

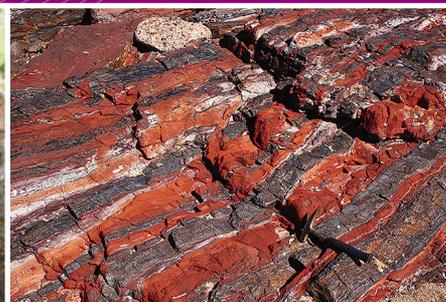


Government of Western Australia
Department of Mines and Petroleum

RECORD 2014/1

GEOLOGICAL SURVEY WORK PROGRAM FOR 2014–15 AND BEYOND

Perth 2014



Geological Survey of Western Australia



Government of **Western Australia**
Department of **Mines and Petroleum**

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**Geological Survey of
Western Australia**

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Geological Survey work program for 2014–15 and beyond

Executive summary

Last year (2013–14) was an exceptional year for the Geological Survey of Western Australia (GSWA) in many respects. It was the busiest year in GSWA's history (in terms of activity and budget expenditure, including funds managed under the Exploration Incentive Scheme [EIS]) and Western Australia achieved some of its highest rankings ever in the Fraser Institute's 2013 worldwide survey of jurisdictions. Western Australia was ranked in first place in the Investment Attractiveness Index, the composite index of 'Mineral Potential' (60%) and 'Policy Perception' (40%). This reflects the Government policy framework reforms undertaken by the Department of Mines and Petroleum (DMP) and the fact that EIS has delivered on its business case outcomes.

However, GSWA's activities planned for 2014–15 are in a macro environment characterized by slowing growth in China, flat or falling commodity prices generally, continued downward pressure on commodity prices, dire shortage of equity raising capacity (particularly of junior explorers), dramatic falls worldwide in exploration budgets and actual expenditure, deferral of capital investment in mining, producers cutting costs to increase margins and to maintain shareholder dividends, and widespread falling employment in the sector [including within CSIRO and Geoscience Australia (GA)]. The long boom cycle in commodities since the early 2000s, interrupted briefly by the Global Financial Crisis (GFC) in 2007–08, has unquestionably ended.

Using its recurrent operational budget of \$18.050 million, 134 planned full-time equivalent (FTE) staff in 2014–15, plus eight FTE staff funded from EIS, GSWA plans to publish the following flagship products:

Books (Reports, Records, non-series)	35
Series maps (1:100 000, 1:250 000)	10
Other maps (including State maps)	18
Digital information packages	18

Other headline deliverables for 2014–15 are to:

- begin construction of the expansion of the storage area of the Perth Core Library
- plan a \$2 million stratigraphic drilling program in the Canning Basin (using funding from GA)
- conduct a workshop to release information from the Eucla drilling and geophysical interpretation of the area
- release the fully interpreted State digital 1:500 000 series bedrock geological map with attributed legend database
- release the Explanatory Notes System on DMP's website
- launch the online application for lodgement of annual mineral exploration reports and related digital data.

Over the next three years, GSWA's planned recurrent budget-funded fieldwork and geophysical program will be dominated by programs carried out in the Southern Cross and Murchison Domains of the Yilgarn Craton, the Capricorn Orogen and Gascoyne Province, the Kimberley, the Albany–Fraser Orogen and adjacent Eucla basement. The Canning, Perth, and Amadeus Basins will continue to be the focus of the Basins and Energy Geoscience section until at least 2016–17. Emphasis will be on the Canning Basin in 2014–15 with interpretation of the deep seismic line of 700 km across the basin, together with drilling of a Commonwealth-funded deep stratigraphic well. The Land Use Geoscience section will give priority to advancing the South West Settlement Indigenous Land Use Agreement (with specific project funding from Department of Premier and Cabinet) and the strategic assessment of the basic raw materials requirements of the Perth–Peel region.

The EIS, previously a Royalties for Regions (RfR) initiative, is funded from Consolidated Revenue from 2014–15 and at a reduced budget of \$10 million per year. This budget includes the \$5 million per year allocated to the industry co-funded drilling program. This is a sharp decrease from the \$24.2 million spent during 2013–14 under EIS, resulting in the almost complete halt in the acquisition of geophysical data that characterized the early years of EIS. The budget reduction also means the end of EIS-funded stratigraphic drilling of the Eucla basement, where eight holes were drilled in 2012–13 and 2013–14. Many collaborative research projects are also gradually finishing or will finish by the end of 2014–15. However, research reports will continue to be released over the next two years. Future budget estimates have EIS funding finishing at the end of 2016–17. Therefore, this year DMP will be arranging an independent, external economic impact analysis of the first five years of EIS — with the aim of extending EIS into 2017–18 and beyond.

Note: all currencies are Australian dollars unless otherwise indicated.



Part 1
Strategic overview

International trends

The global economy continued its steady improvement during 2013–14 but GDP growth of some advanced economies measured in US dollars remained sluggish, including the US, Japan, the UK, India and South Korea (Fig. 1). China maintained growth of 7.5% and all countries except India (Fig. 1) had inflation under control. In 2013, for the first time since the GFC in 2009, Japan’s inflation was in positive territory. The global economy is undergoing enormous structural change as the balance of global economic activity slowly shifts towards Asia, where higher income populations continue to grow, demanding more energy and materials for urban infrastructure and consumer goods. In 2014, most commentators expect that global economic growth will be around 3.5%, largely led by China, Asia generally and by higher growth in the US, the UK and Germany. Further evidence of the improvement in the US economy was provided by the June 2014 monthly unemployment figures declining to 6.1% with 280 000 jobs created that month.

Debt finance has largely recovered from the GFC with even Spanish and Italian ten-year bonds yields at around 3.3% in April 2014, only a little higher than low-risk ten-year bonds issued by the US, and only 1.5% higher than German bonds. Part of the popularity in Euro-denominated bonds is due to the rising Euro/US dollar exchange rate despite Europe’s generally sluggish economic growth. Unfortunately for the exploration sector, high-risk equity funding is in short supply worldwide despite many non-resource equity markets, and particularly the US, rising strongly during 2013 and early 2014.

During 2013 the Australian economy began a transition from the high-growth economic multipliers associated with the largest resources investment boom in Australia’s history to the lower growth trajectory associated with enhanced, highly efficient resource production and export. It is the high level of resource exports that is probably maintaining the high Australian dollar. Resource-related economic growth remains the dominant source of economic growth, although there were signs during 2013–14 that housing construction was providing some stimulus in the non-mining sector at the same time that retail sales were flat. Market values of many stocks listed on the Australian Securities Exchange (ASX) have risen slowly during 2013–14 but the Standard and Poor’s/ASX 300 index did not sustainably break through the 5500 level by the end of June 2014.

Western Australia provides an exemplar for the transition from resources investment to production (Fig. 2). After peaking at about \$50 billion in 2012, Western Australia’s resource-related capital investment declined to \$46.76 billion in 2013 and is likely to continue its decline in 2014. Figure 2 also demonstrates that total mineral plus petroleum exploration expenditure peaked in 2012, but the total figure hides a rapid decline in mineral exploration expenditure described more fully in a later section. Despite generally subdued commodity prices, a persistently high Australian dollar and a slowly declining iron ore price, the total value of Western Australian resource production rose to a record \$113.76 billion in 2013 (Fig. 2) on the back of a 16.3% rise in iron ore production volume.

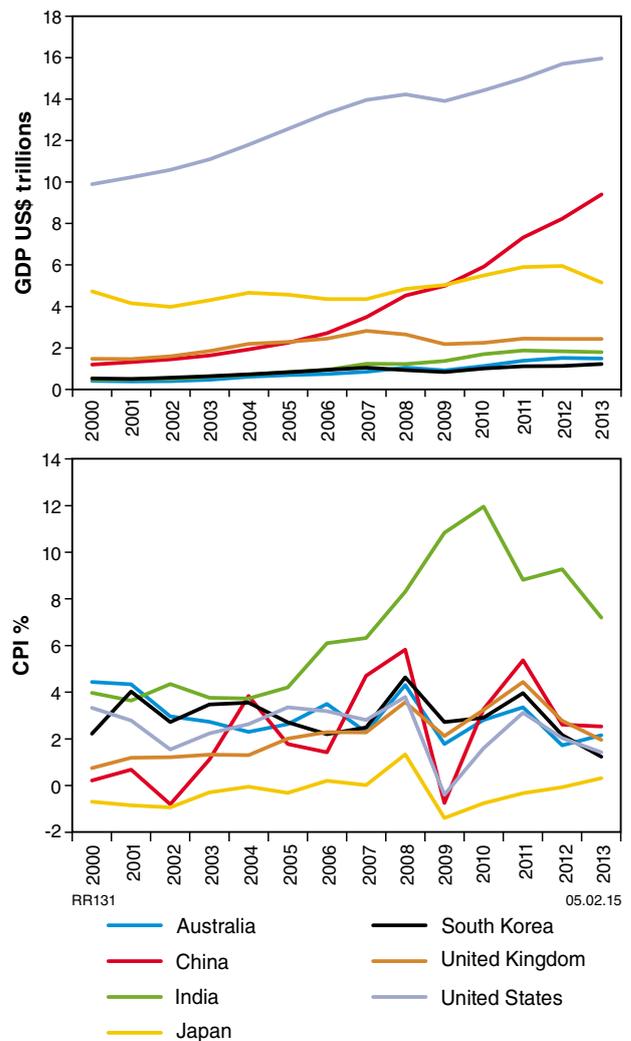


Figure 1. GDP for selected Australian trading partners 2000–13. Data are in current US dollars converted from domestic currencies using single year official exchange rates. Source: World Bank statistics

Subdued commodity prices

In general the Australian dollar, and mineral and energy commodity prices, declined slightly during 2013–14, continuing a trend that began in 2011 (Fig. 3). Nevertheless the Australian dollar remained at around US\$0.93 in June 2014, a historically high price (Fig. 3a). On the cross-rates, the Australian dollar was buying 95 Japanese Yen and 5.8 Chinese Renminbi in June 2014.

Monthly average gold prices kept largely within a narrow band between US\$1200 and US\$1320 during 2013–14 after the sharp decline in early to mid-2013 (Fig. 3b). Economic growth and the winding back of quantitative easing in the US are applying downward pressure on the gold price. These two factors appear to be overwhelming factors suggesting a price rise such as increased demand from China and India and concerns over decreasing South African supply. Unfortunately, the low gold price and increased focus on the profitability of gold production brought about

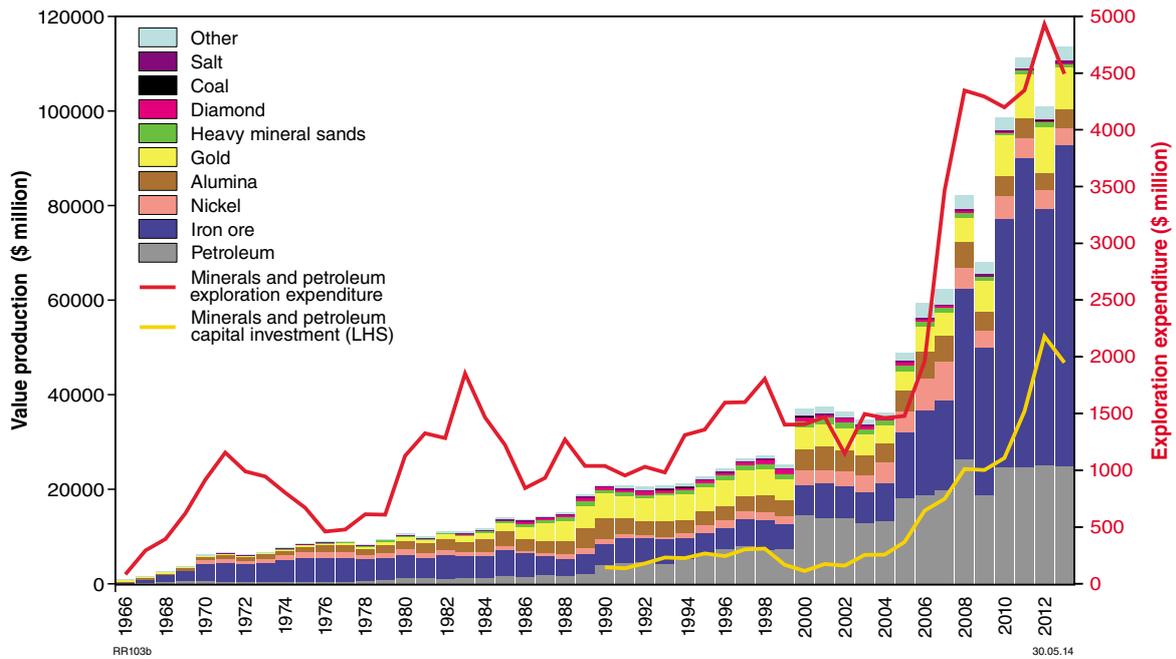


Figure 2. The three resources cycles in WA (2013 AUD). Value of resource production and exploration expenditure statistics are from DMP and the capital investment statistics were sourced from the Australian Bureau of Statistics (ABS).

by the requirement for listed companies to publish all-in sustaining cost information is causing an extra burden for gold exploration and mining companies in raising equity or debt finance.

Average monthly platinum prices (Fig. 3c) are slightly higher than gold but showed a slight upward trend in June 2014 in part due to concerns of supply shortages prompted by industrial action at South African mines. A new use for platinum — as a catalyst used in the production of propene (dehydrogenated propane) from shale gas that is subsequently used to make plastics and polymers — is predicted to raise demand for platinum as new propene plants are built in China and elsewhere.

With the possible exception of nickel, base metals prices have been disappointing in 2013–14, with both zinc and lead price trends almost directionless around US\$2000/tonne and copper prices declining during the July 2013 to June 2014 period from US\$7330 in January 2014 to around US\$6700/tonne in June 2014 (Fig. 3c). In June 2014, price jitters concerning copper were abundant when news came out of China that at the port of Qingdao, the same physical copper (and in some cases aluminium) in bonded stockpiles had been used as collateral for multiple loans from both Chinese and some western banks. So far, the mooted supply issues surrounding zinc, with the closure of Canada’s Brunswick mine and the expected closure of the world-class Century mine in Queensland in 2016, have not resulted in an increase in zinc prices.

During 2014, nickel was the only bright point in the base metals group (Fig. 3c), climbing in average monthly price since January 2014 to just under US\$19 000/tonne, a level

not reached since March 2012. During 2013, higher cost Western Australian nickel mines were undertaking severe cost-cutting measures and some were contemplating care and maintenance in the face of nickel prices declining to US\$13 232/tonne and the high Australian dollar. A number of factors contributed to this rise but the most important is the Indonesian Government’s imposition of a ban on the export of unprocessed ores, including the nickeliferous laterite preferred by nickel pig iron (NPI) producers in China. If there is no change to the ban after the Indonesian presidential elections in July 2014, it will only be a matter of time before Chinese producers shift NPI production to Indonesia and prices once more decline in the absence of demand-side growth.

Western Australia is increasing iron ore production and is the dominant force in world iron ore trade — production has declined marginally in Brazil, India and China, the other large producers. However, with the slowdown of the Chinese economy, and particularly the infrastructure component of that growth, demand for iron ore has declined and large Chinese inventories remain. The result has been a major decline in iron ore prices from US\$137/tonne in August 2013 to around US\$95/tonne at the end of June 2014 (Fig. 3d). At this price, the margins above ‘all-in sustaining costs’ for some small iron ore producers in Western Australia are becoming thin, although the major producers — BHPB and Rio Tinto — maintain comfortable margins.

Phosphate prices (Fig. 3d) appear to have bottomed out at around US\$100/tonne in December 2013 and have risen slightly. Aluminium prices recovered marginally to US\$1857/tonne in June 2014, but overall traded within a narrow US\$110/tonne range all year (Fig. 3d).

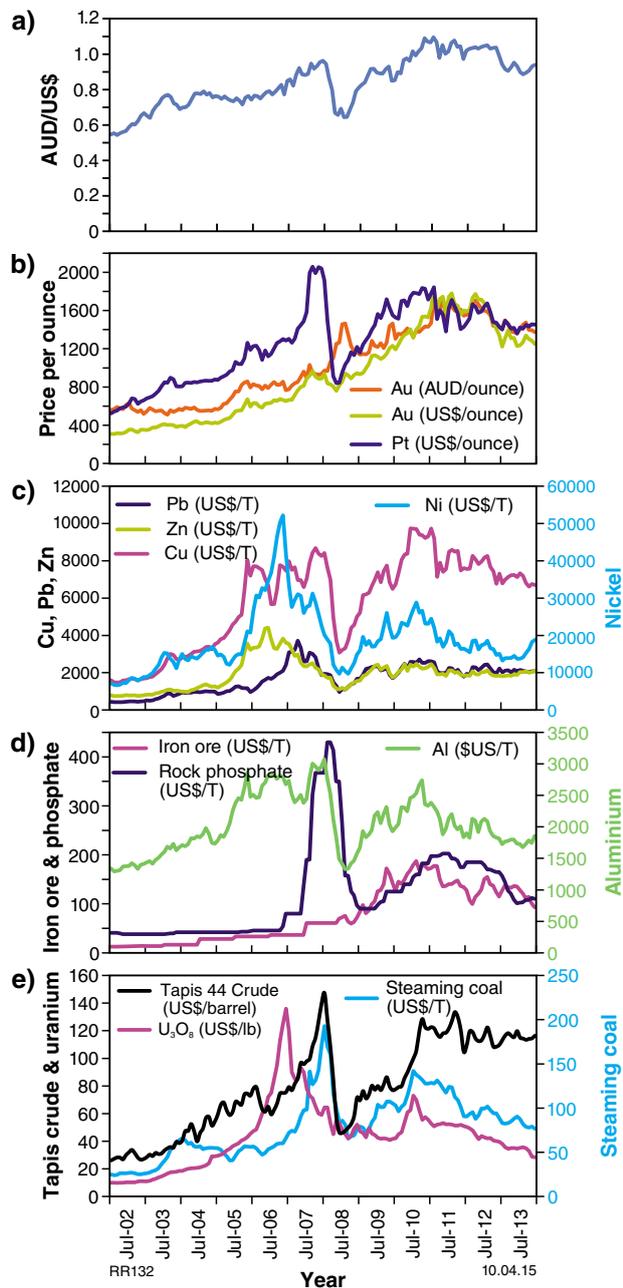


Figure 3. Commodity prices July 2002 – June 2014 (dollars of the day). All precious and base metal, aluminium, and uranium prices are spot prices collated by the Australian Bureau of Resources and Energy Economics (ABARE) and downloaded from the Intierra website (www.intierra.com). Coal (Australian thermal coal, 12 000 btu/pound, less than 1% sulfur, 14% ash, free on board Newcastle/Port Kembla) and iron ore (67.55% iron content, fine, contract price to Europe) prices were sourced from the International Monetary Fund (IMF). Rock phosphate prices (Morocco, 70% Bone Phosphate of Lime equivalent, contract) were sourced from the World Bank. The monthly Malaysia Tapis Blend price was derived by averaging the weekly spot free-on-board export price per barrel downloaded from the US Department of Energy, Energy Information Administration website (www.eia.doe.gov).

Average monthly thermal coal and uranium prices (Fig. 3e) continued to decline throughout 2013–14 in response to substitution by cheap gas produced from tight reservoirs in the US and slow growth in new nuclear capacity, particularly in the US. Uranium inventories are still high and most users continue to source supplies at already contracted prices (typically above US\$70/lb). Most commentators do not see a rebalancing of uranium supply and demand until at least 2017. Crude oil prices (Fig. 3e) were relatively directionless in 2013–14, with Tapis trading in a narrow band between US\$113 and US\$120/barrel.

World mineral exploration slows dramatically

SNL Metals & Mining (2014) estimates that 2013 world non-ferrous minerals exploration declined by almost 30% to US\$15.19 billion compared to US\$21.5 billion in 2012 (Fig. 4) in response to lower demand for metals and lower metals prices. Exploration on iron ore in 2013 was estimated to be an additional US\$1.74 billion, but a marked decrease compared to the estimated US\$2.89 billion in 2012. Investor uncertainty in the face of lower metals prices negatively impacted equity-raising capacity of junior explorers and producers reduced exploration expenditure to increase margins and shareholder dividends.

Australia slightly increased its share of world non-ferrous exploration expenditure to 13% in 2013 while Canada’s share declined from 16% in 2012 to 13% in 2013 (Fig. 5). Most other regions roughly maintained the share they had in 2012. Most pleasing was SNL Metals & Mining (2014) identifying Western Australia as hosting the largest number of announcements of significant gold and base metals initial resource estimates during 2013. This bodes well for Western Australia when equity begins flowing back into the coffers of junior explorers.

Sovereign risk increases in a number of jurisdictions

In January 2014 Indonesia’s sovereign risk profile rose above all other jurisdictions in 2013–14 with the implementation of a ban on the export of unprocessed Type 2 ores (nickel, tin, chromium, bauxite, precious metals) and an export duty on the export of concentrates of Type 1 ores (copper, lead, zinc, iron ore, manganese, ilmenite and titanium). This export duty will gradually increase from 20% to 60% by July 2016. Early announcements of the impending imposition of these measures resulted in an increase in the nickel commodity price and potentially the aluminium price. Exports of lateritic bauxite and nickel to China will be the first commodities impacted. For Western Australia’s nickel industry, this ban has been a bonus and could also prompt renewed efforts by a number of Chinese-backed advanced bauxite projects located in the Perth Hills to fill any potential bauxite supply gap.

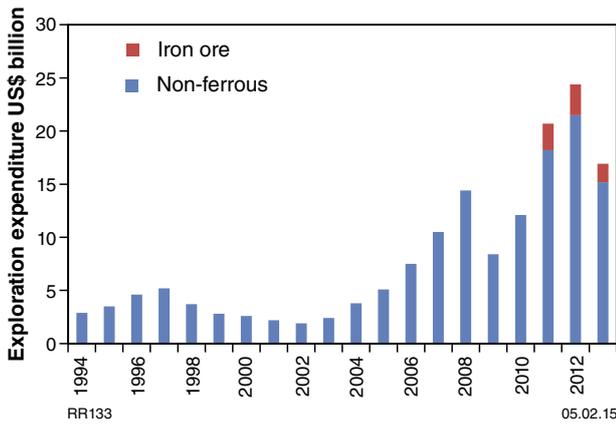


Figure 4. Global exploration budgets 1994–2013. Includes estimated spending on exploration for gold, base metals, platinum group metals, diamonds, uranium (from 2007), silver, rare earth elements, potash/phosphate, and many other hard-rock metals, but specifically excludes exploration budgets for iron ore, coal, aluminium, oil and gas, and many industrial minerals. Source: SNL Metals & Mining (2014) and Metals Economics Group

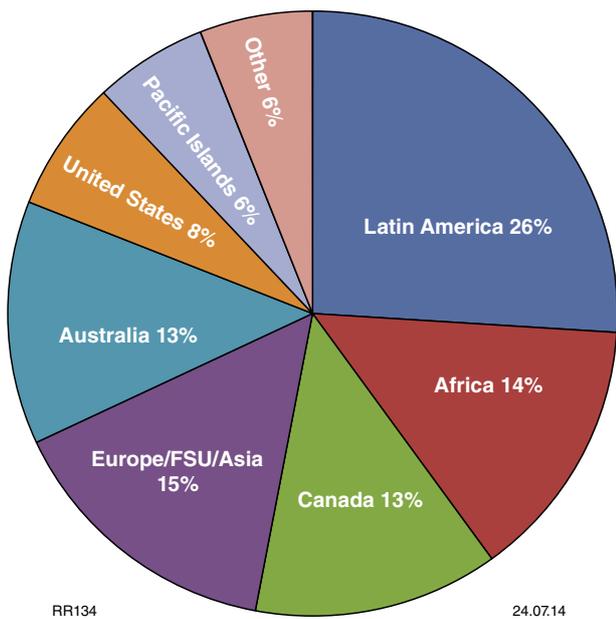


Figure 5. Worldwide non-ferrous exploration budgets by country or region for 2013, presented as a percentage of annual worldwide exploration (data from SNL Metals Economics Group, 2014). In addition to excluding iron ore, this graph excludes expenditure on aluminium, coal, and most industrial minerals.

Other countries to have fared badly in terms of sovereign risk profile in the survey include Kenya (revocation of some mineral licences and increase in royalties), Mexico (new 7.5% profit-based royalty on earnings before interest, taxes and depreciation), Finland (a large backlog of licence applications due to community resistance), and Chile (where the Government has flagged a gradual increase in the corporate tax rate from 20% to 25% and the elimination of a tax exemption for entities that re-invest profits).

On a more positive note, Greenland has amended legislation to end a long-running ban on exploration and mining of radioactive minerals, including uranium and rare earth elements. Mongolia has redrafted its foreign investment rules that should make it easier for minerals investment.

Despite the challenges of operating in Africa, some 195 companies listed on the ASX were operating in Africa in September 2013. Increasing numbers were also active in projects in northern and eastern Europe, and South America.

National trends

Explorers struggle to raise cash

The year 2013 was a terrible year for initial public offerings (IPOs) by mineral companies on the ASX (ASX, Fig. 6) with a total of ten (excluding secondary listings), the lowest for at least ten years. Some advanced exploration projects with at least a completed scoping study have been able to recapitalize using secondary raisings (placements, rights issues, etc.), but most explorers are not in a position to go back to the market.

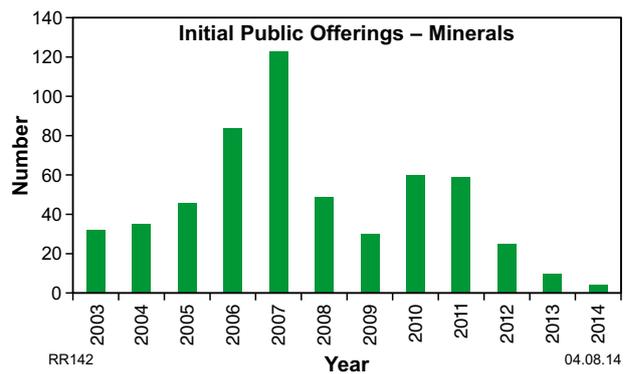


Figure 6. Mineral IPOs (including coal) on the ASX by calendar year. Note that 2014 statistic is for the six months ending 30 June and that the graph does not include companies listing on the ASX that are already listed on a securities exchange overseas.

The situation at the end of June 2014 had not improved with only four mineral IPOs on the ASX in the first half of calendar year 2014. In addition, as at 13 July 2014, out of a total of 483 pure explorers (those not mining or developing a mine) listed on the ASX, 210 (43.5%) had less than \$1 million in cash and deposits shown in the last Statement of Financial Position provided to the ASX. Without a return of more favourable equity-raising conditions, many exploration companies will reach the level of cash and deposits that may breach the finance requirements of listed ASX entities.

The increasing global reach of the 758 ASX-listed exploration and mining companies (as at 13 July 2014 — ASX statistics) is evidenced by the number of companies with operations overseas, including 193 in Africa, 48 in Europe and 89 in South and Central America.

The amount of capital raised by the nine petroleum exploration-related IPOs on the ASX in 2013 was \$65.4 million, considerably more than the total for mineral IPOs.

The aborted merger in early 2011 between the Singapore exchange (SGX) and the ASX highlighted the importance of Singapore as a finance hub, but not necessarily as a resource finance hub. Three years later in early 2014 the launch of the Singapore Mining Club was made in an attempt to tap resource development finance sources among local banks and wealthy families both in Singapore and elsewhere in southern Asia.

Exploration equity — how much longer in the sin bin?

There seems to be no consensus as to how much longer equity for exploration will be in short supply, or for pessimists, how much worse it can get. Upswings in equity raisings are always slower than declines. Currently, investors like what they see in producer cost-cutting, but the outlook for China and other growth economies for sustained commodity price rises is not positive enough for retail investors and institutions to put cash into exploration. The recent spate of mergers and acquisitions of medium-sized producers suggests that Western Australia, and Australia more generally, is at about 4 o'clock on the Widdup cycle (Fig. 7).

Foreign investment declines

For the fourth consecutive year, foreign investment (Foreign Investment Review Board, 2013) into Australia's resources sector declined and was associated with a marked changing of the guard in terms of the source of the investment (Fig. 8a). Total foreign investment was \$45.14 billion but a large proportion of the investment is concealed in the 'Other' category of Figure 8a. During 2012–13, Qatar (7.67%) and Switzerland (34.92%) appear as significant sources of investment (Fig. 8b), with the latter probably investing in coal (Fig. 8c). China once again maintained about 20% of the total investment but at a lower dollar value of \$8.66 billion, down from

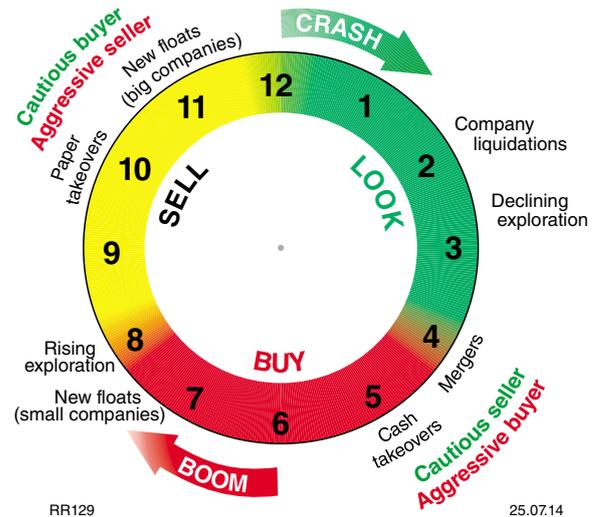


Figure 7. Lion Selection Group's well-known Widdup Cycle named after the Group's founder. Modified from Lion Selection Group (2014)

\$27.48 billion in 2008–09. Total investment from Canada and the US, which are similar in size to China, declined in 2012–13 to a level last seen in 2006–07 (Fig. 8b). Japan contributed 6.44% of inwards investment but in 2012–13 India and South Korea were insignificant sources of investment.

The major destinations for investment were coal, oil and gas in higher proportions than in 2011–12 (Fig. 8c). Investment in other mineral commodity groups was correspondingly lower in 2012–13, with iron ore faring particularly poorly compared to 2011–12. This confirms anecdotal evidence of a marked decline in iron ore investment in Western Australia. Hopefully, construction of the massive Royal Hill mine and associated infrastructure will show up in 2013–14 statistics.

Chinese investment in Western Australia (Fig. 9) over the last three years has moved increasingly towards gold and copper after being dominated by iron ore and uranium in the period from 2003 to 2011. In the current financial environment for explorers, there are some relatively cheap pickings among advanced projects which are attracting interest from China, and to a lesser extent Japan.

New Commonwealth Government promises exploration boost

In September 2013, a new Commonwealth Government was elected on a platform that included a number of commitments that were of considerable benefit to the resources sector including the following:

- formalizing the agreement to sell uranium to India
- establishing a single approvals process for major projects administered by the States while

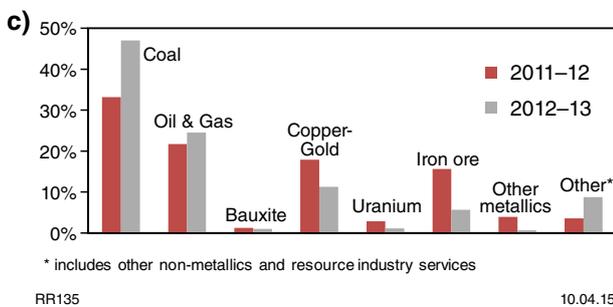
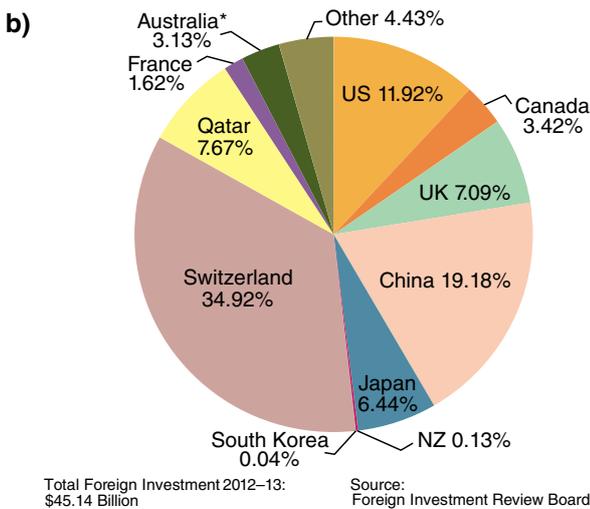
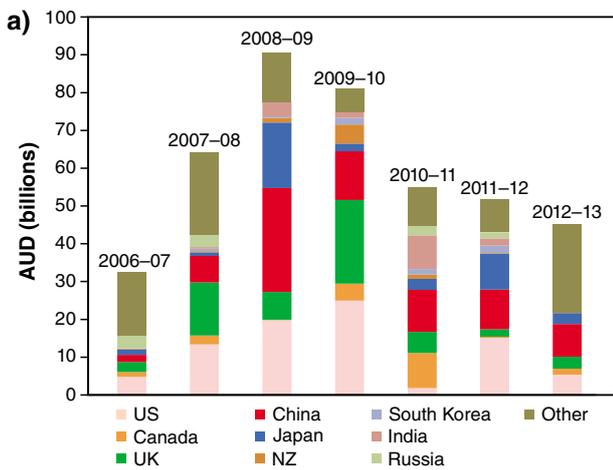


Figure 8. a) Sources of foreign investment into Australia's resource sector for 2006-07 to 2012-13; b) detail for investment in 2012-13; c) investment into different commodity groups in 2012-13. Source: Foreign Investment Review Board (2013)

delegating them the power to give some approvals under Commonwealth legislation (such as the Environmental Protection and Biodiversity Act)

- repealing legislation relating to the carbon tax and the Mineral Resources Rent Tax (MRRT)
- introducing an Exploration Development Incentive (EDI) that will allow investors to deduct the expense of mining exploration against their taxable income.

Streamlining of multijurisdictional approvals processes for major projects or projects in or adjacent to environmentally sensitive areas has long been on the wish list of the resources sector. Repeal of the MRRT and carbon tax legislation should reduce Australia's elevated sovereign risk profile.

Under the EDI, Australian resident shareholders will receive a 'credit' on a dollar-for-dollar basis for exploration expenditure incurred by eligible entities — mainly small exploration companies with activities in greenfields areas. The total credits available to all entities will be capped at \$25 million in 2014-15, \$35 million in 2015-16, and \$40 million in 2016-17, which will be the final year of the program. The distribution of credits to shareholders will be optional, with explorers alternatively able to carry forward their losses. Unfortunately, expenditure on exploration for construction materials (sand, rock, gravel, etc.), petroleum and geothermal will not be eligible for the incentive at this stage.

By the end of June 2014, industry was waiting for more details on the EDI and the Australian parliament had not passed legislation to repeal the carbon tax and MRRT.

State trends

Slowing State economy

Western Australia's Department of Treasury (2014) has pointed out that the State is facing challenging economic and financial times over the next few years while economic growth slows as investment in construction of new resource production facilities and infrastructure gives way to increasing resource production and export income. Treasury expects overall economic growth [as measured by Gross State Product (GSP)] to ease from 5.1% in 2012-13 to an estimated 3.75% in 2013-14 and 2.75% in 2014-15, before rising to 3% in 2015-16 and 4.25% in 2016-17.

Unemployment is expected to rise and therefore payroll taxation receipts, Western Australia's largest source of taxation, are expected to decline.

In 2014-15, Treasury expects resource production royalties to account for 22% of State revenue, with a forecast that this proportion will increase to 25% in 2017-18 (Department of Treasury, 2014). Given that total royalty revenue is highly dependent on the price of iron ore and LNG, and on the AUD/US\$ exchange rate, there is considerable financial risk for the State Government in relying on this potentially volatile revenue stream.

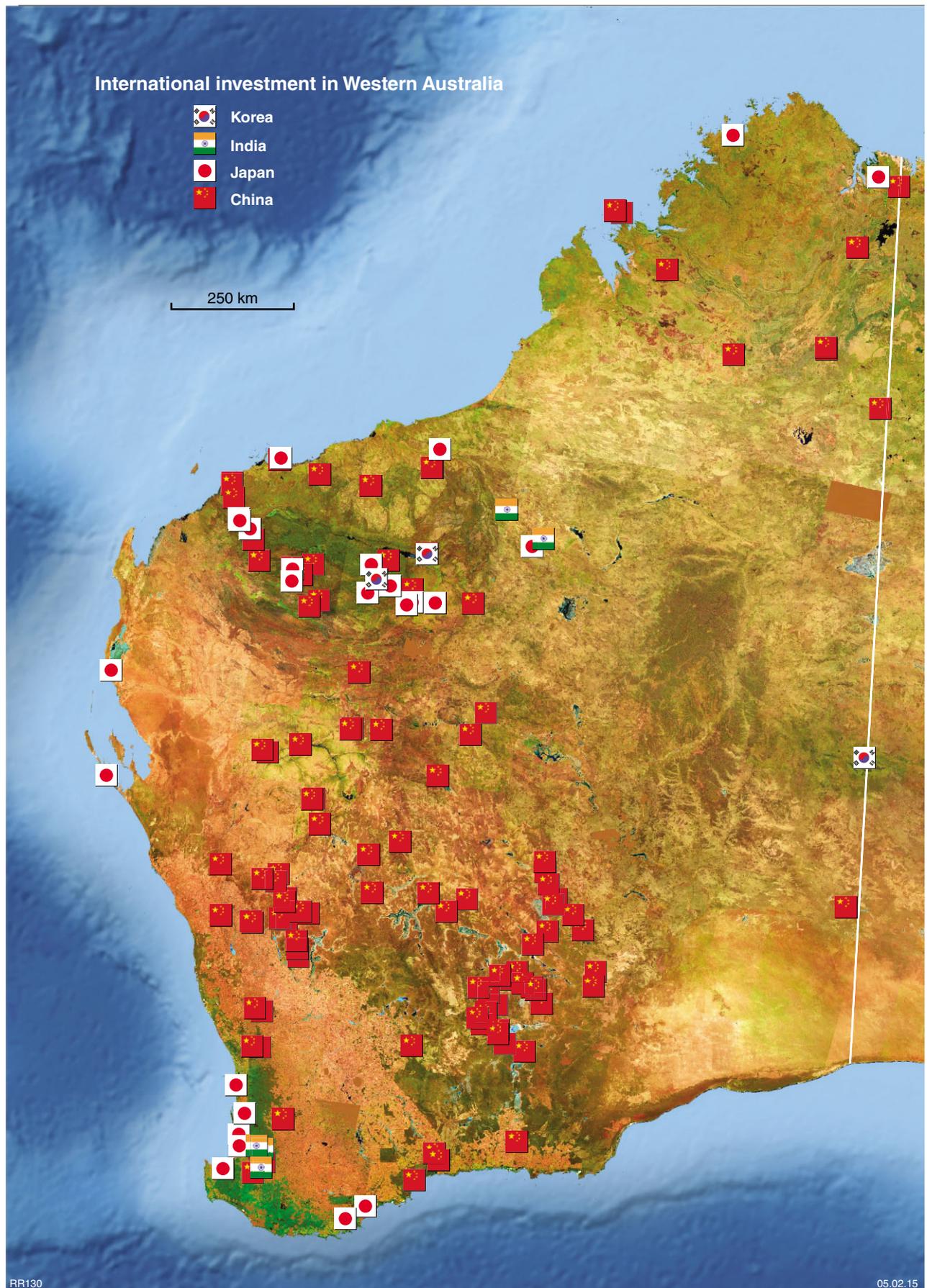


Figure 9. Location of mineral projects with significant Chinese, Japanese, Indian and South Korean investment as at 30 June 2014. Source: DMP's MINEDEX database

Against this background, the Western Australian Royalty Review process continues with a report to the Government expected in early 2015 in time for the 2015–16 budget deliberations. At this stage, there are concerns being expressed by peak industry groups and individual gold explorers and miners that an increase in the gold royalty would have a detrimental impact on margins in the industry. Unfortunately, these concerns are feeding into the responses of industry to investment risk surveys such as ResourceStocks (2013).

Western Australia’s resource production increases in 2013

In 2013, Western Australian resource production reached new records in both tonnage and value, with the latter reaching \$113.76 billion (Table 1, Fig. 10) in response to rising volumes of iron ore (up 16.3%) and LNG (up 5.25%). Indeed, with the exception of crude oil, coal, tin–tantalum–lithium and nickel, most resource volumes increased during 2013 and announcements by the two largest iron ore producers suggest that 2014 production will increase further.

Table 1 shows that production of construction materials (sand, gravel, rock etc.) rose by 13% and value increased 39% in 2013 compared to 2012, attesting to the amount of building and infrastructure development still going on in a slowing State economy. Gypsum production volume rose 89% and although 2013 limestone production volume increased only 5.5% over the previous financial year, its value increased 75%.

Western Australia’s mineral resources investment climate given major thumbs-up

The improvement of perceptions of Western Australia as a mineral resources investment destination continued in 2013. Western Australia has regained its investor reputation mojo that it lost in the early part of this century. The annual Fraser Institute survey of mineral investor sentiments towards 112 individual jurisdictions worldwide (Fraser Institute, 2014) was very good news for Western Australia which increased its rankings in three critical investment climate factors (Fig. 11 and Table 2) — best practice mineral potential, the Policy Perception Index and overall investment attractiveness in which it was ranked first in the world.

Western Australia now ranks first in the three factors among Australian jurisdictions and is testament to the new precompetitive geoscience information delivered by the EIS, improvements in approvals systems, and policy initiatives such as the Mining Rehabilitation Fund.

Table 1 shows that our ranking for ‘geological database’ has been maintained for the last three years after a major improvement in 2011–12.

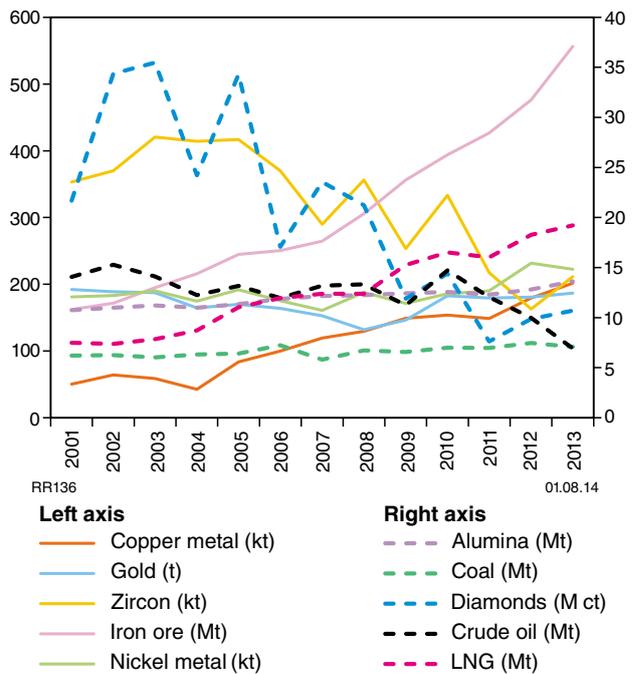


Figure 10. WA production quantity for major commodities 2001–13 (AUD of the day, DMP statistics)

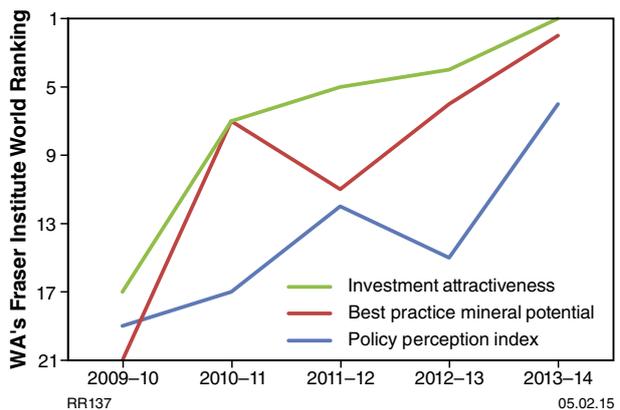


Figure 11. Graph of WA's improvement in the Fraser Institute's three critical mineral investor perceptions categories

Two anonymous survey respondents summarize the more positive aspects of Western Australia’s approvals system:

Native title is a contentious issue but, with departmental assistance, our project was able to get approval and commence in a relatively short time frame. — *An exploration company, Company president*

An ‘exemplary policy’: The new Rehabilitation Fund/Bond Retirement Scheme. — *An exploration company, Company president*

Table 1. Quantity and value of minerals and petroleum production in Western Australia, 2013–14

Commodity	Unit	2012–13		2013–14	
		Quantity	Value	Quantity	Value
Alumina	t	13 530 752	3 856 406 212	13 654 870	4 256 287 394
<i>Base Metals</i>					
Copper	t	197 579 (r)	1 449 297 701 (r)	208 193	1 556 670 782
Lead	t	16 639 (r)	35 093 965 (r)	88 740	202 225 661
Zinc	t	55 848 (r)	103 867 913 (r)	54 305	112 438 163
<i>Total base metals</i>			1 588 259 579 (r)		1 871 334 606
Chromite	t	196 623 (r)	n/a	66 540	n/a
Clays		42 021 (r)	1 227 980 (r)	35 686	1 176 041
Coal	t	7 494 280	310 812 885 (r)	6 365 459	263 541 605
<i>Construction materials</i>					
Aggregate	t	4 391 376 (r)	148 775 764 (r)	5 669 923	205 432 583
Gravel	t	561 135 (r)	3 947 125 (r)	195 114	3 893 726
Rock	t	1 109 761 (r)	27 142 818 (r)	1 281 291	21 453 349
Sand	t	5 415 504 (r)	62 093 160 (r)	7 383 267	88 145 815
<i>Total construction materials</i>			241 958 866 (r)		318 925 474
Diamonds	ct	9 610 436 (r)	350 174 880 (r)	11 610 631	397 663 034
Dimension stone		4 196 (r)	1 221 243 (r)	5 021	1 365 020
Gem and semiprecious stones	kg	218 058 (r)	250 480 (r)	310 673	400 681
Gold	kg	179 838 (r)	9 012 057 007 (r)	195 199	8 841 305 780
Gypsum	t	406 872 (r)	7 474 188 (r)	533 747	10 660 653
<i>Heavy mineral sands</i>					
Garnet	t	317 336 0	n/a 0	360 266	n/a
Ilmenite	t	270 770 (r)	72 680 425 (r)	160 134	36 785 210
Leucosene	t	29 071 (r)	31 524 237 (r)	27 795	25 218 920
Zircon	t	216 238 (r)	189 970 553 (r)	201 695	102 035 448
Other	t		519 870 203 (r)		304 878 446
<i>Total heavy mineral sands</i>			814 045 418 (r)		468 918 024
Iron ore	t	511 738 942 (r)	56 098 517 209 (r)	630 884 173	73 732 803 865
Limesand–limestone–dolomite		4 657 077 (r)	38 240 469 (r)	5 115 618	72 634 490
Manganese ore	t	649 695 (r)	n/a (r)	689 922	n/a
<i>Nickel industry</i>					
Cobalt	t	6 385 (r)	160 191 390 (r)	5 832	176 949 906
Nickel	t	228 709 (r)	3 606 658 311 (r)	209 065	3 450 608 524
Palladium and platinum byproduct	kg	658	15 047 084 0	1 015	28 523 097
<i>Total nickel industry</i>			3 781 896 785 (r)		3 656 081 527
<i>Petroleum</i>					
Condensate	kl	6 116 968	3 922 032 524	5 559 221	4 051 148 891
Crude Oil	kl	8 609 185	5 971 891 930	7 330 800	5 746 477 916
LNG	t	19 804 916	12 468 223 400	20 049 826	14 409 473 141
LPG — butane and propane	t	752 910	639 209 578	630 636	586 349 207
Natural gas	000m ³	8 713 949	1 434 550 772	9 736 820	1 734 960 459
<i>Total petroleum</i>			24 435 908 205		26 528 409 614
Salt	t	12 390 185	381 664 353	12 991 837	416 047 668
Silica – silica sand	t	498 232	16 886 756	449 587	15 847 051
Silver	kg	123 744 (r)	106 533 561 (r)	140 477	98 250 268
Tin–tantalum–lithium	t	n/a	199 285 246 (r)	n/a	122 899 632
Other (includes feldspar, red oxide, manganese, rare earth elements, spongolite, talc)	t		448 587 563 (r)		536 084 241
Total value			101 691 408 884 (r)		121 610 636 668

NOTES: Quantities used in this table only apply to Minerals and Petroleum covered by the Mining Act 1978, the Petroleum Act 1967, the Petroleum (Submerged Lands) Act 1982 and relevant State Agreement Acts.

(r) revised from previous edition

n/a breakdown of chromite, feldspar, garnet, red oxide, talc, spodumene and tantalite not available

Table 2. Western Australia's rankings in Fraser Institute mining company surveys for the period 2008–09 to 2013

	Ranking relative to jurisdictions worldwide						Relative to Australian jurisdictions					
	2008–09	2009–10	2010–11	2011–12	2012–13	2013	2008–09	2009–10	2010–11	2011–12	2012–13	2013
Number of jurisdictions	71	72	79	93	96	112	7	7	7	7	7	7
Policy perception index	21	19	17	12	15	6	3	3	2	1	1	1
Best practices mineral potential index	6	21	7	11	6	2	1	4	1	1	1	1
Investment Attractiveness Index*	6	17	7	5	4	1	2	4	1	1	1	1
Quality of geological database	17	20	17	8	10	11	7	7	6	3	4	3

* Formerly 'Composite policy and best practices mineral potential index'

Western Australia's low ranking in the 'Taxation' factor was probably due to perceptions that the current review of royalty rates was aimed at increasing royalties on a number of commodities and particularly gold.

The annual World Risk Survey (ResourceStocks, 2013) ranked Western Australia 29th out of 89 national (excluding Australia) and subnational jurisdictions in the world and ranked us the third less risky state of Australia after South Australia (first) and Tasmania. The differences in risk ratings between individual Australian states were minor with South Australia on a combined risk rating of 18.42 and New South Wales (6th) on 20.27. This survey is likely to be dominated by a higher proportion of Australian companies than the Fraser Institute survey which has a higher number of North American companies. While the results of the Fraser Institute and ResourceStocks surveys are not directly comparable, the stark difference between Western Australia's rankings in the two surveys is troubling.

Paydirt magazine (Paydirt, 2014) also published a report card on the investment attractiveness of Australian States. It ranked Western Australia highest (A-) with Northern Territory and South Australia equal second on B+ and attributed Western Australia's resurgence to political leadership, the EIS and introduction of the Mining Rehabilitation Fund. The one question mark Paydirt had was over outcomes from Western Australia's royalty review.

The Behre Dolbear (2014) annual survey of country risk ended Australia's four-year reign as the least risky mining country to invest in, dropping to second behind Canada in a survey of 25 major mining nations. Canada moved ahead of Australia based on the former's better management of societal issues and permitting compared to Australia. Unlike other surveys, this survey is compiled from the views of Behre Dolbear's professional staff around the world.

Mineral exploration expenditure declines sharply

At the end of the March quarter 2014, Western Australian mineral exploration expenditure had been declining for the last seven quarters — since reaching a record quarterly expenditure of \$633 million in the June quarter 2012 (Fig. 12). During the March quarter 2014, mineral exploration expenditure was only \$206 million.

The level of mineral exploration in Western Australia has declined to a level even lower than in the immediate aftermath of the GFC in 2007–08, and the level of activity is now comparable to that experienced in 2006.

Western Australia's decline from the previous quarter (December quarter) is 33.1% (from \$308.3 million down to \$206.2 million) and from the March quarter last year (2013) the decline is 52% (from \$434 million to \$206.2 million).

In the March quarter of 2013, Western Australia was enjoying almost record levels of the total Australian minerals spend — attracting almost 63% of the national mineral exploration expenditure, so it is not surprising that the fall in Western Australia was more pronounced and our share of the national expenditure has declined to 50.5% (Fig. 12). Western Australia's long-term share of the national mineral exploration expenditure has averaged 56% since 1990, so the current level is within the normal range of fluctuations experienced historically.

The long-term trends in exploration expenditures for the major Western Australian commodities are shown in Figure 13.

Continued weakness in the prices for iron ore, together with a steady gold and nickel price, means that mineral exploration expenditure in Western Australia will likely remain at subdued levels for at least the remainder of 2014.

