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APPENDIX 1

OUTLINE OF INVESTMENT POSSIBILITIES

STRAND SCENARIOS

BY

The AuScope National Steering Committee:

Future Infrastructure Program

Earth & Geospatial Science for the Australian Continent

1ST DECEMBER, 2010

THIS DRAFT HAS BEEN MADE AVAILABLE TO PROVIDE BACKGROUND FOR DISCUSSION AT THE AUSCOPE II FORUM 20 APRIL 2011

CONTENTS

PREFACE TO APPENDIX

This Appendix details the outcome of a four month long exercise chaired by Prof Peter Flood to deliver through the AuScopeII Steering Committee options for research infrastructure investment in the Earth and Geospatial Science for the Australian Continent and region. The process involved a general call for suggested research infrastructure which resulted in over 50 submissions, several of which did not satisfy the definition of research infrastructure. The Steering Committee considered the range of suggestions and also invited the existing AuScope NCRIS Components to submit recommendations which incorporated submissions in their research areas. As a result, the suggestions for research infrastructure were grouped into seven categories or strands, namely:

1. Composition and Evolution
2. Geoimaging
3. Geospatial, and
4. Materials, Properties and Paragenesis.
5. Simulation, Analysis and Modelling
6. Grid Computing, Interoperability and e-research Infrastructure
7. National Datasets and Maps

Strands 5. (SAM), 6. (Grid) and 7. (National Datasets) were not developed in detail because of their dependency on the specific requirements of the other strands. Representatives from each Strand developed the relevant submissions into 3-tiered proposals based on priorities within funding levels of less than $5million, $5-15million and greater than $15million.

This Appendix contains the infrastructure proposals for the main strands without consideration of priorities, in order to provide a documentation of infrastructure potentially required to enable an Australian Earth Observatory to be created and funded at least in part by a future infrastructure program.

Infrastructure costings are preliminary estimates only, and will require more rigorous estimation for incorporation into an investment plan.

COMPOSITION AND EVOLUTION

The composition of the Earth evolves with pressure, temperature, stress and time. Quantifying the resultant changes underlies quantitative descriptions of the processes involved. Geochemistry and mineral physics are major, process oriented Earth Science sub-disciplines that have played an enormous role in making the overarching subject quantitative. Applications are broad and diverse including (but not limited to) oceanography, sedimentology, igneous and metamorphic petrology, experimental petrology, surficial processes, climate change, minerals exploration, pollution remediation and planetary science. Australia has been at the forefront of this endeavour with a particularly strong community that has frequently set the international research agenda. This has come through both scientific advances and analytical developments, often with the two being symbiotic. The Composition and Evolution (C&E) component of AuScope II will maintain and enhance Australia's prowess in these endeavours through investment in key equipment and technical support.

1. Primary objectives

The primary objective of C&E is to position the geochemistry community to be at the cutting edge of international research for the next decade. Whilst much of the research is blue skies and based in University laboratories, the uptake and application by industry should not be underestimated. Significant geochemical research is done in CSIRO and at the state and national geological surveys. Thus, this research will feed into the geophysical and simulation and modelling communities, ultimately informing government and industry decisions on issues vital to Australia's economy. The key investments are identified as follows.

(a) Many great advances in geochemistry have been driven by, or been facilitated by, analytical breakthroughs. Such an example is a dedicated earth science beam line on the Australian Synchrotron (AS). At present there is only one beam line dedicated to earth and environmental sciences in the world (GSECARS at the Advanced Photon Source, Argonne National Laboratory, and USA) and that is heavily over-subscribed. Similarly, the microflourescence spectroscopy beam line at the AS is 4x oversubscribed, which means that it is difficult to get beam time.

Thus, the establishment of a similar facility in Australia would provide the focus for major international visitation and collaboration. The Australian community has provided considerable investment in the AS, in line with major investments in similar technology elsewhere around the world. However, our earth sciences community knows that this is only the beginning in recognizing the potential of this technology. Although few laboratories around the world have begun such research, the measurements made possible by synchrotron science will benefit every field of geochemistry and related sciences. There can be little doubt that this underlies the cutting edge, with limitless potential. It would be complementary to the NCRIS AMMRF microanalysis facility which includes the AuScope Ion Probe in the CMCA in Perth.

The advent of synchrotron-generated radiation has opened up a number of techniques for characterizing earth materials using various kinds of X-ray spectroscopy that are not possible with existing analytical methods. Because synchrotron availability is so recent, application of these techniques in the Earth sciences is still in the pioneering stage. Their scientific basis is well understood, and examples of applications are numerous, but most Earth scientists do not yet utilize them for their own research on a routine basis. This will surely change as the methods become familiar to the Earth science communities.

X-ray absorption spectroscopy enables the characterization of all except the lightest elements in the periodic table at realistic natural concentrations. X-ray near-edge absorption spectroscopy (XANES) is increasingly used as the method of choice for determining the oxidation states of major and trace-elements in geomaterials, with significant land-mark papers published in the last three years on determining the oxidation states of Fe, Cr, U and S in a variety of matrices. Moreover, the high spatial resolution achievable with X-ray microfluorescence (< 1 μm) enables quantitative mapping of elements in samples. With computer-assisted tomography it is now becoming possible top do this in 3-D. For the first time it will become possible to determine the distribution of trace elements in complex samples. The usefulness of such an approach in geochemistry and environmental sciences is so great that one might predict that the whole current approach to geochemistry and petrology will be revolutionized. X-ray microfluorescence methods have the potential to provide in-situ XRF analyses on a submicron scale. The important point to make is that these techniques will move from the realm of specialists to the routine underpinning of many Earth scientist's research in the next two decades.

Extended X-ray absorption fine-structure spectroscopy (EXAFS) now enables detailed structural information coordination environments (e.g., nearest neighbours) to be obtained not only in crystalline but amorphous materials, and at natural or near-natural trace-element concentrations. It may be argued that this field is poised to carry forward our most significant advance in trace-element geochemistry since Goldschmidt developed quantitative trace-element analysis in the early 20th century.

More specialist research opportunities are also now possible. For example XANES spectroscopy coupled with high-temperature/pressure techniques will enable the reactions and textures to be imaged in situ, e.g., melt distributions in partially molten aggregates or porosity under hydrothermal conditions.

(b) Upgrade existing major geochemistry and geochronology laboratories (John de Laeter Centre, University of Queensland, Macquarie University, Research School of Earth Sciences and Melbourne University) to world-class facilities accessible by the whole community. A world-class Australian Geochemistry and Geochronology Facility (AGGF) is essential for addressing the future research and research training challenges facing Australia in the next decade.

(c) Purchase an existing Patterson Rig from overseas to be installed at the University of Western Australia. Currently, there are 13 such instruments in existence but no further instruments will be built after 2011. This is before the time frame of any AuScope II funding, hence the option to purchase an existing instrument.

(d) Upgrades to Tango Argon mass spectrometry laboratories. Understanding the Australian crust and its processes through development of simulation, analysis, and modelling capabilities: Argon provides key data for the timing of movements in the crust, and is thus key to geological reconstruction and a vital component of data for a world-class simulation, analysis and modelling (SAM) capability. Specifically, argon data will enable better definition of the history of assemblage of the Australian continent and its subsequent modification.

(e) Provide critically needed technical support in the main existing geochemical laboratories. World-class technical support is vital for ensuring analytical development, data quality, productivity and training of the next generation of earth scientists. The idea of stand-alone laboratories equipped for all analytical needs is becoming increasingly impractical because of the growing diversity and cost of analytical machinery. Thus, there is an acute awareness that future advances in geochemistry will increasingly involve centres of infrastructure concentration and multi-node initiatives based on tackling fundamental scientific problems. At present there are probably 5 major hardware-based laboratories, include the John de Laeter Centre, University of Queensland, Macquarie University, Research School of Earth Sciences and Melbourne University. These have strong collaborative links to other groups around Australia and an important goal is to ensure access for outlying groups and individuals. For example, such facilities would provide vital data for the National Virtual Core Library, (NVCL) and proposals to develop an integrated workflow for Frontiers in Mineral System Analyses. Thus, it is clear that there will be a need for funds for access including mobility of a cohort of world-class analysts, students and academics. Provision of additional technicians in the major laboratories around the country would have an impact far outweighing the cost of their salaries, resulting in increases in the number and quality of international level publications.

2. Major outcomes and benefits

Most of Earth's interior is un-sampled and therefore geoscientists need to use laboratory and computer experiments to try to recreate the enormous pressure–temperature conditions in the deep Earth and then measure the properties of minerals under these conditions. In this field of high-pressure mineral physics and chemistry, we apply mineral properties, stress-strain relationships in multiphase rocks, and processes, such as partial melting at high pressures and temperatures, to geophysical observations of the deep Earth. The observables include seismic velocities and attenuation, anisotropies and density at depth. However, quantitative experimental studies of minerals and rocks under deep mantle conditions are challenging, and major progress in this area continues to be associated with the development of new techniques. Until very recently, reliable studies have been conducted only at pressures less than ~0.5 GPa (~15 km depth in Earth). By combining state-of-the-art techniques of synchrotron-based *in situ* hydrostatic and stress–strain measurements in newly designed solid-medium high-pressure apparatuses with novel ‘off-line’ laboratory capability, a new generation of experimental studies of minerals and rocks under deep-mantle conditions (up to 300 GPa) is emerging. Early studies have addressed the pressure dependence of deformation of minerals such as olivine and the slip systems in high-pressure minerals such as wadsleyite and perovskite. These results have important implications for the depth variation of mantle viscosity and the geodynamic interpretation of seismic anisotropy. However, there is still much to be done, including the influence on seismic properties and rheology of specific water-related defects in nominally anhydrous mantle minerals, and virtually nothing has been done on processes we believe to be important in the mantle transition zone. Finally, synchrotron capability is of significant use to the rapidly emerging area of biogeochemistry.

