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**GSWA 2007 EXTENDED ABSTRACTS
PROMOTING THE PROSPECTIVITY
OF WESTERN AUSTRALIA**

by GSWA



Geological Survey of Western Australia



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Record 2007/2

GSWA 2007 EXTENDED ABSTRACTS

Promoting the prospectivity of Western Australia

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Foreword

The Geological Survey of Western Australia (GSWA) annual seminar and poster display, GSWA 2007, again provides an excellent opportunity for geoscientists from industry, academia, and elsewhere to get an update on GSWA activities and product releases through poster displays and technical presentations.

GSWA 2007 highlights the increasing importance of GIS as the preferred mode of delivery for the complex layers of geoscience information now available and in demand by explorers and researchers alike. Recent 1:100 000 Geological Information Series (GIS) releases contain more than 60 layers of information including, in addition to bedrock geology and regolith at four different scales, topographic data, aeromagnetics, radiometrics, Landsat and Aster imagery, sample and observation information, geochronology, mineral tenements, exploration activity, and abandoned mine sites. Also included on the CD or DVD are documents in PDF format covering any GSWA publication or map relevant to the project area. On the latest East Yilgarn 1:100 000 GIS release there are 456 publications included as PDF files on the DVD. GIS compilations for seven active project areas in the State are either now available or are due to be released in the very near future. These are on display in the poster display section at the GSWA 2007 venue, as are demonstrations of GSWA's online geoscience databases from the GeoVIEW website.

Also on display are images of recent aeromagnetic surveys in the west Musgrave, western Officer Basin, and Ashburton areas conducted with the \$3 million per annum additional funding provided by the State government for pre-competitive geoscience data acquisition. Maps showing areas programmed for coverage by this program are also on display.

You are invited to spend time viewing the extensive poster displays and discuss the details of geology with GSWA project geologists who will be in attendance all day.

And don't forget to provide us with feedback on how our products meet your requirements. We are always interested to hear how our customers use our data, and if it is presented in the most useful format. Speak up! We will listen and try to incorporate any suggestions into our future programs.

TIM GRIFFIN
EXECUTIVE DIRECTOR

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Kimberley–Tanami–Arunta: geology and mineral systems

by

I. M. Tyler, L. Bagas, S. Sheppard, and F. Pirajno

Major mineral discoveries have been made in the Proterozoic rocks of the Kimberley, Tanami, and Arunta, and mines currently operating in WA include the world-class Argyle diamond mine, as well as the more recent Sally Malay nickel mine, and the Coyote gold mine. However, much of the area can be regarded as under-explored, either due to poor outcrop, rugged topography, or remoteness.

The Kimberley, Tanami, and Arunta form part of the North Australian Craton, which extends into Western Australia from the Northern Territory (NT). GSWA carried out second edition 1:250 000-scale remapping of the King Leopold Orogen in the Kimberley between 1986 and 1989. Together with the then BMR (later AGSO, and now Geoscience Australia) 1:100 000-scale mapping in the Halls Creek Orogen took place from 1990 to 1995 as part of the National Geoscience Mapping Accord. More recently, the Tanami and Arunta have been the focus of the joint GA–NTGS–GSWA* National Geoscience Accord North Australia Project, the results of which were presented at a meeting in Alice Springs in June 2006 (Lyons and Huston, 2006) and are summarized below. A major initiative of the project was the 2005 Tanami Seismic Collaborative Research Project, which acquired 719 km of deep seismic reflection data across the WA/NT border. GSWA is addressing the previously limited availability of pre-competitive geological data in the WA Tanami and Arunta, with the acquisition and interpretation of new aeromagnetic, radiometric, and gravity data, the database entry of legacy field observations, and the commencement of a 1:100 000-scale geological and regolith mapping program. The release of a Geological Exploration Package for the Arunta, and Geological Information Series Packages for the Tanami and Kimberley are planned.

Paleoproterozoic geology

Kimberley

The King Leopold and Halls Creek Orogens can be divided into three distinct terranes representing different tectonic

settings interpreted to be part of a larger collisional orogen that sutured the Kimberley Craton with the rest of the North Australian Craton. The Hooper Complex and Western Zone of the Lamboo Complex formed as a marginal rift to the Kimberley Craton at c. 1872 Ma. The rift filled with turbiditic sedimentary rocks before being deformed and metamorphosed during the accretionary Hooper Orogeny (1865–1850 Ma). Intrusion of granitic and mafic–ultramafic rocks, and eruption of associated felsic volcanic rocks accompanied the orogeny. Mafic volcanic rocks and turbiditic sedimentary rocks in the Central Zone of the Lamboo Complex developed as an oceanic island arc at c. 1865 Ma. These were intruded by layered mafic–ultramafic rocks at c. 1855 Ma and by tonalite sheets at c. 1850 Ma. Peak metamorphism took place at c. 1845 Ma, coincident with the emplacement of further layered mafic–ultramafic intrusions and with the eruption of felsic and mafic volcanic rocks during rifting of the arc. The Eastern Zone of the Lamboo Complex contains a 1910–1880 Ma passive continental margin sequence that is transitional to an active margin setting at c. 1855–1845 Ma with the development of a foreland basin. During the 1835–1805 Ma Halls Creek Orogeny collision and suturing took place, and was accompanied by deformation, metamorphism and the intrusion of further granitic and mafic–ultramafic rocks in syn- and post-collisional settings. Syn- to post-collisional sedimentary basins include the c. 1835 Ma Speewah Basin overlying the Kimberley Craton, and the younger Moola Bulla and Red Rock Basins overlying the Lamboo Complex. The 1780 Ma Hart Dolerite is part of a large igneous province (LIP) intruded into the Speewah Basin and overlying Kimberley Basin.

Tanami

In the Granites–Tanami Orogen, Archean to early Paleoproterozoic basement underlies a c. 1864 Ma sequence of deep-water sedimentary rocks, turbiditic sedimentary rocks, and mafic volcanic rocks, which may have been deposited in an extensional, possibly back-arc setting related to the development of an arc in the Central Zone of the Halls Creek Orogen. Deformation during the early stages of the Tanami Orogeny (c. 1850 Ma) was followed by deposition of further sequences of deep-

* GA — Geoscience Australia; NTGS — Northern Territory Geological Survey

water sedimentary rocks and turbiditic metasedimentary rocks in a succession of foreland basins. The later stages of the Tanami Orogeny between 1835 and 1815 Ma may represent far-field effects of the Halls Creek Orogeny. Intrusion of two suites of granitic rocks accompanied the later stages of the Tanami Orogeny (1825–1810 Ma), and extension related to the eruption of a sequence of mafic volcanic rocks (1820–1790 Ma). The Pargee Sandstone (1758–1700 Ma) and the Birrindudu Basin (1735–1640 Ma) formed unconformably overlying sedimentary basins.

Arunta

The Arunta Orogen in WA is poorly known. In the NT the Arunta 'Region' is divided into the Aileron 'Province' in the north and the Warumpi 'Province' in the south, separated by the Redbank Thrust. These tectonic units appear to extend into WA. The Aileron Complex is dominated by turbiditic metasedimentary rocks probably deposited at c. 1835 Ma and is separated from the Granites–Tanami Orogen to the north by the extension of the Willowra Gravity Ridge. This is partly coincident with an aeromagnetic low, and may represent a fossil (≥ 1864 Ma) suture zone. The Warumpi Complex is interpreted as part of a terrane that was accreted to the southern margin of the North Australian Craton between 1690 and 1610 Ma during the Liebig Orogeny, prior to collision with the Mawson Craton at 1590–1570 Ma.

Mineral systems

The Kimberley, Tanami, and Arunta appear to be characterized by distinct mineral systems. The Kimberley is dominated by diamonds in kimberlite (Phillips Range) and lamproite (Argyle) diatremes, and by Cu–Ni–Cr–PGE–V–Co in layered mafic–ultramafic intrusions (Panton, Sally Malay), with potential for similar mineralization in mafic sills and associated volcanic rocks. There are also REE deposits associated with alkaline rocks (Brockman), Pb–Zn in volcanic-hosted massive sulfide (VHMS) deposits at Koongie Park, Sn–Ta–Nb in pegmatites

(Mount Heartbreak), and orogenic lode Au (Ruby Queen). Mineralization in the Tanami is dominated by orogenic Au (Coyote and Kookaburra). The Aileron Complex of the Arunta Orogen has potential for the discovery of orogenic Au, iron-oxide Cu–Au–U (IOCG) and VHMS deposits, whereas the Warumpi Complex has potential for the discovery of major IOCG deposits associated with alteration around the Mount Webb Granite (Wyborn et al., 1998). The potential for unconformity-related U exists in all three areas, associated with overlying sedimentary basins (Killi Killi).

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Regolith-terrain mapping in the Tanami

by

R. L. Langford

The visual representation of landform has a long history, typically captured in landscape paintings and photographs. However, as technology advanced, our view of the Earth's surface was largely overtaken by a desire to measure and map. The development of terrain maps is an attempt to represent multiple perspectives of three-dimensional surfaces in a two-dimensional image. Recent advances are now supporting a trend in many sciences, including regolith-terrain mapping, away from polygonization or parameterization of discrete units back to a picture of the world, often through interactive three-dimensional imaging. The argument herein presented is that effective representation of regolith-terrain must incorporate both temporal- and scale-dependencies in the spectral and topographic expression of the landscape to be visualized.

Producing useful regolith-terrain maps for the exploration industry and other land users relies primarily on the analysis and visualization of topographic and multi-spectral data. In addition, mapping and field characterization within a systematic framework brings benefits in interpretation, and the trend both within Western Australia and nationally is towards both extracting maximum value from imagery and applying more robust mapping methodologies. As a result, our understanding of the intimate relationship between landform, material, and process at the surface is constantly improving. This is a prerequisite for understanding three-dimensional and temporal aspects of the regolith.

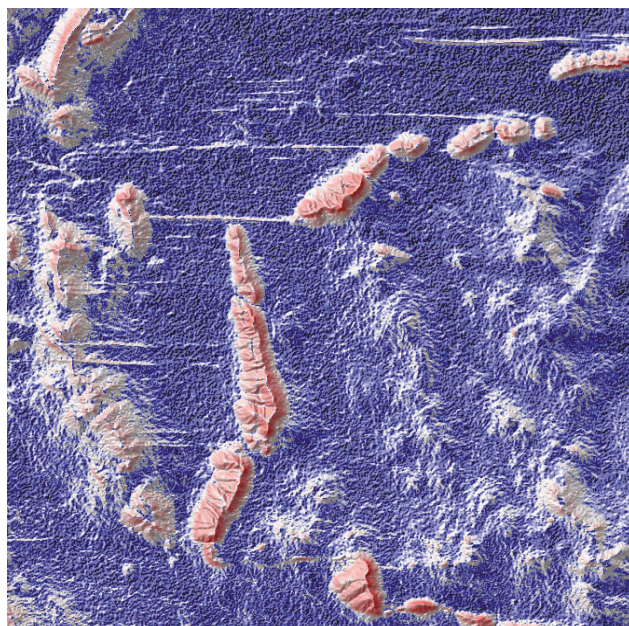
The two most useful datasets for regional regolith-terrain mapping are digital elevation models (DEMs) and Landsat TM. Orthophotograph, radiometric, multi-spectral (ASTER), hyperspectral (HyMap) and radar datasets are all potentially useful, but coverage of remote areas such as the Tanami tends to be patchy. Research and product development for the Tanami, in contrast to areas such as Kalgoorlie, has therefore focused on improving the temporal and spatial analysis and three-dimensional integration of DEMs and Landsat TM.