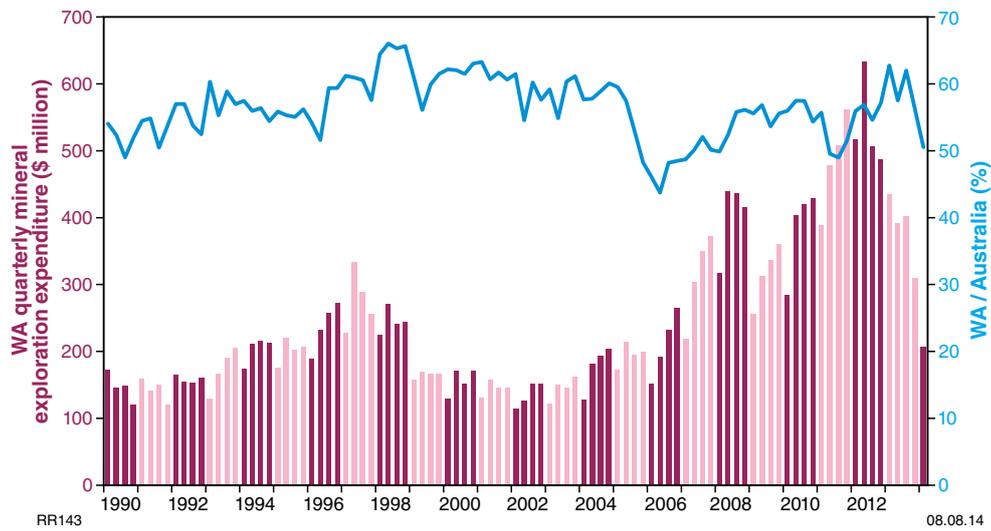


Figure 12. Quarterly mineral exploration expenditure in WA (AUD of the day, ABS statistics)

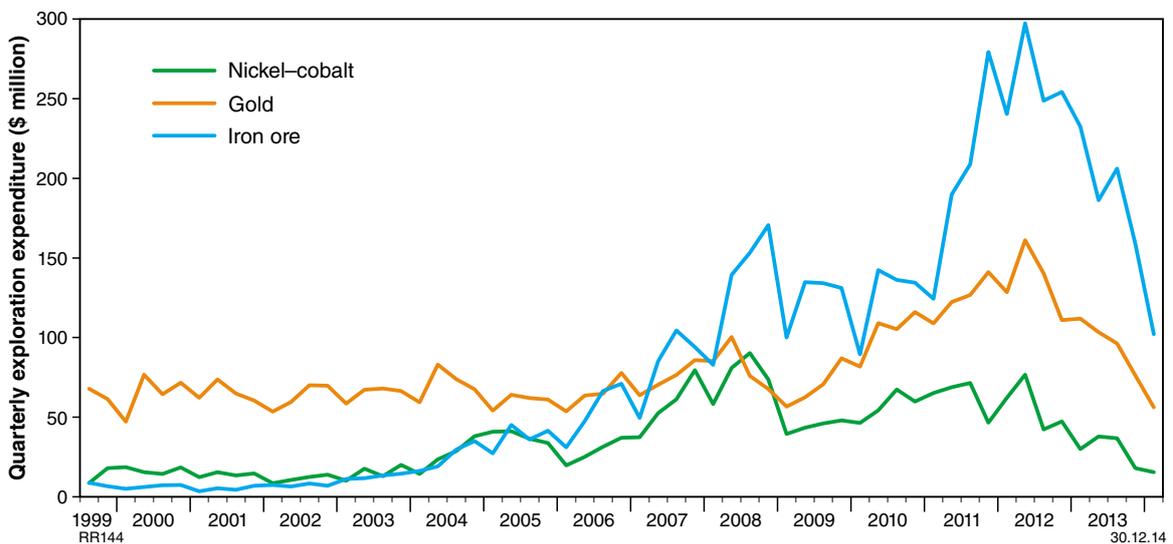


Figure 13. Quarterly exploration expenditure on iron ore, gold and nickel-cobalt (AUD of the day, ABS statistics)

Mineral search focuses on brownfields areas

Mineral exploration in Western Australia directed at discovering new deposits (‘greenfields exploration’) had been rising in dollar terms from 2004 to 2012, in line with rising total mineral exploration expenditure, but the proportion spent in discovering new deposits has been in general decline since 2004 (Fig. 14) — falling from levels of almost 50% of total spend in 2004 and 2005, down to only 26% for the March 2014 quarter. However, the level for the March quarter last year was even lower, at only 22%.

Room to improve in petroleum investment climate

The Fraser Institute’s 2013 annual survey (Fraser Institute, 2013) of jurisdictional investment attractiveness in the petroleum sector revealed that Western Australia’s Policy Perception Index (PPI, though referred to in previous survey years as the All-Inclusive Composite Index) has been declining for a number of years (Fig. 15). A jurisdiction’s PPI is derived from the scores for each of the 16 factor questions capturing investor perceptions, some of which are shown in Figure 15, of conditions affecting investment decisions, and provides a comprehensive assessment of each jurisdiction.

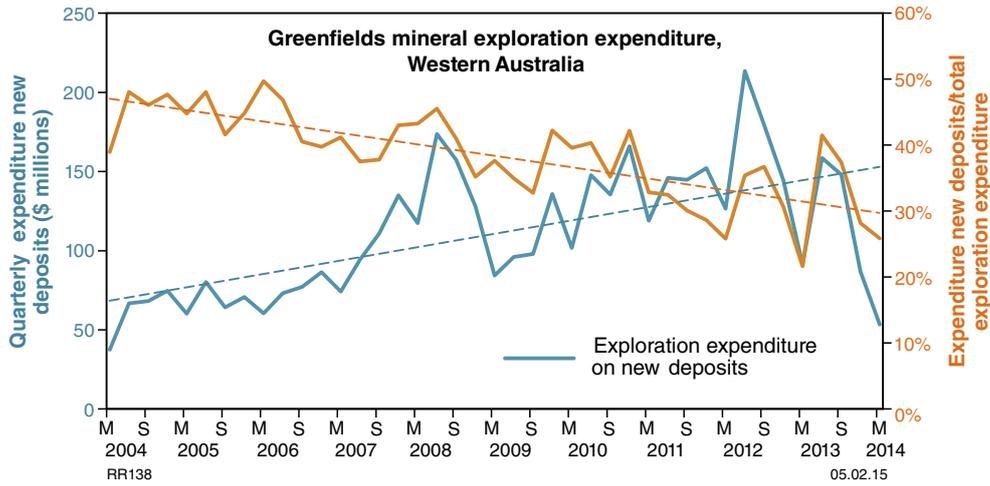


Figure 14. Greenfields mineral exploration expenditure in WA in original dollar terms and as a proportion of total expenditure (AUD of the day, ABS statistics)

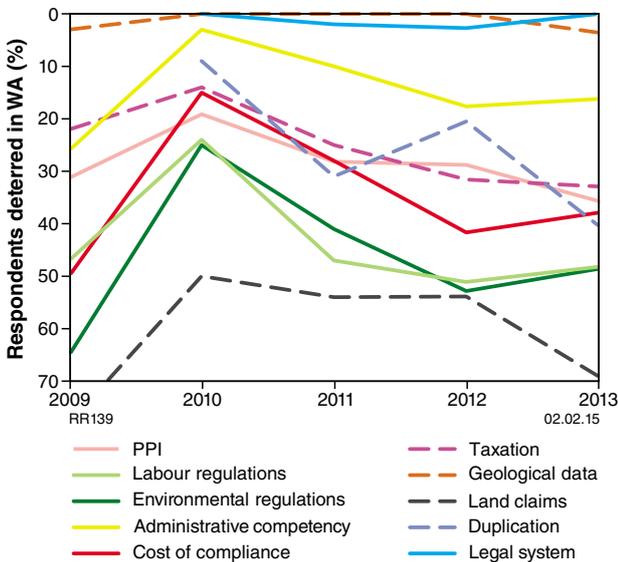


Figure 15. Graph of selected factors contributing to Fraser Institute's petroleum Policy Perception Index (PPI) for WA

In PPI, Western Australia ranks 49th out of 157 jurisdictions surveyed in 2013 and ranks third in Australian jurisdictions after South Australia and Northern Territory. Since 2009, Western Australia has been ranked 56th, 21st, 37th, 40th and 49th for PPI.

Western Australia has for several years been one of the leading jurisdictions for geological data provision and its legal environment but is showing worrying downward trends in a number of factors (Fig. 15). However, the decline in some factors may be the result of uncertainties associated with the establishment of Commonwealth agencies that now administer offshore titles [National Offshore Petroleum Titles Administrator

(NOPTA)] and the National Offshore Petroleum Safety and Environmental Management Authority) and where there is a degree of Commonwealth and State overlap such as Native Title (interaction of Commonwealth Native Title Act and State Aboriginal Heritage Act), environmental legislation (Commonwealth Environmental Protection and Biodiversity Conservation Act and State Environmental Protection Act), and taxation (Commonwealth carbon tax and Petroleum Resource Rent tax extended to onshore Western Australia). One survey respondent made the following statement:

Native title in onshore Western Australia is increasingly painful, caught between state and federal legislation both probably suboptimally conceived and drafted.

Western Australian petroleum exploration activity increases

In the 2014 March quarter, compared to the 2013 December quarter, the national petroleum exploration expenditure decreased by 8.2% to \$1013 million. In Western Australia (which includes adjacent offshore Commonwealth waters), headline petroleum exploration expenditure in the 2014 March quarter remained virtually unchanged with a marginal rise from \$677.4 million in the 2013 December quarter to \$678.1 million in the 2014 March quarter (Fig. 16). As a result Western Australia's share of the national expenditure increased to 66.9% in the 2014 March quarter compared to 61.4% in the 2013 December quarter (Fig. 16).

While Figure 16 paints a rosy picture for exploration expenditure in Western Australia and adjacent Commonwealth waters as a proportion of national petroleum exploration, the results of successful exploration in the State jurisdictional area are more important to the Western Australian community. Figure 17

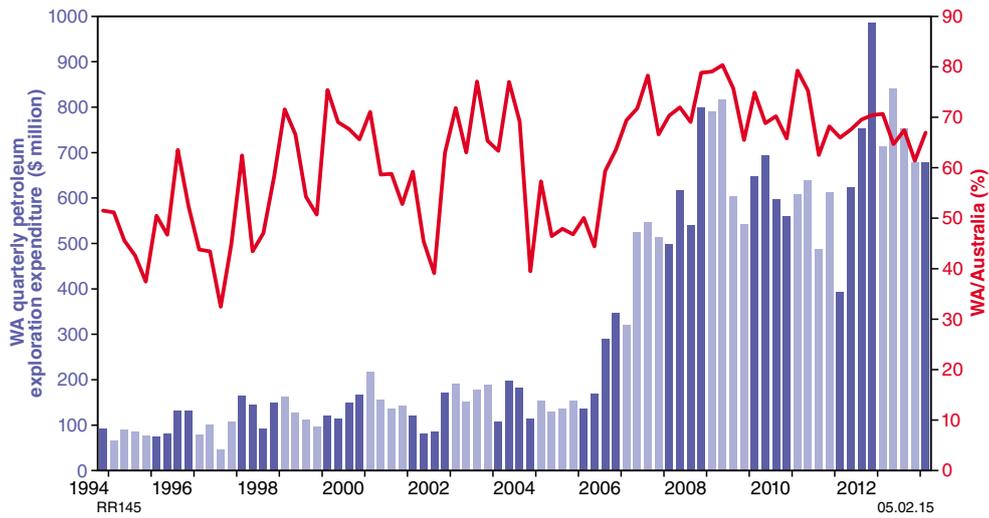


Figure 16. Quarterly petroleum exploration expenditure in WA and adjacent Commonwealth waters and WA's proportion of nationwide expenditure (AUD, ABS statistics)

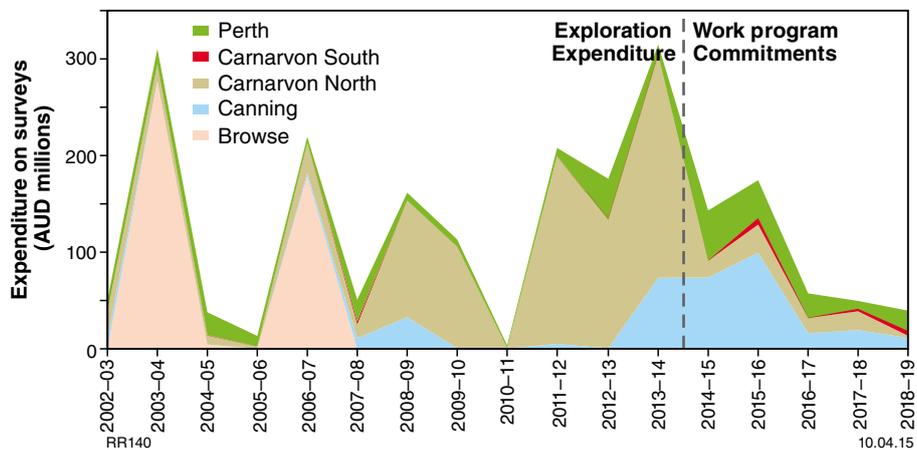


Figure 17. State jurisdiction petroleum exploration expenditure (to 2013–14) and commitments (2014–15 onwards) on wells and survey activities (geoscience studies, geophysics, geochemistry, etc.). Excludes insignificant expenditure in Bonaparte and Officer Basins and expenditure on environmental, heritage and other non-technical activities. Source: DMP statistics

shows that State jurisdiction exploration in the Northern Carnarvon, Canning and Perth Basins has increased enormously since 2011–12, reaching over \$300 million in 2013–14.

However, although there has been elevated exploration expenditure in recent years and 10–20 new field wildcat wells per year, the three new field wildcat wells in 2013 were very disappointing (Fig. 18).

Continued interest in exploration of the onshore Canning and Perth Basins, including for shale gas, is expected to continue.

The very large estimate of 229 TCF of risked recoverable shale gas in the Ordovician Goldwyer Formation within the Canning Basin (US Energy Information Administration, 2011) and high estimates of shale gas resources in other Australian basins has prompted GA to embark on a program of reassessing the economically recoverable reserves of some Australian basins using the latest available information. The Canning Basin will be one of the basins GA reassesses.

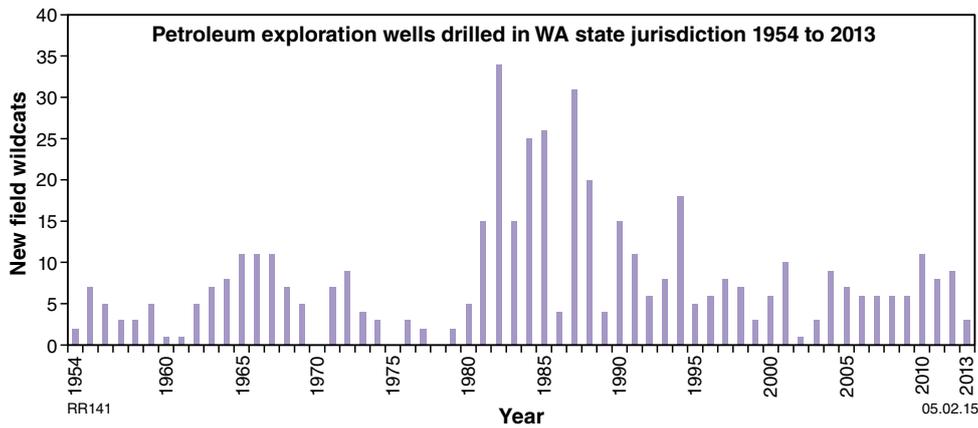


Figure 18. Number of new field wildcat wells drilled in State jurisdiction for period 1954–2013. Source: DMP statistics

Government geoscience trends

Perth hosts new National Resource Sciences Precinct

The National Resource Sciences Precinct (NRSP) is a CSIRO, Curtin University and The University of Western Australia (UWA) collaboration to connect researchers with industry and government to tackle some of the most complex challenges facing the resources industry.

NRSP has been formed to:

- attract the best scientists to lead research on global resource industry challenges
- deliver strategic leadership of the resource sciences agenda through collaboration with industry, government and research institutions
- capitalize on the concentration of multinational companies and world-standard resource research capability already in Western Australia
- undertake research infrastructure projects of scale and quality
- provide access for industry to world-standard research scientists and infrastructure.

NRSP is not a management or funding body. It builds on a foundation of Perth’s existing facilities and partnerships in resource sciences and draws together a network of strong capability and infrastructure within a community of over 400 research staff between its foundation partners. Physically, it is located across a number of established sites within a 6 km radius of the Perth CBD.

GSWA is already involved in joint projects with participants in the NRSP.

Other States have geoscience initiative funding

With the exception of Tasmania, all States and the Northern Territory currently have special funding for pre-competitive geoscience initiatives aimed at attracting new, better-targeted exploration by the private sector (Table 3). Tasmania and Victoria are also expanding their core libraries and South Australia is building a new core library and associated seminar/training facility. Such initiatives represent a significant boost to the base funding of the jurisdiction’s Geological Survey agency and in the case of New South Wales, where the initiative is funded by a levy, this funding is ongoing.

Economic impact of Geological Survey organizations confirmed

Economic impact analyses have been conducted by independent consultants over the last few years on the New South Wales and South Australian Geological Surveys.

ACIL Tasman (2010) concluded that ‘The economy of New South Wales would realize both financial and economic benefits from continuing the New Frontiers Initiative. The present value of the additional Gross State Income compared to terminating the program is \$3054 million. This is 43 times the present value of the net cost of the program.’

The South Australian review focused on the economic impact of the Plan for Accelerating Exploration (PACE) program that is regarded as an exemplar in Australia and overseas for government programs used to promote prospectivity and encourage mineral and petroleum exploration investment. Economic Consulting Services (2014) found that PACE:

Table 3. Ongoing and new State geoscience initiatives 2014–15 onwards

State	Initiative	Funding
NSW	New Frontiers Initiative (2012 onwards funded by industry levy) Geological and prospectivity mapping, geophysical and geochemical surveys, online information delivery upgrades	~\$6 M/year
Qld	Future Resources Program (2013–14 to 2015–16) Collaborative drilling, prospectivity assessments, core library extension, online information delivery upgrades, MT survey, biogeochemistry survey	\$15 M/year
NT	CORE (Creating Opportunities for Resource Exploration) program (2014–15 to 2017–18). Initially launched at \$3.95 million per year, but extended in 2014 by another \$2 million per year. Focuses on acquiring new pre-competitive geoscience information to stimulate exploration, collaborative regional assessments of shale gas potential, industry grants for high-risk exploration, and programs to attract investment into resources projects in the Territory	\$5.95 M/year
SA	PACE FRONTIERS (2013–14 to 2014–15) Eastern Gawler craton: geological, geochemical and prospectivity mapping, regolith and basement drilling Western Gawler craton and Eucla Basin: airborne geophysics, MT and biogeochemistry New core library	\$2 M/year
Vic	Securing Victoria’s Earth Resources program (2013–14 to 2016–17) National Partnership Agreement on coal and coal seam gas	\$32 M capital

- is responsible for an increase in State mining revenue of \$2400 million for an expenditure of about \$50 million
- was the major factor in mineral exploration expenditure increasing to \$355 million then recovering after the GFC to \$328 million in 2011–12
- was instrumental in the discovery of a large copper–gold resource at Carrapateena with the follow-on Khamsin copper–gold discovery a consequential result
- has catalysed an extra \$700 million of mineral exploration investment in South Australia
- has leveraged exploration expenditure valued at least 20 times the cost of pre-competitive geoscience programs.

As part of the ongoing review of the EIS, DMP will institute in 2014–15 an independent study of the economic and financial impact over the first five years of the Scheme.

Part 2
**Recurrent budget and work
program for 2014–15 and beyond**

Context of the program

Progress in implementing recommendations of 2012 GSWA review

The functional review of GSWA undertaken in 2012 (Economics Consulting Services, 2012) strongly endorsed GSWA's programs funded out of both Consolidated Revenue (CR) and RfR, and made 12 recommendations (Table 4).

As updated in the 'Implementation plan' column of Table 4, considerable progress has been made in implementing most of the recommendations. However, the most difficult recommendation to implement is Recommendation 6, where the previous Manager Energy Geoscience (Ted Bowen) retired and attempts to recruit a replacement fell over at the final hurdle. Recruitment attempts will resume again in 2014–15.

Given the high costs involved, extension of EIS programs to survey the geology of frontier areas within the State's territorial sea will depend on additional funding (as well as the magnitude of the funding) after the current indicated end of the EIS in June 2017.

Table 4. Recommendations of the 2012 functional review of GSWA

Recommendation	GWSA response	Implementation plan
1. Develop a new funding model applicable beyond 2016 that recognizes the dependence of the WA economy on the resources industry and the cost of modern geoscience programs.	Accept	EIS was extended in the forward estimates of the State Budget for 2014–15 until the end of 2016–17, and EIS changed from funded by Royalties for Regions to a special account in Consolidated Revenue. But EIS budget reduced from \$20 million per year to \$10 million per year (including co-funded drilling) and is apparently stopping at the end of 2016–17. GSWA is working on extending EIS beyond June 2017.
2. Develop a staff development and recruitment strategy to address the age profile of GSWA with plans for succession.	Accept	Being addressed in graduate MSc program and ongoing recruitment of new staff in geoscience, geological and cartographic groups.
3. Develop a Strategic Plan that reflects the goals of the government and articulates a vision for a geoscience knowledge framework for WA.	Accept	Will be incorporated into 1.
4. Undertake a review of energy geoscience in DMP to raise its profile and increase its capacity given the emerging importance of this sector and the changes taking place in the industry in relation to shale and tight gas, and carbon sequestration.	Accept	Being discussed with new Executive Director Petroleum Division.
5. Develop post-NOPTA arrangements to ensure that geoscience information is not lost to the State.	Accept	NOPTA/GA/GSWA agreements signed in late June 2013 for the continued storage, handling and viewing of offshore core and cuttings; these arrangements are going well. GA/NOPTA yet to release the online NOPIMS; however, GSWA still presents on the Web (via WAPIMS) all offshore petroleum data received by GSWA prior to January 2012.
6. Recruit a Chief Petroleum Geologist for the Executive Team.	Accept	Manager Energy Geoscience appointed early November 2012 and has joined Executive Team, but retired in early 2014. Nominated replacement declined the position in mid-2014; recruitment attempts resume yet again.
7. Approach GA to provide specialist people to engage on joint work programs, particularly on shale and tight gas.	Accept	This is proceeding, especially in the area of processing and interpreting the data from the Canning Coastal seismic survey.
8. More closely integrate the work of the Mineral systems section with the regional mapping teams and research collaborators to produce integrated tectonic and metallogenic syntheses of terranes.	Accept	Review of Minerals Geoscience section in GSWA has resulted in a model involving assignment of a mineral geologist to most mapping teams.
9. Extend EIS programs to cover geology beneath the territorial sea.	Accept	Will be built into future programs (beyond June 2017) if funding is provided for geophysical programs in shallow marine areas.
10. Move to digital online lodgement of exploration reports to streamline submission and assessment of company reports, and their inclusion in WAMEX.	Accept	Being planned as part of the upgrade of the WAMEX system in 2014. Due for release at GSWA Open Day in February 2015.
11. Increase transparency of the EIS collaborative drilling award process to ensure greater clarity of reasons for approvals.	Accept in part	There are too many awardees to do this and the applications (successful and unsuccessful) remain confidential because of the exploration models and concepts presented to argue their case for co-funding. It is only drilling results that are subsequently published, not necessarily the exploration targeting concepts. Applicants who are unsuccessful will be given, on request, reasons they were unsuccessful.
12. Consider working with industry, researchers and the exploration services industry in developing Perth into a 'Global Centre of Exploration Excellence'.	Accept in part	Optimistic that Liberal Party electoral promise, Continuing Growth in Mining and Petroleum, will eventually be funded (involves \$2 million to support marketing of Perth as a resources hub). DMP will support other agencies that lead this initiative. By default, funding of selected collaborative projects through EIS has promoted, albeit indirectly, this concept of Perth as a 'Global Centre of Exploration Excellence'.

Achievements 2013–14

In 2013–14, GSWA maintained the high-level output of products funded from both CR and the EIS (Table 5). ‘Series maps’ and ‘Maps – other’ were produced entirely by funding from CR whereas all geophysical data surveys were funded by the EIS. Other product categories consisted of a mix of CR and EIS funding.

Weighted Total Published Product, GSWA’s main efficiency performance measure, has been maintained above 170; almost double the quantum of 2007–08, the year immediately prior to commencement of the EIS.

Other significant achievements during 2013–14 include the following:

- Release of the Albany–Fraser Orogen magnetotelluric (MT) and seismic survey data and its interpretation.
- The Albany–Fraser Orogen survey line was extended from Haig to the South Australian border and on to Tarcoola.
- The last two holes in the seven-hole Eucla basement drilling program were successfully drilled and sampled.
- The Capricorn airborne EM survey of 30 000 line-kilometres was flown and data released.
- The Canning Coastal seismic survey of 700 line-kilometres across the Canning Basin was completed.
- The mineral drillhole and surface geochemistry databases were released within GeoVIEW.WA.
- Search tools for the mineral exploration reports database (WAMEX) were improved by incorporation into GeoVIEW.WA.

GSWA’s budget 2014–15

The Government’s 2014–15 budget brought down in May 2014 revealed total net appropriations of \$40.719 million for geoscience information (Table 6), the service that supports the outcome of encouraging the exploration and discovery of mineral and energy resources and informed planning in Western Australia.

GSWA contributes to State planning by virtue of Section 16 (3) of the Mining Act that provides for the Minister for Mines to approve all leases and transfers under the *Land Administration Act 1997*. This requires that GSWA analyse the mineral and energy prospectivity of the land parcel and potentially consult with impacted exploration and production tenement holders.

Although Table 6 shows total headline (or base) funding of \$40.719 for GSWA for 2014–15, the amount actually received as discretionary funding for salaries plus operational funding is only \$18.050 million. The difference (\$12.699 million or 41% of the original State budget appropriation) is because employee overheads (superannuation) and public utilities are paid centrally

by DMP, and GSWA also contributes to DMP overheads including finance, human resources, information technology, building rental and other corporate costs.

Budget year 2013–14 was the final year of the \$3 million funding DMP received over three years under the Kimberley Science and Conservation Strategy (KSCS) to undertake baseline geochemical and geophysical surveys in the region. Gaining access to land to undertake the planned surveys had delayed work in the early years of the project, but 2013–14 was a very busy and productive year, with fieldwork conducted right up to the end of the financial year. However, there was a slight carryover of costs (~\$50 000) into 2014–15, with these costs needing to be borne by the recurrent budget.

In 2014–15, funding for the EIS is \$10.0 million per year, which is a significant drop from the average of around \$20 million per year since 2010–11. However, the Government has recognized the early successes of the EIS by extending funding to 2016–17, and at that same new rate of funding support (Table 7). From 2014–15, EIS funding has switched to the CR Fund, rather than from RfR (as it was from commencement in April 2009 to the end of 2013–14). Further details of EIS funding are provided in Part 3 of this Record.

After removal of corporate overheads, GSWA’s discretionary base funding is \$18.050 million, which is only a slight decrease from \$18.475 million in 2013–14 (Table 8) and reflects the general tight DMP and State Government budgetary environment. The specific budget items where there is an increase in budget allocations in 2014–15 are 3D geoscience, field support and business system development. All three cost centres are also required to support a high level of EIS activity but generally do not receive direct EIS funding. Cost centres with a decreased budget allocation at the KSCS (specific project funding stopped completely at the end of 2013–14), Murchison field mapping, and Albany–Fraser Orogen mapping (with the latter, the decrease is largely from one staff member moving to the 3D mapping cost centre). Table 9 shows GSWA’s discretionary budget after support areas are distributed pro rata to geoscience information-producing projects.

Staffing related to base funding 2013–14

Table 8 shows that planned staffing, which is 134 FTE staff in 2014–15 (previously 131 FTEs in 2013–14; excluding EIS and KSCS staffing) is higher than last year and will mean that salaries will account for 73.4% of GSWA’s CR funding (previously 66.7% in 2013–14). Staffing FTE levels and quantum of salaries as a percentage of the recurrent operating budget have gradually increased over the last few years as a result of enterprise bargaining, graduate scheme appointments and internal promotions. In 2014–15 this will be exacerbated by the withdrawal of KSCS funding and the reduction in EIS funding, with some staff being retained by moving to recurrent-funded positions. There are now signs that more of GSWA’s baby boomers will retire during 2014–15. GSWA lost two non-geological staff in 2013–14

Table 5. GSWA products 2013–14

	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14 planned	2013–14 actual
Books (Reports, Records, non-series)	42	26	36	52	35	39	40	39
Maps — 1:100 000 and 1:250 000 Geological Series	9	14	13	12	12	10	10	10
Maps — other (includes geophysical maps)	4	17	11	8	14	17	17	20
Digital information packages	19	19	21	17	18	11	18	20
1000 line-km of airborne geophysical data (EIS)	263	398	908	720	768	1157	—	588
Weighted Total Published Product	92	118	170	188	174	173	—	187

Table 6. GSWA's high-level budget for geoscience information

	2012–13 \$m	2013–14 \$m	2014–15 \$m
Consolidated Revenue Fund			
Base funding (recurrent budget)	28.020	28.128	30.719
Kimberley Science and Conservation Strategy (KSCS)	1.140	1.135	—
Exploration Incentive Scheme*	13.100	24.190	10.000
Total budget	42.260	53.453	40.719

* EIS funding in 2013–14 included a carryover of \$3.590 million from 2011–12.

Table 7. GSWA's projected appropriations (\$ million) 2014–15 to 2017–18 (the limit of budget forward estimates)

	2014–15	2015–16	2016–17	2017–18
Base funding	30.719	30.748	31.370	30.398
EIS	10.000	10.000	10.000	—
KSCS	—	—	—	—
Total	40.719	40.748	41.370	30.398

from accelerated departures using the Government-sponsored redundancy scheme, and another such voluntary redundancy scheme is expected in 2014–15.

Figure 19 illustrates the 25-year trends in GSWA's recurrent expenditure and employment. Staff numbers in GSWA decreased as the mining boom progressed — falling from a peak of 148 FTE staff in 2005–06 to 128 in 2008–09; with the fall stopped by the GFC. Not only did staff retention rates improve after the GFC, but GSWA's baby boomers postponed their retirement. The EIS started in April 2009 and, with the additional funding, provided extra funds for operational-style project expenditure, but where employment under EIS was strictly capped at an additional eight FTE staff (which are not shown in Figure 19). Recurrent-funded staff have crept up to a planned figure of 134 for 2014–15; this creep over the last few years also coincides with the introduction of the sponsored Master's program, through which six staff have been employed. The postponed retirement of more baby boomers is expected during 2014–15 and 2015–16, together with more Government voluntary redundancy offers, and these are expected to reverse the gradual increase in staff numbers. Declining commodity prices during the first part of 2014, especially of iron ore on which the State budget is heavily reliant for royalties, will mean that the Government controls on expenditure and staffing will continue in the medium term.

Fifteen public service contract staff are included in the budgeted FTEs for 2014–15, representing 11.3% of total FTEs. These include some of the sponsored Master's staff who are on contract during their study, but become permanent staff only after successfully completing their Master of Science degree. Budget restraints will not permit an additional person to be recruited to the sponsored Master's program during 2014–15, but staff had been recruited under that program for the four previous years. Additional people are employed through fee-for-service arrangements for specific project work.

The proportion of geoscientists is slowly increasing relative to the other specialist groups, partly as a result of geoscientists taking on some of the cartographic/GIS and specialist geoscience data entry tasks (Table 10).

Strategic allocation of Consolidated Revenue funding 2013–14

Table 11 contains the result of allocating GSWA's CR funding to its two strategic objectives under the Geoscience Information service, viz. 'Encouraging exploration and discovery of resources' and 'Informed land-use planning'.

Table 8. GSWA's 2014–15 recurrent operational budget for both projects and support activities

SERVICE 2 — GEOSCIENCE INFORMATION AND ADVICE — BUDGET ALLOCATIONS

2013–14 Budget \$,000	Project and support activities Operational group/cost centres		2014–15 allocations			Div Plan FTEs
			Salaries \$,000	Non-salary \$,000	Total \$,000	
	Description					
	3101 — Executive and Administrative Support					
633	GS01	Executive team	634	22	656	4.0
384	GS02	Executive support	330	45	375	4.0
1017	Subtotal cost centre 3101		964	67	1031	8.0
	3102 — Minerals and Petroleum Resources					
1485	GS10	Basins and energy geoscience	1286	286	1572	11.6
1023	GS12	Land use geoscience	981	75	1056	9.0
769	GS14	Commodity and industry analysis	504	282	786	4.4
609	GS20	Mineral systems studies	580	80	660	6.0
3886	Subtotal cost centre 3102		3351	723	4074	31.0
	3103 — Regional Geoscience Mapping					
275	GS43	Geochemistry and regolith	246	32	278	2.0
141	GS45	Pilbara Craton	144	1	145	1.0
130	GS47	Gascoyne Province	106	32	138	1.0
282	GS49	Edmund and Collier Basins	238	34	272	2.0
450	GS52	East Yilgarn (Kalgoorlie Office)	288	166	454	3.0
630	GS53	Chief Geoscientist and Terrane Custodians	452	82	534	4.0
684	GS54	Geochronology and isotope geology	507	206	713	5.6
323	GS55	Geophysics and remote sensing	257	76	333	2.0
177	GS56	North Australian Craton	125	68	193	1.0
412	GS57	West Musgrave Province	332	63	395	2.8
758	GS58	Youanmi	588	96	684	5.0
237	GS61	Albany–Fraser Orogen and Eucla Basement	125	56	181	1.0
	GS62	3D geoscience	225	0	225	2.0
4499	Subtotal cost centre 3103		3633	912	4545	32.4
	3104 — Logistics and Field Support					
1073	GS70	Field support	312	956	1268	4.0
1073	Subtotal cost centre 3104		312	956	1268	4.0
	3105 — Geoscientific Editing and Publishing					
827	GS80	Editing and publishing	685	196	881	7.4
770	GS81	Mapping	671	81	752	8.0
223	GS82	Graphics	243	0	243	3.0
662	GS83	GIS services	631	59	690	7.0
946	GS84	Spatial services	470	590	1060	5.0
398	GS85	Geoscience promotions	320	30	350	3.0
3826	Subtotal cost centre 3105		3020	956	3976	33.4
	3106 — Geoscientific and Exploration Information					
728	GS91	Mineral exploration information management	605	212	817	7.6
1139	GS92	Statutory petroleum exploration information	719	422	1141	9.6
841	GS94	Core Library Perth	325	250	575	4.0
331	GS95	HyLogger and National Virtual Core Library	183	176	359	2.0
	GS96	Core Library Kalgoorlie	144	120	264	2.0
3039	Subtotal cost centre 3106		1976	1180	3156	25.2

Table 8. continued

2013–14 Budget \$,000	Project and support activities Operational group/cost centres Description		2014–15 allocations			Div Plan FTEs
			Salaries \$,000	Non-salary \$,000	Total \$,000	
0	3107 — Inventory of Abandoned Mine Sites					
	GS99	Inventory of abandoned mine sites	0	0	0	0.0
17340	GSWA BUDGET		13256	4794	18050	134.0
	3108 — Kimberley Science and Conservation Strategy					
	KS01	Geophysical surveys	0	0	0	0.0
1135	KS02	Geochemical surveys	0	0	0	0.0
1135	Subtotal cost centre 3108		0	0	0	0.0
18475	GSWA BUDGET WITH KSCS		13256	4794	18050	134.0

Table 9. GSWA's 2014–15 recurrent operational budget, with support budgets distributed pro rata to geoscience activities

Cost centres Projects and support activities	2013–14 Total \$,000	2014–15 Fully attributed budget			Div Plan FTEs
		Salary \$,000	Non-salary \$,000	Total \$,000	

SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE

Encouragement of exploration and discovery of mineral and petroleum deposits and informed land use planning

Publish maps, reports and datasets to maintain an up-to-date geological framework of the State and its mineral and petroleum resources. Maintain an archive of statutory mineral and petroleum exploration information and samples.

Regional Geoscience Field Mapping

GS43	Geochemistry and regolith	566.7	449.6	126.5	576.1	4.2
GS45	Pilbara Craton	286.8	245.8	48.2	294.1	2.1
GS47	Gascoyne Province	275.8	207.8	79.2	287.1	2.1
GS49	Edmund and Collier Basins	573.7	441.6	128.5	570.1	4.2
GS52	East Yilgarn (Kalgoorlie Office)	887.5	593.5	307.7	901.2	6.3
GS55	Geophysics and remote sensing	614.7	460.6	170.5	631.1	4.2
GS56	North Australian Craton	322.8	226.8	115.2	342.1	2.1
GS57	West Musgrave Province	805.7	613.0	193.4	806.4	5.8
GS58	Youanmi	1633.0	1097.1	332.2	1429.3	10.4
GS61	Albany–Fraser Orogen and Eucla Basement	528.7	226.8	103.2	330.1	2.1
GS62	3D geoscience		428.6	94.5	523.1	4.2
Subtotal		6495.3	4991.4	1699.4	6690.8	47.4

Petroleum System Studies and Exploration Information

GS10	Basins and energy geoscience	3176.6	2467.1	834.1	3301.2	24.2
GS92	Statutory petroleum exploration information	2052.1	1282.2	787.9	2070.1	15.8
Subtotal		5228.7	3749.3	1622.0	5371.3	39.9

Table 9. continued

Cost centres Projects and support activities	2013–14 Total \$,000	2014–15 Fully attributed budget			Div Plan FTEs
		Salary \$,000	Non-salary \$,000	Total \$,000	
Mineral Resource Services and Exploration Information					
GS12 Land use geoscience	1612.5	1464.3	204.8	1669.1	13.9
GS14 Commodity and industry analysis	1096.5	740.3	345.4	1085.7	6.8
GS20 Mineral systems studies	1338.1	1190.9	363.5	1554.4	12.5
GS91 Mineral exploration information management	1569.0	1119.7	558.9	1678.7	13.4
GS99 Inventory of abandoned mine sites	0.0	0.0	0.0	0.0	0.0
Subtotal	5616.1	4515.3	1472.6	5987.9	46.6
TOTAL GSWA BUDGET	17340.0	13256.0	4794.0	18050.0	134.0
Kimberley Science and Conservation Strategy					
KS01 Geophysical surveys		0.0	0.0	0.0	
KS02 Geochemical surveys	1135.0	0.0	0.0	0.0	
Subtotal	1135.0	0.0	0.0	0.0	1.0
TOTAL GSWA BUDGET	18475.0	13256.0	4794.0	18050.0	134.0
SUPPORT ACTIVITIES					
GS01 Executive team		Distributed pro rata to all projects			
GS02 Executive support		Distributed pro rata to all projects			
GS53 Chief Geoscientist and Terrane Custodians		Distributed pro rata to all mapping and resource projects			
GS54 Geochronology and isotope geology		Distributed pro rata to all mapping and Petroleum Geology projects			
GS59 Geology online		Distributed pro rata to all mapping and resource projects			
GS70 Logistics and field support		Distributed pro rata to all mapping and Petroleum Geology projects			
GS80 Editing and publishing		Distributed pro rata to all mapping and resource projects			
GS81 Mapping		Distributed pro rata to all mapping and resource projects			
GS82 Graphics		Distributed pro rata to all mapping and resource projects			
GS83 GIS services		Distributed pro rata to all mapping and resource projects			
GS84 Spatial systems		Distributed pro rata to all projects			
GS85 Geoscience promotions		Distributed pro rata to all projects			
GS94 Core Library Perth		Distributed pro rata to exploration Information projects			
GS95 HyLogger and National Virtual Core Library		Distributed pro rata to exploration Information projects			
GS96 Core Library Kalgoorlie		Distributed prorata to exploration Information projects GS99 excepted from pro rata distribution KS01 and KS02 excepted from pro rata distribution			

Table 10. Distribution of GSWA staff (excluding EIS- and KSCS-funded staff) among specialist groups funded by the Consolidated Revenue Fund in 2014–15

Specialist group	Actual FTEs 2012–13		Actual FTEs 2013–14		Planned FTEs 2014–15	
	FTEs	%	FTEs	%	FTEs	%
Geoscientists	71.1	53.6	72.1	54.9	75.8	56.6
Cartographers and GIS specialists	27.4	20.9	26.0	19.8	27.0	20.1
Other (technical and field support, data entry administrative support)	33.3	25.5	33.3	25.3	31.2	23.3
Total	131.8	100	131.4	100	134	100

The analysis included in Table 11 reveals that 70% of GSWA's 2013–14 budget will be applied to the outcome of encouraging the exploration and discovery of mineral and energy resources and 30% will be directed towards informed land-use planning. The amounts in the previous year were 66% and 34%, respectively. Within the objective of encouraging exploration and discovery, the split between targeting minerals versus petroleum and coal is 48 basis points versus 22 basis points (totalling 70% of the

GSWA budgetary resources) — with both up three basis points relative to 2013–14.

Pre-competitive geoscience applied to greenfields areas targeting minerals, petroleum and coal (combined) consumes 48% of the budget compared to the 22% directed towards brownfields areas, a ratio of about 70:30. This ratio has been maintained for many years.

Table 11. Distribution of recurrent budgetary resources to high-level strategic objectives in 2014–15

GSWA 2014–15		SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE																TOTAL		
		Encouragement of exploration and discovery of mineral and energy resources and informed planning.																		
		3102			3103										3106					
Cost centres		Mineral resources			Regional geoscience mapping										Exploration Information and Core Libraries			TOTAL		
All figures as \$000		GS10	GS12	GS14	GS20	GS43	GS46	GS47	GS49	GS52	GS55	GS56	GS57	GS58	GS61	GS62	GS91		GS92	
Percentage in 2014–15 budget		1689.1	1085.7	1085.7	1554.4	576.1	294.1	287.1	570.1	901.2	631.1	342.1	806.4	1429.3	330.1	523.1	1678.7	2070.1	16050	
Percentage in 2013–14 budget		16.7	10.9	10.9	233.2	11.5	23.5	11.5	90.1	63.1	63.1	17.1	40.3	285.9	104.6	104.6	671.5	41.4	1086.6	
Project totals (as \$000) include support budgets distributed pro rata by FTE levels		16.7	10.9	10.9	155.4	11.5	26.5	8.6	57.0	45.1	31.6	17.1	40.3	243.0	52.3	52.3	671.5	41.4	894.2	
Established and Producing Areas		16.7	10.9	10.9	155.4	11.5	26.5	5.7	45.1	45.1	63.1	285.9	52.3	285.9	52.3	52.3	671.5	41.4	851.3	
Minerals		16.7	10.9	10.9	77.7	77.7	2.9	2.9	2.9	31.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	346.5
Analysis and publication of geoscience information		16.7	10.9	10.9	155.4	144.0	58.8	86.1	142.5	270.4	189.3	136.8	241.9	142.9	165.1	104.6	419.7	165.6	2066.9	
Greenfields		16.7	10.9	10.9	155.4	144.0	58.8	100.5	256.5	90.1	63.1	102.6	322.6	142.9	99.0	104.6	419.7	165.6	1669.2	
Precious metals		16.7	10.9	10.9	155.4	144.0	58.8	23.7	57.0	90.1	94.7	34.2	80.6	142.9	33.0	52.3	165.6	165.6	1200.8	
Base metals		16.7	10.9	10.9	155.4	144.0	58.8	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	326.5	
Ferro-alloys		16.7	10.9	10.9	155.4	144.0	58.8	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	326.5	
Non-metallics		16.7	10.9	10.9	77.7	77.7	2.9	2.9	2.9	31.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	326.5	
Producing areas		16.7	10.9	10.9	155.4	144.0	58.8	86.1	142.5	270.4	189.3	136.8	241.9	142.9	165.1	104.6	419.7	165.6	2066.9	
Petroleum, geothermal, CO ₂ and coal		16.7	10.9	10.9	155.4	144.0	58.8	100.5	256.5	90.1	63.1	102.6	322.6	142.9	99.0	104.6	419.7	165.6	1669.2	
Frontier areas		16.7	10.9	10.9	155.4	144.0	58.8	23.7	57.0	90.1	94.7	34.2	80.6	142.9	33.0	52.3	165.6	165.6	1200.8	
SUBTOTALS		16.7	10.9	10.9	77.7	77.7	14.7	14.4	14.4	14.4	31.6	14.3	14.3	14.3	14.3	14.3	14.3	14.3	326.5	
Producing areas		16.7	10.9	10.9	155.4	144.0	58.8	86.1	142.5	270.4	189.3	136.8	241.9	142.9	165.1	104.6	419.7	165.6	2066.9	
Frontier areas		16.7	10.9	10.9	155.4	144.0	58.8	23.7	57.0	90.1	94.7	34.2	80.6	142.9	33.0	52.3	165.6	165.6	1200.8	
SUBTOTALS		16.7	10.9	10.9	77.7	77.7	14.7	14.4	14.4	14.4	31.6	14.3	14.3	14.3	14.3	14.3	14.3	14.3	326.5	
INFORMATION SERVICES		16.7	10.9	10.9	77.7	77.7	14.7	14.4	14.4	14.4	31.6	14.3	14.3	14.3	14.3	14.3	14.3	14.3	326.5	
INFORMATION SERVICES		16.7	10.9	10.9	77.7	77.7	14.7	14.4	14.4	14.4	31.6	14.3	14.3	14.3	14.3	14.3	14.3	14.3	326.5	
SUBTOTALS		16.7	10.9	10.9	77.7	77.7	14.7	14.4	14.4	14.4	31.6	14.3	14.3	14.3	14.3	14.3	14.3	14.3	326.5	
TOTALS		16.7	10.9	10.9	77.7	77.7	14.7	14.4	14.4	14.4	31.6	14.3	14.3	14.3	14.3	14.3	14.3	14.3	326.5	
Encouragement of exploration and discovery	Minerals	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	
	Analysis and publication of geoscience information	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	
	Greenfields	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	
STRATEGIC OBJECTIVES	Encouragement of exploration and discovery	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	
	Analysis and publication of geoscience information	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	
	Greenfields	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	48%	45%	
Informed Land-use Planning	Information on resource potential	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	
	Policy advice on resource issues	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	
	Information for R&D and the general public	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	
RESPONSIVE MANAGEMENT, CUSTOMERSHIP AND PROVISION OF POLICY ADVICE AND INFORMATION	Information on resource potential	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	
	Policy advice on resource issues	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	
	Information for R&D and the general public	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	
TOTALS	Information on resource potential	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	14%	
	Policy advice on resource issues	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	10%	11%	
	Information for R&D and the general public	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	6%	9%	

Note: Some totals may contain rounding errors

KEY

- The budget of each project has been attributed in proportion to its perceived contribution to various strategic objectives.
- The vertical total column to the right represents the aggregated weighted contribution of all Service 2 projects to various strategic objectives.

* CO₂: carbon dioxide geosequestration

Project titles

- GS10 Petroleum geology
- GS12 Land use geoscience
- GS14 Commodity and industry analysis
- GS20 Mineralization and exploration assessment
- GS43 Geochemistry
- GS44 Pilbara Craton
- GS47 Gascoyne Province
- GS49 Edmund and Collier Basins
- GS52 East Yilgarn (Kalgoorlie office)
- GS55 Geophysics and remote sensing
- GS56 North Australian Craton
- GS57 West Musorare Province
- GS58 Youanmi
- GS61 Albany-Fraser Orogen and Eucla Basement
- GS62 3D geoscience
- GS99 Inventory of abandoned mine sites
- GS91 Mineral exploration information management
- GS92 Petroleum exploration information management

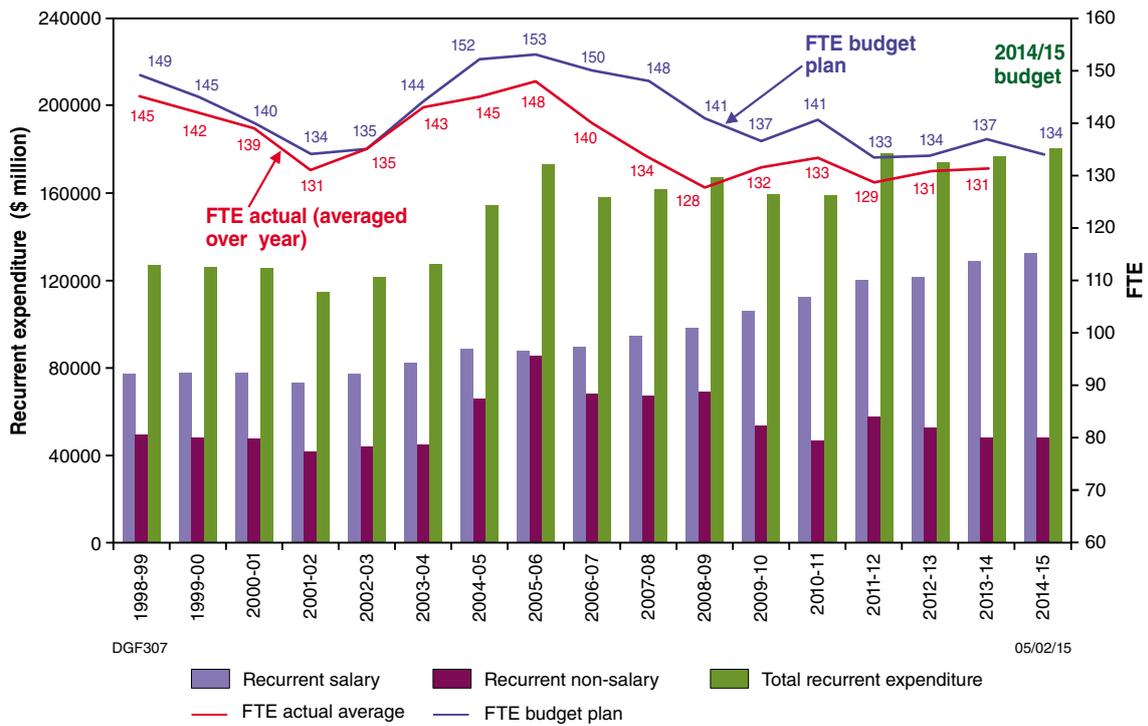


Figure 19. Trends in GSWA annual recurrent expenditure and FTE employment since 1998–99 (excludes EIS and KSCS)

Recurrent budget work program 2014–15

The 2014–15 field mapping program will continue to extend the 1:100 000-scale Geological Series maps and the Geological Information Series (GIS) products (Figs 20 and 21) for the west Musgrave, Granites–Tanami Province, Gascoyne Province, Bangemall Supergroup, and the Murchison and Southern Cross Domains of the Yilgarn Craton. In the west Kimberley a first edition 1:100 000-scale map will be produced covering part of the King Leopold Orogen, together with a further second edition 1:250 000-scale Geological Series map covering the west Kimberley Basin. The GIS products covering the Kimberley and the west Tanami (both EIS products) will be updated. The development of revised interpreted bedrock geology layers at 1:100 000 and 1:500 000 scales, and the introduction of workable stratigraphies for the Kalgoorlie and Kurnalpi Terranes of the Eastern Goldfields Superterrane will continue for a further update of the East Yilgarn GIS product. The revised 1:500 000 interpreted bedrock geology map of the State, will be released and will form the basis of a new 1:2 500 000 Geological Map of Western Australia.

Work of the Minerals Geoscience section (including the HyLogger spectral scanner) is gradually being integrated with the mapping projects (above), as well as being involved as much as possible with the collaborative research projects funded by EIS. Ongoing entry of mineral

deposit information will continue into GSWA’s mines and mineral deposits information database (MINEDEX), which is used throughout DMP for a number of policy and approvals purposes. Improved reporting of mineral production data from MINEDEX is planned for 2014–15.

The Basins and Energy Geoscience section will continue its major investigations of the Canning, Perth and western Amadeus Basins using a mix of recurrent and EIS funding. This work involves the high-priority projects of the Canning coastal seismic survey (700 line-kilometres) and the deep stratigraphic drillhole(s) in the Canning Basin (\$2 million budget, but predominantly funded by the Commonwealth Government).

The Land Use Geoscience section will continue responding to routine and ad hoc requests for prospectivity analyses from the Department of Planning and the Western Australian Planning Commission. Strategic projects for 2014–15 include:

- Continuing the prospectivity assessments of parcels of Crown land in the southwest of the State that could potentially be returned to traditional owners as freehold land as part of the Southwest Settlement
- Continuing strategic assessment of resources and parcels of land needed to be protected (or sequentially developed) from urban sprawl in the Perth–Peel region for an expanded population of 3.5 million people

- Updating prospectivity assessments of pastoral leases purchased by the Department of Parks and Wildlife (DPaW) for conversion to conservation use as a basis for negotiating with that department on the type of reserve to be applied to areas within individual pastoral leases.

Figure 22 shows GSWA’s planned recurrent budget-funded fieldwork and geophysical program for the four years of the budget forward estimates until 2017–18.

Cooperative projects

GSWA is currently involved in 42 cooperative projects with geoscience research organizations including universities, CSIRO, AMIRA, Cooperative Research Centres (CRCs), Centres of Excellence, AuScope and GA. Twenty-four of these projects are directly related to activities funded by GSWA’s operational recurrent budget, whereas 24 projects are funded out of the EIS. Fourteen of the 24 projects related to recurrent activities involve expenditure of GSWA funds — the remainder are associated with ‘in-kind’ GSWA contributions. Further details of these projects are contained in descriptions of individual recurrent and EIS project plans.

