Submission
2016 National Research Infrastructure Roadmap
Capability Issues Paper

Name	**Prof Sue O'Reilly (AM, FAA) and Prof Stephen Foley**
Title/role	**Director and Research Coordinator respectively of the ARC Centre of Excellence for Core to Crust Fluid Systems (CCFS)**
Organisation	**Macquarie University**

ARC Centre of Excellence for Core to Crust Fluid Systems (CCFS) has representatives closely involved with both the Australian Academy of Sciences National Committee for Earth Sciences (NCES), and the UNCOVER initiative. Our views coincide with those of both the NCES and UNCOVER responses and also with the AuScope response.

Instead of writing a separate submission, duplicating concepts and answers in those documents, we wish to formally endorse those views, and thus attach the NCES and UNCOVER submissions for reference. The AuScope response was not attached due to space limits.

Submission Template
2016 National Research Infrastructure Roadmap
Capability Issues Paper

Name	**Phil McFadden**
Title/role	**Chair, UNCOVER Initiative**
Organisation	**UNCOVER**
Preferred contact phone number	**0408 232 617**
Preferred email	**mcfadden@grapevine.com.au**
Would you like your submission to remain confidential, i.e. not published on the website?	**NO**

Questions

Question 1: Are there other capability areas that should be considered?

An issue of particular concern for Australia is that of the falling success rate of mineral exploration and the consequent withdrawal of international exploration funding from Australia. This is because the near-surface easy finds of economically viable mineral deposits have already been made and because more than three quarters of Australia is under post-mineralisation cover. This makes mineral exploration extremely difficult with our current approach to exploration and our current knowledge of how the Australian continent was built, of how and where mineral-bearing fluids moved through the ancient crust, and of the conditions that caused those fluids to precipitate out massive deposits of valuable minerals.

We are currently living on the exploration finds of the past century, those mines are rapidly being depleted, and we are not replacing our inventory with new ones. Yet there will continue to be significant demand for the metals that have traditionally sustained the Australian economy and global demand for minerals to support high-tech industries and the renewable energy transition is projected to explode over the coming decades. This will be particularly true for Australia as we try to diversify our economy.

For example, renewable-energy systems such as solar and wind require four times the copper that conventional systems need for the same amount of energy generated. There will also be an explosive demand for a range of other high-tech minerals. Bulk minerals such as iron will continue to be valuable well into the future and it is inevitable that coal will continue to be part of the mix for energy generation for some time to come.

Australia has an abundance of these economy-sustaining minerals hidden in the covered areas and we need to develop the new geoscience knowledge and technologies necessary to lift the success rate of exploration in the three quarters of Australia that is covered

to the level that we enjoyed 30 years ago in the uncovered areas. If we do not achieve this in the near future then Australia will not only be unable to export these minerals to the rest of the world but will actually have to import them to provide for its own needs - a serious reversal of the historic situation that has supported our economy.

UNCOVER is an initiative, under the aegis of the Australian Academy of Science, created specifically to address this issue through carefully targeted data acquisition and research programs. It is a partnership of the Australian exploration industry, government agencies including all of the State Geological Surveys, Geoscience Australia and the CSIRO, academic institutions and NGOs (see http://www.uncoverminerals.org.au/ for more information). While addressing this issue UNCOVER will also generate significant knowledge that will help in all aspects (groundwater, for example) of human interaction with the solid earth.

AMIRA International in collaboration with UNCOVER, industry, suppliers, research organisations, government agencies and other key stakeholders is developing a comprehensive Roadmap of the data and research programmes required and the infrastructure necessary to support this endeavour. Stage 1 of the roadmap is available at http://www.uncoverminerals.org.au/documents/amira-uncover-roadmap and Stage 2 of the roadmap will be delivered in the second quarter of 2017. This should be an important document in the development of the nation's research needs and the national research infrastructure needs.

In terms of National Research Infrastructure, UNCOVER will be particularly dependent upon AuScope. It will also be heavily dependent upon high-performance data and computational capability and on advanced data analytics for extracting information from sparse data sets (see also Question 23).

