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CEO comment

Secure, reliable and accessible water supplies are essential across the whole of Australia. Water security in the extensive arid parts of the country is reliant upon groundwater to meet the often competing requirements of remote towns, isolated Aboriginal communities, the pastoral and mining industries and the environment. Greater understanding and predictability of groundwater resources in these regions is imperative for current and sustainable future water supplies.

This issue of AusGeo News includes details of a regional-scale project completed by Geoscience Australia on 'Water for Australia's arid zone—Identifying and assessing Australia's palaeovalley groundwater resources'. The work was funded by the National Water Commission and supported by Western Australia (WA), South Australia (SA) and the Northern Territory (NT) government agencies to better understand the characteristics and behaviour of groundwater resources in Australia's arid areas.

The study achieved both a broad scale perspective and new insight in regions where little to no previous hydrogeological work had been conducted and found ways to disclose 'hidden' networks of aquifers and water resources in regions covered by desert dunefields. Geoscience Australia scientists were able to date the groundwaters and reveal the widespread presence of palaeowaters in these aquifers which has some implications for managing this legacy of past climates in Australia's arid and semi-arid zones into the future.

The project has delivered a map of palaeovalleys across the arid and semi-arid zones of WA, SA and the NT.

An article on High Performance Computing (HPC) showcases many of the aspects of where our organisation is heading. The need to be at the cutting edge of national scale geoscientific data analysis in a world of exponentially increasing data volumes has required the adaption and adoption of the latest tools and technologies to enable Geoscience Australia to provide new and improved products and services in a timely way to our stakeholders. There is a need for our organisation to invest in such technology given that Geoscience Australia is extremely data rich and will increasingly be challenged by the demands of data storage, access, utilisation, modelling and scenario building. Geoscience Australia commenced this work in partnership with the CSIRO Minerals Down Under Flagship and the National Computational Infrastructure facility at the Australian National University.

Geoscience Australia is commemorating Canberra's Centenary by hosting a display of maps, satellite images and aerial photography illustrating how the nation's capital has taken shape over the past 100 years. The display highlights the role Geoscience Australia and its predecessors played in establishing the Australian Capital Territory.

Mr Drew Clarke has recently been appointed as Secretary to the Department of Broadband, Communications and the Digital Economy. I would like to take this opportunity to thank Drew for his great support for Geoscience Australia during his time as Secretary to the Department of Resources, Energy and Tourism (RET), and wish him well in his new role. Mr Blair Comley, PSM, has been appointed the new RET Secretary.

Dr Chris Pigram
CEO Geoscience Australia

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Groundwater Investigations in palaeovalleys in the Murchison region

Finding hidden water resources for remote townships and expanding mining activities

Pauline English

Australia's arid zone and water supplies

Secure, reliable and accessible water supplies are essential across the whole of Australia. The extensive arid parts of the country are dependent upon groundwater to meet the often competing requirements of remote towns, isolated Aboriginal communities, the pastoral and mining industries and the environment. Greater understanding and predictability of groundwater resources in these regions is imperative for current and sustainable future water supplies.

Palaeovalleys—sediment-filled old river valleys that exist across much of the continent and which are commonly obscured beneath dunefields and other cover materials—offer a hidden groundwater resource across much of arid Australia. They are particularly important in cratonic provinces where no other significant aquifers exist. The potential of palaeovalley aquifers is beginning to be 'uncovered' to increase understanding of these distinctive aquifers towards long-term sustainability of their precious groundwater resources.

"Geoscience Australia has completed a regional-scale project on: 'Water for Australia's arid zone—Identifying and assessing Australia's palaeovalley groundwater resources'"

Geoscience Australia has completed a regional-scale project on: 'Water for Australia's arid zone—Identifying and assessing Australia's palaeovalley groundwater resources' (English et al, 2012), funded by the National Water Commission (NWC) and supported by respective state government agencies. The work investigated palaeovalleys across arid and semi-arid parts of Western Australia, South Australia and the Northern Territory, including 'demonstration studies' involving fieldwork in widespread regions in different geologic provinces and climatic regimes (figure 1). Investigations were directed towards: (a) characterising representative, distinctive and/or broad-scale palaeovalley systems, (b) assessing methodologies that effectively detect and enable mapping of these aquifer systems at regional to local scales, and (c) supporting groundwater resource investigations needed in the immediate or near future, for example, for mining operations and community water supplies. An improved understanding of the Murchison palaeovalleys was designated a strategic priority by the WA Department of Water, particularly for provision of water resources for expanding iron-ore and gold mining operations, and this region was accordingly nominated as a demonstration study for the NWC project.

Murchison Palaeovalleys demonstration project

The Murchison Province is part of the Yilgarn Craton, composed of Archean granite-greenstone terrain, where there is little or no perennial surface water. There are two salt lakes in the study area: Lake Austin, near Cue township, and Lake Annean, near Meekatharra, with the Great Northern Highway situated close to both (figure 2). The whole Murchison district depends on palaeovalley aquifers for water supplies to towns, pastoralists and mining operations. Most of the numerous existing bores are shallow, less than 20 metres deep, and are typically windmill equipped, accessing water from calcrete or near-surface alluvial aquifers. Scant information has previously been available about the full depths of the Murchison palaeovalleys and the nature of their sedimentary infill and groundwater resources. In contrast, palaeovalleys elsewhere in the Yilgarn have been subject to detailed hydrogeologic investigations.

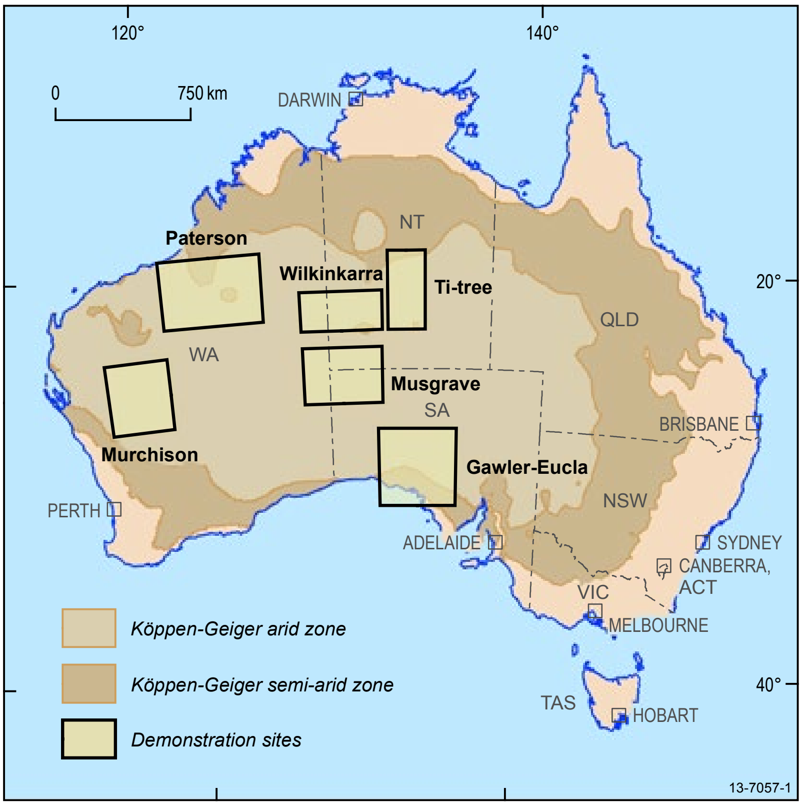

Figure 1. Map of arid and semi-arid zones of Australia, based on the Köppen Geiger climate classification scheme.

Four sites in the Murchison Province (figure 2) were selected for reconnaissance investigation: Beringarra and Mt Padbury stations on the Murchison Palaeovalley (Glenburgh and Byro, and Robinson Ranges 1:250 000 map sheets, respectively), Annean station on the Hope Palaeovalley (Belele 1:250 000 map), and Austin Downs station on the Sanford Palaeovalley (Cue 1:250 000 map). Four methods were used to characterise the palaeovalleys:

- analysis of digital elevation models (DEMs) and derived products
- ground gravity traverses
- drilling and installation of monitoring bores
- hydrochemistry

High resolution Shuttle Radar Topography Mission (SRTM) elevation data were processed to partition the landscape into low-flat and high-steep areas to encapsulate valley extents and networks to provide a basis for ground geophysical traversing. To determine the deepest section of each palaeovalley site, 55 kilometres of ground gravity surveying (130 stations spaced at 400 or 500 metre intervals) were completed. Twelve investigative drill holes (totalling 1195 metres) were sunk using mud rotary and reverse circulation techniques (figure 3). Drilling continued to bedrock wherever possible.

Geophysical and drill-hole data were interpreted to represent the cross-sectional disposition and stratigraphy of the selected palaeovalleys and to guide emplacement of bores (figure 4). Monitoring bores were installed in the deepest part of each palaeovalley at the four study sites, that is, into the sandy basal palaeochannel above the bedrock contact. Screened casing in the bores was inserted in favourable deeper aquifers within the palaeovalley infill. Drill cuttings were logged to determine the stratigraphic and lithologic nature of each hole and for palynological dating; groundwater samples were collected for water chemistry analysis, including stable and radiogenic isotopes. Four new monitoring bores were levelled by surveying, and data loggers installed for time-series measurements of standing water levels (SWL) and salinity monitoring into the future.