Recurrent budget — planned achievements 2014–15

Table 12 shows GSWA’s planned achievements using 2014–15 recurrent budgetary resources. Importantly, production of 1:100 000 Geological Series maps has

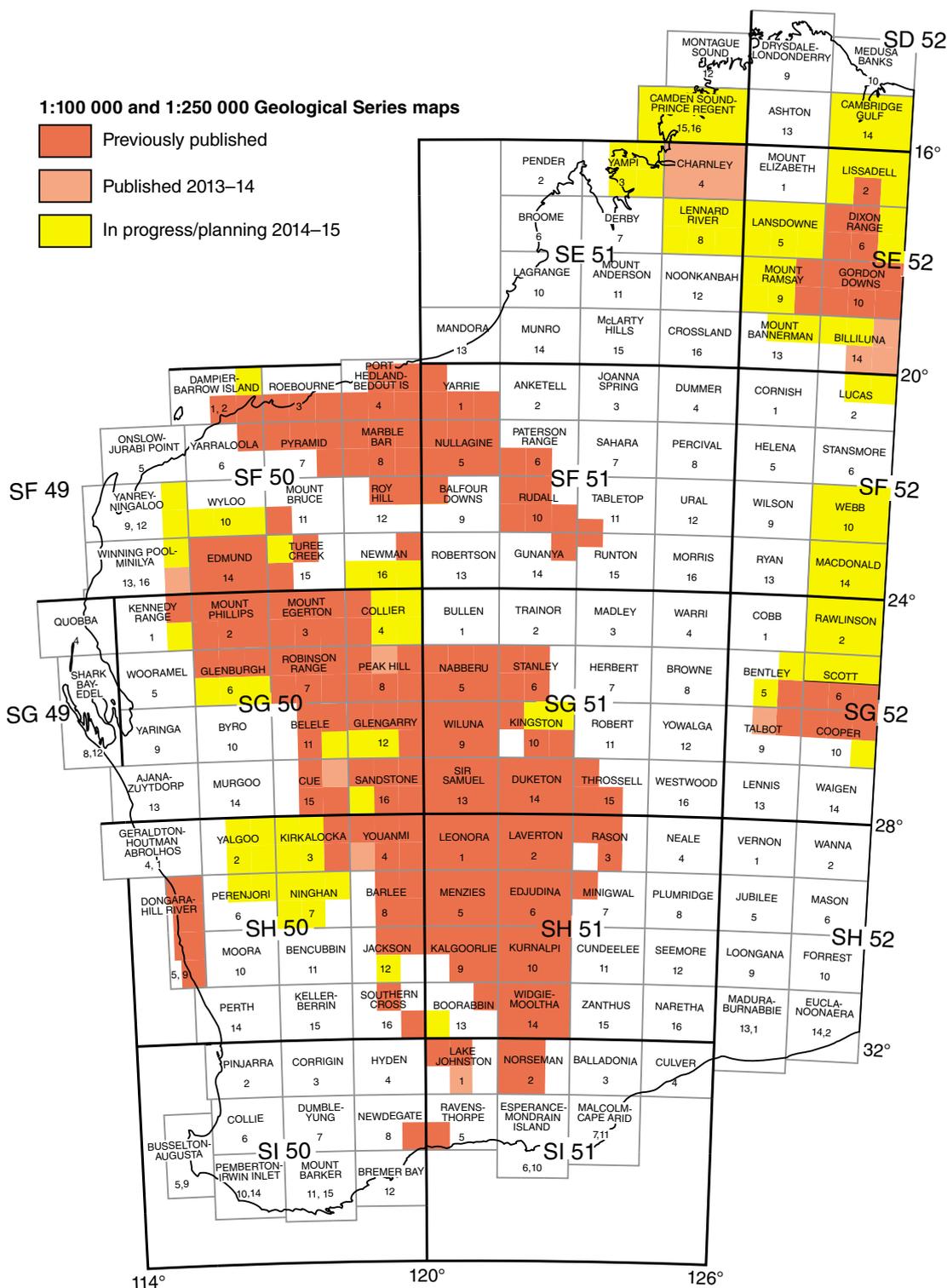
been maintained at 10 maps, and Report and Record production is 35, which is near the long-term average. The planned release of 18 digital information packages and 18 non-series maps (‘Maps — other’) in 2014–15 also maintains the long-term average production level for these products.

Other significant planned outputs of the 2014–15 recurrent budget include:

- an online facility to enable lodgement, including online writing, of WAMEX reports and datasets
- inclusion of land cadastre in GeoVIEW.WA, and release of an iPad version of GeoVIEW.WA
- an options paper(s) of the business requirements and future direction of the WAPIMS database. This will include the options of external hosting of the WAPIMS database (either with Schlumberger or another supplier), either as part of GA’s and NOPTA’s NOPIMS database or completely separate from it.
- Expansion of the Perth Core Library. Funding has been approved for construction of extra storage capacity, and construction should start in early 2015 and be completed by around mid- to late-2016.
- a business case supporting the continuation of the EIS.

Table 12. Planned achievements 2014–15

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15 (planned)
Books (Reports, Records, non-series)	26	36	52	36	39	39	35
1:100 000 and 1:250 000 series maps	14	13	12	12	10	10	10
Maps — other (includes geophysical maps)	17	11	8	14	17	20	18
Digital information packages	19	21	17	18	11	20	18
Line-km of airborne geophysical data	344 k	All in EIS	—				



IMT175d

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Figure 20. Index map showing 2014–15 planned achievements — 1:100 000 Geological Series maps

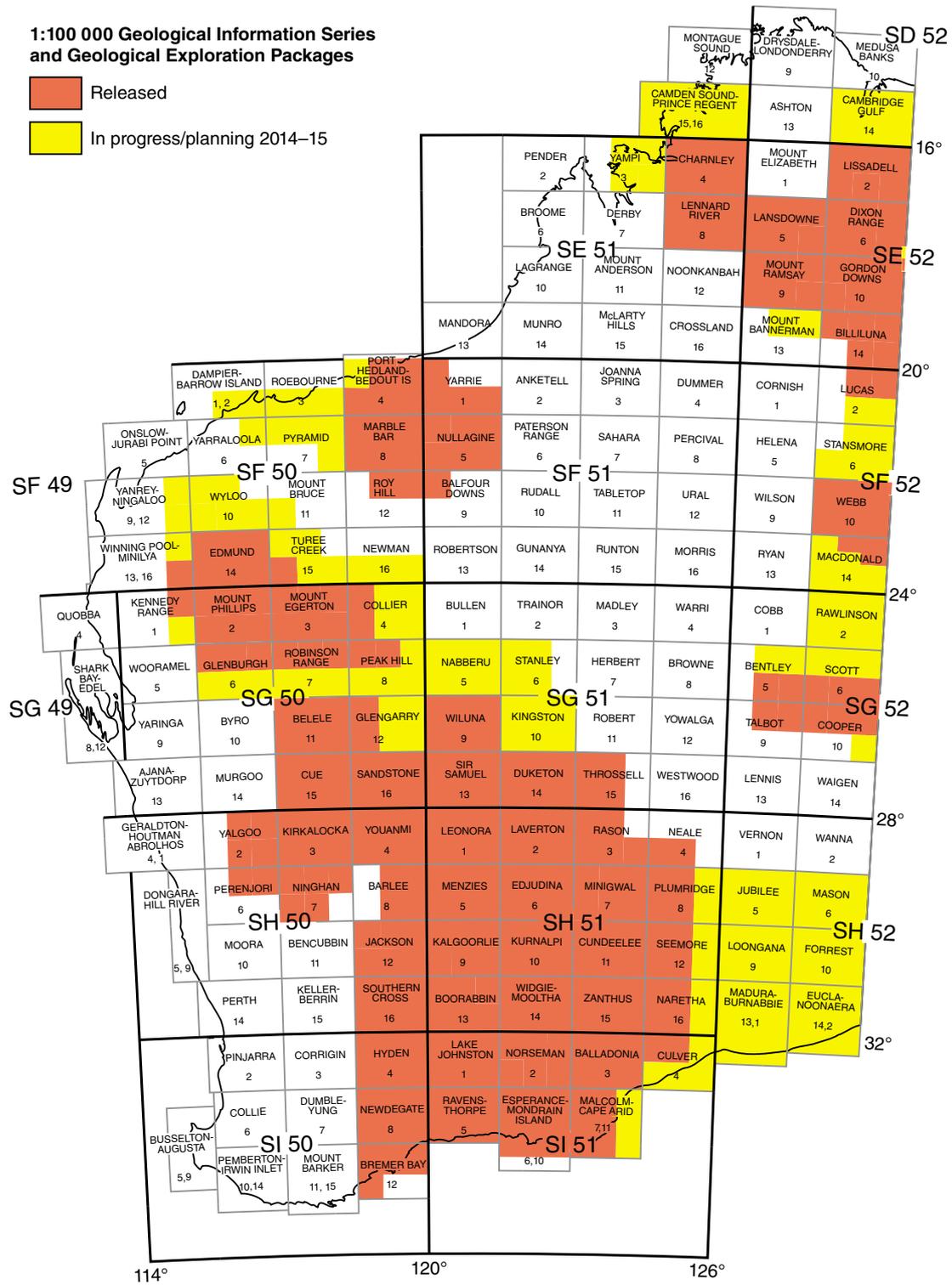


Figure 21. Index map showing 2014–15 planned achievements — 1:100 000 GIS and Geological Exploration Packages

GSWA five-year work program to 2017–18

Geological regions	Age	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
STATE		2.5 M	2.5 M	500 K	500 K	500 K	
KIMBERLEY							
Kimberley Basin	Prot						
Halls Creek Orogen	Prot			M	M		
King Leopold Orogen	Prot						
PILBARA CRATON							
Granite–greenstone terranes	A						
Hammersley Basin	A						
Paterson Orogen	Prot				M	M	M
Sylvania Inlier	A						
YILGARN CRATON							
Eastern Goldfields Superterrane — north	A	M		M	M	M	M
Eastern Goldfields Superterrane — central	A	M					
Eastern Goldfields Superterrane — south	A	M					
Southern Cross Domain — north	A						
Southern Cross Domain — south	A						
Murchison Domain	A	M	M	M	M		
Narryer Terrane	A						
South West Terrane	A			M		M	M
CAPRICORN OROGEN							
Ashburton–Bresnahan Basins	Prot						
Gascoyne Complex — south	Prot		M	M	M		
Gascoyne Complex — north	Prot			M	M		
Edmund–Collier (Bangemall) Basins	Prot	M		M			
Earaheedy Basin	Prot		M				
Bryah–Padbury–Yerrida Basins	Prot	M	M	M	M		
PINJARRA AND ALBANY–FRASER OROGENS							
Albany–Fraser Orogen — east	Prot						
Albany–Fraser Orogen — west	Prot						
Northampton Complex	Prot						
Leeuwin Complex	Prot						
Mullingarra Complex	Prot						
Nullarbor (basement)	Prot						
CENTRAL AUSTRALIA							
West Granites–Tanami Complex	Prot	M	M	M		M	M
Birringudu Basin	Prot						M
Arunta Orogen	Prot						M
Amadeus Basin	Prot						
Musgrave Complex	Prot						
BASIN STUDIES							
Southern and Northern Bonaparte Basins	Phan						
Canning Basin — Lower Paleozoic	Phan						
Canning Basin — Upper Paleozoic	Phan						
Canning Basin — Devonian	Phan						
Southern and Northern Carnarvon Basins	Phan						
Officer Basin	Prot						
Perth Basin — north	Phan						
Perth Basin — south	Phan						
Eucla and Gunbarrel Basins	Phan						

RR114a

10.04.15

Phan Phanerozoic M Mineralization mapping Petroleum systems studies
 Prot Proterozoic 2.5 M 1:2 500 000 State geological map Geological field mapping
 A Archean 500 K 1:500 000 State geological map

Figure 22. GSWA's planned recurrent budget-funded fieldwork and geophysical surveys until 2017–18, by tectonic unit

Part 3
Exploration Incentive Scheme (EIS)
budget and work program for
2014–15 and beyond

Outline of the Exploration Incentive Scheme

This program year (2014–15) is the sixth full year of the EIS and the first which is not funded out of the RfR initiative. The original funding of \$80 million covered the Scheme from its commencement in April 2009 to the end of June 2013. The year 2012–13 was originally to be the final year of the EIS but funding has been extended until the end of 2016–17.

The objective of the EIS is to promote exploration in the State with a particular focus on greenfields areas and frontier petroleum basins, and maintain exploration activity at the levels needed for the long-term sustainability of the State's resources sector. The Scheme also aims to signal that the Western Australian Government welcomes investment in the State's resources sector and is concerned about the sustainability of resource production if discovery rates in some commodities are not increased.

One of the measures of success of the Scheme is the attractiveness of the state as an exploration destination. The ranking of Western Australia in the Fraser Institute's Survey of Mining Attractiveness has improved since the commencement of the EIS from being the least attractive Australian destination for explorers in 2006–07 to being ranked first in the world in the Investment Attractiveness Index, sixth in the world in the Policy Perception Index and best in the world in terms of least uncertainty concerning existing regulations in the most recent survey (Table 13).

The original four-year life of the EIS was extended in the Western Australian State Budget in May 2012 with the re-allocation of funding that had originally been assigned to another RfR project. This additional \$20.6 million funded the activities of the EIS in 2013–14. The 2012 Western Australian State Budget papers showed that funding would be available for EIS out of CR, with \$18 million allocated for 2014–15 and \$19.5 million for 2015–16. However, the 2013 Western Australian State Budget papers show that this has now changed with a total \$30 million being allocated to the second phase of EIS over the three financial years 2014–15 through 2016–17. Funding for the three years of EIS phase 2 will be \$10 million per year.

The EIS was originally made up of six high-level programs, which in turn originally contained 24 subprograms. These are listed in Table 14. Some of these subprograms have been completed or subsumed into other projects, or have been altered due to changes in government policies.

The EIS2 programs, which started in July 2014, continue some of the existing programs but also include new programs. The programs together with the proposed budgets to the end of June 2017 are listed in Table 14.

A flagship program of the EIS has been the geophysics program which has completed the State's coverage by airborne magnetic surveys at line spacing of 400 m or less (Fig. 23). The program is extending the reconnaissance

airborne electromagnetic surveys (Fig. 24), and supports a major expansion of the area covered by gravity surveys with stations spaced less than 2.5 km apart (Fig. 25). The airborne magnetic survey program was completed in late 2012. Availability of medium-spaced, good-quality airborne geophysical data has already greatly contributed to reducing risk and aiding exploration targeting in underexplored areas of the State. Figure 24 shows the gravity survey program for 2014–15, but there are no airborne magnetic or EM surveys planned for 2014–15.

Figure 26 sets out by tectonic unit the geoscience mapping and geophysical survey program carried out under the EIS over the five-year period 2008–09 to 2013–14, together with the program planned for 2014–15.

The other flagship program of the EIS is the Co-funded Government–Industry Drilling Program, which is designed to stimulate geoscience exploration of underexplored areas of Western Australia and contribute to the economic development of these areas. It is funding high-quality, technically and economically sound projects that promote new exploration concepts and new exploration technologies. Core collected by companies that gain co-funding becomes available on open-file access in the relevant core library after a six-month confidentiality period. Reports of the drilling programs are also released online through the WAMEX database after a similar confidentiality period.

Figure 27 shows the location of drilling projects offered funding since the commencement of the program (2009–10), highlighting Round 9 with drilling planned for 2014–15.

Several programs, which aimed to develop template Indigenous Land Use Agreements for addressing heritage issues in the area of exploration for geothermal energy and with the Central Desert Native Title service, were discontinued as a result of changes to government policy and process. However, a new project commenced in 2011 in cooperation with the Department of Indigenous Affairs (DIA), now Department of Aboriginal Affairs (DAA) to re-map the exclusion zones surrounding registered heritage sites. This project has been extended to include the scanning of heritage reports held by DAA, but is now complete with over 7000 heritage reports scanned.

The WAPIMS database has been redeveloped and a Mineral Drillhole database has been developed. The Mineral Drillhole database has been released through the GeoVIEW.WA platform. It contains about 1.5 million open-file data points and will continue to be updated with the release of new exploration drilling data.

A number of modules have been developed to extend online systems to allow mineral exploration companies to submit and manage their tenement applications in a secure online environment.

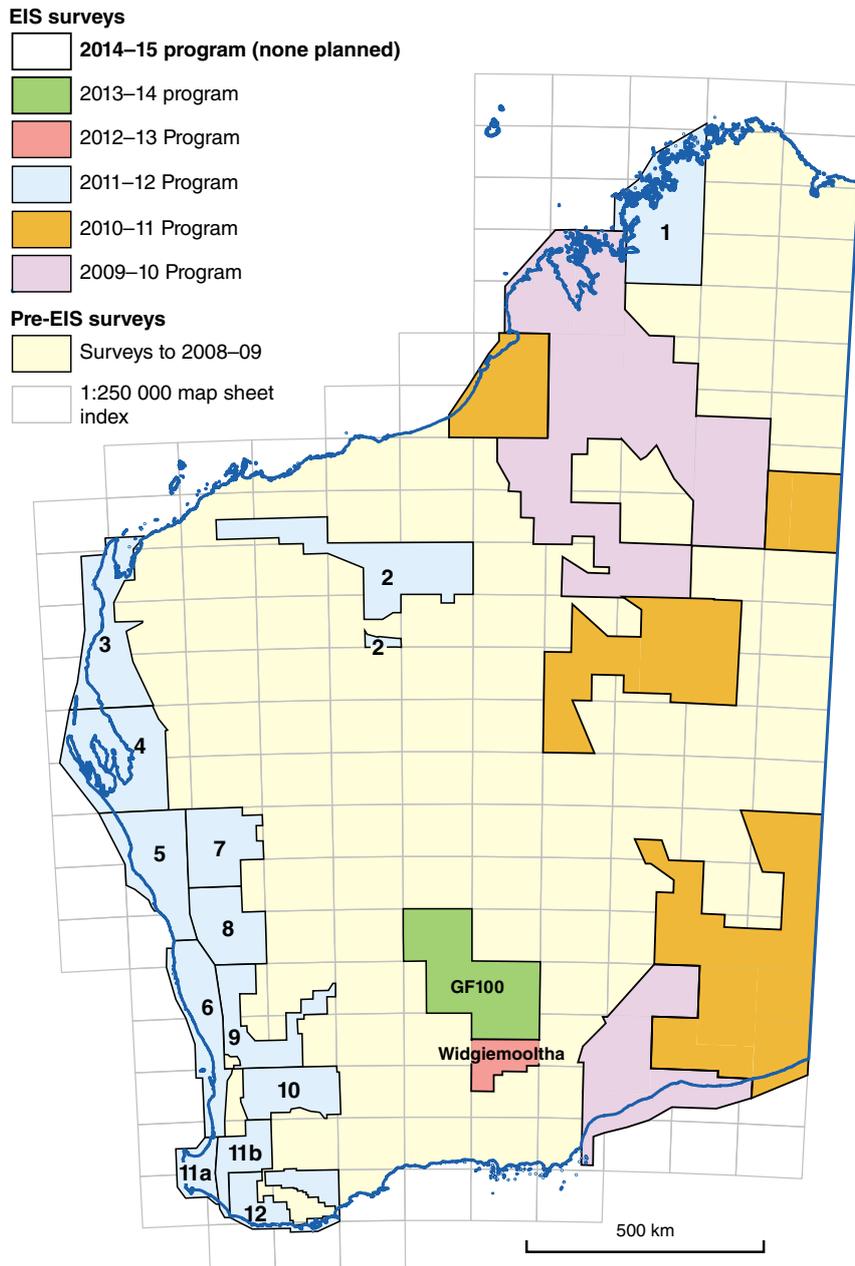
Table 15 sets out the budgets of projects under each component. Projects are described in more detail in Part 4 'Detailed work programs, recurrent budget'.

Table 13. Fraser Institute's Policy Potential Index (Australian States only)

Fraser Institute ranking	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14
1	TAS	WA	SA	SA	SA	SA	SA	WA/NT	WA	WA
2	WA	NSW	QLD	TAS	NT	NT	WA	SA	SA	SA
3	SA	SA	TAS	NT	WA	WA	NSW	QLD	NT	NT
4	QLD	TAS	VIC	WA	NSW	NSW	NT		VIC	QLD
7			WA							
State exploration initiatives	SA: 'PACE' launch			NT: 'Bringing forward Discovery' launched	WA: 'EIS' launched	SA: 'PACE 2020' launched	NT: 'Bringing forward Discovery' extended			

Table 14. Detailed budgets for EIS2 programs in 2014–15 to 2016–17

Programs	2014–15 (\$000)	2015–16 (\$000)	2016–17 (\$000)	Total (\$000)
Exploration facilitation	350	300	80	730
ES01 Graphical tenement display system	350	300	80	730
Innovative drilling promotion	5 800	5 800	5 800	17 400
ES20 Government co-funded exploration drilling	5 675	5 675	5 675	17 025
ES21 Targeted international exploration promotion	125	125	125	375
Geophysical and geochemical surveys	300	600	1 340	2 240
ES31 Deep crustal seismic surveys	300	300	0	600
ES32 Regional gravity surveys	0	300	880	1 180
ES33 Regolith geochemical surveys	0	0	460	460
3D Prospectivity mapping	3 070	2 950	2 430	8 450
ES40 WA Geology Online	150	100	200	450
ES42 3D geological framework	300	300	300	900
ES43 Mineral systems atlas	890	850	200	1 940
ES45 Geological mapping and interpretation	520	500	530	1 550
ES46 Enhanced geochronology and isotopic fingerprinting	310	300	300	910
ES47 Petroleum systems atlas	900	900	900	2 700
Promoting strategic research with industry	480	350	350	1 180
ES50 WA regional researcher and MRIWA support	480	350	350	1 180
TOTALS (\$000)	\$10 000	\$10 000	\$10 000	\$30 000



ID	Area/Name (Stage #)	Lines	Size (km)	Status ¹
2014–15 program (none planned)				
2013–14 program (Stage 5)				
GF100	Goldfields 100 m program			
	Menzies North	100 m; E/W	92 000	Contract
	Kalgoorlie East	100 m; E/W	122 000	Contract
	Widgiemooltha North	100 m; E/W	92 000	Contract
2012–13 program (Stage 4)				
	Widgiemooltha South 2012	100 m; E/W	131 000	Released
2011–12 program (Stage 3)				
1	West Kimberley 2011	200–800 m; E/W	136 000	Released*
2	South Pilbara 2012	400 m; N/S	134 000	Released*
3	Carnarvon Basin N 2011	400 m; E/W	106 000	Released*
4	Carnarvon Basin S 2012	400 m; E/W	123 000	Released
5	Perth Basin North 2011	400 m; E/W	91 000	Released*
6	Perth Basin South 2011	400 m; E/W	120 000	Released*
7	Murgoo 2011	200 m; E/W	129 000	Released
8	Perenjori 2011	200 m; E/W	121 000	Released
9	Moora 2011	200 m; E/W	130 000	Released
10	Corrigin 2011	200 m; E/W	114 000	Released*
11	Cape Leeuwin – Collie 2011	400 m; E/W	95 000	Released*
12	Mt Barker	200 m; N/S	120 000	Released*
2010–11 program (Stage 2)				
		200–400 m	1 100 000	Released
2009–10 program (Stage 1)				
		200–400 m	918 000	Released

¹ Status at 1 July 2014
SHDH40

* Stage 3 surveys released in 2012–13
05.02.15

Figure 23. EIS — airborne magnetic and radiometric surveys

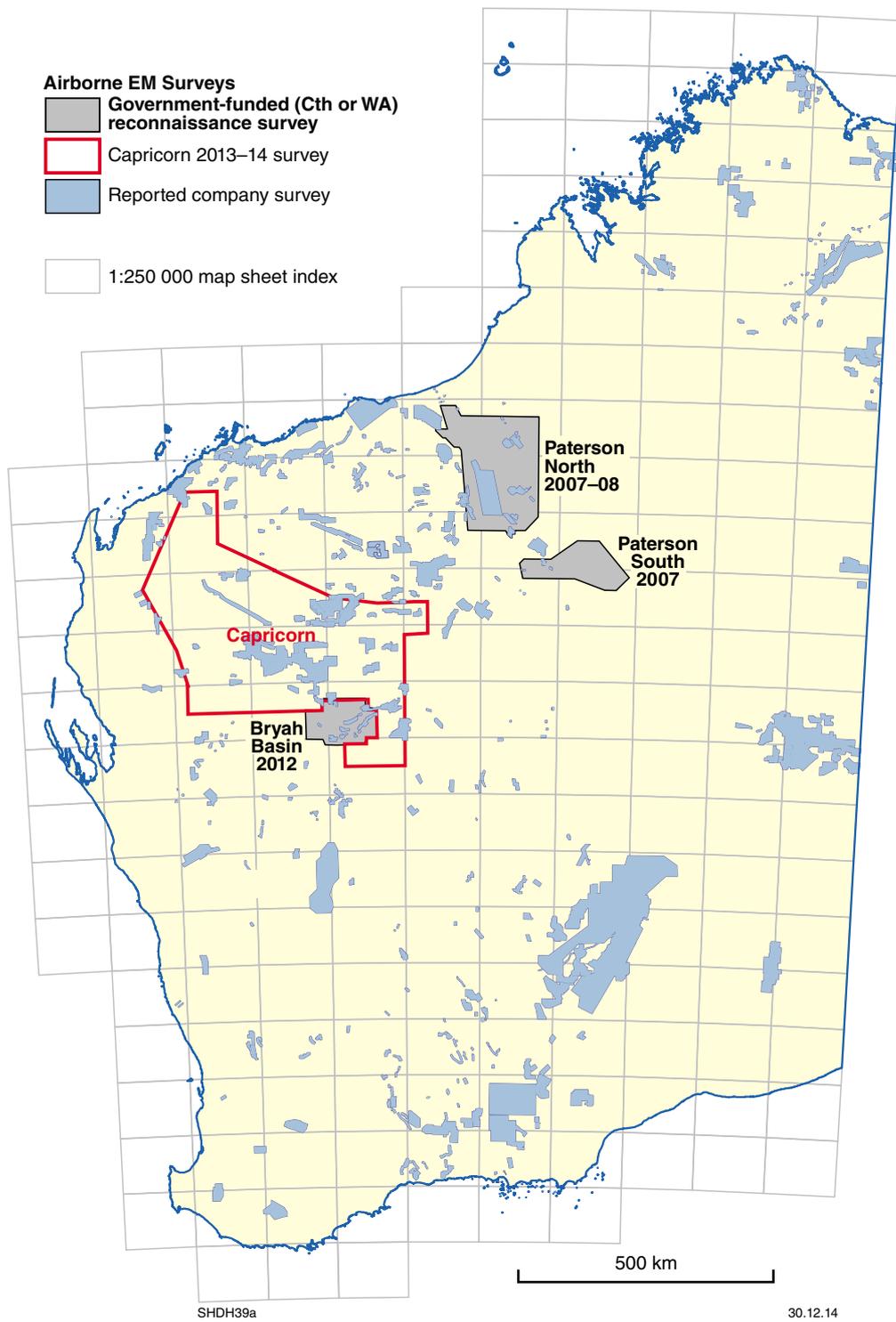
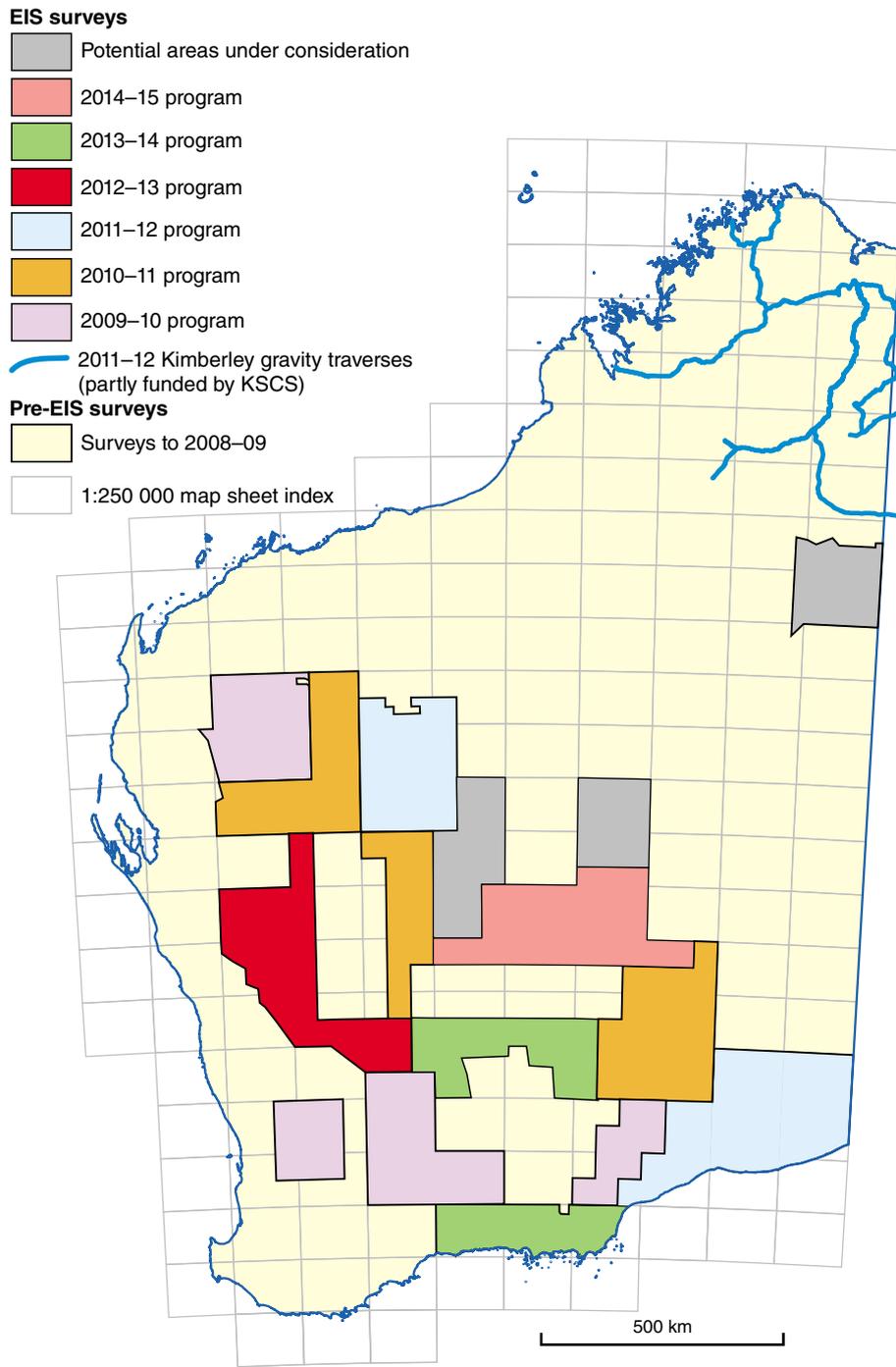


Figure 24. EIS — airborne electromagnetic surveys



Area/Name (Stage #)	Station spacing	Stations	Status ¹
2014–15 program			
Sir Samuel — Throssel	2.5 km grid	11 700	In progress
2013–14 program			
Esperance 2013	2.5 km grid	7 891	Released
Goldfields 2013	2.5 km grid	8 119	Released

¹ Status at 1 July 2014

SHDH41

05.02.15

Figure 25. EIS — ground gravity surveys

EIS work program 2008–09 to 2014–15

Geological regions	Age	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15
STATE		\$						
KIMBERLEY								
Kimberley Basin	Prot				\$	\$	\$	M
Halls Creek Orogen	Prot				\$	\$	M	M
King Leopold Orogen	Prot		\$		\$	M	M	M
PILBARA CRATON								
Granite–greenstone terranes	A							
Hamersley Basin	A		\$		\$			
Paterson Orogen	Prot							
Sylvania Inlier	A							
YILGARN CRATON								
Eastern Goldfields Superterrane — north	A				\$		\$	\$
Eastern Goldfields Superterrane — central	A		\$			\$	\$	
Eastern Goldfields Superterrane — south	A		\$			\$	\$	
Southern Cross Domain — north	A							
Southern Cross Domain — south	A		\$	M	M	M	M	M
Murchison Domain	A		\$		\$	\$		
Narryer Terrane	A		\$		\$			
South West Terrane	A	\$				\$		
CAPRICORN OROGEN								
Ashburton–Bresnahan Basins	Prot		\$				\$ M	M
Gascoyne Complex — south	Prot			\$	M	M	\$ M	M
Gascoyne Complex — north	Prot		\$	\$	M	M	\$ M	M
Edmund–Collier (Bangemall) Basins	Prot						\$ M	M
Earaheedy Basin	Prot						\$ M	M
Bryah–Padbury–Yerrida Basins	Prot			\$			\$ M	M
PINJARRA AND ALBANY–FRASER OROGENS								
Albany–Fraser Orogen — east	Prot		\$ M	\$ M			\$	
Albany–Fraser Orogen — west	Prot					\$		
Northampton Complex	Prot				\$			
Leeuwin Complex	Prot					\$		
Mullingarra Complex	Prot				\$			
Nullarbor (basement)	Prot		\$			\$	\$	\$
CENTRAL AUSTRALIA								
West Granites–Tanami Complex	Prot					\$		\$
Birrindudu Basin	Prot			\$				
Arunta Orogen	Prot		M		M	M		
Amadeus Basin	Prot							
Musgrave Complex	Prot		\$	M	M	M		
BASIN STUDIES								
Southern and Northern Bonaparte Basins	Phan				\$	\$		
Canning Basin — Lower Paleozoic	Phan		\$	\$		\$	\$	\$
Canning Basin — Upper Paleozoic	Phan		\$	\$		\$	\$	\$
Canning Basin — Devonian	Phan		\$	\$		\$	\$	\$
Southern and Northern Carnarvon Basins	Phan				\$			
Officer Basin	Prot					\$		
Perth Basin — north	Phan				\$		\$	
Perth Basin — south	Phan			\$	\$		\$	
Eucla Basin	Phan		\$	\$	\$		\$	

RR110b

Phan Phanerozoic \$ Geophysical and geochemical surveys 3D Geological mapping
 Prot Proterozoic M Exploration targeting Stratigraphic drilling
 A Archean

06.01.15

Figure 26. EIS six-year work program 2008–09 to 2013–14, by tectonic unit, together with planned program for 2014–15

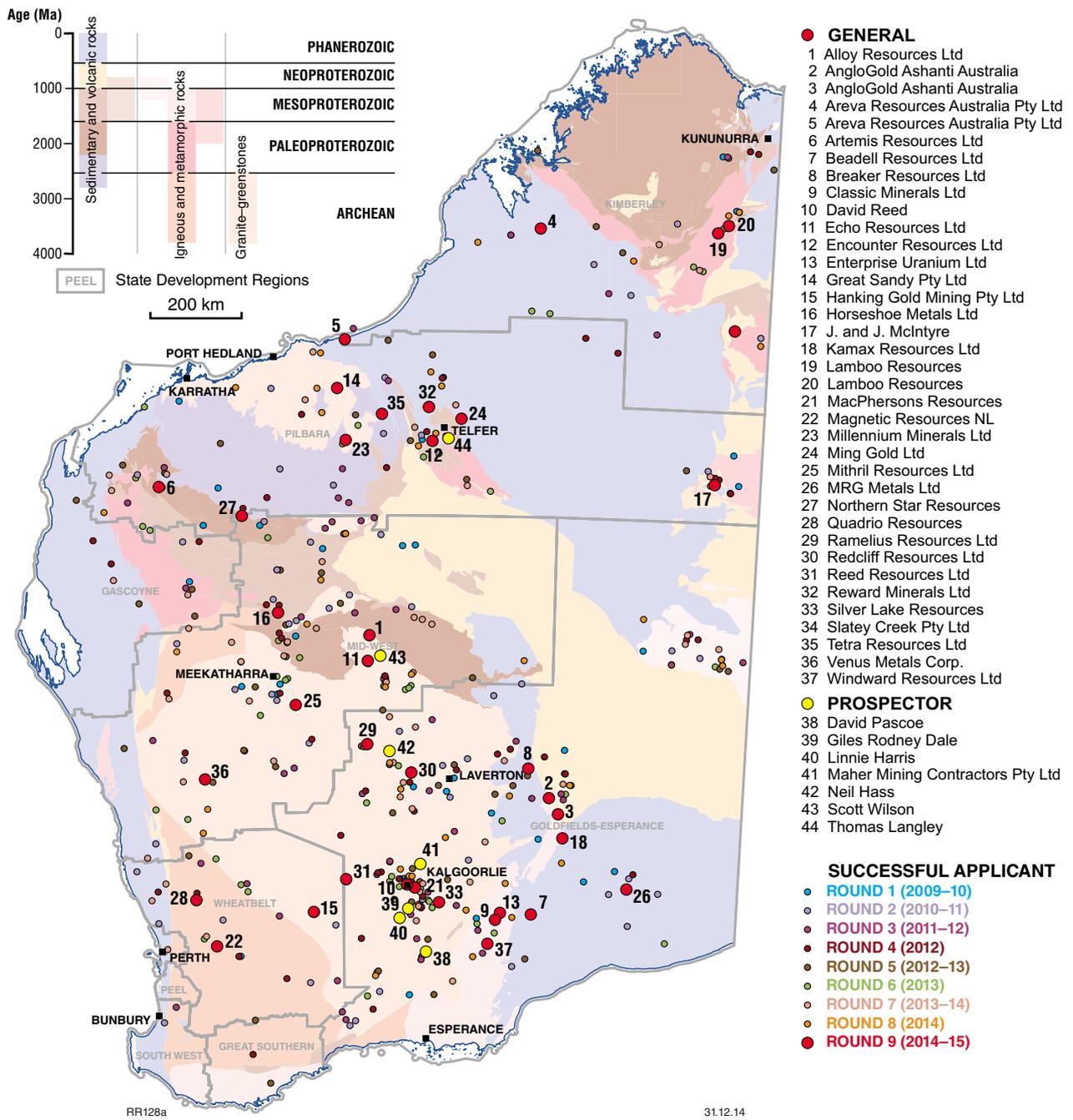


Figure 27. EIS — co-funded drilling projects since start of the program, highlighting Round 9 with drilling planned for 2014–15

Table 15. Royalties for Regions — Components and projects making up the Exploration Incentive Scheme (EIS1 and 1A) — budgets from 2008–09 to 2013–14

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14
Exploration and environmental coordination (Total: \$1.5 million^(a))	0.19	0.66	0.55	0.19	0.142	0.49
Innovative drilling (Total: \$26.9 million^(a))	0.09	2.93	4.19	7.41	6.7	7.13
Government–industry co-funded exploration drilling	0.06	2.36	3.51	4	3.67	4.27
Targeted international exploration promotion	0.02	0.09	0.10	0.14	0.17	0.354
Stratigraphic drilling	0.01	0.48	0.58	3.27	2.86	0.785
Geophysical and geochemical surveys (Total: \$33.33 million^(a))	1.34	11.13	8.25	13.4	1.85	8
Completion of Statewide coverage by airborne magnetic and radiometric surveys	0.68	4.87	5.66	8.28	0.75	5.57
Deep crustal seismic transects	0	4.68	1.03	3.72	0.42	2.41
Regional gravity surveys	0.26	1.29	1.48	1.29	0.61	1.44
Multi-element chemistry of the Yilgarn Craton and its margins	0.4	0.29	0.08	0.11	0.07	0.075
3D geological mapping (Total: \$13.8 million^(a))	0.49	2.09	3.29	4.65	3.83	7.91
WA geology online	0	0.24	0.75	0.66	0.42	1.18
Modernize petroleum information delivery system	0.46	0.6	0.13	0.65	0.16	0.074
3D geoscience	0	0.17	0.19	0.36	0.94	1.61
Open-file geochemistry information delivery	0	0	0	0	0	0
Mineral drillhole information database	0	0.11	0.15	0.38	0.34	0.18
Geological mapping and interpretation	0.03	0.72	0.6	0.97	1.13	0.94
Enhanced geochronology	0	0.16	0.18	0.23	0.28	0.57
Alternative energy studies (shale gas, tight gas, and CO ₂ sequestration)	0	0.09	1.29	1.4	0.56	4.34
Promoting strategic research with industry (Total: \$2.3 million^(a))	0	0.35	0.71	0.62	0.65	0.41
Western Australian Regional Researcher Initiative	0	0	0.36	0.27	0.3	
Supporting MERIWA/MRIWA ^(b)	0	0.35	0.35	0.35	0.35	0.41
Sustainable working relationships with indigenous communities (Total: \$2.17 million)	0.00	0.13	0.39	0.08	0.15	0.17
Develop indigenous land use agreements	0.00	0.00	–	–	0	0
Access-ready land for petroleum and minerals exploration	0.00	0.07	0.35	0.08	0.15	0.365
Heritage clearance for geothermal licences	0.00	0.00	–	0.00	0	0
Community awareness — mineral exploration	0.00	0.02	–	0.00	0	0
Regional heritage agreements for mineral exploration	0.00	0.04	0.04	0.00	0	0
TOTALS (\$ million)	2.11	17.29	17.38	26.35	13.32	25.01

NOTES: (a) Represents the total expenditure for that item since the start of EIS, which means it has increased in the last completed year (2012–13). Thus it does not include the planned expenditure for 2013–14.

(b) The Minerals and Energy Research Institute of Western Australia (MERIWA) was replaced by the Minerals Research Institute of Western Australia (MRIWA) on 1 February 2014, the starting date of the *Minerals Research Institute of Western Australia Act 2013*.

Achievements 2013–14

Achievements during 2013–14, the fifth full year of operation of the EIS, included:

- Drilling projects supported by the Co-funded Drilling Program resulted in 25 508 m of diamond drilling and 57 484 metres of non-cored drilling during 2013–14
- Forty-six successful applicants were announced for Round 8, 2014 and 44 successful applicants for Round 9, 2014–15 grants under the Government–Industry Co-funded Exploration Drilling program
- Drilling of three holes into the Precambrian basement below the Eucla Basin
- Completion of data acquisition of Canning Coastal deep seismic
- Two hundred km deep seismic acquired as an extension to the Western Australia/South Australia border, of the Albany–Fraser deep crustal seismic reflection survey
- Acquisition of data over 660 km of deep crustal seismic in the onshore Canning Basin
- Capture of 29 000 line km of data in the Capricorn Airborne reconnaissance EM (TEMPEST) survey

- Completion of collaborative project with Curtin University researching shale gas potential of Perth and Canning Basins
- Completion of collaborative project with UWA on 3D modelling of Canning Basin for hydrocarbon resources and geological storage potential for CO₂
- Release, via the Web, of the mineral exploration drilling and geochemistry databases.

Full details of the achievements are included in the individual program plans.

Cooperative projects

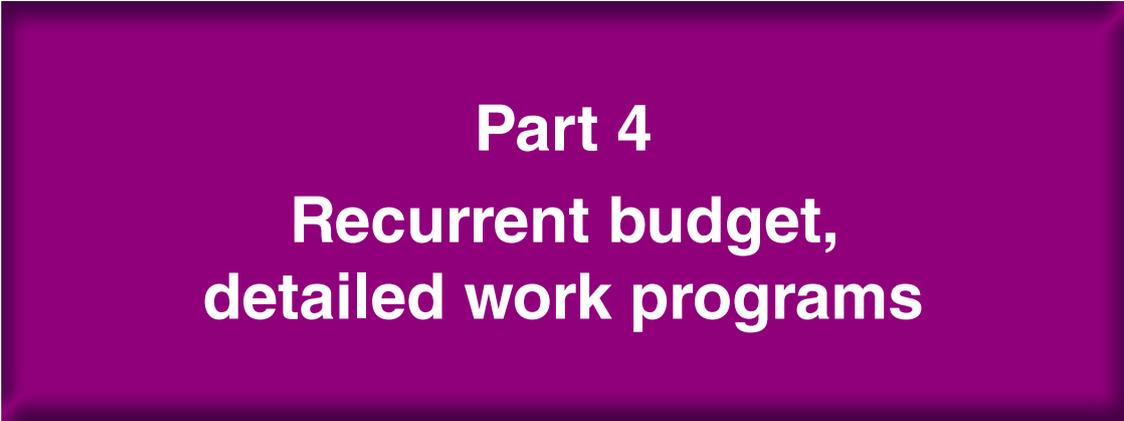
Some large collaborative projects are a major feature of the EIS, as these projects minimize public service appointments and fill critical gaps in GSWA’s skill sets. Table 16 summarizes the major cooperative projects that received, or are receiving, funding since commencement of the EIS in early 2009.

The EIS is providing an additional \$350 000 per annum to MRIWA* (formerly MERIWA) for four years, which in turn leverages funding from industry for minerals and energy research.

Table 16. Major cooperative projects associated with the Exploration Incentive Scheme since its inception in early 2009

Cooperative project	EIS component	Cooperative partner(s)
Mineral exploration targeting	3D geological mapping	Centre for Exploration Targeting (CET)
Albany–Fraser Orogen 3D mineral mapping — part of WA Regional Embedded Researchers program	Promoting strategic research with industry	CSIRO Minerals Down Under
Shale gas resources of the Perth Basin	3D geological mapping	Curtin University
Tight gas reservoir modelling in the South Perth Basin	3D geological mapping	Western Australia Energy Research Alliance (WA:ERA)
Canning Basin study of key system elements relevant to energy exploration and CO ₂ geosequestration	3D geological mapping	The University of Western Australia Centre of Petroleum Geoscience

* The Minerals and Energy Research Institute of Western Australia (MERIWA) was replaced by the Minerals Research Institute of Western Australia (MRIWA) on 1 February 2014, the starting date of the *Minerals Research Institute of Western Australia Act 2013*.



Part 4
**Recurrent budget,
detailed work programs**

GS10 Basins and Energy Geoscience

Acting Manager: Ameen Ghori

Team members: Norman Alavi, Heidi Allen, Louisa Dent, Peter Haines, Lorraine de Leuw, Alan Millar, Sarah Martin, Arthur Mory, Leon Normore, Louise Stelfox, Charmaine Thomas, Yijie (Alex) Zhan

The primary goal of this section is to develop consistent, basinwide stratigraphic and structural frameworks for Western Australia's onshore sedimentary basins. The aim is to encourage increased exploration for petroleum, coal and geothermal energy resources, and thus secure the State's energy future.

Historically, the team's focus has been on conventional oil and gas, although in recent years studies have broadened to include assessing the potential for petroleum resources from tight sand, shale, and coal seam reservoirs; geothermal resources from hot rocks and hot sedimentary aquifers; and potential for carbon capture and storage (CCS).

The team works in collaboration with the Petroleum Division of DMP and other organizations including CSIRO, the Western Australian Energy Research Alliance (WA:ERA), UWA, Curtin University, and GA.

Currently, the section's main focus is the onshore and nearshore Canning and Perth Basins. Both Paleozoic basins have proven petroleum systems and are underexplored, particularly in the case of the vast Canning Basin. The section is also conducting geological mapping of the Amadeus Basin, sometimes referred to as 'the forgotten corner of Australia', to understand better its petroleum potential.

Canning Basin

The main issues and uncertainties in the Canning Basin include:

- unreliable and poorly distributed geochemical data, creating uncertainties regarding the definition and distribution of petroleum systems
- inconsistent stratigraphic nomenclature across the basin, especially in the Paleozoic section, resulting in inconsistent picking of formation tops between wells
- lack of biostratigraphic data in many wells and intrinsic difficulties of biostratigraphically dating some stratigraphic intervals
- uncertain validity of the structural and tectonic framework
- lack of good-quality well and seismic data, and issues regarding the quality and distribution of the data, especially in the Kidson Sub-basin, where there is a lack of well and seismic data.

Perth Basin

The main issues and uncertainties in the Perth Basin include:

- patchy seismic coverage of variable quality
- questionable stratigraphic correlations due to the lack of biostratigraphic control in wells and poor-quality seismic ties
- paucity of well data to assess shale gas and carbon sequestration potential in the northern Perth Basin, and tight gas in the southern Perth Basin
- uncertainty about the tectonic and structural evolution, and depositional history of the basin.

Amadeus Basin

The main issues and uncertainties in the Amadeus Basin include:

- extensive surficial cover and deep weathering of outcrops; stratigraphic sections are incompletely exposed (particularly shaly successions) and source rock properties cannot be determined
- lack of subsurface data
- stratigraphic control and correlation with the remainder of the basin; this problem is currently being addressed, although the details remain problematic
- limited biostratigraphic control, apart from stromatolites
- remoteness and difficulty of vehicular access due to the few roads and tracks, and extensive sand dunes.

Management of project risks

Risks include:

- land access and heritage clearances in the Canning and Amadeus Basins. This has resulted in both financial and implementation risks to the project. However, the project team has had good relations with indigenous people in the area, and heritage clearances do not appear to be a major issue
- permission to gain access to private land and various classes of reserve in the Perth Basin often requires long lead times and can delay work programs

- data quality and availability. Legacy seismic surveys are often of poor quality. However, modern processing techniques have shown improvements in data quality, and it is proposed to reprocess strategic seismic lines to improve quality, and hence, interpretability.

Outcomes of work program 2013–14

Some of the main outcomes from studies in 2013–14 are:

- Interpretation of petroleum geochemistry analytical data available from companies and generated by GSWA for the Canning Basin — published in Report 124
- Interpretation of the Harvey area’s 2D seismic data was published in Record 2014/7
- Western Australia carbon dioxide geological storage atlas was published in Report 126 and also as Report 126 GIS data package (EIS funded)
- CO₂ storage assessment of the on-shore western Eucla Basin was published in Report 138, and also as Report 138 GIS data package (EIS)
- Acquisition of the Canning Basin deep crustal gravity and seismic surveys were completed in June 2014 (Fig. 28), and processing of data is underway. This is a GSWA–GA collaborative project, funded in part by EIS
- Significant contribution in West Australian Basin Symposium (WABS 2013) for publications, field trips, and short courses:
 - Arthur Mory and Peter Haines conducted WABS 2013 Canning Basin field trip, 12–17 August 2013
 - Arthur Mory and Roger Hocking participated in conducting South Carnarvon Basin Woodside field trip, 28 August – 3 September 2013
 - Ameer Ghori presented short course on Petroleum Systems and Geochemistry on 16 August 2013
- Completed geology and petroleum prospectivity for the acreage release areas in the Canning and Perth Basins.
- Continued geological, geochemical, and geophysical studies of the Amadeus, Canning, Perth Basins to improve understanding of their regional structural and stratigraphic framework, impacting prospectivity of oil, gas, coal, and geothermal energy resources.
- Geothermal activities during the year were mainly of an advisory nature with most studies completed and published in previous years.
- Staff of the Basins and energy geoscience section also contributed to the program of work on the South West CO₂ Geosequestration Hub.