The new capability that UNCOVER will need of AuScope relates mainly to the creation of data sets that form critical infrastructure to support not only the research needed for UNCOVER but also for understanding appropriate management of our nation's sedimentary basins (for groundwater, for new energy systems such as unconventional gas, and for waste storage) as well as the underlying fundamental research that facilitates our understanding of how the earth works and how it supports life and human society. The basic need is for an integrated network of geophysical and remote sensors and geochemical sampling and analysis together with ongoing development of the global positioning system.

One of the most significant recent scientific advances in the field of economic geology has been the recognition that mineralisation is a highly punctuated process, occurring (often over wide areas, and manifesting as many different styles) within relatively narrow time windows in the geological history of their host terranes. This advance has occurred at the same time as the mineral systems approach to exploration targeting has emerged. The mineral systems concept sees individual mineral deposits as components of much larger geological systems and considers that if we can define and characterise the overall nature of the system, we can develop a framework to spatially target new mineral deposits. Currently, a major barrier to the definition of these mineral systems is the difficulty in relating particular minor mineral occurrences to a particular mineral system - in many cases there is significant ambiguity. If we knew the age of these occurrences, we would know with some

confidence the broad metallogenic event they related to and therefore would be able to use their spatial distribution to build our understanding of the spatial characteristics of that particular mineral system. This in turn would provide a major benefit to our ability to develop targeting models. Therefore, a program that is focused on providing as much geochronological data as possible for mineral occurrences (not just major deposits) would be of immense strategic value to the mineral exploration industry and would constitute a significant infrastructure for government agencies and academic research.

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure.

A national research infrastructure should be designed to underpin and facilitate a nimble and agile national research capability able to address the changes, demands, and challenges the future will present. This is best achieved by ensuring that the individual facilities form an interactive ecosystem of capability. Hence the governance models needs to include consideration of effective measures for interacting with other facilities. Although AuScope has been effective at this it is probably also worth considering the creation of an overarching Council made up of senior governance/management from within each area to achieve greater coordination.

Generally speaking the most effective governance model has, like AuScope, been a not-for-profit company with an independent board and outstanding leadership ability at the Chief Executive level. This allows for independence from institutional politics and facilitates strategic decision-making for the benefit of the entire community.

Co-investment in national research infrastructure requires special consideration in the governance structure. It should be clear that co-investment is vital but, in order to avoid distortion of the purpose of an infrastructure facility, there should be no specified target; instead the goal should be to gain as much appropriate and effective co-investment as possible. Flexibility about arrangements and timing (particularly with regard to flexible lead times) is important to enable development of a framework for collaborative investment with States and Territories despite the intermittent nature and different funding cycles of their investment programs in research infrastructure. This has proven important for AuScope and therefore for the Earth Sciences, and for the UNCOVER initiative.

Question 3: Should national research infrastructure investment assist with access to international facilities?

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

From the perspective of the UNCOVER initiative, Australia provides an exemplar for most of the problems that need to be solved. Furthermore, Australia has the skill set needed to lead the world in this area and through AuScope and associated CRCs is developing world-leading technology. Hence we would not at this time prioritise access to international facilities over development of national capability. Obviously this is not to preclude the building of effective partnerships with overseas expertise and capability.

Question 5: Should research workforce skills be considered a research infrastructure issue?

Clearly it is not the responsibility of a national research infrastructure system to usurp the role of universities and the ARC in educating the nation's research workforce and the scientific technical workforce.

However, it is inevitable (and this has already happened and is happening) that the specific, high-level operational skills required by the workforce within the infrastructure facilities become significantly improved and sharpened with experience in providing the research workforce with access to the infrastructure capability.

A paradigm shift in the NCRIS model, and a significant contributor to its success, was the provision of high-quality staff (both technical and scientific) within the infrastructure facilities to lower the intellectual cost of effective access to the available capability. This has meant that AuScope and other infrastructure facilities have actually been involved in driving innovation out in the research world and in significantly raising the skill level of the research workforce in accessing and using infrastructure capability to its maximum effectiveness. This is probably the most effective way of improving this aspect of the research workforce skills because it is being driven by those who, on a daily basis, are intimately involved with the infrastructure and its evolution in capability.