The analysis and visualization of Shuttle Radar Topography Mission (SRTM) DEM data has been very effective for regional regolith-terrain mapping. Applying

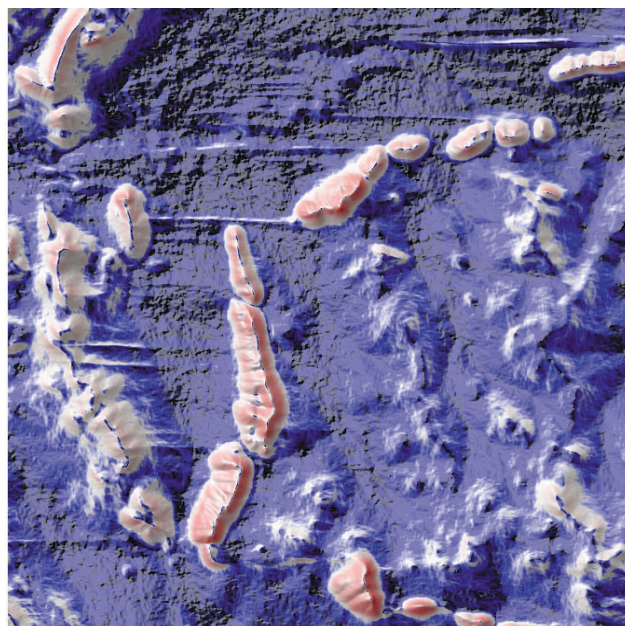
multi-scale analysis to resample the original data has produced the best visualization of what is essentially a level landscape (Fig. 1). Resampling the original 90-m resolution data to 270 m, although counter intuitive, has also been very effective in the visualization of regional landform patterns.

Multi-band remotely sensed image data contain information on landscape pattern and temporal changes that are underutilized in regolith-terrain and bedrock mapping. Among the reasons for this loss of analytical opportunity are the need for improved methods for the systematic extraction of patterns, and the ever-increasing volume and diversity of remotely sensed image data. The merging of Landsat TM data for a range of epochs for use in terrain mapping, producing what are now termed Landsat TM³ images (Landsat TM Temporal Merge Terrain Mapping), effectively tackles the challenge of producing a consistent set of images in an area dominated by seasonal vegetation changes and fire scars. While most users would naturally focus on the most recent images as being of most value, identifying persistent patterns in the landscape that relate to geological materials is best accomplished by removing the short-term effects. The most recent image may be the worst in terms of fire scars, floods, and revegetation. A simple arithmetic mean of data for the Tanami from 1994 to 2005 produces images with improved colour depth and enhanced geological material discrimination that will effectively compliment the detail available in high-resolution orthophotographs (Fig. 2).

The visualization of the regolith-terrain in the Tanami using SRTM DEMs and Landsat TM³ shows that there are numerous colluvial and sheetwash fans up to 20 km across below extensive footslopes, with obvious implications for geochemical sampling, even though the area is masked by eolian sand modified by sheetwash. These regional landform models also contribute to the development of physiographic regions and their component mapping units, which complement the regolith-landform images. A complete synthesis of the regional hierarchy for the Tanami has been completed, and more detail is being extracted from the images as the mapping progresses.

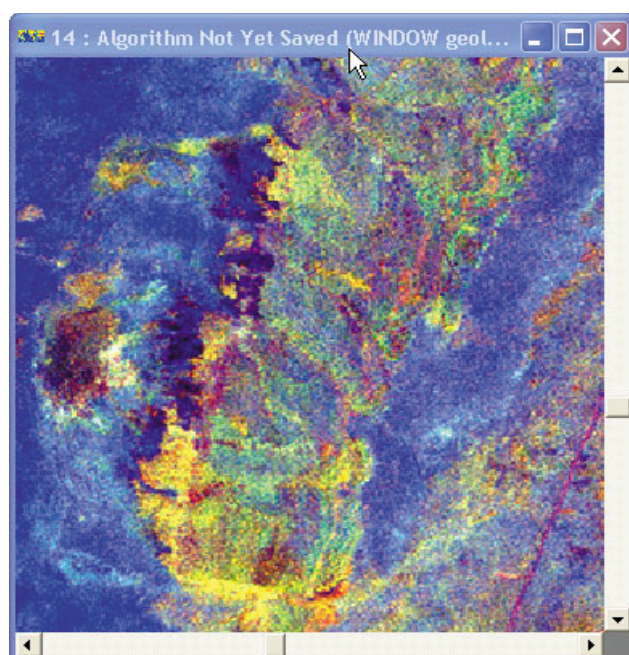


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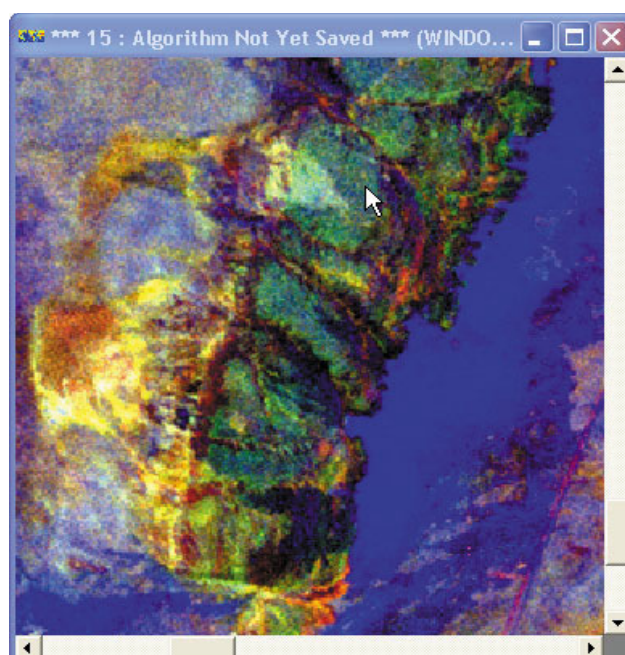


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Figure 1. Hill-shaded slope derived from original SRTM elevation data (left) and multi-scale resampled data (right) for the BALWINA 1:100 000 map sheet. Slopes in the white areas are about 1°



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Figure 2. Landsat TM ratios 5/7, 4/7, 4/2 for 2005 (left) and 1994 to 2005 Temporal Merge (right). Southwest corner of the BALWINA 1:100 000 map sheet, north of Balgo

Timing and geochemistry of felsic magmatism in the west Musgrave Complex

by

R. H. Smithies, H. M. Howard, S. Bodorkos, P. M. Evins, and F. Pirajno

In conjunction with geochronological data, the geochemistry of felsic rocks has proved a vital tool in mapping the west Musgrave Complex (Fig. 1). Despite the obvious economic interest in the mafic rocks of the area, and in particular the copper–nickel–mineralized layered mafic–ultramafic rocks of the c. 1070 Ma Giles intrusions, felsic rocks volumetrically dominate the west Musgrave Complex. It is these rocks, therefore, that will probably provide the most information on the crustal evolution of the area, including processes that led to the formation and final sites of emplacement of the Giles intrusions.

The west Musgrave Complex (Fig. 1) comprises various combinations of crustal components separated into domains with different structural and metamorphic histories. The volumetrically dominant component, feldspar–porphyritic biotite(–hornblende–pyroxene) leucogranite, formed during at least five separate events at c. 1320, c. 1210, c. 1175, c. 1150, and c. 1070 Ma. All of these pre-date the c. 550 Ma Petermann Orogeny, the metamorphic and structural overprint of which has commonly destroyed most reasonable means of confidently identifying individual granite (or gneiss) age groups in the field.

The five granite groups also have superficially similar geochemical features that include high concentrations of K_2O (2–7 wt%), total Fe (1.5–11 wt% Fe_2O_3), high field strength elements (HFSE, e.g. Nb, Zr, Y) and rare earth elements (e.g. La, Ce, Yb). However, subtle but persistent geochemical differences allow individual age groups, and suites within specific age groups, to be uniquely identified and mapped.

The results highlight the specific geographical ranges of each granite group and also some different modes of occurrence. The c. 1320 Ma granites have not been identified in the deep-crustal (high-pressure granulite-facies) segment north of the east-trending Mann Fault (Fig. 1), but they appear to form a major (possibly dominant) component of the lower pressure granulite-facies crust exposed to the south. Granites intruded between c. 1210 and c. 1175 Ma dominate outcrop north of the Mann Fault, but form only a minor component, mainly as dykes and small bodies, to the south. The c. 1150 Ma granites, however, have so far only been identified south of the Mann Fault. Minor dykes of c. 1075 Ma granite have

intruded north of the Mann Fault, but the great majority of these granites, including large (10 km-diameter) plutons, lie to the south.

Geochemical data suggest that the c. 1320 Ma granites are likely to be I-type granites, most of the c. 1210, c. 1175, and c. 1150 Ma intrusions are probably A-type granites, whereas the c. 1070 Ma granites have strongly developed A-type features. Thus, there is a secular trend, from c. 1320 to c. 1070 Ma, to generally increasing K_2O and HFSE concentrations. The Nd-isotopic signatures of the five granite groups are indistinguishable, suggesting derivation from a common (?) crustal source region, possibly with some recycling of older granites into younger magma batches. Notably, however, the deep

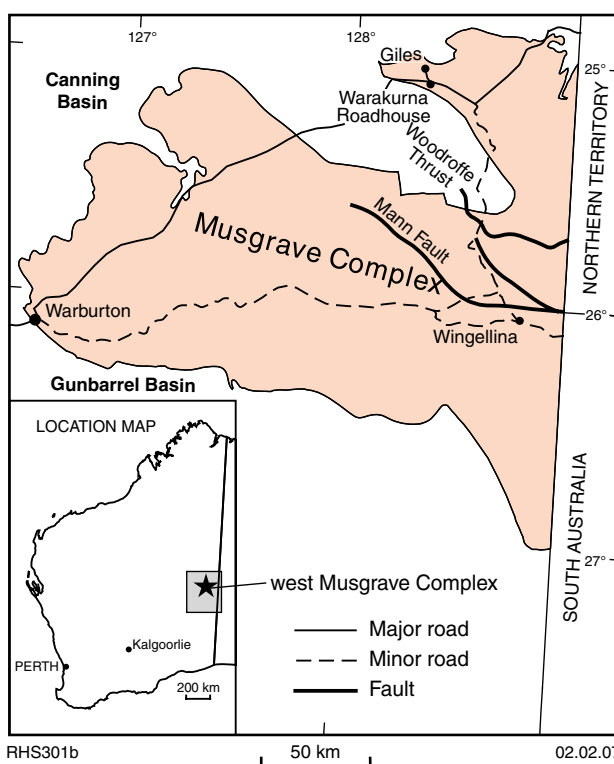


Figure 1. Location of the west Musgrave Complex in Western Australia

crustal c. 1210 to c. 1175 Ma granites north of the Mann Fault cannot have formed through recycling of the higher crustal c. 1320 Ma granites exposed to the south (although this is a possible origin for the c. 1210 to c. 1175 Ma granite dykes and veins in the south).