By equipping the major geochemical laboratories with needed technical support, C&E will empower the next generation of researchers to define the cutting edge of Earth science research. Access to, and training in, advanced analytical techniques will develop and maintain strong collaborative links to other geochemistry groups in Australia and enhance Australia’s international leadership in the field ensuring that research undertaken is not constrained or defined by analytical limitations. Key areas to be strengthened include isotope geochemistry and geochronology for understanding the evolution of the Earth, ore and sulfide analysis, detrital mineral dating and thermochronology for constraining the P-T evolution of the upper parts of the continental crust. All of these feed into developing models for the evolution the planet, including its resources.

Synergies with other AuScope components: The proposed infrastructure shares strong synergies with Simulation, Analysis and Modelling (SAM) and GeoImaging. Geochemical and isotopic data provide one form of basic input data for almost all geodynamic modelling. High-pressure deformation experiments on the synchrotron, along with complementary off-line measurements, provide the only way to constrain the material properties of Earth materials under mantle conditions. These underpin models for the interpretation of deep Earth seismic data and attendant geodynamic simulations.

3. Equipment/Capital investment

Item	**Location**	**Amount**
Australian Synchrotron		
Superconducting multi-pole wiggler (5-100 keV)	Australian Synchrotron	3,500,000
Front end	Australian Synchrotron	450,000

Beam line vacuum system	Australian Synchrotron	350,000
Collimating & focusing mirrors	Australian Synchrotron	900,000
Fixed Exit Monochromator	Australian Synchrotron	500,000
Slits, position monitors, Be window, photon shutter etc	Australian Synchrotron	400,000
Hutches (including utilities)	Australian Synchrotron	900,000
Safety and Control Systems	Australian Synchrotron	300,000
K-B Micro-focus mirror system	Australian Synchrotron	350,000
Detectors	Australian Synchrotron	1,500,000
Misc. Electronics, Ion Chambers etc	Australian Synchrotron	150,000
Hydro-thermal cell	Australian Synchrotron	90,000
Split sphere multi-anvil device	Australian Synchrotron	1,000,000
Laser heating	Australian Synchrotron	113,000
Pressure measurement	Australian Synchrotron	123,000
Items for mico-fluorecence & mapping	Australian Synchrotron	500,000
Australian Geochemistry and Geochronology Facility		
Thermo-Fisher HELIX multi-collector mass spectrometer	AGGF multi-node	800,000
Automated gas handling system	AGGF multi-node	200,000
Cryogenic trap and He compressor	AGGF multi-node	300,000
NewWave UV laser system	AGGF multi-node	200,000
Nu Attom ICPMS	AGGF multi-node	600,000
Resonetics laser ablation system	AGGF multi-node	400,000
Patterson Rig		
Patterson Rig (high pressure deformation apparatus)	University of Western Australia	1,450,000
Tango		
Upgrades to Argon mass spectrometry laboratory	University of Queensland	1,000,000
Upgrades to Argon mass spectrometry laboratory	ANU	1,000,000
TOTAL		17,076,000

4. Technical support for creation and development

Universities are increasingly unable to fund research support positions (as opposed to technical support for teaching) and the ARC LIEF scheme does not support salaries. Yet, good laboratories and equipment are useless without good technical support. These positions are highly skilled (i.e. PhD qualified) and undersupplied but need longevity. World-class technical support is vital for ensuring analytical development, data quality, productivity and training of the next generation of earth scientists. To that extent, technical support should be considered as part of infrastructure and education. For example, AuScope I invested in technical support in the Thermochronology, Terranechron and UWA/Curtin Ion Probe facilities. In less than 4 years, this resulted in a 100% increase in training and publication output at both the Thermochronology and Terranechron facilities (such data is currently not available for the Ion Probe). At a recent GSA SGGMP (Geological Society of Australia Specialist Group for Geochemistry, Mineralogy and Petrology) meeting of representatives from the major geochemical laboratories around Australia, increased on-going technical support was unanimously agreed to be the biggest need for future international competitiveness.

Personnel and function	**Location**	**Annual cost**	**5 yr cost**
2 technicians for Australian Synchrotron	Monash University	195,000	975,000
2 technicians for Ore and Sulfide Analysis	University of Tasmania	195,000	975,000
2 technicians for Argon Geochronology Facility	University of Queensland	195,000	975,000
2 technicians for Geochron/Geochem Facility	AGGF multi-node	195,500	975,000
Technician for Fission Track Facility	Melbourne University	97,500	487,500
2 technicians for Terranechron Facility	Macquarie University	195,000	975,000
Technician for John de Laeter Centre	John de Laeter Centre	97,500	487,500
Technician for rock physics laboratory	RSES, ANU	97,500	487,500
Technician for geochemistry laboratory	Adelaide University	97,500	487,500
Technician for Patterson Rig	University of Western Australia	97,500	487,500
TOTAL		1,462,500	7,312,500

5. Timeframe for investment

Note that the time scale for advertising and hiring high quality technical staff may be quite variable.

Year	**Action**
1	Advertising and hiring of high quality technical staff Commissioning of synchrotron beam line
2	1) Building of synchrotron beam line

	2) Acquisition of geochemical data in the identified laboratories 3) Training of PhD students
3	4) Installation of synchrotron equipment 5) Acquisition of geochemical data in the identified laboratories 6) Training of PhD students
4	• Acquisition of geochemical data in the identified laboratories • Training of PhD students
5	• Acquisition of geochemical data in the identified laboratories • Training of PhD students

6. Support and involvement

James Cook University (Dr Carl Spandler)

University of Queensland (Prof. Paulo Vasconcelos, Dr Kurt Knesel)

University of Sydney (Prof. Geoff Clark)

ANSTO (Dr Richard Garrett)

Macquarie University (Ass. Prof. Tracy Rushmer, Dr. Norm Pearson, Dr Bruce Schaefer)

CSIRO (Dr Steve Barnes, Dr Chris Ryan)

Australian National University (Prof. Hugh O'Neill, Prof. Trevor Ireland, Prof. Ian Jackson)

Geoscience Australia (Dr. Geoff Fraser)

University of Melbourne (Prof. Jon Woodhead, Prof. Janet Hergt, Prof. Andy Gleadow)

Monash University (Dr Andy Tomkins, Prof. Louis Moresi)

University of Hobart (Prof. Leonid Danushevsky)

University of Adelaide (Prof. John Foden)

South Australian Museum (Dr. Joel Brugger)

Curtin University (Dr Katy Evans)

University of Western Australia/CSIRO (Prof. Alison Ord)

GEOIMAGING

1. Major scientific questions addressed that benefit the nation

(a) What is the relationship between tectonic stresses, variations in lithospheric strength and composition, and the occurrence of intra-plate earthquakes?

- Why does the Australian lithosphere respond to the stress field - largely dictated by plate boundary forces - in a way that causes earthquakes in some locations but not in others?
- What is the structure and composition of the Australian lithosphere in regions of significant earthquake activity, and how does this compare with less active regions?
- Can we improve the location accuracy and rupture characterisation of earthquakes from Australia's seismogenic regions and hence improve our understanding of why they occur and risk mitigation strategies?
- What role do local variations in stress and the geometry of fault surfaces play in the occurrence of earthquakes?

(b) Where will the next big tsunamigenic earthquake happen?

- What is the potential for the occurrence of large earthquakes in the eastern Sunda Arc?
- How does the transition from subduction to arc-continent collision in the eastern Sunda Arc influence the intraplate stress field of Australia?

(c) How does the internal structure of the Earth vary laterally, and what does this tell us about the kinematic and dynamic processes responsible for its evolution?

- How has the Australian plate evolved over time, and how can we address outstanding questions through imaging lithospheric architecture? In particular, can we distinguish between the imprint of recent (e.g. those associated with the breakup of Australia and Antarctica) and older events (e.g. the Delamerian Orogeny) that contributed to the evolution of the Australian plate?
- What is the crustal structure of the southern Tasman Orogen - is there a piece of mineralised rifted Precambrian continental crust under the Murray Basin, and

what is the nature of the transition between the Delamerian and Lachlan orogens?

- How do the different parts of the lithosphere (upper crust, middle crust, lower crust, lithospheric mantle) link in with each other, and to what extent does this interaction play a role in the formation and location of mineral deposits?
- Can we exploit Australia's unique geographical and technological position as a regional "scientific superpower" to answer fundamental questions about the structure and evolution of the deep Earth? What is the composition and dynamics of the core, and the anisotropic structure and growth rate of the inner core? How do the core and lower mantle interact? Do subducting plates reach the core-mantle boundary? Do mantle plumes exist?

(d) Can geoimaging techniques normally applied to the solid earth be used to help locate and assess buried resources of economic value?

- Are there major mineral and geothermal resources buried deep undercover, and can we help find them using passive imaging techniques?
- Can high resolution passive seismic arrays be used to image structure at basin scale resolution, and monitor local stress changes? This information is crucial to the geothermal and carbon sequestration industries. Furthermore, images of this type will be key to a better understanding/linking between tectonic scales and reservoir scales, which has important implications for exploration and development of energy resources, including hydrocarbons and deep groundwater systems.

