Fieldnotes

Department of Industry and Resources
Geological Survey of Western Australia

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GSWA leads excursion to the Gascoyne
— WA's Proterozoic mineralization Cinderella

Over seven days from 20 to 26 September 2006, GSWA geologists led a self-catering, safari-style field trip that examined the geology of the northwestern Capricorn Orogen. GSWA's recent field mapping and associated geochronological studies have sparked a major revision of the geological framework of the region — now almost completely covered by mineral tenements and tenement applications.

More than 20 vehicles and 25 non-GSWA participants drawn from industry and Geoscience Australia participated in this geoscience caravan that was conducted in two parts — the northwestern Bangemall Supergroup from 20 to 23 September and the Gascoyne from 23 to 26 September. Many participants did both parts, beginning at the Mt Augustus tourist complex on the afternoon of the

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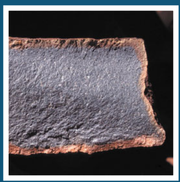

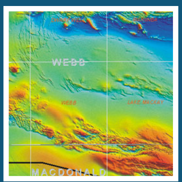

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Excursion to the Gascoyne

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19th September for drinks and an informal talk on the geology of the region by GSWA staff members Alan Thorne, Dave Martin and Steve Sheppard.

The evening talks were a highlight of the excursion, with presentations by Geoscience Australia, GSWA, Abra Mining, and Catalyst Metals. Mincor geologists assisted excursion participants gain an understanding of the link between the new geochronological framework and mineralization in their extensive tenement holdings in the Ti Tree syncline area. An excellent talk by Peter Southgate (Geoscience Australia) overviewed the Proterozoic of Australia with special reference to the spatial and temporal relationships between sedimentation, tectonism and mineralization. All these high-tech talks were made possible by the attachment to the side of a vehicle by magnets of a 'white' bed sheet, from Alan Thorne's swag, as a projection screen.

Participants in the first part of the excursion in the northwestern Bangemall Supergoup examined sections demonstrating the evolution of the Edmund Basin and the slightly younger Collier Basin (these two distinct basins contain rocks belonging to the Bangemall Supergroup —what most of us still call the Bangemall Basin). After getting over the shock of the new basinal nomenclature, participants were introduced to the world of depositional packages, flooding surfaces and regional unconformities and sequence stratigraphy in dominantly fine grained sedimentary rock units.

The second part of the excursion through the Gascoyne Complex showed participants the value of the SHRIMP in unravelling the geological history of terranes dominated by granites and metamorphic rocks of differing ages that look amazingly similar. Regional mapping, integrated with SHRIMP U–Pb zircon dating (and recently SHRIMP U–Pb monazite and xenotime dating with UWA), has transformed our understanding of the Gascoyne Complex. The 'Morrissey Metamorphic Suite' has been resolved into three discrete metasedimentary rock packages, granites were emplaced episodically into the complex over at least 1 b.y., and structures and metamorphic mineral assemblages thought to belong to the Capricorn Orogeny are now known to belong to four separate orogenic events. Recent mapping in the Paleoproterozoic to Mesoproterozoic Edmund and Collier Basins has resulted in major revisions to the previous stratigraphy, including the recognition of significant unconformities at the base of the Kiangi Creek and Backdoor Formations and regional disconformities below the Gooragoora, Discovery, and Ilgarari Formations. Large-scale structural elements, such as the Talga and the Lyons River Faults, exercised a strong control on Edmund Group sedimentation prior to their reactivation during the Neoproterozoic Edmundian Orogeny and appear to have acted as a locus for subsequent mineralization.

Take the time out to participate in GSWA-led safari-style excursions — they represent an unparalleled means of catching up with the latest results emerging from GSWA field and laboratory activities and of hearing the views of other groups that participate.■

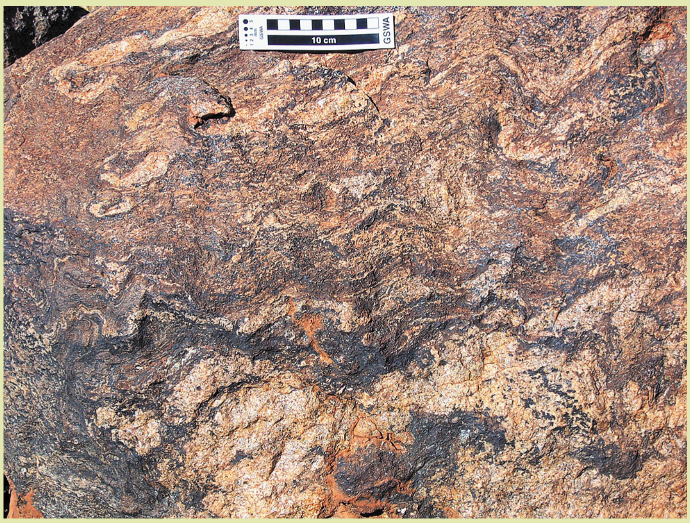
GSWA acknowledges the assistance of pastoral leaseholders, mineral tenement holders, and Geoscience Australia in running the excursion.

