AuScope+: opportunities, challenges and responsibilities

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This presentation will outline some ideas on the opportunities, challenges and responsibilities that the the Australian Earths Science community faces in articulating a coherent infrastructure program for the next decade. The motivation is to seed discussion for a compelling program for whatever follows the NCRIS program that currently underwrites AuScope—i.e. AuScope+. In addition, there will be the opportunity to review the objectives of the AuScope-AGOS EIF round three bid, submitted in late 2009.

AuScope Geospatial: measuring the contemporary deformation of the Australian crust

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Ongoing developments in geodetic positioning towards greater accuracies with lower latency are now allowing the measurement of the dynamics of the Earth's crust in near real time. However, in the Australian circumstance a sparsity of geodetic infrastructure has limited the application of modern, geodetic science to broader geoscience research programs. Recent enhancements to the Australian geodetic infrastructure, through the AuScope initiative, offer opportunities for research into refinement of geodetic accuracies, as well as their application to measuring crustal deformation.

Simulation, analysis and modelling in AuScope

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Computational modelling is often referred to as the 'third branch of science' ranking alongside experimentation and development of theoretical explanations in the construction of an understanding of the natural world (e.g. Pool, 1992, Science, v256, pp44).

The solid Earth sciences rely heavily on computation as the principle means of studying the time-evolution of otherwise agonisingly slow processes that can be observed only where they have been serendipitously preserved in the geological record.

The computational codes which are the engines of models and simulations of natural processes have reached a level of complexity that they require specialist teams of (software) engineers and mathematicians to construct, test and maintain; expertise which comes from outside the specialist scientific domain of application. They are properly considered the basic infrastructure needed for certain disciplines to progress.

AuScope SAM provides such an infrastructure to solid earth scientists in Australia and integrates with the data grid also provided through AuScope. We will show a number of examples where AuScope's SAM infrastructure has been used to create new scientific knowledge at the cutting edge of the Earth Sciences.

AuScope earth imaging—progress with geotransects

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A major component of AuScope activities in Earth Imaging has been directed to elements of a geotransect program, with reflection profiles, passive seismic and magnetotelluric components. Much of the reflection work has been done in cooperation: a 200km spur was added to a major survey in Northern Queensland undertaken by GSQ/GA in 2007 and AuScope supported 200 km of the 580 km GOMA (Gawler-Officer- Musgrave-Amadeus) profile from the southern Northern Territory into South Australia in 2008 that was also funded by GA/PIRSA/NTGS. In November 2009, AuScope carried out approximately 200km of reflection lines from Western Victoria into South Australia across the southern Delamerian, with support from GSV. As a result there is now almost continuous reflection coverage across the Delamerian into much of the Lachlan Fold belt.

Planning is in train for joint GSWA and AuScope work in mid-2010 across the Capricorn orogen to link

from the Pilbara to the Northern Yilgarn.
In addition a program of passive seismic deployments has been made to provide supplementary 3-D information around reflection profiles. A suite of deployments have been made in the Gawler and Curnamona cratons, and instruments are currently in place in a swath that will eventually extend from Mt. Isa to the Queensland coast. Magnetotelluric measurements are being made along the southern Delamerian profile.
By good fortune, the AuScope deployments have been able to be linked with separately funded activities (mostly ARC funding), so that a north-south array of broad-band instruments along the Stuart Highway provides a complement to the GOMA profile. Passive seismic deployments in north-western New South Wales, in part at the same time as the Curnamona array, significantly increase the potential for determining 3-D structure. Similar linkages have also been secured in magnetotelluric work.