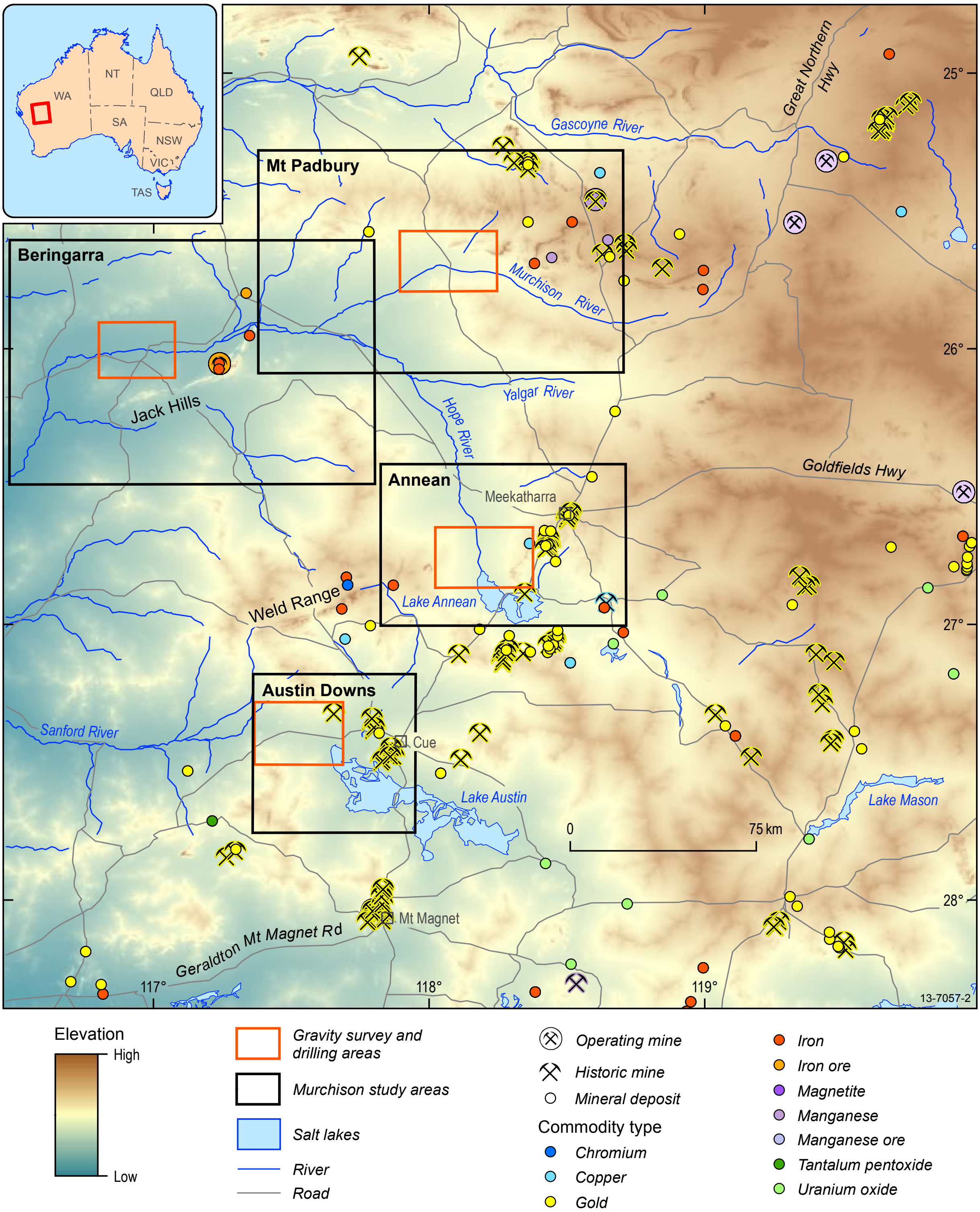

Figure 2. Map of the Murchison region, Western Australia, including study areas for the Palaeovalley Groundwater project and locations of mines, mineral deposits and towns.

Distinctive characteristics of the Murchison palaeovalleys

The Murchison Province palaeovalleys have been incised into Archean bedrock to depths of 150–200 metres below the present ground surface. This contrasts with average depths of around 120 metres in the north-eastern Yilgarn, 60 metres in the south-eastern Yilgarn (Eastern Goldfields), and 40–50 metres in the south-western Yilgarn (Wheatbelt). Geological structures, including faults and major basement contacts (for example, figures 4 and 5), may have influenced incision of the ancient rivers in the Murchison. Buried inset valley profiles are present, indicating multi-phase incision. In places, the palaeo-thalweg and present-day main river channels are offset by up to 2–3 kilometres. This may be attributable to tectonic tilting and/or the role of faulting during the evolution of the palaeovalley systems, or may reflect more recent ephemeral fluvial flow regimes on the flat surface of the now fully infilled valleys. The depositional environment across the region is wholly terrestrial and dominantly fluvial, with subordinate lacustrine or swampy settings. The substantial valley incision, up to 200 metres deep into crystalline bedrock in a valley less than 5 kilometres wide, for example, suggests high-energy fluvial environments.

Figure 3. Reverse Circulation (RC) drilling into buried palaeovalleys that had been defined by gravity profiling.

Sedimentary infill of the Murchison palaeovalleys is sandier than that in other parts of the Yilgarn. This has significant implications for groundwater storage, and for understanding the evolution of the Yilgarn landscape. Sediments in the infilled Murchison palaeovalleys commonly consist of coarse, immature sands that are indicative of local provenance, and which may form alluvial aquifers with high porosity and transmissivity properties. Clayey sediments, where present, indicate more sluggish depositional settings. Palynostratigraphic analysis of drill-chip samples indicates the sediments were deposited during the Pliocene to Pleistocene. This contrasts with palaeovalleys in the eastern and southern Yilgarn where Eocene to Miocene sediments are prevalent beneath Quaternary infill. Pre-existing more ancient Cenozoic sediments in the Murchison palaeovalleys may have been eroded away by more recent dynamic river flow, although there is no substantiating evidence, and such sediments may have been removed to the Indian Ocean before or during the Neogene. Past river gradients in the Murchison Province were steeper than the low-gradient internally-draining systems in the east and south-east Yilgarn Miocene rejuvenation of the Murchison landscape may have deepened the valleys further after pre-Pliocene sediment had been stripped away.

Water quality and antiquity

Palaeovalley groundwater in the Murchison Province is generally less saline than in the southern Yilgarn, and is inferred to relate to the rainfall regime and the lithology and possibility to the fact that outlet to the Indian Ocean has periodically flushed salts from the Murchison valleys. Widespread 'stock quality' water suitable for mining and pastoral activities and some potable supplies are present. Groundwater salinity in Murchison project bores ranges from fresh to highly saline, 650–130 000 mg/l TDS, although it is mostly in the 1100–4600 mg/l range. The freshest water is from relatively shallow silicified calcrete aquifers. Hypersaline groundwater is present at greater than 100 metres depth down-gradient from Lake Annean (figure 2) in the Hope Palaeovalley, indicating leakage from the evaporatively concentrated playa lake brine pool. In contrast, Lake Austin appears to be more hydrologically closed as hypersaline groundwater emanating from beneath the salt lake does not appear to substantially flow down-gradient into the Sanford Palaeovalley. Topographic data also concur that there appears to be considerable segregation of Lake Austin from its host palaeovalley (figure 5).

Groundwater compositions are dominated by sodium and chloride ions (Na, Cl), typical for Australian arid-zone palaeovalleys studied elsewhere. Groundwater in many shallow bores exceeds the Australian Drinking Water Guidelines (ADWG) threshold of 50 mg/l for nitrate (NO_3), although not in the deeper project bores, suggesting sources from the biosphere (soil profile, termites, and nitrogen-fixing vegetation such as mulga). Some groundwater in the deeper bores exceeds ADWG thresholds for fluorine (F), boron (B), manganese (Mn), lead (Pb) and arsenic (As). Groundwater from both pre-existing shallow bores and many of the new bores has levels of uranium (U), approaching or exceeding ADWG thresholds. This is not uncommon for groundwater hosted in, or flowing from, Australian Precambrian granite terranes that are notably rich in uranium concentrations. The presence of elevated uranium concentrations in salt lake sediments is typical of these terranes and is revealed in radiometric imagery (figure 5).

