

Fieldnotes



Government of Western Australia
Department of Mines and Petroleum

Geological Survey of
Western Australia



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IEP: cutting-edge tool for WA explorers

Mineral exploration relies heavily on the interpretation of spatially referenced geoscience datasets of ever-increasing variety and resolution. Traditionally, the successful interpretation relies on subjective expert knowledge, and is therefore hampered by human bias. It has become a challenge for geoscientists to extract the most valuable information from diverse datasets, in order to integrate it all into a coherent interpretation.

A collaborative project between the Geodata Algorithms Team at the Centre for Exploration Targeting (CET) and the 3D Geoscience section at the Geological Survey of Western Australia (GSWA) aims to address this challenge by developing tools that facilitate the use of spatial datasets in Western Australia. The Integrated Exploration Platform (IEP) is an outcome of this project. The IEP was developed to combine human intuition with computer software to maximize geological knowledge, while minimizing visual bias in the interpretation of multiple spatial datasets. It has been developed as a geographical information system (GIS) module that facilitates interpretation of multiple spatial datasets through innovative interactive visualization and image-analysis methods. The first publicly available version of the IEP was launched at the GSWA Open Day 2016 and is freely available to explorers in Western Australia.

The IEP was implemented as an add-in for ESRI ArcGIS, and consists of visualization tools that assist integrated interpretation of different datasets. It includes support tools that improve confidence through data evidence assessment of interpreted features.

Visualization tools

Interactive blending tools in the IEP allow datasets from multiple sources to be simultaneously visualized. Blending combines datasets to form a single display in a way that effectively represents information from each dataset. Within the tool, the user manipulates a blend cursor that determines the component weighting of each dataset in the blend. The IEP contains different interactive multi-image blending tools designed to support different types of data used in mineral exploration. This includes 2D geophysical, radiometric and mineral spectral data, and

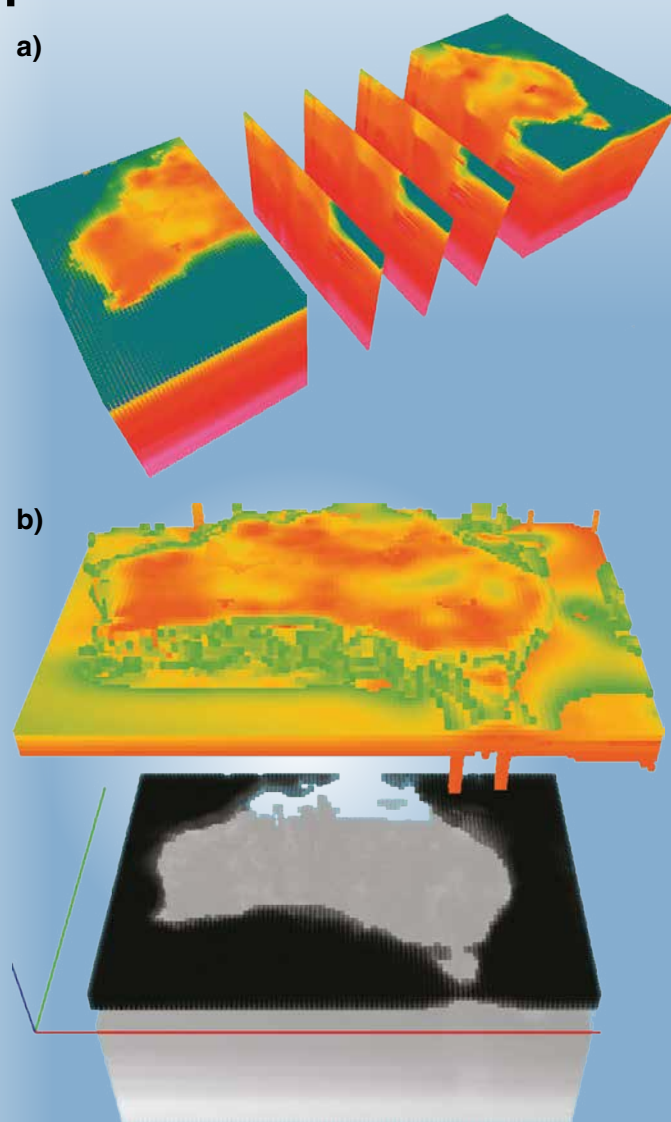


Figure 1. 'Book Slice' visualization mode is one of the options included in the IEP

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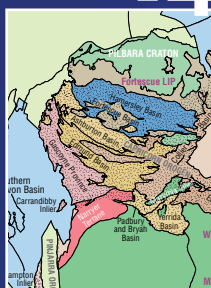
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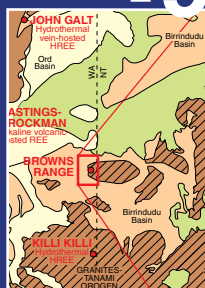
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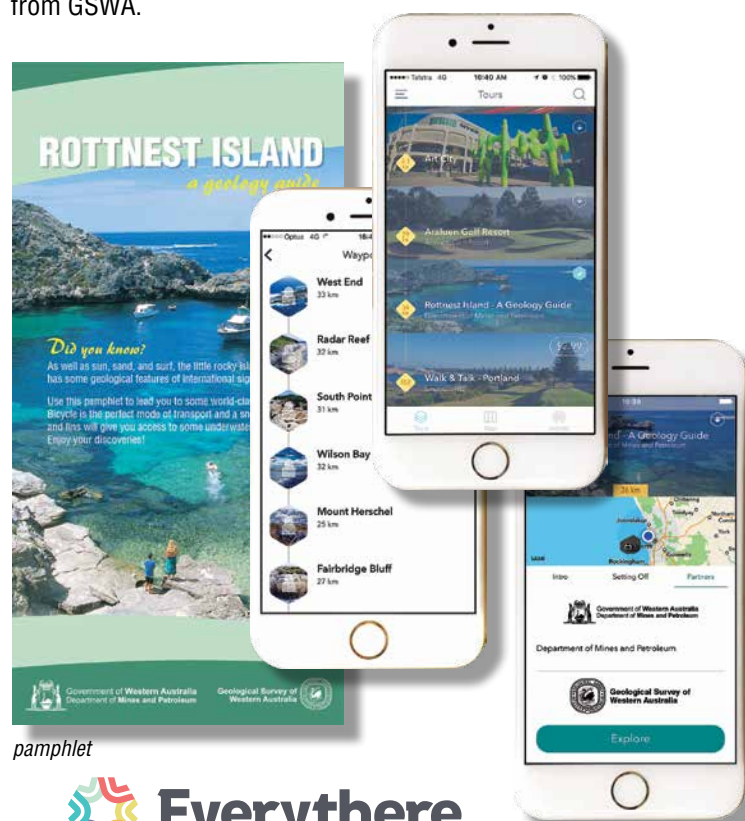
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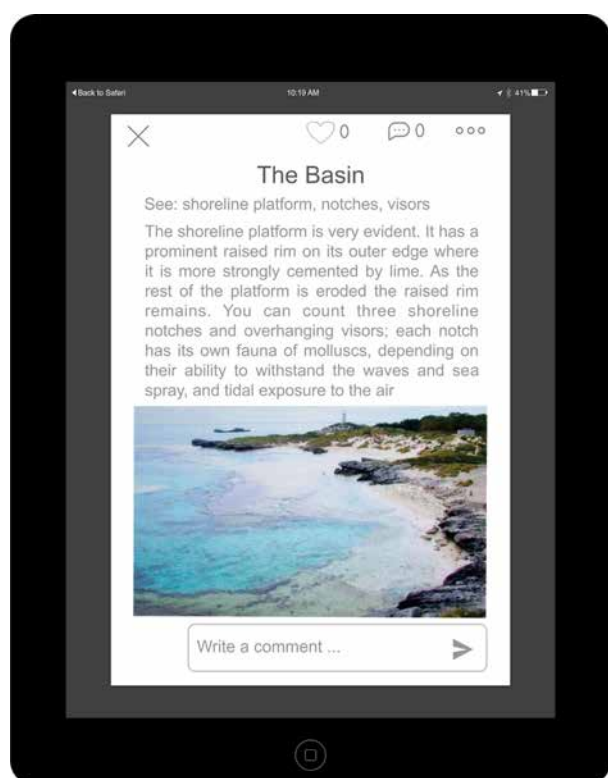
Geology in your pocket, and on your tablet

The Geological Survey of Western Australia (GSWA) has teamed up with **Everythere** to create a Beta version of a new app to explore the geology of Rottnest Island using your smart device.

