Exploring for the Future program update: new data and information from northern Australia

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Introduction

The *Exploring for the Future* (EFTF) program is a $225 million Federal Government-funded initiative spanning the period July 2016 to June 2024. This multi-disciplinary program involves aspects of method development and new pre-competitive data acquisition at a range of scales with the aim of building an integrated understanding of Australia's mineral, energy and groundwater potential. Significant work has been undertaken across northern Australia within regional-scale projects and as part of national-scale data acquisition and mapping activities. Some of these activities have been largely completed and have generated new data and products, while others are ongoing. A comprehensive overview of the EFTF program can be found via the program website[3]. In this paper, we overview a range of activities with implications for resource exploration in the Northern Territory.

Regional-scale studies

A major geographical area of focus within the EFTF program has been the Barkly region, extending from the mining districts of Tennant Creek in the Northern Territory in the west through to Mount Isa in Queensland in the east. Much of the intervening area is characterised by flat and featureless surface geography of black soil plains overlying Mesozoic, Paleozoic and Proterozoic sedimentary basins of variable depth. As a consequence, prior to the EFTF program, the region represented arguably one of the least geologically understood regions in northern Australia; moreover, the region has historically been underexplored relative to the potential for mineral and energy systems analogous to those known in the adjacent outcropping regions. The EFTF program has addressed the challenge of reducing exploration risk in the Barkly region via a broad range of geophysical investigations, followed by stratigraphic drilling campaigns and extensive analyses of the recovered rock samples.

East Tennant area

The East Tennant area was selected as a likely region of enhanced mineral prospectivity on the basis of:

- passive seismic data (Gorbatov 2022) indicating a significant north–northeast-trending gradient or 'step' in lithospheric thickness, with thicker lithosphere (>200 km) to the northwest and thinner (<180 km) to the southeast
- major crustal faults interpreted from potential field data (Clark *et al* 2021b) that parallel the change in lithospheric thickness
- a zone of enhanced electrical conductivity in the crust imaged by the AusLAMP long-period magnetotelluric (MT) survey (Duan *et al* 2020), which is broadly coincident with major crustal faults, and situated above the step in lithospheric thickness.

These three independently measured features define a corridor of interest that extends north–northeast from the outcropping mineralised district of Tennant Creek. This geophysically defined corridor is suspected to be a zone of lithospheric weakness that may have focused fluid flow from the mantle into the upper crust, thereby enhancing its mineral prospectivity. To test this hypothesis, a stratigraphic drilling campaign of 10 diamond drillholes was designed and conducted in collaboration with MinEx CRC as part of the *National Drilling Initiative* (**Figure 1**; Clark *et al* 2021a). Geochemical, petrological, geochronological and isotopic studies on samples from these drillholes have revealed the presence of Paleoproterozoic basement rocks in the East Tennant corridor with ages and event histories that can be correlated with gold–copper-bearing sequences in the Tennant Creek district (Clark *et al* 2022; Kositcin *et al* 2022a,b). One hole (NDIBK04) contains gold–copper–zinc–silver–bismuth mineralisation hosted within graphitic schists, which is inferred to be broadly synchronous with gold–copper–bismuth mineralisation in the Tennant Creek district (Schofield *et al* 2022) on the basis of structural correlations and bracketing geochronological constraints.

In addition to the above mentioned long-period MT data, higher resolution broadband and audio MT data was acquired in a series of traverses across the East Tennant corridor (Jiang *et al* 2022; Jiang *et al* 2023). The broadband MT data provides evidence for connectivity of deep crustal conductivity features into the upper crust along faults and shear zones, potentially mapping out fluid pathways to explorable depths. The audio MT data has been used to provide estimates of depth to crystalline basement, calibrated against known depths in drillholes. This depth to basement 'map' provides a guide to the location of prospective Paleoproterozoic basement rocks at explorable depths (eg < 500 metres) within the East Tennant area.

Collectively, the datasets acquired in the East Tennant area provide an evidence-base for informed exploration through cover via a vastly improved geological map of the subsurface (**Figure 2**; Clark *et al* 2021b) and a well-constrained tectonostratigraphic event framework (Kositcin *et al* 2022a,b), including clear indications of mineral prospectivity in Paleoproterozoic basement rocks at explorable depths.

