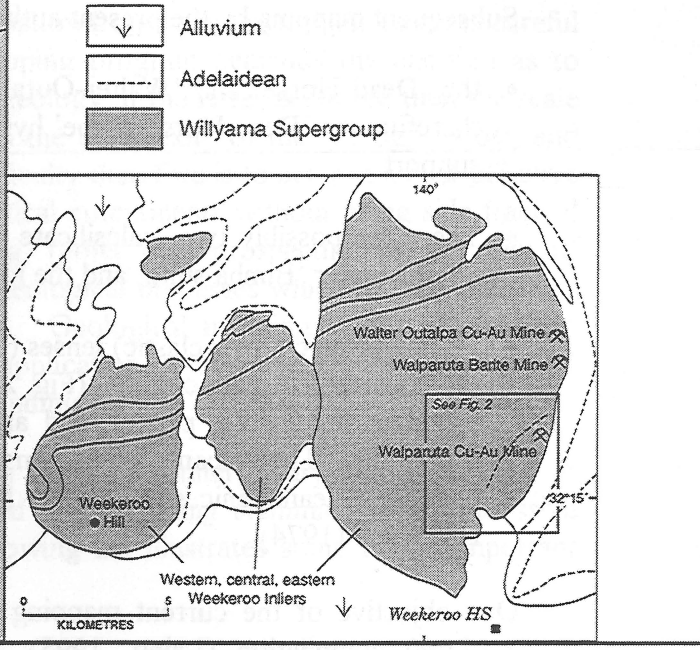


Fig 1. *Location Weekeroo Inliers, Olary Domain, South Australia.*

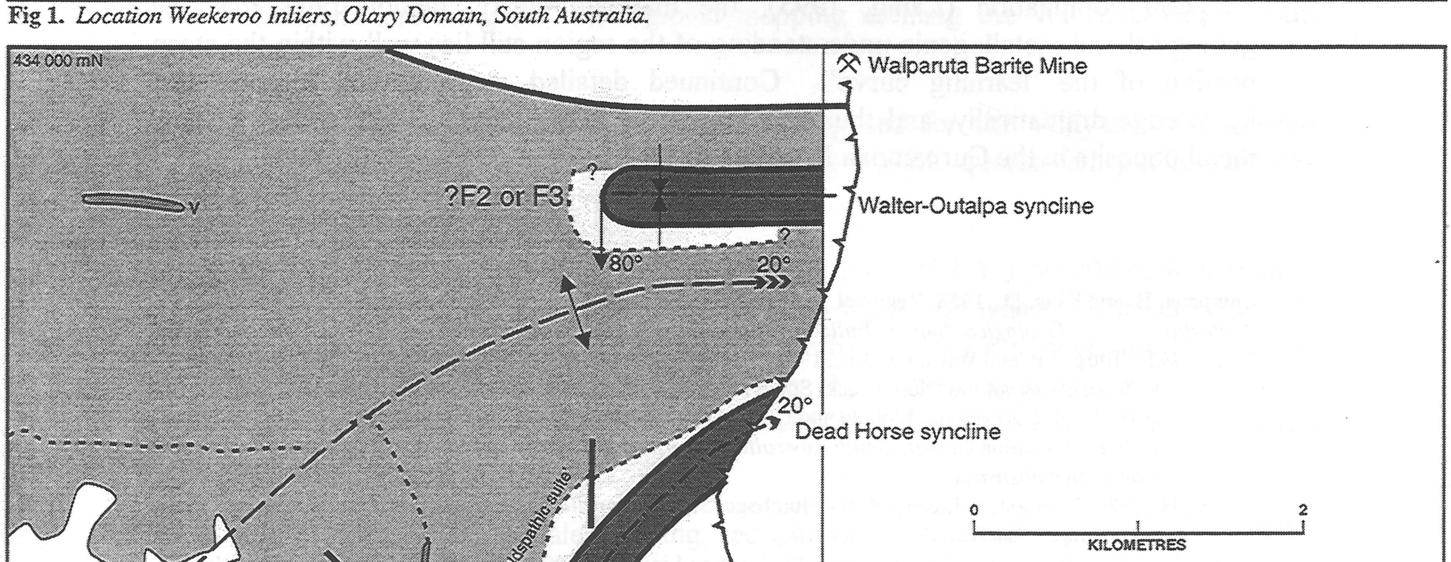


Fig 2. *Walparuta Mine area, Eastern Weekeroo Inlier. Sources: Pitt 1979, Cotton 1980, Curtis pers com 1996, Conor recent mapping.*

Crustal Structure in the Broken Hill region as evidenced by deep seismic reflection profiling and structural mapping

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Deep seismic reflection data collected from the Paleoproterozoic Willyama Supergroup by AGSO as part of the Broken Hill Exploration Initiative are at variance with previously proposed structural models for the region. In previous interpretations, the dominant structures were thought to be northwest-dipping and consistent with tectonic (nappe) transport towards the southeast (eg Marjoribanks et al., 1980; White et al., 1996; Laing, 1996). Contrary to earlier expectations, the major structures in the Broken Hill region dip southeast and accommodated a much greater degree of thrusting, transposition, and internal disruption (imbrication) than previously envisaged. Tectonic transport was largely directed towards the west and northwest. This is in keeping with recent structural mapping undertaken by AGSO (Gibson et al., 1996) in the Broken Hill region showing that the main sense of movement on many northeast-trending shear zones is dominantly reverse-slip in character and westward-directed, thereby explaining why the deepest structural levels, and hence highest grade metamorphic rocks (migmatites and granulite facies), are exposed to the southeast, rather than northwest, of Broken Hill city.

