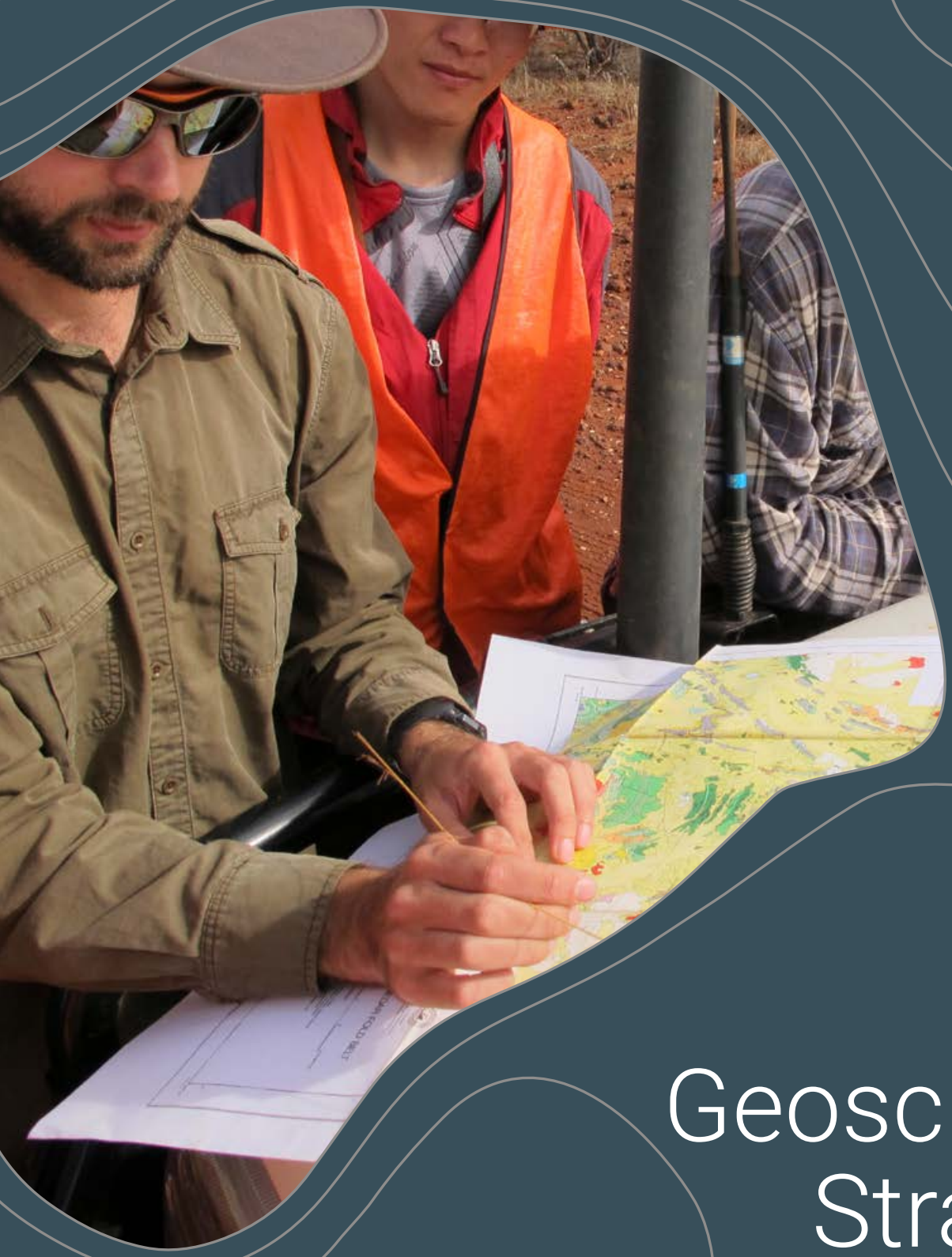
Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

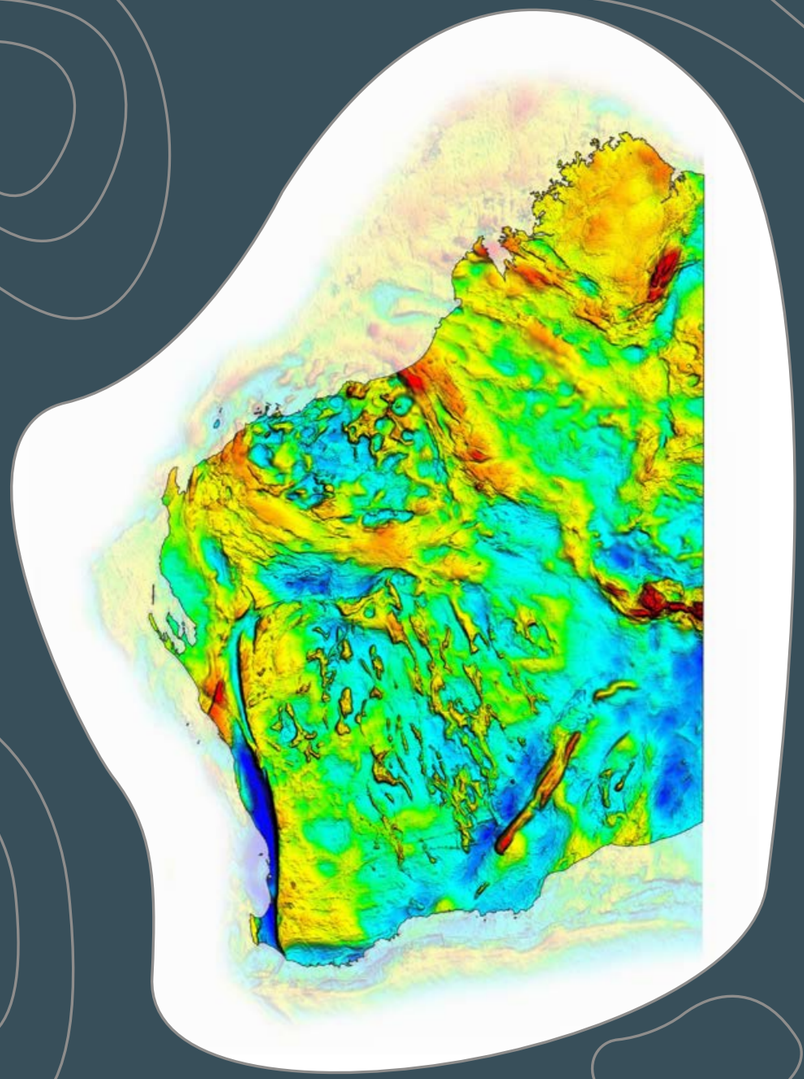


Geoscience Strategy

May 2022

Mission and vision

The Geological Survey of Western Australia (GSWA) is a progressive, world-leading geoscience organisation that unravels the complex geology of Western Australia and its relation to Earth resources. We attract, develop and retain highly skilled scientists and technicians to develop and apply state of the art acquisition, analysis, and interpretation techniques to gather geoscience data and derive from these relevant information and knowledge products. We deliver data, information and knowledge products to stimulate the mineral and energy resources industry to the benefit of the Western Australian community and economy, and to sustain technology-supported human development globally. Our experience and knowledge enables us to inform government, the scientific community and the public on all matters related to Solid Earth science in Western Australia.



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Terms of reference

The Geoscience Strategy aims at providing a guiding framework that covers geoscientific activities within GSWA. Geoscientific activity for this purpose is defined as the rigorous acquisition and verification of knowledge of the Earth system through observation, analysis and hypothesis testing. The Geoscience Strategy does not cover all activities within the GSWA, but is intended to complement the Stakeholder Engagement, Data Transformation and the overarching GSWA 'Unearthing Western Australia' Strategy documents[1].