Sedimentary and volcanosedimentary rocks of the Birksgate Metamorphics are the oldest (>1390 Ma) known rocks in the region and form inclusions, up to tens of kilometres in size, in all granites. Nd-isotopic data indicate that, compared to rocks of the Birksgate Metamorphics north of the Mann Fault, rocks of the Birksgate Metamorphics to the south have a much larger source component that was ultimately derived from Archean crust that is older than 2800 Ma. Nevertheless, the supracrustal rocks of the Birksgate Metamorphics either side of the Mann Fault cannot have formed a major source component of any of the younger granites because the supracrustal rocks have notably less radiogenic Nd-isotopic signatures (and high Nd concentrations).

Granitic magmatism at c. 1070 Ma (and the temporally associated mafic–ultramafic Giles intrusions) was also accompanied by locally extensive felsic volcanism (Tollu Group–Bentley Supergroup). However, although the granites analyses thus far are from a source isotopically identical to that of the older granites ($\epsilon_{\text{Nd}} \sim -3$ at 1070 Ma), the c. 1070 Ma felsic volcanic rocks have a source as isotopically juvenile ($\epsilon_{\text{Nd}} \sim +0.7$ at 1070 Ma) as the least crustally contaminated rocks of the contemporaneous Giles intrusions. The felsic volcanic rocks are associated with locally emergent cryptodomes of granophyric-textured gabbro, and possibly belong to the same, predominantly mantle sourced, magma series.

Geology and mineral systems of the Paleoproterozoic basins of the eastern Capricorn Orogen

by

F. Pirajno

The Paleoproterozoic Yerrida, Bryah, Padbury, and Earraheedy Basins form a belt extending for about 700 km along the northern margin of the Archean Yilgarn Craton, cover a total area of approximately 70 000 km², and are part of the eastern portion of the Capricorn Orogen (Fig. 1; Cawood and Tyler, 2004). The development of these four basins began at about 2.2 Ga and continued for nearly 400 million years, to about 1.8 Ga, recording periods of sedimentation, volcanism, and associated hydrothermal mineral systems (Pirajno et al., 2004; Pirajno, 2004). The Yerrida (c. 2.1 and 1.8 Ga), Bryah, Padbury (c. 1.9 Ga), and Earraheedy (c. 1.8 Ga) Basins contain the Windplain and Mooloogool, Bryah, Padbury, and Earraheedy Groups, respectively, with further subdivision into subgroups for the Earraheedy Group. The present-day geometry of these basins is the combined result of tectonic movements during the c. 2.0–1.96 Ga Glenburgh Orogeny and 1.83–1.78 Ga Capricorn Orogeny, and to a lesser extent the c. 1.79–1.76 Ga Yapungku Orogeny and perhaps again at c. 1.65 Ga during the Mangaroon Orogeny.

Yerrida Basin

The Yerrida Basin volcano-sedimentary succession contains the c. 2.1 Ga Windplain Group and the c. 1.8 Ga Mooloogool Group. The former, divided into the Juderina and Johnson Cairn Formations, is essentially an intracratonic sag-basin sedimentary succession deposited in a stable, shallow coastal marine environment, grading to intertidal–supratidal sabkha lagoons. The Mooloogool Group overlies the Windplain Group and contains the Thaduna, Doolgunna, Killara, and Maraloou Formations. The deposition of the Mooloogool Group marked a younger stage in the geodynamic evolution of the Yerrida Basin. The depositional systems of the high-energy clastic sedimentary rocks of the Doolgunna and Thaduna Formations can be linked to a compressional event, during which the Bryah and Padbury Groups (see below) were thrust over the Windplain Group. Post-compressional relaxation led to extension and the onset of continental mafic magmatism (Killara Formation), followed by the deposition of sulfidic black shales (Johnson Cairn Formation).

Bryah and Padbury Basins

The Bryah Group contains the Karalundi, Narracoota, Ravelstone, and Horseshoe Formations, all deformed and metamorphosed to greenschist facies. The Karalundi Formation forms the base of the Bryah Group and is in fault contact with the Doolgunna Formation in the southeast and east of the basin, and is locally intercalated with basaltic hyaloclastites of the Narracoota Formation, which forms the bulk of the group. In addition to basaltic hyaloclastites, the Narracoota Formation includes metamorphosed and deformed komatiitic basalt, peridotite, gabbro, pyroxenite, and minor felsic and volcanoclastic rocks. The layered mafic–ultramafic Trillbar Complex may be part of this formation. The Ravelstone Formation is a turbiditic succession and the conformably overlying Horseshoe Formation primarily comprises beds of ferruginous shale and banded iron-formation, marking the cessation of detrital influx with deposition of chemical sedimentary rocks in a starved basin. The Narracoota Formation is interpreted as a remnant of an oceanic plateau that was tectonically emplaced on the northwestern margin of the Yilgarn Craton at about 1.9 Ga.

The Padbury Group is subdivided into the Labouchere, Wilthorpe, Robinson Range, and Millidie Creek Formations. The age of the group is constrained by the underlying c. 1.9 Ga Bryah Group and the overlying Bangemall Supergroup (younger than 1.63 Ga). The Labouchere and Wilthorpe Formations are upward-coarsening, deep-water turbidite successions, with the overlying shales and banded iron-formations of the Robinson Range and Millidie Creek Formations heralding a change to shallow-water deposition in a lacustrine or marine-platform environment. The Padbury Group is interpreted as a foreland basin sequence built on top of the Bryah Basin, as a result of the Capricorn Orogeny.

Earraheedy Basin

The Earraheedy Basin comprises the Earraheedy Group, is divided into the Tooloo and Miningarra Subgroups, and lies at the easternmost end of the Capricorn Orogen.

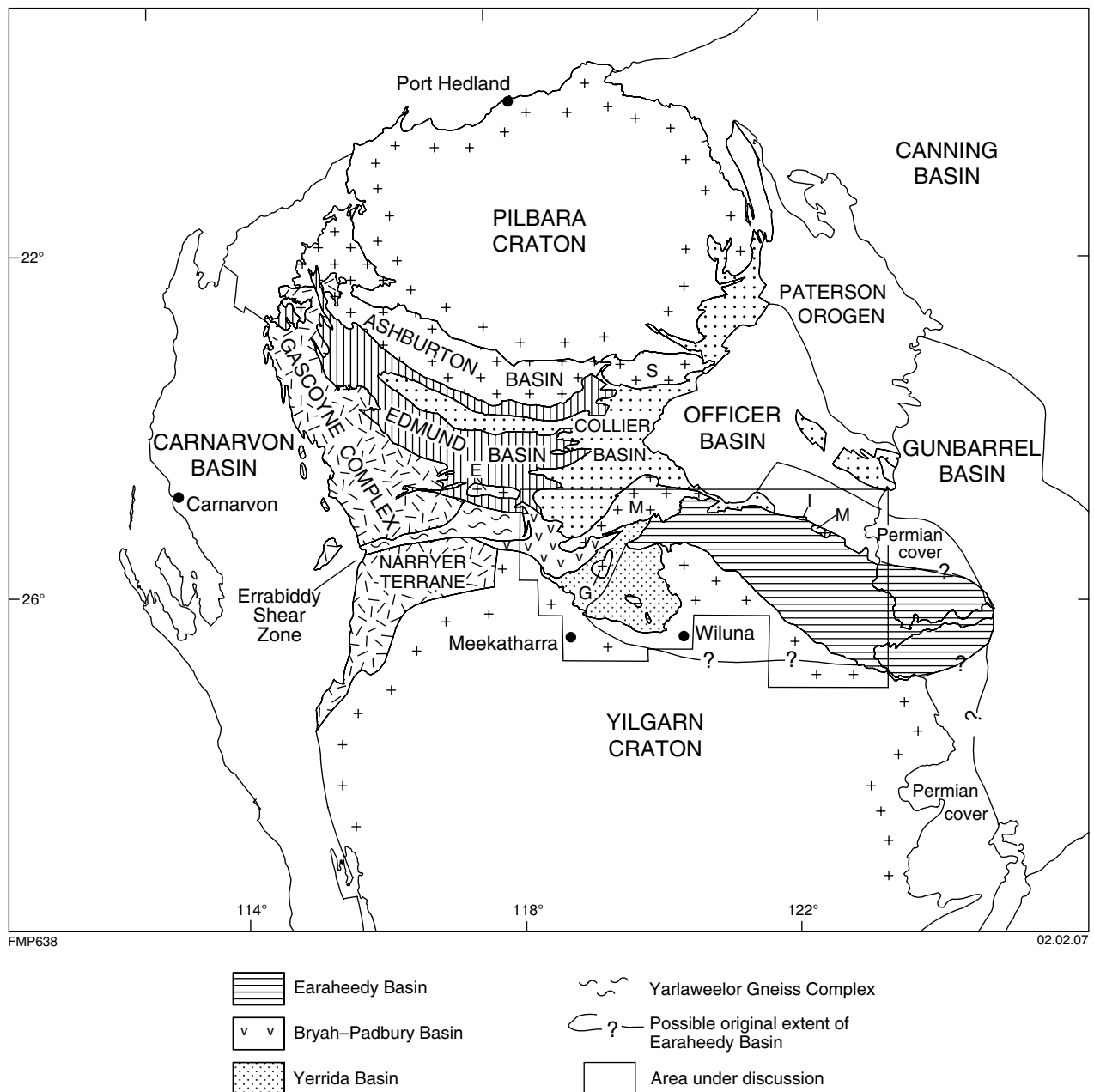


Figure 1. Tectonic units of the Capricorn Orogen and position of the Yerrida, Bryah, Padbury, and Earaheedy Basins. E — Egerton Inlier; G — Goodin Inlier; M — Marymia Inlier; S — Sylvania Inlier

Basement to the exposed Earaheedy Basin is the Archean Yilgarn Craton in the south, and to the west the Yerrida Basin. The regional structure is an asymmetric east-plunging syncline, with a vertical to locally overturned northern limb, due to compressive movements from the northeast, which created a zone of intense deformation along the exposed northern margin of the basin. This zone of deformation, named the Stanley Fold Belt, is characterized by reverse faults and shear zones that consistently dip steeply to the north, the development of slaty cleavage and phyllitic rocks, and the appearance of metamorphic minerals with Ar–Ar ages of c. 1650 Ma. The

Earaheedy Group is a 5 km-thick succession of shallow marine clastic (Yelma Formation) with minor carbonate (Sweetwater Well Member) and chemical sedimentary rocks (Frere Formation), probably deposited in a trailing passive margin developed along the rifted northern margin of the Yilgarn Craton. The depositional age of the Tooloo Subgroup is poorly constrained, but Pb–Pb isochron ages on galena suggest a minimum age of 1.77 Ga. The succession of the Miningarra Subgroup comprises the dominantly clastic and glauconitic Chiall and Wongawol Formations, the stromatolitic Kulele Limestone, and finally the Mulgarra Sandstone.

