# Introduction

It is now well established that modern economies will increasingly depend on the supply of a broad, and in some cases poorly understood and underexplored, group of commodities termed the "New Economy Minerals" (NEM). Northeast Queensland is host to many deposits of new economy metals, in particular tin and tungsten, as well as molybdenum, scandium, cobalt and nickel. The deposits of northeast Queensland comprise various styles with differing geoscientific characteristics.

Knowledge relating to the geology, mineralogy and geochemistry of each deposit, and its associated inner and outer haloes, as they are expressed in common exploration datasets can provide important information for assessment and advancement of exploration projects. This includes:

- Provision of a basis for assessment of mineral system affinity of a new early stage exploration target
- Provision of assistance in the vectoring of exploration drillholes on the basis of geochemical, geological, and/or mineralogical gradients found to exist in known deposits of a similar type.

The approach undertaken in this study is to co-locate all available geoscientific datasets into a consistent 3D space and then to use this information where possible to produce additional interpretive or illustrative components to aid understanding of the controls or halo of the deposit in question.

This report forms part of the New Economy Minerals Initiative (NEMI) undertaken by the Queensland Department of Resources.

This atlas details 13 mineral deposits or districts (Figure 1) in 11 chapters (plus this introductory preface). Data has been sourced mainly from public domain information, but the generous provision of data and support by the organisations and individuals in the Acknowledgements section has been gratefully received.

The aim of each atlas chapter has been to provide a compilation of geoscientific information for each deposit, with a focus on:

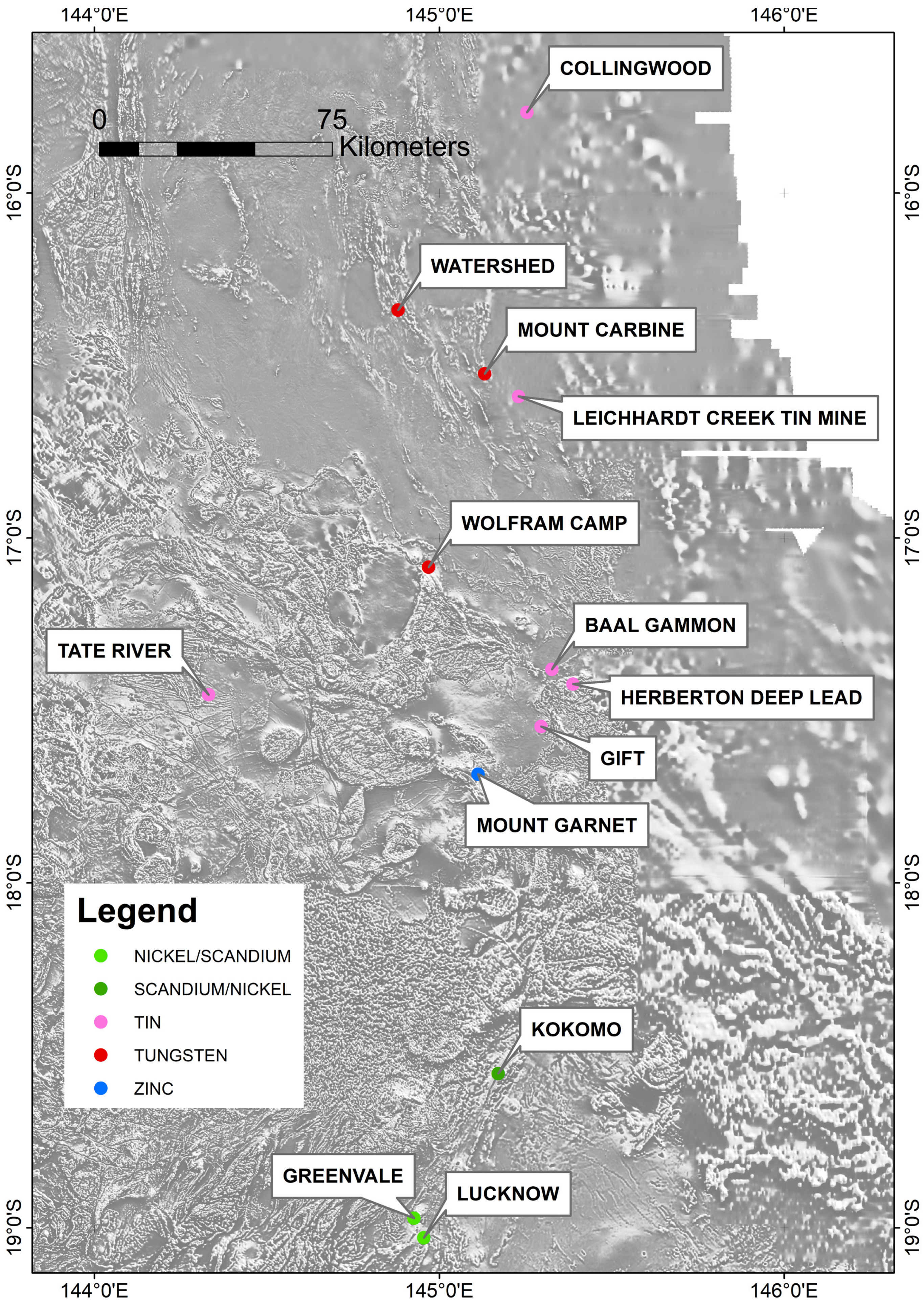
- Location
- Basic resource and production information;
- Geology of host rocks and alteration;
- Orebody dimensions and geometry;
- Basic structural characteristics and history;
- Characteristics of the inner and outer halo of the deposit in terms of:
    - Extent;
    - Geophysical expression;
    - Exploration geochemistry;
    - Lithogeochemistry; and
    - Mineralogy
- Relative and absolute timing of mineralisation (where possible to determine)