2. Primary objectives

1. Build one of the largest pools of state-of-the-art passive seismic recorders in the world.
2. Deploy 170 seismometers as part of three semi-permanent passive seismic networks in regions of pronounced seismic activity (SW Western Australia, Flinders Ranges and southeast Australia). Three component accelerometers will be used to record strong motion activity from nearby earthquakes, and three-component broad band sensors will be used to record body waves and surface waves from local and distant earthquakes, in addition to the ambient seismic wavefield. Furthermore, 3-component magnetometers and portable GPS stations from the ANSIR pool will be co-located

with each seismic station to record electromagnetic field data and crustal deformation respectively. This large infrastructure project will create unique geophysical data sets at a scale which is beyond the capability of a single institution or scientific agency, and will serve the community well into the future as a lasting resource. All data will be processed, archived and distributed to the research community via the web.

3. Deploy an array of 500 broadband seismometers in a transportable array configuration with the long term goal of covering the entire continent at a 50 km station separation. These instruments will be co-located with MT stations to record electromagnetic field data, and together will provide unprecedented resolution of the Australian lithosphere. The initial deployments will target Western Australia.
4. Deploy both OBSs (Ocean Bottom Seismometers) and land based seismic stations along the Sunda Arc, one of the most active belts of tectonic activity in the world. OBSs acquired through AGOS EIF and administered by ANSIR will be utilised in conjunction with those provided by international collaborators. In order to provide complete cross-sectional coverage of the subduction zone, OBSs will be placed in the arc-forearc region, and land based broadbands will be placed in the arc-backarc region.
5. Build on Australia's impressive repository of seismic reflection transects by providing 2,000 km of seismic lines through key geological and mineral provinces of Australia.
6. Provide a highly mobile pool of 100 short period recorders for use in up to three key locations to asses geothermal potential of sedimentary basins or monitor carbon sequestration.
7. Provide a pool of 20 rapid response short period recorders and accelerometers for use in aftershock surveys.
8. Extend the seismometer in schools program to achieve dense national coverage.

3. Major outcomes and benefits

In August 2010, the Australian Academy of Science's High Flyers Think Tank series focused on the topic "Searching the deep earth: The future of Australian resource discovery and utilisation". Most large ore-bodies of economic significance that outcrop at the surface have already been discovered, so it is crucial that those that remain hidden, often under sedimentary cover, be located and utilised to secure Australia's resources future. During the think tank, it was emphasized by both industry and academic representatives that major improvements are required in our first-order understanding of both crust and lithospheric mantle structure if we are going to have any hope of knowing where to look for large buried ore bodies and understand how they formed. The proposed infrastructure will play a major role in demonstrating how high quality passive seismic and electromagnetic field information can achieve this goal. Other potential economic beneficiaries are geothermal energy production and carbon sequestration, which require an accurate knowledge of the stress field and subsurface structure.

Major outcomes and benefits include:

(a) The Australian stress field and intraplate earthquakes

- A substantial improvement in our ability to locate and characterize earthquakes in Australia's most seismogenic regions.
- Vital new information on the nature of the Australian stress field, and how it is accommodated in various regions of the Australian plate. Apart from basic research, this information is also important to the minerals, geothermal and carbon sequestration industries.
- Information such as earthquake magnitude, near-source ground motion attenuation parameters, source mechanism etc. will be crucial for evaluating seismic hazard and contributing to risk mitigation efforts. Earthquake recurrence models and ground motion models play a central role in building code design, which ultimately saves both lives and infrastructure.
- Aftershock deployments will provide critical information on the nature of stress release and the geometry of active faults in Australia. The lack of aftershock studies in Australia has severely limited our understanding of earthquake hazard.

(b) Natural hazards in our region

- The first comprehensive constraints on the potential for large earthquakes in the eastern Sunda Arc, which are likely to impact on the northern coast of Australia.
- Answers to unresolved questions on the role the Sunda Arc convergent margin plays in the pattern of intraplate stresses observed within the Australian continent.
- Fostering of strong international links within the university and government sectors via collaborative deployment of OBSs.

(c) Tectonic evolution and Earth structure

Generational change in the accuracy and resolution of 3-D images of seismic velocity, attenuation and anisotropy structure, complemented by resistivity images obtained from the magnetotelluric data that span a large region of the continent.

Fundamental improvement in the understanding of the structure and composition of the Australian plate from the near surface to the base of the lithosphere. Key areas include regions of high seismic activity and the southern Tasmanides in southeast Australia, where the presence of potentially mineralized Proterozoic crustal fragments will be assessed. The structure beneath Western Australia will be the initial target of AuSarray.

Combined with pre-existing imaging results from projects like WOMBAT in southeast Australia, we will for the first time have the ability to directly address long standing questions on the differences in lithospheric architecture between Precambrian central and western Australia, and Phanerozoic eastern Australia, and how these regions have evolved over time.

High resolution seismic images and accurate earthquake hypocenter locations beneath the Sunda Arc, which will provide crucial new constraints on its structure and geodynamic setting.

The first detailed constraints on mantle discontinuities and core structure from body wave data in a largely unexplored region of the Earth's deep interior.

(d) Energy and resources

- Provide pivotal first-order constraints that will allow development of much needed new strategies for locating and identifying mineral and geothermal resources buried undercover.
- Facilitate a new understanding of the relationship between the crust and underlying lithospheric mantle, and how this impacts on the evolution of the Australian plate and the development of deep earth resources.
- Novel datasets for assessing geothermal resources and carbon sequestration storage formations beneath prospective sedimentary basins.

(e) Community outreach

- The seismology in schools program will directly contribute to the national repository of research-quality seismic data, and will stimulate community awareness of the physical sciences.

Synergies with other AuScope components: The proposed infrastructure shares strong synergies with *Geospatial and Geodesy*. For instance, GPS and InSAR analysis provide high-precision estimates of crustal deformation, which are complementary to deformation information derived from earthquake source mechanisms. 3-D models of seismic and magnetotelluric structure directly relate to the *Composition and Evolution* of the Australian lithosphere. *Simulation Analysis and Modelling* is an important component of seismic imaging, and the constraints supplied by the 3-D seismic/resistivity models naturally feed into sophisticated plate and mantle dynamics software (e.g. Pplates). Finally, the large seismic and magnetotelluric datasets will be distributed to the research community via the *Grid Access and Interoperability* component.

4. Equipment/Capital investment

Item	**Unit cost (Aus$)**	**Total cost (Aus$M)**
Intraplate seismic/MT network		
170 6-component data loggers	15,000	2.55
170 3-component broad band seismometers	10,000	1.70
170 3-component accelerometers	2,000	0.34
170 installation cost (including solar panels, batteries, NextG link etc.)	5,000	0.85
Maintenance cost per site per year	2,000	1.36
Deployment of MT instruments at 170 sites	3,000	0.51
Deployment of GPS stations at 170 sites	5,000	0.85
AuSarray experiment		
500 3-component data loggers (seismic)	10,000	5.00
500 3-component broad band seismometers	10,000	5.00
500x2 installation cost (including solar panels, batteries etc.) - seismic	5,000	5.00
100 3-component data loggers (MT)	10,000	1.00
100 magnetometers	10,000	1.00
100 induction coils	5,000	0.50
100 sets of electrodes	2,000	0.20
100x10 installation cost - MT	3,000	3.00
High resolution passive instrument pool		

120 3-component data loggers	10,000	1.20
100 3-component short period seismometers	5,000	1.00
20 3-component accelerometers	2,000	0.04
120 sets Cables, recording media, batteries etc.	1,000	0.12
Deployment costs for 3x100 instrument arrays	5,000	1.50
Deployment costs for 4x20 instrument aftershock surveys	3,000	0.24
Seismic transects		
2000 km of seismic lines	5,000 per km	10.00
OBS deployments along Australia's plate margins		
3 x OBS deployments along Sunda Arc	1,200,000	3.60
3 x broadband deployments on-land	600,000	1.80
3 x GPS deployments on-land	500,000	1.50
Maintenance costs of OBS equipment	30,000 per annum	0.18
Seismometers in schools program		
50 broadband instruments designed for schools	10,000	0.50
Installation costs x 50	5,000	0.25
Maintenance costs x 50	5,000	0.25
TOTAL		51.04

5. Technical Support for Creation and Development

Technical support is required to maintain the new instruments and data outlined above, as well as support previous infrastructure obtained under AuScope 1 and AGOS EIF.

Personnel and function	**Annual cost (Aus$)**	**Total Cost (Aus$M)**
2 technicians for portable seismic equipment	240,000	1.20
1 technician for portable electromagnetic equipment	120,000	0.60
1 technician for GPS equipment	120,000	0.60
1 technician for OBS equipment	120,000	0.60
2 data technicians for data processing	240,000	1.20
Technical support for reflection processing	80,000	0.40
TOTAL		4.60

6. Timeframe for Investments

Year	**Action**
1	• Build 3- and 6-component data loggers based on ANU design. • Purchase 3-component broadband seismometers, short period seismometers, accelerometers and MT equipment. • Organise deployment logistics and permitting where required for intraplate networks. • Organise deployment logistics and seek international partners for OBS and broadband work in Indonesia. • Organise deployment logistics and permitting for AuSarray stations. • Seek co-contributors to seismic lines of national importance. • Set up protocols and mechanisms for processing, archiving and distributing data. • Assess applications for high resolution passive seismic pool. • Set up protocols to facilitate rapid deployment of strong motion seismometers for aftershock studies. • Purchase equipment for seismometers in school program. • Hire technical support staff.
2	1. Deploy seismic instruments in southwest Western Australia, Flinders Ranges and southeast Australia. 2. Process, archive and distribute data. 3. Deploy MT and GPS stations. 4. Organise deployment logistics and seek international partners for OBS and broadband work in Indonesia. 5. Begin deployment of AuSarray in Western Australia. 6. Begin seismic reflection profiling. 7. Begin rolling out seismometers in schools. 8. Begin first high resolution experiment utilising portable short period array.
3	• Maintain seismic networks (including AuSarray). • Process, archive and distribute data. • Continue deployment of MT and GPS stations as required. • Deploy first set of OBS and broadband stations in Sunda Arc region. • Continue seismic reflection profiling as required. • Continue rolling out seismometers in school program. • Organise logistics and permitting for next phase of AuSarray. • Begin second high resolution experiment utilising portable short period array.
4	• Maintain seismic network. • Process, archive and distribute data. • Move AusArray to a new location. • Continue deployment of MT and GPS stations as required. • Deploy second set of OBS and broadband stations in Sunda Arc region. • Continue seismic reflection profiling as required. • Continue rolling out seismometers in school program.