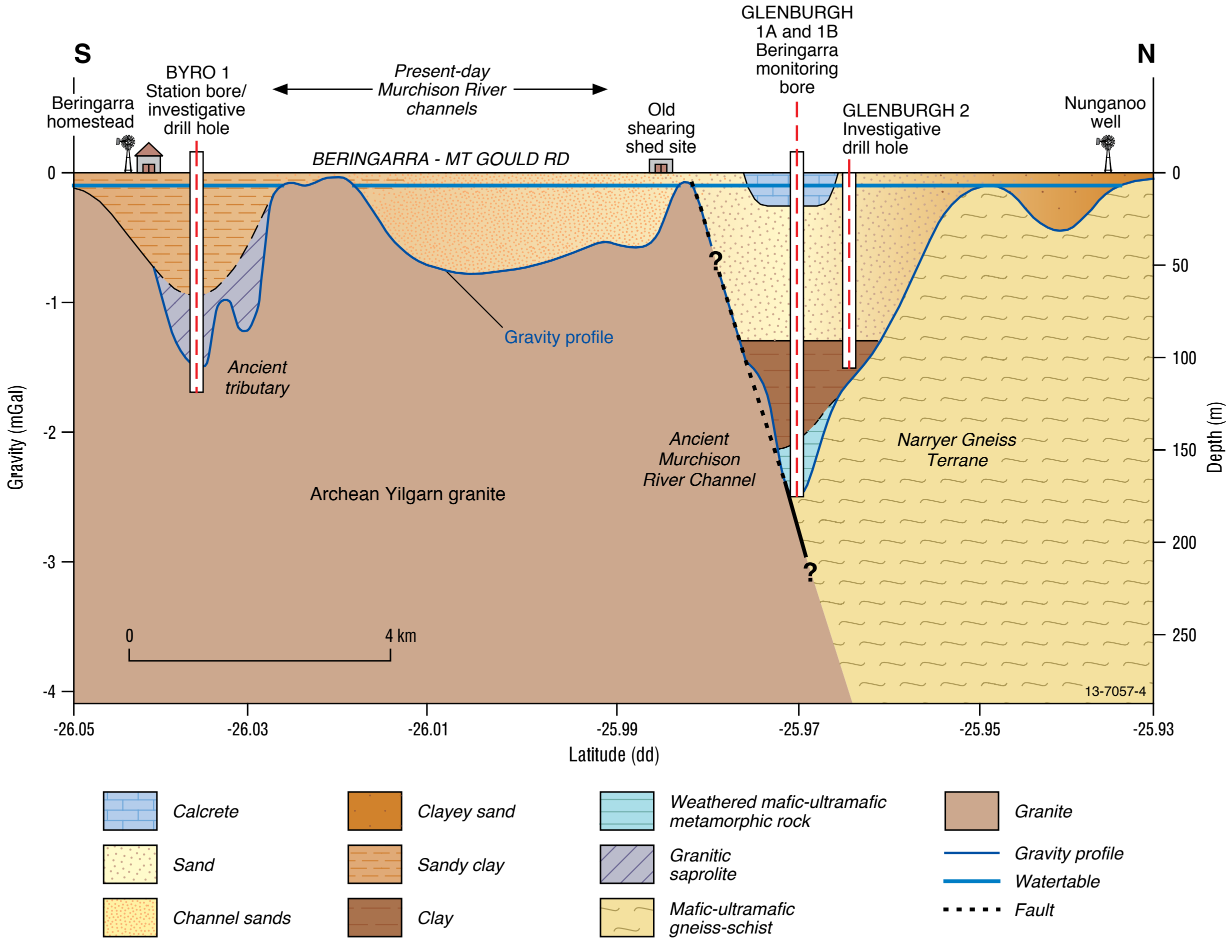

Figure 4. Cross-section across the Murchison River at Beringarra, immediately down steam from Jack Hills iron ore mine.

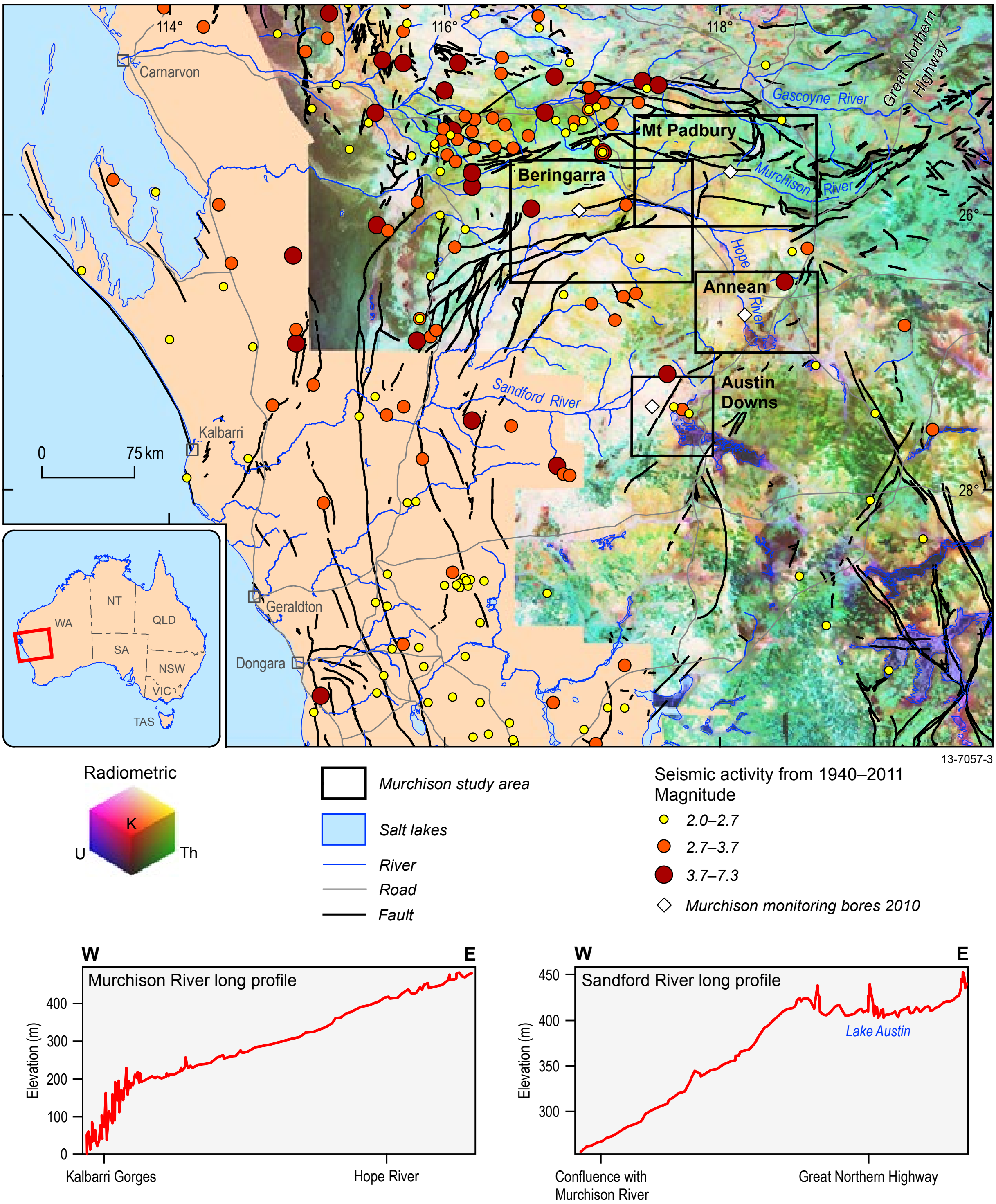

Figure 5. Radiometric image of the Murchison region with faults, seismic activity sites (earthquake centres), and project study sites, including the locations of monitoring bores installed for the Palaeovalley Groundwater project.

Stable isotope data from groundwater show groundwater in the new bores are enriched in the heavier isotopes. This indicates that evapotranspiration is the dominant process affecting groundwater systems. Radiocarbon (^{14}C) data indicate the presence of palaeowaters in the new bores, with percent modern carbon (pMC) ranging from 30 to 1.37 pMC representing uncorrected and uncalibrated ^{14}C ages of 9500 to 34 500 radiocarbon years before present (BP). Thus, all palaeovalleys contain palaeowaters. Recharge of the aquifers in the present climatic regime will need to be assessed from data loggers that have been installed in the new monitoring bores, although it is predicted that some minor periodic recharge occurs from rare high-magnitude rainfall events tracking east-south-east from the coast, from episodic river flow and percolating from semi-permanent pools in the main rivers.

Implications

Groundwater is more abundant in the Murchison than anticipated prior to these investigations because of the greater than expected valley depths and the high proportion of sandy infill, a combination that results in higher aquifer volumes. Data are insufficient to estimate yields and overall volumes for specific palaeovalley reaches or sites. Watertables are shallow (2.5–6 metres below ground level). Very substantial layers or lenses of highly permeable palaeochannel sands are up to tens of metres thick. This has been one of the most significant findings of the investigation, although it must be emphasised that the Murchison palaeovalleys are complex and heterogeneous and have thus far only been investigated at a reconnaissance level. Depending on connectivity between aquifers, groundwater extraction from these sandy aquifers may induce deleterious leakage from overlying sediments, from up-gradient palaeo-tributaries and from adjacent weathered and/or fractured bedrock that may either bring poorer quality water into the bores or deplete higher-quality aquifers elsewhere. Accordingly, further work is required to establish the extent and magnitude of such recharge and throughflow dynamics, and to determine analogies with better-known palaeovalley systems in the Eastern Goldfields. The available data suggest that palaeovalley reaches up-gradient of the salt lakes, that is, east of the Great Northern Highway, may provide relatively fresh groundwater for future town water supplies for Meekatharra, Cue and Mt Magnet and for mining developments in this part of the Murchison Province.

The Murchison demonstration study has shown that the application of efficient ground geophysical surveying and drilling techniques, combined with readily available DEM and regional geological and geophysical datasets, can effectively characterise palaeovalleys prior to more detailed follow-up work. This reconnaissance study has also highlighted the complexity and heterogeneity of the Murchison palaeovalley systems, emphasising the need for additional investigations, particularly coring of complete stratigraphic profiles (to bedrock) across the full width of palaeovalleys, and careful palynostratigraphic analysis. Long-term monitoring of bores is also required, particularly if large groundwater volumes are to be extracted to support expanding mining activities, to improve understanding of any potential variability and impacts in the groundwater systems.

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Related articles and websites

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www.ga.gov.au/webtemp/image_cache/GA17990.pdf

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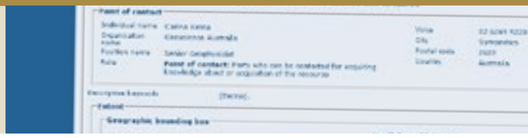
High Performance Computing

New Frontiers, New Paradigms, New Science



Lesley Wyborn

Reviewing Geoscience Australia's forays into High Performance Computing

In September 2010 Geoscience Australia began a trial project to determine if, and potentially how, it could evaluate the potential to utilise High Performance Computing (HPC) to improve seamless access to its large national data sets to enable processing at higher resolution within faster timeframes. The approach consisted of:

- A partnership with the National Computational Infrastructure (NCI) facility at the Australian National University to test Geoscience Australia applications in HPC environments
- An eResearch collaboration project with CSIRO to trial new tools and techniques in online data access and processing
- Several collaboration projects with the national research sector via the Department of Industry, Innovation, Science and Tertiary Education (DIISRTE) eResearch Infrastructure Programs, in particular with the Australian National Data Service (ANDS) and the National eResearch Collaboration Tools and Resources (NeCTAR) Project.