As you walk near key geological locations around Rottnest Island, you'll get notifications about the geology and landforms of each spot. Each location gives you geological information written by geologists from GSWA.



pamphlet



To start exploring Rottnest Island, follow these steps for Apple or Android smart devices:

For Apple

1. *Download* the 'Everythere' app from the iTunes App Store
2. *Open* the app
3. *Tap* on the 'Tours' tab
4. *Swipe* left on the 'Rottnest Island — A Geology Guide' banner
5. *Tap* on 'Download' to pre-download all media ready for your visit
6. *Start* the interactive tour by tapping on the 'Rottnest Island — A Geology Guide' banner followed by the 'Explore' button
7. *Begin* walking or cycling around the island. As you pass each location coordinate, the digital media will activate on your device.

For Android

1. *Search* for 'appsppl' in the Google Play Store
2. *Download* the 'Everythere' app
3. *Open* the app
4. *Search* the tours
5. *Tap* on the hexagon on 'Rottnest Island — A Geology Guide' to download all the media ready for your visit
6. *Tap* on the photo to start the interactive tour (Introduction, Setting off, Explore)
7. *Begin* walking or cycling around the island. As you pass each of the location coordinates, the digital media will activate.

Please note that the locations will not be visible until you are on the island and within range.

Grab your bicycle, snorkel, fins and phone (wrapped in plastic?) and head over to Rottnest Island for some fun lessons in geology.

We would love your feedback. Just follow the prompts on the app and leave your comments.

The pamphlet 'Rottnest Island — a geology guide' is also available at the Visitor Centre should you prefer the hardcopy tour.

For more information, contact Robin Bower(robin.bower@dmp.wa.gov.au).

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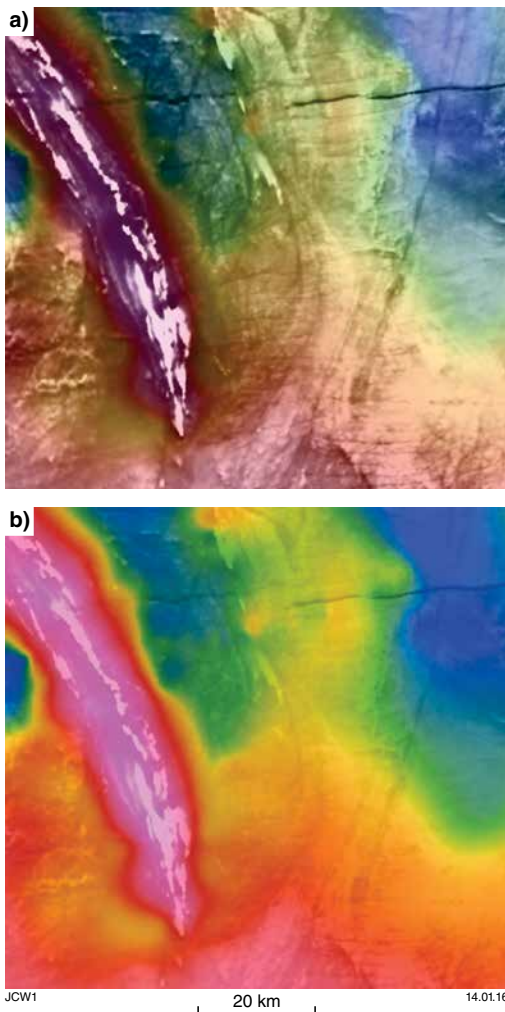


Figure 2. An example of the blend output from one of the 2D blend tools. Images show different blend contributions of two datasets using the Image Wheel blender; ground gravity data is shown in colour and aeromagnetic data in greyscale.

visualization techniques for 3D volumetric data. Additionally, the IEP provides a dynamic range compression (DRC) data enhancement method that allows the user to isolate features of a specific frequency range.

The IEP visualization methods exploit 'interactivity' and 'motion' for data interrogation. It is known that static image blends provide limited clarity on the contribution from each dataset. However, user-controlled transition in blending provides better insight into understanding similar versus conflicting information between datasets and how each dataset contributes to the final blend (Fig. 2). Interactive blending is applied to visualize 3D volumetric data, allowing features normally hidden within a 3D volume (Fig. 1) to show two examples of 3D visualization. In the 'Book Slice' visualization mode three adjacent slice data 'windows' remain fixed in position, while the dataset is moved across these slice windows. In the 'Threshold Offset' visualization mode voxels within a selected range of values are placed above the volume; voxels outside this range remain at greyscale, and negative value voxels are placed below

Interpretation support tools

IEP provides tools to evaluate quantitative feature evidence to aid the structural interpretation of geophysical data. By using image-analysis algorithms (phase symmetry and phase congruency) for

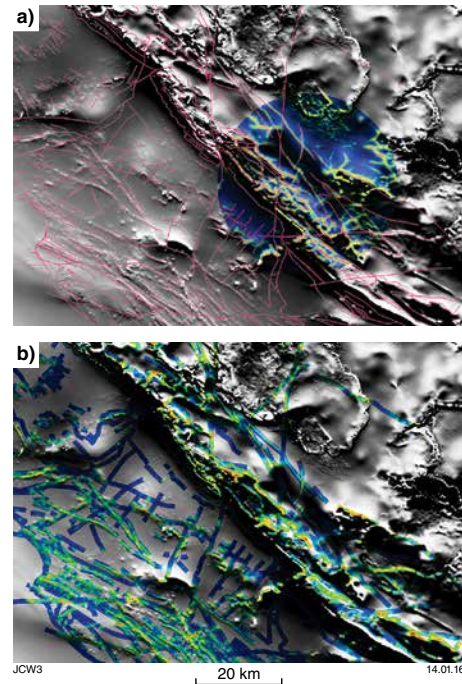


Figure 3. Visualization of feature evidence (cool colours indicate weak feature evidence and warmer colours indicate strong feature evidence) together with the original magnetic data in greyscale and the interpretation lines in red: (a) the spotlight visualization mode: a spotlight region overlain with the ridge feature map is updated in real time as the user moves the cursor; (b) the on-lines visualization mode: the edge feature evidence is shown along each of the interpretation lines, giving an overview of areas supported by feature evidence.

contrast-invariant feature detection, the IEP produces a number of feature-strength maps from 2D geophysical datasets. These feature-strength maps allow the user to identify the locations of ridge-like, valley-like, and step edge-like features. These feature-strength maps provide effective feedback on user-interpreted lines.

The feature-strength map is combined with the original data through contributions to the colour and brightness. This is an effective way to visualize feature evidence while maintaining the primary contribution from the original data. It uses two modes: an interactive spotlight region tied to the mouse cursor position (Fig. 3a), and a buffered rectangle along each interpretation line (Fig. 3b). As the user hovers the cursor over interpretation lines, it generates a display of the quantitative values for the line across the ridge, valley, and edge feature-strength maps. This provides an effective overview of how well aligned the interpreted line is to each feature type according to the input data.