Background: the world around us

Global alignment

Environmental, societal and governance issues including geopolitical developments have significant bearing on the global demand for energy and raw materials. While political and economic consequences of armed conflicts are uncertain and could continue to disrupt the mineral and energy sectors, climate change mitigation is certain to remain a significant factor in the long term.

The urgency to mitigate climate change is influencing the resources industry's choice of commodities on which to focus exploration, production and processing activities. A significant net reduction in global greenhouse gas emissions is now a priority for society and for the resources industry. For a clean energy economy that meets the 2050 net zero carbon dioxide emission target the use of renewable energy sources such as solar and wind, and the availability of low-carbon hydrogen as fuel, energy storage and a processing agent is pivotal[2,3]. Hydrogen can be produced from natural sources, by conversion from electrical energy through electrolysis, or as a by-product of petroleum production and processing, and it can be stored in geological reservoirs. In addition to a shift to hydrogen, carbon capture, usage and storage, as well as intermediate replacement of coal with natural gas are needed to facilitate the transition to a low-carbon economy.

The transition to a clean-energy economy is already influencing the mineral sector, as a much larger capacity is required to generate, store and transport electrical energy. This requirement already has increased the demand for 'battery metals' and other critical minerals that are fundamental to sustain technology-supported human development. Examples are copper, lithium, nickel and cobalt, all of which need to be produced in much larger quantities to sustain a global energy transition but may include other metals in the future. Although Western Australia is presently already a significant producer of lithium, nickel, cobalt and many other critical minerals, there is a need and the potential for more discoveries in our State.

National alignment

GSWA activities are informed by the vision, priorities and recommendations of the Australian Academy of Sciences (AAS), the Australian Government Department of Innovation and Science (DIIS), Amira Global, Geoscience Australia, the Department of Industry, and the Western Australian Department of Jobs, Tourism, Science and Innovation (JTSI).

The 2018 AAS decadal plan for Australian Geoscience[4] considered scientific excellence within a collaborative, interdisciplinary geoscience community to be a requirement to responsibly manage Australia's resources, drive future prosperity and enable a sustainable, renewable-energy future. To better understand Earth's complexity and develop a predictive framework, it was recommended to deepen the understanding of Earth processes, to develop and apply transformational imaging, and analytical, computational, and communication resources.

The 2019 COAG hydrogen strategy[5] is aimed at making hydrogen Australia's next energy export, integrating low-cost renewable hydrogen generation, reducing dependence on imported fuels, and reducing domestic and global carbon emissions. The Western Australian Renewable Hydrogen Strategy[6] aims at establishing our State as a leading participant in a global hydrogen market by developing production capabilities and applications for renewable hydrogen.

The Amira Uncover Roadmap[7], a mineral industry-centred strategy document, in 2017 defined overcoming the 'cover challenge' to be of highest strategic importance. A key recommendation was a focus on characterising cover and major mineral systems including their footprint, with the aim to better understand different deposit types and commodities across scales. To achieve this, 'better science, new knowledge, higher quality data, new technology and tools, increased collaboration, and improved integration' were considered transformational requirements.

A mineral systems-based understanding of critical mineral potential was also recommended by Geoscience Australia's 2019 Critical Minerals review[8], with the aim to position the Australian resources industry to lead the world in critical mineral exploration. According to the 2022 Critical Minerals Strategy[9], expanding the geological knowledge and research base enables the maximisation of production and supply chain opportunities in the critical minerals sector.

The Resources 2030 Task Force[10] recommended that the mining, oil and gas, and resources equipment, technology and services sectors prioritise research on geoscience, exploration, environmental management, innovation and technology, and critical minerals.

Strategic relevance for GSWA activities

There is a growing recognition that Earth processes including how, when and where mineral and energy resources have formed cannot be understood by a focus on exposed rocks alone, but requires mapping of the entire lithosphere through integration of geophysical and geochemical techniques. The 2012–2021 Australian Research Council Centre of Excellence for Core to Crust Fluid systems (CCFS), of which GSWA has been a participant, has demonstrated how innovative collaborative research in an integrated geoscience environment can build capacity and capability on a level of national and international significance[11]. One example of the major CCFS outcomes relevant to this Strategy has been the collaboration between Macquarie University, The University of Western Australia and GSWA to develop and foster passive source seismic imaging capabilities in Western Australia.

While GSWA needs to continue to generate knowledge of Western Australia's basin and bedrock geology, it is essential to better characterise regolith cover, to image and map Earth's lithospheric mantle and to integrate these with our knowledge and understanding of crustal processes. Progressing the understanding of Earth's complexity requires a substantial advance in imaging and computing capabilities and in our knowledge of Earth processes, including the ability to become more predictive in mineral and energy exploration.

Also required are advances in characterising and understanding the potential of Western Australian geology to yield the energy and mineral resources necessary for the transformation of the energy and technology sectors, and provide reservoirs for the storage of new energy sources such as hydrogen or wastes such as greenhouse gases. Although recent geopolitical shifts and the continuing use of natural gas and oil during the energy transition are likely to keep demand at substantial levels in the coming decade, exploration activities may play a lesser role.

Garnering geological knowledge and having impact

The role of GSWA is to provide objective and authoritative geoscientific data, information and knowledge that provide a basis for decisions on all matters concerning the Solid Earth, including the responsible use of the Western Australia's natural resources[1]. To fulfil our role we carry out three scientific action streams (Figure 1):

- Acquisition of geoscientific data;
- Generation of geoscientific information and knowledge; and
- Delivery of data, information, and knowledge.

The application of rigorous, evidence-based scientific procedures and practices is essential for generating information and knowledge from data, and also play an important role in data acquisition. An important aspect of working effectively and efficiently with data, knowledge, and information is adequate data management. Data management is addressed in the GSWA Data Transformation Strategy[12].

Geoscience data acquisition

The range of data GSWA acquires includes geological observations, geophysical measurements, geochemical analyses including radiogenic and stable isotopes, and mineralogical spectra. Geoscience data are acquired in different ways, including targeted acquisition by our technically and scientifically trained staff, via research collaborations or commercial contracts, and from statutory reporting of exploration, mining and petroleum production activities. Data acquisition may include further processing guided by organisational knowledge.

Generating information and knowledge from geoscientific data

Geoscience data become information when datasets are given context and relevance, for example by providing a spatial, temporal or thematic framework. Information becomes knowledge when it is processed intellectually by applying scientific analysis, interpretation and synthesis by experienced and technically skilled geoscientists.

GSWA's organisational knowledge is retained in its people, databases, and on media products such as maps, publications and digital data packages. Management of organisational knowledge encompasses the growth of knowledge through experience and learning, the transfer of personal knowledge through internal communication, and its conversion into deliverable products. The growth of organisational knowledge leads to 'wisdom' around decision-making within GSWA — for example in Land Use Planning — and in relation to external stakeholders.

Where historically humans have been the sole clients of information and knowledge, the current data analytics ecosystem requires a fundamental shift towards the delivery of machine-readable data, information and knowledge.

