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WA-Array takes off

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Abstract

The Government of Western Australia is funding a passive seismic acquisition program, WA-Array, which has been designed to map Earth's lithosphere at an optimal level of station spacing across the State.

The program, which started on 1 July 2022, will involve the deployment of an 'array' of 165 seismometers arranged in a grid pattern spaced at 40-km intervals. The entire State will be mapped over a period of ten years by relocating the instruments on an annual basis across nine regions.

The results of the program will produce a step change in our understanding of Western Australia's lithospheric architecture. This knowledge will provide a sound scientific basis for mineral and energy exploration, but also for evaluating crucial land use decisions over the coming decades, at a time when large areas of the State are expected to accommodate renewable energy projects, including those required to support a future hydrogen energy industry.

In addition, the data will be used to evaluate the risks from seismic events, which would contribute to risk assessments for the placement of industrial infrastructure such as pipelines and hydrogen generation and storage installations, as well as building codes for housing and other structures.

Keywords: WA-Array, lithospheric structure, land use planning, seismic risk

1 Background

WA-Array is the next statewide geophysical dataset to be acquired by the Geological Survey of Western Australia (GSWA). The WA-Array project will create a step change in our understanding of Western Australia's lithospheric architecture across all scales. This knowledge will provide a sound scientific basis for mineral and energy exploration, but also for evaluating crucial land use decisions over the coming decades, at a time when large areas of the State are expected to accommodate renewable energy projects.

The project is primarily designed to investigate the crustal and lithospheric mantle structure with the aim of identifying prospective regions for mineral exploration, especially in areas undercover, but also to assess the seismic hazard of each region and assist in groundwater studies for agricultural purposes.

Funded by the State Government of Western Australia and run by GSWA, the WA-Array project got underway in mid 2022. The project will deploy a series of temporary arrays of 165 seismometers in a grid pattern at 40-km station spacing. Over a 10-year period, WA-Array will cover the entire State (over 2.5 million square kilometres) and is expected to become one of the largest passive-source seismic programs undertaken in the world. From the Archean nuclei to the Phanerozoic passive margins, Western Australia is composed of many domains with a rich tectonic history; thus, WA-Array will also provide an unprecedented opportunity to study lithospheric structure related to early Earth tectonics, Earth evolution and the Earth today.

In addition, WA-Array data will form a systematic study across the State that contributes to the National Seismic Hazard Assessment of seismic risk for industrial infrastructure such as pipelines and hydrogen generation and storage installations, as well as building codes for residential housing and commercial buildings.

2 Strategic rationale

The global transition to a low-carbon economy will support ongoing high demand for critical minerals to keep pace with investment in renewable energy generation and storage technologies. Over the next decade, installed renewable power will need to triple in capacity, electric vehicle production will need to increase ten-fold, and charging infrastructure will need to grow more than 30 times.

Western Australia's future requires optimal strategic planning which balances the competing land uses needed for the State's transition to a low-carbon economy. Locations for renewable energy projects must be balanced against exploring for and developing future mines.

Western Australia is home to one of the most diverse and successful resource sectors in the world. It is a leading global producer of key industrial commodities such as iron ore and gold, and critical minerals such as lithium, nickel and alumina. However, the declining rate of discovery of major new mineral resources has the potential to impact our ability to keep up with demand. The key to helping exploration companies pinpoint the probable location of new resources is through the application of geoscience technology to image the State's geology to sufficient depth beneath the surface. To do this the WA-Array program is seeking to accelerate the collection and analysis of passive seismic data across Western Australia to find areas of higher prospectivity under deep cover.

3 Theory – Lithospheric architecture

The objective of the WA-Array is to: 1) image the Moho and lithosphere–asthenosphere boundary (LAB) so as to provide a model of the deeper crust and the subcontinental lithospheric mantle (SCLM); 2) identify trans-lithospheric structures; 3) potentially find new corridors for mineral exploration; 4) add to the National Seismic Hazard Assessment.