The aim wherever possible is to express these characteristics in a way that can be applied to routinely collected exploration datasets such as widely available geophysical data or commercially available geochemical laboratory suites.

The aim of these atlas chapters is NOT to extensively revisit and update the well-studied and long-debated process models for each deposit type (summarised for example in Taylor, 1979 and Taylor and Pollard, 1984). This is not to say that such process models are not important, as they play an irreplaceable role in the area selection process. As noted by McCuaig et al (2010), as exploration progresses to more detailed scales there is a decrease in the effectiveness of model-based conceptual targeting and an increasing reliance on direct detection, with its associated high risk of "false positives". The best way to maximise the effectiveness of exploration at this scale is to ensure that exploration is being carried out with the most comprehensive knowledge possible of the expression of the outer and inner haloes of the deposit style in question.

The structure of information heading for the atlas entries used as a starting point the structure presented in Meriwa Report Number 193 (Vanderhor and Graves, 1998), which presented summary information on a large number of gold deposits from the Yilgarn Craton of WA. Departures from this structure included more specific sections relating to the inner and outer haloes, as well as a stronger emphasis on the provision of graphical content relating to the expression of the deposits in typical geoscientific datasets.

Figure 1: Location of the deposits covered in this atlas overlain on an image of total magnetic intensity from the GSQ aeromagnetic surveys.



## OVERVIEW

This Atlas details 10 specific mineral deposits plus three tin districts (Gift/Silver Valley, Mount Garnet, and Herberton) in 11 chapters. The deposits are dominated by tin ± tungsten, but also include a zinc skarn and a nickel-dominated laterite deposit. Additional commodities include indium, molybdenum, copper, silver, cobalt and scandium (Table 1).

The Northeast Queensland Mineral Province was once a primary part of Australia's mining industry. However, towards the end of the 20th century, the region's mines were largely abandoned or down-scaled due to a lack of demand for the metals that were prolific in the region (primarily Sn, W, and Mo) (Chang et al, 2017). With the rise of battery technologies, these metals have once again started to gain traction in the mining industry through increasing demand (Lèbre et al, 2020).

The key deposits of northeast Queensland are commonly polymetallic deposits, with the primary mined commodities being tin, tungsten, molybdenum, silver and copper, with lesser zinc and lead (Chang et al, 2017). Northeast Queensland is recognised as a world-class tin district, with the Herberton-Mount Garnet and Cooktown districts specifically documented in Taylor (1979).

