RECORD 2000/8

GOVERMENT OF
WESTERN AUSTRALIA

GSWA 2000 EXTENDED ABSTRACTS
Geological data for WA explorers in the new millennium

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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31 March 2000

Perth 2000

MINISTER FOR MINES
The Hon. Norman Moore, MLC

DIRECTOR GENERAL
L. C. Ranford

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
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REFERENCE
The recommended reference for this publication is:

(a) For reference to an individual contribution
VAN KRANENDONK, M. J., 2000, Evidence of thick Archaean crust in the East Pilbara, *in* GSWA 2000 extended abstracts: Geological data for WA explorers in the new millennium: Western Australia Geological Survey, Record 2000/8, p. 1–3.

(b) For reference to the publication
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 2000, GSWA 2000 extended abstracts: Geological data for WA explorers in the new millennium: Western Australia Geological Survey, Record 2000/8, 27p.

National Library of Australia Card Number and ISBN 0 7309 6678 X

Printed by Optima Press, Perth, Western Australia

Copies available from:

Information Centre
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EAST PERTH, WESTERN AUSTRALIA 6004
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Foreword

GSWA 2000 marks the third year in which customers of the Geological Survey of Western Australia (GSWA) have been invited to listen to talks and to view displays on the work of GSWA. In view of the success of the first two years, this activity will now become an annual event on the GSWA calendar. The emphasis of the 'open day' is on presenting work-in-progress for our customers and, in particular, the mineral industry.

The collection of expanded abstracts gathered in this Record relates to the talks to be presented throughout the day. Although they represent a cross section of current activities within GSWA, they do not present a complete picture.

A more complete view of GSWA activities can be obtained from the extensive displays. Plenty of time during the extended mid-session and lunch breaks has been built into the day's program for viewing displays and for discussions with the staff involved in the project work.

GSWA 'open days' are an opportunity to view the latest data and interpretations relating to Western Australia's regional geology and prospectivity. GSWA 2000 also provides an opportunity for industry representatives to provide feedback on GSWA work programs and the way in which the information is being made available, using the newer digital technologies. The pre-competitive geological information presented in GSWA 2000 highlights the way the State assists mineral and petroleum explorers.

DAVID BLIGHT
DIRECTOR

Contents

Evidence of thick Archaean crust in the East Pilbara

by

Martin J. Van Kranendonk

New mapping and geochronological evidence gathered during the recent joint GSWA–AGSO National Geoscience Mapping Accord project in the Pilbara Craton show that the greenstone succession of the East Pilbara Granite–Greenstone Terrane (EPGGT in Fig. 1) is an upward-younging succession, 12–15 km thick, and that there was no tectonic thickening through thrusting. This, and additional evidence from numerical models, suggests that the crust may have been at least 55 km thick and that its formation may not have involved plate tectonics.

The Marble Bar greenstone belt is located along the western flank of the Mount Edgar Granitoid Complex (Fig. 1). A recent model has suggested that the greenstones represent a tectonically inverted, downward-younging succession with thrusts along bedding-parallel shear zones (van Haaften and White, 1998). This model is inconsistent with several newly obtained U–Pb zircon dates that indicate that the 12–15 km-thick succession was deposited, right way up, over 25 m.y. or more (Fig. 2: Thorpe et al., 1992; McNaughton et al., 1993; Nelson, 1999, in prep.). In addition, field mapping of synvolcanic, listric normal growth faults across unit boundaries, and of chert feeder-dyke swarms that link together large parts of the stratigraphy, indicates that the bedding-parallel shears identified in the previous model accommodated only minor displacement.

The example of the Marble Bar belt is applicable throughout much of the rest of the East Pilbara Granite–Greenstone Terrane, where numerous dates from felsic volcanic units show an extensive blanket of volcanic rocks around the granitoid complexes, spanning an age range from 3471 to 3430 Ma. In these other areas, estimates of the stratigraphic thicknesses are also up to 15 km. These are minimum estimates because they do not allow for tectonic flattening.

The mechanism of generating the dome-and-basin pattern through punctuated partial convective crustal overturn over 800 m.y. has been described previously (Hickman, 1984; Collins et al., 1998). An estimate of the total crustal thickness can be made by scaling the numerical model of diapirs by Mareschal and West (1980) to the actual dimensions of the dome-and-basin pattern. This yields a minimum original crustal thickness of 44 km and indicates that at least 10 km of crust have been eroded away. However, the local occurrence of maximum metamorphic pressures of approximately 6.5 kbars, combined with the fact that Pilbara granitoid complexes are wider than those of the scaled model at 10 km depth, suggests that the crust has been eroded to some 20 km depth and that it may therefore have been at least 55 km thick.

A viable model for the formation of Archaean crust that is 55 km thick or more must account for a) the observed thickness of the volcano-sedimentary successions, b) the lack of thrusts that could structurally thicken the succession, c) the dome-and-basin structural pattern, and d) the distribution of metamorphic assemblages and metamorphic gradients. Although much of the modern oceanic crust is 5–8 km thick, oceanic plateaus formed over mantle hotspots or wetspots may reach 35–42 km (e.g. Iceland and Ontong-Java). At the base of these pieces of crust, and even more so where crust may have been approximately 55 km thick or more, hydrous basalt will melt to form typical tonalite–trondhjemite–granodiorite (TTG) magmas — all that is required is depths great enough for melting to be within the stability field of garnet and/or hornblende in order to generate the high La/Yb ratios typical of Archaean TTG. Whereas Archaean TTG magmatism has been almost exclusively interpreted as having occurred within subduction zones, recent work suggests Archaean TTGs are crustal melts that may not be related to subduction (Smithies, in prep.). A crustal origin for Pilbara TTG and associated felsic volcanism is supported by the fact that these magmas were emplaced over a roughly circular area 220 km in diameter (vs modern arcs which are linear and 50–100 km wide) and that the duration of magmatism was 60 m.y. (compared with modern arc segments that last only approximately 10 m.y.). This suggests that subduction may not have been the main mechanism for TTG magma genesis; rather the Pilbara TTG may have formed through melting of hydrated basalt and/or intraplated gabbros during prolonged plume magmatism.

Emplacement of the TTG as sheeted sill complexes into the lower greenstones stabilized the crust, made it buoyant, and shielded the upper greenstones from the higher heat flow emanating from the primitive, hotter

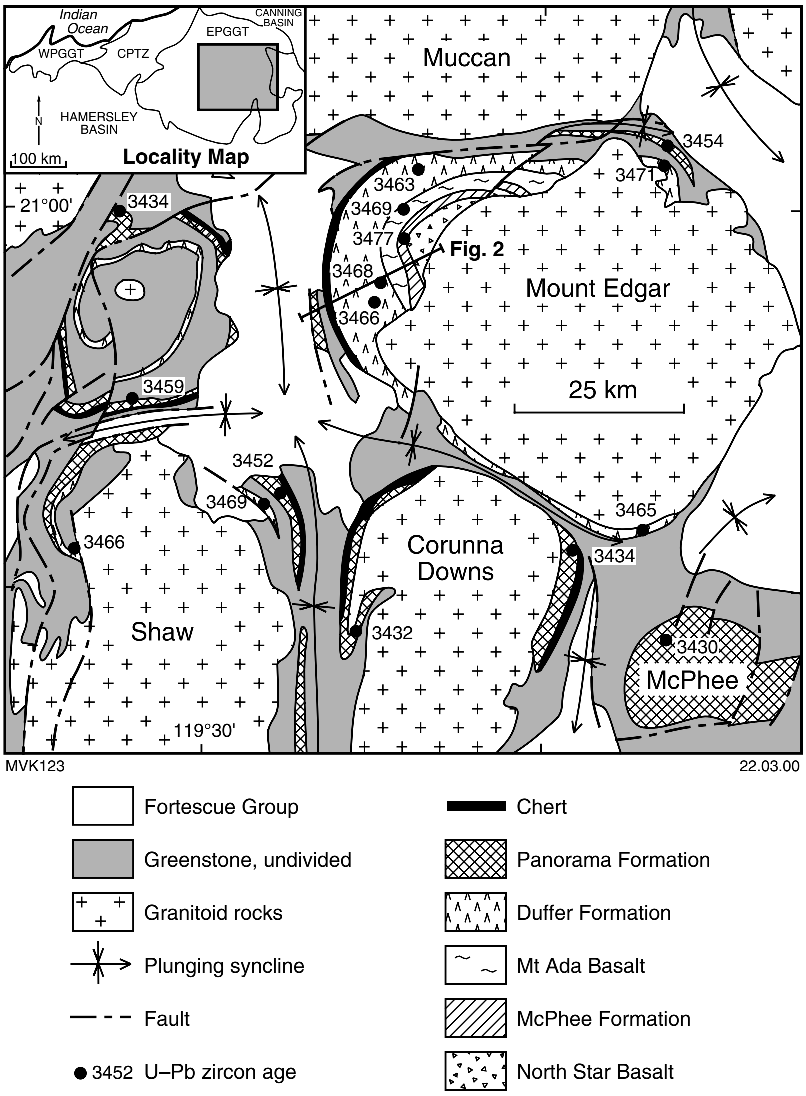

Figure 1. U–Pb zircon data on felsic volcanic rocks in the East Pilbara Granite–Greenstone Terrane. References cited in text. Sub-divisions of the North Pilbara Terrain of the Pilbara Craton: WPGGT — West Pilbara Granite–Greenstone Terrane; CPTZ — Central Pilbara Tectonic Zone; EPGGT — East Pilbara Granite–Greenstone Terrane. Location of stratigraphic column in Figure 2 is shown

mantle. Subsequent tectonothermal events — be they extension, plume magmatism, or compression — served to amplify original topographic irregularities in the sill complex at c. 3300 Ma, 3240 Ma, 2950 Ma, 2850 Ma, and 2760 Ma.

The bedding-parallel shears noted by van Haaften and White (1998) are interpreted to have formed during tilting of the greenstones from the horizontal to the vertical within narrow inter-diapir synclines as a result of deformation associated with granitoid diapirism. The low overall metamorphic grade of the greenstones may also be explained by diaprism, as may the local occurrences of higher grade assemblages (Collins and Van Kranendonk, 1999). Contact metamorphism of greenstones occurred along the margins of progressively more steeply inclined granitoid domes at discrete intervals throughout the protracted history of the region. These domes acted as conduits for the escape of heat from the mantle and lower crust to the surface through conduction, and in this light, the domes may be viewed as very long-lived crustal-scale boils.

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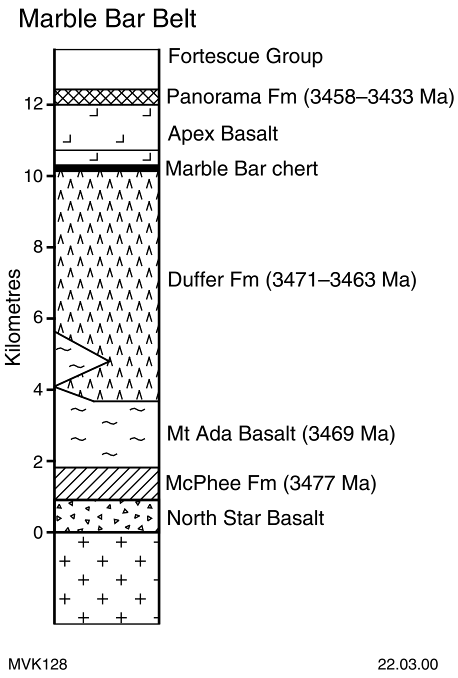

Figure 2. Stratigraphic column of the Marble Bar Belt, showing age range and thickness of the volcanic succession

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Late Archaean volcanism and sedimentation in the central Yilgarn Craton

by

A. Riganti, S. F. Chen, S. Wyche, and J. E. Greenfield

In the central part of the Southern Cross granite–greenstones, felsic volcanic rocks of the Marda Complex and clastic sedimentary rocks of the Diemals Formation were deposited at c. 2.7 Ga. They unconformably overlie an older (c. 3.0 Ga) greenstone succession containing metamorphosed mafic–ultramafic and sedimentary rocks with prominent chert and banded iron-formation.

The Marda Complex (Hallberg et al., 1976) occupies a roughly elliptical area of about 600 km^2 (Fig. 1) surrounded by units of banded iron-formation of the older greenstone succession, which dip moderately to steeply towards the complex. Small outlying areas of felsic volcanic rocks are attributed to the Marda Complex. To the north-northwest, the Diemals Formation (Walker and Blight, 1983) fills a roughly triangular synformal structure largely bounded by faults, but locally unconformable on the older greenstone succession. Metamorphism in these sequences is typically low greenschist facies, with higher grades observed only in contact aureoles.

Rhyolitic ignimbrite of the Marda Complex has a SHRIMP (sensitive high-resolution ion microprobe) age of 2732 ± 3 Ma (Nelson, in prep.). Metasedimentary rocks that unconformably overlie the lower greenstone succession and interfinger with the Marda Complex volcanics have been regarded as equivalent to the Diemals Formation lithologies (Chin and Smith, 1983), suggesting that the Diemals Formation and the Marda Complex were contemporaneous. However, sedimentary rocks of the Diemals Formation differ from those in the Marda Complex in that they do not have a distinct volcaniclastic component.