The mineral systems concept indicates that magma-related ore deposits require two fundamental ingredients: a metal source and a fluid transport system. Subcontinental lithospheric mantle fertilised by, for example, impingement of a mantle plume or by fluids from a subducting slab, serves as the metal source, while trans-lithospheric faults facilitate metalliferous magma ascent and focus for ore deposition. Repeated deformation cycles along craton margins coupled with the 'plumbing' system of abutting lithospheric block boundaries, render craton margins a locus of magmatic ore deposition (Wyborn et al., 1994; Kerrich et al., 2005; Begg et al., 2010; McCuaig et al., 2010; Griffin et al., 2013). Spatial correlations between both magmatic and sediment-hosted deposits and craton margins support such a genetic link. Hoggard et al (2020) demonstrated that 85% of sediment-hosted base metals, including all giant deposits (>10 Mt of metal), occur within 200 km of the transition between thicker and thinner lithosphere.

Archean Cratons have a distinctive approximately 250–350 km-thick continental lithospheric mantle keel with buoyant refractory properties. Proterozoic and younger continental lithospheric mantle is thinner at <150 km thick, it is denser and is less refractory and therefore more easily reworked.

Passive seismology has been at the forefront of illuminating deep Earth structure for decades. In particular, the faster passage of seismic waves through cold, depleted cratons relative to Proterozoic fold belts or Phanerozoic lithosphere provides a means of delineating cratons in 3D (e.g. Lebedev et al., 2009). Passive seismology can thus reliably identify the deep structural topography.

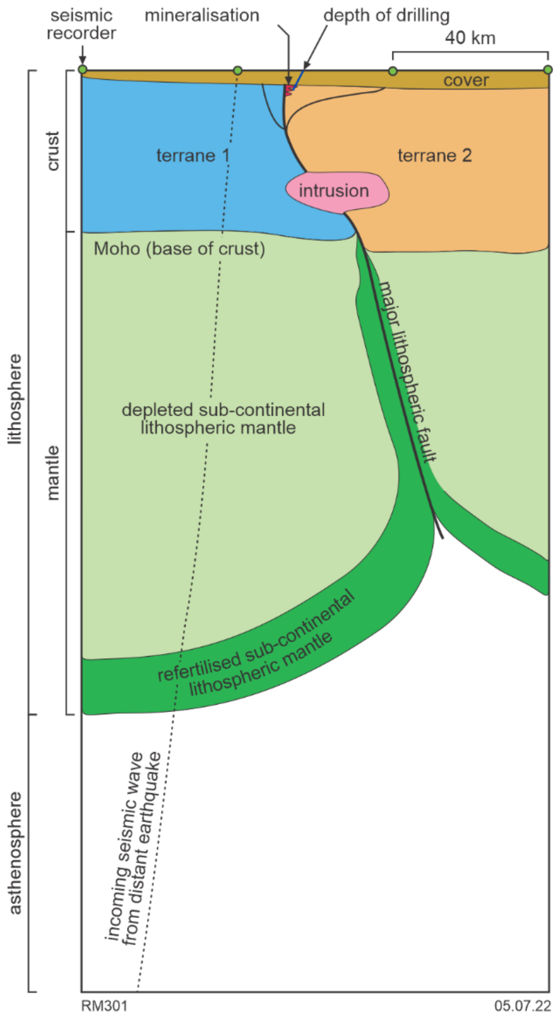

***Figure 1**: Schematic illustration of how a mineral deposit comes to be located on a trans-lithospheric suture between two lithospheric blocks of different ages. Melts sourced from fertilised lower SCLM can migrate upward to the crust via major trans-lithospheric faults at the juxtaposition of lithospheric blocks.*

4 Previous arrays

4.1 International

Other large-footprint transcontinental arrays include the EarthScope Transportable seismic array operated from 2004–2018 in the USA (http://www.usarray.org), which then, in 2017, progressed into the Alaska and Canada Cordillera Array (CCArray http://www.usarray.org). In Europe, AlpArray (2017–2020, http://www.alparray.ethz.ch/home/) was a multinational array across the Alps–Appenines–Carpathians–Dinarides orogenic system and IberArray (2007–2014, https://www.igme.es/TopoIberia/default.html) was a smaller array which focused on the Iberian Peninsula with sites from Morocco to the Pyrenees. In Asia, ChinArray was designed to look at the deep structures under China and the dynamic system comprising the India–

Eurasia collision zone. It started in 2011, with complimentary gravity, magnetotelluric and magnetic surveys.