In addition, this atlas includes a chapter detailing the SCONI Ni-Co-Sc laterite deposits, of which the Greenvale deposit was a historic producer of nickel, and which are now being revisited by Australian Mines Ltd.

Northeast Queensland's largest tungsten deposits are Mt Carbine (containing ~83,706 t $WO_3$) and Watershed (containing ~70,400 t $WO_3$). These two mines account for approximately 90% of known tungsten resources (Chang et al, 2017). The region's tin resources are more evenly divided, with numerous small deposits. Over 80% of tin deposits in northeast Queensland contain under 100 tonnes of Sn (Chang et al, 2017). The Herberton district (Chapter 10) contains two thirds of the known Sn resources.

Regionally, the Sn-W mineralisation is linked to the intrusion of Carboniferous-Permian igneous units, particularly the Kennedy Association. The mineralisation types can be separated into Sn, W, W-Mo, Au-Cu and Au mineralisation, with the mineralisation type varying spatially, with several epsiodes of Sn, W-Mo and Au mineralisation occurring between 351 Ma and 264 Ma. There is a general younging trend within the mineralisation-associated intrusive units from southwest to northeast (Chang et al, 2017).

## DEPOSIT STYLES

The tin-tungsten deposits tend to fall into one of four categories, albeit with significant overlap between the various types:

1. Greisens ± vein component (Dalcouth, Baal Gammon, Wolfram Camp)
2. Vein or stockwork-dominated (Mount Carbine, Watershed)
3. Polymetallic skarns (Pinnacles, Mount Garnet Deeps and Gillian)
4. Alluvial (Kangaroo Creek, Tate River, Herberton Deep Lead, Leichhardt Creek)

The only zinc dominant deposit included in this atlas is the Mount Garnet zinc deposit, which is a skarn-hosted deposit. The single nickel (Ni-Co-Sc) deposit documented is SCONI, which is a laterite deposit.

## DATE OF DISCOVERY

Nine of the thirteen deposits or districts were discovered in the late 1800's, with three discovered in the latter half of the 1900's, being SCONI in 1957, Watershed in 1978, and Leichardt Creek in 1984.

## DISCOVERY METHOD

Given the predominance of discovery dates in the 1800's it is not surprising that nine of the deposits were discovered through prospecting.

The deposits discovered in the latter half of the 1900's were through geochemical methods (stream sediment, rock chipping) or dredging/drilling.

Conceptual targeting does not appear to have played a key role in any of the discoveries.

## GEOPHYSICAL HALOES

The deposits included in this atlas appear to have minimal to no direct geophysical haloes. This is a result of the predominance of tin-tungsten deposits which do not have an abundance of sulphides or magnetite as evident in many base metal deposits, or some precious metal deposit styles, for example.

The Mount Garnet zinc deposit does display a low magnetic signature, which is unexpected given the presence of magnetite in the alteration assemblage. However, this is likely related to historic and current mining activities and impacts.

Instead, geophysical data in the form of airborne magnetic and radiometric datasets can be used to indirectly map the deposit environment. In particular, geophysical data can be used to map the distribution, and potentially the degree of fractionation and redox state, of the many granites in the district for use as exploration indicators (Gow and Lisitsin, 2021).

## GEOCHEMICAL HALOES

Given much of the historic mining in the northeastern Queensland districts included in this atlas commenced prior to the development of modern geochemical analytical techniques, it is difficult to determine with confidence what component of the modern geochemical signatures are primary and which are contamination (particularly for stream sediment data).

However, stream sediment sampling was successfully employed in discovery of the Watershed tungsten deposit, discovered in 1978. The stream sediments were anomalous in W, Sn, As and Cu (Chapter 3).

Soil sampling around the Mount Garnet zinc deposit shows strong anomalism in Cu, Pb, Zn (Chapter 6), suggesting that pre-mining it would have displayed a significant soil anomaly. This is not surprising given it was originally discovered through identification of secondary copper oxide at surface.

The SCONI deposit (Chapter 5) was first identified through mapping and sampling of a laterite (by BMR and GSQ) in 1956. However, it was rock chip sampling of a nickel-enriched silicate zone beneath the ferruginous cap in 1966 that returned nickel values in excess of 3%. This established significant nickel anomalism that was ultimately followed up by RAB drilling to confirm the presence of a significant deposit.