Both the visualization and the quantitative analysis of the feature evidence provide a framework for feedback so that the user may make informed adjustments and improvements to the interpretation, based on the evidence in the input data.

The IEP visualization tools have been built to facilitate user-driven and computer-assisted workflows, with the aim to maximize the benefits of human intuition and computing power, while minimizing the weaknesses from human bias, and algorithm inflexibility.

For more information, contact
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Kurnalpi Terrane prospectivity — evidence from the Fisher East nickel sulfide prospects

Until recently, the Kurnalpi and Burtville Terranes of the far eastern Yilgarn have been considered relatively poorly endowed in komatiite-hosted nickel sulfide deposits compared to the neighbouring Kalgoorlie Terrane, which is known for hosting world-class examples (Fig. 1). However, the presence of large mafic-ultramafic belts and recent discoveries of such deposits

suggest that these terranes might be equally prospective, but underexplored. The Geological Survey of Western Australia (GSWA) has begun testing this possibility by comparing lithogeochemical and mineralogical characteristics of nickel sulfide-mineralized komatiites at the newly discovered Fisher East prospects, with komatiites from the highly nickel-endowed Kalgoorlie Terrane.

Fisher East komatiites are extensively deformed and pervasively altered to talc-carbonate assemblages, with no preservation of primary textures. Nevertheless, it is possible using secondary textures, hyperspectral data and geochemistry to distinguish individual flow units having upper A zones (probably originally spinifex textured) and lower B zones (olivine cumulates).

B zones are commonly much thicker than A zones (Fig. 2), and contain higher proportions of talc, MgO and Ni. These characteristics, in association with generally elevated Ni/Ti and Ni/Cr, and low MgO/FeO ratios, suggest that komatiites at Fisher East were erupted as high-flux, channelized sheet flows with significant olivine cumulates. A shallow mantle melt source is indicated by Al_2O_3/TiO_2 ratios, and high degrees of crustal contamination are implied by elevated incompatible trace element ratios.

The komatiites in the northern part of the Kurnalpi Terrane therefore show characteristics that are favourable for hosting large nickel sulfide deposits. Further work will examine the volcanological settings and nickel fertility of komatiites throughout the Kurnalpi–Burtville region, providing a better understanding of the evolution of this part of the Yilgarn Craton and its potential to be a major new nickel province in Western Australia.

For more information, contact
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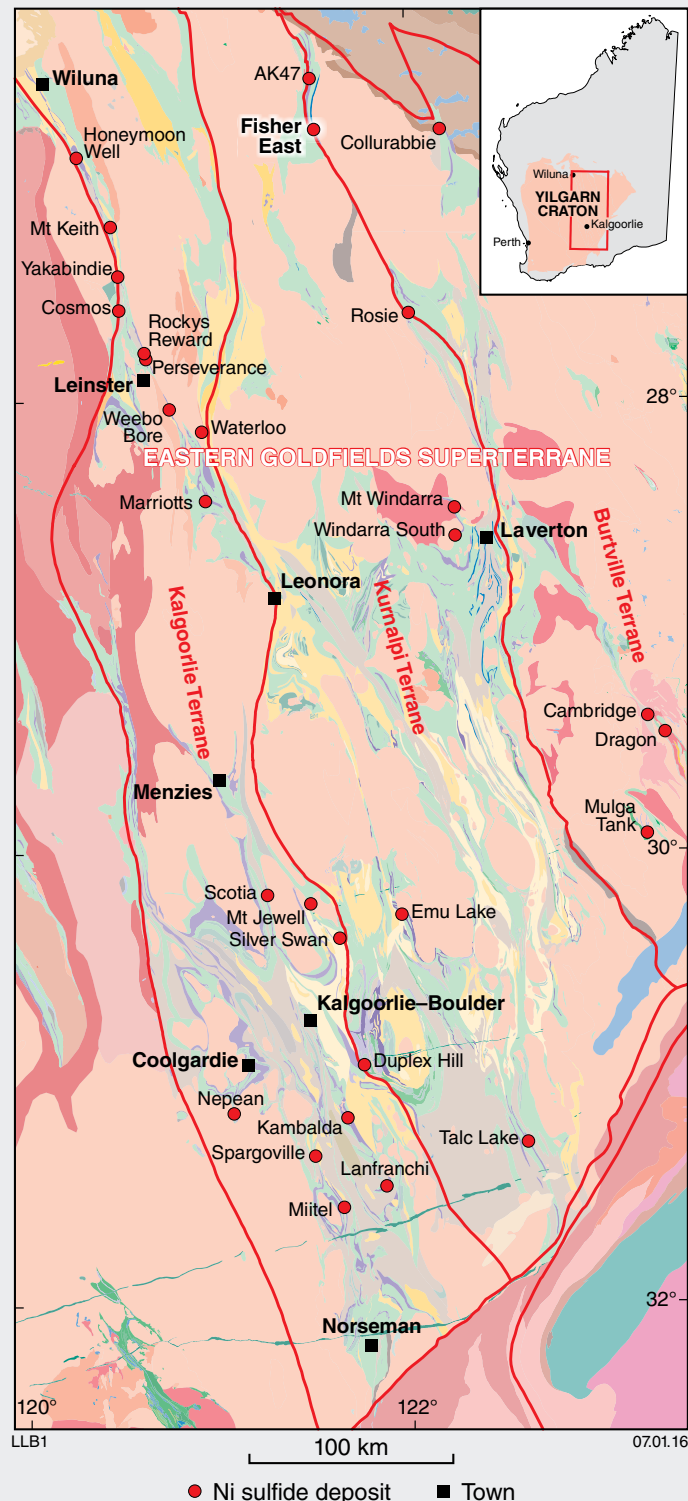


Figure 1. Major greenstone belts of the Eastern Goldfields Superterrane, with major nickel sulfide deposit/prospects highlighted. The Fisher East prospects lie in the far northeastern corner of the Kurnalpi Terrane.

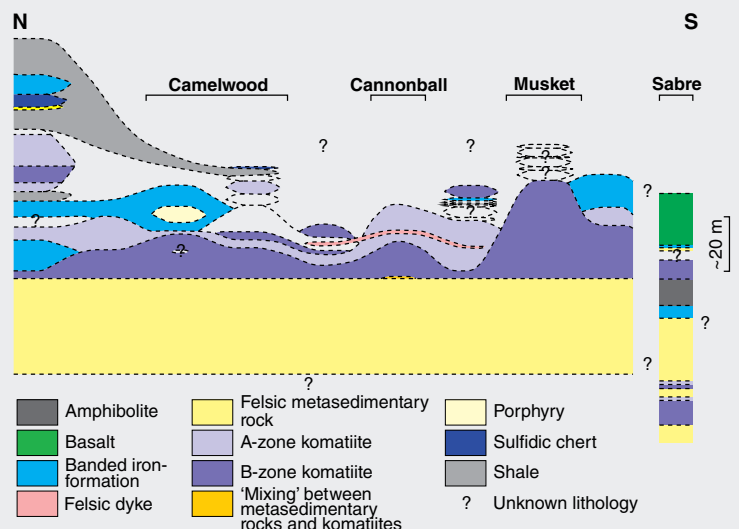


Figure 2. Interpretive flow field model of the Fisher East prospects based on core logging, geochemistry and hyperspectral data. The four areas outlined show prospects that host significant nickel sulfide mineralization. Note the separation of the Sabre prospect, as this prospect is some distance away from the other drillholes. The basal komatiite contact has been used as the horizontal datum to depict variation in thickness of flows. Note no horizontal scaling.