The Diemals Formation is a sequence of clastic metasedimentary rocks which have been folded into a regional-scale syncline with a moderate northerly plunge. In the western limb, silty argillite at the base is overlain by sandstone and pebbly sandstone. In the east, the lowermost exposed part of the formation consists of conglomerate and pebbly sandstone lenses interbedded with siltstone, which are in turn overlain by sandstone. The total thickness of the formation is uncertain, due to poor exposure and medium-scale folding.

The basal unconformity of the Diemals Formation is best exposed southwest of Diemals Homestead (Fig. 1), where a foliated, poorly sorted conglomerate contains clasts of black shale and deeply weathered mafic rocks derived from the underlying greenstones. At this locality, the basal conglomerate and the overlying sandstones dip moderately to the south-southwest, whereas the underlying greenstones dip steeply to the west.

The lowermost portion of the Diemals Formation consists of fawn to yellow–brown and grey (typically purple-weathered) silty argillite, with chloritic schist and graphitic shale horizons near the base. Minor, structurally controlled gold mineralization is hosted by these fine-grained sedimentary rocks. In the eastern limb of the syncline, the silty argillite is interbedded with lenses of polymictic conglomerate and pebbly sandstone. The conglomerate contains variably flattened clasts, up to 50 cm in size, which consist mainly of reworked sandstone and argillite, banded iron-formation, banded chert, and weathered mafic rocks, with granitoid and other felsic clasts present locally. Chert and banded iron-formation clasts commonly contain tight to isoclinal folding, indicating deformation prior to deposition of the Diemals Formation.

Sandstones and pebbly sandstones in the upper portion of the Diemals Formation vary from clean quartz arenite (locally quartzite) to much more immature quartz and lithic greywacke, and ferruginous sandstone, indicating variable conditions of transport and deposition. Graded bedding, cross-bedding and scour troughs are locally preserved.

Field characteristics and facies relationships suggest that the Diemals Formation represents a fluviatile sequence deposited over a deformed greenstone basement, with some contribution from granitoid sources. A predominant transport direction from east to west is indicated by clast lithology and the asymmetric distribution of facies in the lower parts of the formation. The presence of intraformational and mafic clasts within the conglomerate lenses indicates a relatively active tectonic environment, with uplift and erosion of the greenstone

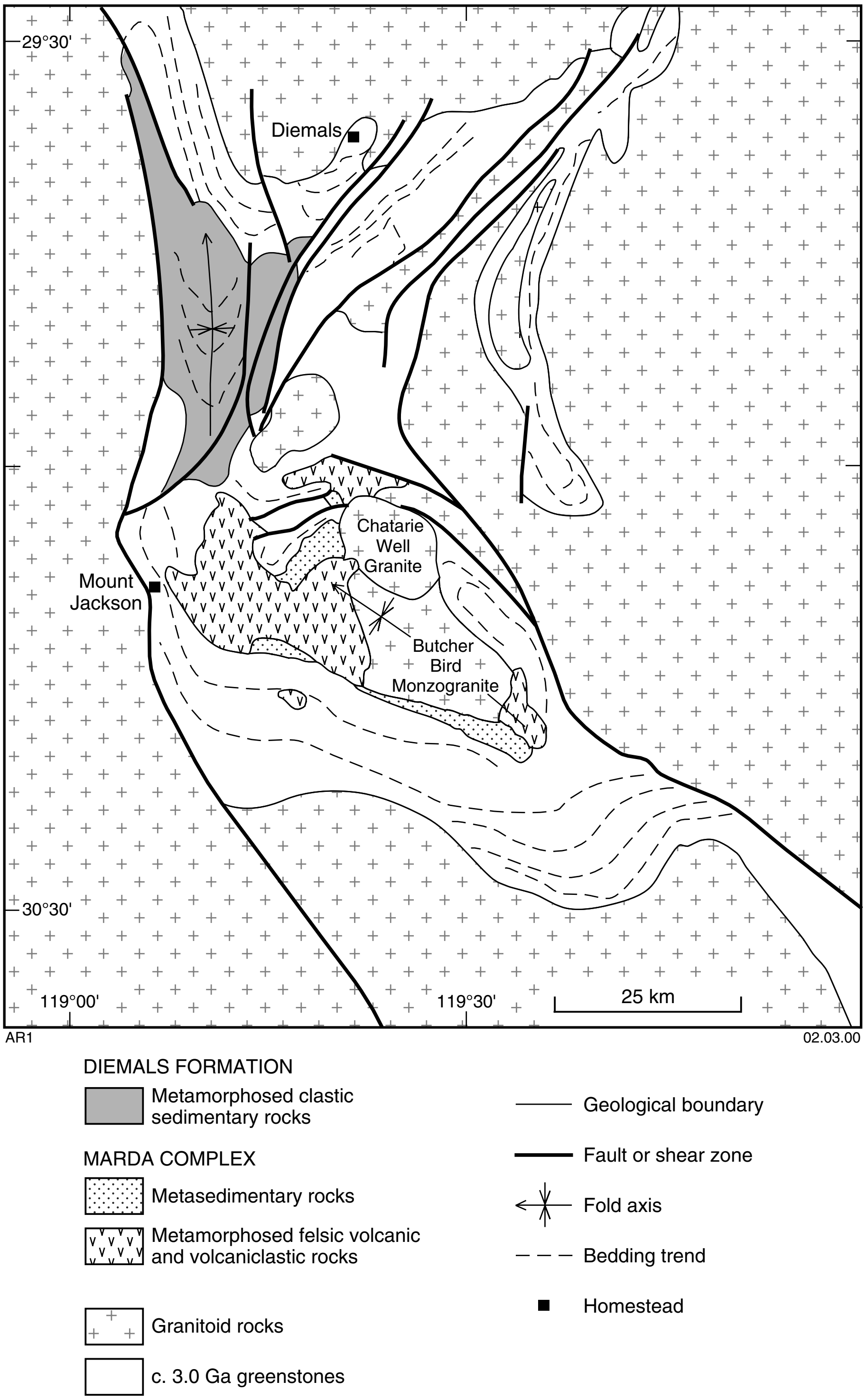

Figure 1. Simplified interpreted late Archaean geology of the central Southern Cross Province, showing the distribution and main structural features of the Diemals Formation and Marda Complex

basement and local reworking of the Diemals Formation sediments.

The Marda Complex comprises interfingering lava flows, pyroclastic rocks and minor volcaniclastic sediments, which were erupted in a largely subaerial environment onto a sequence of clastic sediments derived from the underlying greenstones. The whole succession has been folded at various scales.

The lower part of the Marda Complex is dominated by thick sequences of dark-grey andesitic and subordinate dacitic flows that are generally porphyritic and very commonly amygdaloidal. Overlying the andesites are thick sheets of rhyolitic ignimbrites and subordinate rhyolite flows, with textures indicative of subaerial deposition. Pyroclastic rocks include rheomorphic ignimbrites in which eutaxitic banding is defined by alternating layers of quartz and feldspar that wrap around altered plagioclase phenocrysts and lithic fragments. Fragmental ignimbrites include crystal and lithic lapilli tuffs, as well as minor ash tuffs and agglomerates. Lapilli include rhyolite and devitrified glass, as well as minor dacite, andesite and chert, set in a crystal-rich, welded and devitrified groundmass. In the crystal tuffs, plagioclase and resorbed quartz crystals are commonly surrounded by a matrix of welded shards. Rhyolitic flows are massive to quartz- and plagioclase-phyric, with an aphanitic groundmass of devitrified glass; sericitization is common and locally pronounced.

The sedimentary rocks of the Marda Complex include pebble conglomerate, sandstone and siltstone, commonly with a volcaniclastic component. The clast composition and immaturity of these sedimentary rocks suggests proximal deposition.

The Marda Complex is intruded to the east by the Butcher Bird Monzogranite (Fig. 1). The ubiquitous granophyric texture of this granitoid and its chemical similarity to the Marda Complex rhyolite suggest that it represents the high-level intrusion of the magma which was the source of the Marda volcanic rocks.

Geochemical investigation of the Marda Complex has confirmed that the Marda Complex volcanics form a broadly continuous geochemical series with a distinctive calc-alkaline trend (cf. Hallberg et al., 1976). Differences in the rare-earth element (REE) geochemistry of andesites and rhyolites preclude a simple derivation of the more acid rocks from the andesites by a process of crystal fractionation (Taylor and Hallberg, 1977). A crustal source for both lithotypes is indicated by the lack of significant heavy REE depletion, and is supported by high contents of Th and U.

The mineral potential for volcanogenic massive sulfide deposits (VHMS) in the felsic rocks of the Marda Complex is considerably limited by their largely subaerial nature. Although most Marda Complex andesites show chemical similarities to those hosting the Selbaie mineralization in the Abitibi Subprovince, Canada (Barrie et al., 1993), the Marda Complex lacks the bimodal character typical of volcanic rocks that host significant VHMS deposits. Potential exists in the Marda Complex for structurally controlled gold mineralization. Most of the gold in the Marda area is concentrated in quartz–sulfide vein systems that crosscut the banded iron-formation units around the Marda Complex, but some gold is reported from similar vein systems at the base of the Marda volcanic pile.

Evidence for the tectonic setting of the Marda volcanic rocks is not conclusive. The Marda Complex has the high potassium, calc-alkaline chemistry of Andean-type modern subduction settings, broadly similar to that of some felsic complexes of the Eastern Goldfields for which a subduction-related environment has been postulated (Morris, 1998, and references therein). However, the isolated nature of the Marda Complex within the Southern Cross Province, the lack of rock associations typical of continental subduction, and the inferred crustal derivation for the Marda lavas, preclude a straightforward analogy.

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Palaeoproterozoic orogeny in Western Australia

by

I. M. Tyler

Previous models for Palaeoproterozoic orogeny have assumed that the Australian crust formed a single entity by the late Archaean, and that most tectonic and magmatic activity occurred in an intracratonic setting between 1900 and 1800 Ma (e.g. Etheridge et al., 1987). However, complex Palaeoproterozoic tectonic histories are indicated by more recent geochronological data. Remapping of the Capricorn Orogen, the Paterson Orogen, and the King Leopold and Halls Creek Orogens in Western Australia (Fig. 1), combined with geophysical and geochemical data, indicates that their Palaeoproterozoic tectonic evolution can be interpreted in terms of continental break-up, terrane accretion, and plate aggregation (Myers et al., 1996, Tyler et al., 1998).

The Capricorn Orogen (Fig. 1) formed between the Archaean Yilgarn and Pilbara Cratons. At its northern margin, rifting of the Pilbara Craton initiated the Hamersley Basin at c. 2770 Ma, followed by breakup at 2690 Ma. The upper part of the Hamersley Group may have been deposited in a collisional setting between 2470 and 2440 Ma. The Palaeoproterozoic Turee Creek Group and lower Wyloo Group were deposited in the McGrath Trough, a possible foreland basin developed in front of a northward verging fold belt during an Ophthalmian orogenic event at c. 2200 Ma (Martin et al., 1998).

At the southern margin of the orogen, the Yerrida Basin formed at c. 2175 Ma initially as a sag basin on the Yilgarn Craton, followed by an abrupt change to a rift-fill setting. To the west, in the southern part of the Gascoyne Complex, collision of a late Archaean to early Palaeoproterozoic micro-continent with the northwestern margin of the Yilgarn Craton produced extensive deformation, metamorphism and felsic magmatism during the 2000 to 1960 Ma Glenburgh Orogeny (Sheppard et al., 1999). The Bryah Group may have been deposited in a back-arc basin setting at this time.

The 1840 to 1790 Ma Capricorn Orogeny involved extensive deformation, metamorphism and felsic magmatism (Occhipinti et al., 1998) during the oblique collision and suturing of the geologically distinct Pilbara and Yilgarn Cratons to form the West Australian Craton.