An evening presentation

David Martin, co-leader of the Bangamall Supergroup excursion

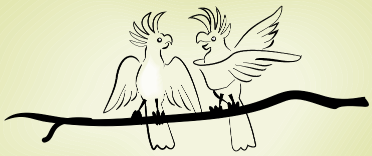
Sign outside the Star of Mangaroon mine

Star of Mangaroon mine



High-grade pelitic migmatite at the Star of Mangaroon mine

Where we are working in the field



Canning Basin project:

Field studies of the Permian, Devonian, and Ordovician succession.
Contact: Roger Hocking, Arthur Mory or Peter Haines
Ph: (08) 9222 3590, (08) 9222 3327 or (08) 9222 3667
Fax: (08) 9222 3633
roger.hocking@doir.wa.gov.au
arthur.mory@doir.wa.gov.au or
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Edmund and Collier Basins project:

Field mapping; lithological, stratigraphic, structural, sedimentological, and metamorphic analysis; sampling for geochemistry and geochronology.
Contact: Alan Thorne
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Western Tanami project:

Field mapping; lithological, structural, and metamorphic analysis; sampling for geochemistry and geochronology.
Contact: Leon Bagas
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leon.bagas@doir.wa.gov.au

Gascoyne Complex project:

Field mapping; lithological, stratigraphic, structural, and metamorphic analysis; sampling for geochemistry and geochronology.
Contact: Steve Sheppard
Ph: (08) 9222 3566
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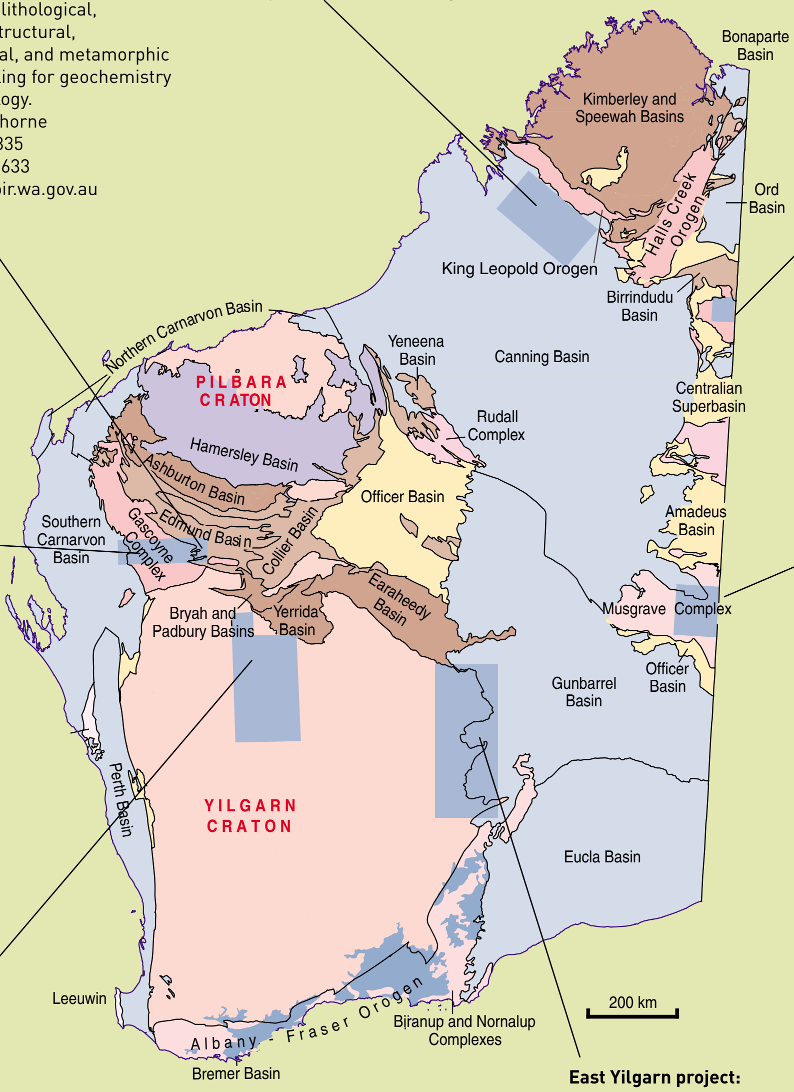
West Musgrave Complex project:

Field mapping; lithological, structural, and metamorphic analysis; sampling for geochemistry and geochronology.
Contact: Hugh Smithies
Ph: (08) 9222 3611
Fax: (08) 9222 3633
hugh.smithies@doir.wa.gov.au