South Nicholson region

In parallel with work described above in the East Tennant area, the EFTF program has acquired a total of

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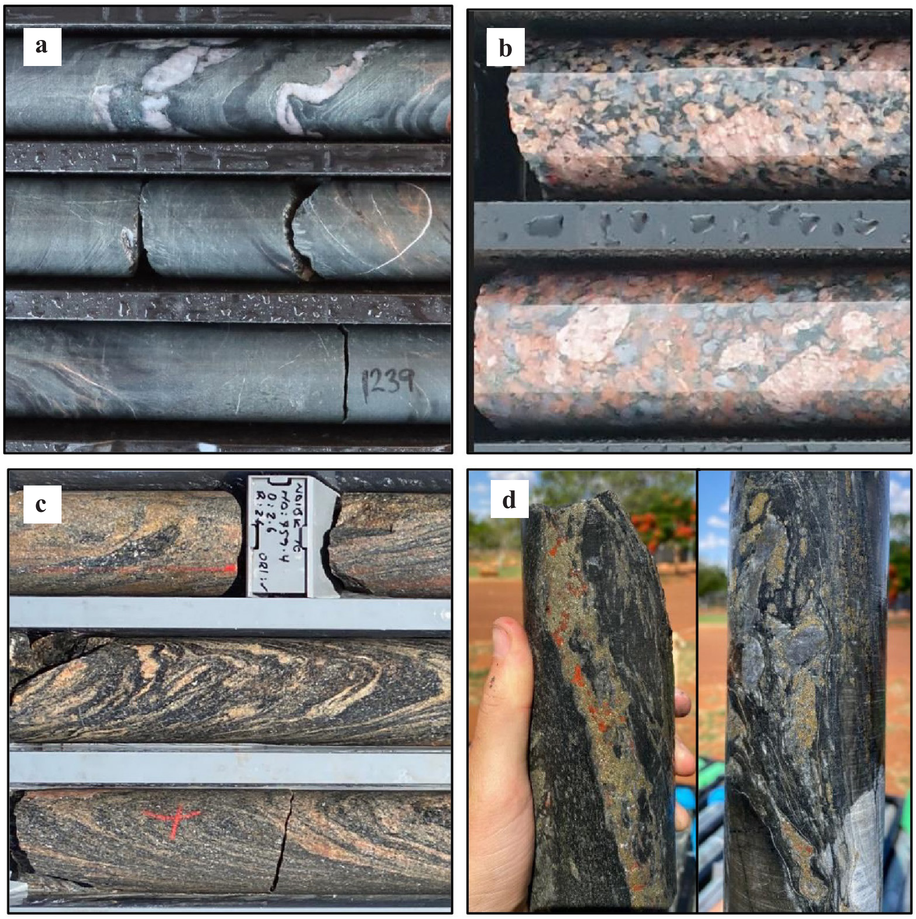

Figure 1. Representative examples of drill core from the East Tennant National Drilling Initiative stratigraphic drilling campaign. (**a**) Folded metasedimentary rocks from NDIBK02. (**b**) Megacrystic granodiorite from NDIBK05. (**c**) Paragneiss from NDIBK10. (**d**) Pyrite, chalcopyrite and arsenopyrite veins from NDIBK04.

2787 line-km of deep crustal reflection seismic data in the Barkly region in two tranches: the South Nicholson and Barkly (Southby *et al* 2021) surveys. Together, these surveys form a network of reflection seismic traverses that link from the Beetaloo Sub-basin in the northwest, across the McArthur Basin beneath the Barkly tablelands and extending beyond the Northern Territory–Queensland border to legacy seismic lines in the Mount Isa region.

A significant outcome of these reflection seismic surveys was the identification of a thick sedimentary depocentre completely concealed beneath the Georgina Basin, straddling the Northern Territory–Queensland border. This depocentre coincides with a prominent gravity low and a low velocity zone in passive seismic data (Hejrani *et al* 2020); this feature is now termed the Carrara Sub-basin (Carr *et al* 2019). The stratigraphy within Carrara Sub-basin was tested by the NDI Carrara 1 deep stratigraphic drillhole in late 2020 as a collaboration between Geoscience Australia, MinEx CRC and the Northern Territory Geological Survey. NDI Carrara 1, located on seismic line 17GA-SN1 on the western flank of the Carrara sub-basin, was drilled to a total depth of 1751 m and intersected ~630 m of Paleozoic Georgina Basin and ~1100 m of underlying Proterozoic stratigraphy (Carson *et al* 2022). An extensive analytical program has been conducted on the drillhole samples from NDI Carrara 1, including petrophysics, geomechanics, petrology, inorganic and organic geochemistry, RockEval pyrolysis, geochronology, biostratigraphy, isotopic tracers, and sedimentology and sequence stratigraphic analyses. A full listing of reports and datasets can be found at Geoscience Australia's South Nicholson National Drilling Initiative web page[4]. Key findings include:

- U–Pb geochronology of thin volcanic horizons have provided direct stratigraphic age control. These results show that the majority of the Proterozoic stratigraphy intersected in NDI Carrara 1 corresponds to the middle to upper Lawn Hill Formation, bracketed in age between ~1611 Ma and ~1588 Ma (Carson *et al* 2022; Kositcin and Carson 2022). This establishes that the Proterozoic stratigraphy of NDI Carrara 1 is contemporaneous with the host stratigraphy at the Century Pb–Zn deposit, some 100 km to the northeast. It is worth noting also that significant older stratigraphy is evident in seismic images at depths beyond those intercepted by NDI Carrara 1.
- Oil stains have been identified at several depths in NDI Carrara 1 in both the Georgina Basin section and the underlying Proterozoic section. The geochemistry of these oil stains indicates the presence of multiple petroleum systems, with implications for the energy resource potential of the Carrara Sub-basin (Grosjean *et al* 2022).