The King Leopold and Halls Creek Orogens are part of the North Australian Craton (Fig. 1) and have a Palaeoproterozoic tectonic history that is distinctly different from that of the Capricorn Orogen. In the Halls Creek Orogen, rifting of a continental margin began in the Eastern zone of the Lamboo Complex at c.1910 Ma and

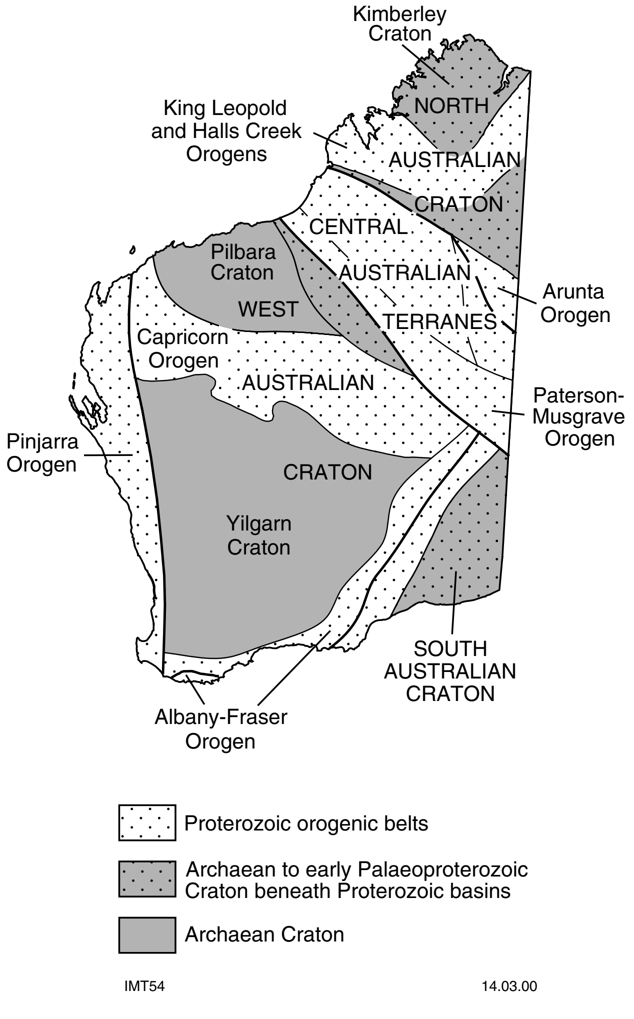

Figure 1. The main components of the Western Australian crust

continued with deposition of the lower Halls Creek Group at c. 1880 Ma.

In the Western zone of the Lamboo Complex and in the Hooper Complex of the King Leopold Orogen accretion of continental fragments to the eastern edge of the Kimberley Craton occurred before c. 1900 Ma. Turbidites derived from late Archaean and early Palaeoproterozoic crust forming the Kimberley Craton were deposited at c. 1870 Ma (Tyler et al., 1999). Deformation, metamorphism and extensive felsic and mafic magmatism occurrred during the 1865 to 1850 Ma Hooper Orogeny (Griffin et al., in press)

The Central zone of the Lamboo Complex formed at c. 1865 Ma either as an island arc (subduction to the southeast) or an ensialic basin marginal to the Kimberley Craton (subduction to the northwest) (Sheppard et al., 1999). Deformation and metamorphism to high grade at c. 1845 Ma (Bodorkos et al., 1999) followed intrusion of numerous felsic, and basic to intermediate sheet-like bodies during convergence and collision of the Central zone with the Western zone. Layered mafic–ultramafic intrusions were emplaced into both the Western and Central zones of the Lamboo Complex at c. 1855 Ma.

Further rifting along the eastern continental margin was marked by alkaline volcanism in the Eastern zone of the Lamboo Complex between 1870 and 1850 Ma. Turbiditic rocks of the upper Halls Creek Group were deposited parallel to the continental margin as a submarine fan.

Eruption of felsic and mafic volcanic rocks during rifting of the Central zone at c. 1840 Ma was accompanied by the emplacement of layered mafic–ultramafic intrusions. Continued subduction of oceanic crust to the northwest led to collision and suturing of the Kimberley Craton with the rest of the North Australian Craton by c. 1820 Ma during the Halls Creek Orogeny. Folding and thrusting accompanied metamorphism in the Central zone of the Lamboo Complex. During and immediately following collision, plutons of granite and gabbro were intruded to form the Sally Downs supersuite at the same time as the intrusion of large layered mafic–ultramafic bodies.

As the Sally Downs supersuite was being intruded into the Lamboo Complex the Speewah Group was deposited on the Kimberley Craton at c. 1835 Ma. The Kimberley Group oversteps the Speewah Group onto the Lamboo Complex, and both sedimentary groups were derived from the north. The intrusion of the Hart Dolerite at c. 1800 Ma may be related to continental break-up centred to the north, at the same time as granite intruded into the southern part of the Lamboo Complex, and into the Granites–Tanami Complex farther to the south.

The Central Australian Terranes have developed between the West Australian Craton and the North Australian Craton (Fig. 1). In the Rudall Complex of the Paterson Orogen a foreland basin may have developed prior to c. 1800 Ma. Granite intrusion took place at c. 1800 Ma, followed by deformation, metamorphism and further granite intrusion between 1790 and 1760 Ma during the Yapungku Orogeny. West-verging thrusting and high-P metamorphism accompanied collision of the West Australian Craton with the North Australian Craton. This event may be represented in the Arunta Orogen by the Strangways Orogeny (Bagas and Smithies, 1997).

The Earaheedy Basin overlies the c. 2175 Ma Yerrida Basin at the northeastern margin of the Yilgarn Craton, but was not affected by the Capricorn Orogeny. Large-scale dextral strike-slip faulting developed along the southern margin of the Pilbara Craton after c. 1790 Ma and extends to the southeast into the Stanley Fold Belt, which deformed the northeastern margin of the Earaheedy Basin. This event represents an intracratonic response to the Yapungku Orogeny.

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Abracadabra! Another Jillawarra-style sub-basin in the Bangemall Supergroup

by

D. McB. Martin and A. M. Thorne

The Jillawarra sub-basin is the only area where significant base metal mineralization has been found in the Mesoproterozoic Bangemall Supergroup. The Abra deposit (Pb–Cu–Ba) is located at the eastern end of the east–west trending sub-basin, and is one of the largest (low-grade) base metal deposits in Australia. The Jillawarra sub-basin is largely fault bounded with granitic inliers at the eastern and western ends. The lower Bangemall Supergroup in the Jillawarra area includes the arenaceous Coobarra Formation, which contains 1.63 Ga rhyolite bodies (Collins and McDonald, 1994). Abra is hosted within dolomitic siltstone and shale of the upper Gap Well Formation, near the base of the Jillawarra succession. The interpreted syngenetic hydrothermal mineralization is disconformably overlain by siliciclastic rocks of the West Creek Formation (Boddington, 1990; Vogt, 1995). Recent GSWA mapping suggests that another Jillawarra-style sub-basin developed on EDMUND*, 250 km to the northwest of Abra.

Martin et al. (1999) proposed a two-fold subdivision of the Bangemall Supergroup into an older EDMUND Group overlain by the Collier Group. The EDMUND Group unconformably overlies Palaeoproterozoic rocks of the Ashburton and Capricorn Formations to the north, and the Gascoyne Complex to the south. Initial basin subsidence was controlled by extension and growth faulting (Chuck, 1984; Muhling and Brakel, 1985), which is reflected in the distribution and thickness of the basal units, and the style of later deformation of the Bangemall Supergroup. On EDMUND, the originally synsedimentary Talga Fault was re-activated as a reverse fault. This fault separates relatively undeformed rocks deposited on the Pingandy Shelf from those deposited in an adjacent graben that are deformed by upright open to tight folds of the EDMUND fold belt (Muhling and Brakel, 1985). The Jillawarra sub-basin is an example of one of these early grabens that was filled with a mixed siliciclastic–carbonate succession (Vogt, 1995). No other grabens have been described previously from the region.

Facies distribution and thickness in the basal Bangemall Supergroup on EDMUND are strongly controlled by the synsedimentary Talga Fault. North of the fault, the Yilgatherra Formation generally consists of a few metres of fluvial sandstone, with palaeocurrents directed towards the south. South of the fault these sandstones are considerably thicker (tens of metres) and are overlain by, or interbedded with, siltstone. Palaeocurrent directions in this area are highly variable and suggest that rapid erosion of granitic uplands, now represented by the Henry–Telfer granite and Gifford Creek Complex, produced immature arenaceous and rudaceous successions in what were adjacent grabens. A granophyric plug intrudes the Yilgatherra Formation on the western flank of the Henry–Telfer granite.

North of the Talga Fault, the Irregully Formation consists largely of peritidal dolostone and sandstone with minor siltstone. The peritidal facies consists mainly of thin cycles of intraclast breccia overlain by stromatolitic dolomite. Two thin sandstone horizons are present in the lower Irregully Formation, which also contains local evaporite pseudomorphs. South of the Talga Fault, the Irregully Formation thickens considerably, and is dominated by thick subtidal cycles of intraclast breccia and dololutite, with rare stromatolites. This facies passes southward into interbedded dololutite, dolomitic siltstone, and sandstone. The upper Irregully Formation is characterized by interbedded shallow-marine sandstone and stromatolitic dolomite on southern EDMUND. Fluvial to shallow-marine siliciclastic facies, with minor dololutite, dominate the Irregully Formation around the western margin of the Gifford Creek Complex.

Gross similarities in stratigraphy, structure, and regional geology between the Jillawarra sub-basin and southwest EDMUND (Table 1) suggest that the latter area has potential for Abra-style polymetallic mineralization. Facies and thickness changes within the Irregully Formation in this area suggest the presence of a fault-bounded sub-basin north of the Mangaroon Syncline and south of the Talga Fault. Sedimentation within this sub-basin was strongly controlled by uplift of adjacent basement inliers, and coincided with minor felsic and carbonatite magmatism within them.

* Capitalized names refer to standard 1:250 000 map sheets

Table 1: Comparison between ore controls in the Jillawarra sub-basin and equivalent areas on southwest EDMUND

Geological control	*Jillawarra sub-basin*	*Southwest EDMUND*
lithostratigraphic units	Gap Well and West Creek Formations	Irregully Formation
lithology	mixed siliciclastic–carbonate succession	mixed siliciclastic–carbonate succession
faulting	Quartzite Well and West Creek Faults, east–west graben	Talga Fault, possible northwest–southeast graben
associated basement highs	Woodlands and Coobarra Domes	Henry–Telfer dome and Gifford Creek Complex
syndepositional magmatism	Tangadee rhyolite	granophyre plugs and alkaline intrusives
potential source rock	arkose (Tringadee Formation)	immature sandstone (basal Yilgatherra Formation)
alteration	chlorite–siderite	?
ore minerals	galena, chalcopyrite, barite, tetrahedrite, sphalerite	?
gangue minerals	hematite, magnetite, carbonate, pyrite, quartz, jaspilite	?

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Stratigraphy, tectonic evolution, and mineral potential of the Earaheedy Basin

by

J. A. Jones, F. Pirajno, and R. M. Hocking

The Palaeoproterozoic Earaheedy Basin contains the Earaheedy Group, and lies at the eastern end of the Capricorn Orogen (Tyler et al., 1998). Recent geological mapping has led to a revision of the stratigraphy (Fig. 1), the development of a new model for basin evolution, and a better understanding of the potential for mineralization. Basement to the Earaheedy Basin is the Archaean Yilgarn Craton, and to the west the early Palaeoproterozoic Yerrida Basin. The Earaheedy Basin is interpreted to have been much larger than its present-day exposure, extending farther to the southwest and to the north, where it is masked by the overlying Bangemall and Officer Basins. The preserved exposure of the basin forms an east-plunging open syncline. The northern limb of this syncline is deformed, forming the Stanley Fold Belt. Deformation decreases southward.

Regional stratigraphic relationships indicate that the Earaheedy Basin is younger than the Yerrida Basin (2200 Ma; Woodhead and Hergt, 1997) and older than the Bangemall Basin (1650 Ma; Nelson, 1995), and that it appears to be unaffected by the 1800 Ma Capricorn Orogeny. Poor age constraints hinder more accurate placement of the basin within the regional framework. Isotopic ages for Earaheedy Group sedimentary rocks and mineralization in the basin cluster around 1800–1700 Ma.

The Earaheedy Group (Fig. 1) is a 5 km-thick package of shallow marine clastic and chemical sedimentary rocks that has been divided into two subgroups. The Tooloo Subgroup consists of the Yelma Formation (base), Frere Formation, and Windidda Formation (top). The overlying Miningarra Subgroup consists of the Chiall Formation (base), Wongawol Formation, Kulele Limestone, and Mulgarra Sandstone (top).

The Yelma Formation contains shale, sandstone and carbonate that were deposited in shallow-marine and locally fluvial environments. In the southwest of the basin, Mississippi Valley-type Pb–Zn–Cu mineralization occurs in an approximately 100 m-thick carbonate facies, the Sweetwaters Well Member. The overlying Frere Formation records the onset of the precipitation of Fe oxides within the basin, and consists of granular iron formation separated by two major shale bands, and minor carbonate. The granular iron formation beds probably formed in the shallow waters of a continental shelf. Ferruginous peloids accreted in wave- and current-agitated iron-rich waters (Beukes and Klein, 1992), and were deposited after some reworking by mechanical processes, with variable terrigenous contamination. The overlying Windidda Formation consists of shale, locally stromatolitic carbonate, minor jasperoidal beds and granular iron formation. The finely laminated shale in the Windidda Formation, in the north and southwest of the Earaheedy Basin, is separated as the Karri Karri Member (Fig. 1). The Windidda Formation is interpreted to represent a carbonate shelf in the southeast, grading northwards to the quiet water deposition of the Karri Karri Member.