Mineral systems

Mineral systems of the eastern Capricorn Orogen basins include: 1) volcanic-hosted massive sulfide (VHMS) related to submarine hydrothermal venting; 2) orogenic to post-orogenic lode deposits related to compressional stages of deformation; 3) syngenetic deposits related to passive continental margins; 4) deposits related to fluid movements during convergence and deformation.

Volcanogenic Cu–Au–Ag mineralization is present in felsic components of the Narracoota Formation at Horseshoe Lights. This mineral system was probably originally formed on the sea floor during eruption of dacitic rocks in an oceanic-plateau setting. The Horseshoe Lights mineralization was subsequently deformed and later enriched by supergene processes.

Orogenic to post-orogenic Au-only lode deposits, present in both the Bryah and Padbury Groups and in parts of the Stanley Fold Belt, were formed during the late stages of compressional deformation and subsequent stress relaxation. They are structurally controlled and associated with retrograde regional metamorphism, probably relating to influx of meteoric fluids into open structures.

Syngenetic deposits are mainly represented by banded and granular iron-formations of the Robinson Range Formation (Bryah Basin) and Frere Formation (Earaheedy Basin). Both are Lake Superior-type iron formations. The Frere Formation is very extensive with a strike length of more than 250 km, constituting a major resource of iron ore. Local supergene enrichment gives grades of up to 66% Fe.

Mineral systems related to fluid movements are of at least two types, both are in the Earraheedy Basin. The Sweetwater Well occurrences, west of the Shoemaker Impact Structure, are classic Mississippi Valley-type Zn–Pb–Cu–Ba hosted in carbonate rocks of the Yelma Formation. The other is the world-class Magellan lead deposit, consisting of lead carbonates and oxides, located in outliers of the Yelma Formation in the Yerrida Basin along the unconformity with the underlying Windplain Group. The Magellan mineralization, termed a ‘nonsulfide’ ore system, originated by the action of low-temperature basinal fluid migration and paleoweathering processes.

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The contribution of geochronology to GSWA's mapping programs: current perspectives and future directions

by

S. Bodorkos and M. T. D. Wingate

Radiogenic isotope geochronology is aimed at determining absolute ages of rocks and geological events. As an integral part of most GSWA mapping programs, it has played a pivotal role in revolutionizing our understanding of the geology of Western Australia. Regional mapping programs require direct dating of geological events as diverse as igneous crystallization (U–Pb zircon, monazite, or baddeleyite), metamorphism (U–Pb monazite or titanite), cooling (Ar–Ar hornblende, muscovite, or biotite), and deformation (in situ laser Ar–Ar muscovite). Geochronology also has several important additional applications, including provenance analysis and maximum depositional ages of sedimentary rocks, and constraining the ages of tectonothermal events via the dating of pre-, syn-, and post-tectonic igneous rocks.

Between 1991 and 2004, GSWA obtained 654 sample-specific geochronological results, of which over 95% are sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon dates. Ongoing work (represented by 133 results obtained in 2005–06) supports current regional mapping and geophysical interpretations in the Murchison Domain and Burtville Terrane of the Yilgarn Craton, the Gascoyne and Musgrave Complexes, the Albany–Fraser Orogen, the Edmund and Collier Basins, and the Perth, Carnarvon, and Canning Basins. Some of the diverse applications of geochronology to GSWA's regional programs are illustrated in the examples below.

Tectono-metamorphic histories from Musgrave Complex zircons

Zircon structure, chemistry, and geochronology data have been integrated with whole-rock Sm–Nd isotopic data to elucidate spatial patterns in the tectono-metamorphism of granulite-facies supracrustal rocks that form basement to the Musgrave Complex. In the south, these rocks have Sm–Nd model ages of c. 2800 Ma, are intruded by the 1330–1290 Ma Wankanki Supersuite, and contain detrital zircon cores (with U–Pb ages in the range 1800–1370 Ma) that are overgrown by 1220–1200 Ma rims with high

uranium contents and low Th/U ratios. In contrast, northern Musgrave supracrustal rocks have Sm–Nd model ages of 2000–1800 Ma, lack evidence for Wankanki plutonism, and contain detrital zircon cores (with U–Pb ages in the range 1650–1290 Ma) that are rimmed by 1180–1170 Ma overgrowths with low uranium contents and high Th/U ratios. These data support the existence of two basement terranes with disparate tectono-metamorphic histories. Clues to the nature of their interrelationship are provided by rocks in the central Musgrave Complex, where both types of zircon rims have been identified at single-grain scale. These rocks are proximal to the crustal-scale Mann Fault, along which the two terranes may have been juxtaposed during the latter stages of the 1220–1160 Ma Musgravian Orogeny.

Reservoir sandstone provenance from Canning Basin zircons

Detrital zircons have been dated from potential reservoir sandstones in the Ordovician Willara (Acacia Sandstone Member), Gap Creek, and Carranya Formations, with the aim of testing the proposed continuity of sand bodies between control points (wells and outcrops), establishing sediment provenance and likely sediment pathways, and constraining the paleogeography of reservoir units by linking them to possible sediment input points along the basin margin. Two of the four dated samples yielded identical provenance spectra dominated by 1880–1840 Ma zircons derived from the North Australian Craton to the northeast. However, two other proposed correlatives are characterized by more diverse age spectra and much higher Meso- and Neoproterozoic inputs derived from the Centralian Superbasin (or directly from its source terrains) to the southeast. This suggests that either the Acacia Member represents several discrete sand bodies of similar age derived from different sediment input points, or that provenance switching during deposition has led to provenance stratification within the unit. Both possibilities have important implications for predicting reservoir distribution and lateral facies changes.

Baddeleyite dating of Proterozoic dolerite in the central Yilgarn Craton

Baddeleyite (ZrO_2) has considerable potential as a U–Pb chronometer in mafic intrusive rocks such as dolerite and gabbro, which usually do not contain magmatic zircon and have previously been considered difficult to date. The mineral separation procedure is complicated by the small size and fragility of baddeleyite and by the high proportion of high-density and magnetic minerals in mafic rocks. However, GSWA's Carlisle Laboratory has successfully implemented crushing, washing, and magnetic separation protocols designed to maximize baddeleyite yield. Consequently, several hundred crystals of baddeleyite (and a small number of zircons) were obtained from a dolerite sill in the central Yilgarn Craton, southeast of Sandstone. The baddeleyite yielded a SHRIMP U–Pb date of 1070 ± 18 Ma that is interpreted as the crystallization age of the sill. Two of 13 zircons furnished dates within uncertainty of the baddeleyite result, whereas the remainder yielded dates in the range 2460–1200 Ma, and are interpreted as xenocrysts acquired from older rocks. This new result confirms that the dolerite sill is part of the Warakurna large igneous province (LIP), and indicates that the Warakurna LIP extends well into the central Yilgarn Craton, with a newly recognized areal extent of some 1.7×10^6 km².

Laser Ar–Ar muscovite dating of Neoproterozoic deformation in the Gascoyne Complex

The Chalba Shear Zone is a crustal-scale structure separating the 1840–1620 Ma northern-central Gascoyne Complex from the 2005–1970 Ma southern Gascoyne Complex (Glenburgh Terrane). Within the shear zone, well-developed S–C fabrics in strongly deformed granites were widely regarded as the product of Paleoproterozoic deformation, overprinted and reactivated during the 1030–950 Ma Edmondian Orogeny. White micas in different textural associations were dated *in situ* (via infra-red laser) using the $^{40}\text{Ar}/^{39}\text{Ar}$ method. Five analyses of coarse-grained C-plane crystals yielded widely variable ages (2790–630 Ma), and probably reflect a combination of heterogeneously distributed excess Ar, and partial resetting of the Ar–Ar systematics. However, the fine-grained S-plane material indicated a single age of 570 ± 10 Ma. This suggests that at least some of the observed structural reactivation may be associated with the development of dextral shear zones that transect the 755 Ma Mundine Well dolerite dyke swarm elsewhere in the Gascoyne Complex. This terminal Proterozoic deformation event may reflect either a far-field response to Petermann Orogeny tectonism in central Australia, or a more northeasterly manifestation of deformation in the Pinjarra Orogen, west of the Darling Fault.

A laterite geochemical map of the western Yilgarn Craton

by

P. Morris and M. Cornelius¹

The majority of datasets used for regional-scale mineral exploration are remotely sensed, such as airborne geophysics and Landsat TM. Geochemical surveys using widely spaced samples have been successful in identifying unanticipated geochemical features in China, Finland and Fennoscandia, reflecting both anthropogenic and mineralization signatures. In Western Australia, regional geochemical datasets have been generated by both CSIRO (Smith et al., 1992; Geological Survey of Western Australia, 1998) and GSWA (Morris and Verren, 2001), with the success of these data in outlining regional geochemical trends related to potential mineralization discussed by Smith et al. (1992), Cornelius et al. (2001), and Morris and Verren (2001). These studies have shown that multi-element analytical data for various regolith sample types can be used to directly identify either mineralization, alteration related to mineralization, or pathfinder element associations indicative of mineralization. However, there are few datasets that combine contiguous and extensive coverage with a unique sample medium and a comprehensive analyte suite. The laterite geochemistry dataset generated for the western part of the Yilgarn Craton addresses these issues, and provides baseline geochemical data that can be used to explore for a variety of commodities.

Ferruginous duricrust (loosely referred to as 'laterite'), which is widely distributed throughout the Yilgarn Craton, in large part results from the weathering in situ of the underlying bedrock. In addition to its widespread availability, two other factors make this an attractive sampling medium for regional geochemical surveys. Firstly, the ferruginization process responsible for duricrust formation can also involve the sequestration of both ore and pathfinder elements from bedrock-hosted mineralization. Secondly, as much of this laterite consists of pea-shaped gravel (pisoliths), mineralization haloes can be enhanced by the mechanical dispersion of pisolitic laterite. The potential for laterite as a sampling medium in regional geochemical surveys has been realized by studies carried out at CSIRO (Smith et al., 1987; 1989) that showed that laterite chemistry can vector towards

known rare-metal pegmatite and gold deposits on the Yilgarn Craton.

The laterite geochemical map of the western Yilgarn Craton comprises more than 3000 analyses of laterite sampled on a nominal 9-km triangular grid (i.e. a sample density of one sample per 70 km²), with each sample analysed for a minimum 53 elements. Where possible, samples from pre-existing laterite geochemical programs were reanalysed (Smith et al., 1992; Geological Survey of Western Australia, 1998). The preferred sampling medium was pisolitic laterite (84% of samples), with smaller proportions of lag derived from pisolitic gravel, and fragments of duricrust. Major results from the program include elevated Au abundances beyond areas of known greenstone-hosted gold mineralization (suggesting a greater extent of greenstones), more extensive areas of Au and base metal mineralization shown by chalcophile element abundances, and the possibility of previously unknown greenstone remnants within granitic terrains. A regional trend in Hg abundances in laterite may be related to craton-scale structures rather than particular lithologies. The decrease in Al₂O₃ abundance from west to east coincides with a decrease in rainfall inland, suggesting some climatic control on aspects of regolith geochemistry.