[4] https://www.eftf.ga.gov.au/south-nicholson-national-drilling-initiative

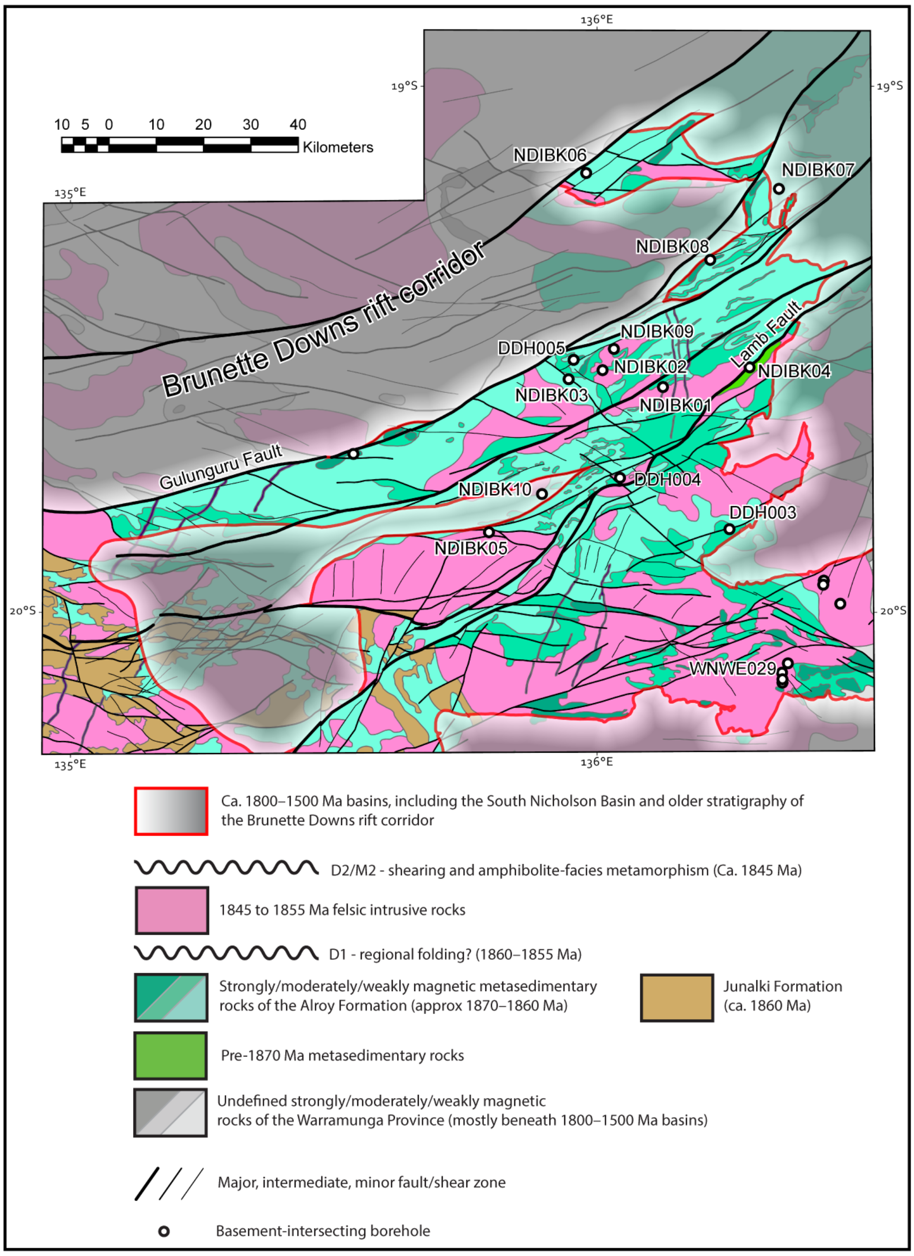

Figure 2. Interpreted solid geology map of the East Tennant area, after Clark *et al* (2021b) and Kositcin *et al* (2022). The map shows interpreted pre-1800 Ma geology beneath the Georgina Basin. Proterozoic basins (ca 1800 Ma–1500 Ma) are shown by semi-transparent grey shading.

