Securing the future of copper, gold, and bismuth resources in northern Australia: A proposal for systematic mineral chemistry and event chronology of the Tennant Creek iron oxide–copper–gold district, Northern Territory

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The high level of life quality that many Australians enjoy today is sustainable only if sufficient natural resources can be discovered, extracted, processed, and manufactured into saleable products efficiently. Added to this is the fact that many mineral resources are being discovered less frequently today than in the past. Therefore, the need for new discoveries of 'Tier 1' critical and strategic mineral resources in Australia – especially copper, cobalt, and rare earth elements (REE) – is greater now than at any point in the past (Tier 1 is defined as a deposit that contains > 4 Mt Cu; Schodde 2022). Mineral explorers across the nation are thus in need of more information and better exploration tools to help them locate such resources in a timely manner, especially in areas that have been overlooked in the past.

One such area is the Tennant Creek iron oxide–copper–gold (IOCG) district in central Northern Territory (Large 1975, Skirrow and Walshe 2002). Tennant Creek is arguably Australia's most underexplored IOCG district but has been and continues to be one of Australia's highest-grade gold-producing regions (Maidment *et al* 2013). Tennant Creek is unique among Australia's IOCG terranes in that many of its deposits are enriched in bismuth, and more than 14 000 t of bismuth have been recovered from the Tennant Creek mineral field (Skirrow and Walshe 2002). Bismuth is included on Geoscience Australia's list of critical minerals that already are or will be in high demand as Australia aims to become a key provider in the critical minerals supply chain by 2030[4]. This aim can only be achieved through increased discovery rates of resources such as those found in the Tennant Creek district – rates which can only increase through improved geological understanding and better exploration tools.

Tennant Creek and its neighbor, the East Tennant region, are currently the focus of significant interest and exploration expenditure by numerous mining companies looking for base, precious and critical metal resources. This interest is driven by the fact that both areas (East Tennant, in particular) are significantly underexplored in comparison to the major Australian IOCG provinces – the Gawler Craton (South Australia) and the Mount Isa Inlier (Queensland) – and as such they garner major attraction as relatively 'unknown' areas with significant potential for new discoveries. A corollary to this is that the geologic understanding of Tennant Creek and the East Tennant region is inferior to that in the other IOCG provinces, which hampers exploration efforts due to lack of knowledge. Moreover, to date, no single Tier 1 copper–gold system has been discovered in the Tennant Creek district, and no copper–gold system of any size has been found in the East Tennant region.

Discovering a Tier 1 ore system in a district where no such system is known to exist, despite having a long history of exploration and mining activity already, is not easy, but there is precedent: for example, the Lachlan Orogen of central-southern NSW has been explored and mined continuously since the mid-1800s, but no Tier 1 ore system was known there until the discovery of the Cadia Hill–Cadia East/Far East–Ridgeway copper–gold deposit complex in the early 1990s (Wood 2014, Harris *et al* 2020).

For a Tier 1 or world-class deposit to form, several key factors are required. One key factor is evidence of multiple metal-forming hydrothermal events in the district (Meffre *et al* 2016). For instance, research at Olympic Dam, South Australia – the world's largest IOCG deposit – has demonstrated that ore-forming events occurred over nearly 1 billion years of Earth history; furthermore, certain events were more productive than others (Ehrig *et al* 2021).

Previous U–Pb geochronology research in the Tennant Creek area has shown that multiple ore-forming events occurred over a >200 my period (**Figure 1**; Johns 2010, Skirrow *et al* 2019, Farias *et al* 2022). These results increase the likelihood of existence of a Tier 1 ore system in the Tennant Creek mineral field. By fingerprinting the age of the most productive events, exploration models can be readjusted accordingly to maximize potential for a discovery. For example, preliminary laser ablation–inductively coupled plasma–mass spectrometry (LA–ICP–MS) work on hematite and chlorite from the Mauretania gold deposit at Tennant Creek has demonstrated their capability to provide geochemical vectors towards ore (**Figures 2**, **3**; Meffre *et al* 2022). When geochronological work such as that described above is combined with mineral chemistry vectoring techniques, such as those developed for epidote and chlorite in porphyry copper deposits using LA–ICP–MS (Cooke *et al* 2020), the result is a powerful tool with great potential to increase the probability of discovery.