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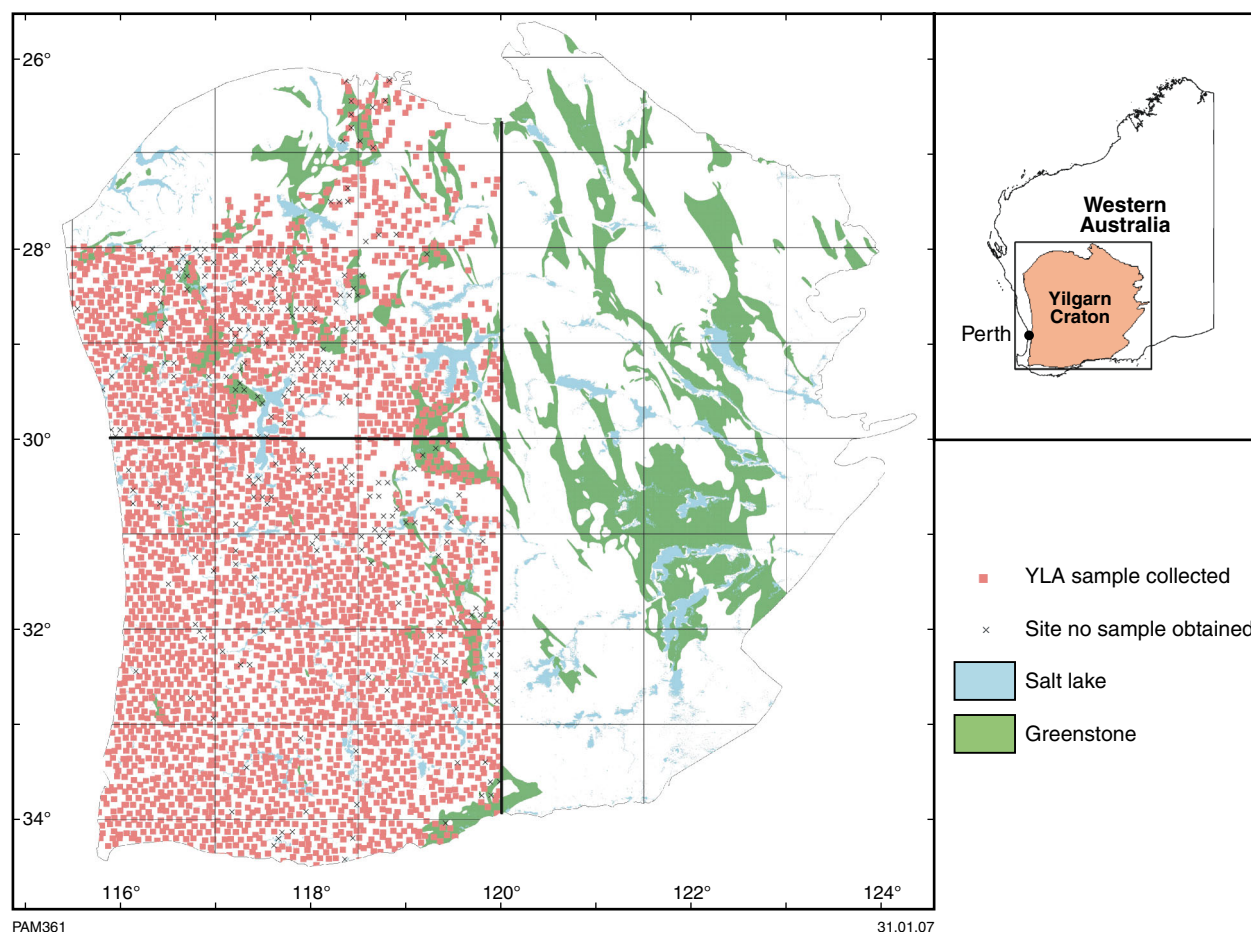


Figure 1. Distribution of samples analysed for the Yilgarn laterite map. Horizontal black line separates approximately 2000 samples from the first phase of the program (south; Cornelius et al., 2006) from approximately 1000 samples from the second phase of the program (north)

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The Burtville Terrane: the Far East of the Yilgarn Craton

by

M. Pawley

Introduction

The past 25 years have seen a wealth of new data generated in the east Yilgarn as a result of regional 1:100 000-scale mapping programs by the Geological Survey of Western Australia (GSWA) and Geoscience Australia, the acquisition of regional-scale geophysical data, particularly aeromagnetic and gravity data, numerous academic studies of mineralization and mineral deposits, and research programs carried out under the auspices of AMIRA International Limited, the Minerals and Energy Research Institute of Western Australia (MERIWA), and the Predictive Mineral Discovery Cooperative Research Centre (pmd*CRIC).

One outcome of all of this new work has been the subdivision of the Yilgarn Craton into six terranes (Fig. 1; Cassidy et al., 2006). The distribution of these terranes is based on rock associations, geological structures mapped in the field and identified in seismic profiles, geochemistry, geochronology, and Sm–Nd isotope data. The three easternmost terranes form the Eastern Goldfields Superterrane, with the Burtville Terrane in the far east, the Kurnalpi Terrane in the centre, and Kalgoorlie Terrane in the west. The three terranes of the Eastern Goldfields Superterrane have been interpreted as a series of continental margin fragments that were amalgamated and then accreted onto the protocratonic nucleus of the Yilgarn Craton (i.e. the Youanmi Terrane; Barley et al., 2003; Cassidy et al., 2006). Lithostratigraphic packages within terranes have been assigned to a series of domains, but relationships between different domains and even some of the bounding structures between the various domains and terranes remain under review.

The Kalgoorlie Terrane (2.71–2.66 Ga) is predominantly composed of mafic–ultramafic successions that are overlain by, and locally interleaved with, felsic volcanic and volcanoclastic rocks. The Kurnalpi Terrane contains a wide spectrum of rock associations with the youngest rocks comprising 2.69–2.68 Ga felsic calc-alkaline and bimodal rhyolite–basalt complexes along its western side. Other rock types through the rest of the Kurnalpi Terrane (mainly 2.72–2.70 Ga) include mafic and ultramafic volcanic, mafic intrusive, calc-alkaline volcanic and volcanoclastic, and medium- and fine-grained clastic sedimentary rocks. The Laverton Domain in the northeast

of the Kurnalpi Terrane (Fig. 1) contains mafic, ultramafic, and felsic volcanic and volcanoclastic rocks, banded iron-formation, and clastic sedimentary rocks that are apparently significantly older than those in the eastern part of the terrane, with maximum depositional ages of clastic sedimentary rocks of 2.81 Ga, and possibly 2.86 Ga.

The Burtville Terrane, the least well documented of the terranes, is separated from the adjacent Kurnalpi Terrane by the regional-scale Hootanui Fault (Fig. 1). Prior to the current mapping program, little new data had been collected in this area since the 1:250 000-scale mapping in the 1970s. However, reconnaissance-scale geochronological studies suggested that it contains older greenstones and granites than the terranes to the east.

The northeast Yilgarn Craton project

The current GSWA northeast Yilgarn Craton mapping project, covering the granites and greenstones of the northeasternmost part of the Yilgarn Craton, commenced in 2005. Fieldwork is largely complete in the Mount Venn, Mount Sefton, and Ulrich Range greenstone belts, with the Yamarna–Mount Gill, Dorothy Hills, Mount Hickox, and Irwin Hills greenstone belts to be mapped in 2007.

The Mount Venn greenstone belt is an upright, north-northwesterly trending syncline. The greenstones have a parallel sheared contact with the granitic gneisses to the east, and several late granites cut the belt. The lowermost greenstones are schistose mafic–ultramafic volcanic rocks, with minor interbedded banded iron-formation and quartzite units preserved on the western limb. On the eastern limb the package is intruded by parallel thin pyroxenite, leucogabbro, and dolerite sheets. These intrusive rocks thicken significantly to the north, forming the thick composite gabbroic complex at the northern end. The mafic–ultramafic package is overlain by interbedded sandstone and siltstones, which are in turn overlain by well-bedded felsic tuffs and volcanoclastic rocks that have a sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon age of 2769 ± 2 Ma. These grade up into volcanoclastic rocks interbedded with andesitic flows, which are then overlain by a series of interfingering,

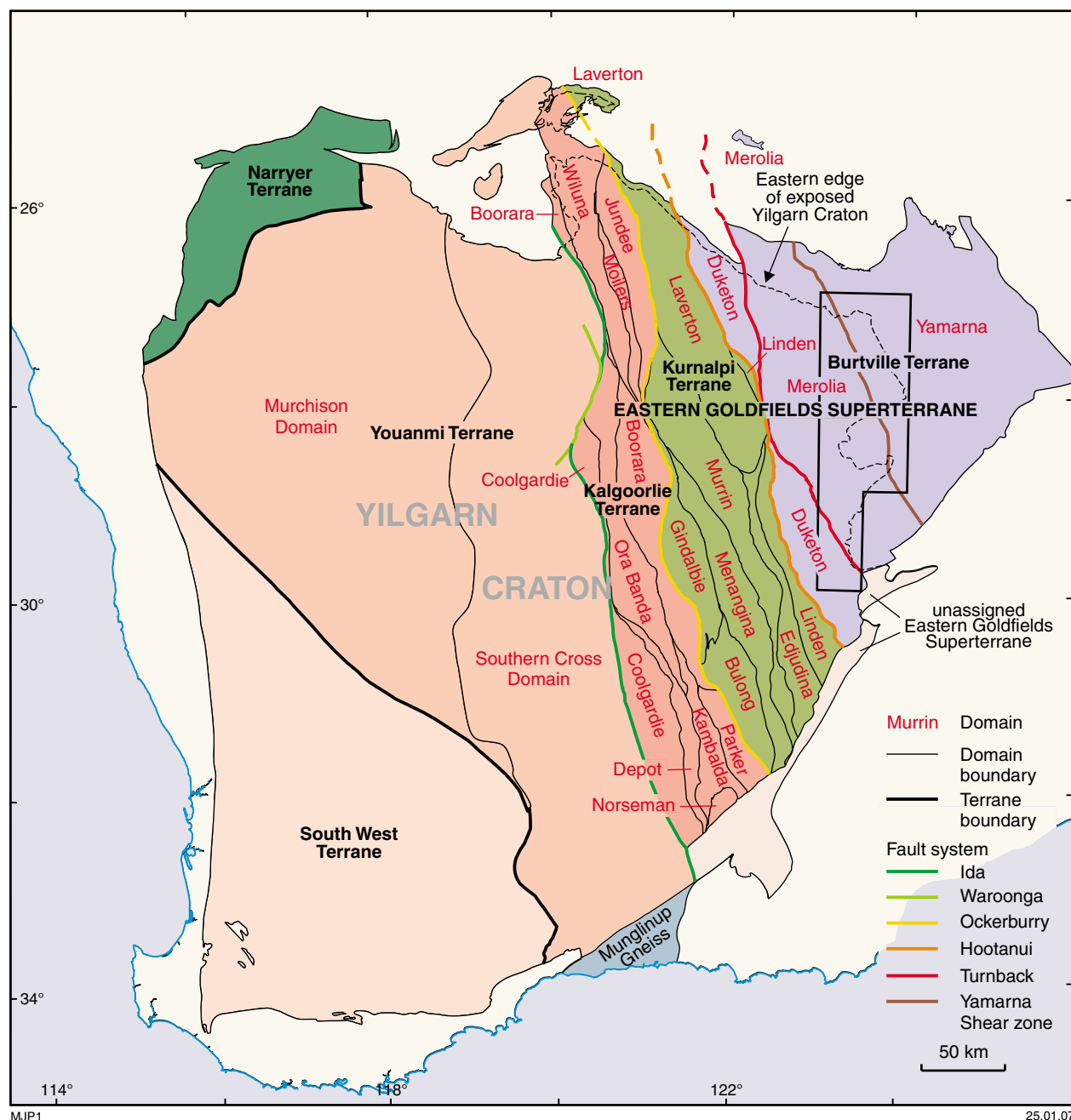


Figure 1. Tectonic division of the Yilgarn Craton, showing the subdivision into superterrane, terranes, and domains. The box in the Burtville Terrane shows the area of the current mapping programme, and the dashed line shows the edge of the exposed Yilgarn Craton. Figure modified from Cassidy et al. (2006)

wedge-shaped rhyolitic and dacitic bodies. The felsic rocks preserve a transition from distal to proximal facies. The uppermost part of the succession is intruded by layered gabbros of the Mount Venn complex.