The AuScope National Virtual Core Library—establishment and achievements

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The AuScope NVCL was established to facilitate wide ranging earth science research into the mineralogy and composition of the top two kilometres of the Australian continent, using the millions of metres of core stored in State and Territory Geological Survey and company core libraries. Traditionally these libraries are physically visited by a small number of geologists wishing to compare and understand the characteristics of mineral deposits sampled over the last 50 years during past exploration programs and now deposited with the Surveys for public use. In addition, cores drilled through public stratigraphic programs, oil and gas exploration, and basin analysis programs are also stored. Such visits are based primarily on visual, experiential and subjective analysis and often require expensive travel to the distributed core libraries.
The AuScope NVCL component's goal is to radically improve the ease, user experience and knowledge derived from these past drill core holdings, plus future drilling, to contribute to the other AuScope objective, a more robust and objective four-dimensional earth model of the Australian continent. Using a new generation of Australian-developed hyperspectral logging technology, CSIRO's HyLogging™ Systems, each State and Territory Geological Survey has been equipped to mineralogically log and image as much of their archived core as possible, to interpret the contained mineralogy, and to database the outputs so they can be interrogated and published via the Internet, in a consistent and standard manner. Phase 1 of the project involved CSIRO designing and constructing seven HyLogger-2 generation instruments.
This phase utilised investment from the Federal Government's NCRIS program and the CSIRO. Phase 2 involves each Geological Survey hiring or assigning staff to operate these instruments in each jurisdiction's core libraries, and interpreting the spectral results using TSG-Core software developed by the CSIRO. This part of the project involves substantial ongoing investment by each Geological Survey. Phase 3 comprises the building of a series of distributed relationship databases and their associated infrastructure in each jurisdiction. These databases are built by synchronisation with the TSG-Core processing software. Using web services technology (Phase 4) these databases are then able to be interrogated by users anywhere in the world and the logged data and images visualised, explored and partially downloaded from the Internet, or delivered by disk on request. Phase 4 is being developed in partnership with the AuScope Grid component. Every one of these Phases poses significant new territory and challenges across a number of quite different disciplines.
At this time six Geological Surveys have operational NVCL nodes based in each capital city, namely Brisbane, Sydney, Hobart, Adelaide, Perth and Darwin. The Melbourne node will be established in late 2010. After training phases, involved with establishing procedures and protocols for standardised logging, the geological survey teams are now logging several hundreds of metres per day. Issues that have arisen at this stage include manpower and scheduling derived from moving large amounts of core around day-in, day-out, plus dealing with sometimes very old and severely degraded cores. Notwithstanding these set-up challenges over 100,000 metres of cores from hundreds of drill holes have been logged and new mineralogical findings documented.
The difficulties involved in consistently interpreting geology, as well as host rock, metamorphic and alteration mineralogy, by conventional visual means, is gradually be replaced by the more objective HyLogging strategy and is producing long lasting digital records that will be available for generations to come. Many examples will be given in the paper. In several States and Territories new

collaborative, publically-assisted drilling programs are also providing new, up-to-the-minute cores that are now required to be logged, thus keeping the NVCL potentially fresh and relevant.

Once the cores are logged a validation phase is also commonly undertaken to clarify, on selected subsamples, the mineralogy evident in the HyLogged cores. This is being conducted using a variety of supporting analytical techniques such as XRD, SEM, electron microprobe, thin section petrography, etc., and is an important part of confirming and justifying confidence in the NVCL.

The logging priorities in each State/Territory are defined by the AuScope Geotransects program and with the intent to cover the nation's 'classic' ore deposit types and stratigraphic sequences. The NVCL logging infrastructure is also available by arrangement for students, individual researchers and research consortia, (e.g. AMIRA, MERIWA, CRCs, etc.), as well as industry. Discount rates are available to researchers.

The NVCL goes far beyond logging alteration mineralogy. Mineralogical and lithological characterisation can be used in many other pursuits, for example, in oil and gas exploration and formation characterisation, for basin analysis, for geothermal research, for geometallurgical characterisation, for studies on the carbon sequestration characteristics of subsurface formations, indeed anywhere where an improved and objective understanding to the geology and past geological processes, and 'stratigraphic' correlation is required.

The AuScope NVCL offers an unprecedented collaboration between Federal and State agencies, CSIRO and industry, and in time for every earth scientist who wishes to augment their research by using the sensing, data or knowledge infrastructure. Please find out more by visiting http://www.auscope.org.au/content.php/category/id/15.