The Chiall Formation combines, as members, the former Wandiwarra Formation and Princess Ranges Quartzite. The Chiall Formation consists of shale, siltstone, and mudstone intercalated with thick sandstone beds and intraclastic breccia. The formation is the product of a change from combined chemical and clastic deposition to dominantly clastic deposition. At the base of the formation in the southeast, a breccia of poorly sorted, angular carbonate clasts in a glauconitic sandstone matrix is interpreted as a hardground, which records the rapid drowning and cementation of the carbonate platform of the Windidda Formation with minimal sedimentation. Sedimentary structures and palaeocurrent data indicate a tidal environment in the southeast, deepening northwards to below fair-weather wave base.

The Wongawol Formation consists of shale, siltstone to very fine grained sandstone, intraclastic breccia, and carbonate–glauconite breccia. Deposition was in a very shallow, locally emergent environment, with periods of minimal sedimentation. The Kulele Limestone is a cyclic platform carbonate succession, consisting of carbonate units which are separated by shale and sandstone. Carbonate units are stromatolitic, oolitic, and pisolitic, with individual stromatolites up to 3 m high and 4 m wide. Compared with the Wongawol Formation, the basin deepened slightly and had less terrigenous influx. At the top of the succession, the Mulgarra Sandstone consists of

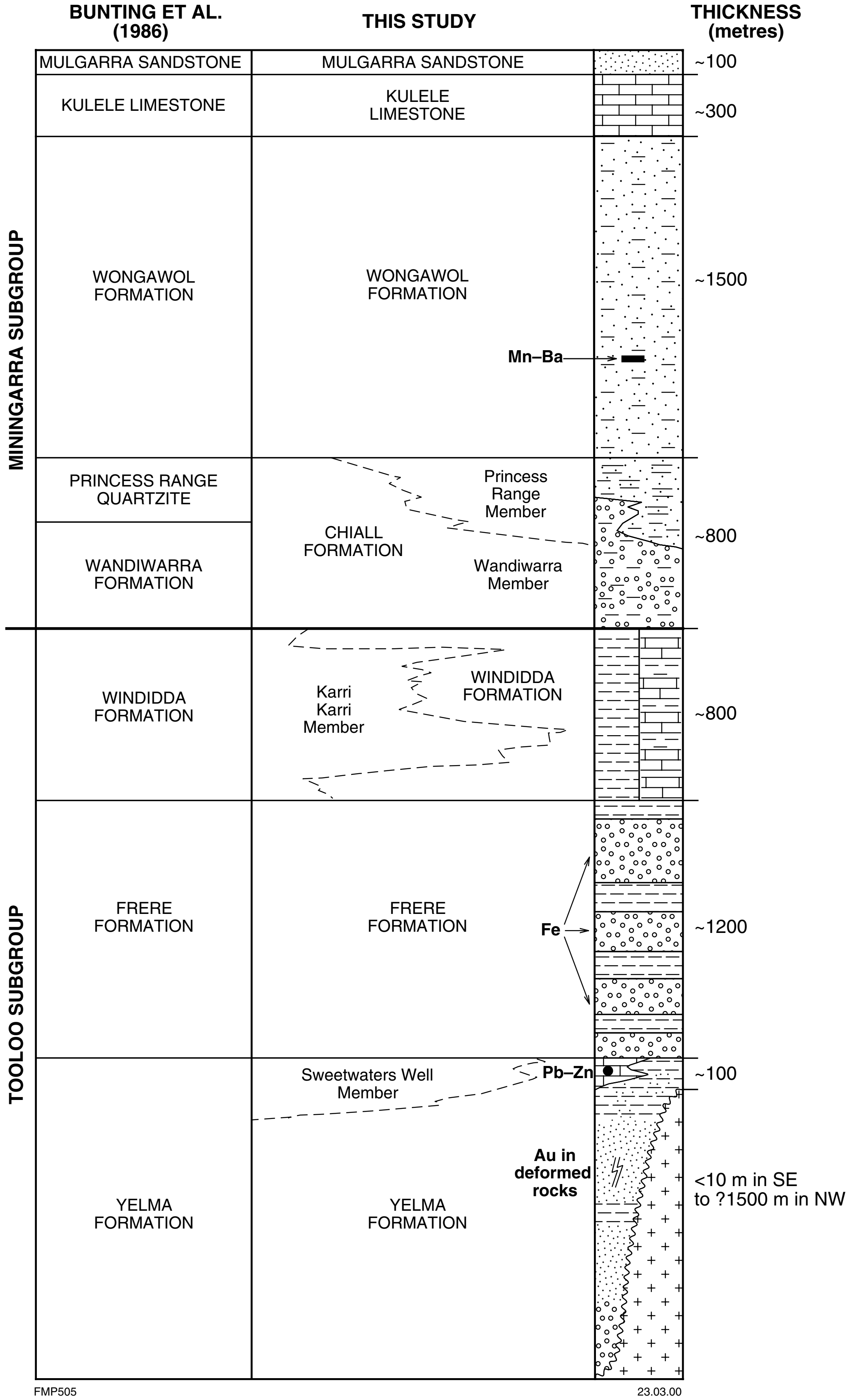

Figure 1. Stratigraphy, broad lithology, and mineralization of the Earaheedy Group

sandstone, shale and minor carbonate, and may reflect a final stage of terrigenous influx and tectonism.

The exposed Earaheedy Group is characterized by a shallow-marine to coastal depositional setting, with a shoreline to the south and southeast, and deepening towards the north. This is consistent with models of granular iron formation being the shallow-water facies equivalent of deeper water banded iron-formation (Beukes and Klein, 1992).

Known mineralization in the Earaheedy Basin consists of MVT Pb–Zn–Cu deposits in the Sweetwaters Well Member, near the Shoemaker Impact Structure. Sphalerite, galena, pyrite, and chalcopyrite occur largely as fracture fill, vug fill, or carbonate replacement. The large (>200 Mt) Magellan Pb deposit is hosted by outliers of the Yelma Formation overlying the Yerrida Group. Minor stratiform Mn and Fe oxides are present within the shale units of the Windidda Formation. These stratiform oxides contain anomalous abundances of Cu, Ba, and Pb, thus enhancing the prospectivity of the Earaheedy Basin for stratabound Cu of the Kupferschiefer type. Gold mineralization is present in the deformed Stanley Fold Belt (the presently exposed northern margin of the Earaheedy Group) where it is associated with mylonite and quartz veins.

Any tectonic model for the inception and evolution of the Earaheedy Basin is hindered by poor age constraints. However, on the basis of current field work we envisage that the basin was part of a rifted continental margin in the northeast of the Yilgarn Craton. Compressive movements, perhaps associated with the collision with the North Australian plate, formed the Stanley Fold Belt. Only the southern shelf portion of the continental margin is now exposed. A mid-ocean ridge, which was probably located some distance north of the presently exposed margin and east of the Pilbara Craton, provided the source of dissolved iron for Frere Formation deposition.

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The Woodleigh impact structure

by

R. P. Iasky and A. J. Mory

The Woodleigh structure is a newly discovered, buried, multi-ring impact feature, approximately 120 km in diameter on the Gascoyne Platform of the Southern Carnarvon Basin. The centre of the structure lies on Woodleigh Station (after which it is named) approximately 160 km south-southeast of Carnarvon and directly east of Hamelin Pool in Shark Bay (Fig. 1).

The structure was first identified as an impact crater in late 1997 during a geological review of the Gascoyne Platform (Iasky and Mory, 1999). Shallow granitic rocks in the Woodleigh 1981/2 drillhole (Layton and Associates, 1981) coincide with the centre of a circular gravity anomaly. Initial modelling showed that the granite in Woodleigh 1981/2 has lower density than the average crystalline basement, indicating the possibility of an impact structure. In addition, photomicrographs of cuttings samples of the granite in the Woodleigh 1981/2 well completion report showed possible planar deformation features (PDF) typical of shock metamorphism. Unfortunately, all of the original samples had been lost or destroyed, so the Geological Survey deepened the original hole in March 1999 (GSWA Woodleigh 1) to verify the impact interpretation. The granite core shows extremely well preserved shock-metamorphic features including thin veins of melted glass (pseudotachylite), breccia, and PDFs, thereby providing indisputable evidence of an impact origin. Subsequently, a second corehole (GSWA Woodleigh 2A) was drilled 13 km to the west of the first to sample the crater-infill section.

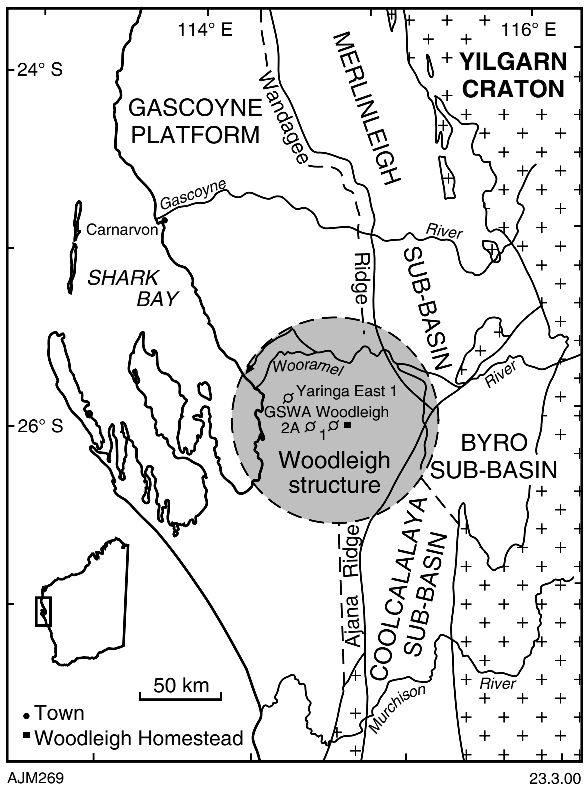

Figure 1. Geographic location and structural sketch map of Woodleigh impact structure, southern Carnarvon Basin, Western Australia

The structure is most clearly shown on the first vertical derivative of the Bouguer gravity as a series of annular ridges and troughs (Fig. 2). The central gravity 'high', approximately 25 km in diameter, is interpreted as the central uplift of the impact. The adjacent gravity 'trough' probably corresponds to a ring syncline filled with the breccia seen in GSWA Woodleigh 2A. Both of the northerly trending Ajana and Wandagee Ridges apparently terminate against the structure 60 km from its centre. In the southeast, the outermost ring is cut by the Madeline Fault, which separates the crater area from the Byro and Coolcalalaya Sub-basins. The outermost ring is not discernable within Shark Bay, where there are no gravity data.

Core from GSWA Woodleigh 1 indicates that the impact shock reduced the density of the basement. The lower density granite was modelled to a depth of about 2.5 km, and a width of about 3.5 km (Fig. 3). The adjacent lower density layer, however, can be interpreted as either highly brecciated low-density basement (making the central uplift area about 20 km across), or as low-density sedimentary rock. The gravity model shows broad folds that decrease in amplitude with increasing distance from the centre. East of the Madeline Fault, the structural style consists of tilted fault-blocks, quite distinct from the style

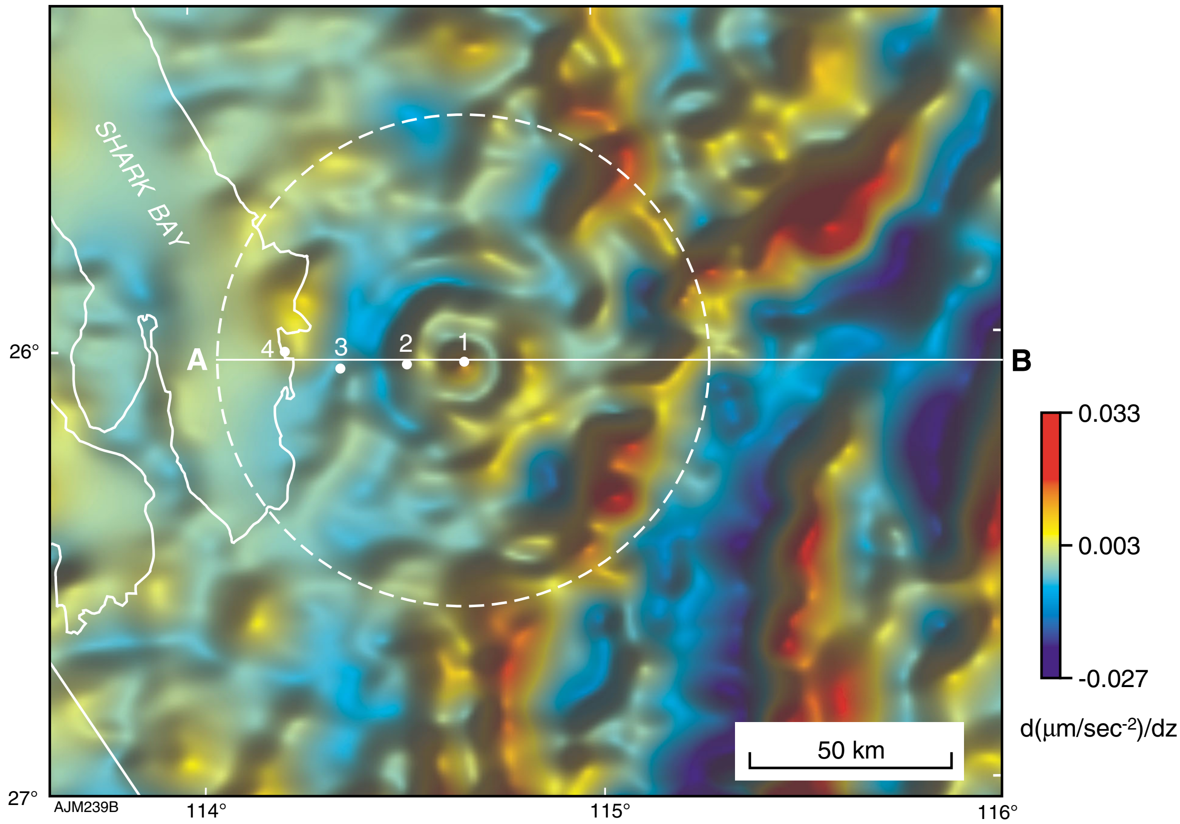

Figure 2. First vertical derivative of Bouguer gravity image of the Woodleigh structure. Illuminated from southeast. 1 = GSWA Woodleigh 1, 2 = GSWA Woodleigh 2A, 3 = Yaringa 1, 4 = Hamelin Pool 1