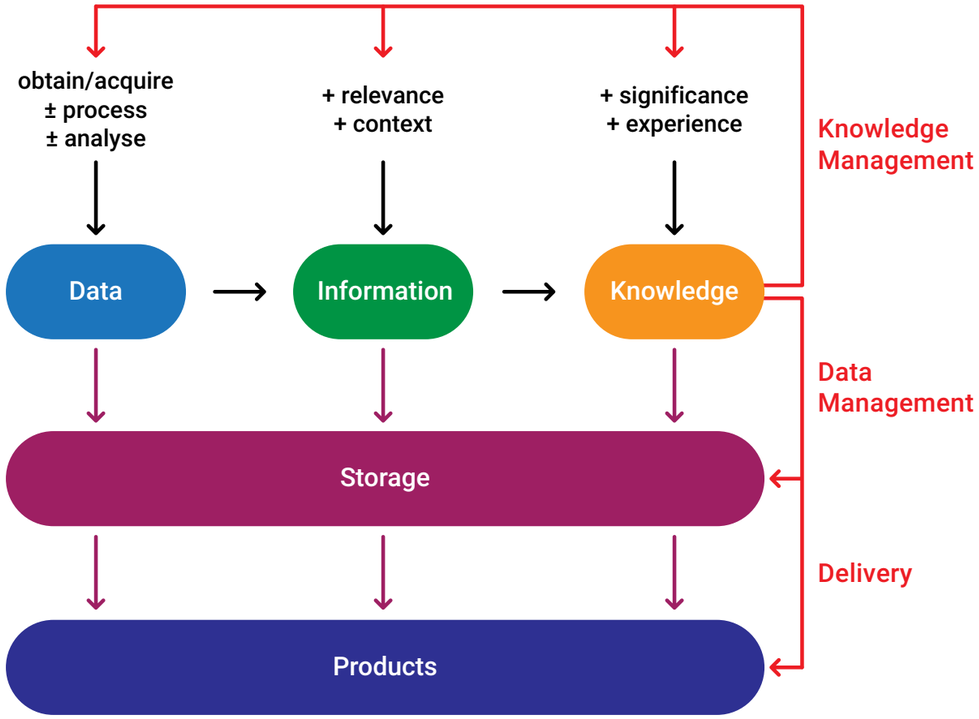


Figure 1: A fundamental enabling factor of knowledge management, evidence-based science underpins the acquisition of data and their transformation to information and knowledge.

Making a difference: from input to impact

Science enables the GSWA to produce and deliver data, information and knowledge that are valuable to our stakeholders. GSWA plans its scientific program by considering and evaluating the level of investment in specific activities against expected outcomes and impact (Figure 2)[13, 14].

For instance, focusing activities in a specific region of Western Australia might deliver a suite of maps, datasets and publications. These outputs can materially influence resource exploration companies to acquire more tenure in that region, hence direct more exploration expenditure to the State that in the longer term may lead to the discovery of a mineral or energy resource that will generate revenue for Western Australia.

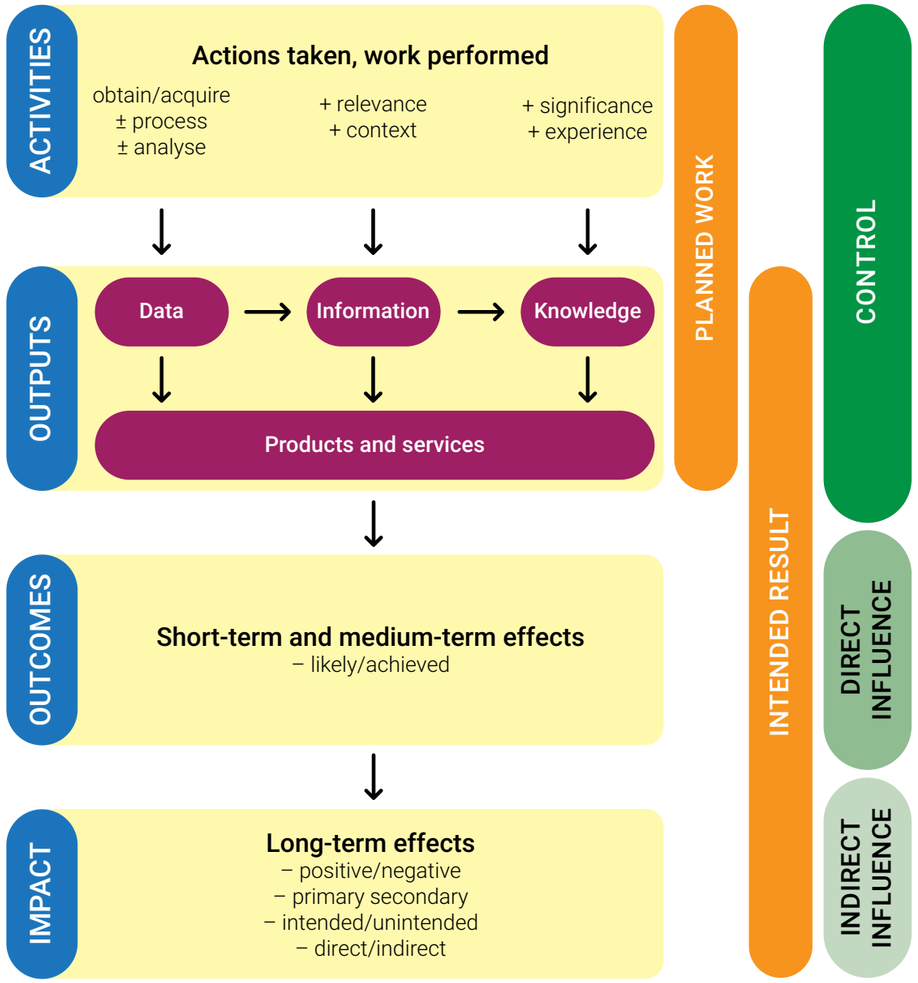


Figure 2: Knowledge generation as output in the context of GSWA's impact and influence.

Strategic relevance for scientific activities at GSWA

The scientific contribution to GSWA activities is through providing context and relevance in order to acquire meaningful geoscience datasets and turn them into valuable information and knowledge.

Only a high level of organisational knowledge — which in the future may need to become encoded and machine readable — enables GSWA to provide trusted advice to our stakeholders including government, industry, scientists, and the wider community.

Activities, products and services need to be planned keeping in mind how our scientific outputs can generate outcomes and impact.

Enabling steps: applying an integrated geoscience framework

Human development is closely tied to the exploration, production and refinement of raw materials and energy resources. While the range of raw materials has expanded immensely over the last centuries, our knowledge of the Earth has evolved. From a paleolithic level of knowledge and understanding Earth materials we progressed via the enlightenment level of description and understanding spatial and temporal dimensions in rocks, and have arrived at quantitative geoscience disciplines that take into account the physics of coupled dynamic processes. Understanding Earth's complexity and becoming predictive, no matter if Earth's crust, mantle, or regolith cover are concerned, requires a step change from fundamental geoscience activities of mapping, analysing and documenting rocks, minerals, structures and landscapes.

The need for prediction in geological engineering and in mineral and energy exploration has led to the development of system-based approaches. Petroleum Systems and Mineral Systems approaches are unifying cross-discipline concepts that encompass the disparate processes and elements relating to the formation of economically viable resources. The success of these unifying concepts highlights the limitations of thinking and acting within organically grown geoscience disciplines such as geology, geophysics and geochemistry while demonstrating the potential of an integrated geoscience approach. Ore deposits and energy resources, however rare and hard to find they may be, have formed as part of a dynamic Earth system. It is therefore essential to understand the geology of Western Australia and its resources from an integrated systems approach.

A simplified approach that illustrates the complexity of the unique, complex nature of the Earth system is the interaction between Earth materials, spatial and temporal dimensions and physical processes (Figure 3). An integrated systems approach can also be used to identify gaps in the characterisation of a geoscience problem, because analysing material, dimension or process components in isolation will leave significant gaps in understanding. GSWA's activities and capabilities can be mapped against this Earth system perspective, and its knowledge management needs to facilitate system analysis workflows.