	• Organise logistics and permitting for next phase of AuSarray. • Begin third high resolution experiment utilising portable short period array.
5	• Maintain seismic network. • Process, archive and distribute data. • Continue deployment of MT and GPS stations as required. • Deploy third set of OBS and broadband stations in Sunda Arc region. • Retrieve AuSarray stations or relocate to new sites contingent on continued support. • Retrieve strong motion network stations or leave in for an extra year contingent on continued support. • Ensure all data is distributed to research community via the Web.

7. Support and involvement

- Australian National University (Prof. Malcolm Sambridge, Prof. Phil Cummins, Dr Nicholas Rawlinson, Dr Hrvoje Tkalcic)
- Geoscience Australia (Dr Bruce Goleby, Dr Ned Stolz, Ms Jenny Maher, Dr Trevor Allen)
- GeoScience Victoria (Dr Tim Rawling)
- Geological Survey of NSW (Dr Dick Glen, Dr David Robson)
- University of Melbourne (Prof. Mike Sandiford, Dr Gary Gibson)
- University of Adelaide (Prof. Graham Heinson)
- University of Tasmania (Dr Anya Reading)
- PIRSA (Dr David Love)
- Geological Survey of Western Australia (Dr Ian Tyler)
- University of Western Australia (Prof. Mike Dentith, Prof. David Lumley, Dr Jeffrey Shragge, Dr Alison Ord)

GEOSPATIAL

An understanding of the relationships between human society and the Earth system including its dynamic crust, changing climate and sea-levels and the movement of water, is critical if we are to manage and understand Australia's future in a sustainable way. Increasingly, with the ongoing development of ground and satellite based geospatial observing technologies, the full complexity of the Earth is being revealed at a wide range of spatial and temporal scales. Geospatial provides the tools and techniques that support an improved understanding of the Earth by enabling leading research in many branches of the Earth Sciences, such as seismology and earthquake physics, geodynamics, volcanology, oceanography, climate studies, hydrology, glaciology, geology and astronomy.

With AuScope II investment, Geospatial will make important and unique scientific contributions towards an improved understand of our continent and more broadly the Earth. Three major science themes that have national significance and importance have been identified, specifically, *natural hazards*, *climate change* and *water management*.

NATURAL HAZARDS

Australian seismicity is indicative of the accumulation of elastic strain on faults that is subsequently released during earthquakes. As such geospatial, specifically geodetic, observations of surface deformation provide insights into the manner of the strain accumulation and release. Such observations have elsewhere been able to provide important constraints on crustal rheology, including estimates of the stresses required to produce earthquakes and also what proportion of deformation occurs seismically. Geodetic observations of co-seismic deformation provide constraints on earthquake mechanisms, stress field orientation, static stress drop, earthquake slip distribution (particularly when the event is relatively shallow), and enables events to be assigned to specific geological structures. Such information can also be used to provide reference seismic events so as to support the assessment and improvement of seismic analysis, for example, by improving seismic velocity models. Independent observations of earthquakes are even more important in Australia given the sparse seismic network coverage. Similarly, important contributions can also me made towards an improved understanding of earthquakes and tsunami which occur at the plate boundaries as well as volcanic eruptions through the measurement of present-day crustal deformation.

The precision of observations of crustal deformation worldwide is limited by the accuracy of the International Terrestrial Reference Frame (ITRF) coordinate system. Determination of the ITRF itself depends in a large part on the quality and completeness of the VLBI data that are used to define the scale of the reference frame and constrain the Earth's orientation in space that are fundamental to all space geodetic techniques. The most severe limitation is presently the lack of data on radio sources deep in the Southern Sky. VLBI observations require simultaneous observations of the same source by many telescopes. This is only possible if the sources are above the horizon simultaneously at many different observatory sites. In the current International VLBI Service (IVS) array there are only three telescopes at middle Southern latitudes that operate regularly with the rest of the network: Hobart, TIGO (Chile), and Hartebeesthoek (South Africa). The two Antarctic stations (Syowa and O'Higgins) can operate for only a few IVS sessions per year, and the data from them arrives at the correlation centres many weeks afterward. In practice, this means that very few observations of radio sources within 50° of the south celestial pole are made by the IVS. This is currently a limiting factor in the precision of the EOPs. The ongoing operation of the AuScope array will completely change this situation. The three AuScope telescopes, plus the New Zealand telescope, will run geodetic VLBI observations at the rate of 180 days per year. With the six baselines available from these four telescopes alone, plus baselines to Chile and South Africa when they can join, it will be possible to monitor calibration sources all the way to declination -90°.

A major goal for the VLBI component of AuScope is to achieve absolute positions of the VLBI telescopes to 1 mm accuracy. This is also a goal of the International VLBI Service's (IVS) VLBI2010 initiative and the choices made on AuScope VLBI infrastructure have followed these IVS recommendations as closely as possible. The VLBI2010 vision is to provide the following capabilities:

- mm position accuracy on global scales
- continuous measurements for time series of station positions and Earth orientation parameters
- turnaround time to initial geodetic results of less than 24 hours

The VLBI2010 requirements are challenging and there are no IVS observatories in the world yet able to meet them, although several have been successful in obtaining funding for upgrades or new observatories. Over the next 5 to 10 years it is expected there will be a transition from the current systems to the VLBI2010 specification. A small fast-moving telescope is required so that it can move quickly across the sky to observe many targets to model the ionosphere and troposphere more accurately. The Patriot 12m antennas, built under AuScope I, are fast moving with a maximum target switching time of 66 sec compared to 480 sec for the old Hobart 26 m antenna.

The main disadvantage of small telescopes is they have poorer sensitivity compared to large ones and this must be overcome by observing more of the radio spectrum: a wide-band radio receiver system. Further, a wide-band system allows for a much greater sampling of the radio spectrum and this permits a more precise model of the ionosphere and hence an improvement in station position measurement. A wide-band system, providing access to four dual-polarisation bands 1 GHz wide over the frequency range 2.2 to 14 GHz, would permit an improvement in the precision of the geometric delay measured between signals arriving at different telescopes from 32 pico-seconds to 5 pico-seconds.

Major scientific questions addressed that benefit the nation:

1. How does the Earth's Crust deform?
    a. What are the basic mechanical underpinnings of the bending, stretching, buckling and breaking of the Australian plate and its boundaries?
        i. What is the relationship between tectonic strain and the occurrence of intra-plate and inter-plate earthquakes?
        ii. What can we learn about plate-boundary forces from observation of crustal deformation?
        iii. How do faults behave in seismogenic zones that are gathering strain to be released in future great earthquakes and the steady plate motion at depth?
        iv. What is the role of aseismic events in the seismic energy budget?
    b. How do the processes that control magma production and ascent work?
        i. How well can we predict eruptive events from precursory observations of deformation?

c. How does the Earth's crust respond to fluid injection and withdrawal processes?
    i. How does CO_2 migrate as a function of time and can geodetic measurements improve the understanding of this process?

Proposed infrastructure:

The ongoing operation of the AuScope gravity program and VLBI array to support the geospatial reference system.

An improved GPS, InSAR and gravity analysis capability developed by building a national facility for geodetic analysis, modelling and delivery systems. Additional and targeted continuous GNSS observations along the plate boundaries will provide insights into natural hazard assessment.

An upgrade of the AuScope VLBI array to broad-band cryogenic receivers will meet the VLBI2010 specification, and position Australia to make a significant contribution to the IVS with direct impact on the quality of the reference system relied upon in Australia

Natural Hazards: synergies with other AuScope Components

The proposed infrastructure shares strong synergies with other AuScope II Strands such as *Geoimaging*, which has a focus on Natural Hazards. Geodetic observations also provide are an important ground-truth of the dynamic crustal models developed in *Simulation Analysis and Modelling*. All the geospatial datasets will be distributed to the research community via *Grid Access and Interoperability*.

Natural Hazards: other Synergies

The proposed infrastructure shares strong synergies with other NCRIS capabilities such as *Optical and Radio Astronomy* and will contribute to a number of important endeavours in the astronomy communities including cosmology (evolution of the early Universe and proper motion of radio sources); determining the acceleration of the Solar system barycentre; constraining the interior structure of the Moon (e.g., lunar fluid core? elastic properties?); and contributing to general relativity theory (e.g., setting of stronger limitations of the parameters β and γ of the Post-Newtonian formalism).

CLIMATE CHANGE

The Earth's climate is changing, due in part to the observed increases in human produced greenhouse gases. These changes include increases in global average air and ocean temperature, widespread melting of snow and ice and rising global sea levels. The extra heat in the climate system has other impacts, such as affecting atmospheric and ocean circulation, which influences rainfall and wind patterns. Sea-level change is sensitive indication of climate change and is caused by glacier melting as well as changes to the thermal and salinity conditions of the ocean.