Murchison project:

Field mapping and structural geology studies; sampling for geochronology and geochemistry.
Contact: Stephen Wyche
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Fax: (08) 9222 3633
stephen.wyche@doir.wa.gov.au

East Yilgarn project:

Geological mapping; structural studies; and sampling for petrography, geochemistry and geochronology.
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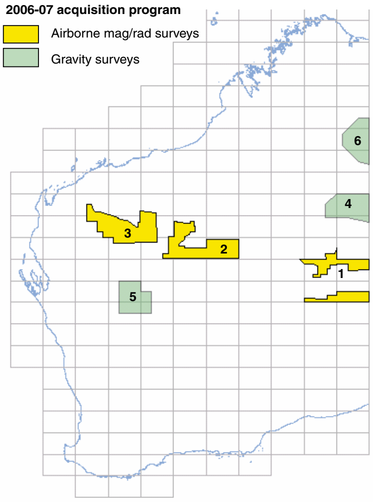
Fax: (08) 9222 3633
stephen.wyche@doir.wa.gov.au
charlotte.hall@doir.wa.gov.au

GSWA Regional Geophysics Survey Program



Preliminary grids from the Musgrave (extension) airborne survey were released on 15 November. Release of final datasets should occur in January 2007.

Preliminary data releases are made periodically on the GSWA website (www.doir.wa.gov.au/gswa). Final data releases are available by download from the GA Data Delivery System at www.ga.gov.au/gadds.

Subscribe to the GSWA newsletter (subscription link located on the News and Events page of the GSWA website) to keep informed of preliminary and final data release dates.

ID	Name	Specifications	Status	Start	End	Release
Airborne magnetic/radiometric surveys						
1	Musgrave 2006	400 m x 60 m; E/W; N/S	Processing	Jun-06	Oct-06	Jan-07*
2	Officer (Trainor) 2006	400 m x 60 m; N/S	Flying (50% complete)	Aug-06	Jan-07	Mar-07
3	Ashburton 2006	400 m x 60 m; N/S	Flying (50% complete)	Aug-06	Jan-07	Mar-07
Gravity surveys						
4	Webb	2.5 km regular	Complete	Aug-06	Sep-06	21 Dec-06
5	Murchison	2.5 km regular	Contract – start delayed	Jan-07	Feb-07	Apr-07
6	West Tanami	2.5 km regular	Deferred to 2007–08	Dependant on Land Access		

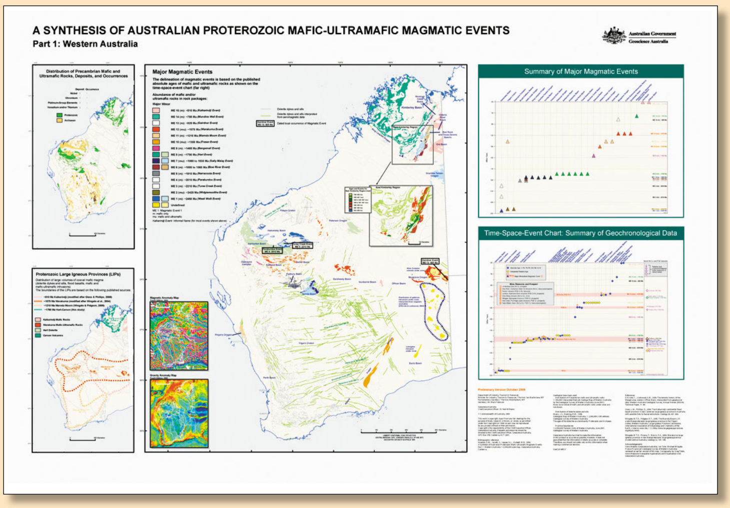
**information current at 6 Dec 2006*

Geoscience Australia

New map for nickel explorers

To assist the nickel industry, Geoscience Australia released a new 1:3 500 000-scale colour map 'A Synthesis of Australian Proterozoic Mafic–Ultramafic Magmatic Events. Part 1: Western Australia', at the 2006 Australian Nickel Conference in Perth (18–19 October). The map, for the first time, summarizes the major known Proterozoic mafic and ultramafic magmatic events and associated mineral deposits in Western Australia. Fifteen major magmatic events have been recognized with tholeiitic mafic systems dominating most provinces. Separate inset diagrams highlight the distribution of large igneous provinces (LIPS: large volumes of coeval mafic magmatism), different generations of dolerite dykes and sills, gravity and magnetic anomalies, and geochronological data, which underpins the main event map. A presentation 'Proterozoic mafic–ultramafic magnetic events: Implications for nickel mineralisation' at the conference highlighted the key features of the map.■

The map is available for download on the Geoscience Australia website at www.ga.gov.au/map/images.jsp.