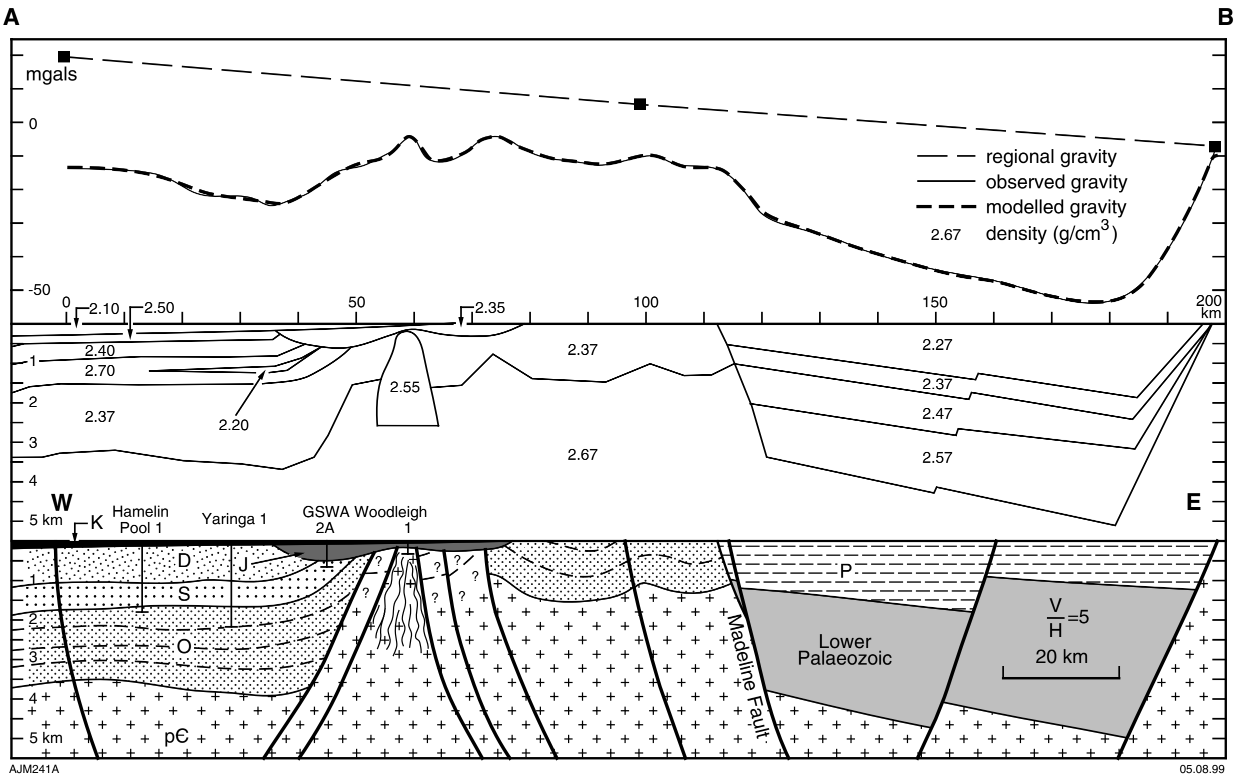

Figure 3. East–west gravity model and cross section through the Woodleigh structure. Section A–B in Figure 2. The thin Cretaceous cover is not represented in the cross section. Densities used in the model are from core and well logs in the region. K = Cretaceous, J = Jurassic, P = Permian, D = Devonian, S = Silurian, p€ = Precambrian, ? = Silurian or low-density brecciated Precambrian. Line of section shown on Figure 1

of deformation to the west. An east–west seismic section supports the gravity model by showing a change in structural style across the Madeline Fault. To the west of the fault, chaotic reflections are due to extensive brecciation and faulting associated with the impact. At about 25 km west of the centre of the structure, however, there are curved reflections that correspond to a gravity ridge (Fig. 2). The gravity and seismic data indicate that the Woodleigh structure is asymmetric in the east–west direction, with basement east of the central peak being about 2 km shallower than to the west. The asymmetry is interpreted as tilting during the Early Cretaceous deformation of the Gascoyne Platform (Iasky and Mory, 1999).

In contrast with other impact structures such as Chicxulub, Gulf of Mexico (Sharpton et al., 1996), the only significant magnetic anomaly detected from the BMR aeromagnetic survey (1956–1961 vintage) is an arcuate anomaly along the eastern outer margin of the structure. This anomaly is coincident with the outermost gravity ring about 60 km from the centre of the structure. Modelling of the arcuate anomaly indicates that it originates from a depth of about 5 km. The anomaly closely coincides with a drainage divide and overlapping creek system implying re-activation of the boundary ring fault, possibly during the Miocene compressive event documented elsewhere in the region (Iasky and Mory, 1999).

A comparison of ground magnetic with the BMR aeromagnetic data along an east–west traverse between GSWA Woodleigh 1 and 2A shows that a ground magnetic anomaly in the centre of the structure was only partially detected by the BMR aeromagnetic survey. The BMR survey was flown at 150 m with traverses spaced at 1600 m, and much of the signal is lost or smoothed by the gridding process. A modern high-resolution aeromagnetic survey should resolve the magnetic anomaly in the centre, and also along the edge, of the structure.

Initial studies constrain the age of the Woodleigh impact to between Early Permian and Early Jurassic (290–200 Ma). The Lower Jurassic lacustrine crater-infill (Woodleigh Formation) defines the younger age limit of the impact. At present the older age limit is constrained by shale clasts containing Early Permian palynomorphs from the basal 8 m of the Woodleigh Formation in GSWA Woodleigh 2A. On presently available data the re-worked Lower Permian clasts were sourced from the Byro or Coolcalalaya Sub-basins, over 55 km from the centre of the structure. However, the presence of Lower Permian strata within the upper part of the structure that was eroded in pre-Jurassic times cannot be excluded. Isotope dating of the shock-metamorphosed gneiss recovered by GSWA Woodleigh 1, has yet to conclusively determine the age of impact. Although a regional thermal event identified by apatite fission track at 280–250 Ma hints at an age close to the Permian–Triassic boundary, the lack of Triassic fossils in the crater fill favours a younger age.

With an estimated diameter of 120 km, the Woodleigh impact structure is the largest found in Australia and the fourth largest in the world after Vradefort, South Africa (300 km), Sudbury, Canada (250 km), and Chicxulub (170 km). To date, a total of 160 terrestrial impact structures have been recognized, of which 26 are in Australia. The size of the Woodleigh impact structure suggests that it may have had a significant role in the tectonic evolution of the Southern Carnarvon Basin — if the hypothesis that large impacts may trigger tectonism (Hughs et al., 1977; Jones, 1987) is accepted. Apart from such tectonic implications, an impact of this size would have caused catastrophic environmental effects that, on the present dating of Woodleigh, may correlate with the end of Triassic or end of Permian mass extinctions.

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Regolith geochemistry in sand-dominated terrain: a case study of the Ajana 1:250 000 sheet

by

A. J. Sanders

The Geological Survey of Western Australia (GSWA) regolith geochemical mapping program provides information on the distribution and composition of regolith to assist bedrock mapping, and to stimulate mineral exploration. This program, which has largely focused on the Yilgarn Craton and adjacent Proterozoic basins, has established a simple relationship between bedrock composition and regolith geochemistry. Recently, the program has included Phanerozoic basins, where limited outcrop and extensive sand and vegetation cover create new challenges in interpreting regolith geochemistry. Despite this, some encouraging results were obtained that are applicable to sampling in sand-dominated terrains elsewhere in Western Australia.

The AJANA 1:250 000 sheet (Fig. 1) includes parts of the Archaean Yilgarn Craton, Proterozoic rocks of Badgeradda Group, Nilling Formation and Northampton Complex, and Phanerozoic rocks of the Coolcalalaya Sub-basin and Southern Carnarvon Basin (Myers and Hocking, 1998). Regolith and regolith geochemical mapping of AJANA was based on regolith characteristics and sampling of regolith at 820 sites at a nominal density of one sample per 16 km^2. The <2mm fraction of the sample was subsequently analysed for 48 elements by a commercial laboratory.

A regolith-materials map was produced using Landsat imagery, aerial photography, synthetic Landsat stereopairs, and sample-site descriptions. Sand-dominated regolith, which accounts for 65% of all regolith on AJANA, was divided into eleven types, based on lithology and geomorphology. Vegetation patterns, in conjunction with periodic fire scarring (resulting in soil destabilization) and recent faulting may have influenced the morphology of some of these sandplain units. In some coastal areas, the sandplain types reflect coastal processes, with significant dune development. Many sandplain subdivisions can be distinguished by subtle chemical variations, suggesting that sandplain chemistry is controlled by several factors, including sand stability, coastal and eolian processes, and the nature of the underlying lithology (Sanders and McGuinness, in press). A simplified version of the regolith-materials map is produced in Figure 2.

Owing to the predominance of quartz sand, many analytes are diluted by SiO_2 and variations in the chemistry of the sandplain are subtle. In the northwest of AJANA, P_2O_5 values in regolith are higher over areas of relatively stable undulating sandplain, whereas lower values are encountered over adjoining depressions and drainage areas, typically dominated by net-like dune systems. The higher P_2O_5 values in the more stable sandplain probably relate to the presence and reworking of underlying carbonates. This area also contains some of the highest Zr values in regolith for the map sheet. As samples containing high Zr are found in zones parallel to the coast, are continuous across numerous regolith types, and are progressively depleted in an easterly direction, it is proposed that the high Zr values represent concentrations of heavy mineral sands enriched by coastal processes (Sanders and McGuinness, in press).

To test the hypothesis that many of the sandplain units on AJANA are chemically different, k-means cluster analysis was undertaken to divide the samples into several chemically distinct groups (Rock, 1988). This approach shows that most of the map sheet is covered with quartz-rich sandplain, although along the coast, the higher SiO_2 concentrations have given way to more carbonate-rich material (Fig. 1). Some of these coastal areas include the highest levels of resistate phases in regolith, including such detrital minerals as rutile, ilmenite, monazite, sphene and zircon. Heavy mineral concentrates constitute up to 4% in some samples. These have probably been derived from the Northampton Complex and Yilgarn Craton and transported by the Murchison River and concentrated by eolian processes, along palaeoshorelines, or in the mouth of a proto-Murchison River (Sanders and McGuinness, in press; Harrison, 1985).

There may be evidence of base metal mineralization in the sand-dominated environment but this requires more detailed work involving low-level detection of pathfinder elements.