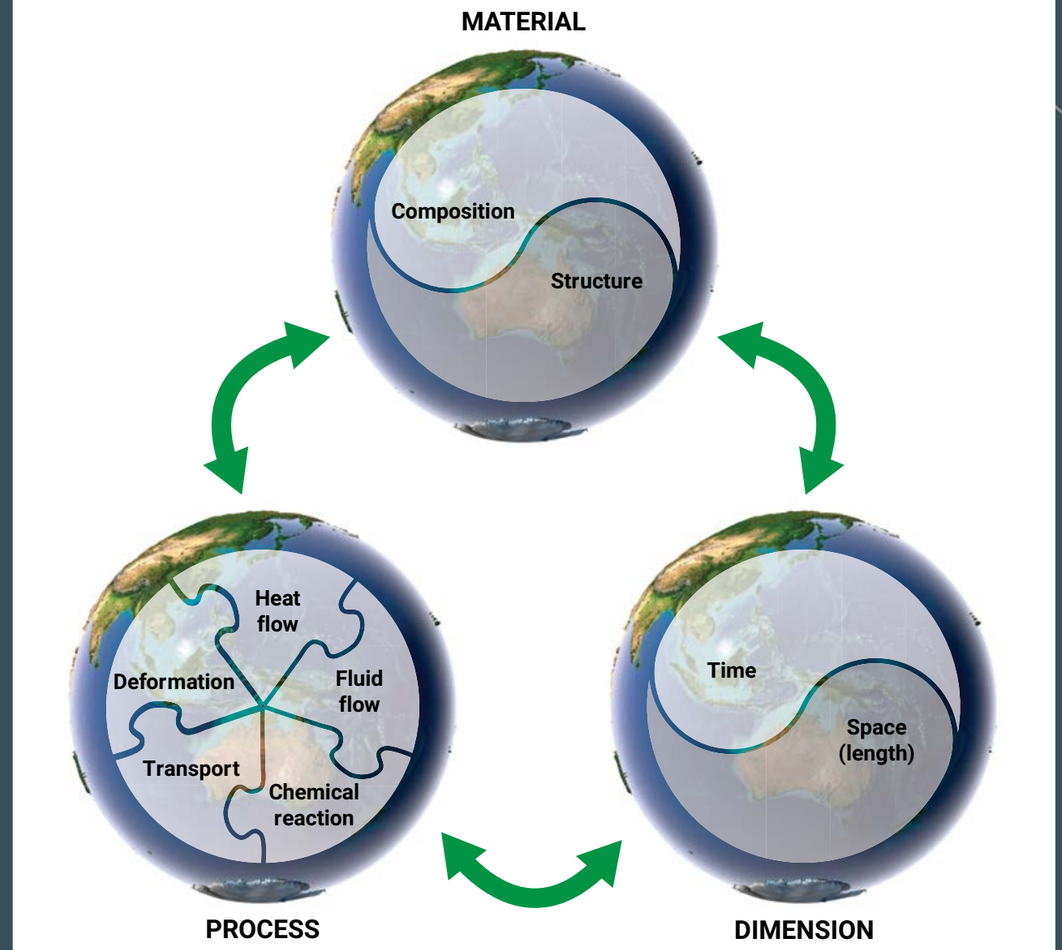
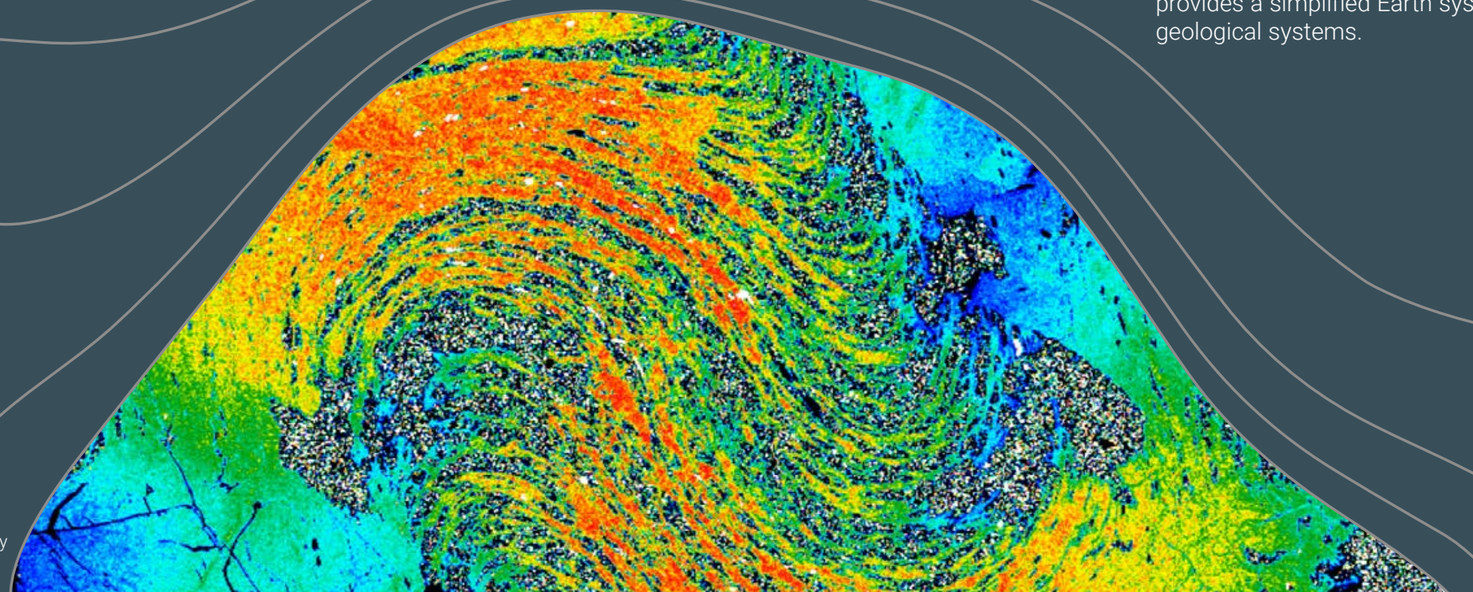


Figure 3: The interaction of materials with physical processes in dimensions of space and time provides a simplified Earth systems perspective on the high level of complexity that is typical for geological systems.



Activity streams

GSWA's geoscience activities are grouped into three streams, (i) Understanding and promoting the geology of Western Australia, (ii) Western Australia's Earth resource potential, and (iii) knowledge management and integration. These three streams can have region- or commodity specific priorities. The components listed in these streams rely on enabling techniques and methodologies that are performed in-house, through external collaboration with research providers, or procured as services. The priority enabling techniques and how these relate to in-house versus external capacity and capabilities is discussed in the following chapter: Enabling steps: building capacity, capability and collaboration.

Stream 1: Understanding and promoting the geology of Western Australia

With **input** including industry reports, geological mapping, drillcore logging, geophysical, geochemical and geochronological data acquisition (internal and external) and integrated imaging, analysis, modelling and interpretation, this activity stream produces **output** that include maps, explanatory notes, publications, datasets and digital information packages. The desired **outcome** is an improved knowledge base, both internal to GSWA and for our stakeholders, of understanding Earth's crust and lithosphere and its evolution across the State. Long-term **impacts** are economic benefits to the State through investment in resource exploration, mining, processing and manufacturing, by improved management of competing land use, and of risks related to seismicity and to geomagnetic storms. This stream comprises more detailed levels of specific tasks.

- **Thermal, mechanical and chemical evolution of crustal and mantle components and their boundaries** encompasses geological mapping, geochemical sampling, the application of structural and metamorphic geology techniques, and geochemical and isotopic characterisation of crust and mantle rocks.

Thermal, mechanical and chemical evolution of crustal and mantle components and their boundaries	Priority	Timeframe
Expanding coverage and improving quality of interpreted bedrock geology and surface geology maps to link knowledge of surface and depth through structural analysis	High	Ongoing
Populating Explanatory Notes System	High	Ongoing
Statewide geochemical and isotopic mapping of crustal and mantle sources (incl. novel isotopes Ti, Si, Cu, Mo, Pb, W, Fe, Mn, O); integration with geophysical data	High	Ongoing
Temporal evolution	High	Ongoing
Metamorphic evolution	High	Ongoing
Crustal fluid evolution	High	Ongoing
Structural evolution, ancient seismogenic zones	High	Ongoing
Recent seismicity and geohazards	High	Ongoing
Thermal history (1D, 2D thermal modelling)	High	Ongoing
Acquisition of basinal and bedrock heat flow data	Medium	10 years

- **Imaging lithospheric building blocks and crustal architecture** comprises geophysical acquisition, analysis and interpretation across a number of spatial scales.