Geospatial can make an important and unique contribution to an improved understand of climate change processes, specifically, geodesy can provide accurate determinations of present-day sea-level change as well as crustal uplift and subsidence around the Australian coastline.

Major scientific questions addressed that benefit the nation:

2. What is the present-day rate of sea-level change around the Australian coastline in both absolute and relative reference frames? To do this we will need additional infrastructure to
    a. Refine present estimates of sea-level change by improving satellite altimeter calibration.
    b. Improve the quality and availability of terrestrial gravity, GPS and satellite Interferometric Synthetic Aperture Radar (InSAR) estimates of the vertical crustal uplift/subsidence along the Australian coastline and, particularly, at the Australian sea-level tide gauges?
    c. To improve the crustal loading models using terrestrial gravity observations in turn to support further improvements in the estimates of vertical crust uplift/subsidence at the Australian tide gauges.
    d. Refine the gravity modelling around the Australian coastline to support sea-level change inundation modelling.

Proposed infrastructure:

An improved GPS, InSAR and gravity analysis capability developed by building a national facility for geodetic analysis, modelling and delivery systems.

Additional (x2) satellite altimetry calibration sites. A national coast-line air-borne gravity survey.

Climate change: synergies with other AuScope components

Geodetic observations will provide an important ground-truth of the dynamic crustal models developed in *Simulation Analysis and Modelling*. All the geospatial datasets will be distributed to the research community via *Grid Access and Interoperability*.

Climate change: other Synergies

The proposed infrastructure shares strong synergies with other NCRIS capabilities such the *Integrated Marine Observing System (IMOS)*.

WATER MANAGEMENT

Geodesy can provide the foundational measurements necessary to monitor the redistribution of water on the Earth. The redistribution of water on the Earth can be determined directly by measuring changes in the Earth's gravitational field as it responds to the moving water mass while the response of the solid Earth due to the weight of the redistributed water can be measured using GNSS. Also GNSS data can be used to measure changes in the amount of water contained in the atmosphere.

Understanding how freshwater is redistributed across the globe is one of the many challenges confronting society. The growing world population, climate change, ecosystems, agriculture, emerging industrialized countries, and energy development all influence and compete for the supply of terrestrial water; human activity and climate change are beginning to alter the natural distribution of global freshwater. Global groundwater depletion may also contribute to sea-level rise.

Geodesy contributes to characterizing changes in terrestrial groundwater storage at a variety of scales, ranging from continental-scale changes in water storage using GRACE, to regional and local InSAR, GPS, leveling, and relative gravity measurements of surface deformation accompanying aquifer-system compaction. Geodesy indirectly measures the change in water levels through gravity and the surface response to natural and anthropogenic water level changes through tracking spatial changes in the land surface elevation over time. Aquifer-system responses to recharge and pumping are directly measured with a number of geodetic tools (gravity, leveling, GPS, InSAR) and can be used to characterize the extent of the aquifer system as well as large-scale heterogeneities including groundwater barriers such as faults. Modeling these changes provides an understanding of the physics that drives the system and the implications of the changes on the regional aquifers. As groundwater levels continue to be pumped to new lows, the storativity of the aquifer-system is reduced, primarily in the fine-grained units. Quantifying the global mass flux and volume of groundwater in storage at both the local and continental scales is needed to fully characterize the water redistribution process.

Major scientific questions addressed that benefit the nation:

3. Where is the water?
    a. What do satellite and air-borne gravity observations tell us about the movement of ground-water in Australia?
    b. What do satellite-radar and GNSS observations of surface deformation tell us about the movement of ground-water in Australia?

Proposed infrastructure:

An improved satellite gravity observational capability by incorporating an Australian prototype “racetrack” system of mirrors and mounting struts that will form the virtual corner-cube reflector within each satellite bus that will enable the laser system on the GRACE follow-on satellite mission to operate alongside the K-band inter-satellite measuring system.

Water Management: synergies with other AuScope components

Understanding exactly how water is redistributed requires an interdisciplinary science approach to quantify how water moves though the water cycle and resides in storage. As such the proposed infrastructure would share strong synergies around all the AuScope Components.

Water Management: other Synergies

Geodetic observations will provide an important ground-truth of the dynamic crustal models developed in *Simulation Analysis and Modelling*. All the geospatial datasets will be distributed to the research community via *Grid Access and Interoperability*.

Geospatial investment options

Investment	***5 Year Cost***
Operation of the AuScope VLBI and gravity observing programs	*$5,000,000*
Upgrade of AuScope VLBI array to broad-band cryogenic receivers	*$6,000,000*
10 x continuous GNSS stations along plate boundaries	*$2,000,000*
A national facility for the development of geodetic analysis, modelling and delivery systems	*$2,000,000*
GRACE follow-on mission prototype laser system.	*$2,000,000*
National coastline air-borne gravity survey *(80,000 line km at $100/km)*	*$8,000,000*
2 x satellite altimeter calibration sites	*$1,000,000*
Total	***$27,000,000***

Geospatial Support and Involvement

- ANU (Dr Paul Tregoning, Dr Simon McClusky, Prof Kurt Lambeck)
- University of NSW (Prof Chris Rizos)
- Curtin University (Prof Will Featherstone, Prof Peter Teunissen)
- Geoscience Australia (Dr John Dawson, Mr Gary Johnston, Mr Michael Moore, Mr Nick Brown, Dr Medhavy Thankappan)
- DSE Victoria (Dr Roger Fraser)
- Lands Department, Northern Territory (Mr Rob Sarib)
- Queensland (Mr Matt Higgins and Dr Russell Priebbenow)
- CRC-SI (Dr Phil Collier)
- The University of Melbourne (Dr Allison Kealy)
- RMIT (Dr Kefei Zhang)

MATERIALS, PROPERTIES AND PARAGENESIS

AuScope's second-generation National Virtual Core Library (NVCL-II) aspires to become the nation's premier infrastructure resource cataloguing the subsurface Materials (rocks and minerals), their gross chemical and physical Properties, and their Paragenesis (chronological sequence of formation) that describes the continent we live on and from which we derive our food, water and resources and wealth. The NVCL combines material, technological, data and human infrastructure, and derived information: critical inputs to understanding and modelling the physical and chemical processes and geodynamic behaviour of the Australian continent, as well as discovering future resources and managing our waste and environmental contaminants. The NVCL content is sourced from voluminously sampling the subsurface of the continent from thousands of past and future drill holes collected by public and private enterprises over at least the last 100 years, as well as surface reference samples. To date the prime mechanism for compositional mapping used by the NVCL I has been rapid, non-destructive and non-invasive reflectance spectroscopy. The next generation NVCL II will significantly expand and integrate this capability with other earth science observations.

1. Major Scientific, Economic and Social Questions addressed

A significant proportion of Australia's national wealth derives from its natural resources endowment (minerals, oil, gas, coal, water, etc.). Maintenance of this wealth in a competitive world environment depends on many factors, including the continued discovery of new resources which will need to come from increasingly deeper sources, from beneath Australia's extensively blanketing and deeply weathered cover. We have reasonably good geological maps of the surface of the nation, but are poorly informed as to the actual mineralogical internal composition of that cover and furthermore woefully ignorant in particular of the material properties (the rocks and minerals) comprising the basement rocks hidden beneath that cover, rocks that will deliver the next generation of wealth-creating, world-class mines and energy resources.

The 2010 Academy of Science Theo Think Tank identified a series of profoundly significant issues around "Searching the Deep Earth", including that new geoscience data will be the foundation of successful exploration strategies in frontier regions, that following the importance of surface geological maps in the 20th century, the 21st century must produce new maps that explore the sub-surface and define the depth of the cover, advocating a national deep drilling program, a program to explore the distal signatures of giant ore systems under cover, and strategies to increase knowledge transfer and access. The NVCL II proposal aligns with virtually all the identified issues and extends these to basin analyses for energy and water resources and waste storage.

Significant AuScope goals are directed at imaging and modelling the subsurface structure, geodynamics, and age relations of the Australian continent. The NVCL proponents believe no interpretation of subsurface imaging or modelling scenarios can be completely representative without considering the lithological and mineralogical compositions and properties of the bodies of rock involved in such models. Mineralogy can significantly influence rock strength, porosity and permeability, as well as leaving a trail of clues as to past thermal and chemical regimes, fluid / wall rock interactions and depths of burial. Below we identify just some of the many questions (both generic and specific) that a better understanding of sub-surface rock properties and composition should be able to address.

What is the composition of the continental cover of Australia as it impacts our ability live on, grow crops, exploit water resources, bury waste and see through it?

What is the composition of the top of the basement beneath the cover that can inform us how to explore the basement and how far we have to drill or sense to make a map of Australia's continental basement?

What is the composition of Australian's near off-shore marine basement and can a more accurate description of this inform research into climate history, or exploration for oil and gas reserves?

What are the mineralogical compositions and physical and chemical properties of rocks that determine their suitability as optimum hosts for carbon (CO_2) sequestration, or nuclear or other waste storage, and where are these located? Can a more thorough sampling of the continental subsurface better inform storage modelling scenarios, scientific and policy decision making.

It is already known that primary clay mineralogy can significantly impact oil and gas reservoir productivity. Thus can faster on-site and low-cost mineralogical mapping of drill cores and cuttings with NVCL style infrastructure significantly improve the understanding and prediction of hydrocarbon play success? The NVCL I has already demonstrated the ability to detect oil signatures in both conventional oil basins and oil-shale deposits.

