Structural mapping and uranium targeting from airborne geophysical data in the Nabarlek region, Pine Creek Orogen

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Introduction

The Nabarlek project is situated within the Alligator River Uranium Province (ARUP) of Arnhem Land in the Northern Territory. It lies within the Nimbuwah Domain near the eastern margin of the Neoarchean to Paleoproterozoic Pine Creek Orogen. The ARUP is regarded as highly prospective for unconformity-related uranium deposits but exploration is complicated by the region's extreme remoteness and limited outcrop. In such terrains airborne geophysical datasets, particularly from aeromagnetic and radiometric surveys, can provide effective means of mapping structures, lithologies and anomalous features potentially associated with alteration or mineralisation.

In 2024, Alligator Energy acquired high-resolution aeromagnetic and radiometric data across the Nabarlek project as part of the *Resourcing the Territory* program Northern Territory Geological Survey (NTGS) Geophysics and Drilling Collaborations (GDC) co-funding initiative. A 1:50 000 scale interpretation of the newly acquired data was undertaken to improve understanding of the structural evolution of the region and to enhance exploration targeting for unconformity-related uranium mineralisation.

Interpretation of the aeromagnetic and radiometric datasets reveals significantly greater geological complexity than indicated by previous mapping, and includes the recognition of several distinct lithomagnetic domains in areas previously mapped as a single unit. In addition to delineating lithomagnetic domains, a detailed structural interpretation was also completed, including identification of fault types (eg thrust, normal, reverse) and assessment of the relative timing of fault movement. These structures were correlated with at least five recognised deformation events, including a late inversion event that coincides with regional uranium mineralisation (Hinman 2015). Recognition of structures active during periods of mineralisation provides an improved framework for targeting potential unconformity-related uranium deposits within the Nabarlek project area.

Regional geology

The Nabarlek project area consists of Archean gneisses of the Nanambu Complex that are unconformably overlain by rocks of the Pine Creek Orogen (**Figure 1**). This sequence includes the ca 2020 Ma shallow marine sedimentary and volcanic units of the Kakadu Group, which are in turn overlain by sedimentary and volcanic rocks of the Cahill Formation and the Nourlangie Schist. These successions underwent moderate- to high-grade metamorphism and deformation during, or shortly after, the emplacement of I-type monzogranitic plutons of the Nimbuwah Complex ca 1867–1860 Ma (Ahmad and Hollis 2013, Hollis and Glass 2012).

Following this phase of deformation and metamorphism, the Nimbuwah Domain experienced significant uplift and erosion. The Archean and Paleoproterozoic-aged granitic and metamorphic rocks were subsequently unconformably overlain by the fluvial sediments of the Kombolgie Subgroup (Katherine River Group), including the basal Mamadawerre Sandstone. The entire stratigraphic succession was later intruded by the Oenpelli Dolerite, which commonly occurs as dykes, sills, laccoliths and lopoliths that are strongly magnetic and highly remanent.

The Alligator River Uranium Province (ARUP) is a region that is highly prospective for unconformity-related uranium deposits and contains several significant deposits, including Ranger, Jabiluka, Koongarra, Nabarlek (now depleted) and Angulari. Mineralisation in the ARUF is typically associated with unconformable contacts between the Neoarchean basement and the Cahill Formation, as well as between the Cahill Formation and the overlying Kombolgie Subgroup. Mineralising fluids are interpreted to have originated within the overlying sedimentary basin and to have migrated downward from the Kombolgie Subgroup into the basement along faults and fractures (Hollis and Wygralak 2012). Interaction of these fluids with reducing lithologies in the basement facilitated the precipitation of uranium-bearing minerals. Mineralisation is predominantly structurally controlled, with thrust faults, steeply dipping reverse faults, and oblique strike-slip faults all constituting key exploration targets.

Data and methods

The airborne magnetic and radiometric data for the Nabarlek project were flown with 100 m line spacing, with several areas infilled at 50 m (Edwards 2024). A suite of filters, including analytical signal, reduction to the pole (RTP), and first and second vertical derivatives (together with visual enhancements such as sun-shading and colour stretches) were applied to the processed data to aid interpretation (**Figure 2**).

The magnetic and radiometric datasets were interpreted at 1:50 000 scale to identify major and minor structures and to delineate lithomagnetic domains. The interpretation was constrained using available geological mapping at both 1:250 000 and 1:100 000 scale.