New 1:250 000 geological map of the east Pilbara Craton should assist future mineral exploration

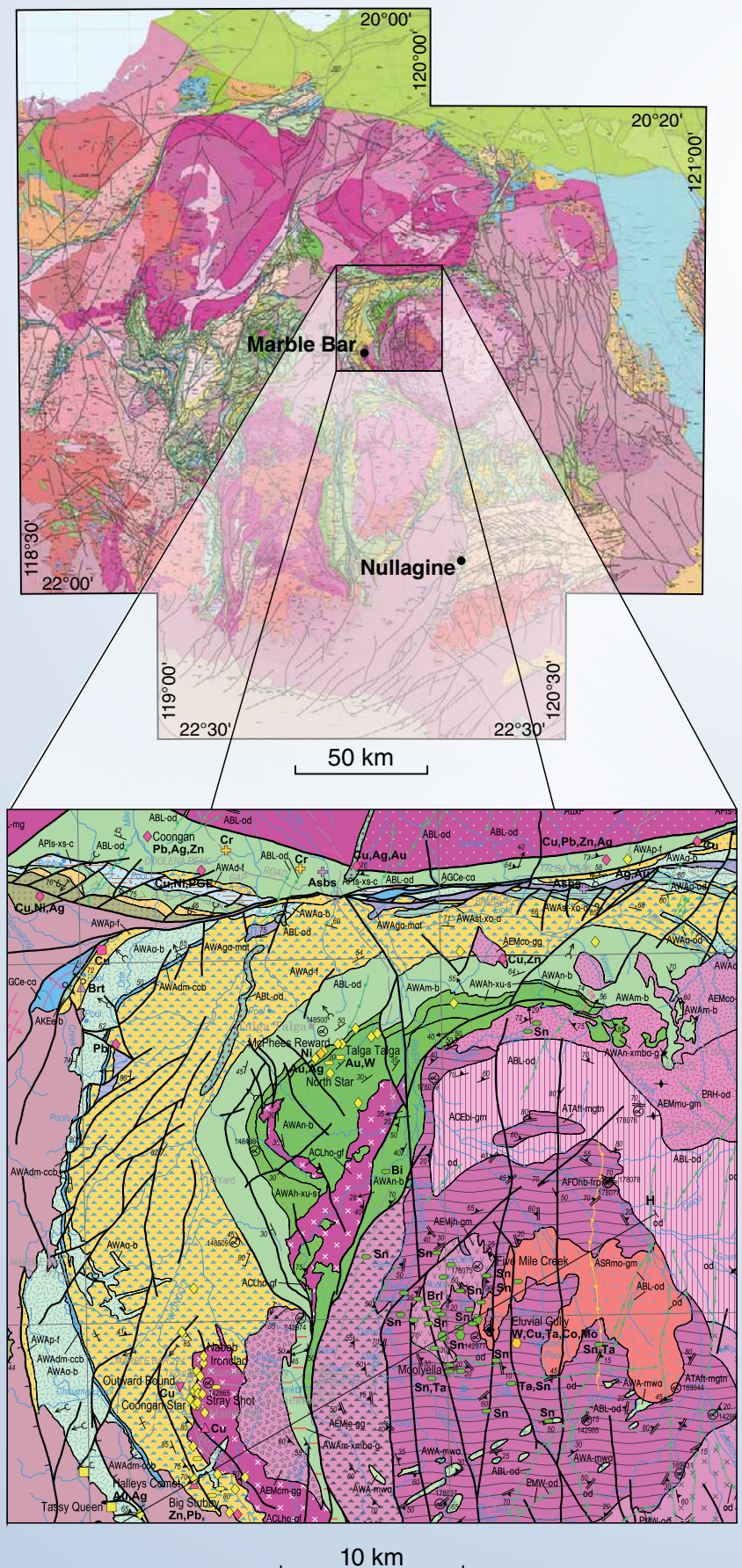
A new geological map released in February 2016 shows the interpreted bedrock geology and mineralization of the east Pilbara Craton at 1:250 000 scale. Covering 55 000 km² of arguably the world's best-preserved and best-exposed Paleoproterozoic–Mesoproterozoic crust, the map was released to accompany a future Geological Survey of Western Australia (GSWA) Report on the area's crustal evolution and mineralization. Simplification of 20 published 1:100 000 geological series maps using GIS software enabled compilation of three plates for the Report.

The most striking geological feature of the east Pilbara is its exceptional exposure of the 'dome-and-keel' type of crustal structure that is present in many Archean terranes worldwide. Visible on satellite imagery and consisting of broad granitic domes separated by narrow greenstone belts, the origin of this structure has been controversial. However, GSWA mapping over the past 45 years has established that in the east Pilbara it was formed by vertical tectonic processes in the Paleoproterozoic. This understanding should assist future mineral exploration in the Paleoproterozoic sections of the east Pilbara because metallogenic models based on Phanerozoic-style plate tectonic processes will be less applicable than in younger terranes.

Mineral deposits added to the east Pilbara map from MINEDEX reveal important structural and stratigraphic controls over mineralization. The distribution of gold mineralization, and potentially also Ni-Cu and PGE mineralization, should relate to deep crustal fractures providing conduits for hydrothermal fluids and magmatic intrusion. In the east Pilbara the distribution of these fractures is governed by the structural geology of the Paleoproterozoic domes. By contrast, the distribution of iron ore deposits, the most economically important mineral commodity in the east Pilbara, is stratigraphically controlled within Mesoproterozoic depositional basins resulting from Pilbara-wide plate tectonic events.

Interpreted bedrock geology of the east Pilbara Craton (1:250 000 scale), Report 143, Plates 1A–C are available to download from www.dmp.wa.gov.au/ebookshop

For more information, contact
Arthur Hickman (arthur.hickman@dmp.wa.gov.au).



West Musgrave Province mapped

The recently released 1:250 000-scale geological interpretation of the west Musgrave Province is a summary map and a culmination of the geoscience work carried out by the Geological Survey of Western Australia (GSWA) in the region from 2003 to 2014.

The key findings from the geoscience mapping carried out on the Mesoproterozoic rocks in the area include:

- The recognition of the widely distributed 1345–1293 Ma Wirku Metamorphics, the protoliths for which were deposited into the ancient Ramarama Basin.
- The much greater extent of the granitic and volcanic rocks belonging to the Wankanki Supersuite, formed and deformed during the 1345–1293 Ma Mount West Orogeny.
- The variable regional distribution of the Pitjantjatjara Supersuite granites, formed during the 1220–1150 Ma Musgrave Orogeny. These metaluminous and ferroan granites have A-type affinities and include orthopyroxene-bearing charnockite. They were formed from high temperature felsic magmas and were subjected to ultra-high
- temperature (UHT) metamorphism for the duration of the Musgrave Orogeny. The Pitjantjatjara Supersuite granites are widespread in the northeast and their abundance progressively decreases to the southwest.
- Intrusive ages of the Pitjantjatjara Supersuite vary systematically from c. 1220 Ma in the northeast to c. 1150 Ma in the southwest.
- The failed intracontinental Ngaanyatjarra Rift that generated voluminous mafic and felsic rocks during the 1085–1040 Ma Giles Event.
- The voluminous mafic–ultramafic Giles intrusions and granites of the Warakurna Supersuite, part of the Warakurna Large Igneous Province (LIP).
- The supervolcano-sized felsic volcanic and volcanoclastic sequences of the Bentley Supergroup that were deposited into the Talbot Sub-basin of the Bentley Basin.