Eastern central Australian basins

The regional studies described above in the East Tennant and South Nicholson regions under the EFTF program are largely complete, whereas work is currently in progress in basins of southeastern Northern Territory straddling the borders with South Australia and Queensland. This collaborative project, *Australia's Future Energy Resources* (AFER), is being undertaken with the Northern Territory Geological Survey and the South Australian Department of Energy and Mining to assess the resource potential for conventional and unconventional hydrocarbons, as well as carbon capture and storage opportunities (CCS), within a number of central Australian basins (Bernecker *et al* 2022). The Warburton, Amadeus, Pedirka, Simpson, Eromanga and Lake Eyre basins form a sequence of stacked basins whose depositional history and tectonic evolution span the Neoproterozoic to the present day. Each of these basins has been explored for various sediment-hosted resources, including hydrocarbons, minerals and groundwater, but contain only a sparse dataset of 42 petroleum wells and ~16,000 km of primarily 1970–80s vintage 2D seismic data across a study area of ~200 000 km^2.

Under the AFER project, Geoscience Australia has reprocessed over 5000 line km of 2D seismic data, resulting in a marked uplift in data image quality across the entire stratigraphic column. By using a regionally consistent play-based framework and drawing on a large knowledge base from each region (Iwanec *et al* in press), the uplifted re-imaged seismic can be tied to the adjacent hydrocarbon sedimentary provinces of the Cooper, Amadeus and Arckaringa basins, thus drawing on the wealth of data and knowledge from those regions. The new results are painting a clearer picture of the basins' evolution, de-risking the exploration play elements for conventional hydrocarbons, and identifying potential sediment-hosted resources that have not yet be tested through exploration drilling.

With respect to assessing the energy resource potential, traditional work flows, initially developed for conventional hydrocarbons, have been modified and expanded to evaluate the carbon storage potential in sedimentary intervals of varying stratigraphic ages. Other energy commodity resources being assessed include the occurrence of native hydrogen, as well as intra-basinal salt deposits that may be suitable for future hydrogen storage.

National-scale datasets

In parallel with regional-scale activities described above, a range of national-scale data acquisition programs are in progress as part of the EFTF program; several of these have acquired and delivered datasets covering the Northern Territory. These national-scale activities comprise the AusLAMP, AusAEM and AusArray geophysical programs; and sub-surface geological, isotopic and heavy mineral mapping programs.

AusLAMP

AusLAMP is a multi-year collaboration between Geoscience Australia, State and Territory geological surveys, and research organisations to acquire long-period MT data on a 0.5^{o} latitude/longitude grid (~55 × 55 km station spacing) across Australia. Over half of the continent has been covered so far. Crustal-scale electrical conductivity features revealed by MT data have been shown to be important in providing first-order constraints on the locations of several mineral system types, including iron oxide–copper–gold (Heinson *et al* 2018) and orogenic gold (Kirkby *et al* 2022). As part of the EFTF program, AusLAMP data have been collected from most of the Northern Territory and western Queensland. The results have been processed to produce a northern Australia 3D conductivity model (**Figure 3**; Duan *et al* 2021). In addition to the conductivity corridor in the East Tennant area mentioned above, this northern Australia conductivity model exhibits numerous intriguing deep crustal conductivity features, many of which correlate with major crustal boundaries (eg Korsch and Doublier 2016) that may represent zones of paleo-fluid flow and enhanced mineral prospectivity. The resolution of the AusLAMP model is sufficient to guide initial exploration area selection; the use of broadband and audio MT methods can then refine exploration targets, as demonstrated in the East Tennant area.

AusAEM

AusAEM is the world's largest airborne electromagnetic (AEM) survey; it commenced in northern Australia as part of the EFTF program (Ley-Cooper and Brodie 2020). AusAEM provides broadscale AEM coverage using ~20 km line-spacing, and has expanded to more than 60% of national coverage with funding and in-kind support from partner State and Territory geological surveys. The majority of the Northern Territory is covered by ~20 km-spaced AusAEM data. The data provide constraints on the uppermost ~300 m of the sub-surface, allowing geological interpretation of paleovalleys, cover thickness, basin distribution, and configuration and identification of conductive features in near-surface basement rocks (Wong *et al* 2020).

AusArray

The Australian Passive Seismic Array Project (AusArray) is a collaborative national survey between government and academia utilising a movable array of broadband seismic stations arranged in a grid pattern at ~200 km-spacing, and covering the majority of the Australian continent. Stations are deployed for approximately a year; the data collected will provide an improved 3D model of the seismic velocity structure of the continent (Gorbatov *et al* 2020). In addition, two higher resolution arrays of 50 × 50 km-spacing were deployed in the Northern Territory as part of the EFTF program between 2016 and 2020 (Hejrani *et al* 2020). Continental-scale data and models will allow recognition of major changes in crustal and lithospheric depth, which may guide future regional studies and resource exploration strategies as demonstrated in the East Tennant and South Nicholson regions described above.