"Geoscience Australia's data and information products are being used to support decision making in the environmental and resource science domains"

Two discipline areas (Earth Observation and Onshore Geophysics) were involved in the early trials that were quickly regarded as resounding successes. Within a few months it was proven that Geoscience Australia could analyse much larger data sets, at higher resolutions and faster utilising the HPC systems at the NCI. Progressively more projects became involved and as of March 2013 there are now 20 active projects across Geoscience Australia that are utilising HPC to improve the quality and resolution of scientific outputs and hence create better business outcomes. Examples of some of these current Geoscience Australia projects utilising the NCI facility include:

- A Geophysics Inversion capability which enables high resolution geophysics inversions of magnetic, gravity, Airborne Electro Magnetic (AEM) and Magneto Telluric (MT) data
- A Geoscience Hazards capability that enables probabilistic modelling of potential impacts of earthquakes, tsunamis, storm surges and severe wind events
- A Geodetic Capability whose activities include measuring surface deformation of the Australian Continent and updating of Australia's National Coordinate reference system
- A Geothermal Capability which enables modelling and prediction of heat flow around buried granites
- An Earth Observation Capability which is creating a seamless, time series data cube of 30 years of Landsat data to enable empirical documentation of changes in land cover.

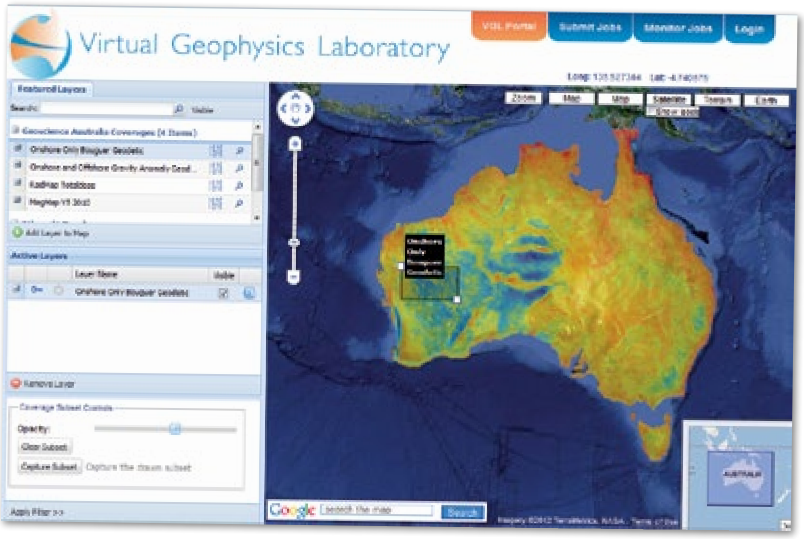


Figure 1. The user interface to the Virtual Geophysics Laboratory

Increasingly Geoscience Australia staff are realising the new opportunities that HPC facilities such as the NCI offer. An end goal is for quantitative, integrated assessment and modelling of complex earth science systems to enable us to respond to decadal challenges in Earth Systems Science including water security, sustainable development of our minerals and energy resources, community safety and emergency management, and sustainable environmental management. Effective participation in these new frontiers requires a capacity in HPC to access multidisciplinary data at high spatial and temporal resolutions and to cover large geographic extents (in 3D wherever possible). It also necessitates considering a range of likely scenarios with uncertainty quantification and sensitivity analysis becoming an inherent part of the modelling process.

A related development is that increasingly Geoscience Australia's data and information products are being used to support decision making in the environmental and resource science domains and there is an increasing demand for transparency in the decision making process with organisations required to justify why they made certain decisions or provided certain advice. As HPC enables the creation of multiple models and scenarios it becomes essential that provenance workflows are also developed to store the input data and capture what processing was done to these data during any modelling and/or processing session.

However, after two and a half years of operating at NCI, there is a realisation that although the NCI facility offers the computational capability to undertake complex analyses, the transition to the HPC environment is not easy. It is a new paradigm. It is not just a matter of transferring existing internal work practices: these have to be radically transformed. Geoscience Australia's experience, and that of many other organisations, is now showing that it is becoming increasingly difficult to scale existing earth science methods and software. The transition to HPC is creating new requirements for:

- New tools and applications that operate in massively parallel HPC environments
- Cohesive, value-added, nationally calibrated data sets that can be accessed within realistic time frames
- Creating online virtual laboratories that allow seamless access to distributed data, software and computer services and can also automatically generate provenance workflows to enable all aspects of scientific process to be automatically captured (figures 1 and 2).

This article outlines how Geoscience Australia is approaching these new requirements and then proposes some future directions that will exploit new opportunities that the new computing environments are enabling.

The requirement for a new generation of Earth Science HPC tools

In recent years, with the ending of Moore's Law, computer hardware trends are towards increased parallelisation and larger memory. However, although HPC can meet the high computational demand that is required for the integration and analysis of data at high resolution and at larger geographic extents, there are very few tools that can fully exploit it. It is becoming increasingly difficult to use traditional Geographic

Information System (GIS) tools on HPC systems and many of the current commercial processing packages in use for earth scientists are struggling to scale. These packages have lagged behind computer hardware trends and are more biased towards a reliance on serial processing and/or can only access a limited number of cores (Bryan, 2013).

Users of HPC therefore have little choice other than to develop new codes or more preferably join in global community groups that are developing Open Source software to tackle similar Geoscientific problems at the scales that meet their requirements. The use of community open source codes in the earth science domain is growing and Geoscience Australia is collaborating with some of these initiatives such as the GEM (Global Earthquake Model) tools and the TOUGH (Transport of Unsaturated Ground Water and Heat) software.

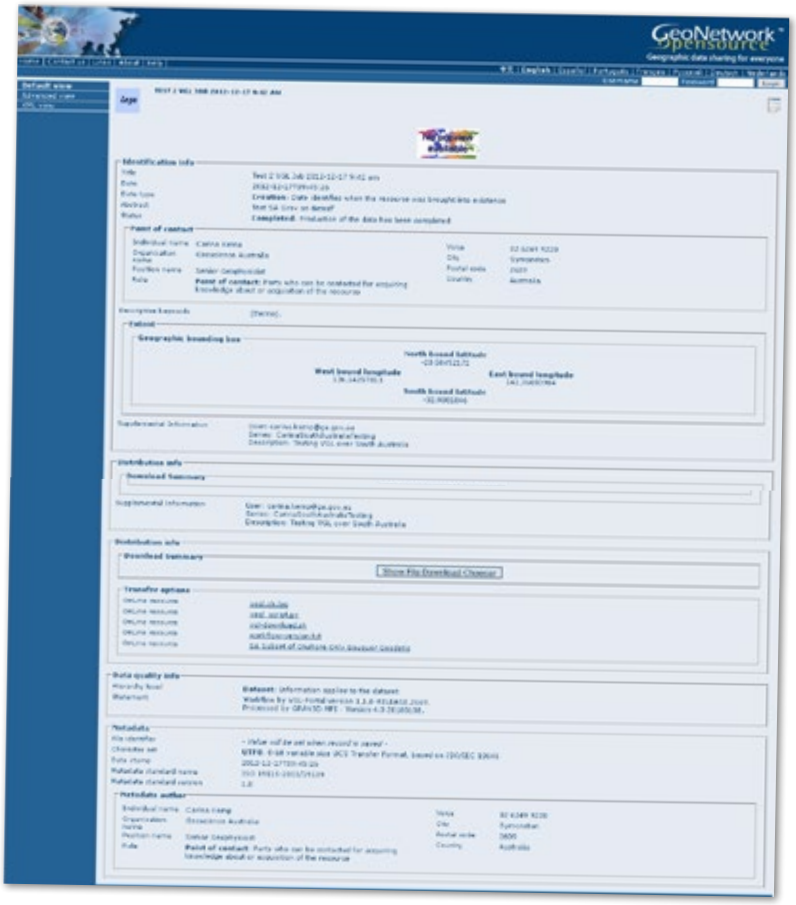


Figure 2: The provenance metadata record that is captured automatically throughout the workflow.

The level of programming skills for HPC environments required is substantially high and is very specialised. Once developed, parallel programs can also be difficult to debug and inevitably the builders of the codes become the only users. There is quite a lag time in having groups adjust to the new environment (Bryan, 2013). It is not just a matter of learning new computer language, but also new operating systems, job schedulers, etc. For Geoscience Australia, the scale of the system often means that entirely new workflows have needed to be developed. The initial transition has required specialised programmer support and there is a need for persistence and commitment to resist the temptation to go back to previous ways of doing things. To many, it has been a non-trivial exercise which requires scientists to know their code (for example, memory requirements, wall time, storage requirements), know how to access their data and to actually understand what is needed to get their model/code installed and what are the dependencies. In summary, operating in the new HPC environments requires the new generation of quantitative scientists to be more mathematically and computer literate than ever before.

The Requirement for High Performance Data Arrays/Data Cubes

It is clear that the move to HPC creates new opportunities for earth scientists to transform the way they do their science and to undertake cross-disciplinary science at much larger scales. Because of the larger capacity of HPC, it is no longer necessary for data to be averaged and subsampled: it can be analysed to its fullest resolution at national or even global scales. Much larger data volumes can be analysed in single passes and at higher resolution: large scale cross domain science is now feasible.