For more information, contact
Heather Howard (heather.howard@dmp.wa.gov.au).

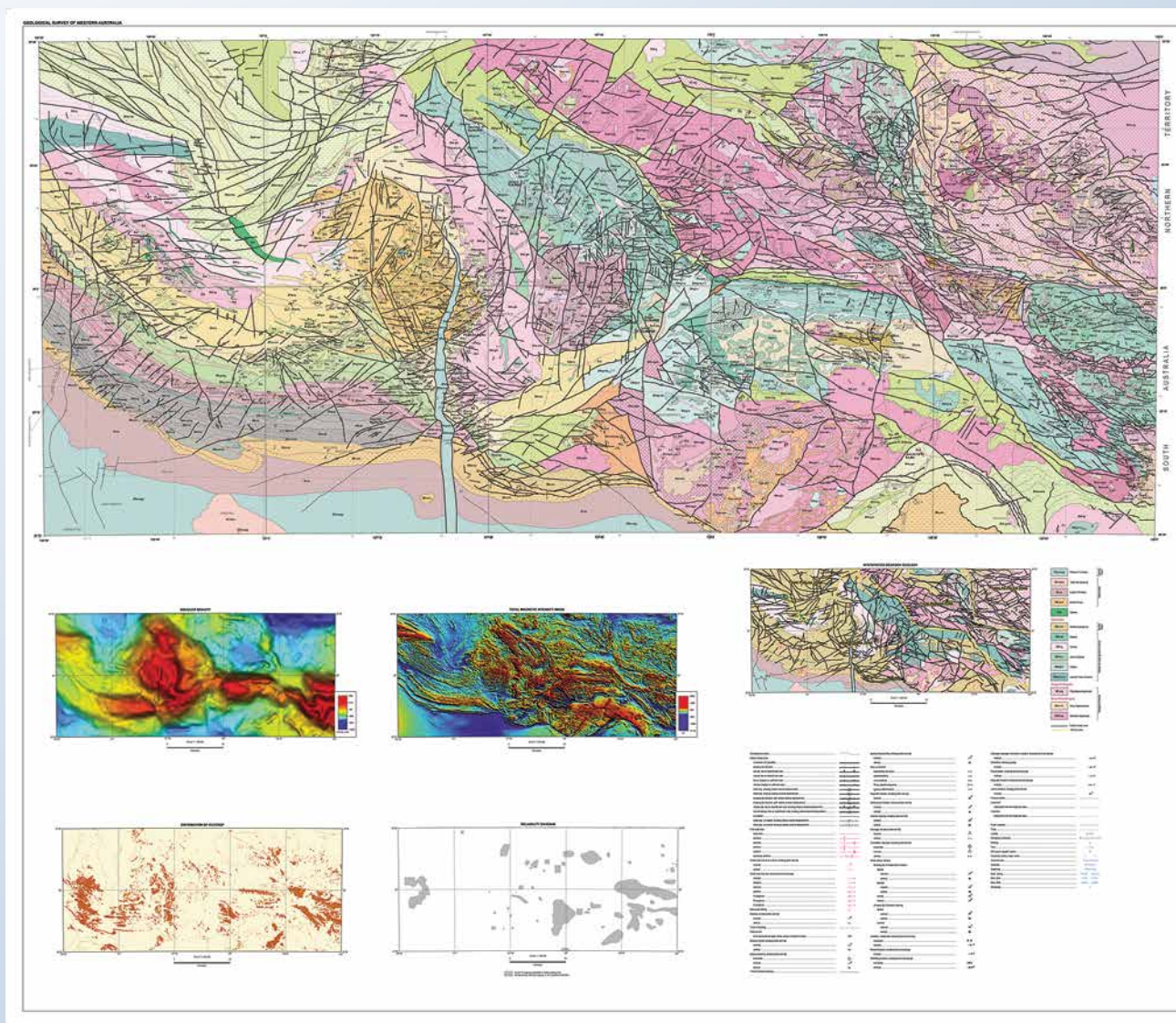


Figure 1. Section of 1:250 000 west Musgrave Province map

Glenburgh — a metamorphosed gold deposit in the Gascoyne Province

Gold deposits are rare in rocks that have been metamorphosed to upper-amphibolite and granulite facies grades, and there is much debate about whether known examples formed at these high temperatures, or instead represent metamorphosed or superimposed (retrograde) mineralization.

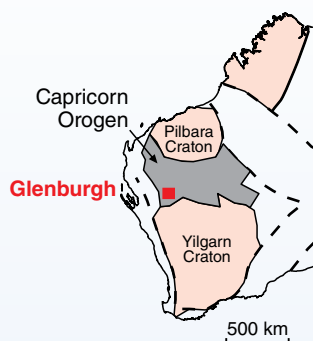


Figure 1. Location of Glenburgh Au deposit

One such example is the one-million ounce Glenburgh gold deposit, which lies in the Paleoproterozoic, upper-amphibolite grade Glenburgh Terrane, in the southern Gascoyne Province of Western Australia (Fig. 1). Gold at Glenburgh is disseminated as a free phase in discontinuous, east-northeast trending lodes, within a tightly folded and steeply north-dipping package of quartz–biotite–garnet gneisses and amphibolites, all offset by late faulting. Gold shows no clear association with any specific host lithology, nor is there any visually distinct alteration associated with mineralization.

Constraints have been placed on the relative and absolute age of gold mineralization at Glenburgh using thin-section petrography, gold–microstructure analysis and zircon U–Pb geochronology of the Zone 126 and Icon lodes. Gold grains show evidence of post-precipitation modification by metamorphism and deformation, such as high-purity veinlets (Fig. 2a), incoherent twinning (Fig. 2b) and low silver content. Sulfides, which are commonly genetically associated with gold in many deposits, are present at Glenburgh as rounded inclusions within peak-metamorphic garnet (Fig. 2c), indicating their presence in the rock prior to the peak of metamorphism. These features strongly suggest that the Glenburgh deposit has been metamorphosed. The absence of an obvious gold-associated alteration assemblage could also be interpreted as resulting from recrystallization and perhaps remobilization during deformation and metamorphism.

Gold mineralization at Glenburgh must have occurred after deposition of the original sedimentary host rocks — later than c. 2035 Ma from U–Pb dating of detrital zircons — and prior to c. 1991 Ma, the peak of metamorphism during the Glenburgh Orogeny (collision between the Yilgarn Craton and Glenburgh–Pilbara Craton).

Report 155 Unravelling the upper-amphibolite facies Glenburgh gold deposit, Gascoyne Province — evidence for metamorphosed mineralization is available to download from www.dmp.wa.gov.au/ebookshop.

For more information, contact
Lisa Roche (lisa.roche@dmp.wa.gov.au).