Products released 2013–14

Record 2014/7 2D Seismic interpretation of the Harvey area
Report 124 Petroleum Systems of the Canning Basin, Western Australia
Report 126 Western Australia carbon dioxide geological storage atlas by 3D-GEO Pty Ltd, and GIS data package
Report 138 CO ₂ storage assessment of the on-shore western Eucla Basin by FROGTECH Pty Ltd, and GIS data package
Exploration success in the Canning Basin, Fieldnotes, October 2013
Geology and petroleum prospectivity of State Acreage Release Areas L14-2, Canning Basin
Geology and petroleum prospectivity of State Acreage Release Areas L14-1, Canning Basin
Geology and petroleum prospectivity of State Acreage Release Areas L12-12 and L12-13, Canning Basin
Geology and petroleum prospectivity of State Acreage Release Area L12-14, southern Perth Basin
External papers — 19 (see Appendix B)

Planned work program and products 2014–15

Work planned for 2014–15 includes:

- Tectonic evolution of the Perth Basin
- Well completion report for GSWA Harvey 1
- Revised Devonian stratigraphic framework
- Geology of the Boord Ridge
- Geosequestration potential of the Permian Grant Group and Permian Poole Sandstone, northwest Canning Basin, UWA
- Mineral prospectivity of the King Leopold Orogen and Lennard Shelf: potential field analysis in the West Kimberley, UWA
- Regional structural and stratigraphic study of the Canning Basin, Western Australia, UWA
- Correlation of the early Permian Poole Sandstone and Noonkanbah Formation and implications for CO₂ sequestration, UWA
- Canning Basin deep crustal seismic and gravity (Fig. 28) — release of raw and processed data packages (in conjunction with GA)

Regional geological, geophysical and petroleum geochemical studies for the Amadeus, Canning and Perth Basins will continue:

- **For the Amadeus Basin** — studies on stratigraphy, structure, biostratigraphy of the Amadeus and Murraba Basins, revised correlations: Amadeus–Officer–Murraba–Kimberley and COBRA and NTGS collaborative projects will continue

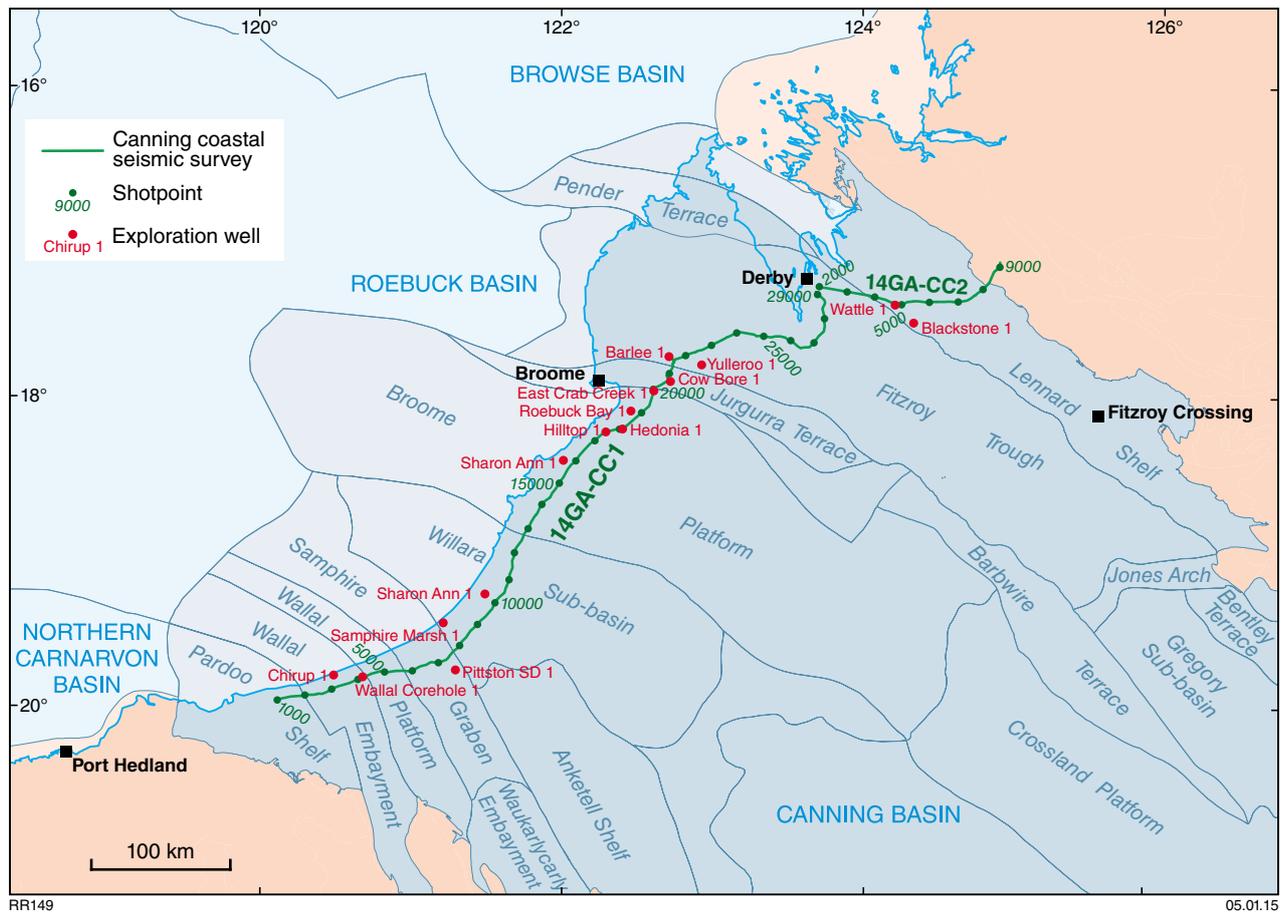


Figure 28. Canning Basin deep crustal seismic and gravity survey — location map

Products planned for release 2014–15

Geosequestration potential of the Permian Grant Group and Permian Poole Sandstone, northwest Canning Basin, Western Australia (Report)

Mineral prospectivity of the King Leopold Orogen and Lennard Shelf: potential field analysis in the West Kimberley (Report)

Regional structural and stratigraphic study of the Canning Basin, Western Australia (Report)

Correlation of the early Permian Poole Sandstone and Noonkanbah Formation and implications for CO₂ sequestration (Report)

Canning Basin (Kimberley) Deep Crustal Geophysical Survey, seismic and gravity data acquisition was completed on 30 June 2014, Raw and processed data packages will be released in 2014–15

Revised Devonian stratigraphic framework of the central and southern Canning Basin

Structural seismic interpretation of the central Canning Basin

Geology of the Boord Ridges — key stratigraphic section in the western Amadeus Basin, Western Australia

Acreage release prospectivity reports

- **For the Canning Basin** — studies of the Ordovician Nambet and Willara formations, Devonian–Carboniferous Fairfield Group, Permian Liveringa Group, interpretation of new regional seismic line, and selection of new stratigraphic well sites will continue
- **For the Perth Basin** — studies on structural interpretation, biostratigraphy, petroleum geochemistry, Harvey stratigraphic drilling and new seismic and well data integration will continue.

GS12 Land Use Geoscience

Manager: Warren Ormsby

Team members: Bill Anderson, Bob Gozzard, Charlotte Hall, Lisa Kirby, Jutta Pagel, Elias Peiris, Kevin Ridge, Suzanne Simons, Colin Strickland, Colleen Thomas, Glendon Wesley

Land use geoscience plays a key role in providing geological information, advice and approval to assist in government decision making related to the most appropriate use of land. The provision of relevant geological information to State and local government authorities, planners and the community contributes to Western Australia's economic sustainability and helps to ensure that the interests and rights of all parties are recognized.

Proposals for land subdivisions and other land use changes are routinely received from State and local government authorities. Each proposal is examined; its implications for access to mineral and energy resources are assessed, and recommendations or advice are made accordingly. The number of referrals received from other government agencies in 2013–14 was significantly higher than for each of the previous three years. The overall workload has also remained high because the group has played key roles in:

- assessments associated with the South West Native Title Settlement and the State Government Esperance Nyungar Indigenous Land Use Agreement, both of which involve examining various land transfer proposals
- provision of information on basic raw material (BRM) supplies, particularly for the Perth–Peel, Pilbara, Mid-West and Gascoyne regions and in the development of whole-of-government initiatives to facilitate long-term access to these materials.

The proposed creation of new conservation reserves throughout Western Australia and proposed upgrading of existing reserves continues to be a significant land use issue affecting the resources industry.

Other roles for the Land Use Geoscience section include:

- providing geological input to other government programs such as assisting in coastal vulnerability studies
- publishing resource potential for land use planning, mapping and developing associated land use planning policy to help inform other government agencies and the public of potential land use conflicts before they arise
- monitoring and assessing exploration performance on mineral tenements and providing geological advice to DMP needed for the administration of, and proposed changes to, the *Mining Act 1978* (WA) and the *Offshore Minerals Act 1994* (Cth)

- assessing mining Sterilization Reports associated with mining proposals
- administering the Western Australian Register of Geoheritage Sites and Geoheritage Reserves.

Management of project risks

The main process risk involves the provision of land use assessments in a timely manner. Some proposals such as subdivision referrals from the Western Australian Planning Commission must be assessed within a statutory timeframe. Most other assessments are related to other government approval processes and must be completed in a timely manner. These processes are managed by providing adequate human resources and training to cover staff absences (including long service and purchased leave); prioritizing workload by date required; and by streamlining, standardizing, and improving processes and procedures. This includes employing fee-for-service staff over specific periods to cover extended staff absences and peak workload periods.

Progress and base (i.e. referral) workload is monitored by monthly reporting of the number of assessments requested and completed. These measures do not capture the entire workload, which also includes the publication of products in the work program and extraordinary additional tasks to support government objectives such as the provision of Indigenous Land Use Agreement (ILUA)-related assessments. The release of planned products may be deferred to achieve such extraordinary objectives within the required timeframe. Overall staff workload is managed by periodic adjustments to the spatial land areas of responsibility.

Outcomes of work program 2013–14

The section produced the following outcomes:

- Additional funding was obtained for the South West Native Title Settlement project (Fig. 29) to assist with the development of resource and prospectivity-related datasets and a new computer-based system for improving the efficiency of the assessment process. This system will integrate with a new land identification and referral system being developed by Landgate for the Department of Lands specifically for the South West Native Title Settlement project.



Figure 29. South West Settlement project — location map

Three additional fee-for-service staff were contracted to facilitate the section's role in this project. One hundred and fifty six referrals for proposed land tenure changes were assessed specifically for this project. These are additional to the 1214 referrals listed below in the 'products released' table.

- Three maps of regionally significant basic raw materials were published for the Swan Coastal Plain from Fremantle to Gingin. Compilation of this mapping included consultation with industry to ensure accuracy and completeness.
- Four maps and a digital dataset were published for basic raw materials in the Karratha and Port Hedland regions. These were completed under a Memorandum of Understanding (MoU) with the Department of Planning (DoP) regarding the provision of information on the potential availability of basic raw materials for these areas. Work on producing similar maps and a digital dataset for the Mid-West and Gascoyne regions under the same MoU was well advanced.

Products planned for release 2013–14	Current status
Provision of information, advice and assessments in response to requests from other government agencies	1214 referrals dealt with
Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2014 (map)	Released
Fremantle–Jarrahdale, regionally significant basic raw materials, resource potential for land use planning (map)	Released
Gingin – Ledge Point, regionally significant basic raw materials, resource potential for land use planning (map)	Released
Perth–Wooroloo, regionally significant basic raw materials, resource potential for land use planning (map)	Released
Karratha, basic raw material resources, resource potential for land use planning (map 1: 200 000)	Released
Karratha, basic raw material resources, resource potential for land use planning (map 1: 50 000)	Released
Port Hedland, basic raw material resources, resource potential for land use planning (map 1: 200 000)	Released
Port Hedland, basic raw material resources, resource potential for land use planning (map 1: 50 000)	Released
Karratha – Port Hedland, 2014, basic raw materials (digital dataset)	Released
A potential long-term source of sand near Boorabbin for the Eastern Goldfields Region (Record 2014/5)	Released

- Results from the sand resource survey north of Boorabbin were published. This area was found to be highly prospective for long-term supplies of construction-grade sand for Kalgoorlie, the wider Goldfields region and beyond.

- Work was in progress on a study of the limesand and limestone resources of southern Western Australia. The scope of this study was expanded to include an explanatory record, resulting in a deferral of publication until 2014–15. This information is needed by government to assist in planning because of the importance of ensuring that there is a continuing long-term supply of lime available for the agricultural sector.

Planned work program and products 2014–15

The section will continue to provide information, advice, and assessment in response to requests from other government agencies. The estimated number of referrals is expected to continue at similar levels to those experienced in 2013–14 (Fig. 30).

Additional funding will continue for the South West Native Title Settlement project to assist with the development of resource and prospectivity-related datasets and a new computer-based system for improving the efficiency of the assessment process. Two to three additional fee-for-service geological staff will continue to be contracted to facilitate the section's role in this project. Other specialist contractors will be involved in associated software development. It is anticipated that these initiatives will lead to ongoing benefits for other geological assessments in the South West. It is also anticipated that there will be substantial land assessment 'screening' and approvals associated with the South West Native Title Settlement.

Negotiation for land-tenure outcomes, and prospectivity assessment for the remaining 60 former pastoral leases and other areas proposed for conservation and managed by the Department of Parks and Wildlife (DPaW) will continue as a matter of priority.

Work will be completed on publishing information on basic raw materials in selected parts of the Mid-West and Gascoyne to assist in government planning for the growth of this region. This will include an extension of the series of resource potential for land use planning maps for regionally significant BRM areas from Lancelin to Geraldton. This will complete the base mapping for the high-growth coastal regions to assist in protecting significant basic raw material resources from being inadvertently developed for incompatible land uses; thus it will contribute to minimizing building and construction costs. It is anticipated that specific BRM protection areas will be defined in high-growth coastal regions in consultation with DoP.

The digital data compilation and associated Record of the limesand and limestone resources of southern Western Australia north of Boorabbin will be published.

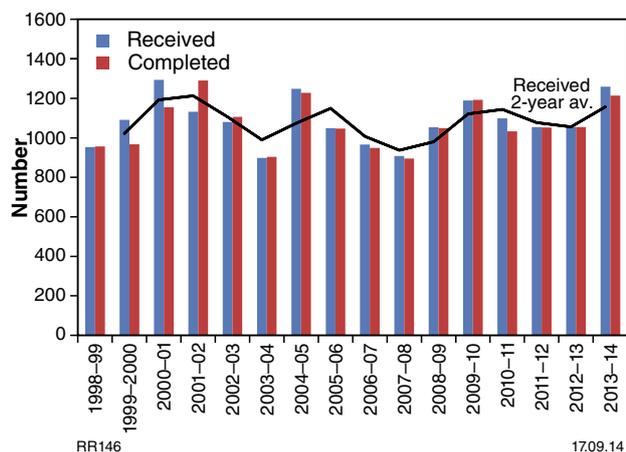


Figure 30. Land Use Geoscience section — annual referral statistics

Products planned for release 2014–15

- Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2015 (map)

- Limesand and limestone resources of southern Western Australia (Record and digital dataset)

- Green Head – Three Springs, basic raw material resources, resource potential for land use planning (map 1:200 000 scale)

- Northampton–Kalbarri, basic raw material resources, resource potential for land use planning (map 1:200 000 scale)

- Geraldton–Mullewa, basic raw material resources, resource potential for land use planning (map 1:200 000 scale)

- Morawa–Perenjori, basic raw material resources, resource potential for land use planning (map 1:200 000 scale)

- Exmouth, regionally significant basic raw materials, resource potential for land use planning (map)

- Carnarvon, regionally significant basic raw materials, resource potential for land use planning (map)

- Northampton, regionally significant basic raw materials, resource potential for land use planning (map)

- Geraldton, regionally significant basic raw materials, resource potential for land use planning (map)

- Dongara–Denison, regionally significant basic raw materials, resource potential for land use planning (map)

- Leeman–Eneabba, regionally significant basic raw materials, resource potential for land use planning (map)

- Green Head – Jurien Bay, regionally significant basic raw materials, resource potential for land use planning (map)

- Mid-West and Gascoyne, basic raw material resources, resource potential for land use planning (digital dataset)

GS14 Commodity and Industry Analysis

Manager: Trevor Beardsmore

Team members: Abey Abeysinghe, Roger Cooper, Lyn Day, Mike Fetherston, Caroline Strong

The Commodity and Industry Analysis section provides statistics and expert analysis on all commodities in the areas of mineral exploration activity, mineral resources and reserves, and mining. Users of the section's outputs are other DMP divisions, other government agencies, industry, and the community at large. The section responds to about 400 ad hoc enquiries annually. A key component of this service is the maintenance and enhancement of Western Australia's mines and mineral deposits information database (MINEDEX), which can be accessed via DMP's website. The MINEDEX data, and products derived from it, are regarded as the point of truth for information on mines and deposits, their location, compilation of mineral resource estimates, and historical production data in Western Australia. The database is also used to produce annual or biannual updates of a number of maps and publications. MINEDEX data are spatially displayed in the TENGGRAPH and GeoVIEW.WA online systems, and on most maps produced by GSWA.

Outcome of work program 2013–14

Significant routine work during 2013–14 included maintenance of systems and content comprising the MINEDEX database, including auditing of all mines, deposits, and prospects shown on (several) 1:100 000-scale Geological Series maps published by GSWA in 2013–14. This audit work removed duplicate sites, revised coordinates, and updated mineralization styles.

Regulatory duties included assessment of about 50 Mineralization or Resource Reports during the year, which were lodged under Sections 74 and 74A of the *Mining Act 1978* in support of Mining Lease applications.

The section also updated a number of standard map and digital products throughout the year:

- Mines – operating and under development, Western Australia — 2014 (map)
- Major resource projects, Western Australia — 2014 (map)
- Iron ore deposits of the Pilbara (digital product)

- Iron ore deposits of the Yilgarn Craton 2014 (map)
- Significant exploration activity in Western Australia ('Hotspots' map)
- Investment opportunity flyers — Au, Fe, Mn, REE, U, V (updates)

Staff commenced a review of Western Australian graphite deposits and occurrences, which will be published as Mineral Resources Bulletin 26 in 2014–15.

Dr Mark Hutchison was contracted to oversee the development and population of a new database of Western Australian diamond and diamond indicator mineral occurrences and geochemistry. Mark is the author of a similar product released for the Northern Territory in 2011. First release of the Western Australian 'diamond' database will be in 2014–15.

Staff continued compiling information for the 'Manganese mineralization of the Pilbara' map and digital product (analogous to the 'iron ore deposits' maps). Product release will be in 2014–15.

Products planned for release 2013–14	Current status
Major resource projects, Western Australia — 2014 (map)	Released
Mines – operating and under development, Western Australia — 2014 (map)	Released
Iron ore deposits of the Yilgarn Craton, 2014 (map)	Released
Iron ore deposits of the Pilbara region, 2013 update (digital data)	Released
Significant exploration activity in Western Australia ('Hotspots' map update)	Released
Graphite in Western Australia (Mineral Resources Bulletin 26)	In preparation
Western Australian diamond and diamond indicator mineral occurrences and geochemistry (database)	In preparation
Manganese mineralization in the Pilbara Craton and Capricorn Orogen (map and digital product)	In preparation
Investment opportunity flyers updates (updates for Au, Fe, Mn, REE, U, V)	Released

Planned work program and products 2014–15

Recurrent MINEDEX maintenance and regulatory activities will continue throughout 2014–15, including assessment of Mineralization Reports, and auditing of mines, deposits, and prospects for those 1:100 000-scale Geological Series maps being prepared for publication during the year.

Regular annual map products will be updated (Mines – operating and under development, Western Australia; Major resource projects Western Australia), as will existing commodity investment flyers – on an ad hoc, as-needs basis. The section also plans to develop and release a new commodity flyer for graphite.

The review of Western Australian graphite deposits and occurrences (Mineral Resources Bulletin 26) will be completed and released in the first half of 2014–15, as will the first edition of the new database of Western Australian diamond and diamond indicator mineral occurrences and geochemistry. The ‘Manganese mineralization of the Pilbara’ map and digital product (analogous to the ‘iron ore deposits’ maps) are scheduled for release later in the year.

The section will also begin new commodity reviews for potash and phosphorus, to be released late in 2014–15, or early in the following year.

Products planned for release 2014–15

Major resource projects, Western Australia — 2015 (map)

Mines – operating and under development, Western Australia — 2015 (map)

Iron ore deposits of the Pilbara – 2015 (map)

Significant exploration activity in Western Australia (‘Hotspots’ map update)

Graphite in Western Australia (Mineral Resources Bulletin 26)

Western Australian diamond and diamond indicator mineral occurrences and geochemistry (database)

Investment opportunity flyers – graphite

Manganese mineralization in the Pilbara Craton and Capricorn Orogen (map and digital product)

Planned work program and products 2015–16 and beyond

Routine updating of databases and regulatory work will continue, as will annual updates of many of the standard products.

Two new reviews of potash and phosphate resources in Western Australia will be completed, and investment opportunity flyers will also be prepared. Other commodity reviews being considered include Ti–Zr heavy mineral sands (a long-deferred update for Mineral Resources Bulletin 10 from 1977), nickel (to update Mineral Resources Bulletin 14 from 1984), rare earth elements and uranium.

The section will also work with the Mineral Systems Studies section to further develop the MINEDEX database in order to more comprehensively capture geological information for significant mineral deposits in Western Australia.

GS20 Mineral Systems Studies

Manager: Trevor Beardsmore

Team members: Lauren Burley, Joshua Guilliamse, Lena Hancock, Lee Hassan, Sidy Morin-Ka, Franco Pirajno, Lisa Roche, Paul Duuring (embedded researcher at UWA), Steven Hollis (embedded researcher at CSIRO)

The Mineral Systems Studies section undertakes comprehensive studies of mineral systems in Western Australia, with the objectives of building metallogenic models and improving our understanding of the geodynamic environment of ore formation, thereby assisting with making exploration targeting in greenfields areas more predictive. Such work typically involves both fieldwork (mapping, core logging, sampling) and laboratory studies (petrology, geochronology, isotope chemistry), and is supported by and supplements existing databases. The section makes extensive use of the GSWA HyLogger to assist with detailed studies of alteration assemblages in diamond drillcore and other specimens from mineral deposits.

All mineral systems knowledge is ultimately made available for the benefit of resource companies, research groups, other government agencies, and the wider community, and is disseminated via GIS packages, and internal and external publications.

Young talented geologists are being enticed to carry out research on mineral systems in Western Australia via the GSWA Geology Masters (GeM) program, whereby Geology Honours graduates are employed whilst obtaining a Master's degree through the Centre for Exploration Targeting (CET) at UWA. A geologist has been employed under this scheme in each of the 2010–11, 2011–12, 2012–13 and 2013–14 budget years.

Management of project risks

The risk associated with obtaining land access approval from indigenous groups to carry out field observations has been, and will be, managed by working closely with GSWA mapping teams also working in the areas of interest, and with mining companies who already have tenements and land access agreements over these areas. Lack of suitable study material has been, and will continue to be, addressed by requesting donation of diamond drillcore from areas of interest, and other logistical support from companies collaborating with GSWA for specific projects. The difficulty in attracting young geologists to a GSWA career is being addressed through implementation of the GeM program.

Outcomes of work program 2013–14

The Mineral Systems Studies section continued its studies of volcanogenic massive sulphide (VMS), rare earth elements, gold, and other polymetallic deposits.

The project is now yielding results in documenting host rocks and alteration, environments of formation, controls on mineralization, and discovery potential at several variably deformed and metamorphosed massive sulphide deposits in the Murchison and SW Yilgarn provinces. A study of the Yuinmery deposits was completed, and the results published as Report 131. A study comparing the Weld Range and Golden Grove VMS systems, originally reported in a Master's dissertation by a section member, was rewritten as a GSWA Report and submitted for peer review. The study of the polymetallic Abra deposit in the Jilawarra Sub-basin (Edmund Basin) is largely complete, and a Report and external paper are being prepared. The CSIRO-embedded researcher funded by GSWA's EIS completed a compilation and analysis of existing public domain lithogeochemical and geochronological data for Yilgarn volcanosedimentary successions, and has submitted for peer review a preliminary Report on the perceived VMS fertility of the Yilgarn based on these data. This work complements the studies of VMS systems being undertaken by other Mineral Systems Studies staff.

The results of field and laboratory work on the rare earth element or REE-U-enriched Gifford Carbonatite Complex were published as Record 2013/12. Geological and metallogenic studies are now underway for a range of styles of Western Australian rare earth element systems, and include Mt Weld, Gifford Creek, Hastings–Brockman, John Galt and Browns Range. This work aims to provide mineral explorers with tools to locate rare earth element mineralization or its larger alteration footprint. The section's second GeM graduate geologist successfully completed his Master of Economic Geology degree, submitting in part fulfilment a dissertation describing his development of a technique for directly detecting rare earth elements using hyperspectral technologies.

Mineral Systems Studies staff continued collaborative research with GSWA colleagues and geologists from Northern Star Resources on the mesothermal, orogenic-lode style Paulsens Au deposit, in the Wyloo Dome, northern Capricorn Orogen. Aims are to determine the age(s) of gold mineralization and host rocks, the composition and distribution of alteration mineral assemblages, and the nature of the gold mineralogy, to better understand the physical and chemical conditions during gold mineralization. A collaborative project also commenced with CSIRO to look at the 3D architecture of the major, mantle-tapping Nanjilgardy Fault system, and spatial and chemical variations of gold mineralization and associated alteration spatially related to this structure (including the Paulsens and Mount Olympus systems, both of which are close to splays from the fault).

The graduate geologist recruited in early 2013 under GSWA's GeM program began a study of gold mineralization and alteration at the Glenburgh deposit in the Gascoyne Province.

The two-year EIS-funded collaboration between GSWA and UWA to evaluate exploration techniques and identify regional targeting criteria for (buried) gold mineralization in the Yilgarn Craton was completed in late 2012. The first volume of the three-volume 'Explorer's guide (targeting atlas) for gold in the Yilgarn Craton' was released as Report 125 in late 2013, the second volume is in peer review, and the third of the trilogy was in preparation at the end of 2013–14.

A fourth graduate geologist was recruited under the GeM program in early 2014, and will undertake as part of her Master's degree an industry-collaborative study of the newly discovered, komatiite-hosted nickel deposits on the Mt Fisher greenstone belt in the northeastern Yilgarn Craton.

The section managed a number of other minerals-oriented research initiatives funded by GSWA's EIS:

- Metallogenic studies of banded iron-formation-hosted (BIF) iron ore systems in the Yilgarn and Pilbara Cratons. Our researcher embedded in UWA's CET has been coordinating a team of postgraduate and postdoctoral workers to examine structural controls and ore and alteration mineralogy at selected iron ore deposits. The Pilbara component is largely funded by MRIWA and in-kind contributions from industry collaborators. The project will be extended through at least 2014–15.
- Chemical fingerprinting of pyrite and magnetite in northern Yilgarn and southern Capricorn gold and base metal systems, being done by the CODES ARC Centre of Excellence for Ore Deposit at the University of Tasmania. The goal is to test whether the trace element compositions of such minerals might be utilized as indicators of regional mineral fertility and deposit 'type'.
- AMIRA Project P1040 – Global Ore Deposit Encyclopaedia (Data Metallogenica).

The results of recently completed EIS-funded regional prospectivity studies of the Gascoyne and West Musgrave Provinces — done by CET at UWA — were published as Reports 117 and 123, respectively. A similar analysis of the King Leopold Orogen was also completed during the year, and one for the Halls Creek Orogen was begun.

Mineral Systems Studies staff prepared numerous 'mineral system' geological summaries for inclusion as inset boxes in the constituent volumes of GSWA's WA Unearthed series.

Products planned for release 2013–14	Current status
	Volume 1 published
Report Explorer's guide for gold in the Yilgarn Craton	Volume 2 in peer review Volume 3 in preparation
Report 117 Mineral systems analysis of the West Musgrave Province: regional structure and prospectivity modelling	Published
Report 123 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province	Published
Report 131 Geology of the Yuiumery VMS mineral system	Published
Record 2013/12 Ironstone veins of the Gifford Creek ferrocarnatite Complex, Gascoyne Province	Published
WA Unearthed series: Geology of Western Australia – Regolith-related mineral systems (text boxes included in Volume 2: Australia goes it alone)	Published
Extended Abstract in Record 2014/2 GSWA's mineral systems research – helping to deliver tomorrow's resources	Published
Extended Abstract in Record 2014/2 Volcanogenic massive sulphide mineralization at Weld Range: a comparison with Golden Grove	Published
Extended Abstract in Record 2014/2 Steps towards explaining the heterogeneous distribution of BIF-hosted iron ore deposits in the Yilgarn Craton	Published
Extended Abstract in Record 2014/2 Crustal structure and mineral prospectivity of the west Kimberley	Published
Abstract (AESC2014) Exploring for rare earth elements using reflectance spectroscopy	Published
External paper Oxygenation of shallow-water environments and chemical sedimentation in Paleoproterozoic peritidal settings: Frere Formation, Western Australia	Published
External paper Riverine mixing and fluvial iron formation: a new type of Precambrian biochemical sediment	Published
Report Geological comparison of the Weld Range and Golden Grove VMS deposits (GSWA Report based on MSc dissertation)	Peer review
Report and external paper – A review and petrochemical study of VHMS mineralization in the Yilgarn Craton, Western Australia	Peer review
Report 3D architecture and mineral prospectivity of the King Leopold Orogen	In preparation
Record The Wheatley massive sulphide deposit	In preparation
Record and external paper – Abra polymetallic breccia pipe	In preparation
Report (authorized release of Company Technical Report) The geology, tectonic evolution and gold mineralization of the Lawlers region: A synopsis of present knowledge	In preparation
Report VMS mineral systems in the western Yilgarn	Provisional

Planned work program and products 2014–15

Research on VMS deposits in the Yilgarn will continue in 2014–15. Studies of sulphide and alteration mineralogy at Wheatley and Austin–Quinns will be completed, and the results progressively published in several Records and Reports, from the latter part of this year and into 2015–16. Also to be published as Reports will be results from the Master of Science study of the Weld Range and Golden Grove VMS deposits; the studies of VMS mineralization in the Abra and DeGrussa deposits; and the EIS-funded study of the lithochemical fertility for VMS systems in Yilgarn volcanosedimentary successions. The last-mentioned project will be expanded to include collection of new geochemical and geochronological data from a number of under-represented terranes. Emphasis in all projects will be on understanding the characteristics and controls on VMS mineral systems, with a view to commenting on terrane prospectivity, and providing vectors for mineral exploration in similar settings.

The recently completed Master's dissertation describing the use of hyperspectral data for directly detecting rare earth element mineralization will be published as a Report. The overall program to study the mineralogy and metallogeny of rare earth element mineral systems in Western Australia is now well established, and will include deposits at Hastings–Brockman, John Galt and Browns Range. These studies will involve (require) continuing collaboration with GSWA's various mapping groups, with rare earth element explorers and miners in Western Australia, and with the Western Australian Museum. The aim of this work is to provide mineral explorers with tools to locate rare earth element mineralization or its larger alteration footprint, using hyperspectral technologies at different scales.

Research on gold systems in the Capricorn Orogen will continue, in close collaboration with other GSWA colleagues, with CSIRO geoscientists, and with relevant industry collaborators. The study of the Nanjilgardy Fault system will continue, but discrete studies of the Paulsens and Glenburgh gold deposits will be completed this year, and the results published as Reports. A new study will commence of the Mt Clement gold deposit, in the Ashburton Basin. All this work will contribute to a much larger, ongoing collaborative investigation of the architecture and metallogeny of the Capricorn Orogen (the Science and Industry Endowment Fund or SIEF), being done under the banner of the National 'Uncover' Initiative (Uncover Group, 2012).

The second and third volumes and associated digital data packages for the 'Explorer's guide (targeting atlas) for gold in the Yilgarn Craton' will be released during 2014–15. Also to be completed and published is the study of gold mineralization and alteration at the Glenburgh gold deposit in the Gascoyne Province.

The section will expand its portfolio of mineral systems research to include nickel sulphides, initially via a Master of Economic Geology study of nickel mineralization in the northeastern Yilgarn Craton, by our most recent recruit.

Mineralogical and metallogenic studies of Archean BIF-hosted iron ore deposits in the Yilgarn and Pilbara Cratons will continue in 2014–15, with some early results to be released to the public in a series of Records and Reports.

The study of diagnostic chemical fingerprints of pyrite and magnetite from different mineral deposit types being done by CODES (University of Tasmania) researchers testing will be completed in 2014–15, and the results will be released as Reports and databases.

CET at UWA will complete the EIS-funded regional prospectivity studies of the King Leopold and Halls Creek Orogens, and the results will be released as GSWA Reports in the latter part of 2014–15 and early 2015–16.

Mineral Systems Studies staff will continue to be involved in the production of new volumes of GSWA's WA Unearthed series, producing as required 'mineral system' geological summaries.

The Mineral Systems Studies section will commence an informal collaboration with GA to compile geochronology data that constrains the ages of mineral deposits in Western Australia. Such data will be included in GSWA mineral deposit datasets and in a national mineral deposit geochronology database, and will inform the future development of an Atlas of Mineral Systems.

Products planned for release 2014–15

- Record and external paper – Abra polymetallic breccia pipe

- Report Geological comparison of the Weld Range and Golden Grove VMS deposits

- Report A review and petrochemical study of VHMS mineralization in the Yilgarn Craton, Western Australia

- Record Alteration associated with the Austin–Quinns VMS mineralization

- Record The Wheatley massive sulphide deposit (provisional title)

- Record The Doolgunna–DeGrussa Besshi-type mineral system in the Paleoproterozoic Bryah Basin, Capricorn Orogen, Western Australia: Re–Os age, tectonic setting and geodynamic evolution (provisional title)

- Reports – Explorer's Guide for Gold in the Yilgarn Craton – Volumes 2 and 3

- Report 3D architecture and mineral prospectivity of the King Leopold Orogen (provisional title)

- Record Main alteration controls on high-grade supergene goethite–hematite iron ore in the Bobby and Glenda pits (Pardoo Mine), Pilbara, Western Australia (MSc dissertation under MRIWA project M426)

- Record Importance of early hypogene and later supergene alteration of Archean BIF at the Alice Extension pit and Joan and Rosita prospects (Pardoo Mine), Pilbara, Western Australia (MSc dissertation under MRIWA project M426)

- Record Alteration mineral zonation associated with high-grade BIF-hosted iron ore; mineral mapping using hyperspectral drillcore data (honours dissertation)

- Record Mapping iron ore and alteration patterns in BIF using hyperspectral data at the Windarling iron camp, Yilgarn Craton, Western Australia

- Record Mapping iron ore and alteration patterns in BIF using hyperspectral data at the Beebyn deposit, Yilgarn Craton, Western Australia

Products planned for release 2014–15

Record Mapping iron ore and alteration patterns in BIF using hyperspectral data at the Mt Richardson deposit, Yilgarn Craton, Western Australia

Report Metallogeny of Archean BIF-hosted iron ore deposits in the Yilgarn Craton, Western Australia (provisional title)

MRIWA Report Project M426: Metallogeny of Archean BIF-hosted iron ore deposits in the Pilbara Craton, Western Australia (provisional title)

Report Hyperspectral characteristics of rare earth element deposits (MEconGeol dissertation)

Record Results of fluid inclusion analysis of samples from the John Galt REE prospect, East Kimberley (provisional title, GA)

Report Geological setting and nature of gold mineralization and associated alteration at the Glenburgh deposit, Gascoyne Province (provisional title, MEconGeol dissertation)

GSWA–CSIRO Report Integrated spectral mapping of precious and base metal related mineral footprints, Najilgardy Fault, Western Australia

Report Metallogenesis of the Paulsens orogenic gold deposit, Wyloo Dome, Pilbara Craton

GSWA–CODES Report and database – Testing LA-ICPMS geochemistry of pyrite as a fertility and vectoring tool in exploration for orogenic gold and VHMS deposits in Western Australia

Report VMS Mineral Systems in the western Yilgarn (provisional title)

Report (authorized release of Company Technical Report) The geology, tectonic evolution and gold mineralization of the Lawlers region: a synopsis of present knowledge

Planned work program and products 2015–16 and beyond

The Mineral Systems Studies section will continue its studies of VMS, iron ore, gold, rare earth elements and nickel mineralization. This work will be done in close collaboration with GSWA's regional mapping sections, and with CSIRO, UWA, Curtin, University of Tasmania, GA and other academic institutions, and an expanding network of affiliated exploration and mining companies. The section will continue managing collaborative Mineral Systems-oriented research projects funded by the EIS.

GS43 Geochemistry and Regolith

Manager: Paul Morris

Team member: Andreas Scheib

GSWA is continuously expanding its approaches to understanding the geology of the State, and the location of its various programs. This requires changes in the scope and type of data, including geochemistry. Geochemical data form not only an integral part of mapping and mineral systems projects, but also comprise products in their own right, such as regional regolith geochemistry surveys. The widespread use of GSWA geochemical data both within GSWA and by the private sector necessitates the measurement of a wide range of analytes using techniques capable of determining precise and accurate concentrations from the nanogram to percentage range. Currently, lithochemical and regolith geochemical analysis involves the determination of more than 60 analytes. To achieve this, and at the same time ensure data quality, a range of analytical techniques must be available, as well as programs to monitor the quality of data. In GSWA, the latter involves measurement of at least 10% quality control samples in each analytical batch (sample duplicates, in-house and international reference materials, and analytical blanks), and an ongoing part of GSWA's geochemistry program is the generation and/or characterization of suitable reference materials.

The majority of geochemical data are generated at commercial analytical laboratories, with which GSWA has contractual arrangements. However, an increasing amount of geochemical data is being generated by real-time equipment, such as field-portable x-ray fluorescence (pXRF) analysers. The refinement of both hardware and software has meant that these devices are now capable of measuring an increasingly wider range of elements (particularly those with lower atomic number) to levels which in some cases approach crustal abundances. GSWA has recently updated a pXRF purchased in 2009, meaning that both of its devices can now measure low atomic number elements as well as some rare earth elements. These changes have been driven not only by technological advances but also by the diversification of GSWA programs.

Regional geochemical surveys using regolith as a sample medium result in important datasets for mineral exploration, but in order to interpret the results of these surveys, knowing whether regolith has developed in situ (and is therefore related to the underlying bedrock) or has been transported is important information. Mapping of regolith and advising mapping groups in this area are routine activities within the GS43 program. In 2013–14, the revised approach to regolith classification, recommended approach to regolith mapping and the recently acquired ASTER satellite imagery were the subject of a workshop given by staff of this section to

mapping and mineralization sections. The workshop also attracted participants from the petroleum sector of DMP, who saw an application to petroleum exploration.

Lithochemical analysis routinely involves the generation of glass fusion discs for XRF determination of major element oxides. A trial of the use of laser ablation ICPMS of these discs to determine a range of trace elements to lower levels of detection than routinely determined by solution-based ICPMS was carried out by Curtin University and Macquarie University using GSWA internal reference materials and international reference materials. The technique shows that solution ICPMS and laser ablation inductively coupled mass spectrometry (LA-ICPMS) provide comparable data in terms of precision and accuracy for a range of trace elements, but higher quality results (i.e. acceptable precision at lower levels of detection) can be attained for some trace elements by LA-ICPMS, although this is dependent on the type of ICPMS technology used. The current GSWA programs do not appear to warrant a change from solution-based ICP to LA-ICP, but developments in the latter will be monitored.

Outcomes of work program 2013–14

Lithochemical remains an important part of GSWA's mapping and mineralization programs. The growth in recent years in the number of samples analysed decreased in 2013–14 from 1184 to 936 (-8%), reflecting the winding down of some projects (e.g. west Musgrave).

The effectiveness of regolith geochemistry in identifying areas of mineralization (as well as tracing the distribution of bedrock lithologies) is a key part of the GS43 program. Regolith geochemistry generated from various grain size fractions from 151 samples collected over a 400-km long area on the Yilgarn Craton – Albany–Fraser margin was compiled and assessed. This work (published as Record 2014/3) emphasized the importance of assessing different grain size fractions of regolith, and noted the efficacy of the <50 µm fraction coupled with a partial digest approach.

Products released 2013–14

Record 2014/3 Regolith geochemistry and mineral prospectivity – the southeast Yilgarn Craton and east Albany–Fraser Orogen

Lithos 190–191 Melting of a subduction-modified mantle source: A case study from the Archean Marda Volcanic Complex, central Yilgarn Craton, Western Australia

Planned work program and products 2014–15

The growing demand for lithochemistry requires ongoing monitoring of data quality and investigation of new approaches to achieve more precise and accurate geochemical data. This is achieved by testing new analytical techniques, assessing new and existing reference materials, and replacing (where necessary) laboratory equipment. The recent acquisition of a replacement pXRF requires assessment of its capabilities, followed by instruction of staff in its use. Publication of a Record on pXRF capabilities will provide some reference for this work.

Other tasks include:

- continuous evaluation of new analytical techniques
- assessment of new and existing reference materials
- further investigation of LA-ICPMS for accurate and precise determination of trace elements at enhanced levels of detection.

GS45 Pilbara Craton

Manager: Arthur Hickman

Team members: GSWA staff as required

The Pilbara Craton is a Paleoproterozoic–Mesoproterozoic tectonic unit that underlies approximately 400 000 km² of northwestern Australia. The craton is unconformably overlain by Neoproterozoic–Proterozoic volcanic and sedimentary rocks. Geological remapping at 1:100 000 scale formed the basis of the project and resulted in a major revision of the area's stratigraphy, structure, geochronology, and crustal evolution. More than 40 new geological maps, mainly at 1:100 000 and 1:250 000 scales, were released, along with a large number of geological reports, GIS packages, and external journal papers. The project included new airborne magnetic and radiometric surveys which were released for use by the industry. The imagery is now available online in GeoVIEW.WA. Geological interpretation of the large volume of new information generated by the project has provided a greatly improved understanding of Paleoproterozoic–Proterozoic mineralization in the Pilbara. This has been particularly important because much of the craton evolved prior to c. 3200 Ma, which is before Phanerozoic-style plate tectonic processes commenced. Consequently, different metallogenic models need to be considered for the Paleoproterozoic. Known mineralization includes gold, silver, copper, lead, zinc, molybdenum, tungsten, nickel, iron, chromium, vanadium, platinum group elements, uranium, manganese, and pegmatite minerals containing tin, tantalum and beryllium.

Work is currently focused on writing detailed geological reports for the west and east Pilbara, and completing geoscientific databases, in particular the Explanatory Notes System.

Management of project risks

The completion of geoscientific databases for the Pilbara must be consistent with current geological interpretations. Data from sources older than 2006, when the current interpretation was established, requires entry by experienced staff. Providing current staff resources are maintained, the work will be substantially complete by the end of 2015.

Outcomes of work program 2013–14

Release of a complete 1:100 000-scale digital data package for the east Pilbara extended the revised 1:100 000 geological coverage across 24 map sheets and added new 1:250 000 interpreted bedrock geology (IBG) for 27 1:100 000 map sheet areas. The new 1:250 000 IBG layer was then used to compile a new east Pilbara 1:500 000 IBG. Other work included writing for a geological report on the Paleoproterozoic–Mesoproterozoic geology of the northwest Pilbara and additions to the

Explanatory Notes database as required for the new State map. A paper on Pilbara impact spherule beds was submitted to the Australian Journal of Earth Sciences and an abstract on Pilbara and Yilgarn Hf and Nd data was submitted to the Australian Earth Sciences Convention, July 2014. Field investigation of a recently discovered meteorite impact crater north of Newman provided additional material for analysis. Following media interviews, an article on the crater was published in the Australian Geographic Journal (May–June edition).

Products released 2013–14

Pilbara 1:100 000 Geological Information Series 2014

East Pilbara 1:250 000 IGB Digital Layer, 2014

Planned work program and products 2014–15 and beyond

Reports on the Paleoproterozoic–Mesoproterozoic geology of the northwest Pilbara and the east Pilbara will be completed. Additional entries will be made to the Explanatory Notes System.

The work program for 2014–15 will include finalization of a Pilbara Craton contribution to the Archean chapter of GSWA's WA Unearthed series. Journal papers based on Pilbara data will result from collaboration with a number of external workers.

Products planned for release 2014–15

Paleoproterozoic–Mesoproterozoic geology of the northwest Pilbara Craton (Report 92)

Paleoproterozoic–Mesoproterozoic geology of the east Pilbara Craton (Report)

Review of investigations on a meteorite impact crater north of Newman (Record)

External: Impact spherule beds of the Fortescue and Hamersley basins (AJES)

Contribution to the Archean part in the WA Unearthed series on the geology of the Pilbara Craton (GSWA book)

External: Hf and Nd constraints on the Pilbara and Yilgarn cratons (AESC)

Work beyond 2015 will include entries for approximately 1500 stratigraphic units in the Explanatory Notes System, allowing release of a digitally generated Explanatory Notes for the northern Pilbara Craton and adjoining units of the Fortescue and Hamersley Basins. This publication will cover the Archean and Proterozoic geology already published on 35 1:100 000 series maps and seven 1:250 000 series maps as part of the Pilbara Craton mapping project.

GS47 Gascoyne Province

Manager: Simon Johnson

Team member: Fawna Korhonen

The Paleoproterozoic to Neoproterozoic Gascoyne Province is the deformed, medium- to high-grade metamorphic core of the Capricorn Orogen and contains subeconomic deposits of gold, lead, copper, barite, uranium, rare earth elements, muscovite, beryl, tantalum, tungsten, graphite and semiprecious gemstones. The Gascoyne Province has been affected by at least five tectonothermal events, and displays an extended, episodic history of intracontinental reworking and reactivation until the end of the Neoproterozoic. Reactivation of major structures during the Mesoproterozoic and Neoproterozoic has controlled the formation and deformation of the overlying Edmund and Collier Basins, and may also have provided pathways for mineralizing fluids. An understanding of the province is essential for interpreting the evolution of the Capricorn Orogen, and the formation of large-scale structures that have controlled mineralization along the northern margin of the Yilgarn Craton and the southern margin of the Pilbara Craton.

The Gascoyne Province was first systematically mapped by GSWA in the 1970s. Products from this program include 1:250 000-scale maps and Explanatory Notes, along with two Reports, one on the geology of the province, and another on the Rb–Sr geochronology of the province. Modern aeromagnetic and radiometric data at 400 m or 500 m line spacing cover the whole province, and SHRIMP U–Pb zircon geochronology is available for much of the province. Recent orthophotography is now available for much of the province. An MT survey across the Gascoyne Province was conducted in 2007, and a deep crustal seismic survey and accompanying MT survey were completed in 2010–11.

Several important advances have been made in our understanding of the Gascoyne Province in the last few years, but there are several major questions yet to be resolved. First, the Gascoyne Province records a protracted (more than 1 Ga) and complicated history of intracontinental reworking and reactivation, but the precise extent of individual events and their causes remains enigmatic. Second, the aerial extent, and depositional age and tectonic setting for the precursors to the Leake Spring Metamorphics (formerly Morrissey Metamorphics), which were deposited before the Capricorn Orogeny, are yet to be firmly established. Third, there are virtually no direct ages on any of the mineralization styles in the province, so the relationship between mineralization and the various orogenic events is uncertain. Finally, the nature of the boundary between the Gascoyne Province and the upper Wyloo Group to the north (in particular, the Ashburton Formation) is not well established.

Management of project risks

There are few risks associated with the project. There are currently no land access issues. Production of several first- and second-authorship Reports depends on the external supply of phosphate dating and isotopic work.

Outcomes of work program 2013–14

The majority of the 2013–14 season was spent mapping high-grade metamorphic rocks in the Mangaroon Zone on the northern part of the TOWERA 1:100 000 Geological Series map sheet. Mapping of TOWERA will be completed early in the 2014–15 season.

Mapping on the northern part of the TOWERA 1:100 000 Geological Series map sheet has identified the Collins Fault as a major crustal structure that has been reactivated multiple times during the Proterozoic. The fault zone was deformed across the brittle–ductile transition and is possibly a former seismogenic zone and a good prospect for gold mineralization. Preliminary results were presented at the 2014 GSWA Open Day presentation ‘Shake rattle and gold’. Further investigation is continuing.

U–Th–Pb phosphate geochronology (in conjunction with Prof. Birger Rasmussen at Curtin University) combined with metamorphic P–T–t studies has better defined the thermodynamic evolution of the 1385–1170 Ma Mutherbukin Tectonic Event. This work is currently being compiled into a GSWA Report for release in October 2014.

U–Th–Pb phosphate geochronology work is continuing to unravel the timing of deformation and mineralization in the northern Capricorn Orogen, as part of the GSWA–Curtin University ARC Linkage grant ‘Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: Constructing a geological framework for understanding mineral systems’.

Products released 2013–14

LYNDON 1:100 000 Geological Series map

Update of the Western Capricorn Geological Information Series (including MOUNT SANDIMAN and LYONS RIVER 1:100 000 sheets; digital product), including digital explanatory notes for the Gascoyne Province

Western Capricorn Explanatory Notes update: MOUNT SANDIMAN, LYONS RIVER and LYNDON (for inclusion in digital product)

Co-author on Report 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province

Co-author on Report A magnetotelluric traverse through the eastern part of the Capricorn Orogen

Products released 2013–14 (continued)

Authored an external paper to the Australian Journal of Earth Sciences summarizing the results of the 2010 deep crustal seismic reflection line through the Capricorn Orogen

Planned work program and products 2014–15

Work during 2014–15 will concentrate on mapping of Gascoyne Province rocks on the UAROO 1:100 000 Geological Series map sheet. Two Reports are proposed for publication during the year. One Report will present the results of U–Pb SHRIMP dating of metamorphic monazite and xenotime from low-grade metamorphic rocks in the province, and a second will present the results of in situ oxygen and Lu–Hf isotopic compositions of magmatic and inherited zircons from the Moorarie and Durlacher Supersuites.

Collaborative work with Prof. Birger Rasmussen at Curtin University will continue under an ARC Linkage agreement (2013–16), which will examine the age of mineralization and low-grade metamorphism and hydrothermal activity in the northern part of the Capricorn Orogen. This will involve the co-supervision of two postdoctoral and two postgraduate researchers, the results of which will be published in numerous GSWA Reports and external publications. Current collaborative research with several exploration companies will be ongoing.

Products planned for release 2014–15**Planned release date**

TOWERA 1:100 000 Geological Series map	April 2015
Update of the Western Capricorn Geological Information Series (including LYNDON and TOWERA 1:100 000 Geological Series maps; digital product), including digital explanatory notes for the Gascoyne Province	April 2015
Western Capricorn Explanatory Notes update: TOWERA (for inclusion in digital product)	April 2015
Report Pressure–temperature–time evolution of the Mutherbukin Tectonic Event: a model for Mesoproterozoic intracontinental reworking of the Capricorn Orogen	Oct 2014
Report The oxygen and hafnium isotopic evolution of the Moorarie and Durlacher Supersuites: contrasts in magma source and emplacement styles	April 2015
Report The timing of deformation, low grade metamorphism and gold mineralization at Paulsens Gold Mine, western Wyloo Dome*	April 2015
Report The age and significance of the Gifford Creek Ferrocarbonatite Suite	June 2015

* EIS product

Planned work program and products 2015–16 and beyond

Work during 2015–16 and beyond will concentrate on mapping the northwestern part of the Gascoyne Province, including the southern part of the Ashburton Basin (UAROO and BOOLALOO 1:100 000 Geological Series maps). This will be conducted in cooperation with members of GS49 (Edmund and Collier Basins) field mapping team. Compilation for these sheet areas will be incorporated into the 2016 release of the Western Capricorn Geological Information Series digital product. Writing will commence on Reports, including the nature and origin of the Mangaroon Orogeny and the transition of metasedimentary rocks across the Gascoyne Province into the Ashburton Basin. Collaboration with Prof. Rasmussen under the ARC Linkage agreement will continue, as well as with various exploration companies.

Products planned for release 2015–16**Planned release date**

Update of the Western Capricorn Geological Information Series (including UAROO and BOOLALOO 1:100 000 Geological Series maps; digital product)	Oct 2016
BOOLALOO 1:100 000 Geological Series map	Oct 2016
UAROO 1:100 000 Geological Series map	April 2016
Report Relationship of the Leake Spring Metamorphics and Ashburton Formation	Dec 2016
Report Thermodynamic evolution of the Mangaroon Orogeny	Dec 2016

GS49 Edmund and Collier Basins

Manager: Simon Johnson

Team members: Huntly Cutten, Olga Blay

The late Paleoproterozoic to Mesoproterozoic Edmund and Collier Basins contain the Bangemall Supergroup, a major geological unit that hosts Western Australia's largest stratabound lead–silver–copper–gold deposit. This, combined with the age and geological setting of the basins make it one of the most prospective areas in Australia for large, blind, sediment-hosted base-metal orebodies. The Edmund and Collier Basins also have a history of minor gold and phosphate production.

The Edmund and Collier Basins were systematically mapped by GSWA in the 1960s and 1970s and this work was followed by more localized mapping in the Jillawarra area during the 1980s. These studies resulted in the production of 1:250 000-scale maps and Explanatory Notes, one Bulletin, and one Report. The region is covered by recent 400 m or 500 m line-spaced aeromagnetic and radiometric data. Aerial orthophotography, Landsat and DEM-derived imagery is available for much of the outcrop area.

Detrital zircon geochronology and zircon and baddeleyite geochronology of crosscutting dolerite sills have produced age constraints on the Edmund Group of about 1620–1460 Ma, and 1170–1070 Ma for the overlying Collier Group, but have not provided any meaningful constraints on the ages of six depositional packages identified during regional mapping studies. These depositional packages are bounded by hiatuses that record important stages in the evolution of Edmund and Collier Basin architecture. The major lead–silver–copper–gold deposit at Abra is hosted in rocks that are interpreted to belong to the lower part of the Bangemall Supergroup (depositional packages 1 and 3). The results of recent monazite geochronology studies indicate that a major mineralization event occurred at Abra around 1250 Ma.

Management of project risks

Few risks have been identified associated with the project. Land access is currently not an issue. No other issues are anticipated for 2014–15. Production of several first- and second-authorship Reports depends on the external supply of phosphate and sericite dating, geochemistry and isotopic work.

Outcomes of work program 2013–14

The 2013–14 work program has focused on mapping Edmund and Collier Group rocks on the THREE RIVERS and UAROO 1:100 000 Geological Series maps, partly under the EIS.

Geochemistry and geochronology studies have identified a new dolerite suite, the Waldburg Dolerite dated at 1513–1500 Ma. These intrude the Irregully and Yilgatherra Formations (depositional package 1) and provide a younger age limit for this package. It is anticipated that ongoing geochemistry and geophysical studies will provide further age constraints on the depositional packages of the Edmund and Collier Basins. These results will be released as a Report in 2014–15.

A study of the structure and deformational history of the Edmund and Collier Basins has identified a 45 degree anticlockwise swing in the compressional axis from a northeast–southwest orientation with sinistral transpressive fault movement during the 1385–1170 Mutherbukin Tectonic Event, to a north–south orientation with dextral transpressive fault movement during the 1030–955 Ma Edmundian Orogeny. These results will be released as a GSWA Report in late 2014.