However, as the systems increase in capacity, access to large earth science data is becoming a pain point. Many current issues with data access are historic and stem from the limitations of early data storage systems. As storage was so expensive, metadata was usually stored separate from the data and attached as a 'readme' file. Likewise, attributes that defined uncertainty, reliability and traceability were recorded in laboratory note books and rarely stored with the data. Many earth and environmental science datasets are fragmented across multiple institutions and the data sets themselves are notoriously heterogeneous and difficult to aggregate. Although many 'big data' collections are of the order of terabytes and even petabytes in size, they actually consist of small individual files each less than 2 gigabytes that have to be accessed individually via associated metadata records stored separately from the data.

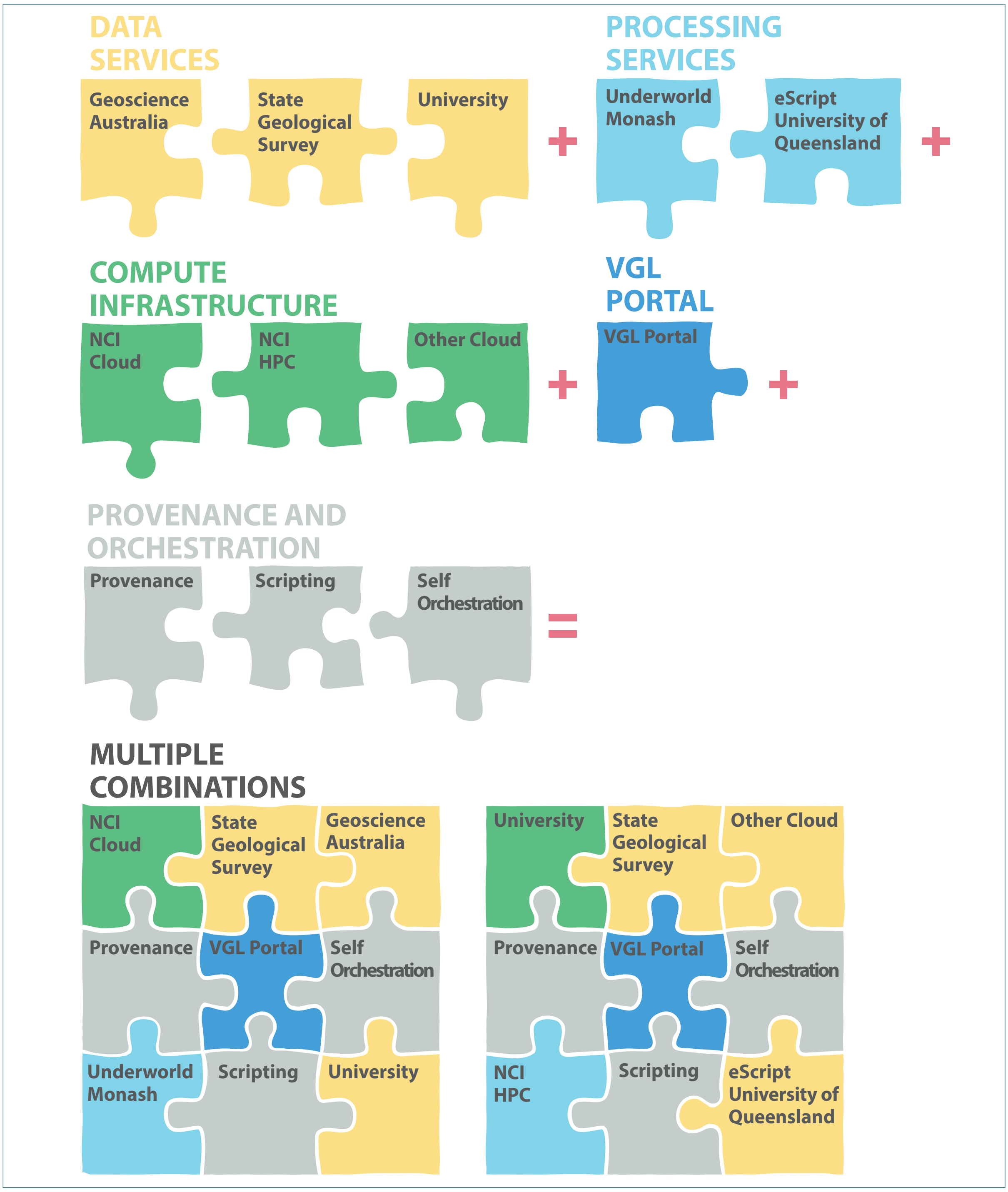


Figure 3: The components of the Virtual Geophysics Laboratory.

Thus, in an HPC environment, it is becoming increasingly difficult to dynamically access these data sets within realistic time frames and there are new requirements for data to be transformed and aggregated into High Performance Data (HPD) data sets that comprise cohesive, nationally calibrated data arrays/clouds or data cubes. Further, for data access and assimilation to be improved, data will need to be self describing. For heterogeneous data to be rapidly integrated, attributes such as reliability, uncertainty and traceability will also need to be systematically recorded with each observation. International standards for machine readability of data become critical and are the enablers of integration. It requires highly specialised skills to create these large volume standard HPD arrays and cubes, but once created, they are easier to access and use by the non-specialist.

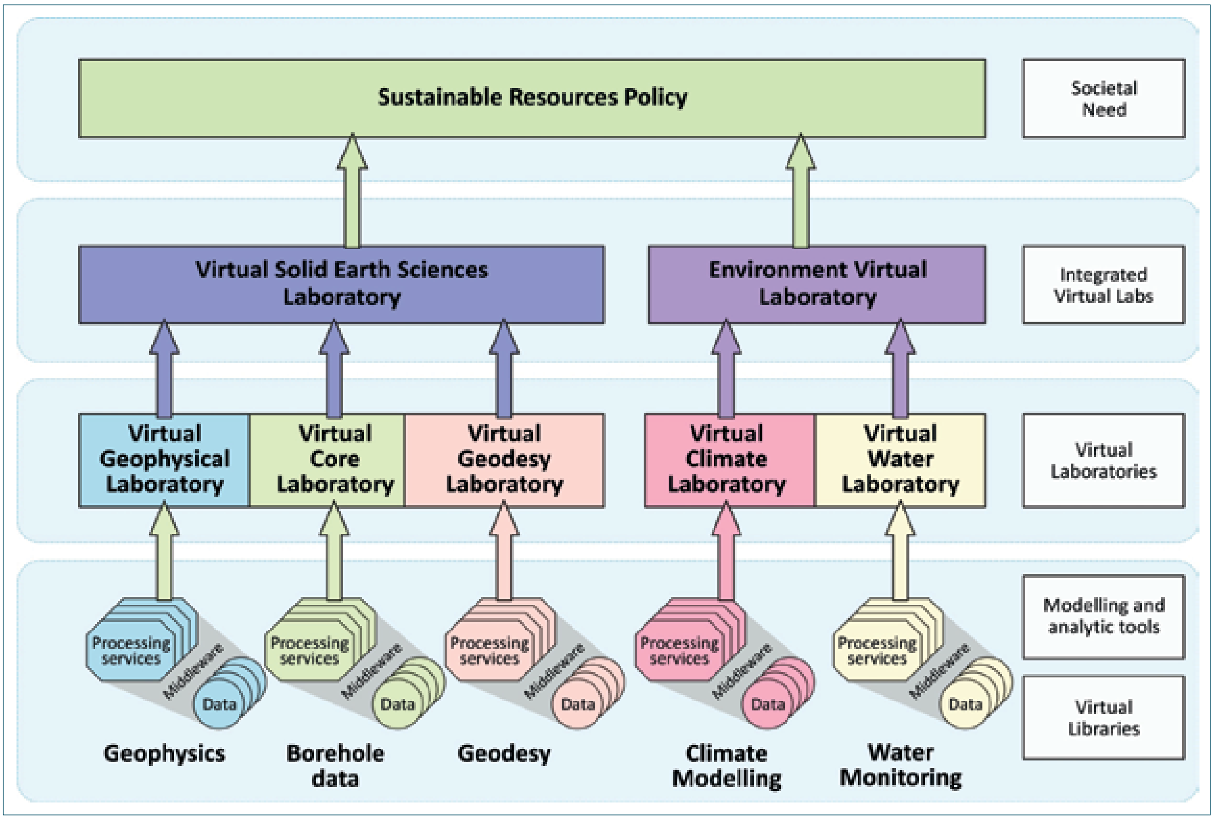


Figure 4: The plan for a national geoscience information infrastructure—linking multiple virtual laboratories via seamless workflows.

The Requirement for Virtual Laboratories to lower barriers to entry

It is clear that HPC is quite a complex environment requiring highly skilled programmers and sophisticated integrated data cubes/ data arrays. Increasingly, virtual online laboratories are being seen as a means of enabling large scale online processing to take place transparently across distributed data, software and compute resources. A virtual laboratory has three phases: data selection; selecting and tuning the processing algorithms; and submitting the job to the most appropriate computational facility and monitoring.

The entire infrastructure can provide geoscientists with an integrated environment that enables seamless access to distributed data libraries and loosely couples these data to a variety of processing tools. A laboratory can link to a variety of compute resources that span from petascale HPC systems to private and commercial clouds and to local desktop. The user accesses the laboratory through an intuitive user-centred interface that enables real-time seamless linkage between all components. A provenance workflow can be automatically generated in the background by capturing information on all inputs to the processing chain, including details about the user and their organisation.

The DIISRTE NeCTAR project is funding a series of 11 such Virtual Laboratories and one of these NeCTAR projects is a collaboration between Geoscience Australia, CSIRO, the National Computational Infrastructure, Monash University, the Australian National University, and the University of Queensland to build a Virtual Geophysics Laboratory (VGL). The VGL provides a distributed system whereby a user can enter an online virtual laboratory and seamlessly connect geoscience data, processing software, and computational hardware available from a variety of cooperating, but independent, Australian Government and university organisations (figure3).