How can we capture a higher rate of return on the billions of dollars spent on exploratory drilling for energy, mineral and geothermal resources, when the bulk of such exploratory activities do not lead to economically-viable and exploitable resources? For example, can we learn more from exploration "failures and mistakes" to better inform and focus future lower risk drill targeting, and how do we transfer these learnings from the private sector, where much of it is initially generated, into the broader public sector research environment for the benefit of society and future explorers at large? Can we increase the capture and flow of non-competitive or pre-competitive knowledge once it has lost its competitive currency? Can a national infrastructure approach foster such a goal?

As indicated above the private sector initiates a large part of the raw earth science data collection. A small fraction of this finds its way into the public sector research world. This begs the question, "How can we better develop productive two-way partnerships between the private and public sectors"? Government legislation currently mandates submission of records and cores from some sorts of exploration. No provision exists yet for the capture or compositional value-adding of RC and RAB drill chips and cuttings, despite this being the most extensive type of drilling by metres drilled.

Can we improve our early-stage discovery of deleterious and hazardous natural materials that either make economic mineral resources less economic (through containing deleterious components) or are hazardous to human life, such as natural occurring and waste asbestiform minerals and products? For example there are housing estates being built in parts of the world where naturally occurring ultramafic rocks are shedding asbestiform minerals onto unsealed public roads! In Australia we may still encounter dangerous asbestiform minerals in iron ore exploration drilling, and in abandoned mines. Nationally-distributed reflectance spectroscopy infrastructure can also inform such issues.

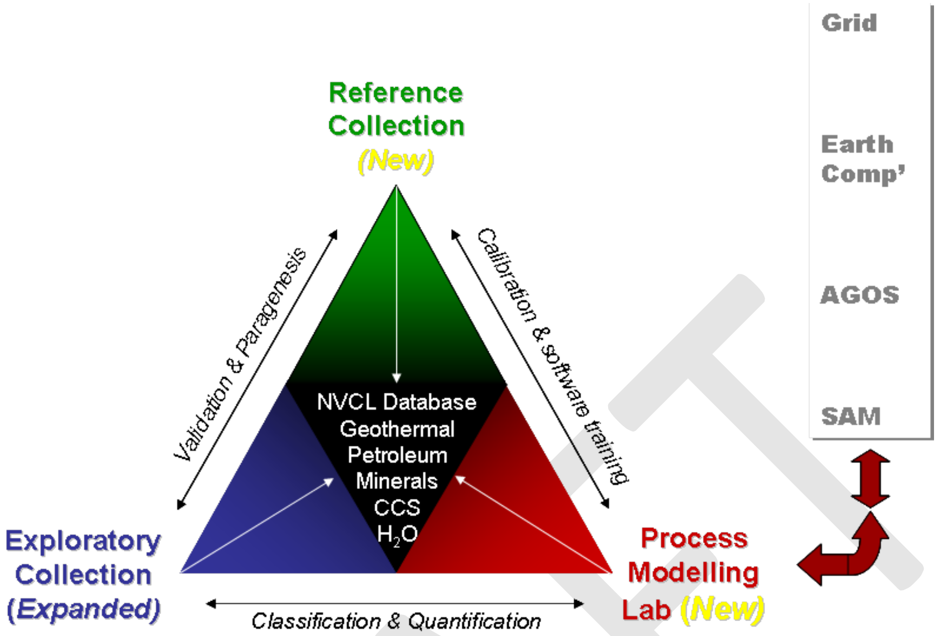
We believe that all the above example questions can be valuably informed through synergies provided by Australia's leading capabilities in voluminous mineral reflectance spectroscopy and selected petrophysics and chemistry as proposed in the enhanced and integrated workflows of the NVCL/Materials Properties and Paragenesis (MPP) Strand.

2. Primary Objectives – New Infrastructure Creation

The next generation NVCL-II will expand the compositional knowledge base about the crust beneath Australia and increase its integration into a coherent virtual research capability (the libs-to-labs model). It will achieve this by building an expanded and better validated network of mineralogical, chemical and petrophysical instrument nodes, comprising a web-accessible exploratory database, a new reference database and a virtual process modelling lab where researchers can access new codes to better simulate and predict the earth processes that took place in the geological past to create today's observed compositional signatures. The feedstock for this infrastructure will be an expanded sampling of the crust through deep and shallow drill holes and surface samples in each National/State/Territory Geological Survey (multiplying the rate of data gathering by eight). The expansion will come through the addition of new agency nodes (e.g. at GA and GSV), and increased engagement with the private sector through a mobile logging node, new commodity applications (e.g. hydrocarbons and geothermal) and the addition of new observations (X-ray mineralogy, XRF-geochemistry, selected geophysical observations and micron scale mineralogical mapping for paragenetic studies. Expanded NVCL database infrastructure coupled to the AuScope-Grid will deliver products and chemical and physical thermodynamic modelling capabilities.

3. Major Outcomes and Benefits

The major infrastructure outcome from the next generation NVCL/MPP investment will be an expanded suite of earth science instruments and observations, organised around an integrated tripartite workflow, thus:



In addition to expanding the output of the existing voluminous mineralogical HyLogging nodes (lower left), this new workflow will include a carefully selected master reference collection (top) both feeding new modelling capabilities (lower right) and other AuScope Strands.

The current Exploratory Collection will be expanded by drawing in GA and GSV more formally to the NVCL community, adding new commodity interests (hydrocarbon production and sequestration (e.g. by targeting such minerals as dawsonite), geothermal and coal seam gas) and devising methods to engage more closely with the private sector to get more of the extensive RC/RAB drilling results and bottom-of-hole (top-of-fresh-rock) samples into the NVCL as part of a goal for a new subsurface map of Australia (the Next Layer Initiative). This will be facilitated by deploying a new mobile HyLogging facility dedicated to building the public sector, fully accessible non-competitive database. Existing public-sector core libraries are not as well representative of many classic mineral deposits that are still in production as they might be. Many of these cores are still in private-sector hands at the mine sites. One goal of an increased two-way industry partnership is to visit the mine sites with the sensing infrastructure to better capture signature examples of Australia's "economic" subsurface.

The Reference Collection database will be built as the "gold standard" of calibrated and validated samples, characterised with a variety of instruments. It will be built from samples collected by characterising and domaining, in near real time, cores from their HyLogged mineralogy, thus minimising double handling material. Primary observations will be derived from:

(i) A new dedicated quantitative x-ray diffraction (QXRD) facility to which samples will be sent from each NVCL node. It has been determined that this will be more cost effective, more consistent and allow for a much larger collection than using commercial laboratories. This free service will be run by Mineral Resources Tasmania on behalf of the AuScope NVCL community. As the NVCL nodes rapidly move into new geological environments and commodity terrains a larger range of minerals is being encountered. Many of these are not yet embodied in automated interpretation algorithms, a pre-requisite for effective data interpretation. Thus the Reference Collection not only increases users' confidence in the HyLogging outputs, by having access to selective validated and quantitative results, but also allows Australia to continue to lead the world in voluminous automated mineral spectroscopy algorithms, algorithms whose developers can benefit from the control and "quantitative ground truth" only such a Reference Collection will provide. These algorithms will be embedded in the NVCL software infrastructure "The Spectral Geologist", which though world-leading has not had its underlying reference library seriously updated for nearly a decade. Increasingly in such disciplines as geometallurgy NVCL outputs must become more quantitative and standardised. In an updated NVCL database the QXRD sample results will be stored with their respective reflectance spectra and images offering another unique piece of research infrastructure.

(ii) The establishment at each NVCL-II node of state-of-the-art, bench scale XRF instruments (such as the Innov-X 5000), magnetic susceptibility meters, and rock density measuring procedures. As above these will be used to sample cores at intervals defined by mineralogical domains and other observations. These results will also be databased and facilitate advanced chemical, geophysical and thermodynamic modelling.

(iii) The establishment at each node of unique bench top hyperspectral petrographic imaging cameras capable of 2D mineralogical mapping at between 30 microns and 1 mm of small samples. The current NVCL HyLogging instruments, while voluminous in their data collection, do not provide much information about mineral paragenesis, a vital requirement for unravelling mineral and basin system histories. These proposed Specim Sisuchema devices will allow new non-invasive and rapid (a few minutes only) sampling at scales and costs hitherto not possible.

(iv) With one of the hyperspectral cameras mentioned under (iii) above we propose collaborating with AMIRA International to scan their entire Data Metallogenica (DM) collection, a globally unique library of representative rock samples, housed in Adelaide, from mineral deposits from across Australia and around the world. AMIRA have indicated their willingness to make the collection available for this purpose. The collection houses upwards of 70,000 samples not available for invasive sampling. Reflectance spectroscopy is one of the few methods available to characterise and document their mineralogy. By hyperspectral mapping this entire collection AuScope will not only enrich Australia's earth science research knowledge base by exposing its mineral deposit mineralogy, but be contributing significantly to international earth science research. The few DM samples studied with prototypes have already brought to light unexpected mineralogical observations that have helped re-think some conventional ore deposit models.