Imaging lithospheric building blocks and crustal architecture	Priority	Timeframe
Acquisition of 'deep' geophysics (passive seismic, MT, e.g. WA-Array, AusArray and AusLAMP) as standalone surveys or in conjunction with 'shallow' geophysical surveys (e.g. combining LP-MT with A-MT)	High	10 years
Systematic statewide analysis of existing thermal data to constrain crustal heat flow	Medium	10 years
Acquisition of 'intermediate depth' geophysics (deep reflection seismic, passive seismic, MT)	High	10 years
Acquisition of gravity data	Low	5+ years
Acquisition of magnetic data	Low	5+ years
Acquisition of rock petrophysical data	High	5+ years
Interpretation and integration of Geophysical data (part knowledge integration, part 3D, part modelling and integration with petrophysics)	High	Ongoing
Regional 3D modelling	High	Ongoing
Geophysical inversion modelling (geophysical software)	High	Ongoing
Geological modelling and stochastic uncertainty analyses (3D visualisation software)	High	Ongoing
Acquisition of basinal and bedrock heat flow data	Medium	10 years

- **Basin evolution** uses geological and geophysical methods to constrain structure, stratigraphy and spatial and temporal evolution of Western Australia's sedimentary basins.

Basin evolution	Priority	Timeframe
Basin litho/sequence stratigraphy	High	Ongoing
Biostratigraphic dating, paleoenvironmental interpretation (palynology, conodonts, other microfossils, macrofossils, stromatolites etc.)	High	Ongoing
Radiometric dating including isotopic, geochemical and mineralogical characterisation of sediments and their sources	High	Ongoing
Chemostratigraphy (stable isotopes, trace element and multi-element analysis)	Medium	Ongoing
Field mapping	High	Ongoing
Stratigraphic drilling	Medium	Ongoing
Petroleum and thermal systems modelling (organic geochemistry, burial and structural history, thermal history)	High	Ongoing
Structural mapping and seismic interpretation	High	Ongoing
Basin 3D modelling from geophysics/well data (e.g. SEEBASE)	High	Ongoing
Geological modelling and stochastic uncertainty analyses	High	Ongoing

- **Regolith landform evolution** identifies, maps and interrogates Western Australia's major regolith provinces, maps the depth of regolith interfaces, and provides knowledge and data on regolith and its influence on society.

Regolith landform evolution	Priority	Timeframe
Refine regolith geology mapping for regions of exploration interest	High	5+ years
Regolith 3D modelling for regions of interest	High	Ongoing
Regolith geochemistry program	High	Ongoing
Acquire next-generation spectral imagery mosaics for regolith mapping	Medium	10 years
Calibrate ground spectral response with regolith samples	Medium	5+ years
Dating of regolith events across Western Australia; (U–Th)/He but also luminescence and fission track dating	Medium	5+ years
Targeted geophysical campaigns and integrated depth of regolith studies according to exploration focus areas	High	5+ years
Acquisition of Airborne EM at min 20 km line spacing (AusAEM, maybe 5 km in some areas)	High	3 years
Drillcore mapping of paleo-regolith at sedimentary basin unconformities	Medium	Ongoing
Updated compilation of paleochannel locations (2D and project based 3D)	High	10 years
Paleochannel mapping through time	High	10 years
Interpretation and integration of paleohydrological data with archeological studies for distribution of homo sapiens	Medium	5 years
Regolith aquifer maps	Medium	Ongoing
Indigenous cadetships in regolith geoscience/bi-directional regolith mapping with traditional owner groups	High	5+ years

- **Understanding the role of the biosphere in Earth systems** is concerned with documenting Western Australia's record of emerging biota through time, biostratigraphy, and geoheritage.

Understanding the role of the biosphere in Earth systems	Priority	Timeframe
Catalogue, document and understand the variation of elements of the biosphere with particular emphasis on those that are linked to prospective time intervals and/or events	High	Ongoing
Maintain a fully catalogued, findable and accessible paleontology and palynology collection	High	5 years
Interpretation and integration of paleontological data at the basin scale, resulting in bio and chronostratigraphic charts	Medium	Ongoing
Catalogue, document and understand the variation of species through time and across the State; correlating local records to national and international stratigraphic and biostratigraphic frameworks	High	Ongoing
Develop or contribute to new or revised biostratigraphic schemes (of various ages and groups) relevent to Western Australia	High	Ongoing
Visit, image and assess sites on Geoheritage sites register regularly and maintain information sources	High	Ongoing
Implement or maintain protective procedures and systems in place to protect vulnerable significant sites	Medium	Ongoing
Promote geoheritage as a concept, procedures relating to State geoheritage, and individual sites as appropriate	High	Ongoing
Identification and registration of new sites of State significance	High	Ongoing

Stream 2: Earth resource potential

Earth resource potential garners **input** such as industry reports, geological mapping, drillcore logging, geophysical, geochemical and geochronological data acquisition and integrated imaging, analysis, modelling and interpretation. **Output** includes maps, publications, datasets, digital information packages and content released through bespoke digital platforms such as the Mineral Systems Atlas and Energy Systems Atlas. The **outcomes** aim at providing an improved knowledge base, both internal to GSWA and for external stakeholders, of the potentially accessible resource endowment of the State, including minerals, energy, wastes and reservoirs. An improved and current knowledge base will generate socio-economic **impact** by facilitating decision making in government and industry and the provision of Earth resource information to the wider community. Stream 2 consists of mineral system and petroleum and energy systems components that are further broken down into more detailed levels of specific tasks.

- The **Mineral systems** component of the Earth resource potential stream includes characterisation and classification of mineral deposits, constraining the temporal evolution of mineralising events and mapping distal footprints of mineral systems. Further activities include methods of detection under and predicting the occurrence of mineral deposits based on integrated data analysis.

Mineral systems	Priority	Timeframe
Deposit- to district-scale mineralisation studies (involving mapping, drillcore logging, spectral data, whole-rock geochemistry, geochronology, isotopes, fluid inclusion, and microprobe / TIMA-based mineral chemistry studies); data sourced through acquisition by GSWA and industry reporting	High	Ongoing
Systematic HyLogging of drillcore	High	Ongoing
3D modelling and integration of mineral deposit data	Medium	Ongoing
Mineral Systems Atlas and Guide	High	Ongoing
Mineral deposit registry creation and data entry	Medium	Ongoing
Battery and other critical mineral resource inventories (amounts and deportment in conventional ores, basin brines, mine wastes)	High	Ongoing
Specific integrated mineral deposit studies	High	Ongoing
Statewide dating of mineral systems (e.g. all rare-element pegmatite mineral systems)	Medium	Ongoing
Mapping of geochemical, mineralogical and isotopic gradients associated with ore deposits	High	Ongoing
Detecting the distal footprints of mineral deposits using geophysics, spectral data, geochemical, isotope, and regolith data and models	Medium	Ongoing
Acquisition of 'intermediate depth' geophysics (deep reflection seismic, passive seismic, MT)	High	Ongoing
Acquisition of regional scale gravity data	Low	5+ years
Acquisition of regional scale magnetic data	Low	5+ years
Acquisition of rock petrophysical data	High	Ongoing
Interpretation and integration of geophysical data (part knowledge integration, part 3D, part modelling and integration with petrophysics)	High	Ongoing
Prospectivity analysis (involving GIS-based probability modelling, data integration, text mining of WAMEX reports, machine learning)	Low	5+ years

- The **Petroleum and energy systems** component of the Earth resource potential stream includes reservoir and seal studies, the delineation of the structural framework, the characterisation of hydrocarbon source rocks and the thermal and fluid migration history of Western Australian basins. Seal and reservoir studies encompass geothermal energy, carbon capture and storage and in hydrogen production and storage. The transition to low-carbon energy economy is addressed by work on critical minerals and energy storage.