Based on overprinting relations, a provisional three-stage deformation history can be constructed for the Mount Venn greenstone belt. The first recognized deformation event is characterized by well-developed, down-dip (i.e. east-plunging) stretching lineations and parallel fold hinges in banded iron-formation on the western side

of the belt. The folds are isoclinal and intrafolial with axial planes concordant with the steeply to moderately dipping, north-northwesterly trend of the belt. The folds are typically asymmetric, but the vergence varies along the unit, suggesting sheath-like geometries (consistent with the parallel stretching lineations and fold hinges). A second deformation resulted in overprinting of the stretching lineation by upright open folds that plunge to the south-southeast (i.e. along the strike of the belt) at a shallow to moderate angle. These local F_2 folds have a consistent 'Z' asymmetry, indicating a westward vergence.

Similar relations were observed on the eastern side of the Mount Venn greenstone belt. Volcaniclastic rocks with a bedding-parallel, solid-state foliation are folded into upright tight 'S' folds that moderately plunge to the south-southeast. To the south, talc-chlorite schists are folded into similarly oriented structures (i.e. eastward vergence). The folded schists have a well-developed crenulation cleavage that is aligned subparallel to the limbs of the fold, suggesting that there might be a composite fabric (i.e. local S_1/S_2) along the belt. The massive granites at Lang Rock have a high-angle veined contact with the north-northwesterly trending greenstones, suggesting that they were emplaced following local D_2 . In turn, the granites and greenstones are cut by a series of east-northeasterly trending quartz veins, interpreted as products of local D_3 , with en echelon quartz vein arrays indicating an apparent dextral sense of shear.

The change in composition from mafic-ultramafic to felsic volcanism is also observed in the Duketon greenstone belt (e.g. Barley et al., 2003), suggesting that there may be a consistent stratigraphy across the terrane. The age of c. 2770 Ma from the middle of the described section is younger than the sequence in the Duketon greenstone belt (i.e. 2805 Ma), but does support the hypothesis that the Burtville Terrane comprises older rocks than the neighbouring terranes. It is possible that the older (>2.8 Ga) northeastern part of the Kurnalpi Terrane (i.e. the Laverton Domain) would be more appropriately assigned to the Burtville Terrane, suggesting that major movement on the Hootanui Fault post-dated the dominant period of terrane assembly.

The provisional sequence of deformation events in the greenstones can be broadly reconciled with those presented for the western Burtville Terrane and other parts of the Eastern Goldfields Superterrane. The prominent Yamarna Shear Zone is probably in the same generation of structures as the Hootanui Fault.

Mineralization

Although the area has been explored for gold and other commodities since the 1890s, there is little recorded production. However, the acquisition of new geophysical data, particularly aeromagnetic and seismic data, has generated new interest in the region, particularly after the discovery of the Tropicana gold deposit to the southeast.

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The Yilgarn Craton meets the Albany–Fraser Orogen: Mesoproterozoic reworking of the southern craton margin

by

C. V. Spaggiari, S. Bodorkos, M. Barquero-Molina¹, and I. M. Tyler

The Albany–Fraser Orogen comprises several Paleoproterozoic to Mesoproterozoic lithotectonic units, and the southern and southeastern margins of the Archean Yilgarn Craton. The orogen is interpreted to have formed during 1345–1260 Ma collision between the West Australian and Mawson Cratons (Stage I Albany–Fraser Orogeny; Myers et al., 1996; Clark et al., 2000), and to have undergone significant intracratonic reworking during Stage II of the Albany–Fraser Orogeny (1215–1140 Ma; Clark et al., 2000).

The recently discovered Tropicana gold deposit has sparked much interest in new greenfields mineral exploration within the orogen. The deposit is located within the deformed, southeastern margin of the Yilgarn Craton, adjacent to the Fraser Complex, and appears to be the result of Paleoproterozoic to Mesoproterozoic orogenic processes related to the Albany–Fraser Orogeny. This potentially makes other reworked parts of mineralized terranes along the craton margin a target for exploration (Fig. 1). The reworked parts of the Yilgarn Craton are being identified using new aeromagnetic data, combined with SHRIMP U–Pb zircon geochronology. The interpreted bedrock geology map shows revised tectonic boundaries and subdivisions, and can be used to speculate on the extent and significance of tectonic events.

From inboard to outboard, the lithotectonic units of the Albany–Fraser Orogen are: the Northern Foreland, the Paleoproterozoic-dominated Biranup Complex, and the Mesoproterozoic Fraser and Nornalup Complexes (Fig. 1; Beeson et al., 1988; Myers, 1990). These units mostly consist of strongly deformed amphibolite to granulite facies rocks intruded by various granitic plutons. The Northern Foreland represents reworked Yilgarn Craton and generally has a transitional boundary with the interior of the craton, where Archean, dominantly north- to northwest-trending structures are increasingly overprinted by Proterozoic, dominantly east- to northeast-trending structures. Where deformation intensity increases, and

the rocks approach granulite facies, the affinities of their protolith provenance become problematic. For example, the Mungrinup Gneiss (Fig. 1) was previously considered to be part of the Biranup Complex, allochthonous to the Yilgarn Craton (Myers, 1995). However, magnetic anomalies within the gneisses suggest the presence of remnant greenstones and, in some instances, these can be traced across the Northern Foreland boundary and into the craton interior. New SHRIMP U–Pb zircon dating has yielded felsic igneous protolith ages of 2681 ± 5 , 2661 ± 15 , and 2658 ± 21 Ma for the Mungrinup Gneiss, which are similar to typical Yilgarn granite ages, and slightly older than those previously reported for the unit (Nelson et al., 1995). Some of these orthogneisses record thermal disturbances at c. 1190 Ma, consistent with reworking during Stage II of the Albany–Fraser Orogeny. We therefore interpret the Mungrinup Gneiss to be part of the Northern Foreland, i.e. reworked Yilgarn Craton.

The Mungrinup Gneiss shows at least four phases of deformation: 1) isoclinal folding of gneissic layering; 2) regional, mostly north-trending, open to tight folds; 3) regional northeast- to east-trending tight folds; and 4) magmatic shear zones. Large-scale fold interference patterns from phases 2 and 3 are prominent on aeromagnetic images, indicating multiple folding is the dominant structural feature of the Mungrinup Gneiss. Phases 1 and 2 are possibly Late Archean in age, but phase 3 structures are oriented parallel to the cross-cutting regional trend of the Albany–Fraser Orogen. The gneissic layering is locally boudinaged, but it is not clear whether this occurred during deformation phase 2 or 3. Phase 2 is cut by major bounding faults to the south (e.g. Red Island), and all phases are cut by the Jerdacuttup Fault to the north.

In contrast to the Mungrinup Gneiss, the Dalyup Gneiss of the Biranup Complex has igneous protolith ages of c. 1680 Ma, and probably represents part of an exotic terrane. The Dalyup Gneiss is dominated by granulite facies orthogneisses, extends from at least the Bremer Bay area in the west, to inboard of the Fraser Complex in the east (Nelson et al., 1995), and forms the main suture to the craton margin. In the Bremer Bay area the structure

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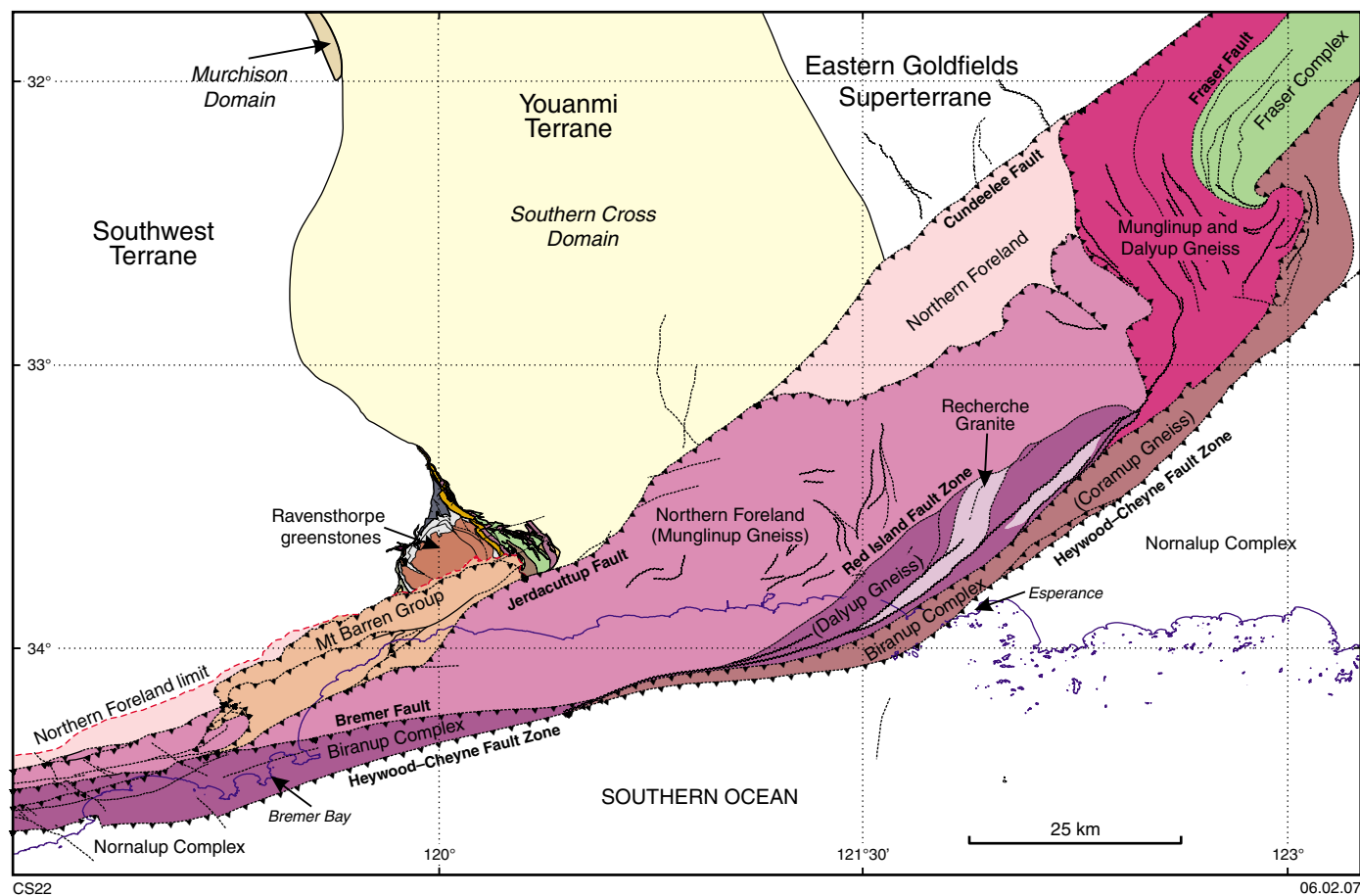