Mineralogical validation of the AuScope NVCL

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The AuScope National Virtual Core Library (NVCL) is being built from nodes in each Australian State and Territory Geological Survey using voluminous mineral spectroscopy of hundreds of thousands of metres of legacy cores. The mineral spectroscopy is undertaken using hardware and software HyLogging™ technologies and the results, in the form of logs and images, are being databased and intended for Web publication. Three critical steps underpin the collection and utilisation of these data: calibration, validation and explanation. The outcomes of these three steps bear importantly on the confidence and benefits that can be ascribed to the outputs and, ultimately, to the downstream utilisation of the geological knowledge contained in the logs and databases by the wider earth science community.

Calibration ensures that the spectroscopy is conducted according to comparable and traceable standards and is provided as part of routine measurement processes. Validation is the process whereby the spectroscopicallyestimated mineralogy is confirmed by a series of independent processes on representative sub-samples. These two steps are critical to having the confidence to go to the third stage. Explanation is the final step that ascribes interpretation and meaning to the observed mineralogical results in terms of geological processes, paragenesis and potential benefit to some branch of the earth sciences, and commonly utilises integration with other geological observations and measurements. This paper concerns itself with the second of these steps based on experiences gained so far from operation of the NVCL.

In the day-to-day research and building of the NVCL validation has multiple purposes. It is not only about confirming that mineral x really does occur at location y, but does so with some probability, and that estimates of the proportions of minerals in an assemblage are more or less correct in some relative or absolute sense.

Results of this then not only feed into downstream use but backwards to improvements in the measurement technology and algorithms and software that provide these estimates.

Armed with the broad brush spectroscopic and mineralogic domains spatially evident in HyLogged drill holes we have used various techniques to validate the outputs. These have included so far, replicate measurements, thin section petrography, x-ray diffraction, SEM, electron microprobe and multi-element geochemical measurements. These have been focused mainly on confirming the mineralogy of spatially coherent domains and also on specific mineral samples where often something unexpected has become evident. Examples are given below. Multiple validation

techniques are often needed as not all methods are truly reliable for all cases; e.g. separation of some clay species by XRD is often also difficult and infrared spectroscopy may in fact be the better method. The potential to map stratigraphically-significant enstatite distribution in high-grade, complexly folded gneiss at the Challenger gold mine, South Australia, was an unexpected find using the HyLogger. A recurring and distinctive spectrum, not present in the TSA training library, was confirmed by petrographic investigation to the presence of the orthopyroxene. Petrology, microprobe and SEM have been used to validate the HyLogging of alteration minerals associated with IOCG-style mineralisation in Emmie Bluff drillhole, SAE6. A distinct spectral response for dickite and illite, noted in the cover sequence of Pandurra Formation sandstone, was confirmed by XRD and SEM. With calibration, the paragenetic sequence of kaolinite/dickite and variously crystalline illite/white mica, reflecting depth of sandstone burial, could be reliably mapped using the NVCL HyLogger. HyLogging petroleum core is a new direction for GSWA. Recently acquired spectral data for several kilometers of petroleum core from the Canning Basin has provided information about litho-stratigraphic unit boundaries (especially between carbonate group minerals), porosity, and water content.
To study the 3D distribution of alteration of the Minnie Spring molybdenum mineralisation in the Gascoyne Province, WA, 1500 metres of core were HyLogged with support from petrographic and XRD analyses. The pervasive development of a phengite-Fe/Mg chlorite-epidote assemblage overprinted an early stage of muscovite formation. This propylitic and sericitic alteration is spatially associated with quartz-pyritemolybdenite veins that are tracked by illitic phengite and calcite. Validation in Queensland and Tasmania has included further confirmation of dickite in sedimentary sequences, and much more common gypsum identification than previously seen. Strategies are also being developed in several States to confirm small mineral proportion estimates and better understand the lower limits of detection in complex multi-component mixtures, particularly those including small carbonate fractions.