National sub-surface geological mapping

In addition to the national-scale geophysical programs of AusLAMP, AusAEM and AusArray, Geoscience Australia is leading the development of national-scale sub-surface geology maps. These sub-surface geology maps complement the national 1:1 M surface geology map (Raymond *et al* 2012). The approach is to produce time-based sub-surface layers depicting the interpreted Mesozoic, Palaeozoic, Neoproterozoic, and pre-Neoproterozoic geology. These map layers have been published for the North Australian Craton (Stewart *et al* 2020) covering parts of Western Australia, Northern Territory and Queensland. Such sub-surface interpretations are subject to change as new information becomes available, particularly in deeply covered regions where the interpretation is less certain. One application of these sub-surface geology maps is in the production of mineral prospectivity maps for particular mineral systems and/or for particular geological eras. An example that utilises the sub-surface mapping of the North Australian Craton is the iron oxide–copper–gold (IOCG) prospectivity map of Murr *et al* (2020).

Isotopic Atlas of Australia

Radiometric ages and complementary isotopic tracers (eg Sm–Nd, Pb–Pb, Lu–Hf, Rb–Sr) provide constraints on timing and geological processes that inform the understanding of known mineral and energy resources, and can guide the search for undiscovered resources. The EFTF program has compiled available age and isotopic results from a wide range of published reports and journal articles and delivered them in standard formats and in map view – collectively termed an Isotopic Atlas of Australia (Fraser *et al* 2020). These data are available online via the GA Portal[5]. For the Northern