Figure 1. Simplified map of the Albany–Fraser Orogen and southern Yilgarn Craton extracted from the new interpreted bedrock geology map (GSWA, in prep.), based on GSWA's regional geological mapping over the map area between 1970 and the present

is complex but is dominated by large-scale boudinage, indicative of at least one extensional event within the orogen. Boudinaged Dalyup Gneiss samples have yielded protolith igneous crystallization ages of 1680 ± 7 and 1689 ± 11 Ma, and the latter underwent new metamorphic zircon growth at 1197 ± 12 Ma. Crystallized melts within the boudin necks yielded crystallization ages of 1178 ± 4 and 1187 ± 5 Ma, and the latter preserves evidence of subsequent metamorphism at 1167 ± 15 Ma. In the Esperance area, the Dalyup Gneiss is dominated by tight to isoclinal folding, shear zones, and mylonite zones, and is in fault contact with the strongly deformed Coramup Gneiss (also part of the Biranup Complex, Fig. 1), which contains both para- and orthogneisses. New SHRIMP U–Pb zircon dates show that garnet-bearing granodioritic gneiss has an igneous crystallization age of 1688 ± 12 Ma (indistinguishable from the Dalyup Gneiss), and underwent metamorphism at 1231 ± 9 Ma. Metamorphosed quartz sandstone (in the Coramup Gneiss) from the same area has a maximum depositional age of c. 1750 Ma, was metamorphosed at 1215 ± 5 Ma, and preserves evidence for post-metamorphic resetting at 1184 ± 7 Ma.

The structural complexity of the Biranup Complex rocks is evident on aeromagnetic images, which show that most of the Dalyup and Coramup Gneisses are contained within major shear zones that wrap around the craton margin. These are interpreted to represent the remnants of terrane amalgamation, possibly during Stage I of the Albany–Fraser Orogeny (1345–1260 Ma), as the main regional structures close to the craton margin are cross-cut by mafic dykes belonging to the c. 1210 Ma Gnowangerup Dyke Suite. Metamorphic ages recorded in both the Munghlinup Gneiss and Biranup Complex rocks between c. 1210 and 1140 Ma represent reworking during Stage II.

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The western Yilgarn: why the Youanmi Terrane?

by

S. Wyche

The earliest subdivision of the Yilgarn Craton (Gee et al., 1981) contained four components: the Eastern Goldfields, Southern Cross, and Murchison Provinces and the Western Gneiss Terrain. However, the relationship between these regions was enigmatic, with the boundaries not strictly based on observed geological features. Various authors (e.g. Myers, 1993) subsequently developed schemes in which the Yilgarn Craton was divided into superterrane and terranes based on greenstone belt shapes and trends, rock associations, and ages of greenstone deposition, granite intrusion, and deformation. Some of these schemes carried an implication of Yilgarn Craton-wide accretionary tectonics.

New regional mapping and precise sensitive high-resolution ion microprobe (SHRIMP) geochronology, and new geochemistry and isotope data obtained by the AMIRA International Limited regional granite study (Cassidy et al., 2002), suggest that in the central and western Yilgarn Craton, the Southern Cross and Murchison 'Provinces' of Gee et al. (1981), or 'Granite–Greenstone Terranes' of Tyler and Hocking (2001) do not represent allocthonous terranes that have come together during an accretionary event. Rather, they more likely formed part of the 3.0–2.7 Ga proto-Yilgarn Craton to which the elements of the Eastern Goldfields Superterrane accreted after 2.7 Ga. Because they are no longer considered to be terranes in the strict sense, they are now called domains within the Youanmi Terrane (Cassidy et al., 2006; Fig. 1).

The Youanmi Terrane is bound to the west by the Darling Fault system, to the north by the Capricorn Orogen, to the southeast by the Albany–Fraser Orogen, and to the southwest by the South West Terrane. The boundary with the Eastern Goldfields Superterrane is marked the Ida and Waroonga Faults. The boundary with the Narryer Terrane is taken to be Yalgar Fault (Myers, 1993), but the nature of this fault and the relationship between greenstones of the Narryer and Youanmi Terranes will be investigated during the current mapping program. The boundary with the South West Terrane is poorly defined, and will be investigated in future mapping programs.

Southern Cross Domain

The Southern Cross Domain contains at least two greenstone successions. The older (3.0 Ga) succession

typically contains abundant banded iron-formation and chert interbedded with mafic and subordinate ultramafic rocks overlain by a mafic-dominated succession. Without more detailed geochronology it is difficult to demonstrate correlations of individual units between greenstone belts and, in some instances, within greenstone belts. In the centre and north, greenstone belts along the eastern and western sides of the domain commonly preserve a quartzite or quartz-rich metasedimentary unit with maximum depositional ages greater than 3.1 Ga at the base of the exposed succession that is either in faulted or intrusive contact with much younger granite. In the far south the Ravensthorpe greenstone belt contains 2.95 Ga calc-alkaline volcanic rocks that host copper–zinc–gold mineralization in an association that has more in common with the succession in the Golden Grove region in the Murchison Domain than with other greenstone belts in the Southern Cross Domain.

The younger succession in the Southern Cross Domain is best known in the Marda–Diemals greenstone belt where it consists of the 2.73 Ga calc-alkaline Marda Complex and clastic sedimentary Diemals Formation. However, other greenstone belts also contain felsic volcanic rocks. For example, 2.72 Ga dacite in the Gum Creek greenstone belt appears to be part of a widespread, but very poorly exposed, younger greenstone succession that also contains clastic sedimentary rocks, including abundant graphitic shale.

Murchison Domain

Greenstones in the Murchison Domain contain a similar mix, but broader range, of rock types than those in the Southern Cross Domain. Previously established stratigraphic schemes (e.g. Watkins and Hickman, 1990) have a lower greenstone succession similar in character to that in the Southern Cross Domain with a complex upper greenstone succession. However, new precise SHRIMP geochronology has demonstrated that simple stratigraphic correlations are difficult across such a broad area (e.g. Pidgeon and Hallberg, 2000). U–Pb zircon geochronology shows 2.95 Ga felsic rocks at Golden Grove and in the Weld Range. However, 2.8 Ga volcanic rocks have been identified at Golden Grove, in the Mount Magnet area, near Windimurra and Youanmi, and in the Pollele Syncline near Meekatharra. In the latter instance the 2.8 Ga age

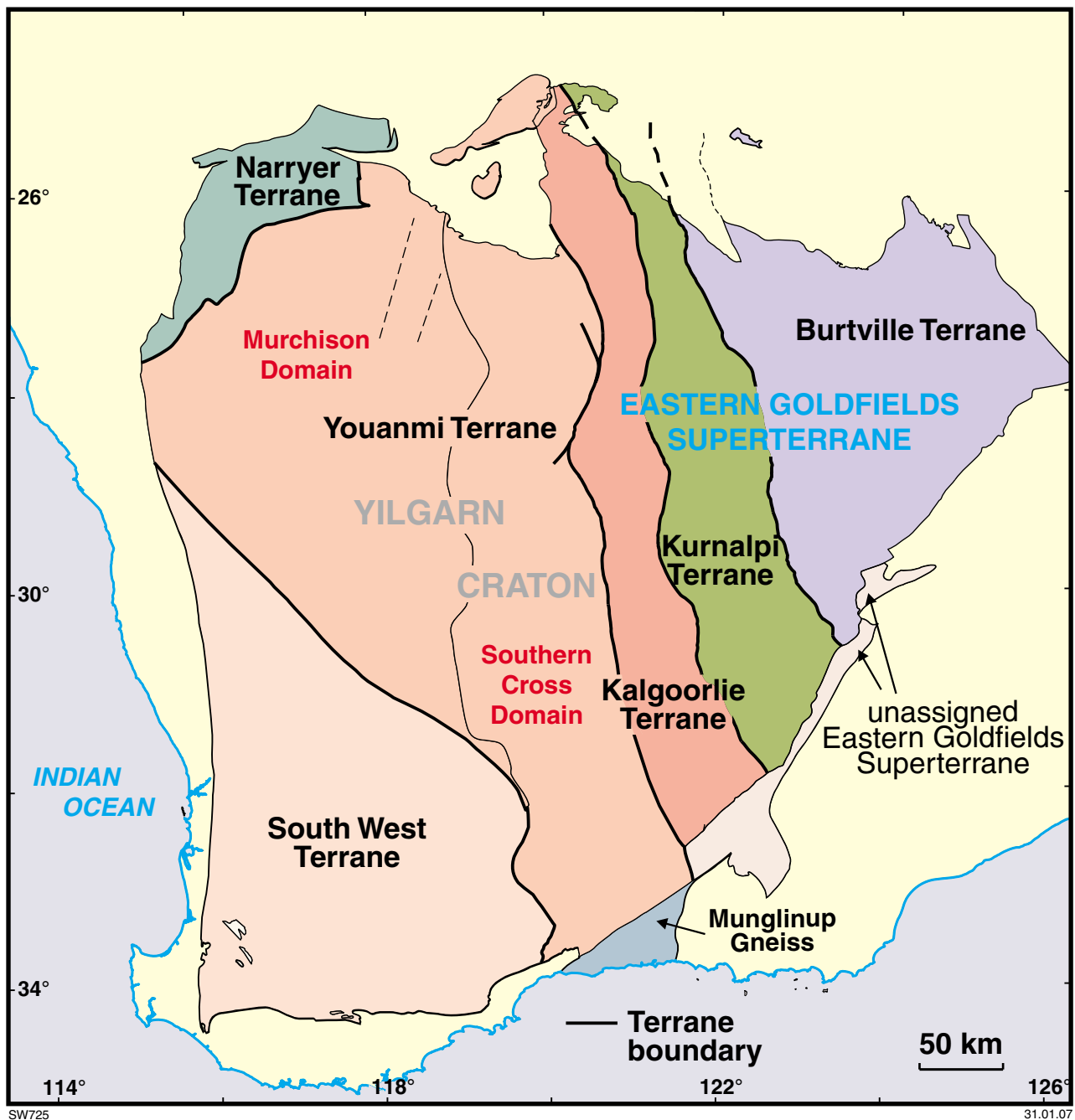


Figure 1. Tectonic division of the Yilgarn Craton, showing subdivisions into terranes and domains (modified from Cassidy et al., 2006)

was obtained on a tuff interbedded with a number of komatiite flows, clearly demonstrating the presence of some komatiite volcanism of this age. Widespread felsic rocks (andesite–rhyolite) range in age from 2.76 to 2.69 Ga. Clastic sedimentary rocks including graphitic shales like those found locally in the Southern Cross Domain are locally associated with the younger felsic volcanic rocks.