AusArray (https://www.ga.gov.au/eftf/minerals/nawa/ausarray) started in 2016 in Australia through the Federally funded Exploring for the Future (EFTF) program with collaboration from the State and Territory Geological Surveys and academia. It consisted of 135 mobile broadband stations spaced approximately 55 km apart with 15 semi-permanent stations. So far the dense coverage of AusArray only covers parts of the NT and NW Queensland. The academic-run Wombat rolling array (Rawlinson et al 2014) provides data coverage in Tasmania, Victoria and New South Wales, Queensland, South Australia (Figure 2). So far, the regions of Tasmania, Victoria and New South Wales have been completed, and Queensland, South Australia and Northern Territory are partially completed (Figure 2). Funding ran out before the program reached Western Australia. The compromise, a 200 km spaced array across the whole of the country, will run between 2022 and 2023.

The Geological Survey of Western Australia felt that Western Australia should continue the national coverage at the same resolution as the rest of the country, and so approached State government for funding, the first 4 years of which have now been secured.

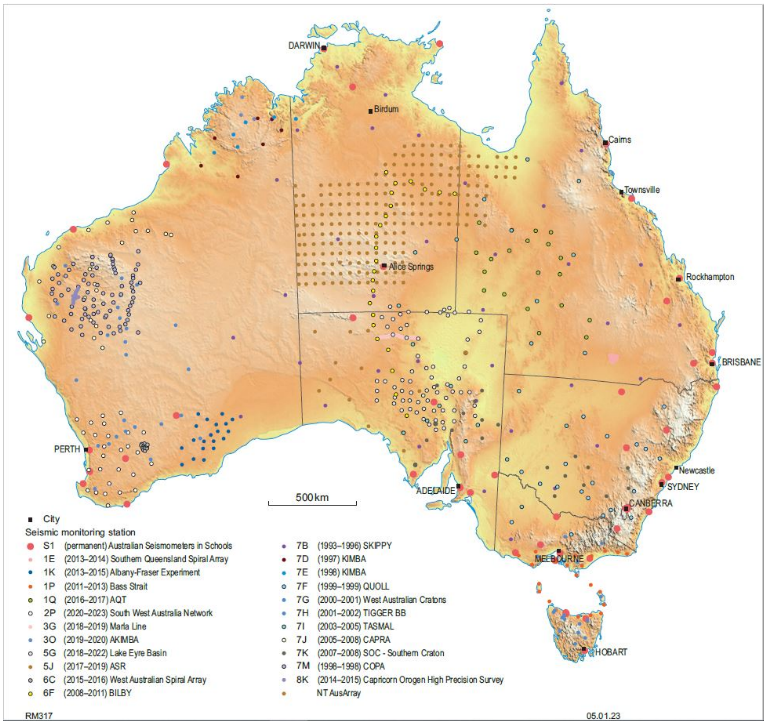

Figure 2: *Current coverage of broadband Australian passive seismic campaigns at July 2022. https://auspass.edu.au/ including the first parts of the high density AusArray in the Northern Territory and Queensland.*

4.2 Previous data in Western Australia

Passive seismic data have been collected in Western Australia by research institutions for many years, each project designed to target a particular geological question (Figure 3, Table 1)

Name	**Date**	**Comments**	**By**
AuSIS	2011-ongoing	Seismometers in Schools Program, permanent with 9 stations in WA	ANU