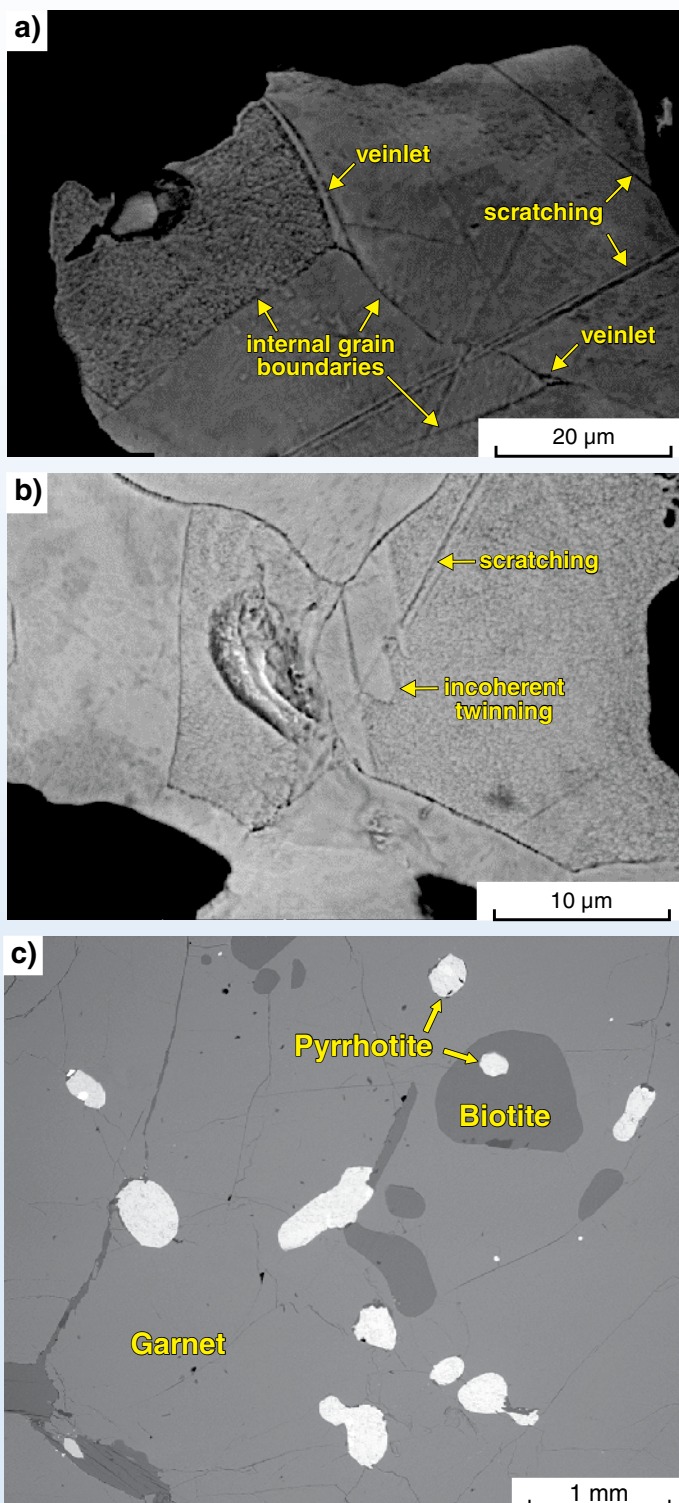


Figure 2. Scanning Electron Microscope images: a) evidence of intergranular high-purity gold veinlets; b) incoherent twinning within gold grain; c) rounded sulfide (pyrrhotite) inclusions within garnet

Alteration and age of the Browns Range heavy rare earth element deposits

Advanced technology manufacturers seek reliable sources for both light (LREE) and heavy rare earth elements (HREE), particularly the latter because of their higher value. The most advanced HREE project outside China is in the Browns Range region of northern Western Australia (Fig. 1a).

HREE mineralization occurs predominantly as hematite-dusted xenotime ($[Y,HREE]PO_4$) infill and matrix replacement in quartz veins and vein-quartz breccias that cut Paleoproterozoic clastic rocks of the Browns Range Metamorphics (Fig. 1b). Host rocks are intruded by c. 1820 to 1790 Ma granite plutons (Fig. 1c), and unconformably overlain by siliciclastic sandstones of the Birrindudu Group (Fig. 1c), which has a poorly constrained age lying somewhere in the range 1735–1640 Ma (Fig. 1c).

Host rocks immediately adjacent to siliceous REE mineralization are texturally indistinguishable from more distant rocks, but non-quartz components are replaced by hydrothermal smectite-illite clays, in haloes much broader than the REE mineralization. The nature and distribution of this alteration suggest permeation of relatively acid, oxidized hydrothermal fluids.

Xenotime from the Wolverine deposit has a SHRIMP U–Pb age of 1646 ± 5 Ma (Table 1). The granites intruding host metasediments, and the overlying sandstones are therefore

both older than the REE mineralization. This implies that ‘spent’ hydrothermal fluids could have passed through the cover rocks, potentially leaving mineralogical pathfinders to buried REE deposits, but also that the granites cannot have been sources of the hydrothermal fluids, nor direct drivers of mineralizing processes.

Other hydrothermal HREE deposits in the region at Killi Killi and John Galt (Fig. 1a) have ages of mineralization broadly similar to Browns Range (Table 1), suggesting that there was a widespread hydrothermal event at c. 1620–1650 Ma, and confirming the prospectivity of the entire region for (H)REE deposits. The magmatic or tectonic events that might have driven the evolution and circulation of these hydrothermal fluids remain unknown.

Deposit	Xenotime(U–Pb)	Citation
Browns Range	1646 ± 5 Ma	GSWA, in prep.
John Galt	1619 ± 9 Ma	GSWA, in prep.
Killi Killi / West Tanami	1632 ± 3 Ma	Vallini et al. (2007)

Table 1. Ages of the hydrothermal HREE deposit in the East Kimberley – West Tanami regions

For more information, contact
Sidy Moran-Ka (sidy.moran-ka@dmp.wa.gov.au).

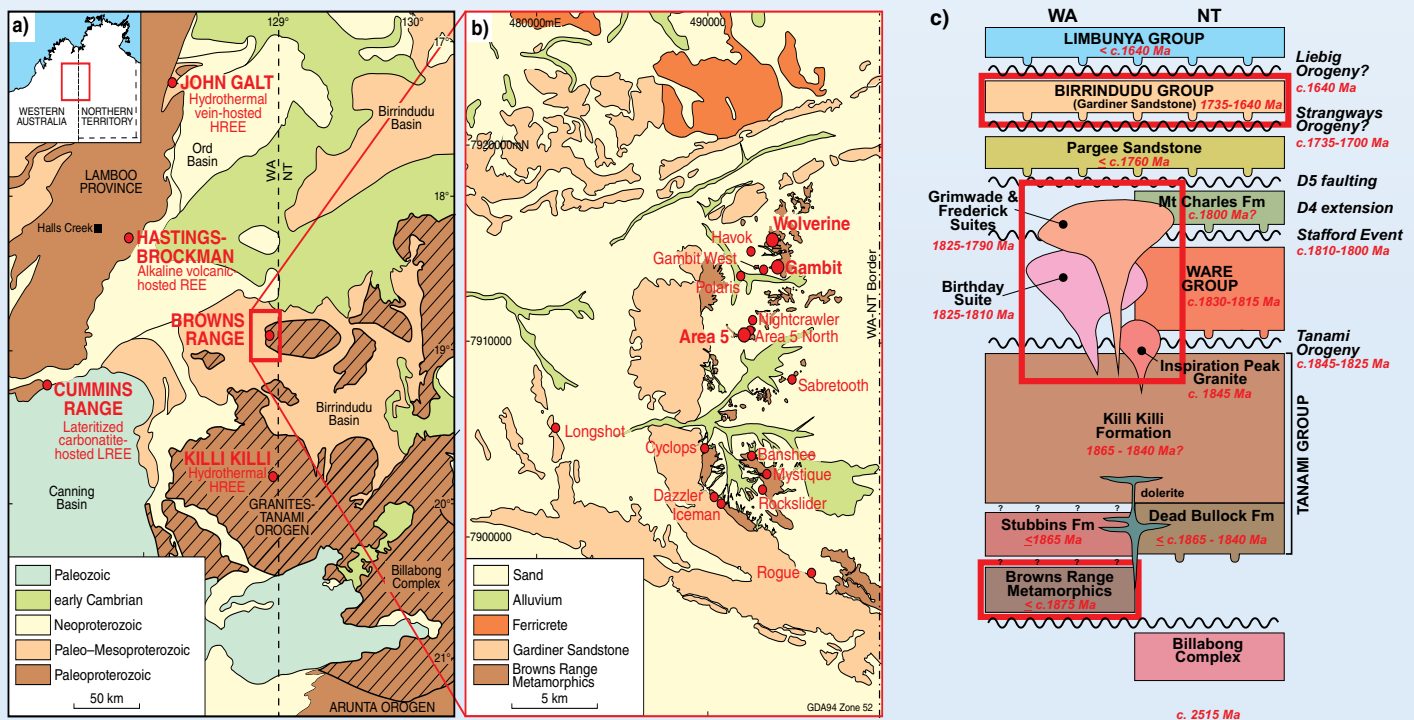


Figure 1. a) Map of Tanami – East Kimberley REE deposits; b) map of the Browns Range deposits; c) stratigraphic column of Tanami region