Minerals Down Under National Research Flagship: linking AuScope to the broader minerals industry value chain

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The CSIRO Minerals Down Under National Research Flagship was launched in 2007 to tackle medium- to longterm challenges facing the Australian mineral industry across the value chain from exploration and mining through mineral processing within the framework of an economically, environmentally and socially sustainable minerals industry. This broad research portfolio provides an ideal environment to link the AuScope research platforms to applications across the industry and, perhaps more importantly, to unlock the value of data integration between traditionally discrete parts of the minerals value chain.
Despite the potential benefits of data integration, it remains an elusive goal within research and industry.
Many studies use only a small subset of available data types in an integrated manner, often maintaining the traditional 'silos' of exploration, mining, processing and mine closure. Integrating data across the entire minerals value chain is an expensive proposition involving multiple disciplines and, significantly, multiple data sources both internal and external to any single organisation. Differing vocabularies and data formats, along with access regimes to appropriate analysis software and equipment all hamper the sharing and exchange of information. In spite of the many intuitive arguments for data integration, the large investments required also demand a clear understanding of the practical benefits to be unlocked. As a result, the cost of data integration is itself a barrier to the research required to justify the investment in data integration. AuScope has addressed the challenge of data exchange across organisations nationally and established an AuScope community earth model. The model contains a wide variety of live and updated data types. The data standards and infrastructure platforms that underpin AuScope provide important new datasets and multiagency links independent of software and hardware differences. AuScope has thus created an infrastructure, a platform of technologies and the *opportunity* for new ways of working with and integrating disparate data at much lower cost. An early example of this approach is the value generated by combining geological and metallurgical data sets as part of the rapidly growing field of geometallurgy. This not only provides a far better understanding of the impact of geological variability on process outcomes but also leads to new thinking on the types and characteristics of data sets collected at various stages of the exploration and mining process.

The Minerals Down Under Flagship is linking its research activities to the AuScope infrastructure and exploiting the technology internally to create a platform for integrated research across the minerals value chain and improved interaction with industry. Referred to as the 'Minerals Down Under Earth Model', the system will be fully interoperable with the AuScope Earth Model with secured access to allow confidential collaboration with industry when required. The Flagship is altering its work practices based on the AuScope approach and developing new ways to deliver research outcomes and interact with its industry partners. Specific examples include:

- Discovering all open access reports published by Minerals Down Under that lie within a given tenement or geologic unit boundary. This will unlock a wealth of historical data that has traditionally been difficult to access on a geographic query basis and greatly improve the accessible knowledge base for many exploration tenements.
- Web and open standards based access to Flagship and partner derived open file information through the Minerals Down Under Earth Model. This allows real time collaboration between disciplines and research/industry partners and immediate access to the latest research outcomes. For example, integration of information from State water records linked to laterite geochemistry provide the opportunity to understand the complex interplay between groundwater's and the regolith profile. Import feedback loops between disciplines and a broader understanding of the potential value of data sets will eventually lead to a fundamentally different approach to data collection.
- More complex workflows involving simulation and analysis being available as on-demand secure computational services directly to industry working against industry supplied data are also under consideration.

The CSIRO Minerals Down Under Flagship is building on the AuScope infrastructure to transform the way that data and data products are identified, shared, integrated, and reused, to unlock the benefits of true integration of research efforts across the minerals value chain.

Implementing spatial information services at GeoScience Victoria

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GeoScience Victoria (GSV) is the Victorian government custodian of geoscience data and knowledge. Since 2004 it has been working toward delivering data held in its information systems using web-based data delivery mechanisms (web services) that conform to international standards for both content and format.

The primary driver for this is twofold: to ensure that the vast holdings of detailed scientific data andinterpretations GSV and its stakeholders have captured are honoured during delivery; and to ensure that GSV's data delivery systems can be seamlessly integrated into computational systems distributed across Australia and the world, regardless of how each individual organisation stores and maintains its data.