## ALTERATION HALOES

There are numerous types of alteration haloes to the NEQ deposits included in this atlas, the most prominent of which include skarn and greisen styles.

Skarn

Skarn type alteration is present at the Watershed, Mount Garnet zinc, and several of

Table 1: Summary of deposits/districts included in this atlas, with commodity, deposit type and discovery details.

| Deposit Name | Metal/Mineral | Type | Date of Discovery | Method of Discovery |
|---|---|---|---|---|
| Wolfram Camp | W | Greisen | 1888 | Prospecting |
| Mount Carbine | W | Sheeted veins | 1883 | Prospecting |
| Watershed | W | Sheeted veins | 1978 | Stream sediments |
| Baal Gammon | W-Cu-(In) | Greisen/stockwork | 1892 | Prospecting |
| Gift/Silver Valley tin district | Sn | Greisen | N/A | N/A |
| SCONI | Ni-Co-Sc | Laterite | 1957 | Rock chips |
| Mount Garnet Zinc | Zn-Cu-Ag | Skarn | 1897 | Prospecting |
| Mount Garnet tin district | Sn | Greisen/stockwork/skarn | 1880 | Prospecting |
| Kangaroo Creek Alluvials | Sn | Alluvial | 1880(?) | Prospecting |
| Tate River Alluvials | Sn | Alluvial | 1880(?) | Prospecting |
| Collingwood | Sn | Sheeted veins/greisen | 1880(?) | Prospecting |
| Herberton tin district | Sn | Greisen/stockwork/alluvial | 1879 | Prospecting |
| Leichardt Creek | Sn | Alluvial | 1984 | Dredging/drilling |

the Mount Garnet district tin deposits (Gillian, Pinnacles). The skarn mineral assemblages comprise various combinations of garnet, clinopyroxene, actinolite, and magnetite.

Greisen

Greisen alteration is common at Wolfram Camp, Baal Gammon and Collingwood. The mineral assemblage comprises qtz-muscovite (or sericite) and various quantities of topaz, tourmaline and fluorite. Apatite is reported at Collingwood.

## ACKNOWLEDGEMENTS

This project received data, funding and support from the Geological Survey of Queensland.

In addition, assistance and/or data was kindly provided by Judy Botting and Paul Dirks of JCU, and Jaime Poblete.

## REFERENCES

Chang, Z., Dirks, P., Spandler, C., Henderson, R., Ford, A., Cheng, Y., Corral, I., Sahlstom, F., Behnsen, H., Poblete, J., Illig, P., Liu, K., Clarke, G., Stokes, M. and Huizenga, J.M. 2017. Characterising and assessing prospectivity of intrusion-related hydrothermal mineral systems in north-east Queensland: Final Report. Geological Survey of Queensland CR116866, https://geoscience.data.qld.gov.au/report/cr116866

Gow, P.A. and Lisitsin, V., 2021. Queensland New Economy Minerals Compilation: TIN-TUNGSTEN, Sustainable Minerals Institute, University of Queensland, GSQ Data Portal: https://geoscience.data.qld.gov.au/report/cr125718

Lèbre, É., Stringer, M., Svobodova, K., Owen, J. R., Kemp, D., Côte, C., Arratia-Solar, A. & Valenta, R. K., 2020. The social and environmental complexities of extracting energy transition metals. Nature communications, 11(1), 1-8.

McCuaig, T., Beresford, G., & Hronsky, J. 2010. Translating the mineral systems approach into an effective exploration targeting system. *Ore Geology Reviews, 38*(3), 128-138.

Taylor, R.G., 1979. Geology of Tin Deposits, Developments in Economic Geology, vol.11, Elsevier Scientific Publishing Company.

Taylor, R.G. and Pollard, P.J., 1984. Recent advances in exploration modelling for tin deposits and their application to the south east Asian environment, EGRU Contribution 10, James Cook University, Townsville.

Vanderhor, F. & Groves, D. 1999 Systematic documentation of Archaean gold deposits of the Yilgarn Block (Project No. 195) Perth: Minerals & Energy Research Institute of Western Australia.