Mapping Western Australia: State geological maps 1894–2015

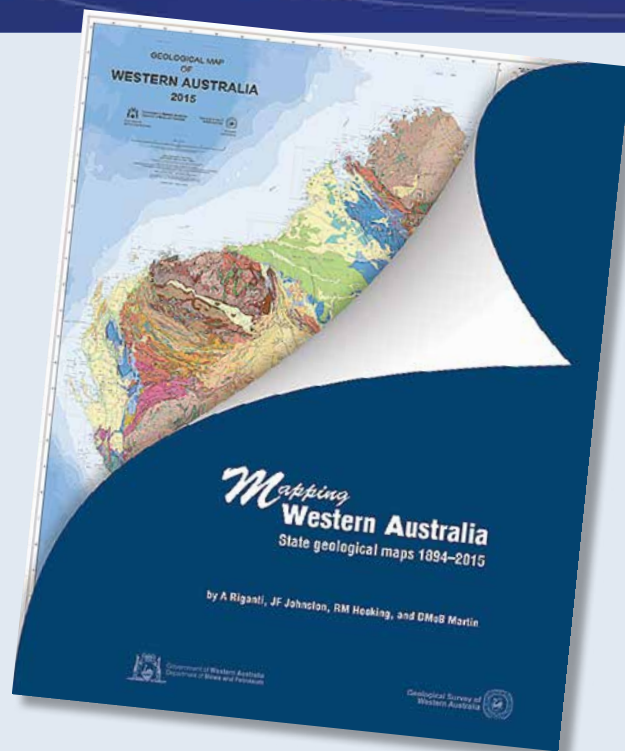
The 'Geological map of Western Australia' released in December 2015 is the 14th in a series that began with the Harry P Woodward map of 1894, published six years after the Geological Survey of Western Australia (GSWA) was established. Since then, 'State' maps have been published roughly every 10 years, with a longer hiatus between the 2015 map and the previous edition of 1998.

To celebrate the launch of the latest map in the series, GSWA released a book that visually documents the milestones in the geological understanding of Western Australia through the lens of each State map. It starts from the early days of exploration with camels and horses, up to the helicopter- and computer-aided mapping of today.

The first part of the book details some of the early geological explorations — and resulting maps — conducted by Government geologists prior to the establishment of GSWA, from Ferdinand von Sommer to Henry YL Brown and Edward T Hardman. It also includes Rev. CG Nicolay's map illustrating the geological collections held at the Geological Reference Museum in Fremantle.

Each State map is illustrated with a two-page spread. An image of each map is complemented by text that describes the main features, including:

- changes in coverage from one map to the next, with details of GSWA's work conducted in the intervening years that translated into more meticulous interpretations
- the evolution of legend layouts from broad lithological and temporal subdivisions to progressively more detailed stratigraphic columns and tectonic sketches, reflecting improved geological knowledge of the State as well as the evolution of significant geological concepts over the last 125 years
- comments on the maps' peripheral information, such as usage of different logos and patronage, and historical costs.

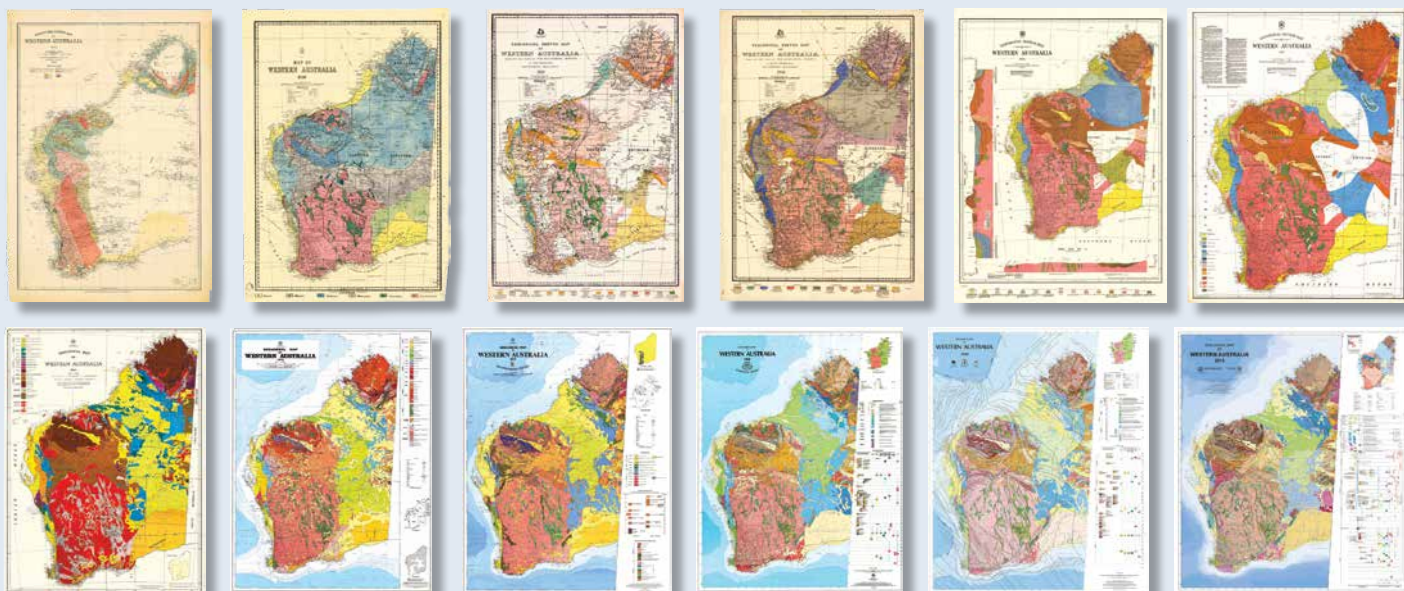


The text is matched by additional images that illustrate historical aspects of fieldwork, emblematic geological locations, or crucial analytical and remote-sensing techniques that in the last century have assisted geologists in unravelling the geological framework of Western Australia (e.g. aerial photography, geophysical imagery, and geochronology). The longer section on the 2015 State map focuses on the digital approach used for the first time to compile and deliver a State map that can be viewed in conjunction with many other datasets.

As stated in the introduction, the book's journey is '... a tribute to the passion of all the geologists who, since the 19th century, have mapped (every part of the) State'.

The book is available from DMP's eBookshop (www.dmp.wa.gov.au/ebookshop). The hard copy can be purchased at a cost of \$11 including GST, and the PDF is available as a free download.

For more information, contact
Angela Riganti (angela.riganti@dmp.wa.gov.au).



GSWA regional geophysics surveys: April 2016 update

Data downloads

Final data releases from the Geophysical Archive Data Delivery System can be found at www.ga.gov.au/gadds.