For further information contact:
Dean Hoatson
Telephone +61 2 6249 9593,
dean.hoatson@ga.gov.au

Burrup Peninsula -

Burrup engravings

Hearson Cove

LNG plant Withnell Bay

Image fro

— geology of rock art

The Burrup Peninsula near Dampier in Western Australia's Pilbara region hosts port facilities for some of the State's major resource projects, including Hamersley Iron, the North West Shelf Joint Venture (LNG), Dampier Salt, and Burrup Fertilizers. The Peninsula also has outstanding cultural value as it contains many thousands of ancient rock engravings made by early Australians at least 4000–5000 years ago.

Burrup Peninsula is a former island 30 km long by about 5 km wide, now connected to the mainland by road and rail causeways. Most of the rock art on the Peninsula is distant from the industrial developments and is in areas to be included in a proposed 5000 ha Burrup Peninsula Conservation Reserve which will be owned by the traditional Aboriginal custodians and jointly managed by a council comprising both indigenous representatives and the Department of Environment and Conservation. A few percent of art sites on the Peninsula have been impacted by site works and infrastructure facilities, and some have been relocated for future display elsewhere.

As part of the government's plan to manage and protect the Burrup rock art, a Rock Art Monitoring Program was established in 2003 to assess any possible damage to the art from industrial emissions. As part of this program, CSIRO scientists have been monitoring physical and chemical conditions at nine sites, including some at areas remote from Burrup Peninsula as controls. The final report on these studies (CSIRO, April 2006) concludes that emissions from industrial activity are not likely to have any impact on the rocks or the engravings. This report is available from DoIR's website at (http://www.doir.wa.gov.au/documents/investment/Burrup_final_report.pdf)

The Burrup Peninsula was geologically mapped at 1:100 000 scale as part of the DAMPIER map sheet. The main rock types that comprise the Peninsula are granophyre and gabbros of the 2725 Ma Gidley Granophyre, minor granites, and numerous dolerite dykes. Engravings occur on all rock types.

As a contribution to the monitoring program, GSWA, in collaboration with the Chemistry Centre of Western Australia, is undertaking limited lithochemical, mineralogical, and petrographical studies of the Burrup rocks to better understand the effects, if any, of differing rock mineralogy and chemical composition on preservation of the ancient engravings. These studies are ongoing, but an early observation is that the engravers generally chose rocks with a relatively thick weathering skin of clay and iron oxide. These can develop on all rock types, despite the granophyre having only about half the total iron content of the gabbros. The engravings are made by pecking off the soft, dark red-brown, iron-rich, thin uppermost surface of the weathering skin to expose the pale clay-rich zone below, which is typically about 1 cm thick. The resulting contrast between the pale engraved image and the dark surrounding weathered rock surface gives the engravings of the Burrup area added impact. The fresh granophyre, gabbro, and dolerite are too hard to be engraved effectively by stone tools. The granophyre, with over 70% SiO_2, is in fact one of the hardest rocks on Earth, and has been used by the North West Shelf Joint Venture as armour stone to protect the sub-sea pipelines that connect the Burrup LNG facility with the offshore production platforms.■

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A Burrup beach

Granophyre and weathering skin

Detail of engraving

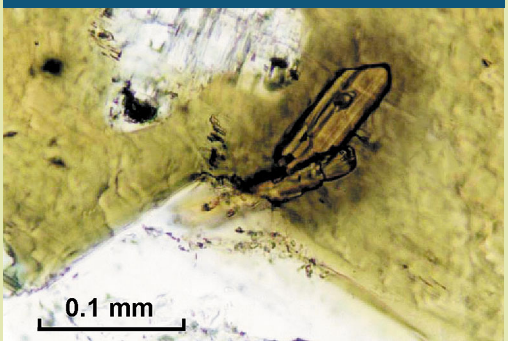
Turtle engraving

m Google earth

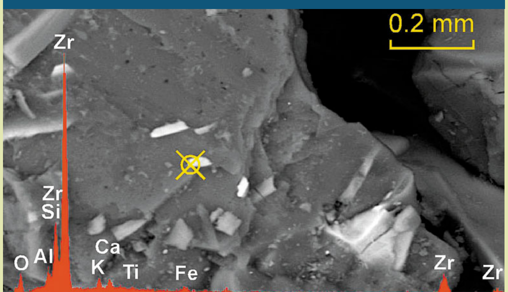
There's something

1070 Ma dolerite sill (foreground) near Sandstone

Peter Boner drilling to obtain unweathered samples



Baddeleyite crystals showing radiation halo in dolerite



X-ray spectrum of baddeleyite acquired using the SEM at the CSIRO

GSWA's Carlisle Laboratory has successfully separated several hundred crystals of baddeleyite (ZrO_2) from a dolerite sill southeast of Sandstone. The separation procedure is similar to that used to extract zircon from granite samples, but is complicated by the small size and fragility of baddeleyite and by the high proportion of high-density and magnetic minerals in mafic rocks. The crystals have been dated using the SHRIMP U–Pb method and yield an age of 1070 ± 18 Ma, an exciting result that extends the Warakurna Large Igneous Province into the central Yilgarn Craton. These results demonstrate GSWA's capacity to determine U–Pb ages for mafic intrusive rocks, such as dolerite and gabbro, which have previously been considered very difficult to date.