As a result, users of our data should spend much less time re-formatting and manipulating data once it is received. They will be able to use the same process when acquiring data from other organisations that use the same standards. Much more time can be spent on modelling and analysis of data that hosted in Victoria and elsewhere, with all data sources integrated seamlessly. Data from other domains, using the same base standards, can also be combined and interpreted. Potential uses for the data range from the obvious, such as regional or localised 3D modelling, exploration project generation and environmental geoscience, to newer, multidisciplinary areas, such as the impact of geology-related activities on agriculture and fisheries.

To achieve this goal, GSV has been collaborating with agencies from North America, Europe, Asia and Australia to develop the GeoScience Mark-up Language (GeoSciML). GeoSciML defines how geological interpretations and observations should be structured when delivered via Open Geospatial Consortium (OGC) compliant web services. This work is integrated with existing standards for borehole and field observation data, and has also been extended to develop an Australian model for earth resources. At the time of writing GSV has deployed web services delivering geological interpretations, earth resource information and borehole locations. It is now working towards delivering enhanced borehole data, field observations and geochemistry.

Despite these well defined standards, the technology required to set up the web infrastructure was either immature or unavailable until relatively recently. AuScope's development of the spatial information services stack has provided us with the technology necessary to deploy our web services.

In addition, AuScope provided expertise to all other Australian geological surveys to set up new Earth Resource web services. This expanded the community of data providers beyond those who are involved standards development, to a significant group of operational data providers.
The collaboration with AuScope has enabled a move from standards with exciting potential to fully operational data delivery systems based on web services. These services deliver data describing a rich variety of geological phenomena and are now ready for use by both the geoscience community, industry and the wider research community. How the data are used is now limited only by the individual user's needs or capabilities, the format and content are no longer a limiting factor.

Developments in the analyses of geodetic GPS data

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Local, regional and worldwide global positioning system (GPS) networks have long been used to monitor geophysical processes which vary spatially throughout both the temporal and frequency domains. It is now possible to estimate position at the 1–2 mm level with data obtained from geodetic quality GPS receivers, comparable to those being installed across the Australian continent as part of the AuScope geospatial component.
The improved precision obtainable from GPS offers new insights into the surface expression of a range of geophysical signals. These improvements have resulted from not only improvements in the tracking network, but incremental improvements in such things as the modelling of the propagation of the GPS signals through the atmosphere and deformation of the surface of the Earth from atmospheric and ocean mass loading effects. Assessing the influence of these incremental advances across a diverse parameter set requires a systematic approach and incurs significant computational burden. Geodetic GPS coordinate time series that are generated from any given analyses often exhibit complex nonlinear behaviour which reflect a combination of real world signal and systematic artefacts caused by such things as aliasing of high frequency periodic motion and errors within the processing models or solution strategies.
In this presentation, we describe the AuScope GPS analysis workflow that provides for the integrated analysis and visualisation of GPS data and subsequent solutions. The workflow aids in the efficient selection and processing of GPS data and includes a novel visualisation of the analysis outputs. This visualisation assists in the comparison of subtlety different solution sets, with the result being a tool that aids in the scientific development of the technique, thereby contributing to the improved understanding of global geophysical processes.
By way of application, we present results from the novel application of GPS to hydrology. We present results comparing time series of hydrologically induced deformation of the Earth's crust, as determined using GPS, which those estimates from space based gravity measurements from the Gravity Recovery and Climate Experiment (GRACE). This application serves to highlight the benefits of dense networks of GPS sites whilst outlining some of the current areas of development within the discipline.