The proposed virtual Process Modelling Lab, the 3rd component of the next generation NVCL/MPP Strand illustrated above, will comprise the ability to take all the observations contained in the other two components (the Exploratory and Reference Collections), plus external data and observations as input to new modelling codes to simulate and test the chemical, physical, thermodynamic and spectroscopic processes that may have occurred to produce the presently observed mineralogical distributions. Some such codes already exist (e.g. THERMOCALC, TWQ, MELTS, Perplex, etc.), but it is felt these need to become more mainstream and integrated in ways that users of the combined NVCL data streams can test and update hypotheses for mineral and basin system evolution, including the explanation of primary sedimentary, igneous, and metamorphic processes and their all important discrimination from secondary, economically-important ore and energy system formation. This work will be undertaken by new computer-literate, geochemically-savvy personnel under the tutelage of the best Australian minds we can locate, including possibly modellers from the SAM component. This NVCL/MPP module endorses the AuScope II concept of "libs to labs" (see figure), virtual libraries feeding virtually labs where researchers can access disparate web-distributed datasets and state-of-the art software codes and undertake leading-edge earth science research about Australia's deeply buried energy, water and mineral resources.

4. Synergies with Other AuScope Components and External Research Programs

As indicated above the NVCL proponents believe no interpretation of subsurface imaging or modelling scenarios can be completely representative without considering the lithological and mineralogical compositions and properties of the bodies of rock involved in such models. Mineralogy can significantly influence rock strength, porosity and permeability, as well as leaving a trail of clues as to past thermal and chemical regimes, fluid/wall rock interactions and depths of burial. Mineralogical alteration can significantly impact seismic and magnetic responses (e.g. probably the cause of the "seismically-bland" response beneath the giant Olympic Dam Cu/Au/U deposit). As a consequence the outputs of the MPP/NVCL Component should find immediate input to the goals and strategies of other AuScope Component[1]: Composition and Evolution, Simulation and Modelling, and Geoimaging. Furthermore some of the chemical and thermodynamic modelling of geo-processes proposed here-in could be undertaken in the SAM Component, should appropriate skills be available. Collaboration with the AuScope Grid will be mandatory for the timely delivery/accessibility of the expanded outputs from this Strand.

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[1] particularly towards pursuing an overarching Australian Earth Observatory.

The proposed infrastructure and its outputs will also find application and encourage collaboration between AuScope and the Deep Exploration Technologies (DET) CRC, the CO2 CRC, and the proposed Australian Crustal Drilling Program.

5. **Equipment / Capital Investment** (subject to exchange rate & inflationary changes)

The NVCL/MPP Strand draws its strength and accessibility from the seven distributed nodes, because that is where the material infrastructure (the core) is located. Following from this much of the infrastructure needs to be duplicated. Where possible single, central capabilities are utilised to minimise expense.

It is proposed to augment the existing mineralogical logging capabilities (the NVCL HyLoggers) with additional geochemical, petrophysical and detailed petrographic imagers, as outlined below. Hardware infrastructure without adequate technical support, including software engineering to create modelling tools, diminishes the value and utility of the initial investment. The existing NVCL HyLogging instruments are operated through in-kind co-investment from the Geological Surveys and it is expected that this will continue under an NVCL-II program. However, increased technical and professional support and funds in the NVCL-II are required (relative to AuScope I) to operate and maintain the increased suite of data collection instruments and build the database and software modelling infrastructure that downstream researchers will require. Fifty percent of system maintenance is shared with the Surveys in the Option-2 budget estimate below.

AuScope I benefitted significantly from stakeholder co-investment. Given the preliminary stage of development of a next generation Earth Science Infrastructure plan, this proposal so far includes very little mention of any such co-investment opportunities.

Two funding scenarios are presented. The Option-2 proposal is considered the optimum and least risky in a support and maintenance sense.

AuScope NVCL II Budget Estimate Nov

Capital	Amoun	Years/Unit	Tota
Pananalytical Empyrean QXRD System + ICDD-PDF4 XRD database	545,00	1	545,00
Bench XRF - 7 * Innov-X	65,00	7	455,00
HyLogging ergonomic	50,00	7	350,00
Mobile HyLogger for GA,GSV &	600,00	1	600,00
Other petrophysics (TBD *	28,57	7	200,00
SisuChema Petrographic	223,76	7	1,566,34
LIBS based core geochem assay	250,00	7	1,750,00
Total			**5,466,34**

Salarie & operating (annual and total

EFT's for modelling/operations			
QXRD Technican (S + O/C)	75,00	5	375,00
Mobile Hylogging operator	100,00	5	500,00
Database software engineer or L4	100,00	5	500,00
Modelling software geochemist or L5	120,00	5	600,00
Spectral library geologist L5	120,00	5	600,00
NVCL Technician *	560,00	5	1,400,00
Specialist maintenance engineer	125,00	5	312,50
Total Labour &	**1,200,00**	**5**	**4,287,50**

Tota		**$**	**9,753,84**

6. Time frame for Capital Investments

Infrastructure	By end year 1	By end year 2	Risk level
Pananalytical Empyrean QXRD system	✓		Low
Bench XRF - 7 * Innov-X 5000	✓		Low
HyLogging ergonomic upgrade	✓		Low
Mobile HyLogger for GA,GSV & Industry	✓		Low
Other petrophysics (TBD * 7)	✓		Low
SisuChema Petrographic Imagers	0.5	0.5	Low
LIBS based core geochem assay system		✓	L-M

People infrastructure to undertake operations and software engineering developments can be expected to take 6 months to ramp up, required by recruiting or await instrument deliveries. It is thus estimated staffing will be at half strength after 6 months and full strength at the end of year 1. These projections are a goal but may be optimistic.

7. Stakeholders and Support

Agency	Supporting Director	Existing Infrastructure Professionals
Geological Survey of NSW	Graham Butt	Dr Bill Reid, Dr Meagan Clissold,
Geological Survey of Queensland	David Mason	Mark Thornton, Dr Suraj Gopalakrishnan, Dr Joseph Tang

Geological Survey of Western Australia	Rick Rogerson	Dr Paul Morris, Dr Lena Hancock,
Geoscience Australia	Dr Clinton Foster	Dr Bruce Goleby, Stuart McKeon
Geoscience Victoria	Paul McDonald	Emily House, Helen Lynch
Mineral Resources Tasmania	Michael Leonard	Dr Geoff Green, Dr David Green, Mike Vicary
Northern Territory Geological Survey	Dr Ian Scrimgeour	Dorothy Close, Tracey Rodgers, Belinda Smith
Primary Industry and Resources South Australia	Dr Tim Baker	Alan Mauger, Georgina Gordon
CSIRO Earth Science & Resource Engineering and CSIRO MDU Flagship	Dr Mike McWilliams, Dr Jonathan Law	Dr Lew Whitbourn, Dr Jon Huntington, Dr James Cleverley, Dr John Walshe, Dr Rob Hough, Peter Warren, Peter Mason, Dr Mark Berman, Dr Andy Green, Dr Martin Schodlok.

SIMULATION, ANALYSIS AND MODELLING

SAM provides a **software platform** for modelling, simulation, and analysis across the Earth sciences in areas not well served by commercial modelling packages.

Repository of expertise in

- Modelling methodology
- High performance computing
- Software engineering
- Computational geoscience
- Geotechnical modelling
- International collaboration / development
- eResearch

There has been $20M+ of public funding, $10M+ of co-investment since 2002 to develop a well established, robust simulation capability for delivery in 2011.

The proposed activity under AuScope 2 will be focused on developing this infrastructure into a number of virtual laboratories where earth scientists can discover, model, explore and analyse public and private data collections, and determine the productive avenues for data acquisition programmes.

The virtual laboratories will be a natural outgrowth of the grid programme and SAM under AuScope 2 and, with sufficient additional investment, would form an AuScope Observatory delivering AuScope data and models to industry, government and researchers.

Examples of virtual laboratories

- Basin analysis & management
- Mine design and safety
- Geodynamics
- Mineral exploration
- Geothermal modelling

a. Technical Challenges

Software components needed to enable geological knowledge generation from simulation are in the areas of

- data storage & retrieval (i)
- forward modelling (ii)
- data visualisation(ii)
- earth model construction(iii)
- data assimilation tools (e.g., stochastic inversion)
- earth data analysis

Items in category (i) fall largely under the data grid and are starting to be delivered in AuScope 1

Items in category (ii) are mature in AuScope 1. Earth model construction (iii) is emerging in AuScope 1 in prototype form. The emphasis in AuScope 2 will be to address the final 2 points, and to ensure that the existing infrastructure is continually improved to meet the following challenges:

1) Forward modelling
   - Very large scale problems in 3D
   - Multiple runs to explore data
   - Capturing sensitivity information
   - Interactivity combined with remote HPC
   - Robust solvers / numerical techniques
2) Earth model construction
   - Mesh construction
   - Representation of subsurface structures
   - Parameterisation of subsurface
   - Automation v. hand-tuning

b. Potential Participants and Roles

- University of Queensland, Monash University, VPAC, ANU(†), GA(†), CSIRO(†)
    - Finite element / volume modelling, Particle based FEM, Discrete element simulation, numerical innovation
- University of Sydney, ANU, Monash University, GSV(†), GSQ(†)
    - Plate tectonic reconstruction, global geodynamic modelling, computational geology
- Macquarie University*
    - Petrology, thermodynamics based modelling
- UWA*, CSIRO
    - non-equilibrium thermodynamics based modelling, reactive fluid transport,
- ANU, UWA, UQ, U. Sydney, GA
    - data assimilation, inversion, model steering

(*) Expansion of participation / activity from AuScope 1

(†) Groups not yet engaged with AuScope

c. Budget Options

The investment made in SAM1 was $8 million with substantial co-investment. In the current financial climate it is unlikely that university partners or the surveys will be able to supply a similar level of support, so the $5 million option represents a sizable reduction in effort and would necessitate streamlining existing infrastructure, taking on limited additional partners, and concentrating on maintenance updates.