"Globally the earth scientists are realising that HPC and new data aggregation technologies offer far more than 'bigger, faster, and at higher resolution'"

The VGL provides a web mapping interface to discover and filter the data sources using spatial and other attributes (figure 1). Once the data is selected the user is not required to download the data—the VGL collates the service query information for later in the processing workflow where it will be staged directly to the computing facilities. Throughout the workflow, provenance information is collected and captured into a metadata record where possible attributes collected are compliant with the ANZLIC profile of the ISO 19115 metadata standard (figure 2). This provenance workflow enables a team to not only keep track of jobs they have submitted, it also enables spatial displays of who ran what, where and when. The system is quite flexible and is glued together via python scripts that can either be reused as is, or adapted by other users.

VGL is therefore more an infrastructure rather than application. It orchestrates the linking of multiple data sets that are available as Open Geospatial Consortium (OGC) compliant web data services to a variety of software resources that are also available as services (figure 3). Thus VGL acts as a broker and can seamlessly integrate data services from distributed locations, meaning that less time is spent locating, downloading and reformatting disparate data sets into integrated standardised data sets that can then be accessed by HPC.

The benefit of the provenance workflow is that all products produced are transparent. As the metadata record captures all input files, including any changes to processing algorithms, time of extraction of the data from the databases, who ran what and where, the components of workflow can be reused by others wanting to run similar workflows. The greatest benefit is that all procedures used are accessible, verifiable and can be used by other investigators to test the results.

Where to next: a National Geoscience Information Infrastructure

Geoscience Australia's experience in successfully trialling HPC to enable new science and new business outcomes, particularly in analysing large volume data sets is not alone. Globally earth scientists are realising that HPC and new data aggregation technologies offers far more than 'bigger, faster, and at higher resolution'. The new paradigm is an opportunity for a transformative change in the way in which geoscience data analysis is routinely conducted and that it has the capacity to create new ways of doing collaborative, 'transparent' analysis in which all relevant data from distributed data sources can be harnessed online.

Infrastructures, such as virtual laboratories, can lower the skills barriers to entry for HPC and can increase uptake. As is illustrated in figure 4, the VGL is a prototype geoscience infrastructure that enables geophysics data to be linked transparently to a variety of software and compute resources. There is no reason why similar systems could not be built for geodesy, boreholes, climate and water and already there a plans to build some of these. Integrated and linked through the use of OGC/ISO standards, they can become a National Geoscience Information Infrastructure and capable of integrating with other major infrastructures including the National Plan for Environmental Information, the ANZLIC One ANZ Foundation Spatial Data Framework and the eMarine Information Infrastructure.

References

Bryan, B. 2012. High-performance computing tools for the integrated assessment and modelling of social-ecological systems. Environmental Modelling and Software, 39, 295-303.

Realated articles and websites

Virtual geophysics Laboratory
http://vgl.auscope.org/VGL-Portal/gmap.html

National Computational Infrastructure
http://nci.org.au/

The National Plan for Environmental Information
www.environment.gov.au/npei/index.html

ANZLIC One ANZ Foundation Spatial Data Framework
http://spatial.gov.au/system/files/public/resources/anzlic/ANZ_FoundationSpatialDataFramework_(FinalWeb).pdf

eMarine Information Infrastructure
http://imos.org.au/emii.html

For more information

email ausgeomail@ga.gov.au

Establishing the ACT: From the ground up

Geoscience Australia and its predecessor organisations played a significant role in the establishment of the Australian Capital Territory (ACT).

Geoscience Australia's history dates back almost to Federation when in 1901 it was decided to set aside land for the national capital. This decision led to the establishment of the Australian Survey Office in 1910, when surveying began for the Australian Capital Territory led by New South Wales surveyor Charles Scrivener.

To commemorate the ACT Centenary, Geoscience Australia is currently hosting a display of maps, satellite images and aerial photography illustrating how the nation's capital has taken shape over the past 100 years. The display—Establishing the ACT: From the ground up—provides an accurate history and record of the land and how it has changed and developed over time. From this central theme, other themes have generated:

- *ACT Geology*—A geological overview of the nation's capital, identifying the various rock types found in the region and the geological maps of the region.
- *Then and Now*—A pictorial history of how the nation's capital has changed over the years. This display shows images collected during the construction of Canberra's infrastructure with a distinct geological flavour.
- *A Bird's Eye View*—Aerial photography and satellite images of the development of the ACT. This display also includes a selection of equipment used to gather these images.
- *Mapping and Surveying*—A story of how mapping and surveying techniques have progressed over the last 100 years. This display showcases a variety of reference and topographic maps of the ACT and the Canberra City region.
- *Scorched Pages*—This display, located within the Geoscience Australia library, showcases a selection of the books that were damaged and salvaged from a fire that occurred in 1953 at the Bureau of Mineral Resources. The collection is of great significance as it contains rare, early Australian publications and international works covering Papua New Guinea, Japan and Korea.

The Geoscience Australia foyer display also acknowledges the role of Charles Scrivener, the New South Wales surveyor who was given the task of mapping a new federal territory.

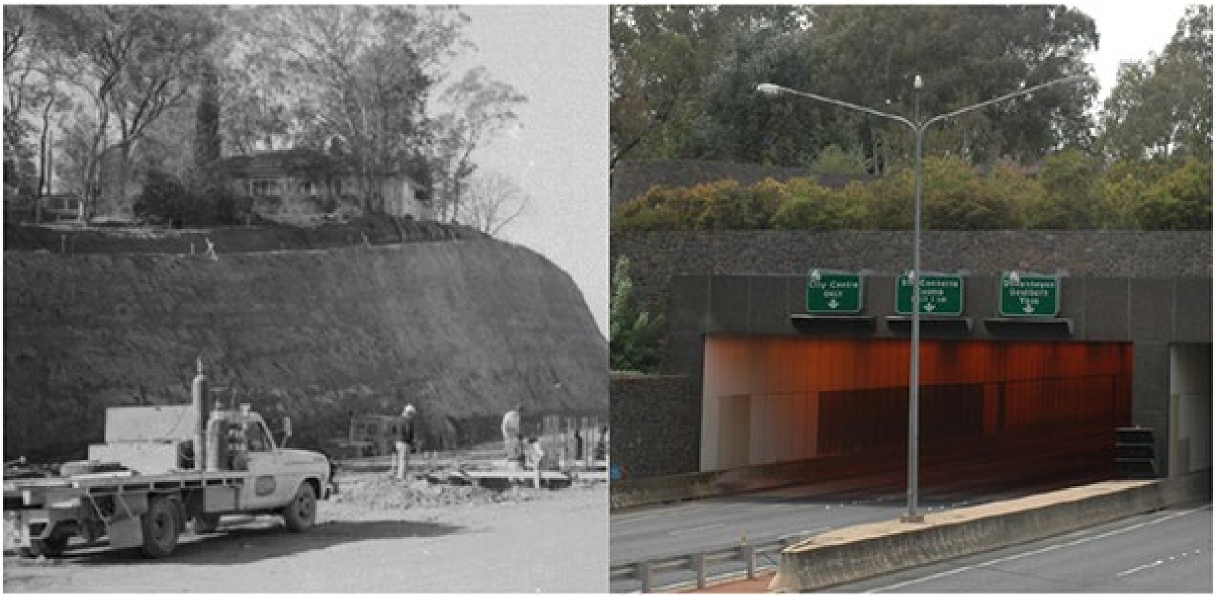


Figure 1: This pair of photos show the Molonglo Parkway (the west end of Parkes Way). The 1977 photo shows the cutting at ANU before it was covered to form the tunnel. At that time the then Bureau of Mineral Resources (now Geoscience Australia) carried out geotechnical studies for the alignment of the Molonglo Parkway from Acacia Inlet to Sullivans Creek.

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In addition to these displays, old mapping and surveying films have been digitalised and made accessible via touch screens, with special film showing events planned throughout 2013. These films explore Geoscience Australia's role in studying Earth processes, our role as key Australian Government advisor on all aspects of geoscience and as custodian of the nation's geoscientific and spatial information.

The display is open to the public Monday to Friday during business hours until the end of the year. Geoscience Australia is located at the corner of Jerrabomberra Avenue and Hindmarsh Drive, Symonston.

Related articles and websites

Geoscience Australia's history
www.ga.gov.au/about-us/our-history.html

For more information

email ausgeomail@ga.gov.au

Education activities off and running for 2013

National Youth Science Forum

Sixty of Australia's top Year 11 science students visited Geoscience Australia in January as part of the 2013 National Youth Science Forum. During their visit the students participated in a half-day workshop interacting with geoscientists to learn about techniques used to identify possible groundwater resources which are essential to Australia's sustainability in a changing climate. More than 30 of Geoscience Australia's scientists and technical staff volunteered their time to spend with the students.

Figure 1: Students analysing sediment samples during their visit to Geoscience Australia.

The students participated in activities to find a paleochannel which would be a suitable source of potable groundwater. Their investigations involved a range of geoscience techniques and included undertaking a scaled seismic and magnetic survey, and analysing sediment and water samples. The students not only had the opportunity to conduct experiments themselves, but to do so in a professional environment using specialised field and laboratory equipment that they would not normally have access to in a classroom.

The highlight of the day came when the students combined data and interpretations from the experiments and, after a series of presentations and discussions, the students successfully revealed the existence of a suitable paleochannel.