[5] https://portal.ga.gov.au/persona/geochronology

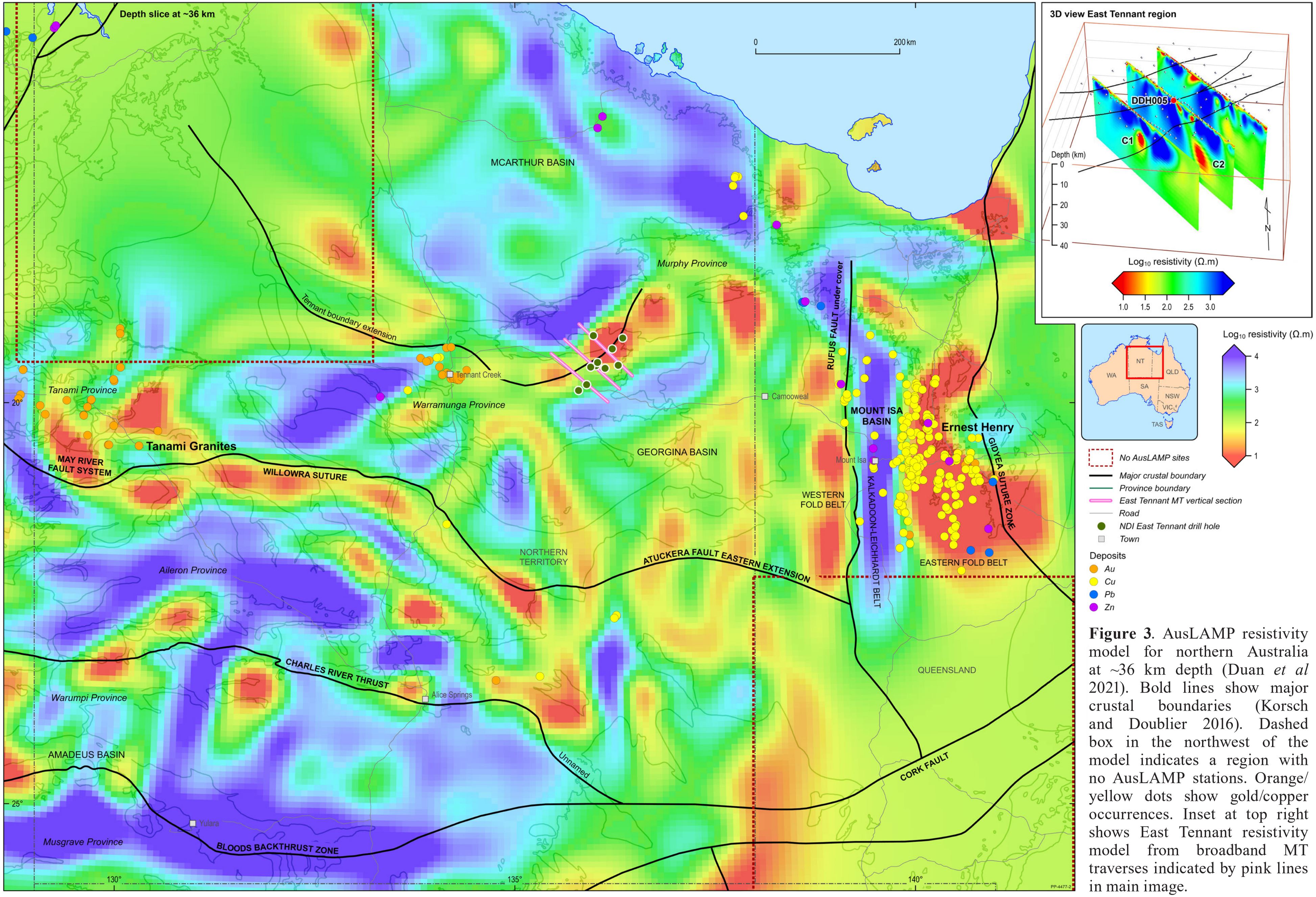

Figure 3. AusLAMP resistivity model for northern Australia at ~36 km depth (Duan *et al* 2021). Bold lines show major crustal boundaries (Korsch and Doublier 2016). Dashed box in the northwest of the model indicates a region with no AusLAMP stations. Orange/yellow dots show gold/copper occurrences. Inset at top right shows East Tennant resistivity model from broadband MT traverses indicated by pink lines in main image.

Territory, relevant data include: map views of U–Pb age data showing the distribution of magmatic and metamorphic events through time and space (Jones *et al* 2018); Nd isotopes in felsic magmatic rocks (Champion 2013) and Hf isotopes in zircon (Waltenberg *et al* 2023) showing the progressive growth of the North Australian Craton; and Pb isotopes in ores showing variations in the chemistry of source areas for mineralising fluids (Huston *et al* 2019).

Heavy Mineral Map of Australia

While most of the activities and datasets described above are focussed on characterising and mapping the sub-surface, a wealth of information is also available from surface materials. A recent and ongoing example is the Heavy Mineral Map of Australia (Caritat *et al* 2022a). This work utilises surface samples that were collected during the National Geochemical Survey of Australia (Caritat 2022). The samples are overbank sediments collected at the lower end of river catchments, with each sample regarded as a natural average of the materials in that catchment. These samples have been reprocessed via a consistent protocol to concentrate the heavy minerals (>2.9 g/cm^3), which have then been cast in epoxy mounts. The occurrence and abundance of heavy minerals is then quantified by automated mineral mapping using a Tescan Integrated Mineral Analyser (TIMA) at Curtin University. So far, datasets have been released covering the Barkly–Isa–Georgetown region of eastern Northern Territory and western Queensland (Caritat *et al* 2022b), and southeastern Australia (Caritat *et al*, 2022c). The data can be visualised and interrogated via an online application[6]. Over 150 different minerals have been identified from over 18 million individual grains across 188 samples in the Barkly–Isa–Georgetown region. These include a range of copper- and zinc-bearing minerals that may provide subtle indications of mineralisation in catchment areas.

Conclusions

The *Exploring for the Future* program continues to acquire and deliver a diverse range of precompetitive datasets and products at a range of scales to characterise the geology and resource potential of northern Australia. Significant exploration tenement uptake has occurred for both mineral and energy resources, particularly in the Barkly region, at least partly as a result of this new precompetitive data. By that measure, the EFTF program has been successful, although the ultimate mark of success will be the discovery of major new resources for the benefit of the region and the nation.

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[6] https://geoscienceaustralia.shinyapps.io/mna4hm/

References

Bernecker T, Bradshaw B, Iwanec I, Kalinowski A, Rollet N and Tenthorey E, 2022. The 'Australia's Future Energy Resources' project: investigating the energy resources potential in central Australia: in '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 5–6 April 2022'*. Northern Territory Geological Survey, Darwin, 96–106.

Caritat P de, 2022. The National Geochemical Survey of Australia: review and impact. *Geochemistry: Exploration, Environment, Analysis* 22(4). https://doi.org/10.1144/geochem2022-032

Caritat P de, McInnes B, Walker A, Bastrakov E, Rowins S and Prent A, 2022a. The Heavy Mineral Map of Australia: Vision and Pilot Project. *Minerals* 12(8), 961. https://doi.org/10.3390/min12080961

Caritat P de, Bastrakov E, Walker A and McInnes B, 2022b. The Heavy Mineral Map of Australia Project. Data Release 2. The Barkly Isa Georgetown Region. *Geoscience Australia, Record* 2022/043.

Caritat P de, Walker A, Bastrakov E and McInnes B, 2022c. The Heavy Mineral Map of Australia Project. Data Release 1. The Darling–Curnamona–Delamerian Region. *Geoscience Australia, Record* 2022/031.

Carson C, Kositcin N, Henson P, Delle Piane C, Crombez V, Grosjean E, Jarrett A and Butcher G, 2022. *Exploring for the Future* – SHRIMP U–Pb zircon geochronology from NDI Carrara 1 and implications for regional stratigraphic correlations, resource potential and geological evolution of the Carrara Sub-basin: in '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 5–6 April 2022'*. Northern Territory Geological Survey, Darwin, 65–74.