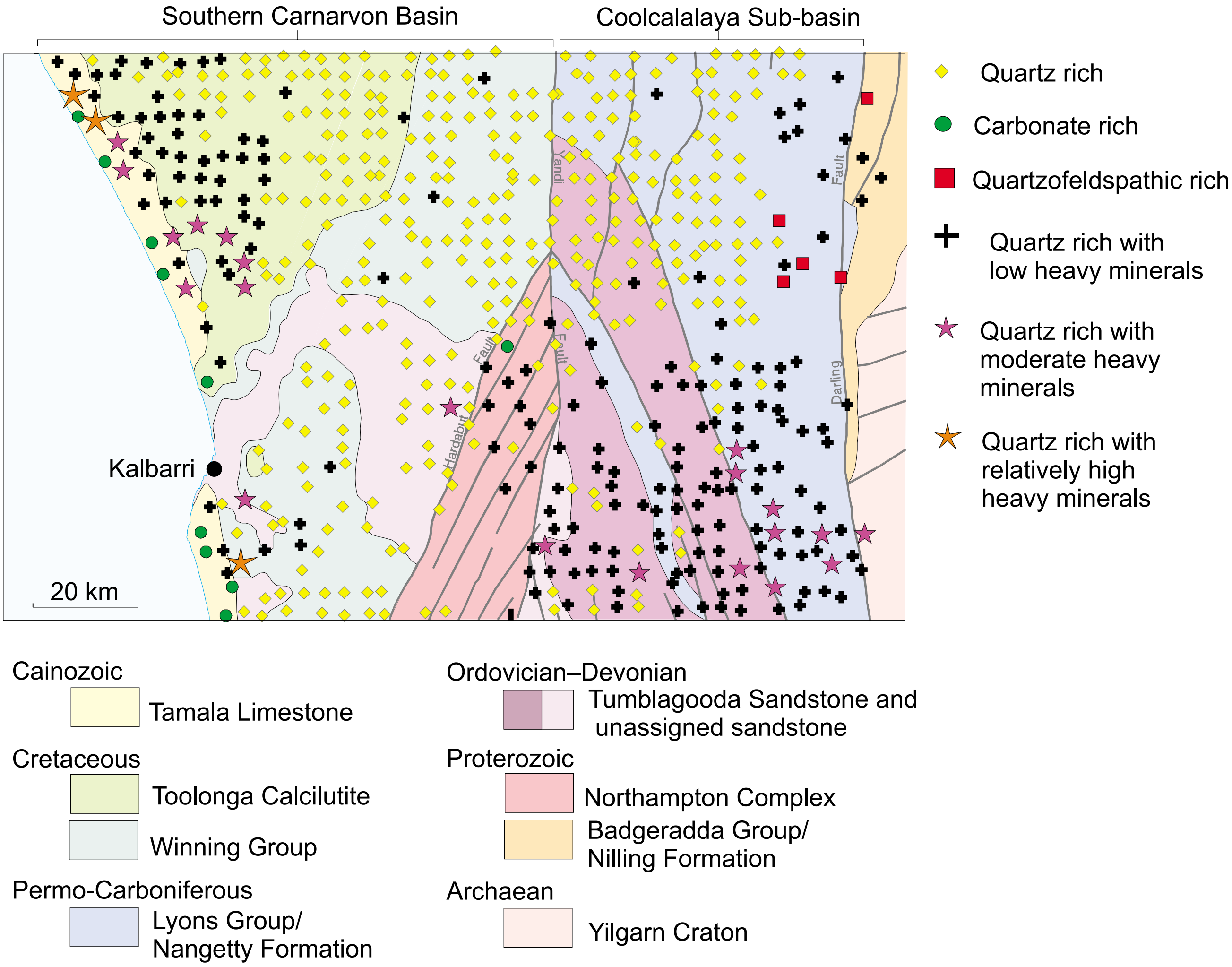

Figure 1. Simplified geology and classification of sand composition after k-means cluster analysis

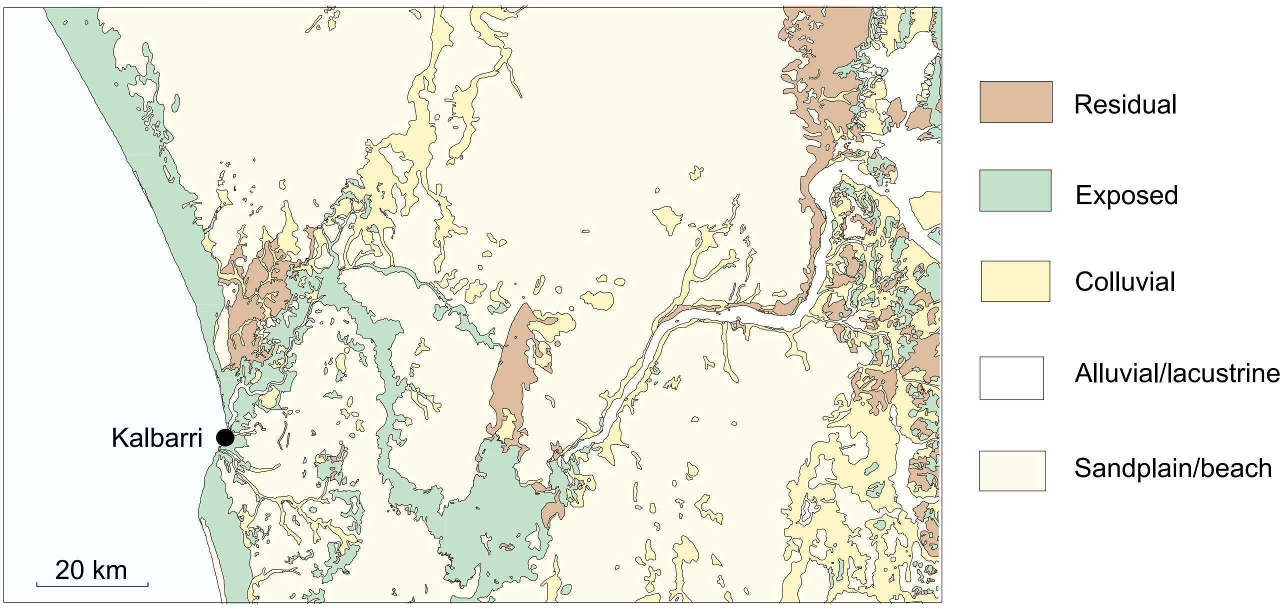

Figure 2. Simplified regolith highlighting the dominance of sandplain on AJANA

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Open-file mineral exploration data in a digital world

by

M. J. Ellis

WAMEX *via the Web*

The Western Australian Department of Minerals and Energy (DME) is custodian of mineral exploration data submitted by tenement holders. The WAMEX database is the means by which the information within these reports is managed and retrieved.

The WAMEX database had previously been accessible to public users in the Department library, its Kalgoorlie office or by remote access (after registration) using emulator software. The user needed to be familiar with the terminology used in the database to conduct a successful search.

In 1999, a web-browser front end named 'WAMEX *via the Web*' was created to provide more user-friendly, intuitive access to the WAMEX database. This front end caters for the most common search parameters that the majority of customers use to find open-file exploration information. Users are not required to register and the database can be found by clicking on 'Computer Databases' and then 'WAMEX' in the DME web site at www.dme.wa.gov.au.

Searches can be conducted using any of the seven parameters on the search screen. These searchable parameters are:

- Area – 1:250 000 and 1:100 000 map sheets
- Tectonic units
- Target commodities
- Keywords
- Company names
- Tenement number
- WAMEX Item numbers

The value to be searched is selected from the drop-down lists which are attached to most of the fields. A maximum of three values can be selected in most fields. However, as boolean 'OR' operators are the defaults within each field, the greater the number of selections made within the same field, the broader will be the search result. The search result is narrowed by including values from another field, as the default boolean operators between fields are 'AND' operators.

The results of the search are displayed on the second screen and consist of a listing of projects with the WAMEX 'I' number and the duration of the project. The project title can be selected by clicking on it to bring up the third screen in the search results sequence. The third screen displays the following details of the project and reports:

- Item no. (including details of number of volumes, fiche, and release date)
- Project title
- Project reporting period
- Companies
- Commodities
- Map sheets
- Tectonic units
- Annotation (since Item 9800 includes abstracts for individual reports)
- Keywords
- Mineralization
- Assays (elements assayed)
- Remarks
- Map codes
- Tenements
- Prospects/localities

Further information about the individual reports which make up the project reporting may also be obtained from the fourth screen. The details listed on this screen are:

- WAMEX 'A' number
- Number of volumes
- Company
- Type of report
- Tenements covered by the report
- Period of exploration covered by the report
- Prospect or location
- Date report written
- Structure of report

Scanned open-file reports

As well as improving access to the WAMEX database, the Department is now releasing open-file reports in a digital medium.

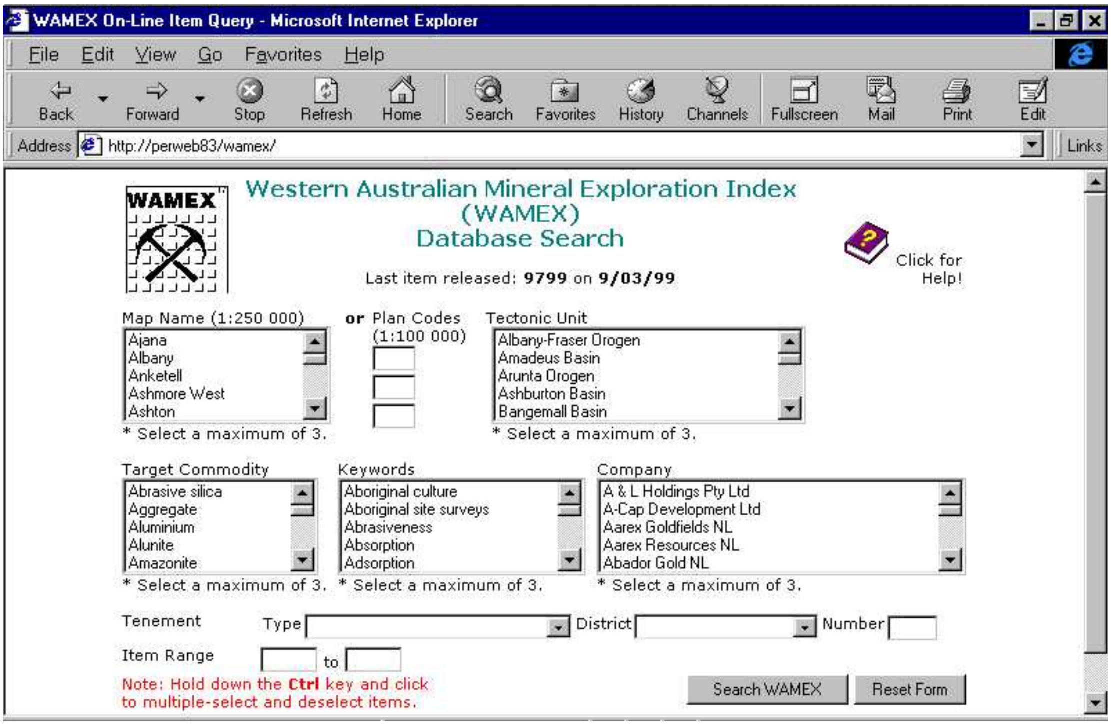

Figure 1. Main search screen for WAMEX *via the Web*

Until mid-1999, open-file reports were released as microfiche. These fiche could be viewed at various Departmental offices or purchased if customers had access to microfiche-viewing facilities.

In 1999, standards for 'dumb' (non-optical character recognition) scanning of reports were developed and over 1200 reports representing 364 WAMEX 'items' that were due for release to open file were scanned by a number of contractors.

The hardcopy reports are scanned at 200 dpi resolution and written to CDRoms as Adobe PDF™ files. This format can be read using Adobe Acrobat™, a freely available viewing tool widely used for viewing documents incorporating graphics on the World Wide Web.

Originals up to A3 in size are scanned, when necessary in colour, whereas A2 and larger plans are scanned in grey scales only. 'Thumbnails' of all pages and plans within a report are constructed so that customers can rapidly navigate through large reports.

In addition, any geochemistry, drilling logs or geophysical data (apart from regional aeromagnetic data) that were submitted in digital form with hard-copy reports are 'zipped-up' with the scanned copy of the relevant report. The reports are then zipped up with other open-file reports from the same project to form a file which is indexed with the WAMEX 'I' number of the project.

Adoption of the Adobe PDF™ for release of scanned reports is consistent with the recently released 'Requirements For The Submission Of Mineral Exploration Data In Digital Format' that call for voluntary submission of exploration reports to DME in PDF™.

Because of the average large file size, it is not possible at this stage to make scanned reports available over the World Wide Web. The Department has appointed a panel of agents who have the ability to reproduce the scanned reports in the medium required by the customer. In addition, scanned reports are also available for viewing in the DME Library and at the Geological Survey of Western Australia (GSWA) Kalgoorlie Office.

By adopting a strategy of scanning legacy statutory reports as they go onto open file, and releasing guidelines to accept new reports in digital form, GSWA is using a two-pronged attack on the issue of improved access to statutory data. These two strategies, combined with WAMEX *via the Web*, represent a significant advance in service provided to mineral exploration geologists, both in Western Australia and elsewhere. Improved access to quality exploration data helps to promote Western Australia's prospectivity and reduces risk involved in exploration investment.

With changes in Internet communications technology, GSWA hopes that it will be possible in the medium term to deliver statutory data to customers via the World Wide Web.

Tectonic evolution and mineralization of the east Kimberley

by

S. Sheppard and L. Y. Hassan

Regional geological mapping of the Halls Creek Orogen in the east Kimberley region was carried out by the Geological Survey of Western Australia (GSWA) and the Australian Geological Survey Organisation (AGSO) between 1990 and 1995. The mapping has resulted in substantial revision of the stratigraphy and tectonic units that make up the Halls Creek Orogen (Tyler, 2000). To augment the geological mapping, a study of the mineralization of the orogen was also undertaken (Sanders, 1999). More recently, further work has been undertaken so as to provide industry with a data package on CD-ROM, comprising digital spatial indexes for exploration activities and all known mineral occurrences, along with a report and a map (Hassan, in prep.). The data package enables the spatial distribution of mineralization to be analyzed within the framework of the revised stratigraphy and new tectonic model for the Halls Creek Orogen; the package also includes parts of the King Leopold Orogen and the Granites–Tanami Complex.