Several major shear zones are evident in the seismic profiles, some penetrating to lower crustal depths. Particularly conspicuous in the seismic profiles is a 20-25 km wide imbricate zone (central block) centred on the Apollyon Valley shear zone which has the character of a fold and thrust belt; it dips southeast in common with other major structures in the region and separates a western block characterised by flat-lying reflectors from an eastern block in which a rift geometry of uncertain age is preserved in the upper 10 km (1-3 sec two-way time). This rift geometry includes rotated fault blocks, one or more asymmetric sedimentary basins, and a number of regionally significant shear zones (Rupee, Mt Darling Range shear zones) which flatten out at depth (~10 km) into a major subhorizontal detachment surface. Both rift-fill and sedimentary sag phases are recognised in the sedimentary basins and there appears to have been minimal subsequent inversion of the basins so that the original extensional geometry has been preserved despite the effects of later deformation. Crustal shortening associated with this later deformation was accommodated by thrusting and folding at near-surface levels, and by rotation of the earlier formed fault blocks at depth.

The central block (imbricate zone) is best interpreted as a thrust and fold belt or broad shear zone (mobile belt) that got caught up between the western and eastern blocks during regional compression (transpresssion) of Delamerian or older age. Throughout this block, packets of shallow-dipping bedding are separated by more steeply dipping shear zones and zones of attenuation; duplex structures are common. Irrespective of their origin, several of the more significant shear zones extend to lower crustal depths and thus have probably acted as important conduits for fluid flow at one time or another. Recognition of these structures not only has major implications for mineral exploration strategies relating to known Ag-Pb-Zn deposits in the Broken Hill region but suggests that the area may have an unrealised potential for other forms of shear-hosted mineralisation (eg Cu, Au). The western limits of the central block coincide with the Mundi Mundi fault which at this point along the seismic line may also correspond to the boundary between the Olary and Broken Hill blocks.

High grade fabrics in the Willyama Supergroup are cut by retrograde shear zones trending northwest and northeast. Their significance is not always immediately obvious although the northwest-trending shear zones lie parallel to the late Proterozoic continental margin and most likely shared a common origin. Late Proterozoic sedimentary basins in the region are similarly oriented northwest. Moreover, most of these basins are fault-bounded and formed in an extensional tectonic regime (Preiss, 1987). It is therefore suggested that at least some of the retrograde shear zones originated during the late Proterozoic break-up of Rodinia; others may be older structures that were simply re-activated during continental break-up or later events. A few northeast-trending shear zones (eg. Redan fault) may have originated as transfer structures (strike-slip faults) during late Proterozoic continental extension.

A late Proterozoic age is most easily demonstrated in the case of the northwest-trending Stirling Hill shear zone which preserves a history of normal faulting followed by later re-activation. This shear zone is also host to hydrothermally altered mafic dykes which carry conspicuous mineralisation (Cu). The age of these dykes is unknown but they are most likely higher level equivalents of the Little Broken Hill gabbro dated at 827 Ma (Wingate et al., this volume). S-C fabrics, shear bands, rotated boudins and other kinematic indicators consistent with thrust faulting on the northeast-trending shear zones are attributed to the lower Paleozoic Delamerian orogeny. Some northwest-trending structures were also reactivated at this time and record evidence of significant sinistral strike-slip motion as well as a minor component of thrust faulting. Late deformation occurred under greenschist-lower amphibolite facies conditions.

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Developing a GIS data package for use in exploration in the Broken Hill region

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The Broken Hill region has a large number of high-quality datasets available from a long history of research and exploration. Several of these datasets have been collected recently as part of the Broken Hill Exploration Initiative (e.g. aeromagnetic and gravity data). Others have been present in the public domain or in company reports for some time (e.g. NSWDMR mapping and industry drillhole data). With this in mind, the BHEI has been developing a GIS data package to facilitate the integration of these datasets for use in exploration.

The area covered comprises six 1:100 000 sheets centred on the Broken Hill Block; namely the Thackaringa, Redan, Broken Hill, Taltingan, Corona and Fowlers Gap sheet areas. The 21 published 1:25 000 scale geological maps produced by NSWDMR form a core to the package. A universal legend for the block is being developed to allow quick comparison of units between sheets. Topographic information generated from airphoto compilations for the geology sheets is also included. These data have been aggregated into four coverages that cover the block: drainage, roads/tracks, rail and fences. Property boundaries will also be converted into digital format.