Question 6: How can national research infrastructure assist in training and skills development?

See answer to Question 5.

Question 7: What responsibility should research institutions have in supporting the development of infrastructure ready researchers and technical specialists?

See answer to Question 5.

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

Access should broadly follow existing NCRIS guidelines - access for little or no cost to meritorious research (merit to be determined externally and independently), data made widely and freely available as soon as possible, industry access with appropriate cost recovery but with guidelines in place to ensure that this does not compete unfairly with Australian commercial providers to industry.

Question 9: What should the criteria and funding arrangements for defunding or decommissioning look like?

At this stage the infrastructure provided by AuScope to the Earth Sciences in general and to the national effort under the UNCOVER initiative is critical to ongoing success. Hence at this stage we would recommend against any consideration of decommissioning.

However, under the current arrangements, the rapidly increasing liabilities and risks for hosting institutions associated with formal decommissioning of NCRIS infrastructure is already impeding the potential for future collaboration with new or existing partners. Hence formal policies and conditions for the decommissioning (including responsibility for and ownership of equipment and funding for wind-down costs) of a

particular facility need to be in place at the beginning to provide clarity for a hosting institution.

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

There is clear evidence from many studies around the world that long-term, strategic funding provides far greater bang-for-buck than short-term ad hoc funding.

Funding bodies such as the ARC should be encouraged to support the NCRIS facilities and there should be sufficient funding in their grants for infrastructure access.

The best approach would seem to be a statutory fund that could not be tampered with (or at least it would be quite hard) by politicians. An annual subvention of a fixed proportion of the capital outlays could be provisioned to support efficient and effective use of the research infrastructure. This would fund expert staff to drive the infrastructure and provide the security of tenure over the planned life of the infrastructure that is necessary to ensure the outcome identified in the previous paragraph. It could also fund the running costs of the infrastructure.

According to the ABS, the Australian Government spends over $9 billion a year on what is referred to as "science". NCRIS was funded by the Australian government as a $500 million program over five years. Considering the enormous positive impact that this infrastructure system has had on the nation's research capability, consideration should be given to whether this is an appropriate balance of funding.

Question 11: When should capabilities be expected to address standard and accreditation requirements?

Whenever that would improve quality and consistency and whenever it would provide a better interface with industry clients.

Question 12: Are there international or global models that represent best practice for national research infrastructure that could be considered?

Question 13: In considering whole of life investment including decommissioning or defunding for national research infrastructure are there examples domestic or international that should be examined?

Question 14: Are there alternative financing options, including international models that the Government could consider to support investment in national research infrastructure?

Health and Medical Sciences

Question 15: Are the identified emerging directions and research infrastructure capabilities for Health and Medical Sciences right? Are there any missing or additional needed?

Question 16: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 17: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Health and Medical Sciences capability area?

Environment and Natural Resource Management

Question 18: Are the identified emerging directions and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed?

See Question 21.

Question 19: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 20: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Environment and Natural Resource Management capability area?

Advanced Physics, Chemistry, Mathematics and Materials

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

Considering the impact for the nation, the Earth Sciences are significantly underrepresented. Research in the solid earth sciences underpins Australia's resources industry, which in 2014 constituted 59% of all Australia's exports and about 10% of GDP. In terms of publications/citations, the geosciences are the highest impact of any science in Australia per researcher.

The Earth Sciences would be better represented, and much more effectively so for the benefit of the nation, if they were included in STEM as has been the case in the recent past.

Question 22: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 23: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Advanced Physics, Chemistry, Mathematics and Materials capability area?

The development of translational data science is a burgeoning area for mathematics and high-performance computing. The cost of mapping Australia with new technologies at standard survey scale (the data being fundamental infrastructure for industry, government, and academia) is massive but it will be possible to extract similar (and perhaps better) information with far less data if the data is acquired incrementally in a manner that is guided through extremely smart data analytics. Hence, both from the point of view of developing fantastic new data analytic technologies for extracting information (including robust understanding of uncertainties) from sparse datasets and massively reducing data acquisition costs while chasing a trillion dollar prize, UNCOVER/AuScope is the ideal laboratory.