The Halls Creek Orogen developed between the Kimberley Craton to the northwest and the North Australian Craton to the southeast. The orogen formed in the Palaeoproterozoic, but it also records a long history of intermittent reactivation until the end of the Palaeozoic. The orogen comprises the Palaeoproterozoic Lamboo Complex, the deformed margins of the Palaeoproterozoic Speewah and Kimberley Basins and their correlatives, and the deformed elements of a number of Mesoproterozoic, Neoproterozoic, and Palaeozoic sedimentary basins.

The Lamboo Complex includes all the deformed and metamorphosed plutonic, volcanic, and sedimentary rocks formed between c. 1910 and c. 1790 Ma, and is divided into three north-northeasterly trending zones: the Western, Central, and Eastern zones (Fig. 1). The zones are bounded by major fault systems, and each zone has a unique geological history: the zones probably represent terranes (Tyler et al., 1995). The presence of terranes, and the different geophysical nature of the crust on either side of the Lamboo Complex (Shaw et al., in press), indicates that it contains a Palaeoproterozoic plate margin. The three zones were probably brought into their current positions by a combination of subduction and large-scale strike-slip faulting (Tyler et al., 1995; Sheppard et al., 1999).

The Western zone of the Lamboo Complex is a continuation of the Hooper Complex in the King Leopold Orogen in the west Kimberley. The Western zone is dominated by the felsic volcanic rocks of the 1865–1850 Ma Whitewater Volcanics and cogenetic granites of the Paperbark supersuite. These felsic rocks were accompanied by unlayered mafic intrusions, and layered mafic–ultramafic intrusions. The mafic and felsic igneous rocks were probably emplaced following accretion of a continental fragment(s) to the eastern edge of the Kimberley Craton sometime before c. 1900 Ma (Griffin et al., in press).

In the Central zone, mafic volcanics, volcaniclastics, and turbidites of the c. 1865 Ma Tickalara Metamorphics may represent either an oceanic arc fringing the Kimberley Craton above a new southeasterly dipping subduction zone, or a basin along the margin of the craton above a northwesterly dipping subduction zone/strike-slip plate margin (Sheppard et al., 1999). The rocks were deformed and metamorphosed at medium to high grade and intruded by sheets of tonalite at 1850–1845 Ma. Mafic and felsic volcanic rocks, and sedimentary rocks, of the c. 1841 Ma Koongie Park Formation were deposited in a basin associated with extension behind the convergent/strike-slip plate margin. The Koongie Park Formation is coeval with the Sally Malay layered mafic–ultramafic intrusions (Hoatson and Blake, in press).

The Eastern zone consists of siliciclastic sedimentary rocks, and mafic and alkaline volcanic rocks of the Halls Creek Group. These were deposited between c. 1880 and c. 1845 Ma on a substrate of continental crust. The Halls Creek Group preserves a record of deposition on a passive continental margin (Sheppard et al., 1999). These rocks were first deformed between c. 1820 and c. 1810 Ma during the Halls Creek Orogeny.

Siliciclastic rocks of the Speewah Group were deposited unconformably on the Western zone at c. 1835 Ma. Voluminous granite plutons of the

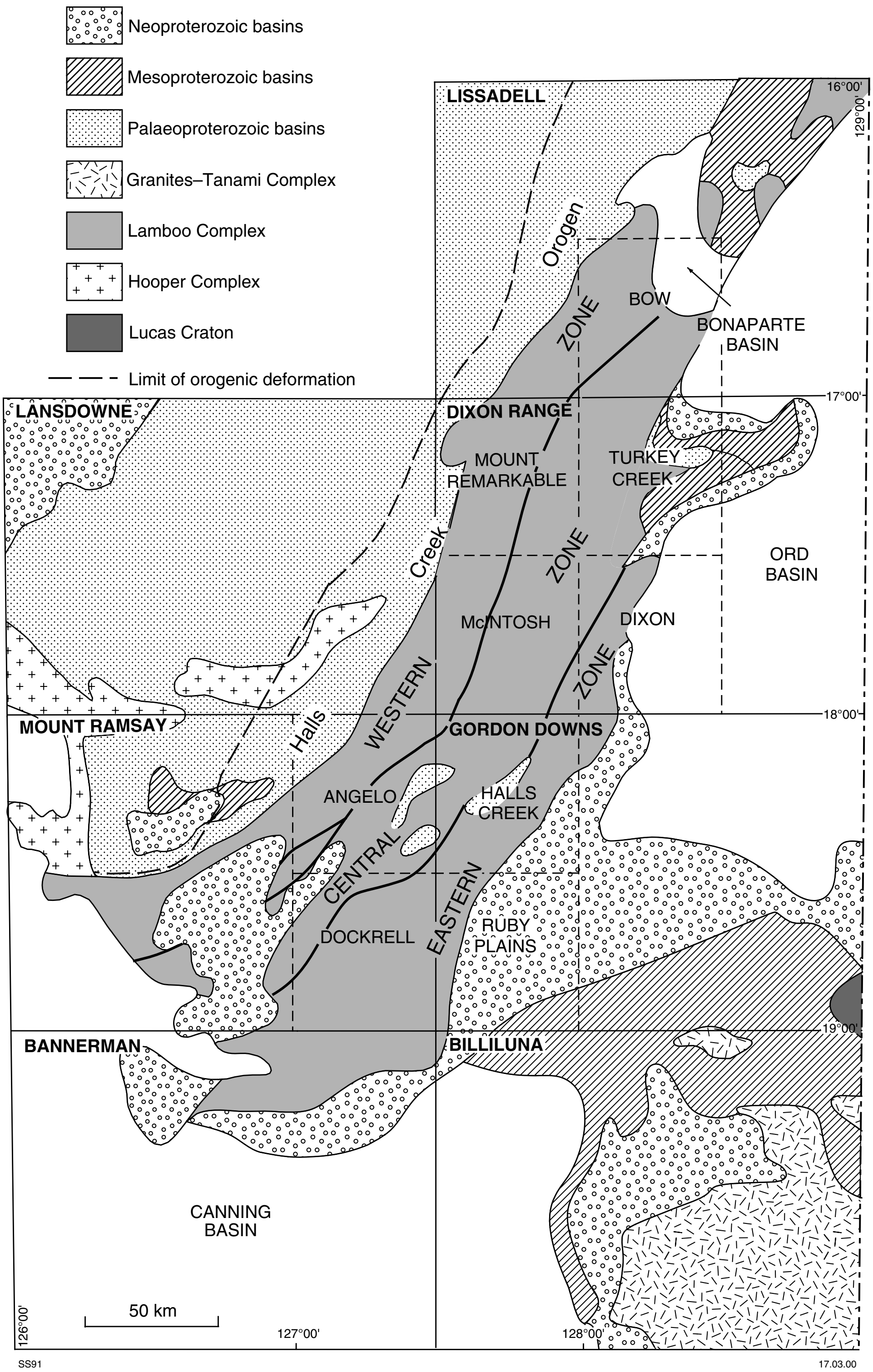

Figure 1. Location of published 1:100 000 and 1:250 000 map sheets in the east Kimberley and their relationship to major tectonic units. Also shown are the three zones that form the Lamboo Complex

1835–1805 Ma Sally Downs supersuite mainly intruded the Central zone during deformation and medium- to low-grade regional metamorphism of the Halls Creek Orogeny, which marked the amalgamation of the Eastern zone with the combined Western and Central zones. Between 1805 and 1790 Ma, the southern end of the Lamboo Complex was intruded by granites of the San Sou suite, which may represent an extension of granite plutonism in the Granites–Tanami Complex (Page and Sun, 1994).

The Speewah Group and Lamboo Complex are overlain by siliciclastic sedimentary rocks and mafic volcanic rocks of the Kimberley Group. Siliciclastic rocks of the Texas Downs, Revolver Creek, and Red Rock Formations were probably deposited at the same time as the Kimberley Group. The Kimberley Group was intruded at c. 1790 Ma by voluminous dolerite sills of the Hart Dolerite. Thus, deposition of the Kimberley Group and intrusion of the Hart Dolerite is coeval with the end stages of granite intrusion in the southern Lamboo Complex.

The majority of the over 1330 mineral occurrences documented in the east Kimberley are hosted in rocks of the Lamboo Complex (Hassan, in prep.). A range of mineralization styles, including orthomagmatic PGE–Cr–Ni–Cu–Ti–V, volcanic-hosted massive sulfide (VMS) Cu–Pb–Zn and REE–Ta, vein and hydrothermal Au, base metals, and U, and pegmatite and stratabound W–Sn–Ta have been recognized.

Vein and hydrothermal gold occurrences are concentrated in the Eastern zone of the Lamboo Complex. Many of these occurrences form a northeasterly trend, roughly parallel to the boundary with the Central zone. Most occurrences are hosted in the Biscay Formation. However, a substantial number also occur near the contact between the Biscay Formation and the overlying Olympio Formation, or in alkaline volcanic rocks in the lower part of the Olympio Formation. The gold mineralization has no apparent association with granite intrusions, and instead, gold may have been derived from the mafic and alkaline volcanic rocks during the 400–300 Ma Alice Springs Orogeny (Warren, 1994). There are a few vein and hydrothermal gold occurrences in the Central and Western zones. Of those in the Western zone, some Au(–U) occurrences in the Whitewater Volcanics have quartz-vein textures typical of epithermal deposits.

Significant vein and hydrothermal gold deposits are present in the Palaeoproterozoic Granites–Tanami Complex; the most important of these are the Coyote and Kookaburra prospects. Vein and hydrothermal unconformity-type U–Au mineralization is also hosted in shears and graphitic sedimentary rocks of the Killi Killi beds close to the unconformity with the overlying Mesoproterozoic Birrindudu Group.

In the Central zone of the Lamboo Complex, felsic volcanic rocks of the Koongie Park Formation contain volcanogenic massive sulfide (VMS) Zn–Pb–Cu–Ag(–Au) mineralization. The Mount Angelo Granite, which is probably petrogenetically related to these felsic volcanic rocks, hosts porphyry Cu–Mo(–Ag) mineralization. Felsic volcanic and chemical sedimentary rocks of the Biscay Formation are associated with exhalative volcanogenic Zn–Cu–Pb mineralization in the Eastern zone. Alkaline volcanic rocks of the Butchers Gully Member in the Eastern zone are host to REE–Ta mineralization at the Brockman prospect.

Orthomagmatic Cr–Ni–V–PGE mineralization is hosted by layered mafic–ultramafic intrusions in the Central zone and, to a lesser extent, the Western zone. Layered intrusions and hence this mineralization style, are absent from the Eastern zone.

Although most of the mineral occurrences in the east Kimberley are hosted in the Lamboo Complex, important mineral occurrences are associated with younger tectonic units. In the Speewah Basin, the Speewah Group and Hart Dolerite contain epithermal base metals, barite, and fluorite mineralization. The exact age of this mineralization is unclear, but it may be as young as Tertiary (Rogers, 1998). Devonian carbonates host base metal mineralization in the Canning Basin. Alkaline igneous intrusions of various ages are also host to significant mineralization. The Mesoproterozoic Argyle (AK1) lamproite pipe contains the world's largest diamond mine. The Neoproterozoic Cummins Range carbonatite has a large inferred resource of REE, and associated Nb and P mineralization.

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Quadrio Lake: we've found the barite, where are the sulfides?

by

R. M. Hocking and F. Pirajno

Barite–hematite mineralization is present at Quadrio Lake, 400 km northeast of Wiluna in the Oldham Inlier (northwestern Officer Basin). This mineralization occurs as veins containing anomalous gold, arsenic, and antimony with gold values up to 110 ppb. The mineralization is in the Quadrio Formation, a shale-dominated unit of probable Mesoproterozoic age in the Oldham Inlier that was previously part of the Cornelia Formation (see below). The Quadrio Formation probably correlates with the Edmund Group (Bangemall Basin) to the west, but may also correlate with the Throssell Group to the north.

The vein material is composed of barite and Fe oxides (mostly hematite) that form an easterly trending stockwork system. The veins cut siliciclastic rocks, mainly shale and siltstone, which are deformed into a local northwest-plunging upright anticline. The host rocks near the veins are silicified and exhibit silica-filled, multidirectional hairline fractures. These hairline fractures are probably the result of hydraulic fracturing due to high-pressure fluids. Scattered barite–hematite veins up to 30 cm across can be traced for at least 2 km towards the northwest, along the margins of Quadrio Lake. Core from the Trainor 1 drillhole, about 10 km to the northeast of Quadrio Lake, contains thin to hairline barite–hematite veinlets, locally associated with pyrite, in hydrothermally altered dark-grey shale. This rock unit is regarded as the Quadrio Formation, thus suggesting an extensive but northwards-waning mineralized area. Hydrothermal alteration in the core consists predominantly of disseminated carbonate porphyroblasts.