In addition to the mapped geology, the Mount Gipps and Stephens Creek 1:25 000 solid geology interpretations recently completed by the BHEI are to be incorporated in the package. Accompanying these will be the interpreted 1:100 000 stratigraphy for the block published by NSWDMR.

Some geophysical data will also be included. An image of the Broken Hill gravity survey recently completed by the BHEI is included, as is a gravity contour coverage to allow easy integration with other datasets. A subset of the detailed airborne geophysical surveys flown by AGSO may also be incorporated, comprising aeromagnetics, spectrometrics and the digital elevation model.

Some 21 coverages have been generated for the whole block portraying individual lithologies. This allows a user to examine the regional distribuiton of a particular lithotype (e.g. amphibolite or composite gneiss - see Fig. 1).

A recently updated version of the mineral deposit database is incorporated in the package. 3400 mineral occurrences are represented and have been attributed with information such as primary commodity, production, deposit style and a summary description. Another coverage comprises drillhole data. 1300 drillholes have been captured into the database and have attributed information, including hole depth and orientation.

A geochemical dataset comprising 2050 analyses has been included and split into coverages containing analyses for major lithotypes (e.g. Potosi gneiss, granite gneiss).

These data are particularly useful for the spatial analysis of geochemical patterns in individual lithologies.

Three RAB/auger drilling programs have been collated and imaged using base metal geochemistry. These programs consist of surveys in the Stephens Creek and Rupee areas plus a huge survey to the southwest of Broken Hill consisting of 30 000+ holes. The surveys have been compiled as three images (Cu, Pb & Zn).

A photo library of representative rock types is also included, with individual images hotlinked to their locations (Fig. 1). This collection can be built upon to provide an introduction to Broken Hill geology to new workers.

Other coverages include 1:25 000 and 1:100 000 map indexes, a Broken Hill Block outline and the trace of the AGSO 1996 seismic line.

The package is due for release in September and will be periodically updated as new datasets are captured and assembled.

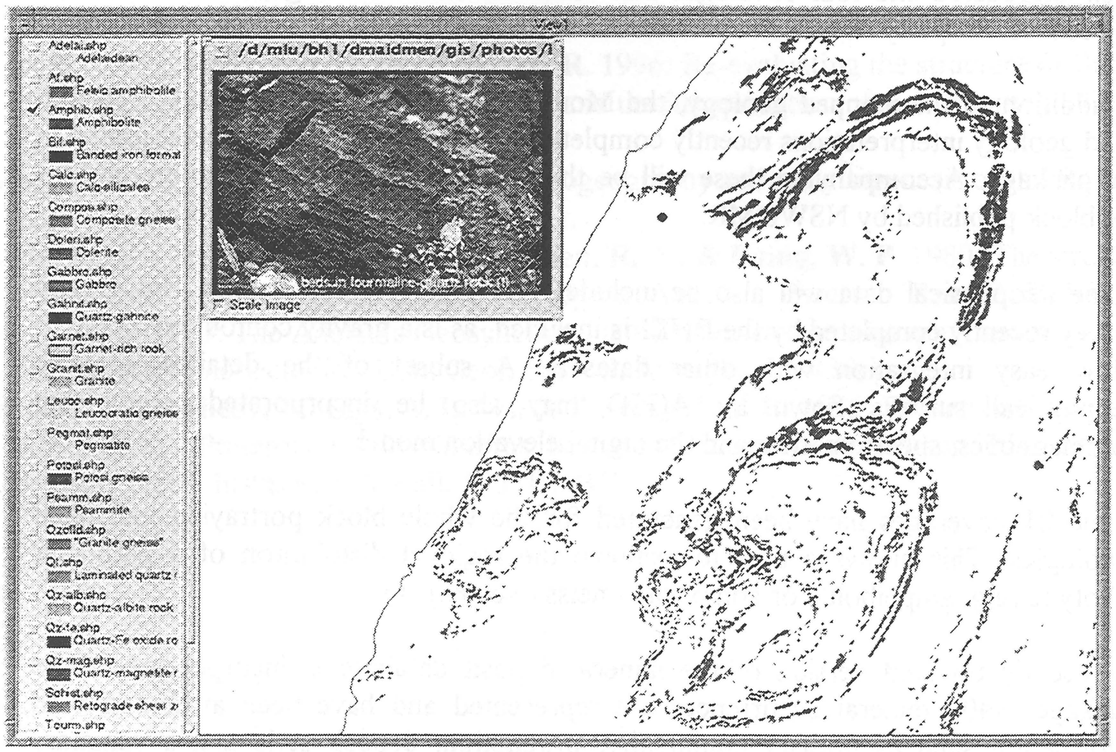

Figure 1. Arcview GIS snapshot showing amphibolite distribution in the Mt. Robe area with a photo of tourmalinite from the same region.