An investment at the $13-15million dollar level would allow us to bring the whole modelling and analysis community into SAM, build easy-to-use virtual laboratories for user communities, and work with the grid programme to establish an AuScope Observatory. At this level of funding, we would envisage being in a position to leverage co-investment for the observatory infrastructure.

Higher levels of funding for SAM infrastructure are justifiable, we believe, but only if the software tools can be taken up by other (post-NCRIS) capabilities or external organisations.

A potential mechanism for this would be to create a “Platforms for Simulation” grouping operating across capabilities (analogous to the “Platforms for Collaboration” capability in NCRIS) with a focus on bringing a common high performance computing, simulation, analysis and visualisation expertise to the data infrastructure built under NCRIS and similar large-scale research infrastructure investments. This entity would engage with / emerge from NCI, PfC, state eResearch groups, and the research and data infrastructure providers.

E-EARTH INFRASTRUCTURE

AuScope's second-generation Grid infrastructure aspires to move AuScope's stage one information sharing infrastructure (Grid) from access and interoperability into the realm of **integration and analysis** – from virtual libraries to virtual laboratories.

The focus of the stage one of activity has been in establishing a broad community of practice and supporting technologies that can share information using open standards across a distributed set of point-of-truth information custodians primarily State and Territory Geological Surveys but not limited to them. Easier access to similar data across multiple data providers provides a platform for national scale information integration and analysis. Previously such studies were hampered by the simple act of gathering all the information together and making it consistent from the data custodians. AuScope stage one has largely achieved its goal technologically, and indications are strong that "business-as-usual" is both desired and considered achievable in the daily operations of the many custodians of geological information involved.

There is a ***strong*** indication from the State and Territory Geological Surveys and Geoscience Australia to see this data infrastructure and services move to "business as usual". There is also an indication that they desire that AuScope remain a key player in achieving that in AuScope II until they are able to fully take over. As such there is a need to sustain a smaller data infrastructure activity in conjunction with the surveys over the next 2-3 years.

AuScope's objective has always been to produce a coherent infrastructure system, one that supports data being transformed into information and ultimately knowledge. This transformation requires analysis and integration to be achieved. As with the data, integration and analysis has both a technological and a social dimension in modern science and a consideration of new software architectures to support diverse flexible workflows. Whilst an algorithm may be written to support sedimentary formation and erosion processes, it may be applied in areas ranging from oil exploration to fisheries habitat monitoring. Likely the application of the algorithm would be performed by two different groups of scientists with differing specialisation, but they can (and do, this is a real example) share the same computational service for the simulation problem.

This separation of *services* occurs at the data level (as exemplified in AuScope 1's Grid), the analytics level and indeed in user interaction in user interfaces and visualisation. As such software architectures have changed (with things like cloud computing and service oriented architectures) to allow for flexible and eased connection of diverse services into workflows on demand. A level of cooperation is required across the community to achieve this, the first of which is design services and not applications. This is exactly analogous to the situation with the web mapping applications that exist at the State and Territory geological surveys to provide access to their data. Each application in and of itself works great, but anyone seeking national synthesis has to learn to use each one and to reformat that data themselves. The Auscope 1 Grid approach formed a community of practice across the surveys which meant they now publish information services (not applications) which the user can then join trivially using whatever form of visualisation user interface they desire (the AuScope Discovery Portal being one example, MS Excel and ESRI GIS being others).

In reviewing submissions one can observe that the responses continue the “application centric” view. This is in part because they seek to address their particular part of the geoscience questions. The AuScope II Grid proposal does not fit into the template as it is a platform to support the outcomes of the other strands, not to produce those particular scientific outcomes itself (by analogy, AuScope Grid did not collect any data, only made it possible for those who collect data to do publish it in a consistent manner to benefit themselves and the community).

The way to approach the virtual libraries to virtual laboratories transition is to develop a platform which moves AuScope from the building of silo applications, to one that architects its strands tools into services (computational, data, visualisation, and physical sensors) that can then be drawn together by the strands into science workflows. This is a platform activity to support these areas and predominantly requires software engineering support to connect the strands together and to assist them in architecting their components into services. Some preliminary work has been done in this regard during AuScope 1 and is underway with Geoscience Australia with the Virtual Exploration Geophysics Laboratory.

This trend is also seen in the other NCRIS areas. This is not surprising and is driven in part by the need for science workflows which span the NCRIS areas (and their associated organisations) for things like the National Plan for Environmental Information. AuScope Grid is considered to be a leader in this field, both for information handling and scientific workflows, because of the Auscope stage 1 work.

The Steering committee recommends to the AuScope board that during the next stage of AuScope II's development an Informatics component be developed. This component would provide the common architectural components as a shared platform for use by the more application specific strands and connectivity to the NeCTAR and future IT infrastructure activities underway in other programs. It will have associated with the objective of achieving a computational services infrastructure and community of practice to go with the sustained and expanded information services infrastructure. This platform is already evident as a desired activity in the Virtual Exploration Geophysics Laboratory, the GPlates activities and in the SAM proposals. This would also fit well with the direction DIISR appears to be heading in regards to the environmental area and would allow AuScope to participate more fully in that agenda in the future. The development of the informatics strand would best be followed up after the current activity to allow for the analysis of the other strands to be properly conducted and the initial community of practice established. It is not possible to suggest a costing for such an activity, particularly given there are overlaps with the other component developments that would need to be resolved, but based on previous experience a core team of 4-6 software engineers and some strong domain experts and software architect is required to support the broader communities activities. This is smaller than the existing AuScope Grid activity (in the order of $6 million) and continued substantial in-kind support is required from the Geological Surveys as they move to "business as usual" operations along with the potential co-invested support through programs like NeCTAR.

The request for future infrastructure support is summarised as follows:

1. Sustain the data infrastructure in conjunction with the Surveys.
2. Continued Software Engineering Support to achieve the transition of the Virtual Libraries to Virtual Laboratories.
3. Continued support to facilitate integration of the various research infrastructure developments and activities and provide a service to their activities.
4. Develop an Informatics capability to assist in data management.
5. The Core Team would require some $5M over 5 years with in kind contributions from GA, CSIRO, and the Surveys.

NATIONAL DATA SETS & MAPS

There were nine submissions received in this group, namely:

1. Legacy Geochemical and Geochronological Data,
2. Depth to important subsurface features,
3. Hyper spectral Archive of space-borne and field-based data,
4. Radiogenic Isotope Map of Crustal Elements,
5. National 1:1M Regolith Map,
6. National Rock Properties Dataset,
7. National 1:1M Solid Geology Map, and
8. Legacy air photos.
9. The Australian Database of Magnetic Field Anomalies Due to Remanent Magnetisation.

Commonwealth organisations such as Geoscience Australia and CSIRO, State and Territory Geological Surveys, and many universities hold "legacy" data sets of rock properties, geochemical analyses, geochronological information, radiogenic isotopic data, resource data, hyper spectral data, etc which is not readily accessible to other institutions or to the public. Such data sets could be made accessible via the AuScope Grid Portal and then utilised in the production of a series of National 1:1M scale maps similar to the 1:1M Surface Geology Map of Australia (that map took eight years to produce).

It has been estimated that the value of the geochronological data which exists has a replacement value in excess of Aus $60M and that the geochemical data value would exceed than amount. It was reported at the 2009 Chief Government Geologists Committee that the cost of capturing that legacy geochemical and geochronological data would be in the vicinity of $0.5M. Similarly the radiogenetic isotope data which can be used to constrain modelling of 2D and 3D distribution of major crustal domains and their boundaries could be captured and used to identify regions of enhanced prospectivity for gold, uranium, base metals and geothermal energy. The cost of capturing this data is estimated to be in the order of $0.5M.

Whilst capturing the aforementioned data it would be desirable to also gather information on the regolith and mineral occurrences that could be used in map production. A regolith map would be of use in the development of effective environmental management practices for the safe disposal of hazardous and non-hazardous waste, groundwater management, and the further application of regolith science in mineral exploration. NT and Queensland have 1:1M regolith maps and it is estimated that to produce the same scale maps for the other remaining states would cost in the vicinity of $0.5M, not including the in-kind contributions by the state geological surveys and GA for salaries.

The other data sets that could be developed and made more assessable and which could be incorporated into 1:1M scale maps are the hyper spectral data for such information displays the relationships of vegetation to regolith and rock type. A range of national issues exist that could use such maps. Things like water resource management, sustainable farming practices, water resource management, land use planning, climate change studies, ecosystem changes over time, etc require access to such maps. It has been estimated that the cost of establishing a national facility to manage the hyper spectral data is in the order of $1.8M.

Another data set is the legacy aerial photographs covering the past 50 years. These could be digitized and made available over the AuScope Grid. However, the NCRIS Guidelines for activities does not cover such digitizing.

Preliminary estimates of the costs of gathering these legacy data and developing data sets is in the order of $5M-$6M, The benefits that would ensue from such compilation and map making would be several orders of magnitude value when compared to the cost of the projects. There is no other organisation like AuScope that has either the capacity or ability to achieve such national coverage and to turn the information into assessable data sets and to compile the data sets into maps.

The Strand labelled National Data Sets and Maps is about putting to use legacy data and data sets and making them accessible and using the information in a series of National 1:1M scale maps.

The national benefit is that for the first time Australia scientists and policy makers will have available information made available via the AuScope Grid to inform them with decisions concerning regolith, rocks, isotopes, geochemistry, geochronology, depth to significant subsurface geological features, structural domains, etc. The equipment/capital investment required is of the order of $5M-$6M. There has been no estimate of the cost of the in-kind salary component. The timeframe for investment is 5 years.