Understanding Cultures and Communities

Question 24: Are the identified emerging directions and research infrastructure capabilities for Understanding Cultures and Communities right? Are there any missing or additional needed?

Question 25: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 26: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Understanding Cultures and Communities capability area?

National Security

Question 27: Are the identified emerging directions and research infrastructure capabilities for National Security right? Are there any missing or additional needed?

Question 28: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 29: Is there anything else that needs to be included or considered in the 2016 Roadmap for the National Security capability area?

Underpinning Research Infrastructure

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

The design of the NCRIS system with its interlocked ecosystem of capability has, in effect, converted a range of activities, such as geospatial, characterisation, fabrication, and 'Omics into underpinning capabilities for other NCRIS facilities and for the national research system as a whole. Whilst this should be recognised as providing enormous value to Australia it should also be recognised that these capabilities are best developed in their natural homes (AuScope, AMMRF, Fabrication, BPA) rather than being abstracted, as major components of eResearch have been.

Question 31: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 32: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Underpinning Research Infrastructure capability area?

Data for Research and Discoverability

Question 33 Are the identified emerging directions and research infrastructure capabilities for Data for Research and Discoverability right? Are there any missing or additional needed?

Question 34: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 35: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Data for Research and Discoverability capability area?

Other comments

If you believe that there are issues not addressed in this Issues Paper or the associated questions, please provide your comments under this heading noting the overall 20 page limit of submissions.

Simply providing equipment to individual disciplines will not provide an effective national research infrastructure system. This can only be achieved by designing and creating an integrated ecosystem of facilities that provide all researchers with meritorious programs effective access to underpinning, enabling capability.

Apart from the obvious need for AuScope, the Earth Sciences and the UNCOVER initiative benefit enormously through integrated access to Characterisation, Fabrication, IMOS and all of the underpinning the capability in eResearch, data management and high-performance computing.

Such a system can only be considered successful as a national research infrastructure if it underpins and facilitates a nimble and agile national research capability that is able to address the changes, demands, and challenges that the future will present and if it is able to support those research challenges regardless of whether they present through the University, government agency, military, or industry research communities.

The NCRIS model has had an enormously beneficial impact upon Australia's national research capability. However, it suffered from operating within a strategy void and, even though the funding through EIF and Super Science was critical for its survival, several important aspects of the NCRIS model were diluted in those funding schemes because of their origins. NCRIS (and, therefore, the national research infrastructure system itself) was damaged through recent uncertainty of funding.

The NCRIS model has also suffered because of the absence of a strong committee to provide ongoing advice to government, overarching strategy to the program, consolidated feedback to educational and training institutions, maintenance of appropriate balance of assigned priorities, and coherent system-based decisions about issues such as decommissioning.

Consideration should therefore be given to the creation of a National Research Infrastructure Council (NRIC), just as there is the ARC and the NHMRC, with oversight from a strongly constituted committee. NRIC should not be a part of either the ARC or the NHMRC because both of those are funding bodies based on competition whereas NRIC should be a non-funding body oversighting a system based on collaboration. However, as with the NCRIS committee, both ARC and NHMRC.

Submission Template
2016 National Research Infrastructure Roadmap
Capability Issues Paper

Name	**Professor Sue O'Reilly & Dr Tim Rawling**
Title/role	**Chair**
Organisation	**National Committee for Earth Sciences**
Preferred contact phone number	**+61 2 9850 8362**
Preferred email	**sue.oreilly@mq.edu.au**
Would you like your submission to remain confidential, i.e. not published on the website?	**NO**

Questions

Question 1: Are there other capability areas that should be considered?

Whist the Geosciences and Solid Earth Science are considered in the document they are only included in the Environment and Resource Management section. This approach undervalues the research impact that geosciences have internationally as well as the importance of the resources and energy industry to the Australian economy.