SKIPPY	1993–1996	Sparse continental-scale experiment which just touched on WA	ANU
KIMBA97	1997	Building on SKIPPY in the Kimberley Region	ANU
WA Craton	2000–2001	To look at the Pilbara and Yilgarn Cratons	ANU
CAPRAL	2005–2008	27 sites looking at the Pilbara and Capricorn Orogen	ANU
ALFREX	2013–2015	70 broadband and short period stations at an approximately 50-km spacing looking at the Moho depth in the Albany Fraser Orogen	ANU, GSWA
COPA and COPA HPS	2014–2018	80+29 stations in the Capricorn Orogen at 50 km grid and 2–8 km high resolution along the deep crustal seismic reflection line 10GA-CP2. This investigated the formation of the Western Australian Craton by the amalgamation of the Pilbara Craton, Glenburgh Terrane and Yilgarn Craton through the associated orogenic collisions	UWA, UMq, GSWA
WA Spiral	2015–2016	Small spiral array in the southern Goldfields designed to enhance weak signals	ANU
Perth Basin*	2017	2 orthogonal profiles with 15 km station spacing, looking at the deep structure of the Perth Basin	ANU, UMq, GSWA
AKIMBA	2019–2022	8 stations in the Kimberley	ANU
EGF*	2018–2019	A high resolution line with 5-km station spacing designed to image the deep crustal portions of the seismic reflection line 91AGSO-EGF1	UWA, GSWA
CANPASS*	2017–2018	Ocean bottom seismometers stations off the coast of Broome	IGG-CAS, GSWA, GA, UMq,
CWAS*	2017–2019	60 stations at 15 km spacing along the Canning Basin Coastal section looking underneath the Canning Basin and its margins with the Pilbara and Kimberley Cratons	IGG-CAS, GSWA, UMq,
SWAN	2020–2022	27 stations in southwest WA at approximately 200 km spacing looking at crustal structure and seismic risk	ANU, GSWA, GA, UMq, UWA, DFES

PLAN*	2021–2023	A high resolution (3–7 km station spacing) survey in the Pilbara looking at the structure of Archean crust	IGG-CAS, GSWA, UMq,
AusArray_200*	2022–2023	A 200 km station grid spacing across the whole continent	GA

*not available yet through the AusPASS portal

Abbreviations:
ANU – Australian National University
DFES – Department of Fire and Emergency Services of Western Australia
GA – Geoscience Australia
GSWA – Geological Survey of Western Australia
IGG-CAS – Institute of Geology and Geophysics at the Chinese Academy of Sciences
UMq – Macquarie University
UWA – The University of Western Australia