The interpretation focused on identifying:

- Linear to arcuate breaks, truncations, or offsets in magnetic anomalies indicative of faults or fractures.
- Linear to anastomosing cross-cutting magnetic features interpreted as potential dykes or sills.

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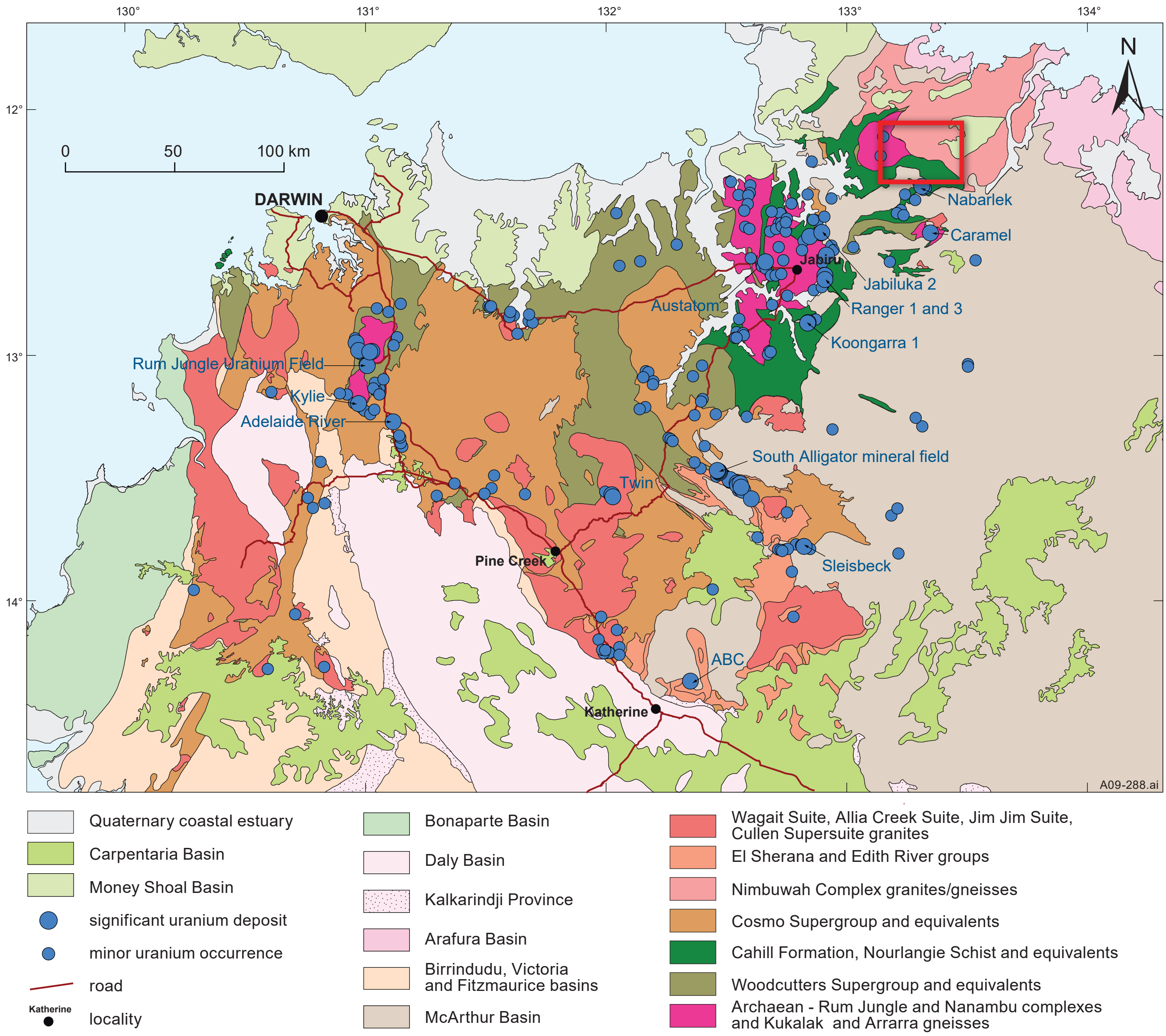


Figure 1. Regional geology of the Pine Creek Orogen. The Nabarlek project area is located in the northeast of the Oenpelli 1:100 000 mapsheet (from Ahmad and Hollis 2013). Red box shows the location of the project area.