The extensive suite of layered mafic and ultramafic intrusions in the middle of the Youanmi Terrane may represent a mantle plume event to which the wide-

spread 2.8 Ga magmatism in the Murchison Domain is related.

Other evidence

The Youanmi Terrane is isotopically distinct from other terranes. A pre-3.0 Ga age for the initial formation of the Youanmi Terrane is based on Sm–Nd and Hf isotope depleted-mantle model ages for granites and felsic volcanic rocks that indicate a 3.3–3.0 Ga felsic crustal component. Detrital and xenocrystic zircon ages suggest 4.3–3.1 Ga

sources for some rocks in the Murchison and Southern Cross Domains. They also suggest that greenstones of the Narryer Terrane that also contain pre-4.0 Ga detrital zircons may have had a common history with some of those in the Youanmi Terrane.

The Murchison and Southern Cross Domains have comparable structural histories with early shallow to recumbent structures overprinted by upright folds, all overprinted by northwest to northeasterly trending shear zones. However, east–west folding that appears to have occurred early during the upright folding phase in the Murchison Domain has not been recognized in the Southern Cross Domain. It is also likely that the Murchison Domain shows evidence of Proterozoic deformation that is not so apparent in the Southern Cross Domain. Major movement on the regional-scale shear zones that have previously been suggested as granite–greenstone terrane boundaries post-dates all greenstone deposition and most granite intrusion.

Mineralization

Gold mineralization in the Youanmi Terrane is found in a variety of geological settings. Base metal deposits in the widely separated Ravensthorpe and Golden Grove areas are associated with 2.95 Ga calc-alkaline volcanic successions. Iron deposits are found throughout the Youanmi Terrane with economic deposits in both the Southern Cross and Murchison Domains. Economic nickel mineralization has only been identified in older-than 2.9 Ga komatiites in the southern part of the Southern Cross Domain. At least some of the komatiites in the Murchison Domain may be related to 2.8 Ga mantle plume activity that produced the vanadium-bearing layered intrusions in the north of the Youanmi Terrane.

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Archean tectonics as a guide to mineralization potential in the Pilbara

by

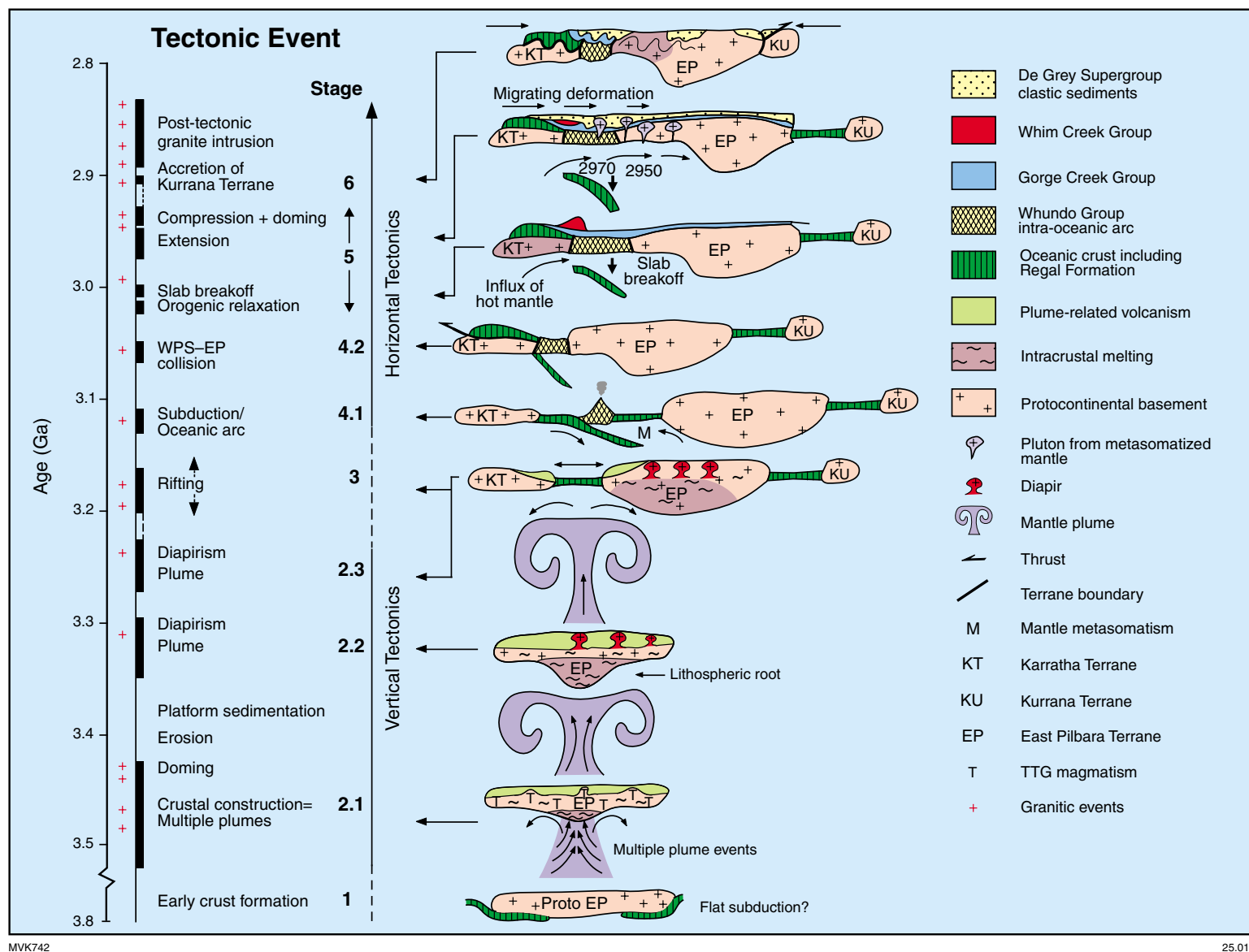
M. J. Van Kranendonk, D. L. Huston¹, and A. H. Hickman

Different mineralization styles in the Archean Pilbara Craton can be ascribed to changes in tectonic style throughout its approximately 800 m.y. evolution, from an early stage of plume-dominated tectonics (3.53–3.2 Ga) to later stages dominated by horizontal tectonics (3.2–2.83 Ga, Fig. 1; Van Kranendonk et al., in press). The Pilbara Craton contains five geologically distinct terranes. The 3.53–3.17 Ga East Pilbara Terrane represents the ancient nucleus of the craton, and comprises predominantly igneous rocks that were produced as a result of three distinct mantle plume events erupted onto yet older, but now largely cryptic, sialic crust (Van Kranendonk and Pirajno, 2004). These events include the 3.53–3.42 Ga Warrawoona Group and coeval Callina (3.50–3.46 Ga) and Tambina (3.45–3.42 Ga) Supersuites; the 3.35–3.31 Ga Kelly Group and coeval Emu Pool Supersuite (3.32–3.29 Ga); and the 3.27–3.24 Ga Sulphur Springs Group and coeval Cleland Supersuite (3.27–3.22 Ga). Heat from plumes caused voluminous ultramafic–mafic–felsic magmatism, uplift, and extension of the crust. Each plume event was accompanied by intracrustal melting that generated early tonalite–trondjemite–granodiorite (TTG), and then progressively more evolved granitic magmas that were emplaced into the upper crust during periods of partial convective overturn. Mantle melting events caused severe depletion of the subcontinental lithospheric mantle, making the East Pilbara Terrane a stable, buoyant, unsubductable protocontinent by 3.2 Ga (Smithies et al., 2005b). Mineralization styles associated with these events include synvolcanic copper–zinc–lead–barite volcanic-hosted massive sulfide (VHMS) deposits and hydrothermal barite–zinc–lead–copper sedimentary replacement deposits; polymetallic and base metal deposits in c. 3.45 Ga felsic porphyries; mesothermal gold deposits in shear zones around granitic domes (3.31 and 3.24 Ga); and local copper–molybdenum porphyry mineralization (3.31 Ga). Underexplored mineralization styles include komatiite-hosted nickel deposits in plume volcanic rocks, and nickel–copper – platinum group element deposits in East Pilbara Terrane rift-margin volcanic rocks.

After 3.2 Ga, horizontal tectonics dominated over vertical tectonics, leading to 3.12 Ga subduction, and 3.07 Ga accretion of the West Pilbara Superterrane with the East Pilbara Terrane. The West Pilbara Superterrane comprises three terranes separated by major structures. The 3.27 Ga Karratha Terrane includes komatiites that host nickel–copper mineralization. It is separated from c. 3.2 Ga N-MORB-type basaltic rocks of the Regal Terrane by a major folded thrust. These terranes are separated from the 3.12 Ga Sholl Terrane by the crustal-scale, predominantly strike-slip Sholl Shear Zone. The 10 km-thick Whundo Group of the Sholl Terrane has stratigraphic and geochemical characteristics of modern oceanic arcs (e.g. boninites and evidence for flux melting), including VHMS copper–zinc mineralization (e.g. Whundo deposit; Smithies et al., 2005a). The c. 3.2 Ga Kurrana Terrane comprises a variety of granitic rocks emplaced within undated greenstones in the southeastern part of the craton.

Terrane accretion and West Pilbara Superterrane – East Pilbara Terrane collision at 3.07 Ga (Prinsep Orogeny) was followed by development of an intracontinental sag basin (3.02–2.93 Ga De Grey Supergroup) and by west-to-east prograding granitic plutonism (3.00–2.93 Ga) and compressional deformation (2.95–2.91 Ga), most likely as a result of a combination of orogenic relaxation and slab breakoff (Fig. 1). Associated mineralization includes banded iron-formation of the 3.02 Ga Gorge Creek Group (e.g. Yarrrie, Sunrise Hill, and Goldsworthy deposits), 3.01–2.95 Ga copper–zinc VHMS deposits (e.g. Whim Creek deposit), 2.95 Ga vanadium–titanium–magnetite in mafic–ultramafic intrusions, and 2.95 Ga nickel–copper – platinum group element – orthomagmatic gold in mafic–ultramafic sills associated with intrusion of sanukitoids. Orogenic gold deposits formed in 2.95–2.91 Ga thrusts and shear zones across the West Pilbara Superterrane and basins of the De Grey Supergroup (Mallina and Mosquito Creek Basins), analogous with gold-mineralized Neoproterozoic orogens. Late-tectonic ultramafic intrusions (2.92 Ga) were emplaced during transtension and host nickel–copper – platinum group element mineralization (e.g. Munni Munni and Radio Hill Intrusions). Post-tectonic granites (2.89–2.83 Ga) host tin–tantalum–lithium mineralization in a linear zone from the Kurrana Terrane to the eastern Mallina Basin.

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