Virtual Rock Labroatory: enablng computational minerals science research

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The Discrete Element Method (DEM) is a powerful and oft utilised numerical tool for minerals science research, particularly for fundamental studies of rock breakage and laboratory-scale simulations of comminution processes. Its power stems from the discretisation of rock into a large number of constituent particles interacting via simplified laws for elasticity, friction, breakage and other phenomena. DEMs capture naturally the self-organisation associated with damage evolution and fragmentation, without the burden of dynamic re-meshing required by continuum-based breakage models. DEM permits investigation of the internal dynamics leading to damage and final failure of rocks—features often beyond direct observation. However DEM research is generally stifled by the computational demand imposed by the method. The ESyS-Particle DEM simulation software (https://launchpad.net/esys-particle/) was developed by the Australian Computational Earth Systems Simulator (ACcESS) MNRF with ongoing software development funding from AuScope Ltd. specifically to address the computational limitations of existing DEM software. ESyS-Particle provides a parallel DEM simulation engine optimised for high-end supercomputers such as the Australian Solid Earth

Simulator (UQ) and the iVEC supercomputer (CSIRO, WA). ESyS-Particle is the most advanced freely available parallel DEM simulation software as evinced by a rapidly expanding global user-base.
One of the key features driving its popularity is the scripting interface that permits rapid construction of new models without changes to the core engine of ESyS-Particle. Whilst the scripting interface is undoubtedly the favoured mechanism for using ESyS-Particle by power-users with programming skills, the lack of a graphical user interface detracts a broad community of end-users familiar with commercial simulation software. The Virtual Rock Laboratory (VRL) has been constructed with this user-base in mind. VRL is a web portal that enables users to execute ESyS-Particle simulations on the AuScope computational grid. Requiring only a JavaScript-enabled web browser, the portal can be accessed from anywhere in the world. It contains intuitive interfaces for constructing simulation scripts, submitting them to a supercomputer, monitoring the progress and downloading the results—all from within the portal. VRL's dialogue-based Script Builder makes it possible to create new simulations without any prior programming experience.
In keeping with the mandate of AuScope to provide state-of-the-art research infrastructure for use by the Australian geoscience research community, the VRL has been tailored for use by postgraduates and researchers without in-depth knowledge of numerical modelling principles. The Workflows implemented in VRL provide the key components for applied numerical modelling aimed at understanding the physics of rock breakage and fragmentation. We have utilised the analogy with a physical rock laboratory to guide development. Users select the type of rock breakage experiment they wish to perform (e.g. a uni-axial compression experiment), provide input parameters such as the material properties and physical dimensions of the rock sample to test, then request execution of the simulation on the AuScope Grid. Once a simulation is completed, the user is informed and the VRL provides tools for visualisation and analysis of the simulation results. We will demonstrate the features and workflows implemented in the Virtual Rock Laboratory with emphasis upon its application for minerals science research.

Scientific results from the AuScope Geospatial infrastructure

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AuScope is one of the capability areas funded under the National Collaborative Research Infrastructure Strategy (NCRIS). The philosophy behind NCRIS is to provide the research infrastructure—and people to operate it—to enable Australian and international scientists to undertake world class research that could not be acomplished without the provision of the infrastructure.
The AuScope Geospatial component comprises three new Very Long Baseline Interferometry systems, new gravimeters, a network of Global Navigation Satellite System (GNSS) sites, upgrades to satellite laser ranging systems and high performance computing hardware. The purpose of this talk is to present some of the research outcomes that have been achieved to date through the use of AuScope infrastructure. Results will be shown that exploit the availability of GNSS observations at new sites across the continent (continental drift, crustal strain, hydrological loading), gravity observations made with new instruments as well as from studies that have utilised the AuScope Terrawulf II computer processing facility. Owing to the fact that the rollout of AuScope Geospatial infrastructure is ongoing, some of the scientific outcomes expected in the future will also be discussed.

Modelling across the scales: the data and resolution challenge

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The physics of many of our Nation's most pressing engineering and ecological problems involve simultaneous processes on multiple scales. These scales range from pore- to mine- to basin- to lithosphere scale, i.e. from nano metres to hundreds of kilometres. Examples of such processes include the predictive simulation of the heat extraction process from hot rock (dry or wet), the simulation of different CO2 sequestration technologies, ore body genesis, mantle models with self consistent plate tectonics and many more. The challenge is to resolve each scale to an appropriate degree of accuracy whilst allowing for the exchange, aggregation and disaggregation of information between the scales. The scale resolution and information exchange challenge requires the management of simultaneous, scale specific modeling technologies e.g. Lattice Boltzmann Methods (LBM) and particle methods on the micro-scale, with finite- element, difference or volume methods