Geoscience Australia's Chief of Energy, Dr James Johnson met with the students and commented that this workshop provided students with a hands-on experience to engage with some of our leading scientists and learn about the major challenges facing Australia—in this instance helping to identify alternative water sources in arid Australia. Dr Johnson hoped that these talented students would be inspired by the experience to consider pursuing a career in the geosciences, and even consider

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applying for a place with Geoscience Australia's work experience and graduate programs in the future.

The National Youth Science Forum is a two-week program held in Canberra in January each year, and hosted by the Australian National University. The program is designed for students moving into Year 12 who wish to follow careers in science, engineering and technology. It offers students an introduction to research and researchers in government and industry organisations. Geoscience Australia is one of the many science education experiences offered to the students as part of the program.

2013 National Science Teachers Summer School (NSTSS)

As part of the 2013 National Science Teachers Summer School program, forty-five science teachers from around the country spent an afternoon in January at Geoscience Australia. The teachers visited the Sensitive High-Resolution Ion Microprobe (SHRIMP), the Australian Tsunami Warning Centre and the Geoscience Australia Education Centre's 3D theatre.

The NSTSS program is designed to provide science teachers a unique experience in Earth science education to stimulate their passion and, in turn, enhance the teaching of Earth science to their students. The teachers left with a more rounded understanding of Geoscience Australia's capabilities—and a showbag brimming full of educational material.

The Geoscience Australia Education Centre is staffed by trained educators, science communicators and geologists and offers structured hands-on activities with science and geography curriculum focus for visiting school groups.

Related articles and websites

Geoscience Australia Education Centre
www.ga.gov.au/education.html

National Youth Science Forum
http://www.nysf.edu.au/

National Science Teachers Summer School
http://asta.edu.au/programs/nstss

For more information

email ausgeomail@ga.gov.au

Series of seismic events in Solomon Islands triggers large earthquake and tsunami

The Santa Cruz earthquake sequence began on 30 January 2013, resulting in a local tsunami and over 120 separate earthquakes in southern parts of the Solomon Islands chain known as the Santa Cruz Islands. A tsunami was produced from a magnitude 7.9 (M7.9) undersea earthquake on 6 February 2013 at 12:12 AEST (01:12:30 UTC), with an epicentre located approximately 80 kilometres west of Nendo Island (figure 1). The undersea earthquake occurred at a depth of 32 kilometres below the seabed, which immediately prompted a tsunami warning for surrounding Pacific nations. The Joint Australian Tsunami Warning Centre (JATWC) advised that there was no tsunami threat to Australia.

The earthquake caused severe shaking on Nendo Island, and generated a tsunami that impacted local islands, with 10 people confirmed dead and 13 people injured in Temotu Province. Over 3300 people were affected as their houses were swept away by the tsunami. In total, almost 600 houses were destroyed and Lata wharf, the key supply point to Nendo Island was damaged. Assessment of tsunami affected areas suggests that the tsunami runup was 3.5 metres above the coastline in Temotu Province (OCHA, 2013). Overall, the impacts of this tsunami were not as severe as damage produced by a M8.1 earthquake and tsunami in the Solomon Islands in 2007, which is reported to have killed 52 people.

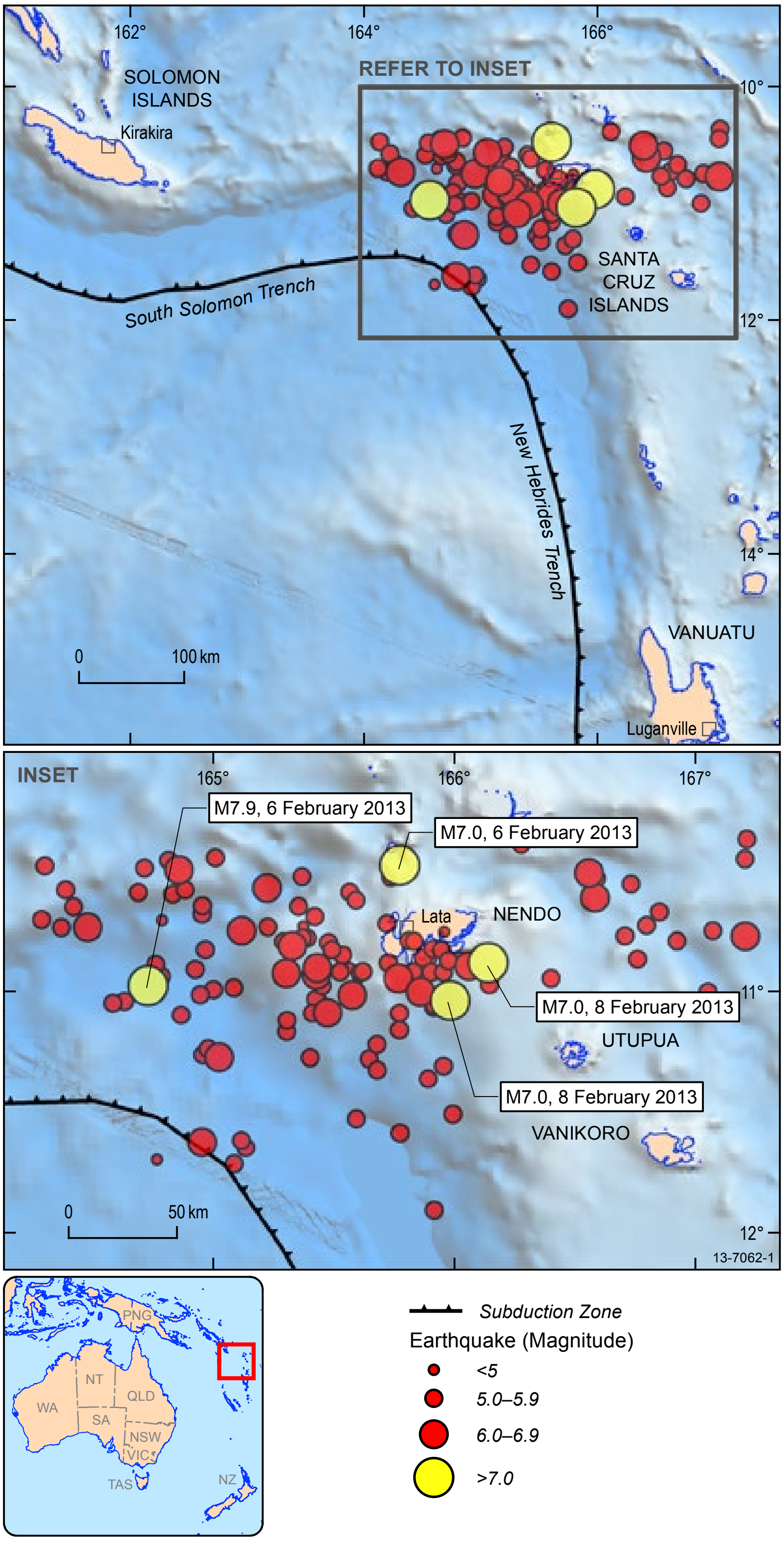

Figure 1: Map showing the magnitude 7.9 earthquake that occurred in February 2013 in southern parts of the Solomon Islands, and all earthquakes above magnitude 4.7 that were recorded around the Santa Cruz Islands from late January 2013, until late February 2013. Earthquakes of magnitude 7.0 and above are highlighted in yellow. The map also shows the tectonic plate boundaries.

There had been a notable increase in earthquake activity in the Santa Cruz Islands in the week prior to the M7.9 earthquake and tsunami. From 30 January onwards, Geoscience Australia recorded eight earthquakes above magnitude 6. This included a magnitude 6.4 earthquake that occurred at 11:07 AEST on the same day as the M7.9 earthquake.

More than 90 aftershocks were recorded in the Santa Cruz Islands region in the week following the M7.9 event; three of these were M7.0 (figure 1). The earthquakes are located on the Australian-Pacific Plate boundary, where the Australian Plate is being subducted beneath the Pacific Plate. The tectonic plate boundary is complex at this location, changing from East-West along the Solomon Trench, to North-South along the New Hebrides Trench. The M7.9 earthquake occurred at the northern end of the New Hebrides section.

Subduction zone tectonic settings around the world are typically very seismically active, and often generate large magnitude earthquakes (for example, March 2011, Tohoku Japan M9.0; December 2004, Sumatra-Andaman M9.1-9.3). The Solomon Islands lie in an active tectonic region, where many significant earthquakes have occurred in the past. This includes a M8.1 earthquake in the Solomon Islands on April 1, 2007. The epicentre from this event was located approximately 850 kilometres north west of the recent M7.9 event. In addition, later the same year on September 2, a magnitude 7.2

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earthquake struck the Santa Cruz Islands. This earthquake was located only 130 kilometres away from the epicentre of the 6 February M7.9. This earthquake activity is a result of a build-up of stress at the plate boundary as the Australian Plate moves towards the north-northeast at a rate of approximately 7 centimetres per year (Blewett, 2012).

Earthquakes and tsunamis are monitored via the JATWC operated by the Australian Bureau of Meteorology in Melbourne and Geoscience Australia in Canberra. The JATWC monitors, analyses and alerts for earthquakes occurring in our region as part of the Indian Ocean Tsunami Warning and Mitigation System, and warns the Australian community of potential tsunami impacts to Australia's coastline and external territories. In the case of the Santa Cruz earthquake, the Duty Seismologist responded with an earthquake solution within 12 minutes of the earthquake origin time.

References

Blewett R. 2012. Shaping a nation: a geology of Australia. Canberra: Geoscience Australia and ANU E-Press.

United Nations Office for the Coordination of Humanitarian Affairs (OCHA), 2013, Solomon Islands: Earthquake and Tsunami Situation Report No. 5 (as of 15 February 2013), OCHA Regional Office for the Pacific.