K–Ar dating of illite from fault gouge material and slickensides recovered from exposed faults, which has been carried out in collaboration with Horst Zwingman of CSIRO, has confirmed a c. 1170 Ma date for latest Mutherbukin Tectonic Event deformation. Material from EIS drillcore crosscutting the Six Mile Fault near the major lead–silver–copper–gold deposit at Abra has identified c. 800–900 Ma fault movements, which support similar dates from basement rocks of the Gascoyne Province. Additional material dated at c. 1020–970 Ma records movement during the 1030–955 Ma Edmundian Orogeny. These results will be released as a GSWA report in 2014–15.

Work on the Explanatory Notes for the Edmund and Collier Basins is near complete and will be included on the 2014 West Capricorn Geological Information Series digital package.

Products released 2013–14

THREE RIVERS 1:100 000 geological map*

West Capricorn Geological Information Series update, MOUNT VERNON* and JAMINDI* 1:100 000 Geological Series maps (digital product)

* EIS product

Planned work program and products 2014–15

Work during 2014–15 will focus mainly on mapping, field checking, and compiling the geology of Edmund and Collier Group rocks on the CARDOWAN and UAROO 1:100 000 Geological Series maps. The compilation of

digital Explanatory Notes for the Edmund and Collier Groups will be edited for inclusion on the 2014 digital package.

In addition, Reports will be produced detailing the Mesoproterozoic structural history of the Edmund and Collier Basins, a detrital zircon Lu–Hf and U–Pb isotopic comparison of the Gascoyne Province and Mesoproterozoic sedimentary rocks, the K–Ar dating of fault gouges in the Edmund and Collier Basins, and the geochemical evolution of Mesoproterozoic mafic dykes and sills that intrude the Edmund and Collier Groups.

Products planned for release 2014–15	Planned release date
CARDOWAN 1:100 000 Geological Series map	June 2015
West Capricorn Geological Information Series update, THREE RIVERS* 1:100 000 Geological Series map (digital product)	April 2015
West Capricorn Explanatory Notes update for MOUNT AUGUSTUS, MOUNT PHILLIPS, PEEDAWARRA, CANDOLLE, ERRABIDDY, MARQUIS, CALYIE, TANGADEE, MOUNT EGERTON, MULGUL, MILGUN, TEANO, ELLIOTT CREEK, ULLAWARRA, CAPRICORN, EDMUND, MANGAROOON, MAROONAH, MOUNT VERNON, JAMINDI and THREE RIVERS 1:100 000 Geological Series maps	April 2015
Report on Mesoproterozoic structural history of Edmund and Collier Basins	Dec 2014
Report on detrital zircon Lu–Hf and U–Pb isotopic comparison of the Gascoyne Province and Mesoproterozoic sedimentary rocks	June 2015
Report on K–Ar dating of fault gouges in the Edmund and Collier Basins	June 2015
Report on the geochemical evolution of Mesoproterozoic mafic dykes that intrude the Edmund and Collier Groups*	June 2015

* EIS product

Planned work program and products 2015–16 and beyond

Work during 2015–16 and beyond will focus on the mapping, compilation and stratigraphic analysis of Bangemall Supergroup rocks in the central and eastern parts of the Capricorn Orogen, including LOFTY RANGE, WONYULGUNNA and ILGARARI 1:100 000 Geological Series maps. Mapping will continue in the northern Capricorn Orogen on the UAROO and BOOLALOO 1:100 000 Geological Series maps where rocks of the Proterozoic Ashburton Basin are exposed.

The geochemical characterization of mafic rocks in the orogen will continue, as well as K–Ar geochronology on fault gouges in conjunction with Prof. Zwingmann at CSIRO.

Products planned for release 2015–16	Planned release date
LOFTY RANGE 1:100 000 Geological Series map (preliminary edition)*	June 2016
WONYULGUNNA 1:100 000 Geological Series map	Oct 2016
ILGARARI 1:100 000 Geological Series map*	Oct 2016
BOOLALOO 1:100 000 Geological Series map*	Oct 2016
UAROO 1:100 000 Geological Series map	April 2016
West Capricorn Orogen Geological Information Series: LOFTY RANGE*, WONYULGUNNA*, ILGARARI*, BOOLALOO and UAROO 1:100 000 Geological Series maps (digital product)	Oct 2016
Western Capricorn Orogen Explanatory Notes update LOFTY RANGE*, WONYULGUNNA*, ILGARARI*, BOOLALOO and UAROO 1:100 000 Geological Series maps	Oct 2016

* EIS product

GS52 East Yilgarn (Kalgoorlie Office)

Manager: Stephen Wyche

Team members: Nicole Patison, Jyotindra Sapkota, Matt de Paoli

The Eastern Goldfields Superterrane occupies approximately the eastern third of the Archean Yilgarn Craton. This highly mineralized region contains world-class gold and nickel deposits, and significant deposits of other commodities including base metals, rare earth elements, uranium, gemstones and industrial minerals. An understanding of the tectonic evolution of the Eastern Goldfields, including the structure and stratigraphy, is essential to the understanding of the controls on formation and distribution of mineralization in the region.

The published 1:100 000-scale mapping that covers the entire Eastern Goldfields Superterrane is available in the East Yilgarn Geological Information Series in GIS form. This product is being upgraded to implement formal stratigraphic concepts which include recent new data and concepts arising from various research projects, particularly the large body of new geophysical, geochronological, geochemical and isotope data.

Management of project risks

There are no significant land access or other risk issues that affect this project.

Outcomes of work program 2013–14

New mapping and integration of data and stratigraphic information derived from various cooperative projects have been applied to the East Yilgarn Geological Information Series (GIS) in the northern Eastern Goldfields around Agnew and in the southern Eastern Goldfields between Kalgoorlie, Coolgardie and Kambalda. Formal stratigraphic nomenclature has been applied in these regions. The new interpretations were published in the 2014 East Yilgarn GIS.

GSWA geologists presented contributions and led field excursions at meetings for the ARC Linkage mafic rocks project with Monash University, Australian National University (ANU), and various companies. This project is investigating the mafic intrusive and volcanic rocks in the Yilgarn Craton and their relation to gold and base metal deposits.

Products released 2013–14

East Yilgarn Geological Information Series update including Eastern Goldfields Superterrane stratigraphy

Planned work program and products 2014–15

The ongoing revision of the East Yilgarn GIS to incorporate the new structural and stratigraphic framework that has developed out of mapping and academic research programs over the past 25 years will continue. In 2014–15, new mapping will focus on the region between Kalgoorlie and Agnew, linking the areas in the current release.

The East Yilgarn mapping team is undertaking a comprehensive review of the GSWA geochemical database for the Eastern Goldfields, assessing it for data quality and coverage. A program of systematic sampling will be undertaken to fill gaps in the existing dataset and provide detailed coverage of greenstone successions in the region.

Products planned for release 2014–15

East Yilgarn Geological Information Series update including Eastern Goldfields Superterrane stratigraphy

Excursion guide for the Gold14@Kalgoorlie conference

Planned work program and products 2015–16

Beyond 2014–15, the incorporation of regional stratigraphy into the East Yilgarn GIS will continue with releases as appropriate. Explanatory Notes will be prepared to cover the whole of the East Yilgarn GIS and will be delivered as part of the Explanatory Notes System. Future stratigraphic interpretation will focus on completing the western part of the Eastern Goldfields Superterrane (Kalgoorlie Terrane) and then extend to the east.

Products planned for release 2016–17

East Yilgarn Geological Information Series update including Eastern Goldfields Superterrane stratigraphy

Explanatory Notes Database update

Publications detailing the new regional stratigraphy for the Eastern Goldfields Superterrane

Review and interpretation of all available east Yilgarn geochemical data

GS53 Chief Geoscientist and Terrane Custodians

Manager: Roger Hocking

Team members: Angela Riganti, Terry Farrell, Dave Martin (fee for service, State geology),
Kath Grey (fee for service, Paleontology)

Terrane Custodians: Stephen Wyche (Archean), Simon Johnson (Proterozoic),
Roger Hocking (basins), Paul Morris (regolith)

The Chief Geoscientist and his section, including the Terrane Custodians, are responsible for maintaining a coherent geological framework for Western Australia and ensuring geoscience information delivered by GSWA is relevant, appropriate, and of a high standard. This includes delivering GSWA geoscience as multi-themed products developed and extracted from information stored in GSWA databases, with static, printed, or downloadable maps, documents, and single-layer datasets only part of the total product. The Chief Geoscientist and his section's part in achieving this is twofold. They work with project teams and groups as appropriate, guiding and overseeing development and population of GSWA databases, coordinating capture of spatial and textual legacy data, contributing to products as appropriate, validating database content, reviewing and approving manuscripts and spatial products, and coordinating work that spans more than one project. They work independently on geological problems not part of current GSWA project work and on Statewide geological issues and datasets. The work of the team is thus partly process, with definable standards but no clearly defined outcomes, and partly program, for which there are outcomes. Legacy data capture and management of quality control and product relevance are processes, whereas outcomes and products arise from management of State-level datasets.

Management of project risks

Much of the work of the Chief Geoscientist's team is the monitoring, integration, and approval of data and products from other teams. There is considerable risk that this role (a funnel for most of GSWA's work) overwhelms independent work on State-level datasets. Overcommitment needs monitoring.

Outcomes of work program 2013–14

Population of the Data Entry module of the Explanatory Notes System (ENS) continued in 2013–14. All textual information for the main legends of series maps is now extracted from ENS, as well as lookup tables for all digital packages. A GeoMap.WA-driven graphical user interface (GUI) for end-user interrogation of ENS is available for selected GIS packages (Musgrave, West Capricorn). Design of ENS search tools for lithostratigraphic units, tectonic units, and events for GeoVIEW.WA continued, as well as the generation of additional types of reports (e.g. tectonic lookup table). Legacy data capture of both spatial and textual field data continues.

Work on the concise Geology of Western Australia project (WA Unearthed) progressed with the release of a second instalment, 'Australia goes it alone — the emerging island continent 100 Ma to present'. This is part 4 of the series; part 2 on the Proterozoic evolution of Western Australia was released in June 2013. Work on the remaining two parts is at varying stages, with releases planned through 2015. Considerable progress was made in the compilation of new 1:500 000-scale geoscience layers, with the geological polygon layer almost complete, after outsourcing. Collaborative work with partly external projects, primarily the ARC 'Devonian chronostratigraphy' project, continued. Monitoring and approval of project work, and incidental but necessary contributions to project work, have impacted severely on work on State-level datasets.

Products planned for release 2013–14	Current status
Geology of Western Australia parts 3 and 4 (WA Unearthed)	Part 4 released, part 3 in progress
1:500 000-scale spatial geoscience layers (geology, structure, tectonic units, linear features)	In progress
1:2.5 million spatial geoscience layers, derived from 1:500 000 spatial layers	Postponed to 2014–15
1:2.5 million geological map of Western Australia, derived from 1:2.5 million spatial layers	In progress
ENS online delivery system progress	In progress
GeoMap.WA interface	Available on selected digital packages

Planned work program and products 2014–15

Completion of 1:500 000 seamless geoscience and data layers is a high priority. The 1:500 000 Interpreted Bedrock Geology will form a set of intelligent spatial layers rather than a single map, comprising:

- interpreted bedrock geology (polygons)
- Cenozoic bedrock geology (polygons), for areas of significant, thick Cenozoic deposits
- interpreted bedrock geology structures (lines), e.g. faults and folds
- tectonic subdivisions (polygons), derived largely from the new interpreted bedrock geology layer

- orogenic events (polygons), illustrating the extent, timing, and nature of major orogenies and derived from the interpreted bedrock geology and tectonic unit layers.

New 1:2 500 000 spatial and data layers and an associated State Map will be generated from the 1:500 000 layers during 2015. Development of a process to ensure regular incremental upgrades of State spatial layers as new products are released for individual projects, rather than infrequent major updates and reinterpretations, will build on hindsight obtained from the current compilation.

Completion of the remaining sections (Archean and Gondwana) of the WA Uearthed series, and finalization (including interrogation modules) of ENS are also targets. Population of ENS and WAROX (GSWA's field observation database), monitoring of the style and quality of GSWA geoscience, and overseeing GSWA database capture and validation will continue as in previous years. In particular, population of ENS is central to GSWA's vision of data-driven product delivery, for projects that have yet to commence entry, for areas not covered by current projects, and by senior geoscientists with accumulated knowledge. The next stage is to deliver ENS online rather than in GIS packages, with a graphical interface allowing textual and spatial interrogation of lithostratigraphic and tectonic units, and events.

A major release of interpretive data arising from the ARC 'Devonian chronostratigraphy' project took place at the AAPG domestic conference in Houston in April 2014, and a follow-up SEPM Special Publication is planned for 2015, when data analysis and integration should be complete. It is hoped GSWA can host the data arising from the project, to ensure its public availability.

Products planned for release 2014–15

Geology of Western Australia parts 3 and 1 (WA Uearthed)

1:500 000-scale spatial geoscience layers (geology, structure, tectonic units, linear features, orogenic events)

1:2.5 million spatial geoscience layers, derived from 1:500 000 spatial layers

1:2.5 million geological map of Western Australia, derived from 1:2.5 million spatial layers

ENS online delivery system

Planned work program and products 2015–16 and beyond

Work for following years will continue to focus on maintenance, upgrading, and population of spatial and textual datasets, extension of the WA Uearthed products to layperson's guides and region-by-region guides, and quality assessment of GSWA products and data. Legacy capture of geoscience for ENS is a long-term goal.

GS54 Geochronology and Isotope Geology

Manager: Michael Wingate

Team members: Chris Kirkland (isotope geochemistry specialist), John Williams (laboratory manager)

The Geochronology and Isotope Geology section determines precise and accurate ages of rocks and geological events to enhance the understanding of the geological history of Western Australia and contribute to the prospectivity of the State. Geochronology is an integral part of GSWA's mapping programs and mineralization studies. A range of isotope systems (including U–Pb, Ar–Ar, and Re–Os) and a variety of minerals (zircon, baddeleyite, monazite, titanite, hornblende, feldspars, and micas) are used to constrain the timing of magmatism, metamorphism, deformation and mineralization. The ages of detrital zircon crystals are used for provenance analysis and to provide maximum ages of deposition for sedimentary rocks. The timing of tectonothermal events is constrained by dating of pre-tectonic, syn-tectonic, and post-tectonic intrusive rocks. The sensitive high-resolution ion microprobe (SHRIMP) equipment in the John de Laeter Centre at Curtin University is used extensively by GSWA to measure uranium, thorium, and lead isotopes in zircon, baddeleyite, and monazite. GSWA also collaborates with Ar–Ar geochronology specialists at the John de Laeter Centre to determine the ages of cooling, deformation, and crystallization of rocks containing potassium-bearing minerals. The varied aspects of the geochronology program are supported by world-class sample preparation services provided by the GSWA laboratory at Carlisle. The Geochronology and Isotope Geology section also provides specialist isotope geochemistry services to GSWA mapping and mineralization projects.

Management of project risks

Delays to the secondary ionization mass spectrometry (SIMS) component of this project could occur due to instrument failure of either the SHRIMP, or of the scanning electron microscopes (SEMs) used to acquire cathodoluminescence (CL) images of minerals prior to SHRIMP U–Pb analysis. Delays to the isotope geology component of this project could occur due to failure of either thermal ionization mass spectrometry (TIMS) or LA-ICPMS instruments at collaborating institutions.

Outcomes of work program 2013–14

About 100 rock samples were processed for U–Pb geochronology by GSWA's laboratory, and 86 were analysed by GSWA geochronologists using the SHRIMP facilities at Curtin University. These samples were dated in support of GSWA geoscience programs in the west Musgrave and Gascoyne Provinces, the Murchison and Eastern Goldfields regions of the Yilgarn Craton, the

Albany–Fraser Orogen, the Kimberley, Padbury, Edmund, and Amadeus Basins, and in basement rocks beneath the Eucla Basin. Some recent highlights are described below.

Enhancements to our understanding of the geological history of the Albany–Fraser Orogen are progressing, with additional U–Pb dating and isotope geology of detrital zircons in sedimentary rocks. An extensive U–Pb detrital zircon geochronology dataset has been analysed statistically and used to understand the provenance of two regional basins — the Barren and Arid Basins — that dominate the stratigraphic record of the Albany–Fraser Orogen. These basins record two cycles of sedimentation related to major uplift and extensional events. The c. 1815–1600 Ma Barren Basin is dominated by Neoproterozoic detritus with age and isotopic similarities to magmatic rocks of the Archean Yilgarn Craton. In addition, detrital zircon age components at 1815–1800 Ma, 1780–1760 Ma, and 1710–1650 Ma reveal an important detrital source into the Barren Basin during the Biranup Orogeny. The c. 1600–1305 Ma Arid Basin contains material similar to that in the Barren Basin, but also an important c. 1455–1375 Ma age component, which does not correspond to any known component within the Albany–Fraser Orogen, but rather reflects an external source. This material is similar in age and Hf isotope characteristics to magmatic rocks of the Madura Province, outboard and to the east of the Albany–Fraser Orogen, indicating that the Madura Province was located close to the West Australian Craton between c. 1400 and 1300 Ma.

Another example of using geochronology to detect changes in the provenance of sedimentary successions through time, and thereby providing valuable information on the nature of tectonic processes, comes from the Kimberley region of northern Western Australia. The Paleoproterozoic Speewah Group and unconformably overlying Kimberley Group have been investigated by SHRIMP U–Pb age and LA-ICPMS Lu–Hf isotope determinations on detrital zircons. The results reveal a marked change in provenance at the base of the Kimberley Group. The Speewah Group is dominated by Paleoproterozoic (1880–1850 Ma) detrital zircons with unradiogenic Hf signatures, whereas the onset of deposition of the Kimberley Group is marked by a dramatic increase in the proportion of mainly Neoproterozoic (2525–2480 Ma) detrital zircons with radiogenic Hf. This change is interpreted to reflect c. 1800 Ma post-orogenic collapse of the Halls Creek Orogen.

Geochronology of sanukitoid granites at Beadell Resources' Neale gold project (Fig. 31a) sheds light on the composition, evolution, and mineralization of the Tropicana Zone of the Albany–Fraser Orogen. The

crystallization age of the sanukitoid protoliths is estimated to be 2692 ± 16 Ma, although interpretation is hampered by intense granulite-facies overprinting (Fig. 31b). At c. 2690 Ma, these rocks are older than compositionally similar c. 2650 Ma rocks in the Yilgarn Craton, although isotopic similarities imply a Yilgarn connection. The Tropicana Zone underwent prolonged granulite-facies zircon growth between about 2720 and 2600 Ma, possibly longer. This zone may represent a deeper crustal level or a different part of the Yilgarn Craton, or both, thrust onto the craton margin. The occurrence of 1780 Ma granite veins in the Tropicana Zone and magmatic rocks of similar age in (para)autochthonous parts of the Albany–Fraser Orogen also imply that the Tropicana Zone was part of the craton prior to c. 1780 Ma. Re–Os dating of pyrite suggests an age of c. 2.1 Ga for associated gold mineralization; this age is distinct from those of major Proterozoic tectonothermal events elsewhere in the Albany–Fraser Orogen. The sanukitoid magmas may have been the source of gold in the Tropicana Zone.

Geochronology of the eastern Albany–Fraser Orogen and of basement rocks from beneath the Eucla Basin continues to progress rapidly in concert with the acquisition and interpretation of new aeromagnetic, gravity, geochemistry, and drillhole datasets. Additional geochronological and isotope studies of basement rocks from EIS-funded drillholes through the Eucla Basin are underway.

Products released 2013–14

Compilation of geochronology information, 2014 (includes 80 Geochronology Records on USB)

Report 137 Basin formation by orogenic collapse: zircon U–Pb and Lu–Hf isotope evidence from the Kimberley and Speewah Groups, northern Australia

Report 133 Tectonic links between Proterozoic sedimentary cycles, basin formation and magmatism in the Albany–Fraser Orogen, Western Australia

Report 129 Sedimentological and structural evolution of the Mount Ragged Formation, Nornalup Zone, Albany–Fraser Orogen, Western Australia

Report 122 The crustal evolution of the Rudall Province from an isotopic perspective

Report 120 Juvenile crust formation and recycling in the northern Murchison Domain, Yilgarn Craton: evidence from Hf isotopes and granite geochemistry

21 external journal articles and five conference abstracts (see Appendix B)

Planned work program and products 2014–15

GSWA's geochronology program will continue to generate U–Pb zircon, baddeleyite and monazite ages in support of regional mapping programs in the Yilgarn Craton (Eastern Goldfields Superterrane and Youanmi Terrane), the Capricorn Orogen (Gascoyne Province and the Edmund and Collier Basins), the western Musgrave Province, the Albany–Fraser Orogen, and the Kimberley and Amadeus Basins. The results of Sm–Nd, Lu–Hf, Re–Os, and oxygen isotope studies, with new results from

isotope dilution thermal ionization mass spectrometry (IDTIMS) U–Pb dating and in situ phosphate dating will be integrated with SHRIMP U–Pb, and geological information by geochronologists and mapping program staff. The timely release of geochronology results will be maintained, through both rapid in-house brief reports and the Geochronology Record Series, published online via GeoVIEW.WA, eBookshop, and the Data and Software Centre.

Products planned for release 2014–15

Compilation of geochronology information, 2015 (includes 80 Geochronology Records on USB)

External journal articles and contributions to GSWA publications (see Appendix B)

Planned work program and products 2015–16 and beyond

Future geochronology work will continue to support GSWA's regional mapping programs. Geochronology results and publications will be informed by a range of additional data (see ES46 Enhanced geochronology and acquisition of isotope data), including the results of Sm–Nd, Lu–Hf, and oxygen isotope studies, and in situ phosphate dating. The geochronology section will continue to expand its range of geochronological and isotopic techniques through in-house research and external scientific collaborations.

Products planned for release 2015–16

Compilation of geochronology information, 2016 (includes 80 Geochronology Records on USB)

External journal articles and contributions to GSWA publications (see Appendix B)

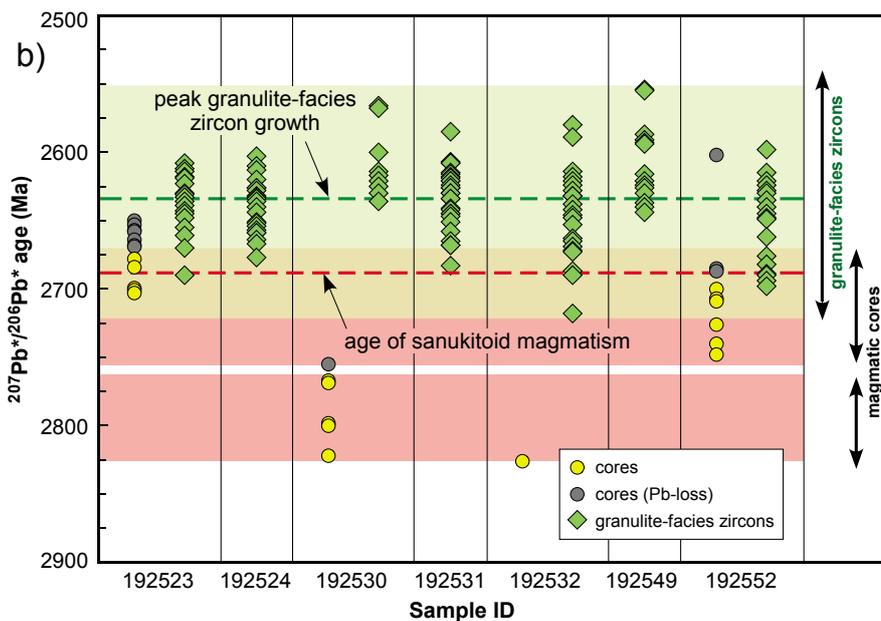
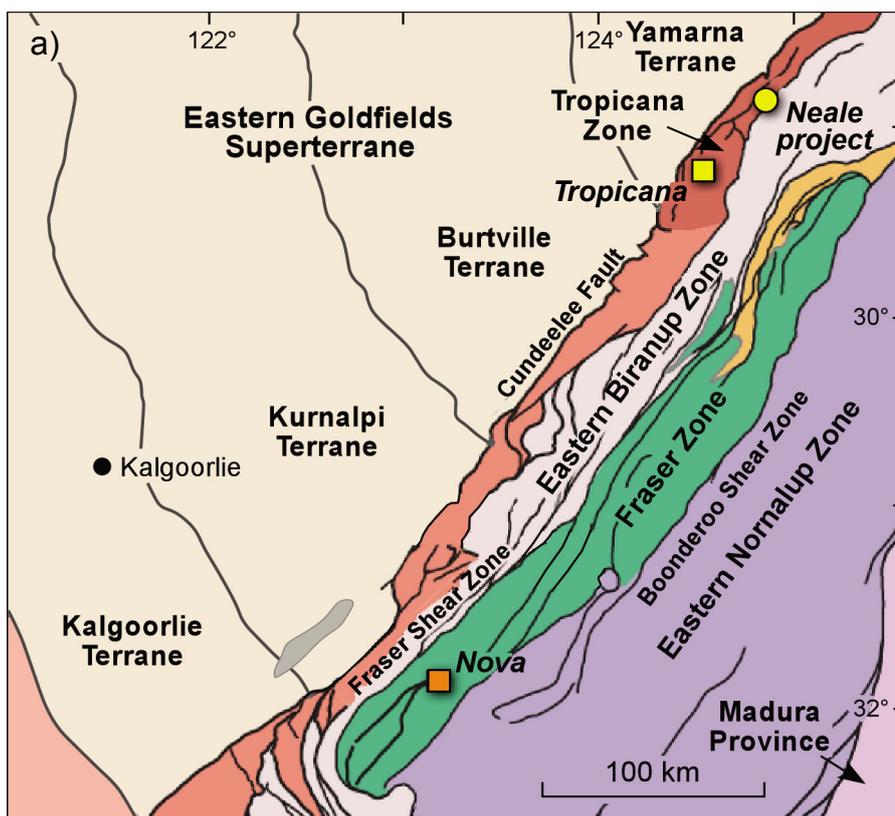


Figure 31. a) Simplified pre-Mesozoic interpreted bedrock geology of the eastern Albany–Fraser Orogen and southeastern Yilgarn Craton, showing the locations of the Tropicana Zone and the Neale gold project, as well as the Tropicana (Au) and Nova (Ni–Cu) deposits; b) individual U–Pb ages for zircons from seven drillcore samples from the Neale gold project. The results indicate prolonged granulite-facies zircon growth and an estimate of c. 2690 Ma for crystallization of sanukitoid granite protoliths.

GS55 Geophysics and Remote Sensing

Manager: David Howard

Team member: John Brett

The acquisition, processing, synthesis and interpretation of geophysical and remotely sensed spectral information are integral parts of GSWA's regional regolith and bedrock geology mapping process. The role of the Geophysics and Remote Sensing section is to plan and manage the various regional geophysical data acquisition projects, to deliver the datasets to the public and internal users and to provide processing and interpretation services and advice as required.

Management of project risks

Survey risk is managed through well-established and regularly reviewed procedures for planning, procurement and contract management.

Outcomes of work program 2013–14

Regional survey data acquisition activities are reported under the EIS programs — ES30 Airborne Geophysical Surveys and ES32 Regional Gravity Surveys.

In September 2013, the data acquired from the last of the medium-resolution (200–400 m) EIS radiometric surveys completed in 2012–13 were compiled into a set of new Statewide grids to provide — for the first time — 80 m-resolution radiometric grid coverage over all of Western Australia (Fig. 32). The complete 80 m-resolution magnetic grids had been released a few months earlier in June 2013 at the same time as a new 40 m-resolution magnetic grid release.

The MAGIX data repository of company airborne survey data continued to grow; during the past three years, almost 80% of surveys received have been submitted within a year of completion. During 2013–14, 195 new company airborne survey datasets containing about 880 000 line-km of data were received for inclusion in the repository. At 30 June 2014, the MAGIX repository contained about 10.25 million line-km of company data from 2 197 surveys (Table 17, Fig. 33).

Products released in 2013–14

All data acquisition product releases planned for 2013–14 were in the context of programs ES30 Airborne Geophysical Surveys and ES32 Regional Gravity Surveys and are reported therein.

As mentioned above, the first 80 m radiometric grids and images were produced and released, replacing the previous 100 m grids. Updates to the 400 m gravity compilation images and grids including the new Esperance gravity data (see ES32 Regional Gravity Surveys) were produced and released in November 2013.

Planned work program and products 2014–15 and beyond

In 2014–15, the data acquisition program for regional airborne magnetic and radiometric surveys and ground gravity surveys will again be entirely funded and undertaken as part of the EIS; however, the work will be managed by the Geophysics and Remote Sensing section. The planned work program is described separately under programs ES30 (Airborne Surveys) and ES32 (Gravity Surveys). New data acquired during the previous and current periods will be included in updates to the Statewide compilation magnetic, radiometric and gravity grids and images.

The section will continue to manage the MAGIX data repository and the submission, archive and release of airborne survey datasets from the exploration industry.

The data acquisition program for 2015–16 and beyond is dependent on the then prevailing GSWA budget.

Table 17. MAGIX data repository — statistics on company airborne surveys, by year. Note that numbers of surveys include all survey methods. Line-km figures apply only to magnetic, radiometric, AEM and gravity methods. Data as at 30 June 2014

Period	Total in database (to end FY)		Added in FY	
	# surveys	km '000	# surveys	km '000
2013–14	2197	10254	194	876
2012–13	2003	9378	174	786
2011–12	1829	8592	173	791
2010–11	1656	7801	148	547
2009–10	1508	7254	184	675

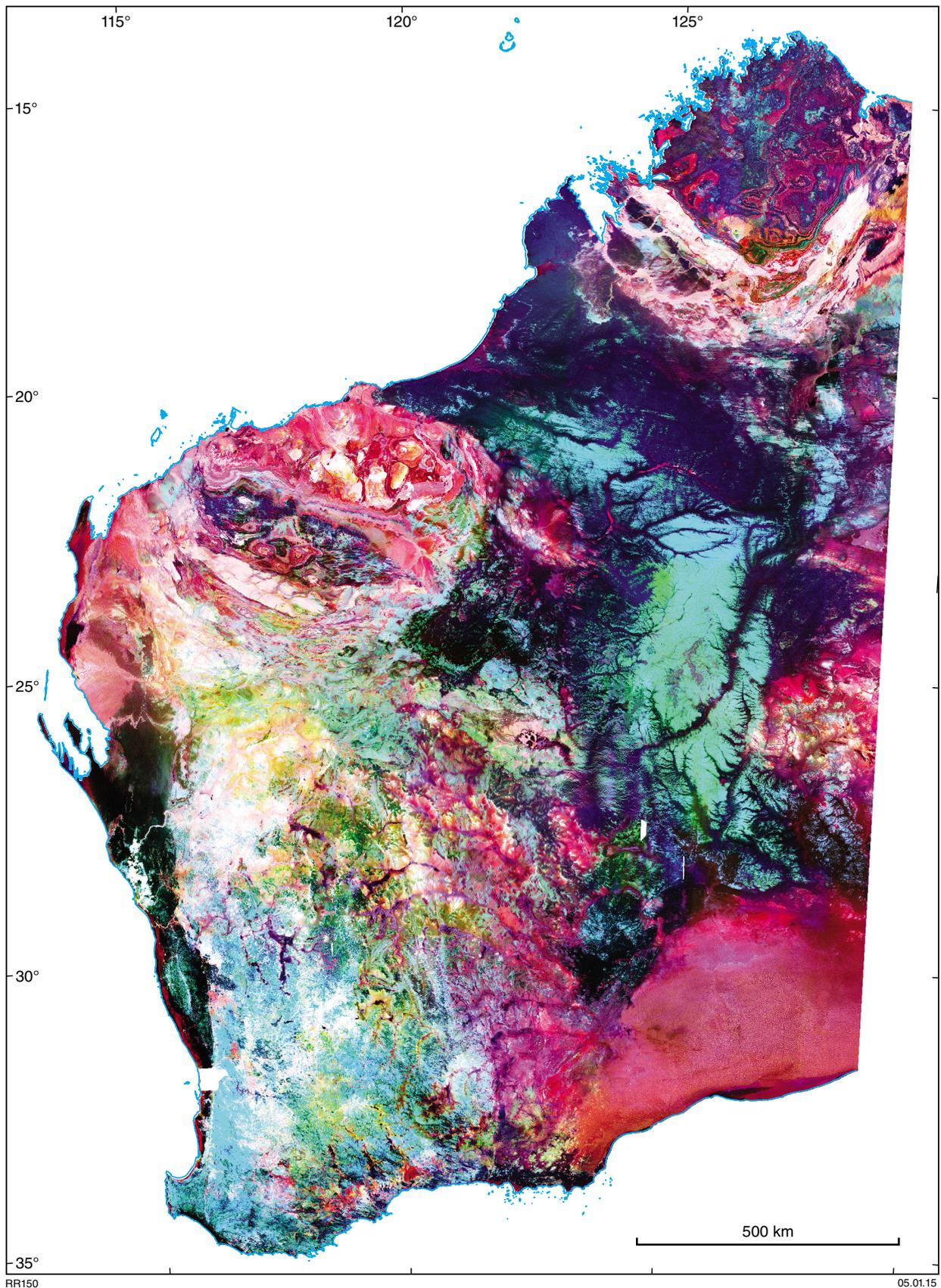


Figure 32. Ternary radiometric map of WA (from the first full-coverage 80 m-resolution grids released in September 2013). This ternary radioelement image was generated from 80 m-resolution grids made from Federal and WA State government datasets supplemented by company datasets. The colour mix results from monochrome histogram stretches of K% in red, eTh ppm in green, eU ppm in blue. Low radioelement concentrations show as dark areas and high concentrations as light areas.

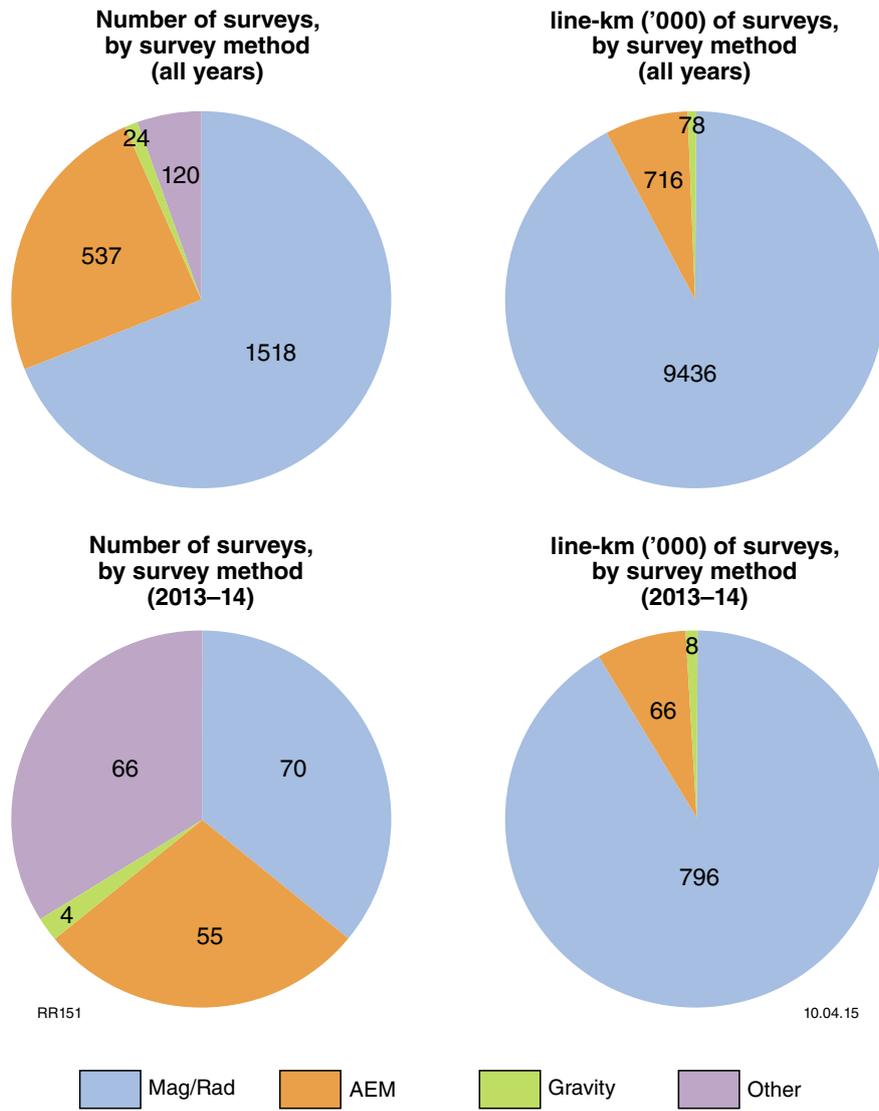


Figure 33. MAGIX data repository — details on company surveys by survey method. Data as at 30 June 2014

GS56 North Australian Craton

Manager: Julie Hollis

Team members: Graham Eacott, Christopher Phillips

The North Australian Craton mainly comprises Neoproterozoic to Mesoproterozoic rocks forming the basement throughout the northern and central parts of the Australian continent. The craton is host to extensive mineral deposits and major mines, including Pb–Zn–Ag (–Cu) (Mount Isa, McArthur River), U (Ranger, Rum Jungle), iron oxide–Cu–Au (Tennant Creek), Au (The Granites, Callie), diamonds (Argyle), Ni (Sally Malay), and Fe (Koolan Island). In Western Australia, the craton crops out in the Kimberley, west Tanami, and west Arunta regions, and is overlain by the sedimentary rocks of the Neoproterozoic Centralian Superbasin and the Phanerozoic Canning, Ord and southern Bonaparte Basins (with potential for oil, gas and Pb–Zn deposits).

In the Kimberley region the Halls Creek and King Leopold Orogens are composed of igneous and low- to high-grade metamorphic rocks of the Paleoproterozoic Lamboo Province, which is overlain by sedimentary and volcanic rocks of the Paleoproterozoic Speewah, Kimberley, Moola Bulla, Red Rock, Texas Downs and Revolver Creek Basins; the Paleoproterozoic to Mesoproterozoic Birrindudu, Crowhurst and Bastion Basins; and the Mesoproterozoic lower Victoria River, Glidden and Carr Boyd Basins. The Speewah and Kimberley Basins were intruded by the Hart Dolerite – Carson Volcanics large igneous province.

In the west Tanami region, the Granites–Tanami Orogen comprises Neoproterozoic gneissic rocks unconformably overlain by Paleoproterozoic low- to medium-grade metamorphic rocks, which are intruded by granites. These are overlain by the late Paleoproterozoic Pargee Sandstone and sedimentary rocks deposited in the Birrindudu Basin. In the west Arunta region, the Aileron Province of the Arunta Orogen is made up of Paleoproterozoic low-grade metasedimentary rocks intruded by granites. These are separated from the latest Paleoproterozoic volcanic rocks and granites of the Warumpi Province by the westward extension of the Redbank Thrust.

First edition 1:250 000-scale mapping covers the North Australian Craton in Western Australia. GSWA carried out second edition 1:250 000-scale remapping of the King Leopold Orogen between 1986 and 1989. Together with the then Bureau of Mineral Resources, Geology and Geophysics (BMR), later Australian Geological Survey Organisation (AGSO), now GA, 1:100 000-scale and 1:250 000-scale mapping in the Halls Creek Orogen took place from 1990 to 1995 as part of the National Geoscience Mapping Accord. SHRIMP U–Pb zircon geochronology and extensive whole-rock geochemistry were carried out. GA published reconnaissance SHRIMP

U–Pb zircon geochronology and whole-rock geochemistry from the west Arunta in 1998, and has undertaken geochronology in the west Tanami as part of the GA–NTGS–GSWA North Australia Project. The 2005 Tanami Seismic Collaborative Research Project acquired 719 km of deep seismic reflection data across the Western Australia/Northern Territory border. Aerial magnetic and radiometric data at 400 m-line spacing is available from government or commercial sources over most of the craton in Western Australia. A detailed gravity survey (2.5 km-station spacing) covers part of the West Arunta region. The area is covered by recent Landsat satellite imagery and recent orthophotography.

Further interpretation of geophysical, geochemical and geochronological data will assist in understanding the evolution of the crust and underlying mantle across the North Australian Craton. The nature of crustal-scale fault structures and their history of reactivation will be examined; this has implications for the location of mineral deposits. Tectonostratigraphic, geochronological and provenance studies on the Paleoproterozoic and Mesoproterozoic basins will help establish tectonic and possible mineral system links with the mineralized Pine Creek Orogen, McArthur Basin and Mount Isa Inlier.

Management of project risks

The North Australian Craton project comprises fieldwork and office-based collation and synthesis of the results of that fieldwork, and subsequent analytical work. Progress depends on factors including retaining fee-for-service personnel with suitable GIS and geological skills and regolith expertise. Field-based work, in part, depends on land access negotiations with Aboriginal groups.

Outcomes of work program 2013–14

A second edition CHARNLEY 1:250 000-scale geological series map (Kimberley region) has been released, along with first edition BALWINA and SLATEY CREEK and second edition WATTS 1:100 000-scale geological series maps (Tanami region). Two new 1:250 000-scale interpreted basement geology maps of the west Kimberley (PRINCE REGENT and CAMDEN SOUND) were released as part of the 2014 Kimberley GIS update, which also includes a 1:100 000-scale interpreted regolith–landform map over much of the Kimberley region. Two Records were released.

Some of the important geological outcomes from the North Australian Craton group in 2013–14 include:

- Interpretation of zircon age and isotopic data from the Kimberley and Speewah Groups in terms of post-orogenic collapse of the Halls Creek Orogen and uplift of (now unexposed) Archean basement to the Kimberley Craton
- Identification of a remnant subducted slab beneath the western zone of the Halls Creek Orogen, and recognition of deep crustal structures within the unexposed Kimberley Craton from MT data.

Products released 2013–14

West Tanami 2014 GIS update*

WATTS, BALWINA, and SLATEY CREEK 1:100 000 geological series maps*

Kimberley 2014 GIS update including new 1:250 000 interpreted basement geology (PRINCE REGENT and CAMDEN SOUND)

CHARNLEY 1:250 000 Geological Series map

Report 136 A magnetotelluric traverse across the Kimberley Craton, northern Western Australia

Report 137 Basin formation by orogenic collapse: zircon U–Pb and Lu–Hf isotope evidence from the Kimberley and Speewah Groups, northern Australia

*See also ES45 Geological Mapping and Interpretation

Planned work program and products 2014–15

The work program for 2014–15 is dominated by work on the Kimberley although it also includes compilation of two 1:100 000 geological series maps for the west Tanami: KEARNEY and LEWIS. One second edition 1:250 000-scale geological series map (PRINCE REGENT – CAMDEN SOUND) and one first edition 1:100 000 geological series map (RICHENDA) for the west Kimberley will be compiled and released. All units relevant to those map sheets will be updated in the Explanatory Notes System. Two Reports will be released – one on the Halls Creek Group of the eastern zone of the Lamboo Province, and one on correlations between the Kimberley Craton and the Pine Creek Orogen based on U–Pb and Lu–Hf zircon data for the Marboo Formation.

Products planned for release 2014–15

Two 1:100 000 Geological Series maps, west Tanami: KEARNEY and LEWIS*

Second edition PRINCE REGENT – CAMDEN SOUND 1:250 000 Geological Series map, west Kimberley

1:100 000 Geological Series map, Kimberley: RICHENDA

Report on the Halls Creek Group, eastern zone, Halls Creek Orogen

Report on Kimberley – Pine Creek correlations based on the Marboo Formation

Kimberley 2015 GIS update including additional new 1:100 000 and 1:250 000 Geological Series maps

Explanatory Notes database update to all units on released maps

* See also ES45 Geological Mapping and Interpretation

Planned work program and products 2015–16 and beyond

The work program for 2015–16 and beyond will depend in large part on the result of ongoing land access negotiations. Nonetheless, one more 1:250 000-scale interpreted basement geology map of the west Kimberley will be compiled. Two related Reports will be released – one on the evolution of the Kimberley and Speewah Basins based on detailed sections and petrographic work on sedimentary rocks, and one on the evolution of the Hart–Carson large igneous province. New mapping and analytical data will be incorporated in Kimberley 2016 GIS update. Two 1:250 000 geological series maps will be compiled and released for the west Arunta region – WEBB and MACDONALD.

Products planned for release 2015–16

Kimberley 2016 GIS update including additional new 1:100 000 and 1:250 000 Geological Series maps and updates to existing maps

Explanatory Notes database update to all units on released maps

DRYSDALE AND ASHBURTON 1:250 000 interpreted basement geology maps

Report on evolution of the Kimberley and Speewah Basins

Report on the evolution of the Hart–Carson large igneous province

WEBB and MACDONALD 1:250 000 Geological Series maps, west Arunta*

*See also ES45 Geological Mapping and Interpretation

GS57 West Musgrave Province

Manager: Hugh Smithies/Heather Howard

Team member: Raphael Quentin de Gromard

The West Musgrave Province is the Western Australian portion of the Mesoproterozoic to Neoproterozoic Musgrave Province that straddles the borders between Western Australia, South Australia, and the Northern Territory. The extremely varied geology encompasses structurally complex low- to high-grade metamorphic terrains that record a history involving up to six magmatic and deformational events including the Mesoproterozoic Musgrave Orogeny and the Neoproterozoic–Cambrian Petermann Orogeny. Forming the junction of Proterozoic orogenic trends in central and southern Western Australia, the Musgrave Province is critical to an understanding of the Proterozoic crustal evolution of Australia. The province includes the voluminous layered mafic–ultramafic Giles intrusions and associated smaller mafic intrusions, and these have been the site of significant nickel, copper and platinum group element discoveries. The economic potential of extensive felsic volcanic sequences has not been fully explored; however, recent exploration in these rocks has also uncovered significant gold mineralization.

Despite its importance in understanding the Proterozoic evolution of Australia, and its economic potential, the Musgrave Province remains one of the most understudied parts of Proterozoic Australia. Some of the main impediments in this regard have been land access issues and the geographical isolation of the region. Very few detailed geoscientific research projects have been carried out in the west Musgrave Province, with focused PhD studies completed in 1971 by CM Gray and in 1997 by RW White being perhaps the most notable. Regional 1:250 000-scale geological mapping of the west Musgrave Province, in the late 1960s culminated in the publication of Bulletin 123 (Daniels, 1972) which documented the regional geology of the area between Warburton and Wingelinna. A subsequent survey was undertaken in the 1990s by GA (then AGSO) focused primarily on the mafic–ultramafic Giles intrusions, but also considering some more regional geological issues, and this culminated in publication of AGSO Bulletin 239 in 1996. In 2004, GSWA released the west Musgrave Geological Exploration Package (Record 2004/9) which combined pre-existing and newly acquired digital datasets, including Landsat TM and Aster satellite image data, 1:25 000 colour orthophotography, and aeromagnetic and radiometric data (at 400 m line-spacing) for six 1:100 000 Geological Series map sheets covering the central eastern part of the west Musgrave Province project area (BATES, BELL ROCK, BLACKSTONE, HOLT, COOPER, and FINLAYSON). Since then, GSWA has acquired similar datasets covering the entire project area (including DEERING, GUNBARREL, DICKENSON, DIORITE, TABLE POINT, BENTLEY, GOLDEN POINT, MOUNT EVELINE, WARBURTON RANGE, and AGNES).

It has become clear that there are major geological differences between the northeastern and southwestern parts of the project area, but it is unclear how significant the boundary between these two regions truly is, and whether that boundary is the Mann Fault, a major east-trending regional structure, or the Tjuni Purlka Zone, a recently defined zone of extensive northwest faulting. The later structural zone was clearly the site of extensive felsic magmatism and deformation during the Mesoproterozoic Musgravian Orogeny, and it seems most likely that it was the main control on the structural architecture of the region, perhaps modified to a large degree by east-trending faults like the Mann Fault, during the Neoproterozoic Petermann Orogeny. One of the main geological differences across this zone is the absence, in the northeast, of the c. 1300–1330 Ma calc-alkaline crust that forms a significant component of the area to the southwest. The possibility that the Tjuni Purlka Tectonic Zone is a terrain boundary remains to be tested. Recently acquired seismic and MT data will be interpreted over the 2012–14 period, and potentially hold clues to many outstanding questions regarding the structural and stratigraphic architecture of the west Musgrave Province.

The economically important mafic intrusions emplaced during the c. 1085–1040 Ma Giles Event primarily occupy the tectonic contacts bounding either side of the Tjuni Purlka Tectonic Zone. The Giles Event has now been shown to be much more magmatically and structurally complicated and long-lived than previously thought. This hampers exploration models for orthomagmatic deposits. Our dating of copper-mineralized gabbros shows that at least some of the orthomagmatic mineralization relates to intrusions that are late (c. 1067 Ma) in the geological history of the larger mafic intrusions, small with respect to the main mafic intrusions, and most likely peripheral to those larger intrusions.

Management of project risks

The west Musgrave mapping project operates entirely within land over which there has been a Native Title Determination. GSWA operates the project jointly with the Ngaanyatjarra Council and local traditional owners under a signed agreement. This agreement sets out the procedure adopted to ensure culturally sensitive areas are not disturbed during the course of normal mapping and sampling operations.

Outcomes of work program 2013–14

Some of the main geological outcomes from the west Musgrave Province mapping program to arise from the 2013–14 period include:

- Geological mapping and geochronology have helped identify a c. 1575 Ma basement component (Warlawurru Supersuite) in the Wannarn area and further geochronology and geophysical interpretation will aid in defining the extent of this basement.
- Recent mapping of the northern part of DEERING and southern part of RAWLINSON (1:250 000 Geological Series map sheet) investigates the western part of the Petermann Nappe Complex, the interleaved basement and Tjauwata Group rocks. Comparable field relationships are also seen on DIORITE where thrust slices of Kunmarnara Group (equivalent to the lower Formations of the Tjauwata Group) are interleaved with basement granites.
- Geochemical investigations reveal that the Mount Harris Basalt of the Northern Territory is the equivalent of Western Australia's Mummawarrawarra Basalt and is the widest spread preserved mafic volcanic unit in the Musgrave region.
- Further investigation into the possible tectonic setting for the layered intrusions, bimodal volcanics and associated intrusions of the c. 1085–1040 Ma Giles Event led to the publication of a paper entitled 'The Mesoproterozoic thermal evolution of the Musgrave Province in central Australia—Plume vs. the geological record' in Gondwana Research.
- The results of geoscientific investigation over the duration of this mapping program and our increased understanding of the province have been incorporated into a review paper submitted to Gondwana Research.

Products planned for release 2013–14	Current status
WARBURTON RANGE 1:100 000 geological map	Editing
West Musgrave Geological Information Series, 2014	Editing
Explanatory Notes update	Editing
Report Mafic–ultramafic intrusions of the Giles Event, Western Australia: petrogenesis and prospectivity for magmatic ore deposits	Editing
Report Mineral prospectivity analysis of the West Musgrave Province	Editing
GA Record Yilgarn Craton–Officer Basin–Musgrave Province Seismic and MT Workshop	In preparation
Report Mineral prospectivity analysis of the West Musgrave Province	Released
Report Geochemical evolution of rhyolites of the Talbot Sub-basin and associated felsic units of the Warakurna Supersuite	Released

Planned work program and products 2014–15

The GOLDEN POINT 1:100 000 Geological Series map as well as a further update of the West Musgrave Geological Information Series will be released. Mapping (at 1:250 000 scale) of the area over AGNES, DEERING, GUNBARREL, REBECCA, MOUNT BUTTFIELD and RAWLINSON map sheets will continue.

Product	Planned release date
GOLDEN POINT 1:100 000 geological map	30/06/2015
Explanatory Notes update: Warburton Range	30/06/2015
West Musgrave Geological Information Series, 2014	30/06/2015
Record Mitika Basement Geology	30/06/2015
Record The exhumation history of the Mitika Area	30/06/2015

Products planned for release 2015–16 and beyond	Planned release date
DIORITE 1:100 000 geological map	2016
West Musgrave Geological Information Series, 2016	
West Musgrave Geological Information Series (includes AGNES and DEERING) 2017	2017

GS58 Youanmi Terrane

Manager: Stephen Wyche

Team members: Shefa Chen, Tim Ivanic, Ivan Zibra, Sandra Romano

The Murchison Domain of the Youanmi Terrane occupies the northwestern part of the Archean Yilgarn Craton. It contains significant deposits of gold, iron ore, copper, lead, zinc, tungsten, molybdenum, bismuth, vanadium, titanium, beryllium, lithium, tin, tantalum and uranium, and has the potential for more discoveries of these commodities. The Youanmi Terrane has a long and complex geological history. An understanding of the tectonic evolution of the Youanmi Terrane, including the structure and stratigraphy, is essential to understanding the controls on formation and distribution of mineralization in the region.