- Domains characterised by distinct magnetic intensity and texture (eg smooth, stippled, cross-hatched) that may represent different lithological units.
- Anomalous magnetic zones (high, low, reversed) that may reflect magnetite enrichment or destruction associated with alteration.

Interpretation

The aeromagnetic data exhibit a wide range of textures and magnetic responses that are interpreted to represent different structural features and lithological units (**Figure 3**). The most prominent features are the highly magnetic and strongly remanent signatures of the Oenpelli Dolerite, which appear as strong linear negative (reversely magnetised) anomalies corresponding to the margins of sills, laccoliths and lopoliths. Additional magnetic domains are evident, characterised by linear fabrics, smooth responses, or highly variable and complex magnetic textures. In contrast to previous geological mapping (NTGS 1983) that shows only a single lithological unit (comprising granites of the Nimbuwah Complex) throughout the area, the newly defined magnetic domains suggest much greater lithological complexity. Further geological mapping is required to confirm the lithologies represented by these magnetic domains.

In addition to defining lithomagnetic domains, the new data allowed for detailed interpretation of the fault architecture across the project area. The fault interpretation included an assessment of the relative sense of motion (eg thrust, normal, reverse; **Figure 3**) and relative timing of fault movement with respect to key structural events previously described by Hinman (2015). For all major faults (and where possible also secondary and minor faults) kinematic characteristics and chronological relationships were assessed.