The inclusion of a capability area that focuses on the Solid Earth from a Crustal Services perspective (nascent energy systems, subsurface waste and energy storage, groundwater, mineral resources, crustal stability) would serve a significant portion of the research community's needs, have strong support from Government (State and Federal Geological Surveys, Surveyors General Departments, Primary Industries etc), as well as industry research users. It would also better align with the Federal Government's stated Science and Research Priorities, which contain both Energy and Resources as separate priority areas.

The geosciences are an integrative science, which through geophysics, geochemistry, geodesy and observational geology provide a connection between the traditional STEM sciences and the Environment and Resource Management sectors. Whist it is appropriate to consider part of the solid earth geoscience in the Environment and Resource Management capability area, the grouping does not capture the full scope of the pure or applied research being undertaken in the field. Consideration of major aspects of the geosciences in the context of the Physics/Maths/Chemistry group as well would be more appropriate. It is pertinent to note that the Australian Academy of Sciences formally endorses the inclusion of Earth Sciences as an integral part of the Advanced Physical Sciences (along with Physics and Chemistry.

The mineral exploration industry, government geological survey organisations and academia have recently collaborated to develop the UNCOVER research initiative. This

collaboration is likely to produce a decade-long research program funded from a variety of sources that will have significant research infrastructure requirements ranging from drill-hole access, development and deployment of new monitoring and imaging sensors, national-scale data acquisition collation and delivery programs, specialised data modelling, analytics, discover and machine learning algorithm development.

Additionally, as a minimum, energy should be specifically identified along with environment or else have its own specific capability category.

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure.

In our experience the establishment of a not-for profit company with an independent board specifically to invest in, develop and manage that facility or capability provides optimal governance of national research infrastructure facilities. The organisation must have the support of the research community that it represents and must engage widely and have open and transparent management processes in place. This allows for independence from institutional politics, allows for the development of truly national infrastructure and facilitates strategic decision making for the benefit of the entire community.

The formation of industry and/or science advisory panels, to provide advice to the CEO or to the Board, can greatly enhance community engagement and be valuable in making specific investment decisions where specific sectorial knowledge is critical.

Independent access committees should be put in place to assess meritorious access for use of the infrastructure or facilities.

Whist the above model has served the Earth and Geospatial community well, through the development of AuScope Ltd over the last 10 years, there should be recognition that all facilities and capabilities are likely to be very different and so flexibility in the governance structures is important.

Successful governance of National Research Infrastructure Capabilities depends on the ability of the boards to develop medium to long-term strategic plans for the organisations. This requires sufficiently secure and long-term funding cycles to be secured and should require the development by the capabilities of 5 and 10 year science and investment strategies that align with the broader government, academic and industry research agenda's.

Question 3: Should national research infrastructure investment assist with access to international facilities?

Where the case cannot be made for the development of an Australian infrastructure capacity, but there are international facilities that can be accessed then it is appropriate and prudent to fund access to the with research infrastructure funds.

Examples may include the International Ocean Drilling Program (IODP) membership or access to facilities such as CERN and international synchrotron facilities.

National infrastructure research investment should not be used to fund research on, or in collaboration with, these facilities but rather to provide access to them through program membership. These memberships should only be purchased with national infrastructure

research investment funding where that membership is in the national interest and there are barriers to Australian researcher access to those facilities without it.

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

It is appropriate to consider access to international facilities where overall impact for Australian science does not justify the effort and investment of developing the capability here due either to the cost, scale or broad community need.

Question 5: Should research workforce skills be considered a research infrastructure issue?

Operational workforce *should* definitely be considered a research infrastructure issue but the funding of research-based staff and the undertaking of research utilising that infrastructure should not.

A skilled operational workforce is critical to ensuring that the infrastructure investment serves the research community effectively and provides the best long-term impact for the investment. This workforce can also facilitate the development of Significant National Datasets utilising the infrastructure when not undertaking specific research programs.

Funding researchers and research through infrastructure schemes such as NCRIS is not appropriate as it will reduce the ability of those schemes to fund the research infrastructure requirements of the entire national research community, it will complicate the relationship between NCRIS and research funding sources such as ARC and NHMRC and will run the risk on focussing on funding expensive research projects rather than the development of research infrastructure capability that serves the wider Australian research community.