***Table 1**: List of passive seismic surveys completed or active in Western Australia*

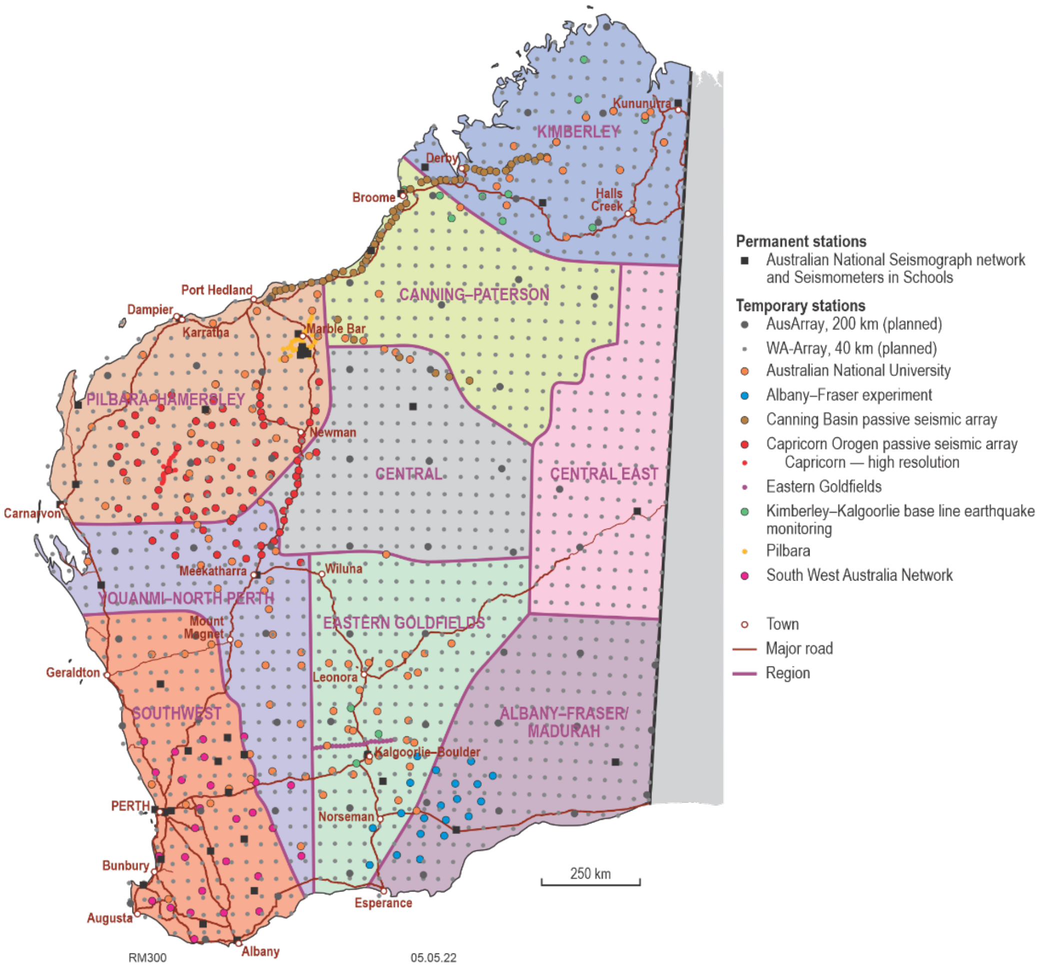

***Figure 3:** Passive seismic stations in Western Australia and proposed WA-Array sites*

These temporary arrays, along with the permanent stations of the Australian National Seismograph Network (ANSN) run by Geoscience Australia (GA) and deep crustal seismic reflection lines, have provided data for the generation of initial statewide products like AuSREM 2012 (Salmon et al., 2012), 3D WA Geomodel (Murdie, 2021), Major Crustal Boundaries of

WA (Martin et al., 2022), AusMoho 2022 (Kennett et al., in review), and new crustal models of Australia (Chen et al., in review).

The existing data are randomly located across the State and there are many areas with no data, particularly in areas of little prior exploration interest or difficult accessibility. WA-Array aims to cover the State in an unbiased sampling distribution covering all areas to build a complete statewide model which can be integrated into the national model. All these existing data points will be assessed for quality and either incorporated into the new data or repeated as necessary.

5 WA-Array

Fieldwork for WA-Array started in November 2022. It will comprise a movable array of 165 stations spaced on an approximate 40 km grid. The broadband seismometers are from a selection of makes and providers (Table2). In addition, the SWAN array (Murdie et al., 2021) will be also on the ground at the same time as the first deployment which is in the SW of Western Australia.

Table 2: Initial listing of equipment to be used for WA-Array

Number of instruments	**Seismometer**	**Digitizer**	**Provider**
28	Reftek Colt 60 s and 120 s	Reftek Wrangler	GSWA
30	Silicon Audio optical seismometer	ESS Gecko	GSWA
40	GaiaCode Theta	Guralp Minimus	GSWA
40	Nanometrics Trillium 120 s	Nanometric Taurus Reftek 130	IGG-CAS
45	Nanometrics Trillium 120 s Compact	Terrasawr (SWAN) LPR200	ANSIR

These instruments will be placed on a grid across a region (Figure 3), taking into account permanent stations and previously acquired data. Each deployment will be left in place for one year. Data will be recorded locally on removable media, and retrieved after 6 months and again at the end of the year when the stations are redeployed. The 6-month data download will also serve as a check that all stations are functioning properly with data quality control. Any adjustments that need to be made can still mean that the station is in the ground long enough to acquire meaningful data, even if there is some data loss. At the end of a year, the stations will be retrieved and the array will be moved to a different region. This will allow products to be published on a region-by-region timetable. There are nine regions (Figure 3) and it is anticipated that, providing there are no major incidents, events or pandemics, it will take 10 years to complete this program. Deployment will be by 4WD in as many places as possible, but much of the State (approximately 50%) is inaccessible by vehicle so deployment to these sites will be by helicopter. Nodal network data transmission is being looked into for these remote sites to save costs on a 6-month data download.