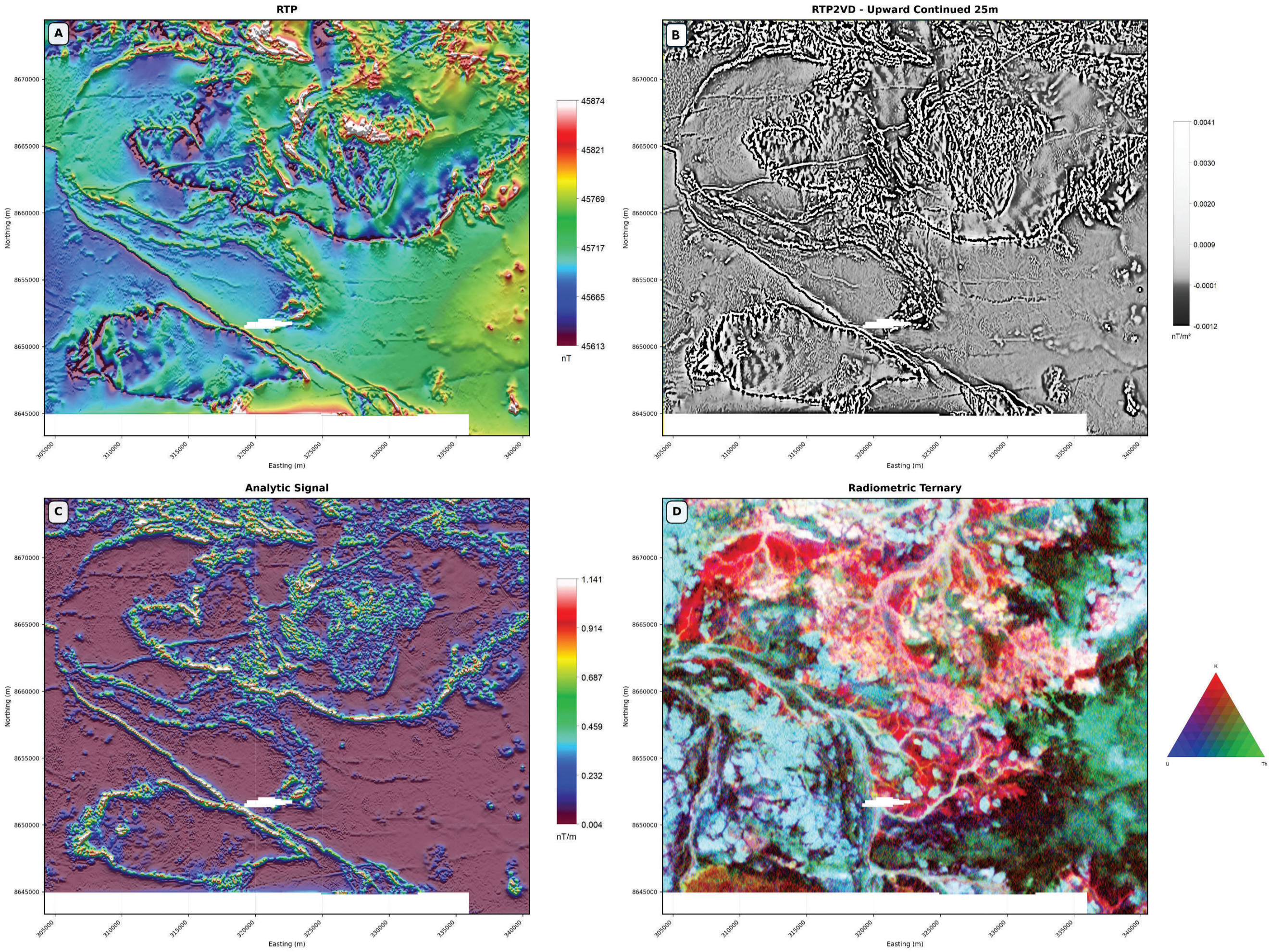
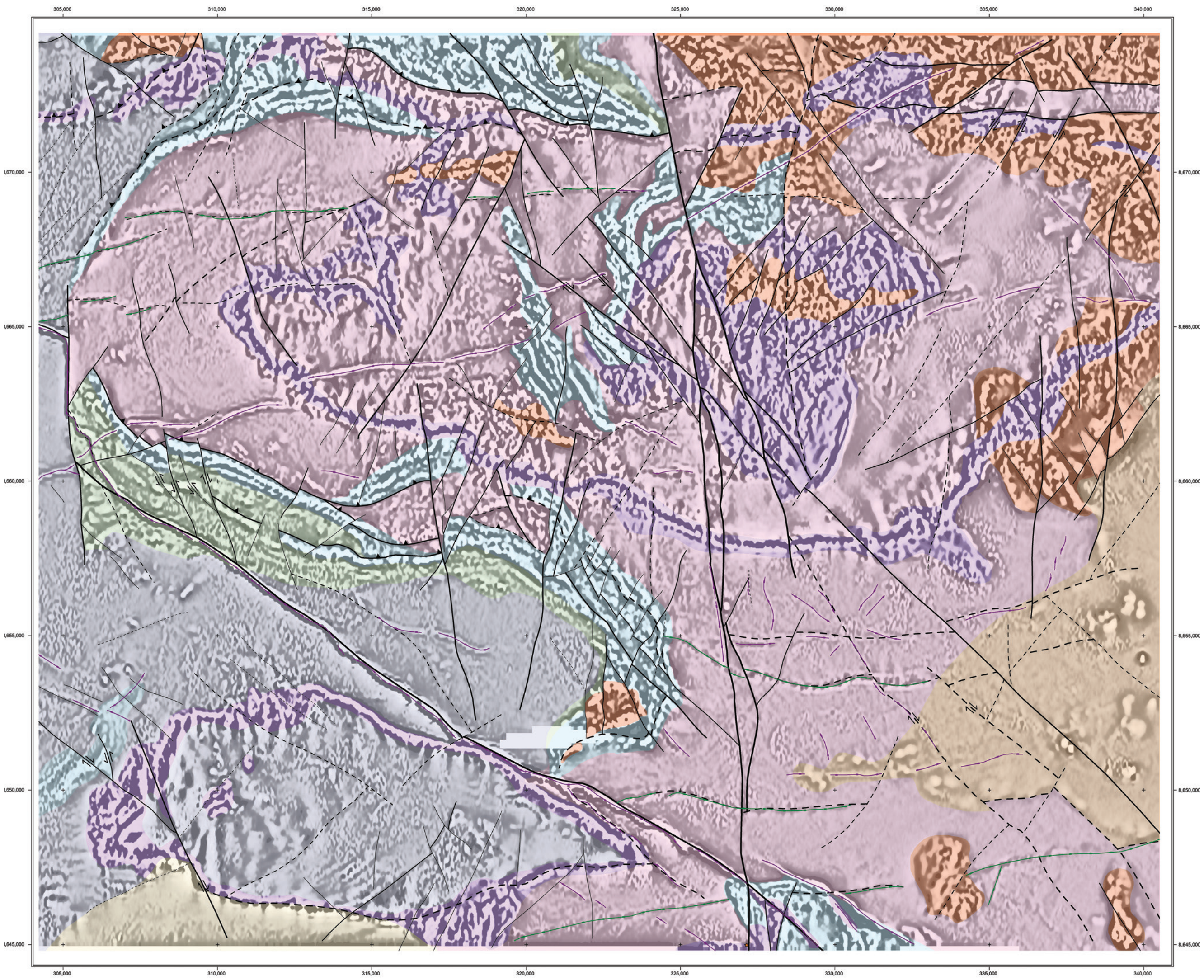


Figure 2. Geophysical data for the Nabarlek project. (**a**) RTP magnetics (linear stretch, shaded from the north). (**b**) RTP second derivative magnetics, greyscale. (**c**) Analytic signal. (**d**) Radiometric ternary image.