Petroleum and energy systems	Priority	Timeframe
Routine core (and outcrop) analysis (porosity, permeability, petrography etc.)	High	Ongoing
Hyperspectral data	High	Ongoing
Petrophysical interpretation (existing wireline data)	High	Ongoing
Petrophysical acquisition	Medium	Ongoing
Seal capacity/distribution	Medium	Ongoing
Source (richness, quality, kerogen kinematics)	High	Ongoing
Biomarker analysis	Medium	Ongoing
Source potential for H_2, He and CO_2	High	Ongoing
Coal data	Low	
Maturity analysis	High	Ongoing
Charge and thermal history modelling	High	Ongoing
Fluid inclusion studies	Medium	Ongoing
Formation fluids (salinity, hydrocarbons, other gases)	High	Ongoing
Seismic reprocessing/interpretation (existing data)	High	Ongoing
Seismic acquisition	Medium	Ongoing
Aeromagnetic/radiometric acquisition	Low	Ongoing
Gravity acquisition	Low	Ongoing
GIS-based data compilation and delivery in Energy Systems Atlas	High	Ongoing
Geological resources for greenhouse gas sequestration (bedrock, mine wastes)	High	2 years
Basin temperature gradient	High	Ongoing
Battery and other critical mineral resource inventories (amounts and deportment in conventional ores, basin brines, mine wastes)	High	Ongoing
Water resource inventory for hydrogen production	Medium	1 year
Geological resources for anthropogenic geothermal energy	Medium	2 years
Mine infrastructure inventory for energy storage (pumped hydro)	Medium	1 year
Underground storage potential for CO_2 (permanent), H_2 and CH_4 (temporary)	High	2 years

Stream 3: Knowledge management and integration

Knowledge management and integration predominantly has an operational aspect, which encompasses the optimisation of storing, handling, archiving and delivery of data, information and knowledge. While these activities are addressed by GSWA's Data Transformation Strategy[12], there is a substantial scientific component in prioritising data handling, in encoding geological information and in prospectivity and uncertainty analysis. The implementation of these scientific components are the **input** into knowledge management and integration, whereas the **output** is a prioritised and relevant state of data products that generate **impact** by assisting decision making in government and industry and by providing up-to-date Earth resource information to the community.

- **Knowledge management and integration** encompasses decisions on the availability of physical assets such as rock samples, fossils, and cores, the completion of observational and stratigraphic databases, including from legacy data, the encoding of geological information and knowledge, the integration of spatial and geological history information in a semantic knowledge environment, and the automation of prospectivity analyses and of 3D modelling.

Knowledge management and integration	Priority	Timeframe
Population of GSWA compiled databases of geological observations (WAROX), explanatory notes (ENS), geochemical (WACHEM), petrophysical (NN), geochronological, isotopic and metamorphic (WAGIMS and GIMENS) data	High	Ongoing
Legacy data/knowledge capture	Medium	Ongoing
Derivative products from drillholes database and WAMEX data	Medium	Ongoing
Linking crustal architecture (basement and basins), geological evolution and stratigraphy (ENS) in a machine-readable logic framework (e.g. LOOP3D topology tool, geological event manager)	High	Ongoing

Enabling steps: building capacity, capability and collaboration

Knowing Western Australia inside out requires GSWA to acquire, store and deliver spatial data, information and knowledge on rock composition, structure and stratigraphy. These types of geodata are indispensable assets for managing the natural resources and natural hazard risks of the State and to support government, industry and the scientific community with evidence-based information of the highest quality possible.

Geoscience is a dynamic research field that can have significant and direct economic and scientific impact, including major breakthroughs in:

- geophysical and geochemical detection methods;
- the increasing use of data analysis, in particular artificial-intelligence-based approaches; and
- understanding the formation of mineral and energy resources relative to the evolution of Earth's mantle and crust.

As active members of the dynamic community in Western Australia and globally, GSWA staff have been at the forefront of innovative geoscience. To sustain the corporate knowledge built on evidence-based research, it is essential to retain this standing. GSWA must be in a position to attract, develop and retain geoscientists and technicians that embrace progress and change and can operate at the highest possible level of skill, training and experience. As a competitive and valued employer, GSWA needs to be an attractive workplace with opportunities that allow staff to grow and develop, including:

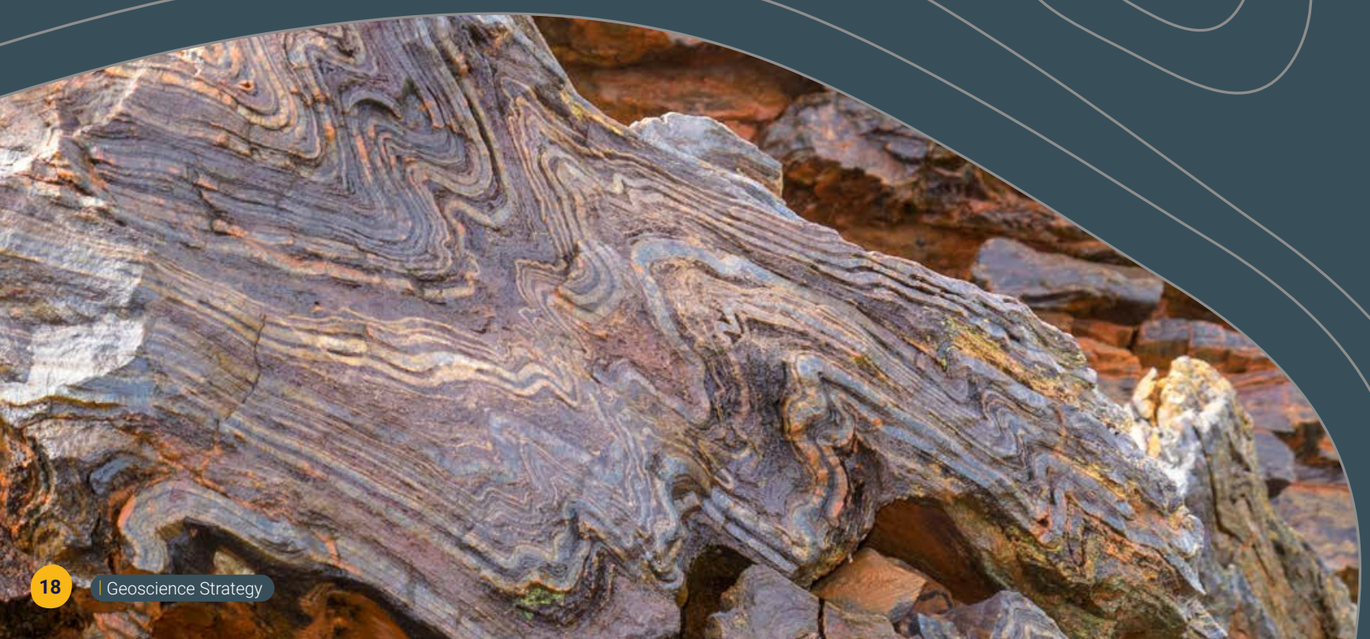
- fair remuneration commensurate with skills and experience, including a promotion pathway; and
- opportunities for staff to develop and progress their professional careers and to establish a reputation as experts.

The increasing specialisation in analysis and detection methods brings with it a need to engage with external providers through scientific collaboration or service provision where GSWA lacks the resources to undertake specific activities. While service provision through government procurement channels is adequate for established acquisition and analysis programs, research collaboration is the preferred vehicle for activities that involve significant GSWA input or that can benefit staff development through knowledge transfer. GSWA scientific capacity and capability, and its collaborations are summarised in the tables below, where colours of fields reflect strategic priority and pictograms represent the current balance between in-house and external work.