This proposal aims to continue and expand mineral chemistry and event chronology research across the entire district with the goal of identifying the most likely target areas for Tier 1 IOCG resources. Tennant Creek and the East Tennant region represent two of the most well-endowed mineral regions in the Northern Territory. Gold was first discovered near Tennant Creek in the early 1930s (Ahmad *et al* 2009), and many companies have explored or mined parts of Tennant Creek over the last 80 years. Moreover, the Tennant Creek and East Tennant areas have significant potential to become major critical mineral producers, including not just additional bismuth but also cobalt, selenium, REE, and uranium.

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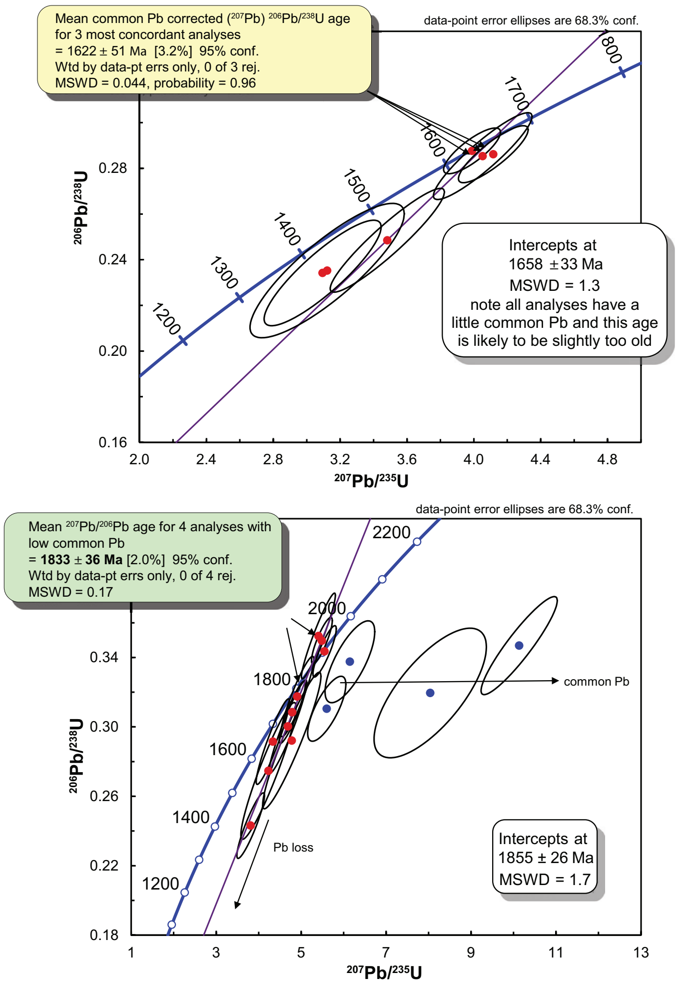

Figure 1. Uraninite U–Pb ages from the Northern Star IOCG deposit, Tennant Creek (Johns, 2010). Note the ~200 my spread in ages between the two samples (ie 1650 Ma vs 1850 Ma).

IOCG deposits such as those in the Tennant Creek district typically contain elevated levels of cobalt, REE and uranium; and in certain cases, there are sufficient concentrations of one or more of these metals to form a mineable resource (eg uranium at Olympic Dam; Ehrig *et al* 2021). Furthermore, granites of the Tennant Creek district exhibit strong enrichments in REE, but few constraints exist on the size and deportment style of the REE mineralisation in these rocks. This project will address these knowledge gaps by developing and using several geochemical and geochronological tools to be provided to Tennant Creek explorers with the aim of de-risking exploration programs in the short- and medium-term and increasing the long-term probability of discovery of a Tier 1 ore system.

The four primary geochemical tools for this work will be:

- bulk-rock digestion via aqua regia
- ultra-fine fraction (UFF) gold-in-soil anomaly detection
- electron microprobe (EPMA)
- LA–ICP–MS.