Zircon and baddeleyite

In the late stages of crystallization of many igneous rocks, zirconium and silica combine to produce small amounts of tiny zircon crystals, $ZrSiO_4$. When zircon forms it incorporates uranium within its crystal structure, which, over time, decays at a known rate to produce lead. Using the sensitive high-resolution ion microprobe (SHRIMP) at Curtin University of Technology, the relative amounts of uranium and lead in zircons can be measured, and the amount of time elapsed since the zircon crystallized can be calculated.

For years, zircon has been the mainstay of GSWA's U–Pb geochronology programme, and this approach has been used to date hundreds of rocks. These data have been instrumental in helping geologists decipher complicated geological histories throughout Western Australia. Unfortunately, zircon is generally restricted to rocks that are enriched in silica, whereas mafic rocks, such as dolerite and gabbro, have relatively low silica contents and commonly do not contain zircon. Thus, mafic rocks have, for many years, been difficult to date using the U–Pb method. This is a serious restriction because dolerite and gabbro are common throughout Western Australia, and many host important mineral deposits.

In recent years, however, the mineral baddeleyite (ZrO_2) has been found to be relatively common in many mafic rocks. Baddeleyite, like zircon, is enriched in uranium, and is ideal for precise U–Pb dating. In addition, it has been recognized that zircon can also be found in some mafic rocks, typically in the very last parts of the rocks to crystallize.

Baddeleyite also offers two particular advantages over zircon. Firstly, baddeleyite is less susceptible to lead loss. Secondly, in contrast to zircon, which is robust and can survive many geological processes, such as weathering and erosion, sedimentary transport, and incorporation into new granite magmas, baddeleyite crystals are exceedingly fragile and hence are very unlikely to be inherited from older rocks. This means that baddeleyite U–Pb ages for a mafic igneous rock can be confidently interpreted to reflect the time of crystallization.

Enhanced mineral separation procedures

Both zircon and baddeleyite are extracted from rock samples at GSWA's Carlisle Laboratory, which is managed by John Williams. In 1998, technical staff at the laboratory carried out experimental separations for extraction of baddeleyite (reported in GSWA 1997–98 Annual Review) and improved techniques have now been developed by John and laboratory technicians Marianna Brzusek, Lisa Clancy, and Peter Boner, resulting in what is now a routine mineral extraction procedure. Compared to rocks with higher silica contents, mafic rocks contain much higher proportions of high-density and magnetic minerals, making zircon and baddeleyite separation more difficult. GSWA geochronologist Michael Wingate is collaborating with Michael Verrall at the CSIRO Australian Resources Research Centre to develop scanning electron microscope (SEM) techniques for identifying baddeleyite-bearing samples prior to separation.

Because baddeleyite crystals are very small and fragile, crushing must be conducted with extreme care, to avoid breakage. Particle size is first reduced in a custom-built jaw crusher, followed by a continuous-feed ring mill, and then sieved to remove large particles (>400 microns), which are crushed and sieved again. Washing in a custom-built elutriation system removes very fine particles, and reduces sample weight by at least 50%.

Once the pulverized sample is dried, it is placed into a high-density liquid (sodium polytungstate, SG = 2.9), to float off low-density minerals. The resulting high-density fraction is passed through several magnetic steps, to progressively remove magnetic minerals and concentrate the nonmagnetic portion that contains baddeleyite and zircon. The first steps are performed using a rotating rare-earth magnetic separator, designed and developed at GSWA's laboratory, to rapidly remove most of the magnetic material. This simple but effective instrument reduces the sample size by a further 70%, and significantly reduces the time spent removing the remaining magnetic minerals with the Frantz isodynamic separator. The nonmagnetic fraction is then placed into methylene iodide (SG = 3.3), to concentrate the heavy minerals zircon and baddeleyite. Finally, baddeleyite or zircon crystals are individually hand-picked under a high-power stereoscopic binocular microscope.