New mapping in association with high-resolution SHRIMP U–Pb zircon geochronology data has allowed the development of a new stratigraphic scheme for the northern Murchison Domain. This mapping is being extended to the southern Murchison Domain. Also, new geophysical data in the Murchison Domain that include aeromagnetism, radiometrics, gravity, MT, and a deep crustal seismic survey, have helped define both regional- and local-scale structures that play a role in the distribution of mineralization.

A three-year cooperative mapping project with the China Geological Survey (CGS) commenced in 2012. The joint mapping is being carried out in the Yalgoo–Singleton greenstone belt.

Field mapping, along with interpretation of new geochemical, geophysical and isotope data in the southern part of the Southern Cross Domain, which contains significant gold, nickel and base-metal deposits, has assisted in revision of the stratigraphy and the setting of these greenstone successions in their broader Yilgarn context.

Management of project risks

There are no significant land access issues affecting this project. However, some work is required on numerous existing mining leases in part of the project area. Cooperation with relevant companies will be sought.

Outcomes of work program 2013–14

New mapping in the Yalgoo–Singleton greenstone belt has established stratigraphic relationships, which are being tested with geochronology and geochemistry. Field mapping has been completed over most of the greenstones around the Yalgoo dome. Ongoing structural studies in the Yalgoo dome are aimed at determining the relationship

between granite emplacement and the greenstone stratigraphy.

GSWA geologists assisted with mapping and geochronological and geochemical sampling in the East Tianshan area of China as part of the cooperative project.

The South Yilgarn 1:100 000-scale mapping project in the Southern Cross – Forrestania – Lake Johnston region, in the southern part of the Southern Cross Domain of the Youanmi Terrane, has generated several new maps and a revised stratigraphy for the Lake Johnston greenstone belt. The 2014 GIS package has been released. An excursion guide that describes localities investigated as part of the ARC Linkage project with UWA's CET to look at structural and metamorphic controls on gold mineralization was also released. Further publications from this study are being prepared.

Products planned for release 2013–14	Current status
MOUNT MAGNET 1:100 000 Geological Series map	In preparation, release in 2014–15
REEDY 1:100 000 Geological Series map	Released
YOUANMI 1:100 000 Geological Series map	Released
Murchison Geological Information Series, 2014	Released
Youanmi seismic line report (Record 2013/6 final edition)	Released
Youanmi structural geology field excursion guide (Record 2014/8)	Released
Hf isotopes Report 120	Released
Structural evolution of the Yalgoo dome (Honours thesis: Record 2014/4)	Released
External paper: Granite emplacement in the Murchison region (Tectonophysics)	Released
External paper: Magmatism and regional deformation in the Yilgarn (Journal of Structural Geology)	Released
TAY 1:100 000 Geological Series map	Released
Southern Cross structural geology field excursion guide (Record 2013/11)	Released
External paper: Lake Johnston greenstone belt stratigraphy (AJES)	Released
South Yilgarn Geological Information Series, 2014	Released

Planned work program and products 2014–15

Field mapping will continue in the Yalgoo–Singleton greenstone belt. Compilation of mapping undertaken as a joint project with the CGS will be compiled with the YALGOO 1:100 000 Geological Series map sheet scheduled as the first co-authored release.

Cooperative projects include a geochemistry and isotopes project in the Narryer Terrane with Dr Tony Kemp from UWA and an ARC Linkage project with Sydney University to study the geochemistry and tectonic setting of the Murchison region will commence in 2014. Structural studies in the Yalgoo dome in cooperation with Monash University will continue.

Reciprocal arrangements arising from the cooperative project with the CGS will result in GSWA contributions to CGS map products.

Products planned for release 2014–15

MOUNT MAGNET 1:100 000 Geological Series map

YALGOO 1:100 000 Geological Series map

YOUANMI 1:100 000 Geological Series map

Murchison Geological Information Series, 2015

Yalgoo structural study (Record)

LAKE PERCY 1:100 000 Geological Series map

South Yilgarn Geological Information Series, 2015

External paper: Structural and metamorphic controls on gold mineralization in the Southern Cross greenstone belt

Planned work program and products 2015–16 and beyond

Field mapping in the Yalgoo–Singleton greenstone belt will continue in 2016–17. Data will be compiled for release in future versions of the Murchison GIS.

Products planned for release 2015–16

Murchison Geological Information Series update

Explanatory Notes System update

BADJA and THUNDELARRA 1:100 000 Geological Series maps

GSWA mapping with CGS in East Tianshan

New mapping from the Yalgoo–Singleton greenstone belt

South Yilgarn Geological Information Series update

LAKE PERCY and BRONZITE RIDGE 1:100 000 Geological Series maps

GS61 Albany–Fraser Orogen and Eucla Basement

Manager: Catherine Spaggiari

Team members: Catherine Spaggiari (project manager, Albany–Fraser Orogen and Eucla basement),
Hugh Smithies (project manager, central and southern Australia),
Chris Kirkland (senior geochronologist), Lucy Brisbout

The Albany–Fraser Orogen extends over a distance of approximately 1200 km along the southern margin of the Archean Yilgarn Craton, and is part of the West Australian Craton. The orogen is dominated by Paleoproterozoic and Mesoproterozoic rocks formed during reworking of the southern Yilgarn Craton from at least 1810 Ma through to 1140 Ma. Fragments of Archean crust, interpreted to be remnants of the Yilgarn Craton, are also preserved within the orogen. The eastern part of the orogen and adjoining Proterozoic Madura and Coompana Provinces (incorporating the Forrest Zone) comprise the Eucla basement, and are entirely covered by Cretaceous siliciclastic rocks and Cenozoic limestone of the Bight and Eucla Basins. Very little is known about these Proterozoic provinces.

The main resource in the Albany–Fraser Orogen is gold, which includes the 7.89 Moz Tropicana–Havana deposit in the northeastern part of the orogen. The recent Ni–Cu sulphide discovery at Nova in the Fraser Zone has proven that the orogen is also prospective for Mesoproterozoic commodities. This is significant because it demonstrates that regions previously thought as unprospective, often because they were perceived to be ‘the wrong age’, are simply poorly understood. The provinces of the Eucla basement have potential for Cu–Au, IOCG, Ni–Cu–PGE, and Ni-sulphide deposits, although it is conceivable that other types of deposits could occur. Both the Albany–Fraser Orogen and the adjoining Eucla basement are major greenfields exploration provinces.

Previous work and modern datasets available

Previous work in the Albany–Fraser Orogen consists of first edition 1:250 000-scale geological mapping, limited university research studies focused mainly on the central and western parts of the orogen, and reconnaissance mapping and sampling by GSWA (John Myers) in 1985 and in the early 1990s. Since that time geophysical datasets for both the Albany–Fraser Orogen and Eucla basement have been acquired and include 400 m to 200 m line-spaced aeromagnetic data and 2.5 km grid-spaced gravity data. These are combined with numerous, higher resolution company datasets that are continually becoming available due to new exploration interest in the region. These datasets are critical because much of the region is covered by either extensive regolith or basin rocks. Four deep crustal seismic lines (west Esperance [12GA–AF2], east Esperance [12GA–AF1], Trans-Australian Railway [12GA–AF3], and Tropicana region [12GA–T1]) and three MT lines have been acquired and interpreted. In addition, seismic line 12GA–AF3 has been continued from

Haig to the South Australian border (Western Australian component), and through to Tarcoola (South Australian component; the Eucla–Gawler line). The Western Australian component of these data will be available for preliminary interpretation in June 2015.

The increasing availability of exploration diamond drillcore (most of which is through the EIS co-funding initiative), and the EIS stratigraphic drilling program (see program plan ES22) in the Eucla basement are providing essential material for analytical work such as geochemistry, isotopes, geochronology, structural analysis, and mineral systems studies under cover. Combined with the geophysical data, these drillcores provide a valuable means of mapping of the crust under cover.

Major issues and uncertainties relating to the geological framework and occurrence of mineral deposits

Significant progress has been made in recent years, and there is now a greater understanding of the architecture and geodynamic evolution of the Albany–Fraser Orogen. Work is continuing on eastern extents of the orogen, particularly the eastern Nornalup Zone, to determine its age, tectonic setting, and relationship to the Yilgarn Craton and Biranup Zone. The eastern extent of the Albany–Fraser Orogen, and adjoining Eucla basement, remain the most challenging regions largely because of the extensive cover. The Eucla basement contains the Madura and Coompana Provinces (including the Forrest Zone), which are separated from the Albany–Fraser Orogen by the Rodona Shear Zone. Although recognized as a major structure related to a suture zone, the kinematic history of the Rodona Shear Zone can only be determined through geophysical analysis, aided by data from the few available drillcores. Drillcores, particularly diamond cores, are of utmost importance in regions that are entirely unexposed, because they allow current project methods of integrating geophysical interpretation, extensive geochronology and geochemistry sampling and analysis, and structural and metamorphic analysis to continue under cover, to help constrain the evolution of the various tectonic units and their prospectivity.

While a handful of diamond drillholes exist in the Madura Province, no basement exploration holes have been drilled in the Forrest Zone of the Coompana Province. The EIS Eucla basement stratigraphic drilling program has addressed this deficiency, with five stratigraphic holes recently drilled in the Forrest Zone, as well as three in the Madura Province.

Initially, most companies exploring along the margin of the Yilgarn Craton within the Albany–Fraser Orogen were using a model of reworked Archean (reworked Yilgarn Craton) gold. However, it has become increasingly clear that Proterozoic tectonics have played a role, and that the craton margin has been intruded by both Paleoproterozoic and Mesoproterozoic magmatic rocks. Therefore, it is vital to understand the tectonic evolution and crustal architecture of the orogen, to help understand the environments of gold deposition, and the prospect for other economic minerals at different stages of the orogen's evolution. This is exemplified by the discovery of the Ni–Cu sulphide deposit at Nova in the Fraser Zone. Previously, the Fraser Zone was interpreted to be a remnant of one or more oceanic arcs. Analysis of new whole-rock geochemical data has shown that this is not the case, and that the Fraser Zone gabbros were intruded into Yilgarn–Biranup continental basement in the presence of a high geothermal gradient, in what is likely to have been an intracratonic rift or distal backarc setting. The Madura Province and Forrest Zone of the Coompana Province are virtually unexplored, although there is some indication of Ni and PGE mineralization in the c. 1410 Ma Loongana intrusion, now interpreted as an oceanic arc. The Forrest Zone of the Coompana Province presents an entirely new region that is likely to be part of the South Australian Craton, linked tectonically to the Gawler Craton in South Australia. The new drillcore from the EIS Eucla basement stratigraphic drilling program, and the Eucla–Gawler seismic line, will help constrain these relationships.

Management of project risks

There have not been any land access issues to date. For fieldwork and sampling in national parks and nature reserves a Regulation 4 permit has been obtained from the former Department of Environment and Conservation (DEC) (now DPaW) for the past three years. In keeping with the regulations for the permit, we have maintained contact with DPaW personnel prior to and during fieldwork. Heritage clearances for the Eucla basement stratigraphic drilling program were carried out successfully. Working in the Nullarbor presents some challenges in its remoteness and lack of any shelter from the elements, so requires good logistical planning.

Outcomes of work program 2013–14

Significant advances have been made in our understanding of the evolution of the Albany–Fraser Orogen and Eucla basement, and the main points are summarized below:

- Further constraints on the evolution, architecture, and tectonic setting of the Fraser Zone through whole-rock geochemistry and isotope analysis, metamorphic studies, and geophysical modelling
- A greater understanding of, and tectonic models for the formation of the two regional basin systems of the Albany–Fraser Orogen (Barren and Arid Basins) and associated magmatism and tectonic events

- Mapping and interpretation of the Mount Ragged Formation, Ragged Basin
- Interpretation of four deep crustal seismic lines showing the crustal architecture, which gives insight into the geodynamic history and mineral systems
- Combined with the interpretation of the deep crustal seismic lines, detailed geochronological, geochemical, and isotope analysis has led to a much greater understanding of the formation of the Tropicana gold deposit, and its environs
- Whole-rock geochemical analysis of the Recherche and Esperance Supersuites, which has helped constrain the magmatic history and tectonic environment
- Preliminary work on the stratigraphic drillcore from the Eucla basement (ES22) indicates the presence of previously unrecognized lithotectonic elements.

Products released 2013–14

Sedimentological and structural evolution of the Mount Ragged Formation, Nornalup Zone, Albany–Fraser Orogen, Western Australia, Report 129 Curtin University Masters thesis

Tectonic links between Proterozoic sedimentary cycles, basin formation and magmatism in the Albany–Fraser Orogen, Western Australia, Report 133

Extended abstract volume for the seismic interpretation workshop, Record 2014/6 preliminary edition

Interpreted bedrock geology maps of the Albany–Fraser Orogen, and seismic line interpretations, Record 2014/6, Plates 1–4, preliminary editions

Posters for GSWA 2014

Planned work program and products 2014–15

The integrated geophysical, geochemical, isotopic and field studies of the Albany–Fraser Orogen and Eucla basement will continue, with focus remaining on the largely undercover eastern part of the orogen and Eucla basement provinces. This is essential to understanding the nature of the Albany–Fraser Orogeny (1345–1140 Ma) so that potential links to other provinces, such as the Musgrave Province, as well as the South Australian Craton, can be explored. Analysis of the diamond core from the EIS Eucla basement stratigraphic drilling program includes geochronological, geochemical, isotopic and structural analysis, as well as mineral system footprint studies where appropriate. Additionally, all co-funded EIS diamond core will continue to be analysed in the same manner. The results will be linked to interpretations of the geophysical data (magnetic, gravity and seismic data) of the Eucla basement to help constrain the spatial relationships of tectonic units and the crustal architecture and evolution.

A major focus for 2014–15 is the analysis of the stratigraphic drillcore from the Eucla basement (see ES22). Planning has commenced for the results to be released at a public seminar, with an accompanying Report. The drillcore analysis will greatly aid the interpretation of the Western Australian component of the

Eucla–Gawler seismic line, due to commence in 2015–16. In April 2014 preliminary versions of the interpretations of the four deep crustal seismic lines and MT data acquired across the Albany–Fraser Orogen in 2012 were released to the public as talks, extended abstracts and four plates. The final versions of these products will be released in 2014–15. Following the seismic line interpretations, an ARC Linkage bid with ANU to examine the 3D structure of the lithosphere of the Albany–Fraser Orogen and adjacent Yilgarn Craton through passive seismic data acquisition and analysis is underway with 40 stations currently recording data adjacent to 12GA–AF3 for one year. These stations will be moved south adjacent to 12GA–AF1 and 12GA–AF2 to collect data for another year. The first interpretation workshop for the Western Australian component of the Eucla–Gawler deep crustal seismic line is planned for June 2015.

A GeM project Master’s thesis, which includes the construction of a crustal-scale cross-section using modelled potential field data of the east Albany–Fraser Orogen integrated with structural mapping, has been submitted, and will be released as a Report. In collaboration with Prof. Tom Blenkinsop and Dr Jan Marten Huizenga of James Cook University, an honours structural mapping project on the Pleiades prospect area, east of Tropicana in the northeastern Albany–Fraser Orogen, is nearing completion. The project was designed to help constrain links to alteration and mineralization, and the structural evolution of the Tropicana Zone. The honours work will be released as a Record.

Products planned for release 2014–15	Planned release date
Tectonic links between Proterozoic sedimentary cycles, basin formation and magmatism in the Albany–Fraser Orogen, Western Australia, External abstract for AESC poster	Jul 2014
Sedimentological and structural evolution of the Mount Ragged Formation, Nornalup Zone, Albany–Fraser Orogen, Western Australia, External publication, Precambrian Research	Oct 2014
Extended abstract volume for seismic interpretation workshop, Record 2014/6 Final version	Oct 2014
Structural evolution of the Pleiades Lakes area, Record	Oct 2014
Building the crust of the Albany–Fraser Orogen; constraints from granite geochemistry, Record	Nov 2014
Archean crust of unknown affinity on the Yilgarn–Albany–Fraser Orogen boundary: implications for gold mineralization in the Tropicana Zone, Record	Nov 2014
Interpreted bedrock geology maps of the Albany–Fraser Orogen, and seismic line interpretations, Record 2014/6, Plates 1–4, Final versions	Dec 2014
Integrating geological and geophysical data to determine crustal architecture: application to the east Albany–Fraser Orogen, Report	Dec 2014
1:250 000 IBG and GEP of the east Albany–Fraser Orogen, update of the 2011 package	Feb 2015
Eucla basement stratigraphic drilling, Report	April 2015

In 2014–15 targeted mapping of key localities in the Albany–Fraser Orogen will commence, with the aim being to understand the kinematic history of large-scale shear

zones identified in geophysical data (magnetic, gravity and seismic data), and their relationship to magmatism and mineralization where appropriate. Sampling of granitic rocks for geochemistry in the eastern Nornalup Zone will continue. This will be enhanced by forthcoming geochronology and isotopic results. Geochemical, isotopic, and petrographic analysis of Fraser Zone metagabbroic, metagranitic and metasedimentary rocks, including selected drillcore samples from under cover regions of the Fraser Zone, is underway.

The collaborative ARC Linkage project on multiscale dynamics of orebody formation is still in progress and includes numerical modelling of the crustal evolution of the Albany–Fraser Orogen.

Planned work program and products 2015–16 and beyond

The main focus for 2015–16 will be production of the first interpreted bedrock geology (IBG) map at 1:250 000-scale of the Eucla basement, as part of a Geological Exploration Package (GEP). The IBG will utilize the results of the Eucla basement stratigraphic drilling. This will coincide with the interpretation of the Western Australian component of the Eucla–Gawler deep crustal seismic line and MT data, scheduled to commence in June 2015. The uninterpreted, processed seismic and MT data will be released at the GSWA open day in February 2016, and the interpretations of those data are scheduled for public release in June 2016.

Phase two of the passive seismic ARC Linkage project data acquisition will finish in about October 2015. The results of both phases will be published in a Report, conference abstracts, and external journal articles.

Structural mapping of key areas and large-scale shear zones in the Albany–Fraser Orogen will continue, to provide an understanding of the kinematic and magmatic history of these crustal-scale features, and potential links to mineralization.

Results from the geochemical and isotopic work on the Fraser and Nornalup Zones will be released as a Record.

Beyond 2015–16, selected areas for 1:100 000-scale mapping may commence, as well as mapping of the western Albany–Fraser Orogen in conjunction with the interpretation of new geophysical data.

Products planned for release 2015–16	Planned release date
1:250 000 IBG and GEP of the Eucla basement	Dec 2015
Geochemistry of the Fraser and Nornalup Zones, Record	Dec 2015
ARC Linkage passive seismic project, Report	Feb 2016
Kinematic history of large-scale shear zones, Albany–Fraser Orogen, Record	June 2016
Interpretation of the Eucla–Gawler deep crustal seismic line, abstract volume and plates	June 2016

GS80 Editing and Publishing GS81 Mapping GS82 Graphics GS83 GIS Services GS84 Spatial Services GS85 Geoscience Promotions

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Experienced and qualified staff are critical to the quality and delivery of geoscience information produced by GSWA. These staff members include:

- geoscience editors
- cartographers
- graphic designers
- product designers
- desktop publishers
- database managers
- GIS specialists.

These program areas reside in the Geoscience Information Branch (GIB). This branch is responsible for the production of all GSWA products, including geoscientific maps, manuscripts and digital datasets for delivery in hardcopy, on digital media and via the internet. In addition, the team creates high-quality artwork for display and promotion, and prepares pamphlets, catalogues, flyers and other exhibition materials. The branch also manages development and maintenance of quality assurance processes that align with national and international standards. In cooperation with internal and external geoscience groups, GIB develops the data models and standards required for spatial geoscience information management. GIB's data specialists manage GSWA spatial geoscience databases by developing and maintaining appropriate data storage, retrieval and display systems.

Management of project risks

There are minimal risks associated with these programs. Most work involves the production and delivery of products and services, which are process driven. The risks associated with application development are assessed as part of the project execution plan.

Outcomes of work program 2013–14

There was continued focus on improving access to geoscience data. Enhanced management and delivery of the data was also achieved. Major outcomes of the work program included:

- Promotion of Western Australia's prospectivity at international and national conferences, and trade shows
- Release of a new Web interface to geochemistry and mineral drillhole data
- Continued development of an updated mineral open-file exploration reports (WAMEX) continued. A new spatial search tool was released.

Products released 2013–14

- 30 geological maps, including 10 Geological Series maps at 1:100 000 or 1:250 000 scale
- 39 geoscientific Bulletins, Reports, Records, Explanatory Notes and other non-series publications
- 20 digital information packages
- 26 external publications
- 65 posters.

Planned work program and products 2014–15

The team will continue to produce geoscientific maps, manuscripts, digital datasets and promotional materials as follows:

- 35 manuscripts
- 10 Geological Series maps (1:100 000 and 1:250 000 scale)
- 1 State Geology of Western Australia 2015
- 17 geological maps at other scales
- 18 digital products
- Complete the development of an updated version of WAMEX and an online submission Web interface
- Continue to promote Western Australia's prospectivity at international and national conferences, and trade shows
- Complete a search and delivery Web interface for the National Virtual Core Library (NVCL)
- Release a mobile device application called WA Geology
- Update GeoVIEW.WA to include new layers and functionality.

GS91 Mineral Exploration Information Management

*Acting Manager: Ann Fitton**

Team members: Monique Brouxhon, Subashni De Biran, Joyce Edmonds*, Fiona MacCorquodale, Yvonne McGorin, Robert Pizzi, Christine Suchodolski, Julia Thom*

GSWA has a statutory obligation to manage the collection, storage, and release of exploration company statutory reports containing geoscience information on mining tenements in Western Australia. The archive of statutory information relating to exploration is a valuable resource, providing a means whereby companies can assess the potential of an area and develop exploration strategies that minimize duplication of previous activities and enables more efficient exploration.

The reports and information also provide a valuable input to a number of GSWA mapping and resource assessment projects.

Outcomes of work program 2013–14

A new version of the WAMEX search was developed as part of GeoVIEW.WA and was released to the public in October 2013. The new version of the search includes extensive spatial searching by live and pending tenements or by defining an area. This has been well received by the industry.

The seventh annual release of 1892 exploration reports was completed in May 2014. They were reports submitted to DMP in 2008 and were released under the provisions of Mining Regulation 96(4), commonly known as the ‘sunset clause’.

In addition, a total of 3135 reports were released to open file as part of the normal cancellation process of dead tenements.

Redevelopment of the WAMEX database is nearing completion including an online submission system for the mineral exploration reports. It is anticipated that the new version of the WAMEX database will be completed in the September quarter of 2014, and the online submission of reports will commence in the December quarter 2014.

The mineral drillhole and surface geochemistry database was launched at the GSWA Open Day in February 2014. The database contains around 1.5 million drillholes and 4.5 million surface geochemical samples, the data from which are available to the public. The database has been welcomed and well received by many company geoscience staff.

<i>Products planned for release 2013–14</i>	<i>Current status</i>
A new version of the WAMEX search tool using GeoVIEW.WA was launched in October 2013	This has been welcomed by industry, particularly the ability to search spatially.
Annual release of reports under the ‘sunset clause’ legislation	The seventh annual release of 1892 exploration reports under the ‘sunset clause’ was successfully completed in May 2014
Release of reports on dead tenements	A total of 3135 reports was released under the normal cancellation process
Review of mineral exploration reports for compliance with the Guidelines for Mineral Exploration Reports on Mining Tenements	Reports are reviewed in the month after receipt to ensure that companies comply with the most recent guidelines
Redevelopment of WAMEX is nearing completion	An online submission system for mineral exploration reports has been developed and will be launched in the December quarter 2014
Identification of mineral exploration core suitable for inclusion in the Perth and Kalgoorlie core libraries	Drillcore of interest is being identified from exploration reports. Donations of core increased significantly in 2013–14

* Part time

Planned output 2014–15

Planned output is:

- The updated version of the ‘Guidelines for Mineral Exploration Reports on Mining Tenements’ will be gazetted and published on the website. It will incorporate new exploration techniques, the data required, and data formats.
- Online submission of mineral exploration reports
- Redevelopment of the WAMEX database will be completed
- Review and release will continue of surrender reports and their associated annual reports as they are received, together with the seventh annual release of reports under the sunset clause legislation. This will ensure that access to this historical data continues to increase. A total of more than 75 000 reports are available on the DMP website
- Release of reports that relate to exploration on dead tenements will continue, although many of these relate to tenements under the *Mining Act 1904* to which the ‘Sunset Clause’ does not apply
- The drive to identify and collect historical drillcore suitable for the Perth and Kalgoorlie core libraries will be continued. It was successful in 2013–14 and will continue in 2014–15
- The capture of attribute information for legacy mineral exploration core submitted to the core libraries in Perth and Kalgoorlie in the last three years in the WAPIMS database and any associated reports and geochemical data.

GS92 Statutory Petroleum Exploration Information

Manager: Felicia Irimies

Team members: Yanrong Li, Yasinta Situmorang, Fiona Dodd, Richard O'Brien, Alan Bloore, George Karniewicz, Brian Bradshaw, Janine Malligan, Kelvin Masters

The Statutory petroleum exploration information section is involved with the monitoring, administration and release of petroleum and geothermal data submitted under the State Petroleum Act covering onshore and territorial sea.

From 1 January 2012, the National Offshore Petroleum Titles Administrator (NOPTA) assumed responsibility for a range of regulatory and administrative functions for Commonwealth waters that had previously been the responsibility of the designated authorities. This includes the regulation of documentary information and petroleum mining samples (petroleum data), in accordance with Part 7 and Part 8 of the Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011 (RMA Regulations).

Under the State–Commonwealth National Collaboration Framework, DMP will continue to provide services to the Commonwealth in the handling of core, cuttings and thin sections that relate to petroleum exploration in offshore Commonwealth-controlled waters and on making those samples available for viewing, further sampling and loan.

The section adds quality-assured geoscience information to the WAPIMS database, undertakes transcription and scanning programs related to the State activities, and ensures data submitted are complete and in a format easily used by explorers. It also manages the release of data online through the Western Australian Petroleum Information Management System (WAPIMS), including documents related to offshore activities occurring before 1 January 2012.

Priorities for transcribing and scanning legacy data are set in part by the future activities of GS10 Basins and energy geoscience and the Specific Area Gazettes conducted twice yearly by Petroleum Division.

Outcomes of work program 2013–14

The necessary WAPIMS technical upgrade was done in order to maximize the interoperability of the main core modules and other departmental applications relying on WAPIMS.

Planned outcomes 2013–14	Current status
Accessioned 986 new items received from the industry (well logs, reports and seismic data)	Ongoing — items accessioned as received; no backlog. From 1 January 2012 only onshore data have been accessioned
Accessioned 13 496 thin sections (backlog and new submission)	Ongoing

Planned outcomes 2013–14	Current status
124 wells and seismic data requests, including data packages, acreage release for petroleum and geothermal	Ongoing
121 sampling approvals	Ongoing
WAPIMS	New forms and reports created in eSearch and ProSource
Review petroleum physical assets storage at Carlisle (Norton Building), DMP and Recall facilities. Separate State and Commonwealth assets (tubes, reports and well log boxes, microfiche). Commonwealth reports, seismic sections and well logs relocated to Canberra	Done
Scanning contents of tubes	Ongoing

Planned work program and products 2014–15

The work program will continue loading legacy scanned and transcribed data for access via the Web and to add new data as received, continue quality control for onshore well log data submitted from industry, and create reports and data packages, available through WAPIMS.

Planned outcomes 2014–15
Checking and archiving the hardcopy reports from Norton Building, Carlisle
Continue transcribing the remaining seismic nine-track tapes (around 3500 tapes)
Review petroleum physical assets storage at Carlisle (Norton Building) – to finish by March 2014
Continue scanning state seismic sections stored at Carlisle in Norton Building
Start digitizing to SEG-Y all the onshore line sections without digital data – priorities based on work done by Basins and energy geoscience section.
Start planning to transcribe the 3950 tapes
Continue creating comprehensive data packages and acreage release data packages for petroleum and geothermal acreage release twice yearly
Continue to generate public reports in WAPIMS on the Web — addressing the most common requests from the industry
Continue accessioning the remainder of the thin sections in eSearch database
Import Core Library Access database in eSearch database
Continue quality control of State well log data and seismic data received from petroleum companies
Full assessment of WAPIMS modules and the links with the other Departmental applications and upgrade to 2013 versions

GS95 HyLogger and the National Virtual Core Library

Manager: *Lena Hancock*

Team members: *Bala At, Edward Rogers, Trevor Beardsmore*

GSWA uses HyLogger scanning technology to extract objective mineralogical information from drillcore, which improves understanding of the composition of the Australian crust, as part of a national program involving most State and Territory Geological Surveys. The HyLogger collects mineral reflectance spectra from drillcore in the visible, shortwave infrared, and thermal infrared spectral ranges, at a rate of approximately one metre every 30 seconds. It simultaneously obtains a high-definition digital image of the core. Mineral assemblages in the core are interpreted by comparing data to a reference library of mineral spectra using ‘The Spectral Geologist’ (TSG) software, and all data are posted to a dedicated national website, and GeoVIEW.WA where they can be viewed using open-access software.

Outcomes of work program 2013–14

For the year ending 30 June 2014, the GSWA HyLogger facility collected and processed VNIR–SWIR–TIR spectral data for 25 650 m of core from 99 mineral drillholes (including 26 partially funded under the EIS co-funded drilling program), and 17 petroleum wells. This work included collecting and interpreting spectral data for drillcore from GSWA’s drilling in the Eucla Basin, from EIS co-funded drilling in the Albany–Fraser Orogen, the Paterson Province, Speewah V–Ti–Fe prospect (East Kimberley), Glenburgh gold project (Gascoyne Province), Turee Creek iron project (Hamersley Basin), and Pincher Well VMS deposits (Youanmi). Hyperspectral data were also collected for core from petroleum wells in the North Carnarvon, Officer and Canning Basins.

The GSWA HyLogger was also fitted with the HyChips system, allowing acquisition of data from percussion chips in trays. This new system was initially tested on chips collected from 420 one-metre intervals of percussion drilling from the Glenburgh gold project, as part of a Master of Economic Geology research project being undertaken by one of GSWA’s GeM graduate geologists (see GS20).

HyLogger staff provided spectral data and advice (including formal supervision) for several postgraduate research projects: (i) high-grade metamorphism in the Glenburgh gold deposit (MSc, UWA/DMP); (ii) identifying rare earth elements in carbonatites (MSc, UWA/DMP); (iii) alteration mineralization associated with gold in Southern Cross, nickel in Windarra and Sherlock Bay, and V–Fe mineralization in Windimurra

(MSc students, Curtin), BIF-hosted iron ore deposits in the Yilgarn Craton (Honours, UWA), Speewah V–Fe mineralization (MSc, UWA), Eucla Basin lithology (Honours, Curtin), and stratigraphy of the Northern Carnarvon Basin (Honours, UWA student and PhD, Manchester University student). The HyLogger team also collaborated with CSIRO staff at the Earth Sciences Centre (Sydney) and the Western Australian Centre of Excellence for 3D Mineral Mapping (C3DMM) for hyperspectral data interpretation, presentation, and HyLogger maintenance.

The HyLogger team collaborated in the development and initiation of several new collaborative research projects: (i) the utility of hyperspectral analysis for quantifying Total Organic Carbon (TOC) contents in petroleum cores, with GSWA Energy Geoscience staff; (ii) characteristics of alteration and gold mineralization in the Paulsens gold deposit, with GSWA Capricorn Mapping staff and geologists from Northern Star Resources; and (iii) the relationship between gold mineralization, hydrothermal alteration and the Nanjilgardy Fault in the Ashburton region, with C3DMM staff.

Other notable activities with which HyLogger staff were associated included: (i) provision of a jointly sponsored GSWA/CSIRO/FLSmidth workshop for external users to showcase/promote the utility of the HyLogger for understanding mineral systems; (ii) development of the ‘HyMeta’ database that contains drillhole locations and other metadata, and that informs a new ‘HyLogger’ layer within GSWA’s GeoVIEW.WA graphical information interface; and (iii) commencement of an audit of the GSWA ‘gold specimen’ collection.

HyLogger Technician Bryce Denn left the team towards the end of 2013–14, and the position was subsequently filled by Eddie Rogers.

Products planned for release 2013–14	Current status
Record The GSWA NVCL HyLogger-3: implications of the addition of a new thermal-infrared sensing system	Released
External publication: Harvey1 core characterization for CO2 capture and storage	Released
Poster on Application of the HyLogger to mineral system projects for GSWA Open Day	Released
Poster on Application of the HyLogger to petroleum core for DMP Petroleum Open Day	Released
Attachment to Abra Record: Forms of gold in the Abra base metal and gold deposit	In preparation

Planned work program and products 2014–15

The HyLogger facility will continue to collect and interpret spectral data from drillcore that contributes directly to increasing the knowledge of Western Australian geology and/or capabilities of the HyLogger system. Material to be analysed will include that requested by GSWA staff, academic researchers, students, and industry engaged in collaborative or other research with GSWA (including core obtained as part of the EIS). Priority of scanning is evaluated by a GSWA committee.

Other regular activities for 2014–15 will include periodic uploading of processed HyLogger data to the NVCL database, ensuring the release of non-confidential data to the AuScope national portal and to DMP's newly developed GeoVIEW.WA 'HyLogger' layer; and supervision of GSWA GeM geologist Lisa Roche while she undertakes her UWA Master of Economic Geology study of alteration and gold mineralization in the Glenburgh gold deposit.

HyLogger staff will continue several special projects to completion in 2014–15:

- The characteristics of gold and associated alteration at the Paulsens mine, in collaboration with Northern Star and GSWA Capricorn mapping geologists.
- The collaborative study of the spatial and genetic relationships between gold mineralization, hydrothermal alteration and the Nanjilgardy Fault, with CSIRO. Drillcore HyLogger and regional ASTER data will be collected and validated using petrography, geochemistry, X-ray diffraction (XRD), SEM-energy-dispersive X-ray spectrometry (EDS), analytical spectral device (ASD), microprobe analyses of surface (regolith) samples, and open-file drilling geology and geochemistry. The final project will include a 3D model incorporating all these data.
- Determination of TOC content in petroleum core using SWIR spectral analysis, in collaboration with GSWA Basins and Energy Geoscience staff and GA staff.
- Finalize development of the new 'HyLogger' layer for DMP's GeoVIEW.WA application. This layer will show the locations of scanned drillholes, and provide hyperlinks to summaries of spectral data, images of core and a range of subsidiary information. It will provide an alternative to the AuScope portal for delivery of HyLogger data to the public.

- Finalize an audit of the GSWA gold collection; capture all data and images in a gold collection database.
- Collaborate with CSIRO and FLSmidth (commercial manufacturer and developer of HyLogger and HyChip machines) to organize and deliver to GSWA, academic, and industry personnel a workshop promoting the use of the hyperspectral technology. This follows the successful GSWA HyLogging workshops delivered in May 2014.
- Commission, manage access to, and support GSWA geological staff in the use of a new portable/desktop XRD instrument. Responsibilities will include developing procedures for the systematic and rapid validation of mineral identifications made in core and hand specimens using visual logging and the HyLogger.

Products planned for release 2014–15

3D model of alteration in Mount Olympus gold mineralization (Report and GIS dataset)

Paulsens gold mineralization and related alteration (Report)

Gold collection (Record or Atlas)

Portable XRD: applications to mineral identification in core (Record)

Attachment to Abra Record Forms of gold in the Abra base metal and gold deposit

HyLogger activities — A new data layer for GeoVIEW.WA (Fieldnotes article)

Zircon spectral signatures (Record)

Planned work program and products for 2015–16 and beyond

Collection and interpretation of hyperspectral data from mineral and petroleum core will continue. HyLogger staff will also continue to collaborate with GSWA colleagues and other researchers, to undertake and publish outcomes from research projects that use the HyLogger facility to collect significant fundamental data.

The HyLogger will be moved to a climate-controlled location inside the DMP's Carlisle Core Library when such dedicated space is made available.

Part 5
**Exploration Incentive Scheme,
detailed work programs**

ES01 Exploration and Environmental Coordination

Manager: Stephen Bandy

Team members: Steve Brown

This program aims to:

- integrate the approval process into the minerals tenement management system
- track tenement applications through the various approval stages, with online access to metrics by stakeholders
- lodge and process tenement applications online and associated reporting obligations.

Outcomes of work program 2013–14

Several modules in the minerals titles management system were delayed or development work planned to continue into 2014–15 as 2013–14 saw a significant reduction in funding.

Planned outcomes 2013–14	Current status
Implement appraisal into online applications, determination and native title processing	Quick appraisal module completed. Full appraisal module partially completed; will continue in 2014–15
TENGRAPH enquiry replacement module using Geocortex Framework — stage 1	Under development. Substantially completed. Will continue in 2014–15
Auto creation and attachment of TENGRAPH maps to notices using the Geocortex Framework	Map creation process completed. Integration into the mineral titles management system will continue in 2014–15

Planned work program and products 2014–15 and beyond

The activities below are new TENGRAPH replacement initiatives, with the aim not to just replace TENGRAPH functionality but to integrate the business processes that TENGRAPH supports into the electronic Mineral Titles System (eMiTS).

Planned outcomes 2014–15
Implement full appraisal into the mineral title management system, specifically in the area of title determination and native title management
Implement TENGRAPH enquiry replacement module in the Geocortex Framework, inclusive of quick appraisal and map-quality print functionality
Develop Mineral Titles geodatabase model
Develop and prototype options for the replacement of TENGRAPH surveyed maintenance, unsurveyed maintenance and general maintenance modules
Continued integration of TENGRAPH-specific business processes and workflows into the mineral titles management system (eMiTS)
Design and implement clustered ArcGIS server/Geocortex infrastructure for scalable delivery of Web application services

Beyond 2014–15, the plan is to:

- replace surveyed maintenance, unsurveyed maintenance, general maintenance and appraisal functionality
- continue integration with eMiTS business workflows
- integrate with Landgate Cadastral, Topography and georeferenced Images Services.

ES20 Government Co-funded Exploration Drilling

Manager: Margaret Ellis

This program supports innovative drilling by companies in underexplored areas. It is designed to stimulate geoscience-based, targeted exploration, and contribute to the economic development of underexplored areas in Western Australia, where additional drilling and exploration activities will lead to new discoveries.

The program is preferentially funding high-quality, technical and economically based projects that promote new exploration concepts and technologies. Proposals from applicants are assessed by a panel on the basis of geoscientific and exploration targeting merit.

An Advisory Committee, chaired by the Director General DMP and consisting of representatives from the main industry representative groups and research sector, provides advice to DMP on program guidelines. The committee, which meets twice yearly, also ensures that the program is relevant to the exploration industry.

The program refunds up to 50% of direct drilling costs. The funding has a cap of \$30 000 for genuine prospectors, \$150 000 for multihole projects, and \$200 000 for deep single-hole projects.

As a result of feedback from previous rounds of applicants, beginning in 2011 there are now two rounds of co-funding per year running either over a financial or calendar year. Successful applicants are required to complete the proposed drilling project within either the relevant financial or calendar year. Interim and final drilling reports plus core are submitted to DMP before payment of the subsidies, and the final report and core are released to open file six months after completion of the project.

During 2013–14 drilling from three rounds was undertaken by exploration companies. As can be seen highlighted by the red rectangle in Figure 34, three rounds were overlapped by the 2013–14 financial year. Round 6 projects covered the 2013 calendar year, with a number of projects drilled between July and December 2013. Round 7 projects were drilled between July 2013 and June 2014, whereas Round 8 covered projects drilled during the 2014 calendar year; hence, a number of Round 8 projects were drilled in the first six months of 2014 thus falling into the 2013–14 reporting year.

Outcomes of work program 2013–14

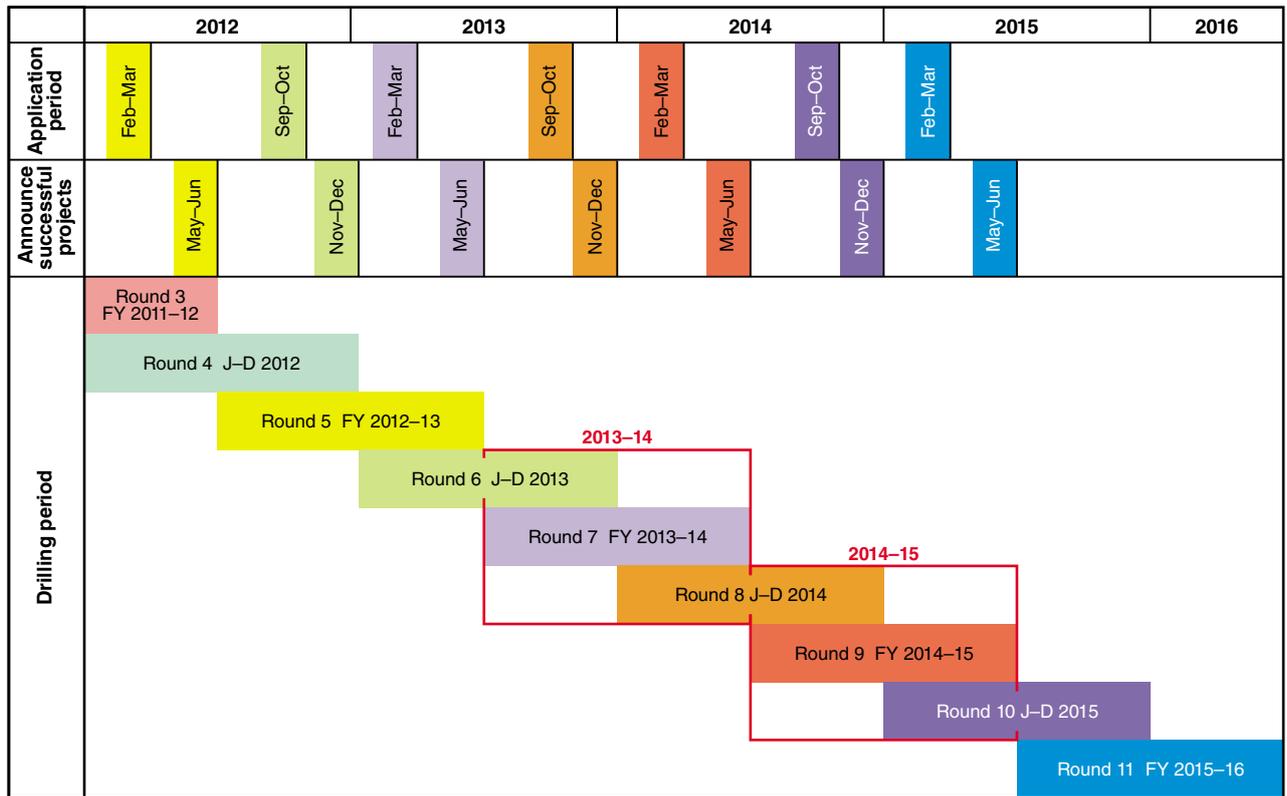
Successful drilling projects usually cannot be deemed to be so after one drilling campaign. The successes listed below are some of those announced for drilling projects which have received co-funding in 2013–14 or in previous years.

Highlights of the 2013–14 program include the following:

- Lamboo Resources: continuing good results at McIntosh graphite with resource upgrade
- Encounter Resources: 800 m long zone of copper sulphide with end of hole (EOH) primary copper intersections: 6m at 0.7% Cu from 150 m to EOH
- 30 m at 0.4% Cu from 118 m to EOH
- MacPhersons Resources: deep exploration drilling at Nimbus confirmed extension of high-grade Ag–Zn–Au. First production is scheduled for September quarter 2016
- Rox Resources: maiden mineral resource at Camelwood of 1.6 Mt at 2.2% nickel. The mineral resource contains 34 600 tonnes of contained nickel with a higher grade core of 520 000 tonnes at 3.1% nickel. Mineralization is open at depth and along strike
- Panoramic Resources: co-funded drilling at Savannah demonstrates for the first time that the North Olivine Gabbro at Savannah is a mineralized intrusion very similar to the Savannah Intrusion, thus opening up an entirely new avenue for exploration at Savannah.

The following outcomes were also achieved during the year:

- Completion of 59 exploration drilling projects by successful recipients between July 2013 and June 2014
- Drilling of 25 500 metres of diamond drilling and 57 500 metres of non-cored drilling
- Call for applications for the 2014 round of drilling, and evaluation of applications for co-funding
- Announcement of successful applications, including from prospectors, for the eighth round of Government Co-funded Exploration Drilling to be undertaken during the 2014 calendar year, and distribution of those agreements
- Call for applications for the 2014–15 round of drilling (Round 9), and evaluation of applications for co-funding
- Announcement of successful applications for Round 9 of Government Co-funded Exploration Drilling for projects to be drilled during the 2014–15 financial year, and the distribution of those agreements.



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Figure 34. EIS — co-funded drilling that impacted on the 2013–14 budget (Rounds 6, 7 and 8) and will impact on the 2014–15 budget (Rounds 8, 9 and 10)

- Successful applicants for the eighth round of Government Co-funded Exploration Drilling (to be undertaken during the 2014 calendar year) and the ninth round (to be undertaken in the 2014–15 financial year) are shown in Table 18 and Table 19, respectively.

Table 18. EIS Co-funded Drilling Round 8 (for drilling during the 2014 calendar year)

<i>Applicant name</i>	<i>Drilling project title</i>	<i>Target commodities</i>
Agnew Gold Mining Company	Agnew Strategic Stratigraphic	Au
Antipa Minerals Ltd	Corker Program	Au, Cu, Ag, Cu, Zn, Pb, W
Atlas Iron Ltd	Corunna Downs Regional Drilling	Fe
AusQuest Ltd	Bald Hill	Cu, Au, Ni
Barrick (Kanowna) Ltd	Red Eye	Au, Cu, Mo
Black Raven Mining Pty Ltd	Erayinia VTEM Drilling	Au, Cu, Zn, Pb, Ag, Fe
Breaker Resources NL	Dexter	Au
Buxton Resources Ltd	Zanthus Nickel Copper Project	Ni, Cu
Cassini Resources Ltd	West Musgrave	Ni, Cu, PGE
Complex Exploration Pty Ltd	Milly Milly Intrusion Byro East	Cu, Ni, PGE
Conglomerate Gold Exploration Pty Ltd	Beatons Creek Deep Drill Hole	Au
Conglomerate Gold Exploration Pty Ltd	Contact Creek Deep Drill Hole	Au
Cullen Resources Ltd.	Eureka – Southern	Au
Echo Resources Ltd	Gladius Targets	Au
Encounter Resources Ltd	Fishhook Prospect	Cu, Co
Encounter Resources Ltd	Stirling	Cu–Au
Energia Minerals Ltd	Nyang	U
Enterprise Metals Ltd	Plato Drilling	Ni, Cu, PGE
Hazelwood Resources Ltd	Southern Lights	W
Horseshoe Metals Ltd	Kumarina Deeps	Au, Cu, Zn, Pb
Iluka Resources Ltd	Broome	Heavy minerals
Independence Group	Wilson Creek	Cu, Zn, Pb, Au, Ag
Kamax Resources Ltd	Peninsula Project	Ni, Cu, PGE
Karlawinda Pty Ltd	Frankopan Exploration	Au
Kinloch Resources Pty Ltd	Mt Carson Project	Ni, Cu, REE
Ming Gold Ltd	Obelisk Prospect	Au, Cu, Ni, W, PGE
MRG Metals Ltd	East Yilgarn — Robert	Au, Ni, Cu, PGE
Newcrest Mining Ltd	Matthew's Dome	Au
Newmont Jundee Operations	Jundee Deeps Drilling	Au
Northern Minerals Ltd	John Galt Project	HREE
Northern Mining Ltd	Kanowna Lights	Au
Panoramic Resources Ltd	Chasing the Savannah Intrusion	Ni, Cu, Co
Platina Resources Ltd	Rason Project	Au
Redstone Resources Ltd	Blackstone Range (Tollu)	Cu, Ni, Co
Reed Resources Ltd.	Mt. Finnerty	Ni, Cu, PGE
Rumble Resources Ltd	Fraser Range Project	Ni, Cu
Sandfire Resources NL	Doolgunna Project	Au, Cu
Segue Resources Ltd.	Pardoo Ni–Cu	Ni, Cu, PGE
St Barbara Ltd	Poker Target	Au
Tanami Gold NL	Coyote Deeps 2014	Au
Traka Resources Ltd	Tollu Project	Ni, Cu, PGE, REE
Venturex Resources Ltd	Southern Hills	Cu, Zn, Pb
White Cliff Minerals Ltd	Mt Glasse Nickel Prospect	Ni, Cu
John Brady (prospector)	Princess Royal East	Au
Alex Jones (prospector)	Sparks Lease RAB drilling 2	Au
Melville Dalla-Costa (prospector)	The Duke Project	Au

Table 19. EIS Co-funded Drilling Round 9 (for drilling during the 2014–15 financial year)

Applicant name	Drilling project title	Target commodities
Alloy Resources Ltd	Horse Well Project – Dusk Til Dawn Prospect	Au
AngloGold Ashanti Australia Ltd	Apocalypse, Tropicana JV	Base metals
AngloGold Ashanti Australia Ltd	Belvedere Ni–Cu Prospect	Ni, Cu, PGE
Areva Resources Australia Pty Ltd	North Canning Project	U
Areva Resources Australia Pty Ltd	South Canning – Pardoo Project	U
Artemis Resources Ltd	Eastern Hills – Dugite Zone	Sb, Pb, Ag, Au
Beadell Resources Ltd	Zanthus AEM Anomaly	Au, Cu, Ni, Pb, Zn
Breaker Resources NL	Kurrajong South	Au
Classic Minerals Ltd	Fraser Range Diamond Drilling	Ni, Cu, Co, Zn
David Reed	Kalgoorlie Project	Au
Echo Resources Ltd	Lucius Targets	Au
Encounter Resources Ltd	Millennium	Zn, Pb, Cu
Enterprise Uranium Ltd	Lake Harris	U, Ni, Cu, Co
Great Sandy Pty Ltd	Eginbah Iron Project	Fe
Hanking Gold Mining Pty Ltd	Jupiter Dilation Targets	Au
Horseshoe Metals Ltd	Horseshoe Lights Deep Drilling	Cu, Au
J. and J. McIntyre	Webb Diamonds	Diamonds
Kamax Resources Ltd	Peninsula Project	Ni, Cu, Co, PGE
Lamboos Resources Ltd	Panton North Graphite Project	Graphite
Lamboos Resources Ltd	Black Rock Graphite Project	Graphite
MacPhersons Resources Ltd	Brindabella Ag–Au	Au, Ag, Zn, Cu, Pb
Magnetic Resources NL	Kauring	Fe
Millennium Minerals Ltd	High-grade feeder to Golden Eagle deposit	Au, Sb
Ming Gold Ltd	Havieron	Au, Cu, Ni, W
Mithril Resources Ltd	Nanadie Well	Cu, Ni, Au
MRG Metals Ltd	Loongana	PGE, Ni, Cu
Northern Star Resources Ltd	Titus Prospect – Ashburton Project	Au
Quadrio Resources Ltd	Calingiri Diamond	Cu, Mo, Ag, Au
Ramelius Resources Ltd	Vivien Deeps Diamond Drilling	Au
Redcliffe Resources Ltd	Kelly Deep Drilling Initiative	Au
Reed Resources Ltd	Green Dam Prospect – Blind NiS target	Ni, Cu, PGE
Reward Minerals Ltd	Lake Waukarlycarly	Potash brines
Silver Lake Resources Ltd	Mt Belches Strat. Correlation & Fluid Pathways	Au
Slatey Creek Pty Ltd	Selby Prospect Exploration Drilling	Cu, REE, Au
Tetra Resources Ltd	Midgengadge Manganese Project	Mn
Venus Metals Corp	Yalgoo Ni–PGE–Base Metals Project	Ni, PGE, Base metals
Windward Resources Ltd	Fraser Range North Win-Eye	Ni, Cu
David Pascoe (prospector)	New Waverley	Au
Giles Rodney Dale (prospector)	Breakaway Andalusite Project	Andalusite
Linnie Harris (prospector)	Miracle7	Au, Ag, Cu, Fe
Maher Mining Contractors Pty Ltd (prospector)	Gindalbie	Au
Neil Hass (prospector)	Goanna Patch Extensions	Au
Scott Wilson (prospector)	Cowza South Prospect	Au, Ni
Thomas Langley (prospector)	Grace Gold Project	Au

ES21 Mineral and Exploration Promotion

Manager: Gaomai Trench

The objective of the section is to promote opportunities for investment in Western Australia in order to attract investment capital, and enhance mineral exploration and discovery. The promotional activities are undertaken proactively, individually through GSWA's own direct efforts, and by GSWA/DMP collectively cooperating with 'Australia Minerals' to establish and enhance government relations with potential investment jurisdictions.

Outcomes of work program 2013–14

In 2013–14, the section attended key international events as part of Australia Minerals:

- Prospectors and Developers Association of Canada Annual Convention, Trade Show and Investors Exchange (PDAC)
- annual China Mining Conference
- annual Federation of Indian Mineral Industries (FIMI) Mining Exploration Convention and Trade Show
- Asia exploration and mining seminars aimed to target Chinese, Japanese, Korean and other Asian investors (many seminars were jointly hosted by Austrade and Australia Minerals).