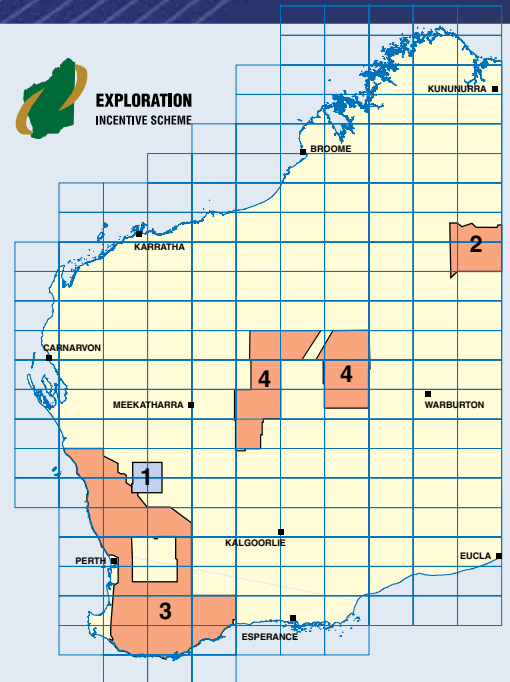
Grids and images from the GSWA website are available from www.dmp.wa.gov.au/geophysics.

Subscribe to the GSWA eNewsletter for alerts of preliminary and final data release dates.

Survey outline shapefiles are available online at www.dmp.wa.gov.au/geophysics.

For more information, contact
David Howard (david.howard@dmp.wa.gov.au).

 Airborne mag-rad surveys
 Ground gravity surveys



ID	Area/Name	Method	Configuration	Units	Status	Start	End	Release
1	Yalgoo 2015	Mag-Rad	100 m; E/W	111 000 km	Released	31/05/15	27/09/15	10/12/15
2	Ngururpa 2015	Gravity	Grid 2.5 km	4 964 stns	Released	10/05/15	13/06/15	30/07/15
3	SW Yilgarn 2015	Gravity	Roads 2 km	23 719 stns	Pre-release	12/06/15	02/12/15	11/02/16
4	Wiluna 2016	Gravity	Grid 2.5 km	17 000 stns	Assessment	tbd	tbd	tbd

Information current at: 1 April 2016

* Estimated date

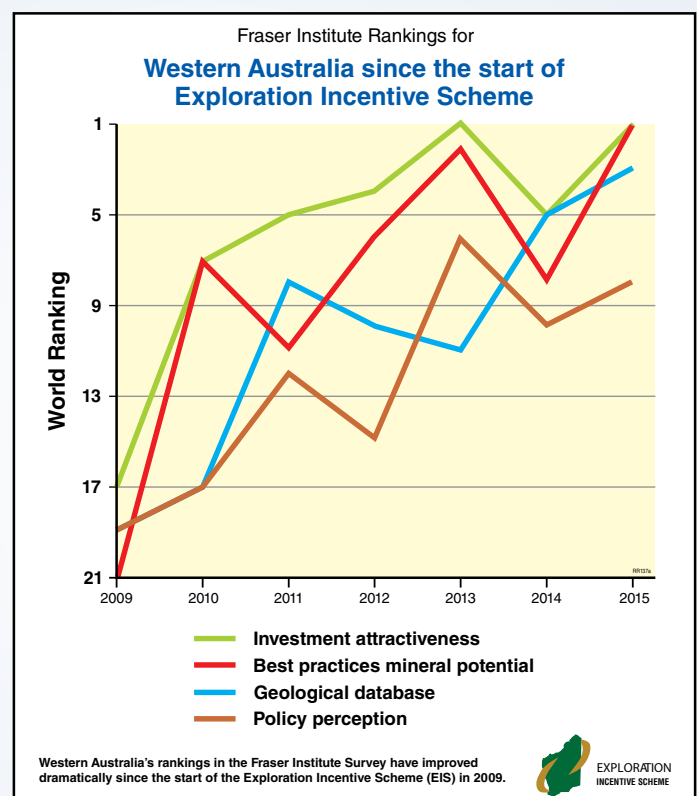
Survey of mining companies 2015

The Fraser Institute, Canada's leading public policy think-tank, has conducted annual surveys since 1997 of senior exploration and mining companies to identify the effects of public policies on mining investment in key global mining jurisdictions.

Mostly, jurisdictions are assessed as whole countries, while Canada, Australia, the US and Argentina are assessed on a state or province level (due to policy differences between jurisdictions within these countries).

The Fraser Institute uses several individual policy factors that influence company decisions to invest in various jurisdictions. The factors are aggregated into several key indices in order to rank each jurisdiction.

- Western Australia is the best investment destination in the world and in Australia**
 Western Australia is ranked number one in the 'Investment Attractiveness Index'
- Western Australia is the most mineral prospective region in the world**
 Western Australia is ranked top in the 'Best Practices Mineral Potential Index'
- Geological Survey of Western Australia provides free geological database information**
 Western Australia is ranked third in the world in terms of 'Geological database'



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■ 1:100 000 GEOLOGICAL SERIES MAP

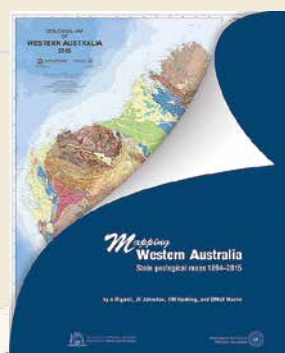
DIORITE, WA Sheet 4347

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Regionally significant basic raw materials — Esperance



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Major resource projects, Western Australia — 2016

by RW Cooper, NL Wyche, C Strong, G Hall, LJ Day, and F Irimies

Mines — operating and under development, Western Australia — 2016

by RW Cooper, C Strong, NL Wyche, LJ Day, and G Hall

■ PLATES

Interpreted bedrock geology of the East Pilbara Craton — Plate 1A

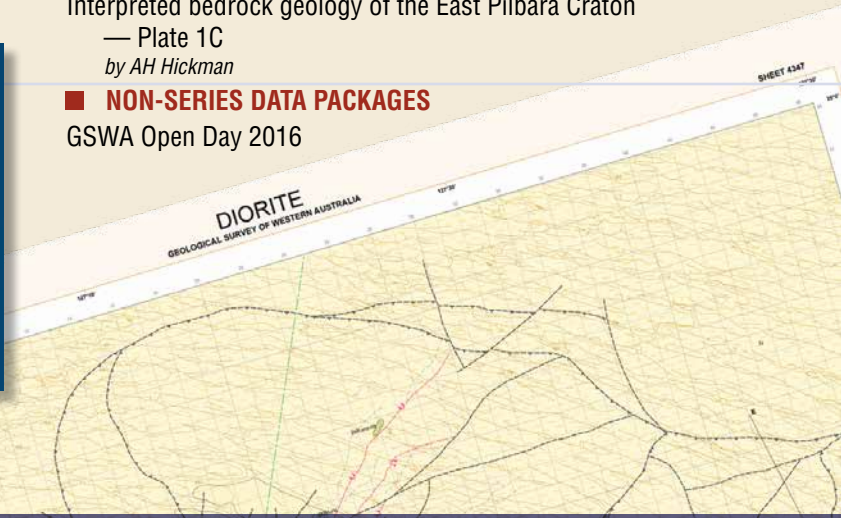
Interpreted bedrock geology of the East Pilbara Craton — Plate 1B

Interpreted bedrock geology of the East Pilbara Craton — Plate 1C

by AH Hickman

■ NON-SERIES DATA PACKAGES

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Thursday 27 October

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Thursday 3 November

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