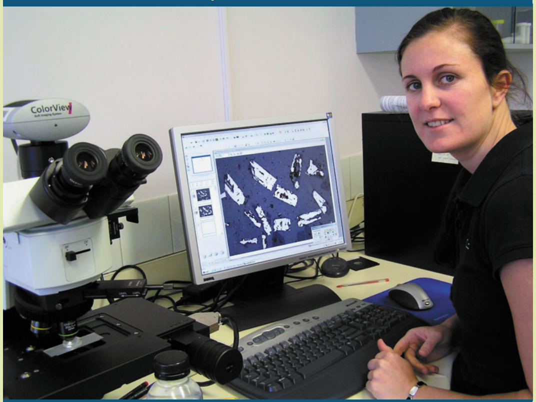
The hand-picked crystals are cast, together with reference standards, into an epoxy resin mount, which is polished to expose the interiors of the crystals. The mount is then documented using a state-of-the-art imaging system, consisting of a petrographic microscope equipped with a motorized stage and high-definition digital camera. Images obtained in transmitted and reflected light are invaluable during SHRIMP analysis to enable the geochronologist to select the most appropriate parts of the crystals to analyse.

A proven technique

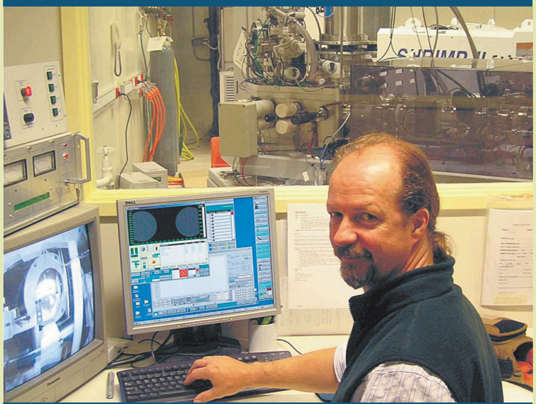
GSWA now has a demonstrated capacity to date mafic rocks, following the Carlisle Laboratory's recent success in separating several hundred baddeleyite crystals from a 3 kg sample of a dolerite sill southeast of Sandstone in the central Yilgarn Craton. The resulting SHRIMP U–Pb age of 1070 ± 18 Ma (million years) from 30 baddeleyite crystals shows that igneous rocks related to the Warakurna Large Igneous Province extend well into the central Yilgarn Craton. The new developments in equipment and procedures implemented over the last year are expected to make U–Pb geochronology of mafic intrusive rocks a routine procedure at GSWA.■

Lab manager John Williams with rare-earth magnetic separator

Marianna Brzusek hand-picking crystals with the binocular microscope



Lisa Clancy acquiring digital images of baddeleyite crystals



Michael Wingate operating the SHRIMP ion microprobe

A laterite geochemical database for the western Yilgarn Craton helps iron out problems in mineral exploration

Regional-scale datasets are required information in the identification of structural trends and mineralization haloes indicative of economic deposits. Most of these datasets are remotely sensed, such as aeromagnetics, radiometrics, Landsat™ or ASTER. In terms of 'on-ground' data, gravity and surface-sample geochemistry are two of the most common types of regional-scale data. GSWA combined capture of both data types in its gravity and regional regolith geochemistry program (1997–2001), which generated multi-element geochemical data for soil, lake sediment, stream sediment, and sandplain samples collected at a density of one sample per 16 km^2 over twenty 1:250 000-scale map sheet areas in Western Australia, largely focused on the Capricorn Orogen between the Pilbara and Yilgarn Cratons.

Figure 1. *Typical pisolitic 'laterite' found over large parts of the southwest Yilgarn Craton. Bag is 25 cm wide*

In 2003 a collaborative project was initiated between CSIRO, CRC-LEME and GSWA (with financial support from the Minerals and Energy Research Institute of Western Australia, MERIWA), to provide regional geochemical coverage over part of the Yilgarn Craton, and to underline the importance of low-density geochemical programs in mineral exploration. The exercise is known as the **Yilgarn Laterite Atlas** (YLA) program. In the planning of the program, it was recognized that geochemical data are easier to work with if the same type of material is collected for analysis at each sample site (i.e. uniform sample medium), analyses are carried out by a single laboratory using well-established analytical techniques, and a variety of elements are accurately and precisely analysed, meaning the data can be used to explore for a variety of commodities. In terms of sample media many parts of the Yilgarn Craton support iron-rich surface material derived by in situ weathering of underlying bedrock, loosely referred to as 'laterite'. The application of laterite chemistry to regional mineral exploration has been proven by CSIRO studies (e.g. R.E. Smith and co-workers), which showed that elements of economic interest, such as Au and base metals (e.g., Cu, Pb, Zn), and non-economic elements commonly associated with economic elements (i.e. pathfinder elements) are associated with the development of secondary iron oxides that make up laterite. In many cases, laterite units include pea-like gravel (pisoliths; Fig. 1) which are prone to roll downhill from their place of formation, thereby effectively spreading the mineralization signature. The YLA program is based on the multi-element analysis (53 analytes) of samples taken on a 9-km triangular grid over the western part of the Yilgarn Craton (Fig. 2). All of these samples comprise nodules or pisoliths, with some collected during an earlier pisolite chemistry program (AGE), and others from a previous CSIRO–industry program (Astro).