Related articles and websites

Earthquake Monitoring
www.ga.gov.au/earthquakes/staticPageController.do?page=earthquake-monitoring

Solomon Islands 2007 tsunami: GA Earth Observation and Satellite Imagery
www.ga.gov.au/earth-observation/basics/gallery/international-locations/solomon-islands-2007-tsunami.html

The Joint Australian Tsunami Warning Centre
www.bom.gov.au/tsunami/about/jatwc.shtml

Earthquakes @ Geoscience Australia
www.ga.gov.au/earthquakes

If you have felt an earthquake, you can find earthquake information and fill in an online felt report at Earthquakes @ Geoscience Australia or you can contact the Earthquake Hotline on 1800 655 739.

For more information

email ausgeomail@ga.gov.au

New geophysical datasets released

Datasets from three new geophysical surveys have been released since December 2012.

Table 1: Airborne Magnetic—Radiometric—Elevation Surveys.

Survey	Date	1:250 000 Map Sheets	Line Spacing (m), terrain clearance (m), orientation	Line Km	Contractor
Perth Basin South	March 2011–July 2012	Dongara (pt), Perenjori (pt), Hill River (pt), Moora (pt), Perth (pt), Pinjarra (pt)	200 m 50 m east–west	88 000	Fugro Airborne Surveys Pty Ltd
South West 3 (Cape Leeuwin)	March 2011–January 2012	Busselton (pt), Collie (pt), Augusta (pt), Pemberton (pt)	200 m 50 m east–west	28 050	Fugro Airborne Surveys Pty Ltd
Grafton–Tenterfield	June 2011–December 2012	Goondiwindi (pt), Warwick (pt), Tweed Heads (pt), Inverell (pt), Grafton (pt), Maclean (pt)	250 m 60 m east–west	100 000	GPX Surveys Pty Ltd

For more information

email ausgeomail@ga.gov.au

Geoscience Australia Multibeam Bathymetry Data Released Online

Figure 1: Map of the 50 metre Multibeam Dataset of Australia.

Geoscience Australia has released a new multibeam bathymetry dataset that provides improved visualisation of the topography and nature of the seafloor of offshore Australia.

Bathymetry is the measurement or mapping of seafloor topography. One of the most accurate ways of collecting bathymetry data is through the use of multibeam echosounders which are acoustic ship-bourne instruments designed to map the ocean floor.

Geoscience Australia is the national custodian of an extensive multibeam dataset. The 50 metre Multibeam Dataset of Australia

2012 is a tiled compilation of the entire multibeam dataset held by Geoscience Australia, including all data lying within the outer edge of the offshore area of Australia, as well as some data in international waters. Some of the multibeam data was collected by Geoscience Australia with the remaining data having been submitted by other institutions in the international scientific community.

Several formats are provided for download (projected in WGS84 UTM zones) including:

- ASCII xyz
- CARIS Grid file (viewable on the free CARIS Easyview software)
- GeoTIFF
- ESRI Grid

This dataset is available to download as individual tiles from the Geoscience Australia website, or the entire 50 m Multibeam Dataset of Australia 2012 is available on a hard drive and can be purchased from the Geoscience Australia Sales Centre, for a cost of $55 (please quote GeoCAT number 73842).

Realated articles and websites

50m Multibeam Dataset of Australia 2012
www.ga.gov.au/marine/bathymetry/50m-multibeam-dataset-of-Australia-2012.html

Geoscience Australia Sales Centre
www.ga.gov.au/products-services/how-to-order-products/sales-centre.html

For more information

email ausgeomail@ga.gov.au
email bathymetricrequests@ga.gov.au

Arid Zone Palaeovalley Map

A map of palaeovalleys across the arid and semi-arid zones of Western Australia (WA), South Australia (SA) and the Northern Territory (NT), the 'WASANT Palaeovalley Map', is now available for download from Geoscience Australia's website. It provides a synoptic view of the distribution and disposition of ancient valley networks across the continent and is aimed at providing guidance for more locally focussed investigations for groundwater resources within palaeovalley aquifers.

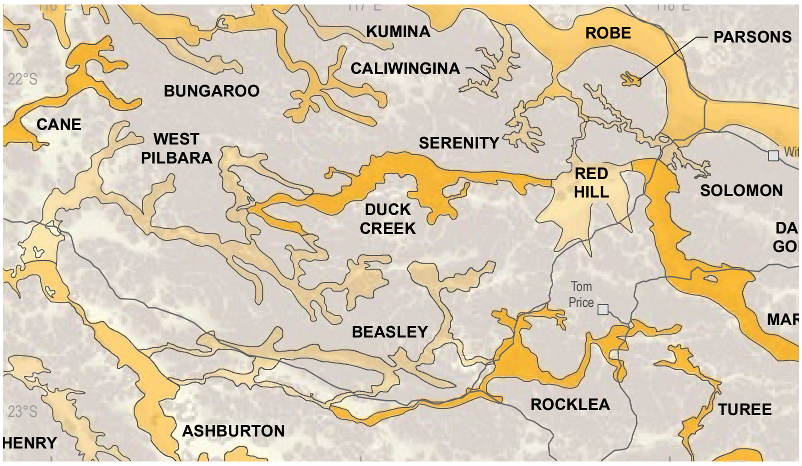

Figure 1: Part of the WASANT (Western Australia-South Australia-Northern Territory) Palaeovalley Map (Bell et al, 2012). This section shows palaeovalleys in the Hamersley Province, in the Pilbara region of WA.

The map extent is defined by the Köppen-Geiger classification of arid and semi-arid zones. The map was produced as part of Geoscience Australia's project: 'Water for Australia's arid zone—Identifying and assessing Australia's palaeovalley groundwater resources' which was funded by the National Water Commission. The four year project (2008–2012) was directed towards providing information about the role of palaeovalleys as aquifers in widespread regions where groundwater resources are scarce or need to be investigated for the future.

The WASANT Palaeovalley Map was compiled using national-scale datasets, including digital elevation models (DEM) and geological maps, along with *product news*

existing geoscientific data and reports in combination with expert knowledge for local areas. An example of the map output, over the Hamersley Province in the Pilbara region of Western Australia, is shown in figure 1. The map includes palaeovalleys that are obscured beneath desert dunefields and sand plains, for example, the Dune Plains Palaeovalley in the NT (figure 2). New information was obtained through demonstration studies in selected sites within the three states. Examples of palaeovalley cross-sections from selected sites are shown on the map to illustrate the heterogeneity and distinctive characteristics of palaeovalleys that have evolved under different climatic and fluvial regimes in respective geologic provinces. Enlarged inset maps of areas where palaeovalleys are dense or particularly distinctive are displayed around the main national-scale map. Inset maps of arid zone climate regimes, geologic provinces, demonstration study sites, a processed DEM, and relevant references are also included.

The methodology adopted to generate the WASANT Palaeovalley Map is described in English et al (2012), along with interpretative descriptions and some noteworthy observations of palaeovalleys in specific regions. The map is sub-titled 'first edition' in anticipation that future updates, extensions and refinements might be made.

Figure 2: Dune Plains Palaeovalley, located between Uluru and Kaṯa Tjuṯa, NT, part of the Katiti Palaeovalley system in Central Australia. Aquifers in the 100 metre deep palaeovalley provide groundwater for Yulara Resort.

References

Bell JG, Kilgour PL, English PM, Woodgate, MF, Lewis, SJ, & Wischusen, JDH (compilers). 2012. WASANT Palaeovalley Map—Distribution of Palaeovalleys in Arid and Semi-arid WA-SA-NT (First edition), scale: 1:4 500 000. Geoscientific thematic map (Geocat No 73980).

English P, Lewis S, Bell J, Wischusen J, Woodgate M, Bastrakov E, Macphail M, Kilgour P. 2012. Water for Australia's arid zone—identifying and assessing Australia's palaeovalley groundwater resources: summary report, Waterlines report, National Water Commission, Canberra.

Related websites and articles

WASANT Palaeovalley Map—Distribution of Palaeovalleys in Arid and Semi-arid WA-SA-NT (First edition), scale: 1:4 500 000. Geoscientific thematic map
www.ga.gov.au/cedda/maps/96

https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=73980

Water for Australia's arid zone—identifying and assessing Australia's palaeovalley groundwater resources: summary report
http://archive.nwc.gov.au/library/waterlines/86

For more information

email ausgeomail@ga.gov.au

events

Surveying and Spatial Sciences Conference 2013
15–19 April 2013

National Convention Centre, Canberra
Contact: The Surveying and Spatial Sciences Institute (SSSI)

www.sssi.org.au
www.sssc2013.org

2013 APPEA Conference and Exhibition
26–29 May 2013

Brisbane Convention & Exhibition Centre
Contact: Australian Petroleum Production and Exploration Association (APPEA)

www.appeaconference.com.au

Conference of the Australia Science Teachers Association (CONASTA 62)
7–10 July 2013

La Trobe University, Bundoora, Melbourne, Victoria
Contact: Australian Science Teachers Association (ASTA)

conasta@asta.edu.au
www.asta.edu.au

International Geoscience and Remote Sensing Symposium
21–26 July 2013

Melbourne Convention and Exhibition Centre
Contact: Institute of Electrical and Electronics Engineers (IEEE) Geoscience and Remote Sensing Society

info@igarss2013.org
www.igarss2013.org

National Science Week 2013—A Century of Australia Science
10–18 August 2013

Contact: National Science Week Office

scienceweek@innovation.gov.au
www.scienceweek.net.au

ASEG-PESA 2013—23rd International Geophysical Conference and Exhibition
11–14 August 2013

Melbourne Convention and Exhibition Centre
Contact: The Australian Society of Exploration Geophysics and the Petroleum Exploration Society of Australia

www.aseg-pesa2013.com.au

For more information

email ausgeomail@ga.gov.au