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

National research infrastructure should broadly follow existing NCRIS guidelines - access for little or no cost to Australian researchers, data made widely and freely available as soon as possible after collection, industry access with some cost recovery to support the infrastructure but with guidelines in place to ensure that research facility operation complies with competitive neutrality principles in relation to Australian commercial research or analysis providers.

Question 9: What should the criteria and funding arrangements for defunding or decommissioning look like?

The capability should be able to demonstrate broad research community support and ongoing usage for continued support. Where it is clear that: (a) there is no longer a use-case or community need for the capability, (b) new developments, technologies or practices have made the capability unviable and there is no clear path to return the capability to a position of effectiveness, or (c) where the capability has had poor governance and is functioning poorly as a result it may be appropriate to defund that capability.

Potential defunding decisions should involve research community consultation to ensure that this really is the best approach for that group.

In these circumstances it is critical that the de-funding is managed appropriately between the department and the capability and that decommissioning plans are put in place to transition skilled staff into other positions over reasonable timeframes.

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

There is clear evidence from many studies around the world that long-term, strategic funding provides far greater "bang-for-buck" than short-term *ad hoc* funding. The Australian government has often said that it wants science to help drive forward the Australian economy. This can only happen by choosing to transform science into a genuine national capability, as has happened in the United States of America. This means that science needs to be funded as a genuine national strategic capability and then used as a national strategic capability.

The Australian Government needs to change its perception of science from a "cost" to an investment in the nation. This will require the rather difficult cultural change to the point where the Australian Government is willing to articulate a genuine science strategy, clearly articulate its priorities as to the areas where science can constitute genuine underpinning infrastructure for national development, allow the scientific community to develop genuinely effective responses with longer-term funding, and then respect and value the impact that the science has.

Question 11: When should capabilities be expected to address standard and accreditation requirements?

Where a topic is being pursued in close collaboration with industry, it is likely industry standards have to be adhered to. Where a baseline study relating for example to an environmental issue is being undertaken, which could have a significance decades ahead, then standards and perhaps accreditation must be adhered to.

Environment and Natural Resource Management

Question 18: Are the identified emerging directions and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed?

The link between understanding the solid earth (geosphere) and its relationships to the hydrosphere/biosphere/atmosphere will be critical to research and application in this space over the next decade - this link is not adequately identified in the current document.

Utilising a Crustal Services approach to our consideration of "Resources" provides a pathway to strengthen this link. What services does the Earth's crust provide to us and what science needs to be undertaken and what research infrastructure needs to be in place to allow us to utilise these services to benefit Australian society?

In order to facilitate this type of research, on the scale of the Australian Continent, an integrated network of geophysical and remote sensors and geochemical sampling and analysis is required. This deployment would build on existing AuScope infrastructure and Geoscience Australia data acquisition programs and will create a geological telescope, that looks into the Earth not away from it. The Earth Science *Million Square Kilometre Array* if you like! This very large research infrastructure investment will support research from

applied mineral discovery, to new energy systems as well as the underlying fundamental research that facilitates our understanding of how the earth works and how it supports life and society.

A series of key science questions, developed in consultation with and seen as critical to the earth and geospatial science community over the next decade, are articulated in more detail in the AuScope Australian Earth Observing System strategic overview document which is available for download from http://www.auscope.org.au/future-directions/

A significant national consultation campaign on behalf of the UNCOVER Research Initiative has clearly stated to need for collaborative industry-academic research programs to better understand the covered regions of the Australian. The case for these programs and some consideration to supporting infrastructure requirements is outlined in the UNCOVER Roadmap. http://www.uncoverminerals.org.au/documents/amira-uncover-roadmap

Question 19: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

- EarthCube and its European equivalents - data and data delivery
- USArray and IRIS – Geophysics and earth observation
- International Ocean Drilling Program
- International Synchrotron facilities (USA, Japan, Europe)

Question 20: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Environment and Natural Resource Management capability area?