Discipline group	Activity	Acquisition	Processing	Provide context	Integrating	Delivery	Priority
		(Data stage)		(Information stage)	(Knowledge stage)		
Geology	Mapping	🏠	🏠	🏠 > 🌍	🏠	🏠	H
	Drilling	🌍	🌍	🏠 > 🌍	🏠 > 🌍	🏠	H
	Outcrop imaging	🏠 > 🌍	🏠	🏠	🏠	🏠	M
	Petrography (microscopic)	🌍 > 🏠	🌍 > 🏠	🏠 + 🌍	🏠 > 🌍	🏠	H

Discipline group	Activity	Acquisition	Processing	Provide context	Integrating	Delivery	Priority
		(Data stage)		(Information stage)	(Knowledge stage)		
Geochemistry and mineralogy	Automated drillcore analysis (HyLogger)	🏠	🏠	🏠 > 🌍	🏠 + 🌍	🌍 > 🏠	H
	Drillcore analysis (pXRF, pXRD)	🏠 + 🌍	🏠 + 🌍	🏠 + 🌍	🏠 + 🌍	🏠 + 🌍	M
	Whole rock major and trace element	🌍	🌍	🏠 > 🌍	🏠 > 🌍	🏠	H
	TIMA	🌍	🏠	🏠	🏠	🏠	H
	RAMAN	🌍	🌍	🏠 + 🌍	🏠	🏠	M
	EPMA	🏠 > 🌍	🏠	🏠	🏠	🏠	H
	SEM	🏠	🏠	🏠	🏠	🏠	H

Development stage
Refining stage (categories/resolution)
Completing coverage
🏠 Work undertaken by GSWA
🌍 Work undertaken by external stakeholders



Discipline group	Activity	Acquisition	Processing	Provide context	Integrating	Delivery	Priority
		(Data stage)		(Information stage)	(Knowledge stage)		
Geochronology and isotope geology	SHRIMP U–Pb zircon and baddeleyite	🏠	🏠	🏠	🏠	🏠	H
	SHRIMP U–Pb monazite	🏠	🏠	🏠	🏠	🏠	H
	LA-ICPMS U–Pb zircon and monazite	🏠 > 🌍	🏠	🏠	🏠	🏠	H
	Re-Os isotope	🌍	🌍	🏠	🏠	🏠	H
	U–Pb and Sm–Nd apatite	🏠 + 🌍	🏠 + 🌍	🏠	🏠	🏠	M
	Ar–Ar (mica, amphibole, kfsp)	🌍	🌍 > 🏠	🏠	🏠	🏠	M
	K–Ar (mica, clay)	🌍	🌍 > 🏠	🏠	🏠	🏠	M
	Rb–Sr (mica)	🌍	🌍 > 🏠	🏠	🏠	🏠	M
	Zircon and whole-rock Lu–Hf isotope	🏠 + 🌍	🏠	🏠	🏠	🏠	H
	Whole-rock Sm–Nd isotope	🏠 + 🌍	🏠 + 🌍	🏠	🏠	🏠	H
	Zircon oxygen isotope	🏠 + 🌍	🏠 + 🌍	🏠	🏠	🏠	H
	S and novel isotopic systems (Ti, Si, Zr, Cu, Fe, Cl)	🌍	🏠 > 🌍	🌍	🌍	🌍	M
	Zircon and apatite thermochronology	🌍	🌍	🏠	🏠	🏠	M
	Optically stimulated luminescence	🌍	🌍	🏠 + 🌍	🏠 + 🌍	🏠 > 🌍	M

Discipline group	Activity	Acquisition	Processing	Provide context	Integrating	Delivery	Priority
		(Data stage)		(Information stage)	(Knowledge stage)		
Paleontology	Palynology	🏠	🌍	🏠 + 🌍	🏠	🏠	H
	Microfossils (including microvertebrates)	🏠	🌍 > 🏠	🏠 + 🌍	🏠 > 🌍	🏠 > 🌍	H
	Stromatolites	🏠	🏠 > 🌍	🏠 > 🌍	🏠 > 🌍	🏠 > 🌍	H
	Macro-invertebrates	🏠	🏠 > 🌍	🏠 > 🌍	🏠 > 🌍	🏠 > 🌍	M
	Imaging and morphometrics	🌍 > 🏠	🏠 + 🌍	🏠	🏠	🏠 > 🌍	M

Development stage
Refining stage (categories/resolution)
Completing coverage
🏠 Work undertaken by GSWA
🌍 Work undertaken by external stakeholders

Discipline group	Activity	Acquisition	Processing	Provide context	Integrating	Delivery	Priority
		(Data stage)		(Information stage)	(Knowledge stage)		
Geophysics	Active seismic	🌍	🌍	🏠 > 🌍	🏠 + 🌍	🌍 > 🏠	H
	Passive seismic	🏠 > 🌍	🏠 + 🌍	🏠 > 🌍	🏠 > 🌍	🌍 > 🏠	H
	Magnetotellurics (MT)	🌍	🌍	🌍 > 🏠	🌍 > 🏠	🏠	M
	Gravity	🌍	🌍	🏠	🏠	🏠	M
	Magnetics	🌍	🌍	🏠	🏠	🏠	M
	Radiometrics	🌍	🌍	🏠	🏠	🏠	M
	Electromagnetics	🌍	🌍	🌍 > 🏠	🌍 > 🏠	🌍 > 🏠	M
	Electrical (resistivity/ IP, etc)	🌍	🌍	🌍	🌍	🏠	H
	Petrophysics bedrock	🌍	🌍	🌍	🌍	🏠	H
	Petrophysics sediments	🌍	🌍	🌍 > 🏠	🏠 + 🌍	🏠	M
	Heatflow	🌍	🌍	🌍	🌍	🏠	M
	Reflectance spectra	🌍	🌍	🌍	🌍	🏠	H
	Environmental geophysics (e.g. GPR)	🌍	🌍	🌍	🌍	🏠	M
	Downhole logging	🌍	🌍	🌍	🌍	🏠	H

Discipline group	Activity	Acquisition	Processing	Provide context	Integrating	Delivery	Priority
		(Data stage)		(Information stage)	(Knowledge stage)		
Computational geoscience	Inversion (2D, 3D)	🌍 > 🏠	🌍 > 🏠	🏠 + 🌍	🏠 + 🌍	🏠 + 🌍	H
	Seismology	🏠 > 🌍	🏠 + 🌍	🏠	🏠	🏠	H
	3D modelling	🏠 > 🌍	🏠	🏠	🏠	🏠	H
	Prospectivity analysis	🌍	🌍	🌍 > 🏠	🌍 > 🏠	🌍	H
	Seismic modelling	🌍 > 🏠	🌍 > 🏠	🏠 + 🌍	🏠 > 🌍	🏠 > 🌍	H
	Multivariate statistics	🌍	🌍	🌍 > 🏠	🌍 > 🏠	🌍 > 🏠	M
	Machine learning/AI	–	–	–	–	–	M

Discipline group	Activity	Acquisition	Processing	Provide context	Integrating	Delivery	Priority
		(Data stage)		(Information stage)	(Knowledge stage)		
Mineral systems	Mineral system studies	🏠 + 🌍	🏠 + 🌍	🏠 + 🌍	🏠 + 🌍	🏠 + 🌍	H
	Mineralisation studies	🏠 + 🌍	🏠 > 🌍	🏠 > 🌍	🏠 > 🌍	🏠 + 🌍	H
	Prospectivity analysis	🌍	🌍 > 🏠	🌍 > 🏠	🌍 > 🏠	🌍 > 🏠	M
	Machine learning/AI	🌍	🌍 > 🏠	🌍 > 🏠	🌍 > 🏠	🌍 > 🏠	M
	GIS data processing	🏠	🏠	🏠	🏠	🏠	H
	3D modelling	–	–	–	–	–	M

Development stage | Refining stage (categories/resolution) | Completing coverage

🏠 Work undertaken by GSWA | 🌍 Work undertaken by external stakeholders

Strategic implications

The list of capabilities has implications for strategic management directions. It can be used to assess, in a dynamic and periodical manner, where gaps exist between priorities on the one hand, and capabilities and capacity on the other hand that can be addressed by staff training and new positions, or by collaboration and contracting.