5.1 Rationale for 40 km station spacing

The completed part of AusArray in the Eastern States has been conducted at 55 km spacing. However, pressure from industry and academia for a higher resolution grid resulted in a 40-km grid for WA-Array. The reasoning behind this is to provide a dimple-free Moho model. Teleseismic waves arriving at a station from a variety of earthquakes and azimuths have a cone-like footprint on the Moho which gets wider as the Moho deepens. In Western Australia, there are areas of very shallow Moho, especially in the Archean regions as seen by deep-crustal seismic reflection lines; e.g. the 10GA-YU and 12GA-AF lines. The width of the footprint at these depths is narrow. Therefore, to sample the Moho without any intervening spaces between stations, a 40-km spacing was considered optimal (Figure 4). Although there are other methods of imaging the Moho, this is one of the fundamental ones.

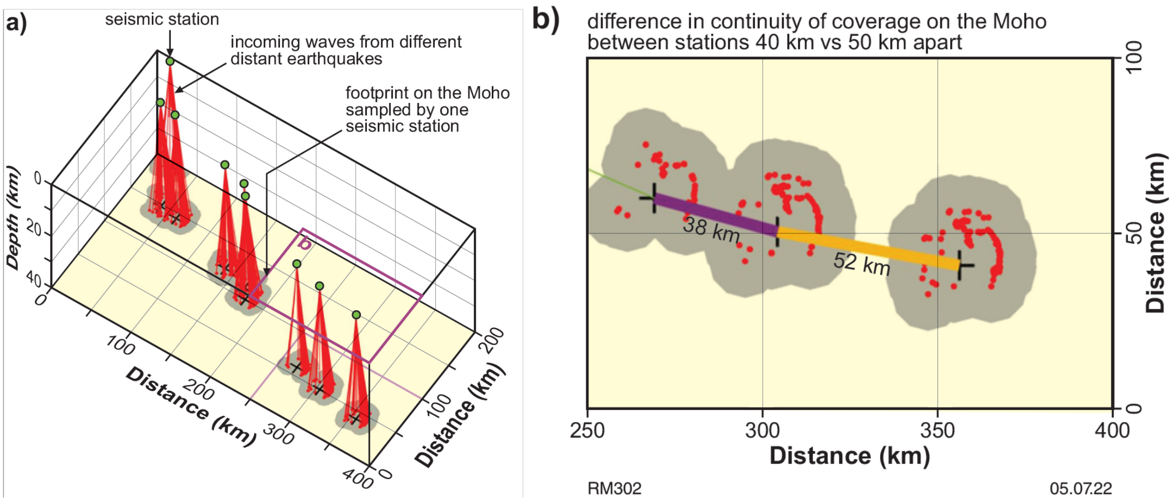

__Figure 4:__ Diagram showing how, by using receiver function techniques, a well sampled Moho is gained from overlapping footprints of incoming teleseismic waves.

6 Data and products

Data will be quality assessed and controlled and after one year from the time of ingestion into the data centre, and will be made available through public portals such as AusPASS. For each yearly data package GSWA will release a limited number of essential ‘Tier 1’ products which will be produced on a ‘production line’ basis. We have been working on the algorithms for these products over the past few years and can push the data through them relatively quickly.

Tier 1 products and methods include:

- 3D shear wave velocity (V_{SV}) model of the crust using Rayleigh phase and group velocity data extracted from ambient noise correlation (i.e. ambient noise tomography; (O'Donnell et al., 2019a)
- 3D shear wave velocity (V_{SV}) model of the uppermost mantle using teleseismic Rayleigh waves (i.e. surface wave tomography; O'Donnell et al., 2019b)
- 3D compressional and shear wave (δV_P & δV_S) models of the uppermost mantle using teleseismic body waves (i.e. relative arrival time tomography; e.g. Rawlinson et al., 2014b)

- Maps of crustal azimuthal anisotropy based on the ambient noise correlation data (i.e. anisotropic ambient noise tomography; e.g. Rawlinson et al., 2014a)
- Maps of shear wave (SKS) splitting parameters — fast polarisation direction and strength of anisotropy — at each station to delineate the lithosphere's fossil strain field (e.g. Long and Becker, 2010)
- Seismic hazard mapping and 3D V_P wave speed models (Everingham, 1966; Allen et al., 2018; Allen, 2018)

Additional products will be produced in collaboration with research partners.

7 Acknowledgements

This work is published with the permission of the Executive Director of the Geological Survey of Western Australia.

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