on the macro-scale, combined with efficient mesh adaption schemes. The third challenge (besides scale resolution and scale communication) with the potential to substantially increase the value to be gained from modeling and simulation is the self consistent integration of geoscientific data (gravity, magnetic, GPS, INSAR etc) into dynamic computational simulations of earth processes (Inverse modeling technologies) The computational realisation of the various algorithms, code and data integration, and the sheer size of the problems involved in terms of unknowns, represents a significant innovation in terms of regional modeling capability, an innovative challenge the AuScope SAM team (with its track record of delivery of strong outcomes) is uniquely poised to meet.

Advances in geochemistry, past, present and future

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Advances in geochemistry have often been heavily facilitated by analytical breakthroughs. For example, the publication in 1928 of the book by Norman L. Bowen that laid down the foundations to understand the formation and evolution of igneous rocks. Most of the magmatic processes that he proposed are still used and discussed today, and his search for which physical parameters to understand these processes are major themes of current research. However, whole rock analyses involved laborious wet chemical techniques. The development of fast XRF methods completely revolutionised this field allowing for faster and more detailed studies. Also at the time of Bowen's publication, radioactivity had been known for almost 30 years, yet determining accurate isotope ratios of natural rocks for the purposes of dating and understanding their formation would not come until 1960s with technological advances in mass spectrometry that were largely developed for other purposes. The most obvious outcomes were constraining the age of the earth and the spawning of the field of isotope geochemistry as applied to both high- and low-temperature processes. Development of the electron probe and ICP-MS has similarly had major impacts on all fields of geochemical endeavor. More recently development of energy filters has allowed precise analysis of short-lived isotopes leading to a proliferation of studies of the time scales of physical processes on Earth. MC-ICP-MS has had a similar affect upon the use of the isotopes of the transition metals. In Australia the development of the SHRIMP fundamentally changed the way in which zircon dating was performed and this remains the instrument of choice worldwide for precision and spatial resolution. Looking to the future, the development of Ion Probe ability to analyze stable isotopes, increased spatial resolution, synchrotron applications and others will have major impact upon geochemical research and the broadening of its application. However, such equipment is expensive and strong geochemical groups in Australia, as elsewhere, tend to be clustered around a few well-equipped laboratories. It is therefore important to decide how to keep these laboratories at the cutting edge and to appraise the need for the establishment of new laboratories to seed research in other institutions. The key role that geochemistry has played in our growing understanding of geological processes is heavily underscored by the publication by Elsevier of the 7800 page, ten volume Treatise on Geochemistry in 2003. Continuing advances in the field will require commitment to investment in appropriate infrastructure.

The future of geodetic science: implications for Australia's infrastructure and investment

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Geodesy is the science of measuring and mapping the geometry, orientation and gravity field of the Earth including the associated variations with time. One of the missions of Geodesy has been to provide the foundation for high accuracy surveying and mapping, in effect underpinning the geospatial information sciences and industry.
Modern Geodesy involves a range of space and terrestrial technologies that contribute to our knowledge of the solid earth, atmosphere and oceans through earth observation of many parameters. These technologies include: Global Positioning System/Global Navigation Satellite Systems (GPS/GNSS), Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Satellite Altimetry, Gravity Mapping Missions such as GRACE, CHAMP and GOCE, satelliteborne Differential Interferometric Synthetic Aperture Radar (DInSAR), Absolute and Relative Gravimetry, Precise Surveying (Levelling & Traversing). A variety of services have been established in recent years to