In addition, the section represented DMP/GSWA at the Annual Asia Mining Congress, Mines and Money Hong Kong, and the China – ASEAN Mining Cooperation Forum. In Australia, the group attended Diggers and Dealers (Kalgoorlie), Mining 2013 (Queensland), and the AMEC conference (Perth).

GSWA and the China Geological Survey joint mapping program is a great enhancement of Western Australia and Chinese Government relations.

The section provided guidance to investors on more than just mineral potential and mineral exploration opportunities, including on:

- the *Mining Act 1978* — an equitable and secure titles system
- approvals procedures — transparent and efficient

- safety, health, and environmental standards to meet State and Commonwealth legislation and policies
- online database systems — information is comprehensive, free, up to date and readily available
- mining taxation and FIRB policy information.

Products and achievements 2013–14

Products and achievements in 2013–14 were:

- high-impact presentations and exhibition booths
- publication of mineral promotional materials, including maps and flyers
- new ground tenement applications that resulted directly from promotional activities
- new joint ventures formed and foreign investment turned into exploration in Western Australia
- DMP information seminars held quarterly to Chinese State-owned enterprises (SOE)
- successful joint mapping program in 2014–15.

Planned work program and products 2014–15

Similar promotional events will continue to be the focus of future work programs, which will again be undertaken in cooperation with Australia Minerals. This should see Western Australia consolidate its position in north Asian markets. In addition, promotional activities in the emerging economies of India, Taiwan and Vietnam are under consideration. The European market will be closely monitored for promotional opportunities.

ES22 Stratigraphic Drilling

Manager: Catherine Spaggiari

The Precambrian basement beneath the Eucla Basin represents one of Western Australia's most poorly understood regions, and it remains relatively unexplored due to a lack of knowledge and inherent high-risk factors. The stratigraphic drilling program is designed to aid interpretation of geophysical domains interpreted from aeromagnetic and gravity data, to define stratigraphic units and tectonic boundaries, and to constrain their relationship to the crustal architecture and tectonic settings. The results from this program have a direct bearing on our understanding of adjacent greenfields regions such as the Albany–Fraser Orogen and Musgrave Province, leading towards a much greater understanding of the formation of southwestern Proterozoic Australia. This information is necessary to constrain exploration models used to generate economic targets in this virtually unexplored, remote greenfields region.

Outcomes of work program 2013–14

Following the 2013 program of five diamond drillholes, a further three holes have been completed. One hole (MAD011) was drilled just west of the Mundrabilla Shear Zone, near Loongana siding, and the other two holes were drilled in the Forrest Zone of the Coompana Province (FOR008 and FOR012). A total of 600 m of high-quality, HQ-sized core of basement has been recovered, with the deepest hole drilled to a depth of about 640 m. The Eucla Basin cover was not sampled and was drilled using mud rotary. The results from the drilling are greatly assisting in the interpretation of the deep crustal seismic reflection lines acquired in 2012 and 2013–14. They are also being used to construct IBG maps of the basement from gravity and aeromagnetic data. These cores provide the only means to directly assess the regional geology, and its prospectivity. Initial results from core logging, geochronology and geochemistry of the five 2013 stratigraphic cores are being enhanced by more detailed work.

In addition, the Eucla Basin component of the cores are being analysed by a team from Curtin University, as part of a collaborative project with GSWA. This work will not only provide insight into the formation of the Bight and Eucla Basins, but also provides valuable information about drilling depths and materials encountered.

Planned work program and products 2014–15

There are no further plans to drill stratigraphic holes in the Eucla basement at this stage. See program plan for GS61 for product information.

Planned work program and products 2015–16 and beyond

See program plan for GS61.

ES30 Regional Airborne Surveys

Manager: David Howard

Team member: John Brett

The Regional Airborne Survey component of the EIS 2009–14 had, as its initial objective, the completion of medium-resolution (200–400 m line-spacing) aeromagnetic and radiometric coverage of the State by June 2014. This objective was completed by the end of the 2012–13 financial year when the focus shifted to the acquisition of detailed (100 m line-spacing) surveys in project-specific areas. Commencing in 2013–14, the EIS remotely sensed geophysical data acquisition program was expanded to include regional reconnaissance (5 km line-spacing) electromagnetic surveys — the Western Australia Reconnaissance AEM project (WARAEM).

Outcomes of work program 2013–14

The Goldfields 100 m airborne magnetic and radiometric program — the first of the project-specific areas selected for detailed (100 m line-spacing) coverage and survey which commenced in 2012–13 — was also completed with the acquisition and release of 588 000 line-km data from the six remaining survey blocks for a total project size of 720 000 line-km of new data (Figure 23; Table 20).

The first project in the regional airborne electromagnetic survey program was completed with the acquisition and release of almost 30 000 line-km of TEMPEST AEM data from the Capricorn project area (Figure 35).

Planned work program and products 2014–15

An airborne magnetic and radiometric survey at 100 m line-spacing in the area of the Yalgoo–Singleton greenstone belt may be undertaken pending the finalization of the GSWA budget (Figure 23; Table 20).

A second stage survey in the reconnaissance AEM program is under consideration with target area and extent yet to be defined.

Planned work program and products 2015–16 and beyond

The airborne survey program for 2015–16 and beyond will be dependent on the then prevailing GSWA budget, but is expected to continue with the detailed (100 m line-spacing) aeromagnetic and radiometric surveys and the reconnaissance (5 km) electromagnetic surveys.

Products planned for release 2013–14	Current status
Three airborne magnetic and radiometric surveys at 100 m line-spacing in the Kalgoorlie–Norseman belt will be undertaken to continue the 'Goldfields 100 m' program that commenced in 2012–13.	Surveys completed together with three other blocks to complete the 'Goldfields 100 m' program. Data from all six survey blocks were released.
A reconnaissance airborne electromagnetic survey at 5 km line-spacing will be undertaken over an area of up to 146 000 km ² (29 000 line-km) depending on the bid prices received.	A TEMPEST AEM survey of 30 000 line-km was completed and the data released.

Table 20. Exploration Incentive Scheme — Extended Airborne Survey Program

Program	Area/Survey name	Lines	Size (km)	Status*
YS100	Yalgoo–Singleton 100 m airborne magnetic and radiometric program			
	2014–15 program			
	Yalgoo 2014 (central block)	100 m; E/W	108 000	Proposal
GF100	Goldfields 100 m airborne magnetic and radiometric program			
	2013–14 program			
	Menzies North 2013	100 m; E/W	94 850	Released
	Menzies South 2013	100 m; E/W	93 650	Released
	Kalgoorlie East 2013	100 m; E/W	121 500	Released
	Kurnalpi North 2013	100 m; E/W	92 640	Released
	Kurnalpi South 2014	100 m; E/W	92 100	Released
	Widgiemooltha North 2013	100 m; E/W	92 800	Released
	2012–13 program			
	Widgiemooltha South 2012	100 m; E/W	131 400	Released
WARAEM	WA Reconnaissance AEM program			
	2013–14 program			
	Capricorn 2013 AEM	5 000 m; N/S	30 100	Released

NOTE: * Status at 2 July 2014

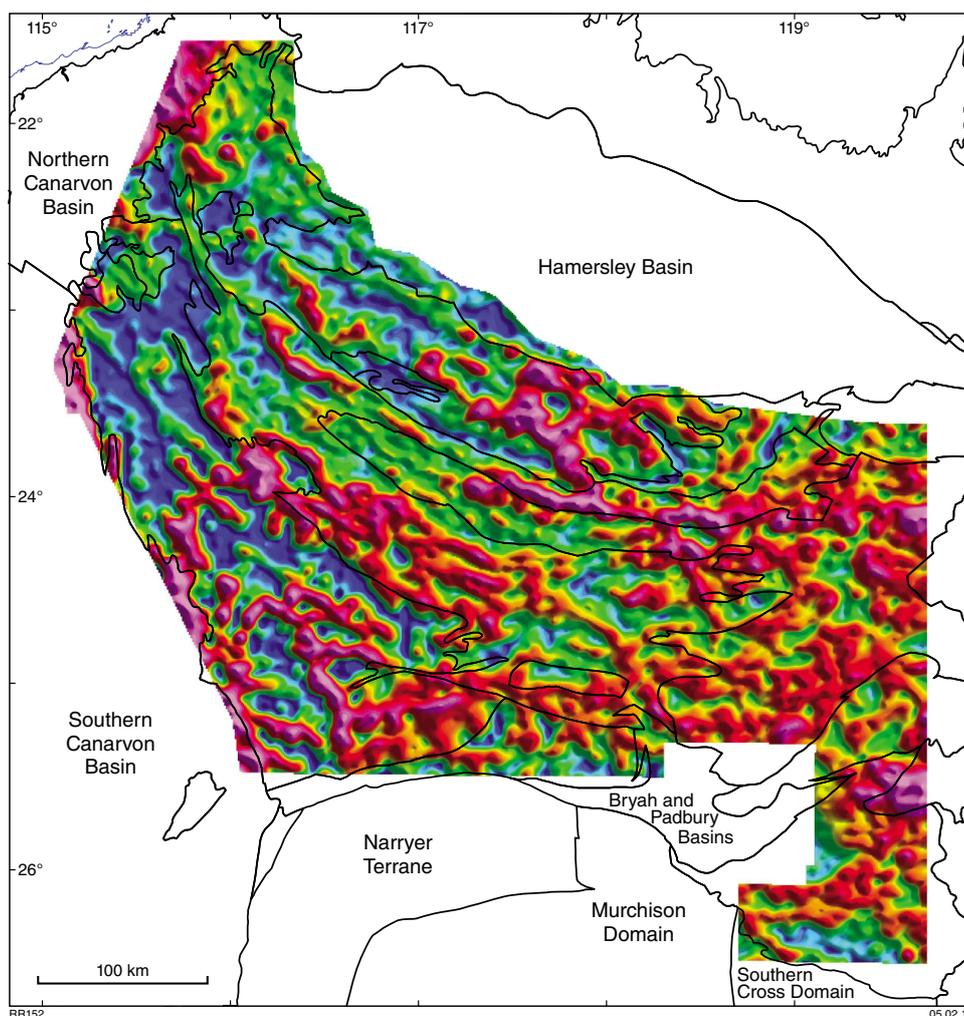


Figure 35. EIS — Capricorn 2013 airborne EM survey; computed conductivity 20–30 m depth slice. The conductivity image is overlain by tectonic boundaries (1:10 000 000 scale), with tectonic unit boundaries only labelled outside the survey area

ES31 Deep Seismic Survey Program

Manager: Ian Tyler

Team members: Hugh Smithies, Chris Kirkland, Klaus Gessner, Ruth Murdie, Lucy Brisbout and Catherine Spaggiari (Albany–Fraser Orogen Survey and Eucla–Gawler Survey)

Integrated geophysical and geological transects across the West Australian, North Australian and South Australian Cratons and their margins in Western Australia, and the intervening Neoproterozoic and Phanerozoic basins, provide a key to the geological evolution of the Australian lithosphere over some 4 billion years of Earth history. They also provide an understanding of the localization of mineral systems within the upper crust.

Deep seismic reflection surveys are being acquired in consultation with GA and making use of National Research Facility for Earth Sounding equipment (ANSIR) where available. Exploration companies are able to contribute to lines in their areas of interest. The lines use existing roads wherever possible to minimize costs, cultural and environmental impact, and rehabilitation. Land access clearances are obtained through ES61.

Each seismic reflection survey line is sampled for gravity, and usually for MT. Separate MT lines have been funded under ES31, and also through ES42 or KS01. Ongoing MT survey work, together with processing and interpretation will be consolidated under ES31 and will include cooperative work with CET in the Albany–Fraser Orogen, and in the Capricorn Orogen.

The seismic reflection surveys and MT are being complemented by targeted deployments of passive seismic arrays in collaboration with CET and ANU to provide additional information about large-scale structures to mantle depths.

Outcomes of work program 2013–14

In February 2014 the preliminary migrated seismic lines processed by GA, together with the locations of the seismic shot points, were released for 12GA–AF1, 12GA–AF2 and 12GA–AF3 for the Albany–Fraser Orogen deep crustal seismic reflection survey. A fourth line, 12GA–AFT, acquired by ANSIR in association with AngloGold Ashanti Ltd across the Tropicana gold deposit, was released in April 2014. A public workshop was held in April 2014 in conjunction with GA, ANSIR, AngloGold Ashanti and Independence Group, to release the interpreted lines Albany–Fraser Orogen seismic sections in the form of a preliminary edition of Record 2014/6 and accompanying plates. The Record contains a series of extended abstracts summarizing the geological evolution of the southeast Yilgarn Craton and the Albany–Fraser Orogen traversed by the survey together with preliminary interpretations of the seismic line, discussions

of the acquisition and processing, and the potential field geophysics. Abstracts also discussed the geochemistry geochronology and isotope geology, the nature of the lithosphere in the region, the Tropicana gold deposit and implications for mineral systems. An interpretation of the Fraser Range MT survey acquired by CET was also presented.

During 2013–14 a seismic reflection survey and MT acquisition in Western Australia was carried out as part of the Eucla–Gawler deep seismic reflection line (13GA–EG1), which was completed in February 2014 (Fig. 36). The new line joins the previously acquired Albany–Fraser Orogen line (12GA–AF3) at Haig (Western Australia), extending the seismic coverage for a further 834 km along the Trans-Australian Railway eastwards to Tarcoola (South Australia). The data acquired by GA and the Geological Survey of South Australia were as part of their pre-competitive data acquisition programs, with data–infrastructure investment from AuScope to complete the line. The first interpretation workshop for this survey will be held in Canberra in November 2014.

CET completed reprocessing and interpretation of the east Capricorn MT survey using a 3D inversion algorithm as the data showed significant 3D MT responses that could not be modelled using standard 2D modelling methods, and a revised Report 135 was published. Further MT acquisition in the Capricorn Orogen, supported by GSWA, is being carried out through CET as part of the SIEF UNCOVER project ‘Distal footprints of giant ore systems: Capricorn Orogen case study’.

Two targeted surveys of passive seismic arrays were deployed in 2013–14 in the areas of the Capricorn and Albany–Fraser Orogens. The Capricorn Orogen Passive Array (COPA) in the Capricorn Orogen is being run in collaboration with CET and the Centre of Excellence for Core to Crust Fluid Systems (CCFS) as part of the SIEF UNCOVER project. The ALFREX array is being run in the Albany–Fraser Orogen as part of a three-year ARC Linkage project with ANU.

The Canning Basin deep crustal seismic and gravity surveys (14GA–CC1 and 14GA–CC2) by Terrex Seismic were completed in June 2014 (Figs 28 and 36), with the 700 km line extending across the full width of the Canning Basin by following the Great Northern Highway, Derby and Gibb River Roads and then connecting with (partially overlapping) the Kimberley MT and gravity survey line. As well as to examine the top section of the Canning Basin, the survey was designed to image deep crustal architecture beneath the Canning Basin, together with

the basin's boundaries with the Pilbara and Kimberley Cratons. This is a GSWA–GA collaborative project, but data acquisition was fully funded by EIS.

Products released 2013–14

Record 2013/6 Youanmi and southern Carnarvon seismic and MT workshop (June 2013), together with three plates

GA Record 2013/28 Yilgarn–Officer–Musgrave seismic and MT workshop

Preliminary migrated seismic line cross-sections, seismic shot point locations and common depth points (CDPs) for for lines 12GA–AF1, 12GA–AF2, 12GA–AF3 and 12GA–AFT

Record 2014/6 Albany–Fraser Orogen seismic and magnetotelluric (MT) workshop 2014: preliminary edition, with four plates

Report 135 A magnetotelluric traverse across the eastern part of the Capricorn Orogen

Products planned for release 2014–15 and beyond

Report A magnetotelluric survey across the Albany–Fraser Orogen	Sep 2015
Release of east Eucla seismic survey preliminary seismic sections	Feb 2016
GSWA/GA/GSSA Record Seismic sections and interpretation of the Eucla–Gawler seismic survey	June 2016
Report Crustal structure of the Capricorn Orogen (including MT)	June 2016
Report on the COPA passive seismic array	June 2016
Report on the ALFREX passive seismic array	Oct 2016

Planned work program and products 2014–15 and beyond

Processing and interpretation of MT in the Capricorn Orogen, supported by GSWA, will be carried out through CET.

GSWA will continue to support the deployment of the COPA and ALFREX passive seismic arrays in the Capricorn and Albany–Fraser Orogens. A new permanent seismic station will be established at Carnegie station, funded by GSWA and installed and maintained by GA.

Workshops will be held in Adelaide and at Mineral House to interpret the Eucla–Gawler seismic line, with a final interpretation workshop planned for Mineral House in November 2015. The release of the full line is planned for the Australian Earth Science Convention in Adelaide in July 2016, with a follow-up release workshop in Perth.

Release of the raw data acquired from the Canning Basin deep crustal seismic and gravity surveys (14GA–CC1 and 14GA–CC2; Fig. 28) is planned to coincide with DMP's Petroleum Open Day (11 September 2014), with release of the processed data planned for early 2015. GSWA and GA will subsequently interpret the processed data.

GSWA is providing funding to GA to continue processing and interpreting deep seismic reflection surveys acquired under EIS, and it is planned to complete the processing and interpretation of all EIS-funded deep seismic and associated MT surveys by June 2016.

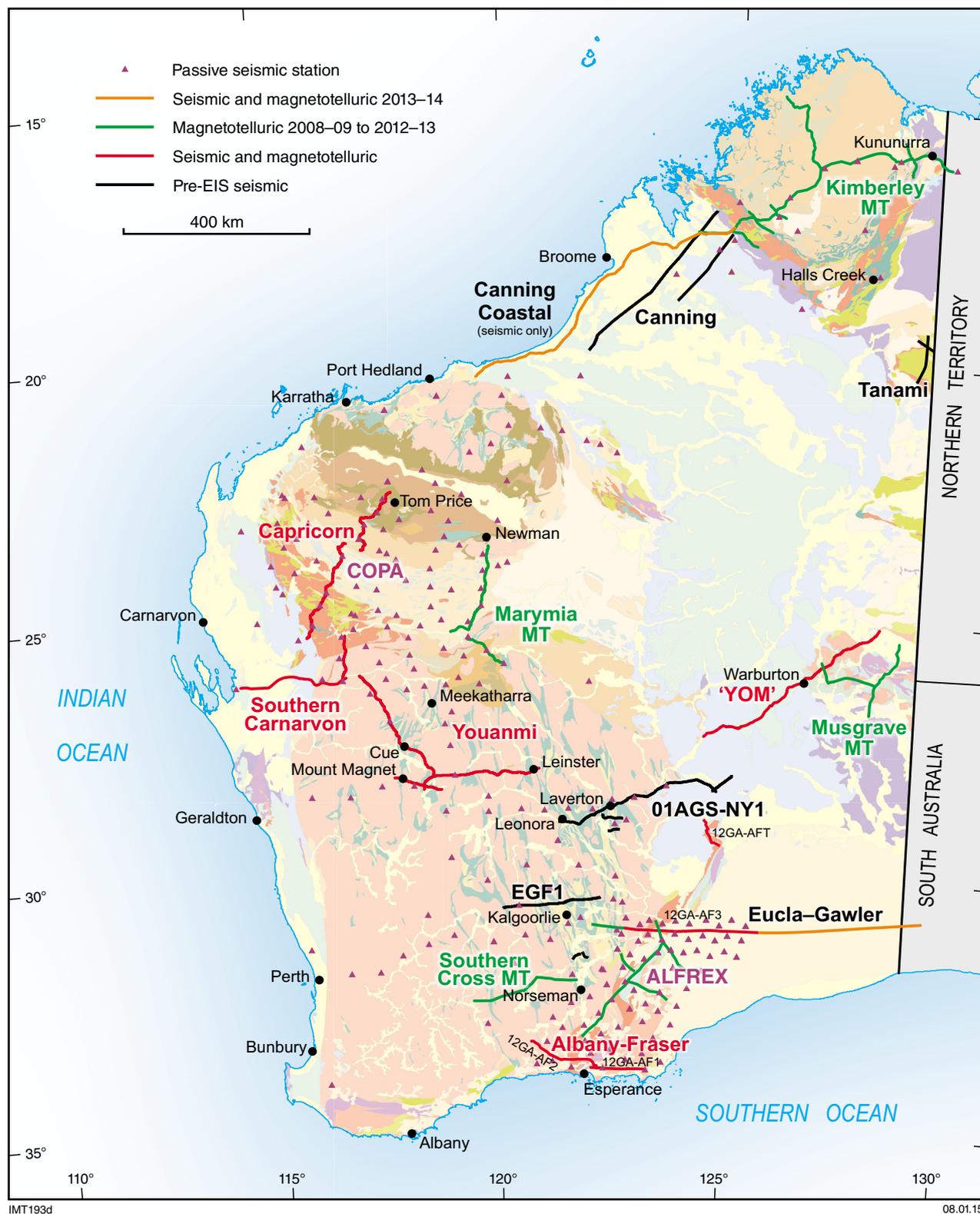


Figure 36. EIS — deep crustal seismic and MT surveys, including the passive seismic stations (deployed and planned)

ES32 Regional Gravity Surveys

Manager: David Howard

Team member: John Brett

The Regional Gravity Survey component of the EIS has the objective of completing regional medium-resolution (<4 km station spacing) gravity coverage of Western Australia — the Western Australia Reconnaissance Gravity project (WARGRAV2).

Outcomes of work program 2013–14

Data from a total of 16 010 gravity stations were acquired and released during the year from surveys around Esperance and in the Goldfields just north of Kalgoorlie. A third survey at 2.5 km commenced in the Sir Samuel – Throssel area to acquire an anticipated 11 700 stations (Fig. 25).

Planned work program and products 2014–15

Completion of the Sir Samuel – Throssel gravity survey and release of the data. A survey at 2.5 km station spacing may be undertaken in the Ngurrurpa area depending on the outcome of access clearance activities and availability of EIS funding (Fig. 25).

Planned work program and products 2015–16 and beyond

Areas for new surveys in 2015–16 will be determined over the course of 2014–15.

<i>Products planned for release 2013–14</i>	<i>Current status</i>
New gravity surveys with the acquisition and release of data from approximately 7000 stations on a 2.5 km grid in the Esperance area and, possibly, one or more surveys in the area of the northeast Yilgarn	Data from 16 010 new gravity stations in the Esperance and Goldfields areas were released.

ES33 Yilgarn Margin Geochemistry

Manager: Paul Morris

Team members: Andreas Scheib, Nadir de Souza Kovacs

The Archean Yilgarn Craton is well known for its mineral endowment, with most deposits found in the craton interior. Following the discovery of significant economic mineralization on the craton's southeastern margin (the Albany–Fraser Orogen) and in basin successions on the northern margin (Bryah–Padbury), there has been increased interest in the mineral potential of the craton edge. In part due to the extensive regolith cover of these areas and the relatively limited amount of mineral exploration, the geological history, age, nature and extent of mineralization are often poorly understood.

The ES33 Yilgarn Margin Geochemistry program aims to provide geochemical and related metadata from different sample media (regolith, rocks, water, vegetation) at a variety of scales to support and encourage mineral exploration in these greenfields areas. To achieve this, GSWA has entered into collaborative projects with CSIRO, which has demonstrated expertise in sampling and analysis of water and vegetation in relation to mineralization. A particular emphasis of the GSWA part of program ES33 is to determine the usefulness of regolith as a sampling medium for geochemistry (especially in areas of thick and transported regolith), and whether these data can be used to provide information on not only buried mineralization but also bedrock type and distribution.

Using EIS funding, GSWA completed a soil and rock sampling program in the Kiwirrkurra area of northeastern Western Australia in 2007. The increased mineral exploration activity resulting from this program has seen the discovery of gold and base metal mineralization and diamond indicator minerals. At a request from a neighbouring indigenous group (Parna Ngurrurpa), GSWA is formulating a plan to extend this area to the Ngurrurpa area to the north, involving capture of closely spaced gravity and soil samples on a 5 km grid.

Outcomes of work program 2013–14

Outcomes planned for 2013–14 are:

- Completion of sampling and analysis of water bores in the northwest Yilgarn Craton (MRIWA project M414), which is sponsored by GSWA. The program involved the collection of about 1400 water samples, which have been analysed for a range of elements and isotopes.
- GSWA has sponsored an embedded CSIRO researcher to examine the relationship of bedrock-hosted mineralization and its surface expression in parts of the Albany–Fraser Orogen. This has been carried

out by geochemical analysis of surface and drilling samples, interpretation of airborne electromagnetic data to estimate regolith thickness, and examination of field exposures (MRIWA project M411).

- A key issue in understanding the usefulness of regolith geochemistry to detect buried mineralization is knowledge of the thickness of regolith cover. In the absence of drilling data, GSWA has been pursuing the use of passive seismic to estimate the thickness of both regolith and sedimentary rock cover in the east Wongatha area (following a project on the application of fine-fraction regolith chemistry to detect mineralization) and as part of a basement drilling program under the Eucla Basin. Results are encouraging, with this approach seen as a way of estimating regolith thickness in a cost-effective and timely manner. A Record about the technique (with selected case studies) has been compiled and submitted for editing.
- In 2009, GSWA acquired a compilation of open-file mineral exploration report data and viewing software from TerraSearch Pty Ltd, and released stream sediment, soil, drill sample and rock chip geochemistry and associated metadata on USB. Recognizing the importance of these data, in 2013–14, GSWA acquired a further tranche of data covering parts of the Bryah–Padbury basins, increasing the sample count of these data to 1 179 771.

Products released 2013–14

Exploration geochemistry of Western Australia 2014 (update of TerraSearch Pty Ltd 2009 data release). Digital data on USB including new data on the Bryah–Padbury basins

Products planned for release 2014–15

Record on results of hydrogeochemistry (M414)

Record on results of MRIWA project M411 (Yilgarn Craton – Albany–Fraser margin)

Record on passive seismic methodology and examples of its use

Acquisition of regolith samples on Ngurrurpa country in northeast Western Australia

ES40 Geology Online

Manager: Darren Wallace

Team members: Angelia Riganti, Terry Farrell, Bhumita Fadadu, Kiran Gavni, Derek Canham, Ibrahim El-Fayoumi, Frank Matera, Stephen Bandy

The WA Geology Online project will better integrate GSWA’s online product delivery by developing and facilitating the population of new databases and data services. These will include the development of a range of exploration databases and Web-based search tools.

Planned outcomes 2014–15

- Complete the redevelopment of company exploration reporting database (WAMEX) online lodgement website
- Complete an external Web interface for the Explanatory Notes System (ENS)

Planned outcomes 2013–14	Current status
Further enhancement of the WAROX application and GIS extension tool	Complete
Implement a Mineral Drillholes database and Web search tool	Complete
Redevelopment of company exploration reporting database (WAMEX) including online lodgement and search tools	Complete except online lodgement
Implement a company exploration geochemistry database and Web search tools that integrate with GSWA geochemistry database	Complete
Building an external Web interface for Explanatory Notes System	Ongoing
Building desktop extraction tool for catalogue database (KitCat)	Complete

ES41 Modernize Petroleum Information Delivery System

Manager: Felicia Irimies

Team member: Yanrong Li

The objective of this project is to have a full assessment of WAPIMS modules and their links with other Departmental applications — OFM, Eclipse, Petrel — as well as to review the data management workflows in order to provide a more streamlined data submission and release system for the petroleum industry. The scanning of all state seismic sections to high-quality jpeg format in preparation for future transcribing to SEG-Y format will improve the amount and quality of data delivered online.

Planned work program 2014–15

Work will focus on:

- WAPIMS assessment and upgrade to the 2013 version
- the continuation of scanning hard copy seismic sections stored at the Norton Building (Carlisle) to high-quality jpeg format in preparation for future transcribing to SEG-Y format.

Outcomes of work program 2013–14

The necessary WAPIMS technical development and enhancements were done in order to incorporate core libraries databases (Carlisle and Kalgoorlie) including the mineral core submitted by mineral companies.

Outcomes planned 2013–14	Current status
WAPIMS enhancements	The core libraries' databases are included in eSearch and fully functional; issues with ProSource views fixed
Scanning of seismic sections	Ongoing

ES42 3D Geoscience

Manager: Klaus Gessner

Team members: Ruth Murdie, Lucy Brisbout, Huaiyu Yuan (Macquarie University)

The aim of the 3D Geoscience program is to increase the knowledge of Western Australia's subsurface through the integration of geophysical, geological and geochemical data in 3D structural models.

The objectives of the 3D geoscience program are:

- developing the capability to build, manage, analyse and store 3D models according to GSWA quality standards and stakeholder needs
- engaging in collaborative research with leading research institutions that complement GSWA's data collection, analysis and modelling capabilities.

Faults, fracture zones and shear zones can be pathways for fluids and melts within the solid Earth. Earth's 3D structure therefore not only reflects the distribution of physical properties of the rock mass in bedrock, sedimentary basins and regolith cover, but often relates very closely to the spatial distribution of mineral deposits and energy resources that formed as a consequence of fluid flow in the Earth's crust. 3D structural modelling and numerical simulation of geological processes are emerging techniques that can be used to extend knowledge from exposed and well-understood areas to inaccessible or data-poor parts of the Earth's crust and lithosphere, and to test the validity of conceptual models and interpretations.

3D models are constructed at different scales and for different purposes, as follows:

- Nanometre- to centimetre-scale 3D models characterize the spatial variation in physical properties of rocks and minerals by taking into account chemical composition, crystal lattice orientation, and shape and distribution of individual grains, pores and fractures. Small-scale data are acquired by optical or electronic imaging and chemical probing of rock sample surfaces, or by 3D imaging using X-ray tomography.
- Metre-scale models of rock outcrops, and engineered rock surfaces are imaged to analyse bulk properties of the rock mass. Data are acquired by mapping and by optical surface imaging techniques such as laser scanning and photogrammetry.
- Models at the 100 m to kilometre scale can show large geological structures such as folds and fault zones, and mineral systems, petroleum reservoirs and geothermal systems, or carbon storage sites. At this scale data are acquired using a range of geological, geophysical and geochemical mapping and detection methods that provide point, line and surface data types that are imaged and interpreted in 3D space.

- Solid Earth models at the tens of kilometres scale and larger are used for imaging composition and structure of the Earth's crust and mantle. Acquisition includes active and passive source seismic data, as well as measurements of mineral spectra, radiation, potential fields (magnetic and gravity) and electrical properties as modelled from airborne electromagnetic (AEM) and MT methods.

The higher the resolution of the data and the more data types are available, the more robust are the resulting interpretations and conceptual models. A good understanding of the surface geology is essential where available, combined with drillholes, and geophysical data. Aeromagnetic and deep seismic reflection surveys are often used to image structures within the shallow levels of Earth's crust, whereas gravity, MT and passive source seismic imaging provide information on the deep crust and underlying mantle. Potential field inversions and forward modelling of magnetics and gravity are essential workflows that help to integrate surface geology information with subsurface data and test the validity of geological interpretations at depth.

The workflow to generate 3D models involves data acquisition, processing, visualization, interpretation, publication and archiving. The state of the art in generating models is currently not well defined; hence, there is a need to develop a framework that satisfies the requirements of GSWA and its stakeholders, and that integrates with existing databases and products. The risks and uncertainties of the task lie in the complexity of data transfer, integration of datasets and an unknown level of interoperability of storage and delivery systems.

Outcomes of work program 2013–14

People

Ruth Murdie is a Senior Geophysicist-3D Modeller, who has built 3D models of the northwest Yilgarn Craton at various scales. These models are key to developing GSWA's capability to manage, analyse and store 3D data, and to establish the workflows necessary to generate 3D models from data acquisition, through to processing, visualization, interpretation, publication and archiving.

Lucy Brisbout, a GSWA Geophysicist-Geologist, joins the 3D Geoscience section on 1 July 2014. Lucy's expertise is in structural geophysics and she will work on geophysical forward modelling and 3D model building.

Huaiyu Yuan is a GSWA-funded research associate at Macquarie University in the ARC CCFS. Huaiyu is a seismologist based at CET at UWA, where he works on passive seismic imaging of the Capricorn Orogen, and on large-scale seismic imaging of the Western Australian lithosphere.

Projects

Supporting GSWA programs

Contributions have been made to regional mapping sections by work on the seismic interpretation of the Youanmi survey, and the Albany–Fraser Orogen, the Capricorn Orogen and the Kimberley region.

Research collaboration

GSWA continued its contribution to the ARC CCFS by funding Dr Huaiyu Yuan's position at Macquarie University. Dr Yuan's specialties are crustal and lithospheric structural imaging using earthquake data. The passive source (earthquake) component of the project started in the second half of 2013 with planning of the COPA. COPA is carried out in collaboration with the SIEF project 'The Distal Footprints of Giant Ore Systems: UNCOVER Australia'. SIEF includes collaborative research between CSIRO, UWA, Curtin University and GSWA that targets the mineral systems in the Capricorn Orogen. The deployment of the COPA commenced in early 2014 (see also ES31 Deep Seismic Survey Program). In parallel to the COPA study and in order to develop a technical template for revolving seismic anisotropy structure for long-operating stations, Dr Yuan, and his US colleague Vadim Levin, targeted several permanent sites in the US, where they observed promising anisotropic signals that may be related to fossil rifting processes and the current plate–asthenosphere coupling. The newly developed technique will be applied to the previously collected seismic waveform data and data from the semipermanent sites in Western Australia in the coming year. Yuan intends to report preliminary results of the COPA deployment at the American Geophysical Union General Meeting in San Francisco in December 2014.

A similar study commenced in October 2013 as a collaborative Australian Research Council Linkage Project LP130100413 'Craton modification and growth: The east Albany–Fraser Orogen in three dimensions' (see also ES31 Deep Seismic Survey Program). This project includes Dr Hrvoje Tkalcic, Prof. Brian Kennett and Dr Christian Sippl from ANU, and Catherine Spaggiari and Klaus Gessner from GSWA, who will investigate the lithosphere structure of the Albany–Fraser Orogen using a passive seismic array. GSWA has supported the instrument deployment and data collection, and collaborates on the geological interpretation.

3D Geoscience intensified its work with Eun-jung Holden's research group at CET on the Integrated Exploration Platform project that focuses on novel approaches to imaging, analysing and integrating geoscience data. 3D Geoscience has supported a

successful research proposal 'Reducing 3D uncertainty via improved data interpretation methods' that was submitted to the ARC Linkage program for funding beginning in 2014.

X-ray microtomography data of rocks from the northern Yilgarn Craton that were acquired in a research collaboration between GSWA, UWA, CSIRO, Otago University and the Advanced Photon Source (APS) at Argonne National Laboratories in the US were analysed and interpreted in the context of craton evolution and the formation of gold mineralization. Preliminary results are expected to be released in 2014–15.

GSWA has continued to support ARC Linkage project LP100200387 Multiscale Dynamics of Ore Body Formation at CET. This project is developing models for hydrothermal mineralizing systems from the scale of the Earth's lithosphere down to the scale of an orebody to define measurable parameters that control the size of such systems and that can be used as mineral exploration criteria.

In 2013–14 CET researchers contributed to ES42 by interaction with GSWA staff from the Yilgarn Craton, Albany–Fraser Orogen and Musgrave Province mapping teams.

Products released 2013–14

Several papers in final version of Record 2013/6 as follows:

Interpretation of the potential field of the South Carnarvon Basin, and the Narryer and Youanmi terranes in Western Australia: multiscale edge detection (worms), forward modeling, and cross-gradient joint inversion

Main crustal-scale features of the Youanmi seismic transect

Preliminary interpretation of the Youanmi deep seismic reflection lines for Proterozoic intrusive rocks

Preliminary interpretation of deep seismic line 10GA–YU2: Youanmi Terrane and western Kalgoorlie Terrane

Preliminary interpretation of the 2010 Youanmi deep seismic reflection lines and magnetotelluric data for the Windimurra Igneous Complex

Preliminary interpretation of deep seismic lines 10GA–YU3 and the southeastern part of 10GA–YU1: Murchison Domain of the Youanmi Terrane

Preliminary interpretation of the northern section of deep seismic line 10GA–YU1: Narryer Terrane to Murchison Domain of the Youanmi terrane

Geodynamic implications of the Youanmi and Southern Carnarvon deep seismic reflection surveys: a ~1300 km traverse from the Pinjarra Orogen to the eastern Yilgarn Craton

Youanmi and Southern Carnarvon traverses: implications for mineral systems

Several papers in the preliminary version of Record 2014/6 as follows:

Interpretation of Albany–Fraser seismic lines 12GA–AF1, 12GA–AF2 and 12GA–AF3: implications for crustal architecture

Interpretation of gravity and magnetic data across the Albany–Fraser Orogen

Geodynamic implications of the 2012 Albany–Fraser deep seismic reflection survey: a transect from the Yilgarn Craton across the Albany–Fraser Orogen to the Madura Province

Products released 2013–14*Other*

Structure and timing of Neoproterozoic gold mineralization in the Southern Cross district (Yilgarn Craton, Western Australia) suggest leading role of late Low-Ca I-type granite intrusions

3D Fault Network of the Murchison Domain, Yilgarn Craton

The Mesoproterozoic thermal evolution of the Musgrave Province in central Australia — plume vs. the geological record

Integrated Exploration Platform: An Interactive Multi-Data Interpretation Tool

On shearing, magmatism and regional deformation in Neoproterozoic granite-greenstone systems: Insights from the Yilgarn Craton

Planned work program and products 2014–15 and beyond

Projects — supporting GSWA programs

3D Geoscience will continue to contribute to regional mapping project groups. The focus will be on a number of regional 3D modelling studies, potential field interpretations accompanying the seismic interpretation of the Eucla–Gawler seismic survey, and on fieldwork in the Murchison Domain, Musgrave Province and Narryer Terrane areas. Contributions are planned to external manuscripts on the Yilgarn Craton, the Capricorn Orogen and the Albany–Fraser Orogen.

3D models and accompanying Records are planned within the 3D Geoscience section for the Sandstone region, and the Albany–Fraser Orogen as well as a 3D fault network model the northwest and central Yilgarn Craton. Further 3D modelling work will be carried out by external collaborators on the Capricorn Orogen and the Kimberley region. We will also continue geophysical validation of cross-sections for map production for the 1:100 000 Geological Series maps, with an accompanying short explanatory record.

Research collaboration

Within the ARC CCFS Huaiyu Yuan will focus on the COPA to investigate crustal structure of the Capricorn Orogen and the architecture of the lithospheric mantle. A suite of passive source methods will be applied in conjunction with the COPA to develop a technical template for resolving seismic anisotropy structure for long-operating stations.

3D Geoscience will continue to support and collaborate with the ARC Linkage project at CET on ‘Multi-scale Dynamics of Ore Body Formation’. ES42 is providing support for a MRIWA project at CET on ‘Multi-scale Dynamics of Hydrothermal Mineral Systems’, supported by a number of mineral exploration companies.

3D Geoscience will work with the research groups of Eun-jung Holden and Western Australian Fellow Mark Jessell at CET on the recently awarded ARC Linkage project LP140100267 ‘Reducing 3D uncertainty via improved data interpretation methods’, that will start later in 2014.

ES42 will also support Adam Beall, a PhD student at The University of Melbourne, who carries out numerical studies on Archean lithosphere dynamics.

Products planned for release 2014–15

Contributions to Record on interpreting the Albany–Fraser Orogen and Eucla basement seismic surveys

Contribution to Report on Alteration and Geochemical Footprint of VMS-style mineralization, Quinns district, Murchison Domain, Western Australia

Report Multiscale Dynamics of Ore body formation

Report Determining crustal architecture in the east Albany–Fraser Orogen from geological and geophysical data

Sandstone and Windimurra 3D models and accompanying Records

GSWA and international journal publications on the crustal structure and mantle architecture and type in the northwest, central and eastern Yilgarn Craton

ES45 Geological Mapping and Interpretation

Manager: Julie Hollis

The objective of this program is to undertake regional mapping of bedrock and regolith, and the interpretation from geophysical data of bedrock under thin regolith and sedimentary basin cover. Work concentrates on remote greenfields areas in Western Australia, including the Kimberley region, west Arunta, west Tanami, and Capricorn Orogen. These areas are underexplored due to their remoteness, land access issues, and the lack of up-to-date pre-competitive geoscience datasets. This activity is providing new mapping and interpretations, and making existing legacy data available in digital format.

In the Capricorn Orogen, the accelerated mapping is improving the understanding of the geological setting of mineralization. Mapping is focused on the late Paleoproterozoic to Mesoproterozoic Edmund and Collier Basins, which contain Abra, Western Australia's largest stratabound lead–silver–copper–gold deposit. This, combined with their age and geological setting, makes the Edmund and Collier Basins together one of the most prospective areas in Australia for large, blind, sediment-hosted base metal orebodies. The Edmund and Collier Basins also have a history of minor gold and phosphate production. Additional work will be carried out in basement rocks of the Gascoyne Province, which also host a variety of poorly understood mineral deposits including base metals, gold and uranium. Work will concentrate on understanding the geological evolution and architecture of the northern part of the province in order to better constrain the timing and setting of these deposits.

In the Kimberley region, high-quality geoscience mapping is available although some is not in GSWA's current format for digital GIS datasets. A seamless solid geology layer at nominal 1:100 000 scale and a seamless regolith layer are being created for the region. This is complemented by new field mapping, focused on understanding the timing and nature of tectonism in the Paleoproterozoic Lamboo Province and the depositional environments and crustal architecture of Paleo- to Neoproterozoic sedimentary successions including the Speewah, Kimberley and Mount House Groups.

An understanding of the derivation of regolith and distribution of different regolith types using remotely sensed imagery and field observations not only provides a complementary regolith coverage to bedrock distribution, it can also provide information on the genetic relationship between regolith and bedrock, and an estimate of the extent and likely thickness of transported regolith. This information is important in designing and interpreting the results of regolith geochemistry programs. Further, regolith itself can host significant mineralization, including iron ore, nickel and gold.

Under this program GSWA has entered into a Research Agreement with CET at UWA to provide exploration targeting products. These are designed to communicate effectively the potential of underexplored regions of Western Australia in easy-to-understand formats for geoscientists in the exploration industry.

Outcomes of work program 2013–14

In the Capricorn Orogen, field mapping has produced interpreted bedrock geology and regolith maps of the THREE RIVERS 1:100 000 map sheet (see GS49 Edmund and Collier Basins and GS47 Gascoyne Province).

One second edition (WATTS) and two first edition (SLATEY CREEK and BALWINA) 1:100 000 Geological Series maps were released for the West Tanami region.

During 2013–14 the targeting program continued with completion of Report 123 on the 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province, and Report 135 on an MT traverse across the eastern part of the Capricorn Orogen.

Products released 2013–14

WATTS, SLATEY CREEK, and BALWINA 1:100 000 Geological Series maps^(a)

West Tanami GIS 2014^(a)

THREE RIVERS 1:100 000 Geological Series map^(b)

West Capricorn Orogen GIS 2014 including MOUNT VERNON and JAMINDI 1:100 000 Geological Series maps^(b)

Report 123 and data package 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province

Report 135 A magnetotelluric traverse across the eastern part of the Capricorn Orogen

(a) See also GS56 North Australian Craton

(b) See also GS49 Edmund and Collier Basins

Planned work program and products 2014–15

During 2014–15, work in the Capricorn Orogen will focus on rocks of the Edmund and Collier Basins, and the northern Gascoyne Province. In the Edmund and Collier Basins the CARDAWAN 1:100 000 Geological Series map will be field checked and released. Also preliminary versions of ILGARARI, WONYULGUNNA and LOFTY RANGE 1:100 000 Geological Series maps will be compiled.

A Report on the geochemistry of mafic dykes and sills in the Capricorn Orogen will be released, as will the West Capricorn Explanatory Notes (Edmund and Collier Basins).

In the west Tanami region, work during 2014–15 will concentrate on compiling first edition KEARNEY and LEWIS 1:100 000-scale Geological Series maps.

Targeting studies of the King Leopold Orogen and the Halls Creek Orogen will be completed.

Products planned for release 2014–15

CARDAWAN 1:100 000 Geological Series map^(a)

Report Geochemistry of mafic dykes and sills in the Capricorn Orogen^(a)

West Capricorn Orogen GIS 2015^(a)

West Capricorn Explanatory Notes (Edmund and Collier Basins)^(a)

Report on the mineral prospectivity of the King Leopold Orogen

Report on the crustal architecture of the Halls Creek Orogen

Preparation of two new 1:100 000 Geological Series maps (KEARNEY and LEWIS), West Tanami^(b)

West Tanami GIS 2015^(b)

(a) See also GS49 Edmund and Collier Basins

(b) See also GS56 North Australian Craton

Products planned for release 2015–16

Report Northern Capricorn Orogen targeting

Report Southeast Capricorn Orogen targeting

LOFTY RANGE 1:100 000 Geological Series map

WONYULGUNNA 1:100 000 Geological Series map

ILGARARI 1:100 000 Geological Series map

West Capricorn Orogen 2016 GIS update^(a)

West Capricorn Explanatory Notes update^(a)

Report east Kimberley targeting product

WEBB 1:250 000 Geological Series map^(b)

MACDONALD 1:250 000 Geological Series map^(b)

(a) See GS49 Edmund and Collier Basins

(b) See GS56 North Australian Craton

Planned work program and products 2015–16 and beyond

Work during 2015–16 and beyond will focus on the mapping, compilation and stratigraphic analysis of Bangemall Supergroup rocks in the central and eastern parts of the Capricorn Orogen, including LOFTY RANGE, WONYULGUNNA and ILGARARI 1:100 000 Geological Series maps. Mapping will continue in the northern Capricorn Orogen on the UAROO and BOOLALOO 1:100 000 Geological Series maps where rocks of the Proterozoic Ashburton Basin are exposed. The geochemical characterization of mafic rocks in the orogen will continue, as well as K–Ar geochronology on fault gouges in conjunction with Professor Zwingmann at CSIRO.

In the west Arunta region, work will focus on the compilation of two 1:250 000-scale geological series maps – WEBB and MACDONALD.

Targeting products will cover the southeast Capricorn Orogen (Yerrida, Bryah, Padbury and Earraheedy Basins) and the Kimberley region (Halls Creek Orogen).

ES46 Enhanced Geochronology and Acquisition of Isotope Data

Manager: Michael Wingate

Team members: Chris Kirkland (isotope geochemistry specialist), John Williams (laboratory manager)

This project aims to extend and enhance GSWA's U–Pb geochronology program with the addition of Lu–Hf isotope analysis of dated minerals, in situ dating of phosphate minerals, and Sm–Nd isotope analysis of whole-rock samples. These data contribute directly to our understanding of crustal evolution in Western Australia. Variations in the abundance of isotopes (principally Sm–Nd, Lu–Hf, and Rb–Sr) reveal information about the composition of the sources of rocks and minerals, and their fractionation in the Earth's crust and mantle. This information allows the timing of crust formation and juvenile mantle input to be determined. Knowledge of crustal evolution is important for understanding mineralization, because the addition of juvenile material from the mantle into the crust is commonly associated with mineralizing events.

In situ phosphate geochronology is conducted in collaboration with researchers at Curtin University, as part of a new three-year GSWA – Curtin University ARC Linkage project 'Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: constructing a geological framework for understanding mineral systems'. Measurement of Hf isotopes in previously dated zircon and baddeleyite crystals provides important information for understanding the evolution and architecture of the crust. Nd isotopes, in a similar manner to Hf isotopes, reveal fractionation processes in the crust and can provide an estimate of the time at which a source melt was separated from the mantle — a key process that directly influences the mineral endowment of a region. Using these techniques to elucidate both the temporal and spatial input of juvenile material into the crust is an important tool for reducing exploration risk.

Management of project risks

Delays to the isotope geology component of this program may occur due to failure of either TIMS or LA-ICPMS instruments at collaborating institutions. Slow return of datasets and interpreted results from collaborating external researchers may delay the release of GSWA products that rely on this information.

Outcomes of work program 2013–14

About 2000 previously dated minerals (mainly zircons) from c. 110 samples were analysed for Lu–Hf isotopes during 2013–14. The samples represent igneous, metamorphic, and sedimentary rocks selected from the Pilbara Craton, the Eastern Goldfields Superterrane and

Murchison Domain of the Yilgarn Craton, the Albany–Fraser Orogen, the Gascoyne Province, and the Kimberley and Amadeus Basins. The results are significant for understanding the crustal evolution of Western Australia, and feature prominently in new GSWA publications and external journal articles. Notable highlights include:

- a refined delineation of crustal blocks within the Yilgarn Craton, including evidence for reworking of Eoarchean crust during Meso-Neoproterozoic magmatism in the Murchison, and charting this evolution in three dimensions (Fig. 37)
- confirmation that the Biranup and Fraser Zones of the Albany–Fraser Orogen are autochthonous and that the gold-mineralized Tropicana Zone has a Yilgarn-like crustal source
- the discovery of a new basement component within the Musgrave Province and its extension into the Rudall Province and northern margin of the Gawler Craton
- improving our understanding of the Mesoproterozoic Giles magmatic event in the west Musgrave Province, including one of the largest supervolcanoes in Earth's history
- refining our understanding of the crustal architecture of the Gascoyne Province by demonstrating the spatial distribution of old crust (Glenburgh Terrane) at depth, and imaging its influence on magma genesis over space and time.

In situ U–Th–Pb geochronology of the phosphate minerals monazite and xenotime continue to improve our understanding of complex tectonic, low-temperature metamorphic, and mineralization events in the Capricorn Orogen. Together with studies of the P–T–t evolution of metamorphic rocks, the new data help to define the tectonic setting and thermodynamic evolution of the 1385–1170 Ma Matherbukin Tectonic Event (see GS47 Gascoyne Province). Additional U–Th–Pb phosphate geochronology has been completed from the Abra polymetallic deposit.

About 160 samples for Sm–Nd whole-rock analysis were submitted for analysis in 2013–14, mainly from underexplored areas of Western Australia, including the Kimberley region, Musgrave Province, and the Albany–Fraser Orogen. Data received so far have been normalized to accepted GSWA standard values, checked for consistency and disseminated to GSWA projects, and made available on the GSWA Geochemistry (GeoChem Extract) Web page.

The Sm–Nd data, together with complementary Lu–Hf data, have contributed significantly to understanding the

geological evolution of the Musgrave Province, Albany–Fraser Orogen, and Yilgarn Craton. New and revised data from Proterozoic granites of the Albany–Fraser Orogen and Madura Province are helping to unravel the complex geometry of the southeastern margin of the West Australian Craton. Granites in the southeastern Nornalup Zone of the Albany–Fraser Orogen have non-radiogenic compositions, reflecting variable recycling of Archean crust, and supporting the interpretation that the entire Albany–Fraser Orogen was constructed upon Yilgarn Craton basement variably influenced by new radiogenic mantle additions. In contrast, radiogenic Nd isotopic compositions of the most southeasterly syenogranites reflect melting of an exotic juvenile source, suggesting that the Rodona Shear Zone constitutes the boundary between the Albany–Fraser Orogen and the Madura Province.