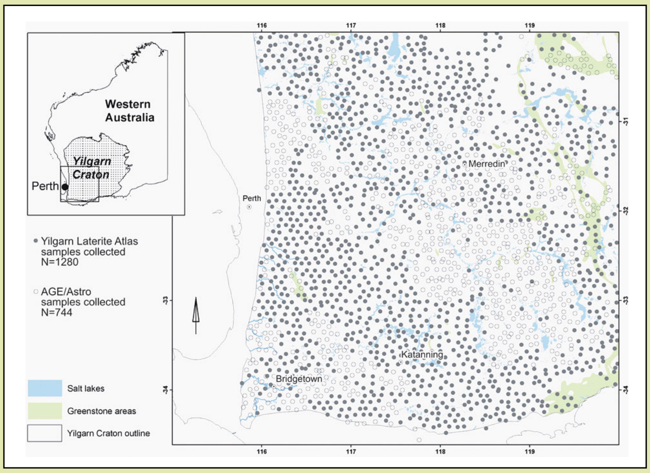


Figure 2. *Sample locations, comprising new samples collected for the YLA program (Yilgarn Laterite Atlas) and re-analysed samples from previous studies (AGE/Astro)*

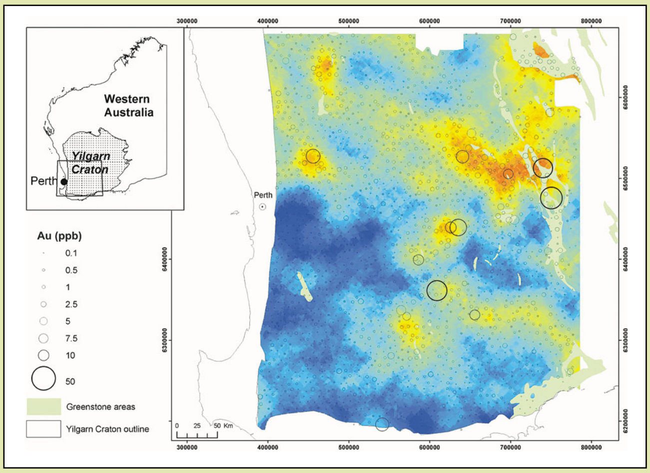


Figure 3. *Kriged image and bubble plot of Au (ppb) in 'laterite'*

To date, about 3000 samples have been collected, and analytical data for about 2000 of these samples from the southwest quadrant of the Yilgarn Craton were released earlier this year (Cornelius et al., 2006; CRC LEME