Decisions whether scientific activities are to be conducted internal or external to GSWA may carry a risk to the business, as critical knowledge and learning may become outsourced. Some areas in which internal capabilities may need to be developed are:

- new energy and critical minerals, including how to transfer skills from traditional energy exploration;
- computational geoscience, including machine-readable data for GIS; data science and process modelling; and
- addressing the change in fieldwork, including the change to regional thematic mapping and sampling and synchronisation with geophysical deployments and drilling.

Recommendations

The understanding of Earth's complexity, including the predictive capability in mineral and energy exploration, requires a substantial advance in imaging and computing capabilities and in earth processes knowledge. While GSWA needs to continue to generate knowledge of Western Australia's basin and bedrock geology, it is essential to advance the characterisation of regolith cover and of the lithospheric mantle beneath Western Australia.

Existing petroleum production can stabilise global energy supply during times of geopolitical uncertainty and transition to a low-carbon economy. Nevertheless, the transformation of the energy sector hinges on the availability of renewable energy, and hydrogen production and storage including CO_2 sequestration. The systematic exploration of sedimentary reservoirs and the exploration for natural hydrogen are essential. Scientific advances in the field of critical mineral are of local and global importance for the battery minerals value chain.

The scientific contribution to GSWA activities is through providing context and relevance in order to acquire meaningful geoscience datasets and turn them into valuable information and knowledge. Activities, products and services need to be planned keeping in mind how scientific outputs can generate outcomes and impact. Only high quality human and machine accessible organisational knowledge will keep GSWA being able to provide trusted advice to stakeholders.

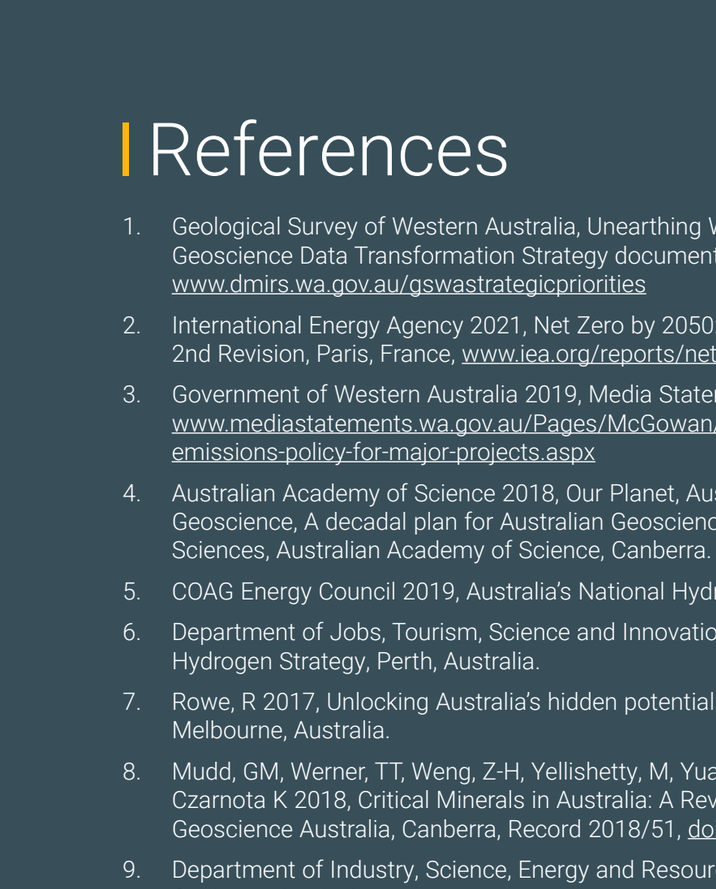
Scientific activities in GSWA need to be planned with a view towards their impact. Understanding and promoting the geology of Western Australia is a fundamental part of an impact chain that generates economic benefits to the State. These include investment in resource exploration, mining, processing and manufacturing, improved management of competing land use, and of risks related to geohazards. An improved and current knowledge base of Western Australia's Earth resource potential generates socio-economic impact by facilitating decision making by internal and external stakeholders. Scientific advances in knowledge management and integration are essential to keep GSWA's activities, products and services current in a changing data and information environment.

The increasing specialisation in analysis and detection methods requires GSWA to engage in scientific collaboration and service provision. Such interactions also provide an opportunity for staff to develop and progress their technical expertise. To sustain its standing GSWA must attract, develop and retain staff that embrace progress and change, and can operate at the highest possible level of skill, training and experience. GSWA needs to be an attractive workplace where staff can grow and develop.

The capability and capacity to carry out geoscience internally versus externally needs to be evaluated periodically to inform strategic management directions to ensure that knowledge and learning critical to GSWA are developed, retained and grown.

References

1. Geological Survey of Western Australia, Unearthing Western Australia Strategy 2030 and Geoscience Data Transformation Strategy documents, on DMIRS website www.dmirs.wa.gov.au/gswastrategicpriorities
2. International Energy Agency 2021, Net Zero by 2050: A roadmap for the global energy sector, 2nd Revision, Paris, France, www.iea.org/reports/net-zero-by-2050
3. Government of Western Australia 2019, Media Statements, 28 August 2019, www.mediastatements.wa.gov.au/Pages/McGowan/2019/08/State-Government-details-emissions-policy-for-major-projects.aspx
4. Australian Academy of Science 2018, Our Planet, Australia's Future, A decade of transition in Geoscience, A decadal plan for Australian Geoscience 2018–27, National Committee for Earth Sciences, Australian Academy of Science, Canberra.
5. COAG Energy Council 2019, Australia's National Hydrogen Strategy, Canberra, Australia.
6. Department of Jobs, Tourism, Science and Innovation 2021, Western Australian Renewable Hydrogen Strategy, Perth, Australia.
7. Rowe, R 2017, Unlocking Australia's hidden potential: An industry roadmap: Amira International, Melbourne, Australia.
8. Mudd, GM, Werner, TT, Weng, Z-H, Yellishetty, M, Yuan, Y, McAlpine, SRB, Skirrow, R and Czarnota K 2018, Critical Minerals in Australia: A Review of Opportunities and Research Needs, Geoscience Australia, Canberra, Record 2018/51, doi:org/10.11636/Record.2018.051
9. Department of Industry, Science, Energy and Resources 2022, 2022 Critical Minerals Strategy, Canberra, Australia.
10. Department of Industry, Innovation and Science 2018, Resources 2030 Taskforce: Australian resources — providing prosperity for future generations, Canberra, Australia.
11. Australian Research Council Centre of Excellence for Core to Crust Fluid Systems, CCFS Annual Report Archive, Macquarie University, Sydney http://ccfs.mq.edu.au/AnnualReport/Index.html
12. Geological Survey of Western Australia 2021, Geoscience Data Transformation Strategy 2021– 2025: Geological Survey of Western Australia.
13. Organisation for Economic Co-operation and Development (OECD) 2010, Glossary of Key Terms in Evaluations and Results Based Management: OECD, 2002 (reprinted in 2010).
14. Commonwealth Scientific and Industrial Research Organisation 2018, How CSIRO ensures it delivers impact, www.csiro.au/-/media/About/Files/Our-impact-framework/How_CSIRO_ensures_it_delivers_impact-PDF.pdf



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