Products released 2013–14

Report 137 Basin formation by orogenic collapse: zircon U–Pb and Lu–Hf isotope evidence from the Kimberley and Speewah Groups, northern Australia

Report 133 Tectonic links between Proterozoic sedimentary cycles, basin formation and magmatism in the Albany–Fraser Orogen

Report 129 Sedimentological and structural evolution of the Mount Ragged Formation, Nornalup Zone, Albany–Fraser Orogen, Western Australia

Report 122 The crustal evolution of the Rudall Province from an isotopic perspective

Report 120 Juvenile crust formation and recycling in the northern Murchison Domain, Yilgarn Craton: evidence from Hf isotopes and granite geochemistry

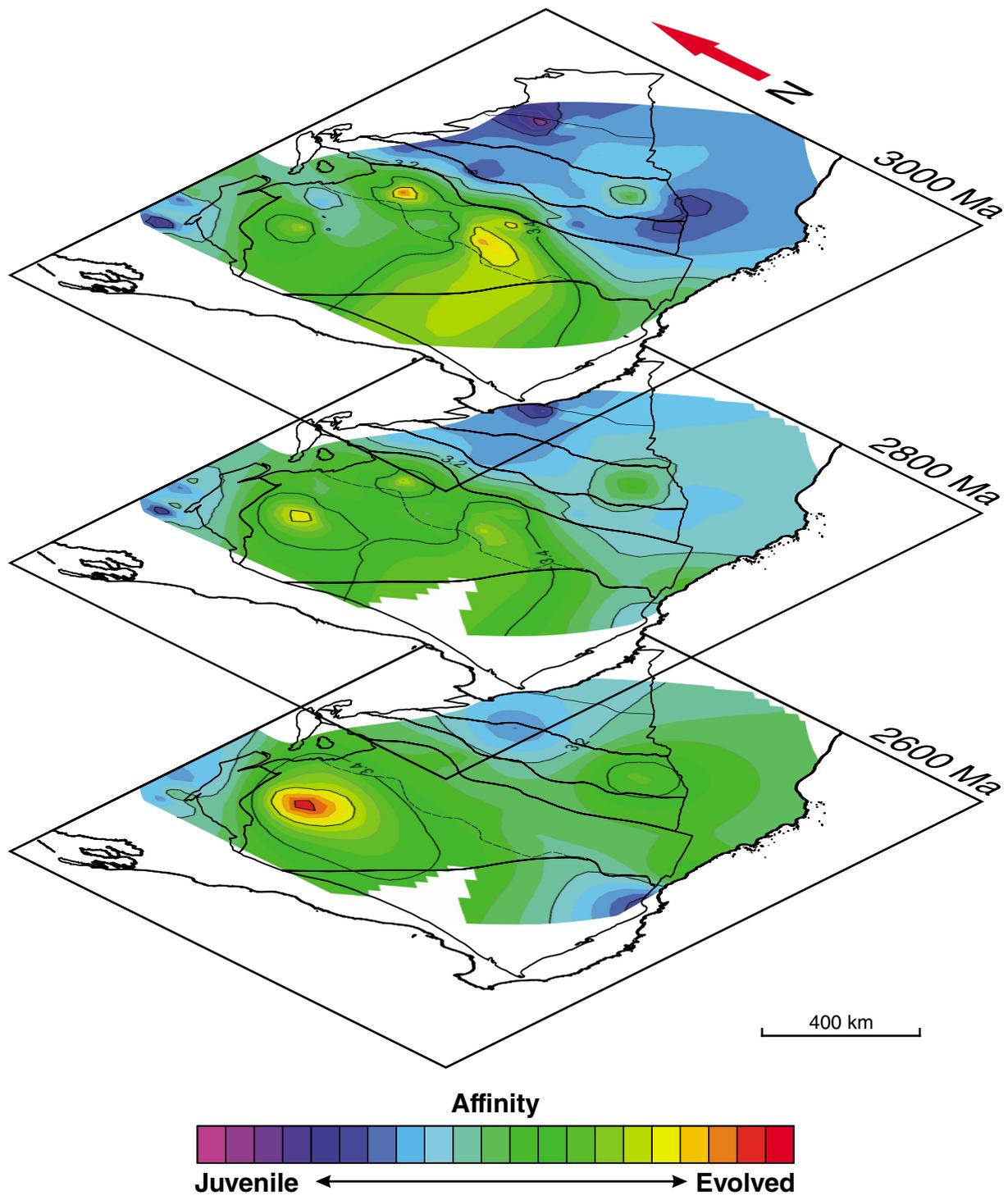
More than 200 Lu–Hf and Sm–Nd datasets released to online viewing applications (GeoVIEW.WA and GeoChem Extract)

Planned work program and products 2014–15

The three work streams (Lu–Hf, Sm–Nd, and in situ phosphate dating) in this project will continue in 2014–15. Data generated by this program will be checked for accuracy and consistency, provided to GSWA projects, and published on the GSWA website as they become available. The results will be integrated with geological and geochemical data and newly acquired gravity, aeromagnetic, seismic, and MT datasets, to advance our understanding of crustal architecture, geological evolution, and mineralization. Syntheses will be published as GSWA Reports or Records and will inform other GSWA and external publications. The work will be aimed in part at addressing specific geological questions in key areas, particularly along new geophysical transects, and in underexplored regions, where the new information will also improve the targeting of mineral exploration.

Planned work program and products 2015–16 and beyond

The planned work program for 2015–16 and beyond will be similar to that for 2014–15. New samples will be collected during the normal course of GSWA fieldwork to address specific geological problems.



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Figure 37. EIS — spatially interpolated average Hf isotopic signatures at three times during Yilgarn Craton evolution. These maps are derived from Lu–Hf isotope ratios in zircons from intrusive rocks that have effectively sampled various levels of the cratonic crust. The maps reveal the evolution of the crust in space and time, and highlight juvenile (rift) zones, areas of cratonization, and lithosphere-scale structures.

ES47 Shale Gas, Coal and CO₂ Geosequestration Program

Manager: Ameen Ghori

Team members: Alan Millar, Charmaine Thomas

The objective of this program is to collect pre-competitive data to assist in determining the State's potential for alternative energy sources that might provide for the State's growing energy requirements. This program comprises a number of distinct subprograms.

The Perth Basin has undeveloped tight gasfields with up to 226 Gm³ (8 TCF) of reserves located near infrastructure. However, technical and geological issues have left this resource untouched. Nevertheless, innovations in technology in the US and Canada make tight gas a viable addition to the State's domestic gas market.

During the last decade, shale gas plays have become an important supply of natural gas in the US. Interest in exploring shale gas plays is rapidly spreading worldwide, including the sedimentary basins of Western Australia. A collaborative project with Curtin University researching the shale gas potential of the Perth and Canning Basins is part of this program.

Current geothermal projects have been completed and reported on, and there are no plans to continue geothermal research under the current EIS program.

Finally, the need for CO₂ geosequestration sites near the major emitters requires further geological studies and data acquisition. Projects, funded jointly by the Commonwealth and EIS, involving the acquisition of new seismic data and stratigraphic drilling are planned for the Canning and Perth Basins. In addition, the Basins and Energy Geoscience section will continue to supply expertise and assistance to the program of work on the South West CO₂ Geosequestration Hub, which is managed by Dominique Van Gent, Carbon Strategy Branch of the Strategic Policy Group, DMP.

Outcomes of work program 2013–14

The following collaborative projects with GA, on CO₂ geological storage and a long deep seismic line that crosses the entire Canning Basin (from the Pilbara to the Kimberley) have been completed:

- The carbon storage atlas of strategic basins in Western Australia was completed in late 2013, and results were published in Report 126. Its GIS package on USB was completed in early 2014. For this study a contract was awarded to 3D-GEO Pty Ltd in January 2011.

- The carbon storage assessment of the on-shore western Eucla Basin was completed in June 2014 and results were published in Report 138 and also as a GIS package. For this study a contract was awarded to FROGTECH Pty Ltd in late 2013.

- Acquisition of seismic and gravity data for the Canning Basin (Kimberley) Deep Crustal Geophysical Survey was completed on 30 June 2014. For this survey, a contract was awarded by GA to Terrex; it was completed in 41 days (21 May – 30 June 2014). Raw and processed data will be released progressively in 2014–15.

The following research collaborative projects with universities and CSIRO have been completed and reports submitted to GSWA for publication; results will be published in 2014–15:

- Geosequestration potential of the Permian Grant Group and Permian Poole Sandstone, Northwest Canning Basin, Western Australia, UWA
- Regional structural and stratigraphic study of the Canning Basin, Western Australia, UWA
- Correlation of the early Permian Poole Sandstone and Noonkanbah Formation and implications for CO₂ sequestration by Louisa Dent, MS thesis, supervisor Annette George, UWA
- Mineral prospectivity of the King Leopold Orogen and Lennard Shelf: potential field analysis in the West Kimberley, UWA
- A study of the shale gas geomechanics in the Northern Perth Basin, Western Australia, MRIWA report 307, published in May 2014, Curtin University.

Products released 2013–14

Report 126 Western Australia carbon dioxide geological storage atlas and GIS data package

Report 138 CO₂ storage assessment of the on-shore western Eucla Basin and GIS data package

Canning Basin (Kimberley) Deep Crustal Geophysical Survey, seismic and gravity data acquisition. Raw and processed data packages will be released in 2014–15

MRIWA Report 304 — A study of shale gas geomechanics in North Perth Basin, Western Australia

Planned work program and products 2014–15 and beyond

Ongoing studies for the shale gas, coal and CO₂ geosequestration program include:

- completion of a review of the coal resources of Western Australia and their suitability to the extraction of coal bed methane and use in underground coal gasification
- completion of the Harvey 1 Well Completion Report
- continuing CO₂ geological storage studies, in collaboration with GA, in the Perth and Canning Basins. This is expected to include drilling of one to two stratigraphic wells, with perhaps one in each of the Canning and North Perth Basins
- publication of research result projects as GSWA publications.

Products planned for release 2014–15

Report Geosequestration potential of the Permian Grant Group and Permian Poole Sandstone, Northwest Canning Basin, Western Australia

Report Mineral prospectivity of the King Leopold Orogen and Lennard Shelf: potential field analysis in the West Kimberley

Report Regional structural and stratigraphic study of the Canning Basin, Western Australia

Report Correlation of the early Permian Poole Sandstone and Noonkanbah Formation and implications for CO₂ sequestration

Canning Basin (Kimberley) Deep Crustal Geophysical Survey, seismic and gravity data acquisition. Raw and processed data package will be released in 2014–15

Report Harvey 1 Well completion report

ES50 Strategic Industry Research Program

Manager: Margaret Ellis

Team members: Don Flint, Ian Tyler, Stephen Wyche, Trevor Beardsmore, CSIRO, MERIWA/MRIWA

This program encompasses the following two activities:

- Expansion of research into greenfields exploration with funding support by EIS to MERIWA/MRIWA of \$350 000 per annum
- The Western Australia Regional Researcher Initiative.

This latter activity is aimed at the rapid transfer of new geoscience concepts, skills and technologies into GSWA and the Western Australian minerals exploration industry. Three Western Australian Researcher Initiative projects are funded by the EIS with the main focus of the program in the Albany–Fraser Orogen and adjacent basement to the Eucla Basin where some formidable exploration challenges exist.

Outcomes of work program 2013–14

Five MERIWA/MRIWA projects are being supported by EIS funding, as follows:

- High-grade gold deposits: processes to prediction
- Geochemical greenfields exploration in a regolith dominated terrane: the Yilgarn margin and Albany–Fraser belt, implications for mineral systems prospectivity
- Improved hydrogeochemical exploration in the northwest Yilgarn: adding value to an underexplored area
- A study of shale gas geodynamics in the Perth Basin
- Multiscale dynamics of hydrothermal mineral systems.

The Western Australia Regional Researcher program is managed by CSIRO with three projects with embedded researchers being undertaken in the Yilgarn and Albany–Fraser – Eucla regions.

A multicompany sponsored project in the Albany–Fraser – Eucla margin, employing a CSIRO Embedded Researcher is focusing on the geology and geochemistry in partnership with industry and GSWA. The project is designed to integrate a range of expertise to provide research and development support for exploration in the region and to learn from the discovery of the Tropicana and Havana gold deposits.

GSWA has integrated a researcher into its operations, to undertake research with the aim of increasing the level of copper and zinc prospectivity in the Yilgarn Craton.

The third project of the Western Australian Regional Researcher initiative is focusing on cutting-edge analytical technologies on understanding the formation of eastern Yilgarn gold deposits, simultaneously providing ‘line of site’ through the minerals system framework to the problems of exploration. The outcome will be a template for precision targeting within architecturally and geodynamically constrained domains of the Eastern Goldfields Province.

Planned work program and products 2014–15

Most of the Western Australia Regional Researcher Initiative projects are due for completion in the second half of 2013 and reports from these projects will be prepared for publication with release during 2014. Funding is continuing for the ‘Volcanic Hosted Massive Sulphides (VHMS) Exploration in the Yilgarn Craton’ embedded researcher program, which is due for completion in 2015.

The additional funding from EIS to MERIWA/MRIWA will continue to support projects through to June 2017.

ES60, ES62, ES64 Indigenous Programs

Manager: Margaret Ellis

These programs encompass the following activities:

- Development of an Indigenous Land Use Agreement (ILUA) for airborne geophysical surveys for petroleum exploration over the Central Desert Basin
- Development of a two-part Regional Land Access and Cultural Heritage Agreement ('Regional Agreement') for exploration activities associated with geothermal energy in the South West Aboriginal Land and Sea Council (SWALSC), Yamatji Marlpa Aboriginal Corporation (YMAC) Representative Body Areas, Mullewa Wadjari Community and Burrabalayji Thalanyji Aboriginal Corporation (BTAC) areas
- Development of a model ILUA with the Central Desert Native Title service that facilitates heritage surveys being conducted ahead of ground disturbing work on exclusively determined lands.

Planned work program and products 2014–15

No work is planned in 2014–15 and beyond. These programs are not funded under EIS2 for the period 2014–15 to 2016–17.

Outcomes of work program 2013–14

No work was undertaken on these projects in 2013–14. These projects have been suspended as a result of the State Government's streamlining of the process of negotiating land access with traditional owners.

In a move to improve services to indigenous communities, all negotiations for ILUAs and access agreements are now being managed by a single government body (Department of Premier and Cabinet) on a whole-of-government basis.

ES61 Access Ready Land for Petroleum and Mineral Exploration

Manager: Margaret Ellis

This program is focused on establishing networks that promote good working relationships with Aboriginal and community interests. These links are vital in gaining long-term and sustainable land access for GSWA and the mining industry throughout Western Australia.

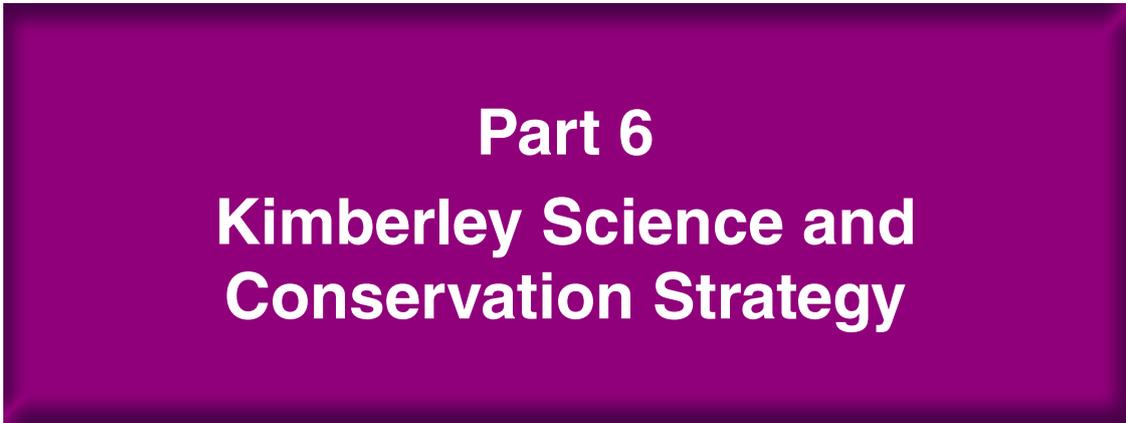
Planned work program and products 2014–15

No further work is planned for 2014–15.

Outcomes of work program 2013–14

A project to remap the 10-km buffer zones around registered heritage sites was completed. This project was carried out in association with the Department of Indigenous Affairs (DIA).

A project to scan hard copies of DIA heritage reports continued with over 7000 reports being scanned. This project was carried out in association with DIA.



Part 6
**Kimberley Science and
Conservation Strategy**

KS01 Kimberley Science and Conservation Strategy Geophysical Surveys

Manager: Ian Tyler

Team members: David Howard, John Brett, Julie Hollis

Outcomes of work program 2012–13

Two Geophysical Survey Programs (gravity and MT) were planned under the Kimberley Science and Conservation Strategy (KSCS). The collection of gravity data at 400 m-spacing along public roads across the Kimberley Basin has been completed and has been released through the Geophysical Archive Data Delivery System (GADDS), which can be accessed via the National Geoscience Web Portal (www.geoscience.gov.au).

The MT method is a deep-penetrating passive electromagnetic method suitable for deriving conductivity–depth variations within the entire crust and the underlying mantle. MT is a useful tool for terrane-scale studies designed to delineate major crustal blocks and associated fault structures. A survey following the same lines as the gravity traverses, investigating the structure of the crust and mantle underlying the Kimberley Basin and the adjacent King Leopold and Halls Creek

Orogens, was completed in August 2012 (Fig. 25 and 38) and Report 136 was released in 2013–14. It is part of a series of MT surveys that are being collected across Australia as part of the National GeoTransect Program to build up a 3D image of the Australian plate, and its evolution through time.

Product released 2013–14

Report 136 A magnetotelluric survey across the Kimberley Craton, northern Western Australia

The project is now complete as project funding finished at the end of 2013–14; hence, no work is planned for 2014–15 or beyond.

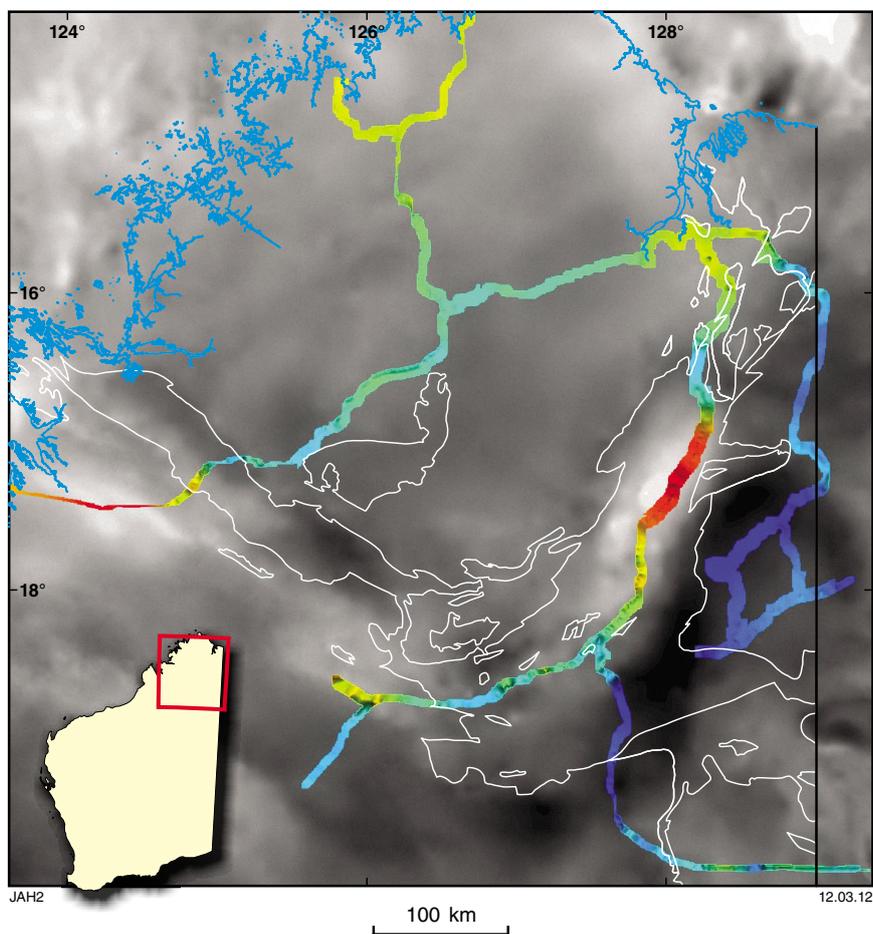


Figure 38. KSCS — 400 m spaced gravity traverses data across the Kimberley Basin, overlain on a regional Bouguer anomaly image

KS02 Baseline Geochemical Surveys

Manager: Paul Morris, Julie Hollis

Team members: Nadir de Souza-Kovacs, Christopher Phillips, Andreas Scheib, Karin Orth

GSWA's contribution to the three-year (2011–12 to 2013–14) KSCS is to provide an improved understanding of the geological evolution of the Kimberley area. The majority of GSWA's contribution to this initiative has been the generation of geochemical data for both grid-based soil samples and representative rocks. To put these data in both a spatial and geological context, the program has also included either the revision to, or generation of, both bedrock and regolith maps. The initial aim of the GSWA program was to collect about 3500 soil samples (at a density of one per 25 km²) and rock samples from about 170 locations, over the 88 000 km² of the KSCS area.

These data will provide information on the nature of the crust and mantle in the Kimberley region (in conjunction with geophysical data), landform evolution, and the relationship of rock units to regolith. The results of this program will be integrated into GSWA's Statewide geoscience datasets and databases.

At the conclusion of the initiative, GSWA has carried out regolith and rock sampling programs in four areas of the KSCS — Balangarra, Bunuba, Yuriyangem–Taam and Dambimangari (Fig. 39). Due to the limited road or track access, the ruggedness of the terrain and the necessity to gain access to all sample sites with minimal environmental impact, all soil sampling and most rock sampling was carried out by helicopter. Although rock sampling and detailed examination of stratigraphic successions focused on the Proterozoic Carson Volcanics and Hart Dolerite (which are widespread within the program area, but little understood), representative sections of all bedrock units were examined and samples collected. The ensuing data (including about 250 litho-geochemical analyses and ten isotopic age determinations) will provide information on the evolution of the Kimberley and Speewah Basins, the nature of the mantle underlying the Kimberley Craton, and the amalgamation of the North Australian Craton. Regolith sampling comprised collection of 407 from the Balangarra area, 152 from Bunuba, 137 from Yuriyangem–Taam and 323 from Dambimangari. In parallel with these programs, a regolith–landform map of the KSCS area has been completed, which required regeneration of a remotely sensed dataset.

Outcomes of work program and products 2013–14

Outcomes for 2013–14 include:

- Completion of interpretive 1:100 000-scale regolith–landform map encompassing the KSCS area, and incorporation of this coverage on a Kimberley GIS
- Regeneration of ASTER satellite data to account for

the influence of green vegetation in the Kimberley area, with 21 improved ASTER scenes incorporated on a Kimberley GIS

- Heritage assessment of Yuriyangem–Taam and Bunuba areas with traditional owners as a precursor to regolith and rock sampling
- Agreement from Dambimangari Aboriginal Corporation to carry out regolith and rock sampling on Dambimangari country
- Collection of 1019 regolith samples and rock samples from the Balangarra, Bunuba, Yuriyangem–Taam and Dambimangari areas
- Generation of multi-element geochemistry [65 analytes as either oxides or trace elements, plus pH and total dissolved solids (TDS)] for regolith and oxide and trace-element data for rock samples collected on the Balangarra program and incorporation of these data on a Kimberley GIS, and into the WACHEM database.

Products released 2013–14

Kimberley GIS, a compilation of available geological data for the KSCS area

Report 136 A magnetotelluric survey across the Kimberley Craton, northern Western Australia

Report 137 Basin formation by orogenic collapse: zircon U–Pb–Hf isotope evidence from the Kimberley and Speewah groups, northern Australia

CHARNLEY 1:250 000 Geological Series map

Products planned for release 2014–15

Multi-element analysis of soil and rock samples collected on Bunuba, Yuriyangem–Taam and the southern part of Dambimangari country, and generation of petrographic and geochronological data for rock samples collected in these areas and the Balangarra area

Generation of explanatory notes discussing the regolith chemistry from the Balangarra, Bunuba, Yuriyangem–Taam and Dambimangari programs, and incorporation of all regolith geochemical data into the WACHEM corporate geochemistry database

Compilation of geological mapping, petrographic, geochemical and isotopic data, to be released in 2015–16 in two Reports on the evolution of the Kimberley and Speewah Basins and the Hart–Carson large igneous province

Kimberley GIS, a compilation of available geological data for the KSCS area

PRINCE REGENT – CAMDEN SOUND 1:250 000 Geological Series map

RICHENDA 1:100 000 Geological Series map

Continued negotiation with indigenous groups to facilitate ongoing access to the Kimberley area

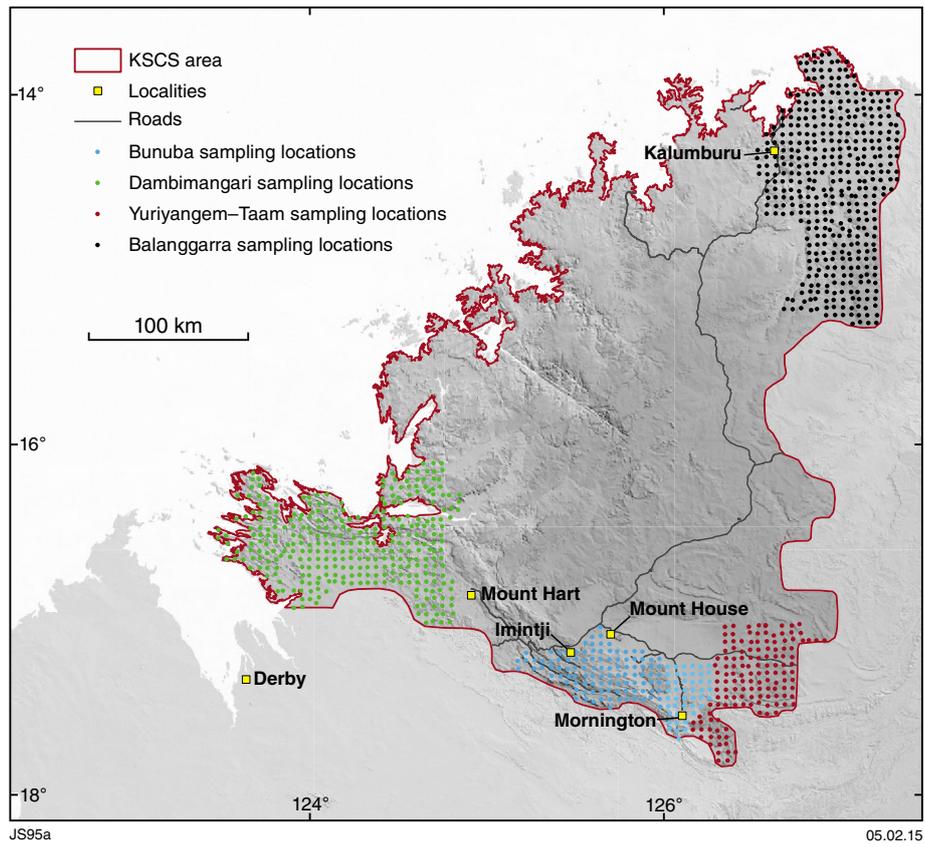


Figure 39. KSCS — regolith and rock sampling programs in four areas — Balangarra, Bunuba, Yuriyngem-Taam and Dambimangari

References

- ACIL Tasman 2010, New Frontiers program: Financial and economic analysis, Report prepared for the NSW Department of Investment and Industry: ACIL Tasman, Melbourne, 88p.
- Behre Dolbear 2014, 2014 ranking of countries for mining investment, "Where not to invest": Behre Dolbear Group Inc., Denver, 10p.
- Department of Treasury 2014, 2014–15 Budget: Economic and fiscal outlook, Budget Paper No. 3: Government of Western Australia, Perth, 319p.
- Economics Consulting Services 2012, The Evaluation of the Plan for Accelerating Exploration (PACE), Report prepared for the South Australian Department of Manufacturing, Innovation, Trade, Resources and Energy: Economics Consulting Services, Perth, 110p.
- Foreign Investment Review Board 2013, Annual Report 2012–13: Commonwealth of Australia, Canberra, 67p.
- Fraser Institute 2013, Global petroleum survey 2013: The Fraser Institute, Vancouver, Canada, 116p.
- Fraser Institute 2014, Survey of Mining Companies 2013: The Fraser Institute, Vancouver, Canada, 132p.
- Lion Selection Group 2014, Investor presentation January 2014: Lion Selection Group, Melbourne, 14p.
- Paydirt 2014, Ranking Australia's states: Paydirt magazine, April 2014, p. 4.
- ResourceStocks 2013, 2013 World Risk Survey: ResourceStocks magazine, October 2013, p. 17–26.
- SNL Metals & Mining 2014, World exploration trends 2014, A special report from SNL Metals Economics Group for the PDAC International Convention 2014: SNL Metals & Mining, Charlottesville, USA, 7p.
- Uncover Group 2012, Searching the deep Earth, A vision for exploration geoscience in Australia: Australian Academy of Science, Canberra, 40p.
- US Energy Information Administration 2011, World shale gas resources: an initial assessment of 14 regions outside the United States: United States Department of Energy, Washington, 365p.

Appendix A

Maps, books and datasets released 2013–14

Geological maps

Geological Series maps

BALWINA, WA Sheet 4558 by *Eacott, GR, de Souza Kovacs, N and Hollis, JA*

CHARNLEY, WA Sheet SE 51-4 by *Phillips, C and de Souza Kovacs, N*

LYNDON, WA Sheet 1950 by *Korhonen, FJ, Johnson, SP, Krapf, CBE and Hocking, RM*

REEDY, WA Sheet 2543 by *Zibra, I, Van Kranendonk, MJ and Chen, SF*

SLATEY CREEK, WA Sheet 4659 by *Eacott, GR, de Souza Kovacs, N and Hollis, JA*

TAY, WA Sheet 3032 by *Romano, SS*

THREE RIVERS, WA Sheet 2747 by *Blay, OA, Cutten, HN and Thorne, AM*

WARBURTON RANGE, WA Sheet 4245 by *Howard, HM, Quentin De Gromard, R and Smithies, RH*

WATTS, WA Sheet 4658 by *Eacott, GR, de Souza Kovacs, N and Hollis, JA*

YOUANMI, WA Sheet 2640 by *Ivanic, TJ*

Non-series maps

Iron ore deposits of the Pilbara region, 2013 by *Cooper, RW*

Iron ore deposits of the Yilgarn Craton — 2013 (1:1 500 000 scale) by *Cooper, RW*

Iron ore deposits of the Yilgarn Craton 2014 by *Cooper, RW*

Major Resource Projects, Western Australia — 2014 by *Cooper, RW, Abeyasinghe, PB, Strong, C and Irimies, F*

Mines — operating and under development, Western Australia — 2014 by *Cooper, RW, Abeyasinghe, PB, Strong, CA and Day, LJ*

Resource projects, Goldfields region — 2013

Resource potential for land use planning series

Aboriginal land, conservation areas, mineral and petroleum titles, and geology, Western Australia — 2014 by *Ridge, KJ*

Basic raw material resources, Karratha 1:200 000

Basic raw material resources, Karratha 1:50 000

Basic raw material resources, Port Hedland 1:200 000

Basic raw material resources, Port Hedland 1:50 000

Plates

A potential long-term source of sand near Boorabbin for the Eastern Goldfields region by *Normore, LS*

Geological interpretation of the Albany–Fraser Orogen and southeast Yilgarn Craton seismic lines, 12GA–AF1, 12GA–AF2, 12GA–AF3, and 12GA–T1 by *Spaggiari, C and Occhipinti, SA*

Interpreted pre-Mesozoic bedrock geology of the east Albany–Fraser Orogen by *Spaggiari, C and Brisbout, L*

Interpreted pre-Mesozoic bedrock geology of the east Albany–Fraser Orogen T1 preliminary by *Spaggiari, C*

Interpreted pre-Mesozoic bedrock geology of the east central and east Albany–Fraser Orogen and southeast Yilgarn Craton by *Spaggiari, C and Brisbout, L*

Plate 1A Geological interpretation of the northwest Yilgarn Craton by *Doublier, MP, Romano, SS and Johnson, SP*

Plate 1B Geological interpretation of the northwest Yilgarn Craton (reference for Plate 1A and Plate 3) by *Ivanic, TJ, Zibra, I, Doublier, MP and Wyche, S*

Plate 2 Geological interpretation of the northwest Yilgarn Craton margin by *Doublier, MP, Romano SS and Johnson, SP*

Plate 3 Geological interpretation of the Youanmi and Southern Carnarvon seismic lines 10GA-YU1, 10GA-YU2, 10GA-YU3, and 11GA-SC1 by *Ivanic, TJ, Zibra, I, Doublier, MP and Wyche, S*

Publications

Bulletins

Bulletin 146 The geology of Shark Bay by *Playford, PE, Cockbain, AE, Berry, PF, Roberts, AP, Haines, PW and Brooke, BP*

Reports

Report 117 Mineral systems analysis of the west Musgrave Province: regional structure and prospectivity modelling by *Joly, A, Aitken, ARA, Dentith, MC, Porwal, A, Smithies, RH and Tyler, IM*

Report 123 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province by *Aitken, AR, Joly, A, Dentith, MC, Johnson, SP, Thorne, AM and Tyler, IM*

Report 124 Petroleum geochemistry and petroleum systems modelling of the Canning Basin, Western Australia by *Ghori, KAR*

Report 125 Regional-scale targeting for gold in the Yilgarn Craton: Part 1 of the Yilgarn Gold Exploration Targeting Atlas by *Witt, WK, Ford, A, Hanrahan, B and Mamuse, A*

Report 126 Western Australia carbon dioxide geological storage atlas by *3D-GEO Pty Ltd*

Report 129 Sedimentological and structural evolution of the Mount Ragged Formation, Nornalup Zone, Albany–Fraser Orogen, Western Australia by *Waddell, P-J*

Report 130 Sedimentology and stratigraphy of the Paleoproterozoic Frere Formation, Western Australia: Implications for the evolution of the Precambrian ocean by *Akin, SJ*

Report 131 The Yuinmery volcanogenic massive sulfide prospects: mineralization, metasomatism and geology by *Hassan, LY*

Report 133 Tectonic links between Proterozoic sedimentary cycles, basin formation and magmatism in the Albany–Fraser Orogen, Western Australia by *Spaggiari, CV, Kirkland, CL, Smithies, RH and Wingate, MTD*

Report 134 Mafic–ultramafic intrusions of the Giles Event, Western Australia: petrogenesis and prospectivity for magmatic ore deposits by *Maier, WD, Howard, HM, Smithies, RH, Yang, S, Barnes, SJ, O'Brien, H, Huhma, H and Gardoll, S*

Report 135 A magnetotelluric traverse across the eastern part of the Capricorn Orogen by *Dentith, MC, Johnson, SP, Evans, S, Aitken, ARA, Joly, A, Thiel, S and Tyler, IM*

Report 136 A magnetotelluric survey across the Kimberley Craton, northern Western Australia by *Spratt, J, Dentith, MC, Evans, S, Aitken, ARA, Lindsay, M, Hollis, JA, Tyler, IM, Joly, A and Shragge, J*

Report 137 Basin formation by orogenic collapse: zircon U–Pb and Lu–Hf isotope evidence from the Kimberley and Speewah Groups, northern Australia by *Hollis, JA, Kemp, AIS, Tyler, IM, Kirkland, CL, Wingate, MTD, Phillips, C, Sheppard, S, Belousova, E and Greau, Y*

Report 138 CO₂ storage assessment of the on-shore western Eucla Basin by *FROGTECH Pty Ltd*

Records

Record 2013/1 Geological Survey work program for 2013–14 and beyond

Record 2013/3 HyLogger-3: Implications of adding thermal-infrared sensing by *Hancock, EA, Green, AA, Huntington, JF, Schodlok, MC and Whitbourn, LB*

Record 2013/6 Youanmi and Southern Carnarvon seismic and magnetotelluric (MT) workshop 2013 by *Wyche, S, Ivanic, TJ and Zibra, I*

Record 2013/11 Geological setting of mineral deposits in the Southern Cross district — a field guide by *Doublier, MP*

Record 2013/12 The ironstone veins of the Gifford Creek ferrocarnatite complex, Gascoyne Province by *Pirajno, F and Gonzalez-Alvarez, I*

Record 2014/2 GSWA 2014 extended abstracts: promoting the prospectivity of Western Australia

Record 2014/3 Regolith geochemistry and mineral prospectivity — the southeast Yilgarn Craton and east Albany–Fraser Orogeny by *Scheib, AJ*

Record 2014/4 Structural evolution of the Yalgoo Dome, Yilgarn Craton, Western Australia by *Caudery, JN*

Record 2014/5 A potential long-term source of sand near Boorabbin for the Eastern Goldfields region by *Normore, LS*

Record 2014/6 Albany–Fraser Orogen seismic and magnetotelluric (MT) workshop 2014: extended abstracts (preliminary) by *Spaggiari, C and Tyler, IM*

Record 2014/7 2D seismic interpretation of the Harvey area, southern Perth Basin, Western Australia by *Zhan, Y*

Record 2014/8 Linking grain-scale to crustal-scale structures along the Youanmi seismic traverse — a field guide by *Zibra, I, Pawley, MJ and Wyche, S*

Non-series books

GSWA calendar 2014

Fieldnotes: A Geological Survey of Western Australia Newsletter July 2013 Number 67

Fieldnotes: A Geological Survey of Western Australia Newsletter October 2013 Number 68

Fieldnotes: A Geological Survey of Western Australia Newsletter January 2014 Number 69

Fieldnotes: A Geological Survey of Western Australia Newsletter April 2014 Number 70

GSWA house style 2014–15

Petroleum State Acreage Release Area L12-12 and L12-13 (Canning Basin)

Petroleum State Acreage Release Area L12-14 (Perth Basin)

Petroleum State Acreage Release Area L14-1 (Canning Basin)

Petroleum State Acreage Release Area L14-2 (Canning Basin)

Spelling and other useful stuff 2014–15

WA unearthed series: Australia goes it alone — the emerging island continent, 100 Ma to present by *Cockbain, A*

Datasets

Non-series digital product

APPEA 2014

Compilation of geochronology information, 2014

Exploration geochemistry of Western Australia 2014 (TerraSearch)

GSWA Open Day 2014

Iron ore deposits of the Pilbara region — 2013

NAPE 2014

Western Australian petroleum acreage release, April 2014

1:100 000 Geological Information Series

East Yilgarn, 2014: Geological Information Series

Murchison, 2014: Geological Information Series

Pilbara, 2014: Geological Information Series

South Yilgarn, 2014: Geological Information Series

West Musgrave, 2013: Geological Information Series

West Tanami, 2014: Geological Information Series

Western Capricorn, 2013: Geological Information Series

Data packages

Karratha – Port Hedland: Basic raw material resources

Report data packages

Report 117 Mineral systems analysis of the west Musgrave Province: regional structure and prospectivity modelling
by Joly, A, Aitken, ARA, Dentith, MC, Porwal, A, Smithies, RH and Tyler, IM

Report 123 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province *by Aitken, AR, Joly, A, Dentith, MC, Johnson, SP, Thorne, AM and Tyler, IM*

Report 125 Regional — Explorer's Guide: Yilgarn Gold Exploration Targeting Atlas *by Witt, WK, Ford, A, Hanrahan, B and Mamuse, A*

Report 126 Western Australia carbon dioxide geological storage atlas *by 3D-GEO Pty Ltd*

Report 138 CO₂ storage assessment of the on-shore western Eucla Basin (supplementary material) *by FROGTECH Pty Ltd*

Appendix B

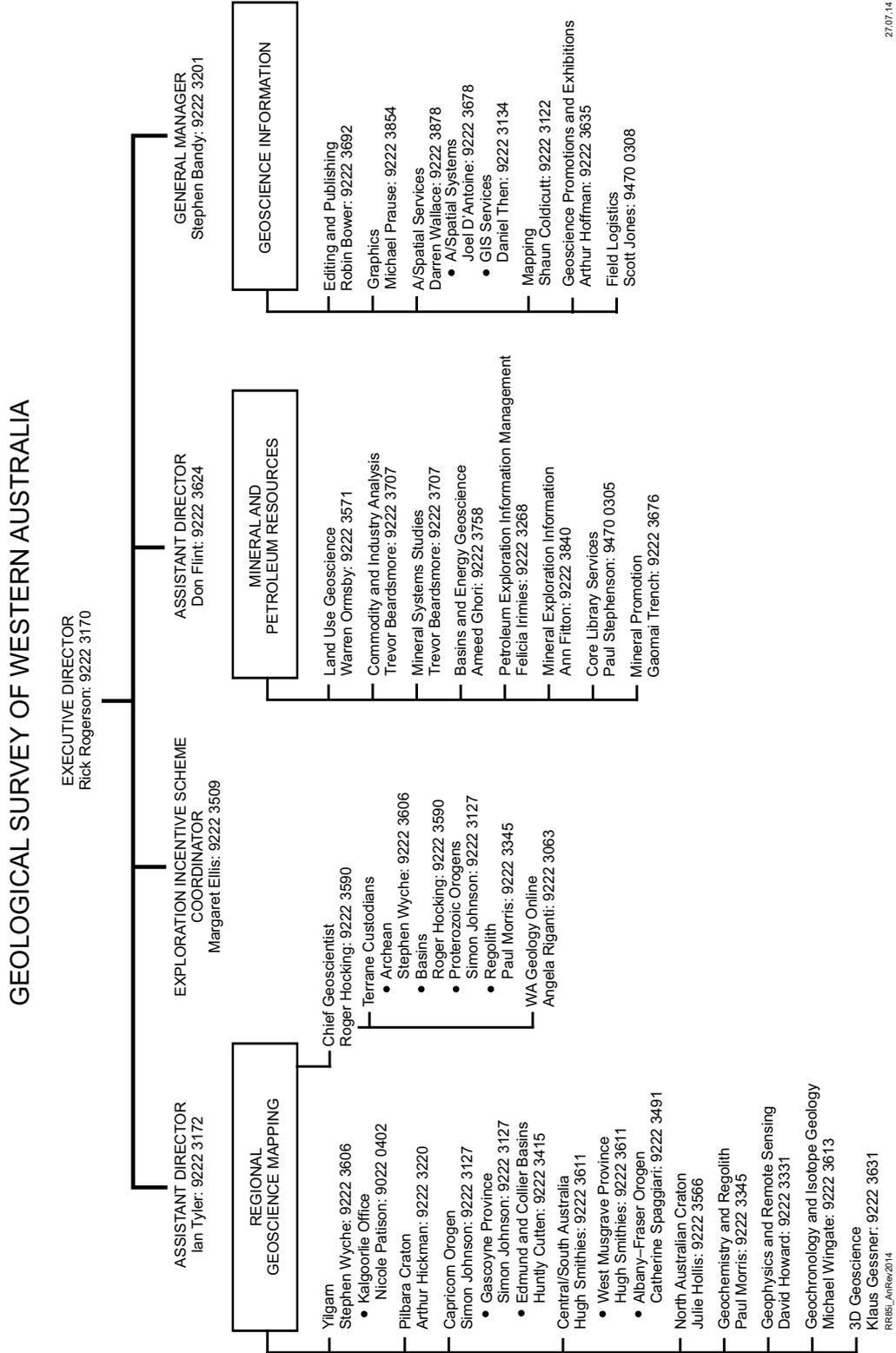
GSWA external papers on Western Australian geoscience 2013–14

- Aitken, ARA, **Smithies, RH**, Dentith, MC, Joly, A, Evans, S and **Howard, HM** 2013, Magmatism-dominated intracontinental rifting in the Mesoproterozoic: The Ngaanyatjarra Rift, central Australia: *Gondwana Research*, v. 24, no. 3–4, p. 886–901, doi: 10.1016/j.gr.2012.10.003.
- Brooke, BP, Olley, JM, **Playford, PE**, **Haines, PW**, Murray-Wallace, CV and Woodroffe, CD 2014, Chronology of Quaternary coastal aeolianite deposition and the drowned shorelines of southwestern Western Australia – a reappraisal: *Quaternary Science Reviews*, v. 93, p. 106–124, doi: 10.1016/j.quascirev.2014.04.007.
- Gazley, MF, Tutt, CM, **Brisbout, LI**, Fisher, LA and Duclaux, G 2014, Application of portable X-ray fluorescence analysis to characterize dolerite dykes at the Plutonic Gold Mine, Western Australia: *Geochemistry, Exploration, Environment, Analysis*, v. 14, no. 3, p. 223–231, doi: 10.1144/geochem2014-270.
- Gorczyk, W, **Smithies, H**, **Korhonen, F**, **Howard, H** and **Quentin de Gromard, R** 2014, Ultra-hot Mesoproterozoic evolution of intracontinental central Australia: *Geoscience Frontiers*, v. 6 (1), p. 23–37, doi: 10.1016/j.gsf.2014.03.001.
- Grice, K, Tulipani, S, Melendez, I, Greenwood, P, Schwark, L, Playton, T, **Haines, P**, **Hocking, R**, Foster, C, Summons, R and Maslen, E 2014, Late Devonian Extinctions: A Novel Conceptual Model for the Paleoenvironment of the Canning Basin, Gogo Formation, WA and Associated Oils: Exceptional Preservational Conditions of Biomarkers and Organic Matter, *in Carbonate Concretions and Basinal Muds: AAPG Annual Conference and Exhibition 2014*, Houston, TX, 6–9 April 2014, Abstracts, <www.searchanddiscovery.com/abstracts/html/2014/90189ace/>.
- Haig, DW, McCartain, E, **Mory, AJ**, Borges, G, Davydov, VI, Dixon, M, Ernst, A, Groflin, S, Håjabssib, E, Keep, M, Dos Santos, Z, Shi, GR and Soares, J 2014, Postglacial Early Permian (Sakmarian–Artinskian) shallow-marine carbonate deposition along a 2000 km transect from Timor to west Australia: *Palaeogeography Palaeoclimatology & Palaeoecology*, v. 409, p. 180–204, doi: 10.1016/j.palaeo.2014.05.009.
- Haines, PW**, **Wingate, MTD** and **Kirkland, CL** 2013, Detrital Zircon U–Pb Ages from the Paleozoic of the Canning and Officer Basins, Western Australia: Implications for Provenance and Interbasin Connections, *in The Sedimentary Basins of Western Australia IV edited by M Keep and SJ Moss: Proceedings of the Petroleum Exploration Society of Australia, West Australian Basins Symposium, Perth, Western Australia, 18 August 2013*, 19p.
- Hillbun, K, Katz, D, Playton, T, Lewarch, E, Trinajstic, K, Tohver, E, **Haines, P**, Hansma, J, **Hocking, R**, Kirschvink, J, Yan, M, Ratcliffe, K, Pisarevsky, S, Ducea, M, Montgomery, P, Harris, P and Ward, P 2014, Stable Carbon Isotopes in Carbonates of the Devonian Lennard Shelf, Canning Basin: Use as a Chronostratigraphic Constraint, Oceanic Indicator, and Limitations: *AAPG Annual Conference and Exhibition 2014*, Houston, TX, April 6–9, 2014, Abstracts, <www.searchanddiscovery.com/abstracts/html/2014/90189ace/>.
- Hocking, RM**, **Haines, PW** and **Allen, H-J** 2014, The Devonian reef complexes of the Canning Basin in context: subsurface and adjacent basins: *AAPG Annual Conference and Exhibition 2014*, Houston, TX, April 6–9, 2014, Abstracts, <www.searchanddiscovery.com/abstracts/html/2014/90189ace/>.
- Hollis, JA**, Van Kranendonk, MJ, Cross, AJ, Armstrong, RA and Allen, CM 2014, Low $\delta^{18}\text{O}$ zircon grains in the Neoproterozoic Rum Jungle Complex, northern Australia: An indicator of emergent continental crust: *Lithosphere*, v. 6, p. 7–25.
- Johnson, SP** 2014, The birth of supercontinents and the Proterozoic assembly of WA: *The AusIMM Bulletin*, Issue no. 1, February 2014, p. 53–56.
- Johnson, SP**, **Thorne, AM**, **Tyler, IM**, Korsch, RJ, Kennett, BLN, **Cutten, HN**, Goodwin, J, **Blay, O**, Blewett, RS, Joly, A, Dentith, MC, Aitken, ARA, Holzschuh, JJ, Salmon, M, Reading, A, Heinson, G, Boren, G, Ross, J, Costelloe, RD and Fomin, T 2013, Crustal architecture of the Capricorn Orogen, Western Australia and associated metallogeny: *Australian Journal of Earth Sciences*, v. 60, no. 6–7, p. 681–705, doi: 10.1080/08120099.2013.826735.
- Jourdan, F, Hodges, K, Sell, B, Schaltegger, U, **Wingate, MTD**, Evins, LZ, Söderlund, U, **Haines, PW**, Phillips, D and Blenkinsop, T 2014, High-precision dating of the Kalkarindji large igneous province, Australia, and synchrony with the Early–Middle Cambrian (Stage 4–5) extinction: *Geology*, v. 42, no. 6, p. 543–546, doi: 10.1130/G35434.1.

- McLoughlin, S, **Martin, SK** and Beattie, R 2013, The record of Australian Jurassic plant–arthropod interactions: Gondwana Research, available online 16 December 2013, doi: 10.1016/j.gr.2013.11.009.
- Montgomery, P, Playton, T, Ratcliffe, K, **Hocking, R**, Tohver, E, Hillbun, K, Katz, D, **Haines, PW**, Trinajstic, K, Yan, M, Hansma, J, Pisarevsky, S, Kirschvink, J, Cawood, P, Grice, K, Wray, D, Tulipani, S, Ward, P, Caulfield-Kerney, S and **Playford, P** 2014, Development of a Regional Stratigraphic Framework for Devonian Reef Complexes Using Integrated Chronostratigraphy: Lennard Shelf, Canning Basin, Western Australia: AAPG Annual Conference and Exhibition 2014, Houston, TX, April 6–9, 2014, Abstracts, <www.searchanddiscovery.com/abstracts/html/2014/90189ace/>.
- Mory, AJ** and **Haines, PW** 2013, A Paleozoic Perspective of Western Australia, *in* The Sedimentary Basins of Western Australia IV *edited by* M Keep and SJ Moss: Proceedings of the Petroleum Exploration Society of Australia, West Australian Basins Symposium, Perth, Western Australia, 18 August 2013, 25p.
- Nebel, O, Arculus, RJ, **Ivanic, TJ** and Nebel-Jacobsen, YJ 2013, Lu–Hf isotopic memory of plume–lithosphere interaction in the source of layered mafic intrusions, Windimurra Igneous Complex, Yilgarn Craton, Australia: Earth and Planetary Science Letters, v. 380, p. 151–161, doi: 10.1016/j.epsl.2013.08.019.
- Olierook, HKH, Delle Piane, C, Timms, NE, Esteban, L, Rezae, R, **Mory, AJ** and **Hancock, L** 2014, Facies-based rock properties characterization for CO₂ sequestration: GSWA Harvey 1 well, Western Australia: Marine and Petroleum Geology, v. 50, p. 83–102, doi: 10.1016/j.marpetgeo.2013.11.002.
- Playton, T, **Hocking, R**, Katz, D, **Haines, PW**, Hillbun, K, Tohver, E, Trinajstic, K, Montgomery, P, Yan, M, Hansma, J, Pisarevsky, S, Kirschvink, J, Cawood, P, Grice, K, Tulipani, S, Ratcliffe, K, Wray, D, Caulfield-Kerney, S, Ward, P and **Playford, P** 2014, Unraveling Upper Devonian reefal carbonate platform heterogeneity and architecture using integrated chronostratigraphy: Lennard Shelf, Canning Basin, Western Australia: AAPG Annual Conference and Exhibition 2014, Houston, TX, April 6–9, 2014, Abstracts, <www.searchanddiscovery.com/abstracts/html/2014/90189ace/>.
- Poňavič, M and **Scheib, A** 2014, Distribution of selenium in European agricultural and grazing land soil: in Chemistry of Europe’s Agricultural Soils, Part B: General Background Information and Further Analysis of the GEMAS Data Set, *edited by* Clemens Reimann, Manfred Birke, Alecos Demetriades, Peter Filzmoser and Patrick O’Connor, p. 131–144.
- Roelofs, B, Trinajstic, K, Playton, T, Barham, M, **Haines, PW**, **Hocking, R**, Grice, K and Hillbun, K 2014, Utilisation of Microvertebrates in Biostratigraphy and Chemostratigraphy for the Late Devonian and Early Carboniferous in the Canning Basin, Western Australia: AAPG Annual Conference and Exhibition 2014, Houston, TX, April 6–9, 2014, Abstracts, < www.searchanddiscovery.com/abstracts/html/2014/90189ace/>.
- Scheib, A** 2014, Distribution of Aeolian Deposits in Europe and Their Influence on Soil Geochemistry, in Chemistry of Europe’s Agricultural Soils, Part B: General Background Information and Further Analysis of the GEMAS Data Set, *edited by* Clemens Reimann, Manfred Birke, Alecos Demetriades, Peter Filzmoser and Patrick O’Connor, p. 161–168.
- Smithies, RH**, **Kirkland, CL**, **Korhonen, FJ**, Aitken, ARA, Maier, WD, **Wingate, MTD**, **Quentin de Gromard, R** and **Gessner, K** 2014, The Mesoproterozoic thermal evolution of the Musgrave Province in central Australia – plume vs. the geological record: Gondwana Research, available online 21 January 2014, doi: 10.1016/j.gr.2013.12.014.
- Tohver, E, Playton, T, Pisarevsky, S, Yan, M, Hansma, J, Kirschvink, J, Trinajstic, K, **Hocking, R**, **Haines, PW** and Montgomery, P 2014, Magnetostratigraphy of Frasnian-Famennian (Devonian) Carbonates of the Canning Basin, Western Australia: Evaluating the Potential for Regional and Global Correlations: AAPG Annual Conference and Exhibition 2014, Houston, TX, April 6–9, 2014, Abstracts, <www.searchanddiscovery.com/abstracts/html/2014/90189ace/>.
- Vachard, D, Haig, DW and **Mory, AJ** 2014, Lower Carboniferous (middle Viséan) foraminifers and algae from an interior sea, Southern Carnarvon Basin, Australia: Geobios, v. 47, no. 1–2, p. 57–74, doi: 10.1016/j.geobios.2013.10.005.
- Zhan, Y** and **Mory, AJ** 2013, Structural interpretation of northern Canning Basin, Western Australia, *in* The Sedimentary Basins of Western Australia IV, *edited by* M Keep and SJ Moss: Proceedings of the Petroleum Exploration Society of Australia, West Australian Basins Symposium, Perth, Western Australia, 18 August 2013.

Appendix C

GSWA organizational structure



27/07/14

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