Results of analyses of three samples collected from the vein system are shown below. These samples were taken randomly, from barite-rich material. Gold, arsenic, and antimony show anomalous abundances and are shown in boldface.

Regional geological and geophysical data suggest that the stockwork system may be part of a larger mineralized system. A major change in magnetic character and structural orientation is recognizable about 15 km to the southwest, along the northern margin of the Oldham Range. This marks the boundary between the Oldham and Cornelia Sandstones and is a major fault, possibly a thrust, because of the stratigraphic relationships. No other change in magnetic character is present between the area in question and Trainor 1, or over Quadrio Lake. However, the Cornelia Sandstone occupies a gravity 'terrace', the northern boundary of which is just south of Phenoclast Hill, so another fault could be present south of the hill. A gravity low below Phenoclast Hill may represent a basement feature.

Table 1. Stratigraphy of the Oldham Inlier

Williams (1995) and earlier stratigraphy	*Hocking et al. (in prep.) stratigraphy*	*Lithology*	*Age, correlation*
Cornelia Formation	Oldham Sandstone	Silicified sandstone; moderately dipping	?1 – 1.2 Ga, ?Collier Group
	Quadrio Formation	**Shale, minor sandstone; subvertical.**	**?1.6 Ga, ?Edmund Group**
	Cornelia Sandstone	Intensely silicified sandstone; steeply dipping	?1.6 Ga, ?Edmund Group

Table 2. Selected trace element abundances of barite vein material

Sample No.	Au ppb	V ppm	Mn ppm	Ni ppm	Cu ppm	Zn ppm	As ppm	Mo ppm	Ag ppm	Sn ppm	Sb ppm	Ba wt%	W ppm	Pb ppm
161270A	***90***	24	200	50	64	11	***70***	2.2	<0.1	<0.1	***19.0***	***27.5***	0.7	24
161270A (repeat)	***110***													
161270B	***40***	26	125	6	82	19	42	0.9	<0.1	0.1	8.6	***39.0***	0.5	10
161270C	***80***	42	120	9	44	12	***80***	2.6	<0.1	0.2	***27.5***	***26.0***	1.1	16

NOTE: Analysis performed by Genalysis, Perth. Au analysis of sample 161270A was repeated by fire assay

An ore deposit model for the auriferous barite–hematite veins must consider the tectono-stratigraphic context of the region. The Ba±Au mineralization is epigenetic because it cross-cuts deformed sedimentary rocks. Two groups of mineralizing events and associated orogenies can be distinguished in the region (Fig. 1): one Palaeoproterozoic, associated with the Capricorn Orogeny (c. 1800 Ma); and a second, younger group (~ 700–600 Ma) between the Miles and Paterson Orogenies (Tyler et al., 1998). The Telfer gold mineralization is associated with this younger event. The Quadrio Lake mineralization, being epigenetic, is younger than 1600 Ma. Since there is no recorded mineralizing event between 1600 and 800 Ma, the Quadrio Lake barite is probably related to the event that produced the Telfer gold and other metalliferous occurrences in the Throssell and Lamil Groups.

Barite deposits are generally grouped into those associated with continental margins in foreland basins, and those associated with intracratonic rifts (Maynard et al., 1995). In the latter, barite is commonly a distal facies to stratiform Pb and Zn deposits. The northwest Officer Basin is intracontinental, and thus conducive to SEDEX deposits. In our preferred model, there are three main facies associated with feeder channels: a vent complex, proximal stratabound sulfide ore, and distal stratabound sulfate and oxide ore. Mineralization can extend for hundreds of metres to tens of kilometres from feeder channels, and a halo of hydrothermal alteration (albite, chlorite, carbonate, and silica) surrounds the feeder channel.

The feeder channels most readily lie along structural breaks, such as faults or shear zones. The known and probable faults bounding the Cornelia Sandstone could be the structural controls and fluid channels for mineralization. A typical feeder channel is a vent complex, characterized by brecciated material cemented by sulfides. Sedimentary rocks lie above the feeder and form a stratabound/stratiform massive sulfide zone. In the general model, layers and stockworks of barite are present distal to the sulfide zone. The Quadrio Lake stockwork may be this distal zone. The presence of trace amounts of gold in the barite suggests that hydrothermal fluids carried gold and other metals in solution, most of which precipitated in sites closer to the venting structures. The 'spent' solutions always carry trace amounts of the main solutes, which in this case probably included gold, arsenic, and antimony. Interestingly, silica alteration is present around the barite veins, whilst carbonate alteration is present in the barite–sulfide mineralization detected in the Trainor core.

The Ward Inlier, to the northwest, is also prospective but has not been assessed. From aeromagnetic imagery, Landsat /SPOT images and existing mapping, the southern part of the Ward Inlier appears to be Oldham Sandstone, and the northern third, Quadrio Formation. If the Cornelia Sandstone is present, it is less extensive than in the Oldham Inlier.

The Quadrio Lake deposit is significant by itself because it is a signpost to possible SEDEX mineralization in the Oldham and Ward Inliers. This deposit has similarites to the Abra deposit in the Bangemall Basin but probably developed during a different event, so the two areas are not genetically linked.

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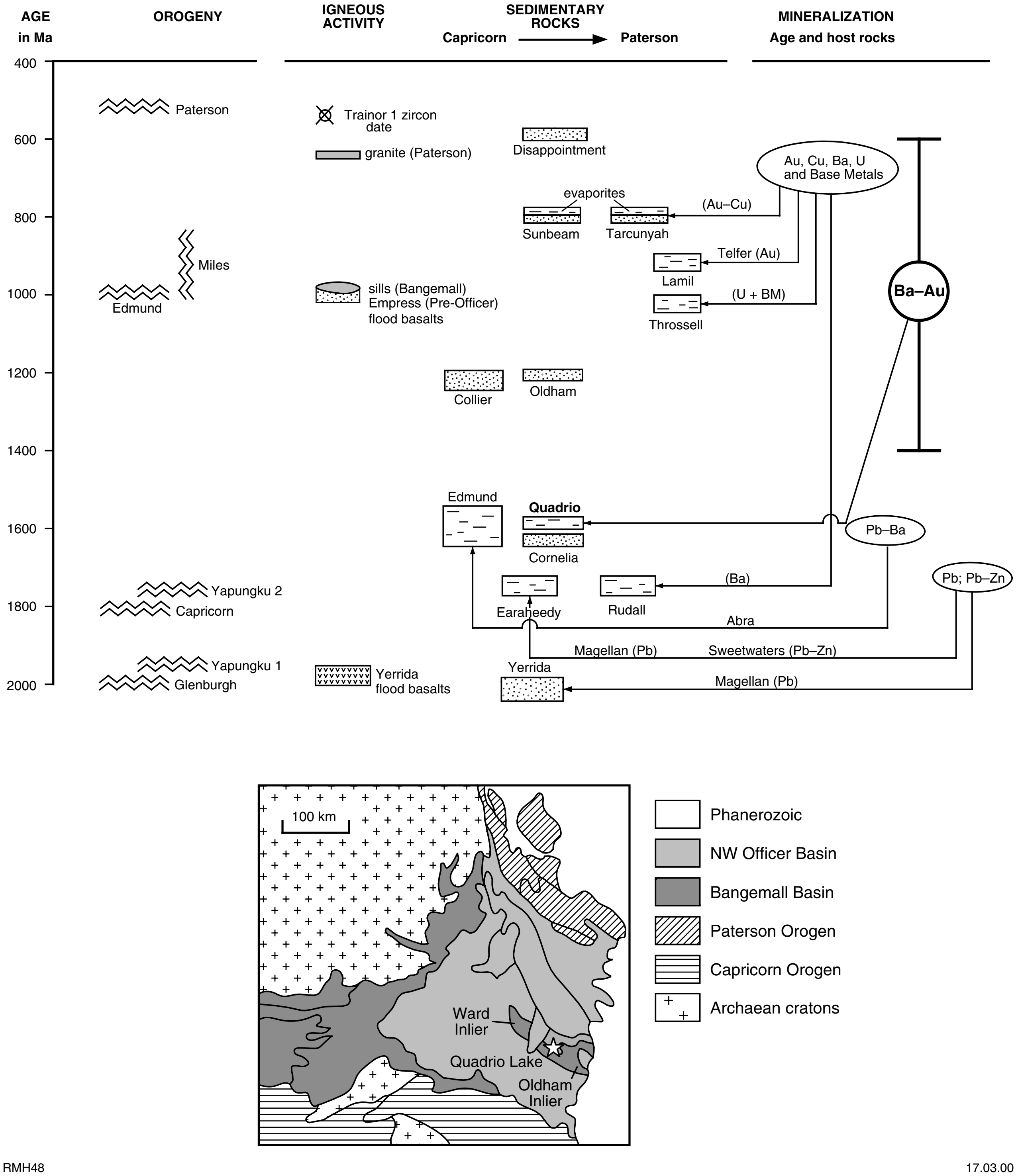
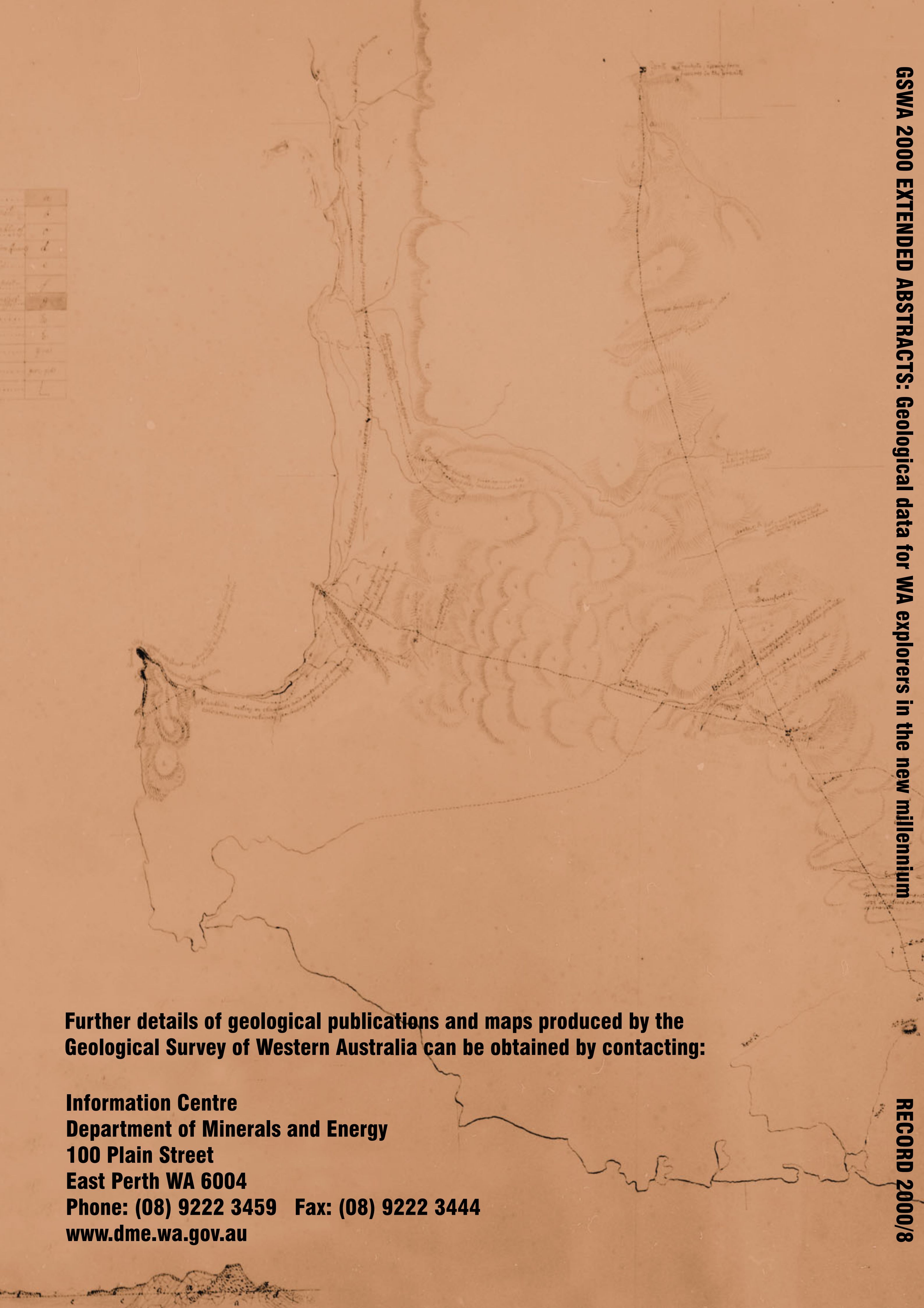


Figure 1. Orogenies, igneous activity, sedimentary successions, and mineralizing events relevant to the Quadrio Lake region, and location of Quadrio Lake mineralization



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