Yilgarn Craton Geochemistry

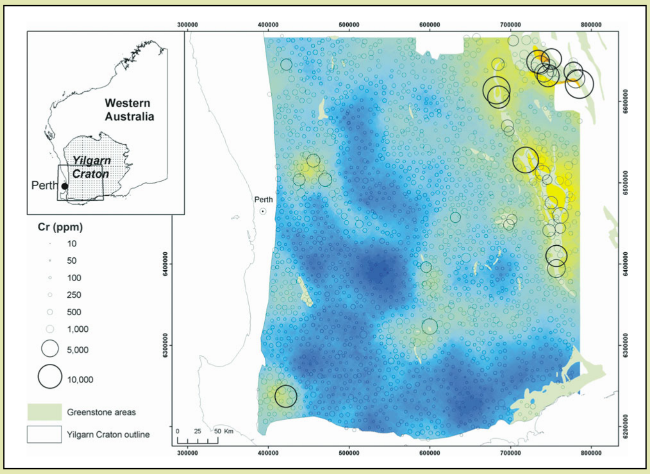


Figure 4. *Kriged image and bubble plot of Cr (ppm) in 'laterite'*

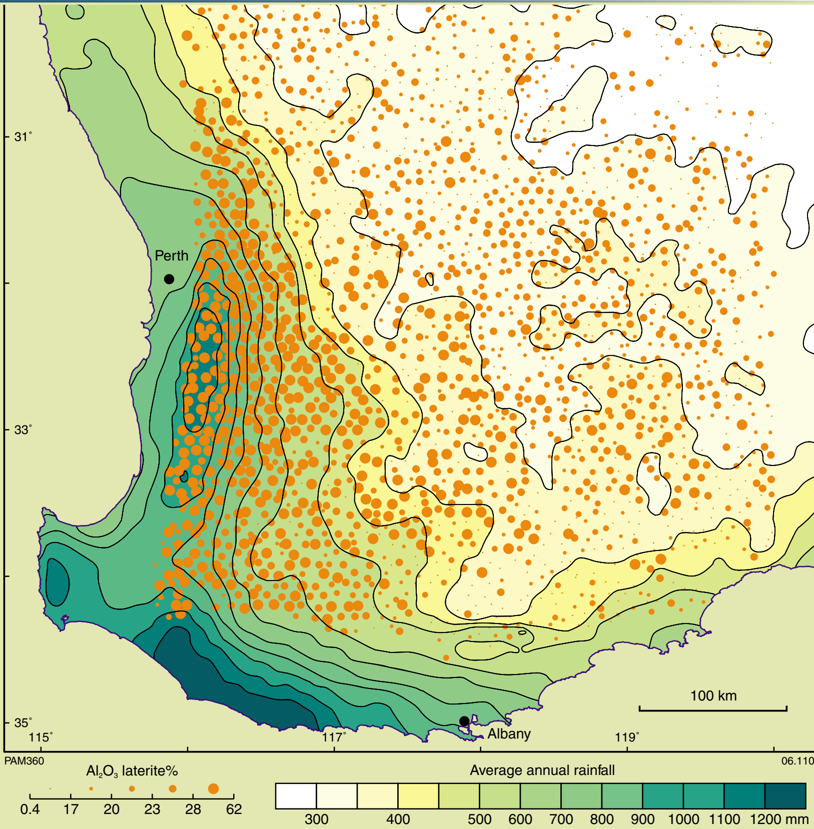


Figure 5.
Al_2O_3 (%) in 'laterite' shown in relation to rainfall distribution in southwest Yilgarn Craton. Rainfall data from Australian Bureau of Meteorology

Open File Report 201/CSIRO Report P2006/75). Release of these data had an immediate impact on exploration activity in the State's southwest. In the four weeks immediately preceding data release, tenements covering about 3000 km^2 were pegged in the southwest Yilgarn, compared to tenements covering more than 10 000 km^2 in the four-week period after data release — a three-fold increase.

The laterite geochemical data show some interesting mineralization-related patterns. The distribution of gold (Fig. 3) overlaps with (but also extends beyond in some cases) areas of gold mineralization, which is itself commonly tied in with areas of greenstones. The subdued response for WA's biggest producing mine (Boddington) reflects leaching of gold in the high-rainfall area of the western Yilgarn Craton margin.

Although elements such as Cr (Fig. 4) show the expected correlation with known areas of greenstone, high concentrations of Cr are found beyond the margins of some greenstone belts (e.g. northeast of Perth), suggesting that some areas of greenstone (established targets for gold or nickel mineralization) may be larger than those mapped.

Apart from relating laterite chemistry to specific lithologies or areas of known or potential mineralization, other controls are apparent on certain elements. For example, a gradual decrease in aluminium (Al_2O_3) in laterite from west to east in the southwest part of the Yilgarn Craton (Fig. 5) can be correlated with a decrease in rainfall inland, suggesting that the intensity of chemical weathering decreases from west to east. The distribution of mercury (Hg) in laterite (Fig. 6) cannot be easily reconciled with any specific lithology or known mineralization, but the broad NW–SE trend roughly parallels regional fault sets, and could also relate to the distribution of metasedimentary rocks and migmatites.

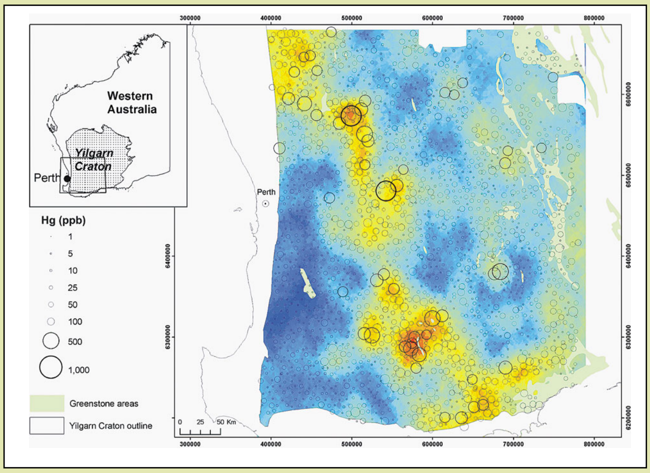


Figure 6. *Kriged image and bubble plot of Hg (ppm) in 'laterite'*

The YLA program has taken an established mineral exploration concept and applied it as a low-cost, regional exploration tool. The comprehensive range of analytes determined means that the dataset is applicable to exploring for a variety of mineralization types, as well as having application in agricultural and environmental areas. Analysis of the remaining samples from the northwest part of the Yilgarn Craton will be completed in 2006, and the data will be released in 2007, with a final report on the project slated for distribution in the same year.

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