Champion DC, 2013. Neodymium depleted mantle model age map of Australia: explanatory notes and user guide. *Geoscience Australia, Record* 2013/044.

Clark A, Schofield A, O'Rourke A, Doublier M, Roach I, Budd A, Jiang W and Cross A, 2021a. Results from the MinEx CRC National Drilling Initiative campaign in East Tennant: what's there and why you should care: in '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 20–21 April 2021'*. Northern Territory Geological Survey, Darwin, 80–83.

Clark A, Highet L, Schofield A and Doublier M, 2021b. *Solid geology map of the East Tennant region*. Geoscience Australia, Canberra. http://pid.geoscience.gov.au/dataset/ga/145260

Clark AD, Morrisey LJ, Doublier M, Kositcin N, Schofield A and Skirrow RG, 2022. A newly recognised 1860–1840 Ma tectono-magmatic domain in the North Australia Craton: Insights from the Tennant Region, East Tennant area, and the Murphy Inlier. *Precambrian Research* 375, 106652. https://doi.org/10.1016/j.precamres.2022.106652

Duan J, Kyi D, Jiang W and Costelloe M, 2020. AusLAMP: imaging the Australian lithosphere for resource potential, an example from northern Australia: in Czarnota K, Roach I, Abbott S, Haynes M, Kositcin N, Ray A and Slatter E (editors). '*Exploring for the Future: Extended Abstracts'*. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/134997

Duan J, Kyi D and Jiang W, 2021. Electrical resistivity structures and mineral prospectivity from *Exploring for the Future* AusLAMP data (2016–2019) in northern Australia. *Geoscience Australia, Record* 2021/21. http://dx.doi.org/10.11636/Record.2021.021

Fraser G, Waltenberg K, Jones S, Champion D, Huston D, Lewis C, Bodorkos S, Forster M, Vasegh D, Ware B and Tessalina S, 2020. *An Isotopic Atlas of Australia*: in Czarnota K, Roach I, Abbott S, Haynes M, Kositcin N, Ray A and Slatter E (editors). '*Exploring for the Future: Extended Abstracts'*. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/133772

Gorbatov A, 2023. *Receiver Function volumetric model of north-eastern Northern Territory and north-western Queensland*. Geoscience Australia, Canberra. https://dx.doi.org/10.26186/147547

Gorbatov A, Czarnota K, Hejrani B, Haynes M, Hassan R, Medlin A, Zhao J, Zhang F, Salmon M, Tkalcic H, Yuan H, Dentith M, Rawlinson N, Reading AM, Kennett BLN and Budgen C, 2020. AusArray: quality passive seismic data to underpin updatable national velocity models of the lithosphere: in Czarnota K, Roach I, Abbott S, Haynes M, Kositcin N, Ray A and Slatter E (editors). '*Exploring for the Future: Extended Abstracts'*. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/135284

Grosjean E, Jarrett A, Boreham C, Butcher G, Carson C, Bailey A, Wang L, Munson Tand Henson P, 2022. The energy resource potential of the Carrara Sub-basin revealed by new stratigraphic drilling: in '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 5–6 April 2022'*. Northern Territory Geological Survey, Darwin, 75–83.

Heinson G, Didana Y, Soeffky P, Thiel S and Wise T, 2018. The crustal geophysical signature of a world-class magmatic mineral system. *Nature Scientific Reports* 8, 10608. https://doi.org/10.1038/s41598-018-29016-2

Hejrani B, Hassan R, Gorbatov A, Sambridge M, Hawkins R, Valentine A, Czarnota K and Zhao J, 2020. Ambient noise tomography of Australia: application to AusArray deployment: in Czarnota K, Roach I, Abbott S, Haynes M, Kositcin N, Ray A and Slatter E (editors). '*Exploring for the Future: Extended Abstracts*'. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/135130

Huston DL, Champion DC, Ware B, Carr G, Maas R and Tessalina S, 2019. Preliminary national-scale lead isotope maps of Australia. *Geoscience Australia, Record* 2019/001. http://dx.doi.org/10.11636/Record.2019.001

Iwanec I, Bradshaw B, Bernecker T, Doig A, Jarrett A, Strong P and Yarmohammadtooks Z, in press. Post-drill analysis to assess the prospectivity and geological risks for energy resources in the Pedirka, Simpson and western Eromanga basins: in '*Proceedings of the 4th Central Australian Basins Symposium (CABS IV), Darwin 2022'*.