From oldest to youngest, the interpreted faults and their association with tectonic events (after Hinman 2015) are:

- **Barramundi Orogeny** (ca 1860 Ma, northeast-southwest-oriented shortening)
  - Curvilinear thrust faults that are now expressed as east-trending structures, locally rotated toward either the southwest or southeast.
- **Shoobridge Event** (ca 1800 Ma; east-west-oriented shortening)
  - Northwest to north-northwest-trending thrust and reverse faults.
- **Seigal Event** (ca 1790–1750 Ma; northeast-southwest-oriented extension)
  - Northwest-trending normal faults and northeast-trending strike-slip faults.
- **Tawallah Extension Event** (ca 1740–1700 Ma; north-south-oriented extension)
  - East-trending normal faults and northeast-trending strike-slip faults.
- **Post-Tawallah Inversion Event** (ca 1700–1680 Ma; east-west-directed shortening) coincident with regional uranium mineralisation
  - Reactivation of multiple fault orientations, including northeast-trending strike-slip faults, east-trending normal faults, and northwest- to north-trending thrust and reverse faults.

Numerous dykes, both normally and reversely magnetised, are also interpreted within the project area. These dykes commonly follow pre-existing structures and cross-cut most lithomagnetic units, indicating that they postdate the major fault movements.



MAGNETIC DOMAINS

***indicates inferred lithology, further geological data required to confirm**

Oenpelli Dolerite | Dolerite
Strongly magnetic with variable and complex magnetic character. Has strong remnant response with both normally and reversely magnetised anomalies observed.

Kombolgie Sandstone | Sandstone
Broad domain with flat magnetic response.

Nimbuwah Complex (a) | Granite or gneiss*
Broad domain with flat magnetic response. Often intruded by dykes of variable orientation.

Nimbuwah Complex (b) | Gneiss*
Moderately magnetic domain with curvilinear magnetic fabrics, often appearing to be tightly folded. Possible domains of gneissic rocks within the Nimbuwah Complex.

Nimbuwah Complex (c) | Gneiss*
Weakly magnetic domain with curvilinear magnetic fabrics, often appearing to be tightly folded. Possible domains of gneissic rocks within the Nimbuwah Complex.

Nimbuwah Complex (d) | Mafic or felsic intrusive*
Domains of strong magnetic intensity, often with diffuse margins. Possible intrusive or larger zone of granitic rocks.

Nimbuwah Complex (e) | Mafic or felsic intrusive*
Broad zone of elevated magnetic intensity and relatively smooth texture. Isolated magnetic highs hosted within domain. Possible intrusive.

Nanambu Complex | Gneiss*
Broad domain with flat magnetic response. Often intruded by dykes of variable orientation.

Mafic Dyke | Linear magnetic anomaly, normal magnetisation

Mafic Dyke | Linear magnetic anomaly, reversely magnetised

FAULTS ***dashed line indicates lower confidence**

Regional-scale fault or shear zone

Major fault or shear zone

Secondary fault or shear zone

Minor Fault

Strike-Slip fault

Thrust fault

Figure 3. Aeromagnetic interpretation overlain on reduced to pole 2nd vertical derivative (RTP2VD) greyscale image.

Conclusions

Newly-acquired high-resolution aeromagnetic and radiometric datasets have enabled detailed mapping of lithomagnetic domains and recognition of a complex network of structures within the Nabarlek project area. This interpretation provides substantially greater structural resolution than previous regional studies and indicates that the lithological framework is likely more heterogeneous than suggested by existing maps of the sparsely exposed terrain. Integration of fault geometries and inferred kinematic histories, constrained relative to major tectonic events, improves the ability to identify structures that were active during periods favourable for uranium mineralisation. This results in more effective targeting of potential unconformity-related uranium deposits in the region.

Acknowledgments

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This data and interpretations from this work are available on GEMIS as part of CR2024-0677 (https://geoscience.nt.gov.au/gemis/ntgsjspui/handle/1/93652).

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