ensure high accuracy and reliable 'geodetic products' to support geoscientific research. The reference frame defined by Modern Geodesy is now the basis for most national and regional datums. The Global Geodetic Observing System (GGOS) is an important new international initiative. GGOS aims to integrate all geodetic observations in order to generate a consistent high quality set of geodetic parameters for monitoring the phenomena and processes within the 'System Earth'—the solid Earth, the hydrosphere (including oceans, ice-caps, continental water), and the atmosphere. In parallel with this international initiative AuScope NCRIS Capability 'Structure and Evolution of the Australian Continent' has as one of its components the establishment of 'National Geospatial Reference Framework'. This is giving a significant boost to Australian, and international, geodesy through the installation of new VLBI antennas, absolute and relative gravimeters, and almost 100 new GNSS reference stations. GNSS technology is nowadays a crucial geopositioning tool for both Geodesy and Surveying and this is being increasingly recognised in the form of an expanding ground infrastructure of permanent reference GNSS stations. This paper will describe the background to Australian Geodesy, highlight some of the trends in international geodetic science, discuss the crucial link between geodetic infrastructure and technology on the one hand and the geospatial sciences (mapping, remote sensing and imaging, precise navigation) on the other hand, and speculate on what might be the implications for future geodetic/geospatial national infrastructure and capability investments.

Imaging beneath the Australian continent: infrastructure needs to meet the challenges of the 21st century

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For the last half century, Australia has enjoyed an enviable international reputation in solid earth geophysics, particularly in the field of deep seismic imaging on regional and continental scales. Much of this reputation has been built on the development of novel data inference techniques, innovative use of seismic recording equipment, and the advancement of new paradigms for describing the structure and evolution of continents.

For example, the idea for deploying a rolling array of seismic instruments to eventually cover an entire continent with passively recording seismometers had its origins in the SKIPPY project, and resulted in the first high resolution images of mantle structure beneath a continent. This idea has now been adopted by USArray, a massive US$100M+ project designed to progressively cover continental USA with seismometers at a 70 km spacing.

In order to maintain its position at the coal-face of new developments and discoveries in seismology, Australia must continue to facilitate its researchers with the necessary resources to foster innovation. From an infrastructure point of view, there are a number of areas that can be targeted in order to maximise return. A traditional strength is our ability to deploy passive seismic arrays to record distant earthquakes in order to build 3-D models of Earth structure, usually at mantle depths. While this work should continue, the potential returns can be greatly enhanced by the use of new generation equipment capable of recording three component data over a wide range of frequencies (from mHz to a 1000Hz). This will allow a variety of other useful information to be recorded (e.g. local earthquakes, higher frequency microseisms generated by the oceans, atmosphere and cultural activity) that can be integrated with the distant earthquake information to image structure throughout the full thickness of the lithosphere. The ability to illuminate structure from the shallow crust all the way down to the base of the upper mantle will provide key information on the development of the continental lithosphere, and help contribute towards a regional framework for the future exploration of prospective regions. Moreover, instruments capable of recording high frequencies make them useful for detecting explosions, vibroseis and airguns, which are used for a variety of purposes including reflection profiling and wide-angle surveys. Thus, deployments which record both active and passive data help provide a basis for the seamless joining of information collected at the exploration scale, and at the regional scale. In the past, this has been one of the major stumbling blocks for greater collaboration between exploration and solid earth geophysicists. A new pool of at least 150 three component instruments is required to meet the needs outlined above.

A second research area that opens up a wealth of opportunity for Australian scientists is marine geophysics. Although land-based seismic imaging has a strong future, the fact that Australia is surrounded on all sides by vast tracts of submarine continental terrane and ocean basins that are largely unexplored means that opportunity for new research and discoveries abound. A fleet of at least 20 OBS's (Ocean Bottom Seismometers) will allow a new chapter to be opened in the history of seismic imaging in Australia. OBS's can be placed almost anywhere on the ocean bottom, allowing them to record a variety of information that is invisible to land-based instruments. Applications include improved imaging and understanding of active seismogenic regions such as subduction zones, many of which lie on Australia's doorstep, and pose major earthquake and tsunami hazards to Australia and its neighbours; imaging of submarine sedimentary basins, which is relevant to exploration; and improving our understanding of the structure of the Australian continent beneath the oceans.