Jiang W, Duan J, Doublier M, Clark A, Schofield A, Brodie RC and Goodwin J, 2022. Application of multi-scale magnetotelluric data to mineral exploration: an example from the East Tennant region, northern Australia. *Geophysical Journal International* 229(3), 1628–1645. https://doi.org/10.1093/gji/ggac029

Jiang W, Brodie RC, Duan J, Roach I, Symington N, Ray A and Goodwin J, 2023. Probabilistic inversion of audio-frequency magnetotelluric data and application to cover thickness estimation for mineral exploration in Australia. *Journal of Applied Geophysics* 208, 104869. https://doi.org/10.1016/j.jappgeo.2022.104869

Jones S, Anderson J, Fraser G, Lewis C and McLennan S, 2018. A U–Pb geochronology compilation for Northern Australia: version 2, 2018. *Geoscience Australia, Record* 2018/049. http://dx.doi.org/10.11636/Record.2018.049

Kirkby A, Czarnota K, Huston DL, Champion DC, Doublier MP, Bedrosian PA, Duan J and Heinson G, 2022. Lithospheric conductors reveal source regions of convergent margin mineral systems. *Nature Scientific Reports* 12, 8190. https://doi.org/10.1038/s41598-022-11921-2

Korsch RJ and Doublier MP, 2016. Major crustal boundaries of Australia, and their significance in mineral systems targeting. *Ore Geology Reviews* 76, 211–228.

Kositcin N and Carson C, 2022. Exploring for the Future – SHRIMP U–Pb geochronology of NDI Carrara 1, South Nicholson region, Northern Territory. *Geoscience Australia, Record* 2022/042. http://dx.doi.org/10.11636/Record.2022.042

Kositcin N, Cross AJ, Clark A, Doublier MP, Fraser GL and Schofield A, 2022a. Geological framework of the concealed East Tennant area constrained by SHRIMP U–Pb zircon geochronology: Implications for Paleoproterozoic stratigraphic correlations in northern Australia. *Precambrian Research* 383, 106886. https://doi.org/10.1016/j.precamres.2022.106886

Kositcin N, Clark A and Doublier M, 2022b. New SHRIMP U–Pb geochronology of *in-situ* monazites from the East Tennant area, Northern Territory: Results from the MinEx CRC National Drilling Initiative program. *Geoscience Australia, Record* 2022/18. http://dx.doi.org/10.11636/Record.2022.018

Ley-Cooper AY and Brodie RC, 2020. AusAEM: imaging the near-surface from the world's largest airborne electromagnetic survey: in Czarnota K, Roach I, Abbott S, Haynes M, Kositcin N, Ray A and Slatter E (editors). '*Exploring for the Future: Extended Abstracts*'. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/134528

Murr J, Schofield A, Doublier MP, Goodwin J, Skirrow RG, Coghlan RA, Duan J, Haynes M and Czarnota K, 2020. *North Australian Craton iron oxide–copper–gold (IOCG) mineral potential assessment: geospatial data*. Geoscience Australia, Canberra. https://doi.org/10.26186/144502

Raymond OL, Liu S, Gallagher R, Zhang W and Highet LM, 2012. *Surface geology of Australia. 1:1 million scale dataset 2012 edition*. Geoscience Australia, Canberra. https://dx.doi.org/10.26186/74619

Schofield A, Clark A, Kositcin N, Cross A, Doublier M, Skirrow R, Fraser G, Budd A, Close DF, Jiang W, Murr J, O'Rourke A, Pitt L, Roach I, Thomas M, Whelan JA and Wynne P, 2022. Shining new light on the (previously) dark depths of the East Tennant region: in '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 5–6 April 2022'*. Northern Territory Geological Survey, Darwin, 115–120.

Southby C, Rollet N, Carson C, Carr L, Henson P, Fomin T, Costelloe R, Doublier M and Close D, 2021. The Exploring for the Future 2019 Barkly Reflection Seismic Survey: Key discoveries and implications for resources: in '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 20–21 April 2021'*. Northern Territory Geological Survey, Darwin, 24–29.

Stewart AJ, Liu SF, Bonnardot M, Highet LM, Woods M, Brown C, Czarnota K and Connors K, 2020. Seamless chronostratigraphic solid geology of the North Australian Craton: in Czarnota K, Roach I, Abbott S, Haynes M, Kositcin N, Ray A and Slatter E (editors). '*Exploring for the Future: Extended Abstracts'*. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/134486

Waltenberg K, Curtis C, Lem A and Bodorkos S, 2023. Isotopic Atlas of Australia: Lu, Hf and O isotopic data structure and delivery. Version 1.1. *Geoscience Australia, Record* 2023/03. https://dx.doi.org/10.26186/147720

Wong SCT, Roach IC, Nicoll MG, English PM, Bonnardot M-A, Brodie RC, Rollet N and Ley-Cooper AY, 2020. Interpretation of the AusAEM1: insights from the world's large airborne electromagnetic survey: in Czarnota K, Roach I, Abbott S, Haynes M, Kositcin N, Ray A and Slatter E (editors). '*Exploring for the Future: Extended Abstracts*'. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/134283