Australia needs to develop an integrated distributed network of geophysical and remote sensor deployments and geochemical sampling and analysis that will form a geological telescope - looking inward not outward - supporting research from applied mineral discovery (UNCOVER) to new energy systems (unconventional gas, waste storage and geothermal – extending the AusDEEP concept regionally). Nationally and internationally significant open file datasets produced by these deployments will provide the currently missing links between solid earth geophysics and geoscience, geodesy and geospatial analysis of the earths response to natural and human activity, mineral and energy system science, groundwater mapping and modelling and links to agricultural, biological, ocean and climate science research and monitoring systems.

This multi-sensor network - analogous to, but more ambitious than the USAarray, will provide time series data that will facilitate research enterprise ranging from the analysis of the evolution of our planet and continent, to the development of our energy and mineral deposits, groundwater systems and soils. It will facilitate integrative science that will have direct impact within government and industry and will provide datasets that will underpin informed policy development by allowing monitoring of human impacts on the earth and its systems.

These datasets, and related simulation models utilising existing and new technologies that consume the data, provide 3D and 4D models of the Australian crust and facilitate prediction of natural and human induced changes on a variety of temporal and length scales.

Understanding the Earth's crust (the source of all resources for "civilisation" from water to energy to metal supplies) requires that the deeper Earth is also well characterised. This

requires new-generation geophysical and geochemical datasets probing as deeply as possible and extending current knowledge of the lithosphere (the outer Earth's layer to about 200km beneath the surface) as far as possible to the Earth's core at about 3,000km. The heat energy and the movement and composition of the fluids in this deep Earth control the location of surface geological hazards (tsunamis, earthquakes, volcanoes), as well as being the ultimate source of the crust's resources. Again, this reflects the *inner telescope* investigation of Earth's unknown depths introduced above.

Advanced Physics, Chemistry, Mathematics and Materials

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

Many of the current research issues facing the earth and geospatial communities are more strongly aligned with those proposed in the Advanced Physics, Chemistry, Mathematics and Materials sections.

In particular:

(1) Issues relating to the modelling of crustal and mantle evolution, plate tectonics and the physics and chemistry of the solid earth – essentially computationally intensive fluid dynamics and physics modelling
(2) The development of new geophysical imaging tools and related and analytics and in particular advanced inversion codes ,
(3) Applications of Synchrotron science to imaging and characterisation of geological materials and related applied processing research,
(4) Precision measurement at varied length scales related to geodetic earth measurement,
(5) High throughput geochemistry laboratory developments which are currently revolutionising geochronology science and mineral exploration processes in Australia,
(6) The development of new sensor technologies for geological mapping and monitoring utilising new deployment technologies such as UAV systems and/or aligned to any new space science programs in this country.

National Security

Question 27: Are the identified emerging directions and research infrastructure capabilities for National Security right? Are there any missing or additional needed?

There is no consideration given in the National Security capability section to either energy security or natural resource security. Australia is particularly vulnerable to threats to gas and electricity supply. Concentration of power generation infrastructure in regions of significant seismic hazard (such as the Gippsland Basin) put continuity of supply at significant risk in the event of a moderate to large earthquake.

Better understanding of crustal stability (and the related mantle state) as well as more research into nascent energy technologies is required to address these issues. Of particular importance is additional capability designed to understand the impact of human activity on the state of the Earths crust. The development of unconventional energy systems and the subsurface storage of waste materials have the potential to trigger significant earthquakes. Significant new deployments of earth monitoring systems across sedimentary basins will facilitate research into human impacts the state of the crust, the impacts on basin contained

resource systems (including groundwater) as well as more fundamental research into the formation of the Australian Plate and its surrounding ocean basins.

Underpinning Research Infrastructure

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

The emerging underpinning research infrastructure directions are generally good. Of particular relevance to the Geosciences are the requirements for, (1) high performance computing, high capacity networks and secure fast storage, (2) increased capacity and precision in the geospatial and earth monitoring space, and (3) digitisation of data to support national scale research programs that rely heavily on historical data, such as the Uncover initiative, will be critical.