Each technique is suited for a different purpose and has a different level of access. For instance, aqua regia digestion and UFF are well-known and commercially available techniques that all explorers can and do use on a regular basis. On the other hand, EPMA and LA–ICPMS are more restricted in their availability to the public and more cost-intensive. However, all bulk-rock techniques suffer from an inherent lack of spatial/mineralogical context, so in cases where aqua regia or UFF results are unclear or unusual, EPMA and LA–ICPMS will be employed in the workflow to resolve discrepancies and other mineralogical issues.

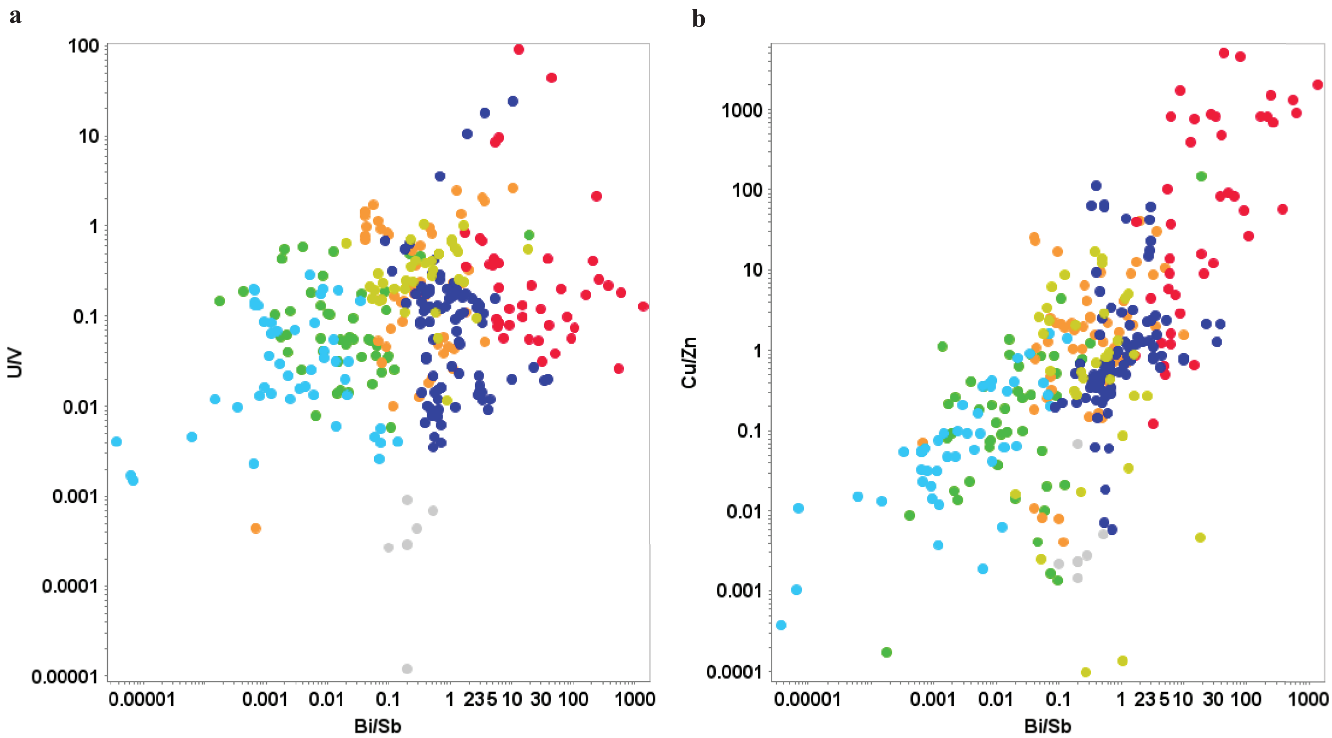

Figure 2. Element ratios in hematite analyses from the Mauretania IOCG deposit, Tennant Creek (Meffre *et al* 2022). Colours are coded according to distance from the deposit, with blue representing the furthest sample and red representing the closest sample. (**a**) U/V vs Bi/Sb. (**b**) Cu/Zn vs Bi/Sb.

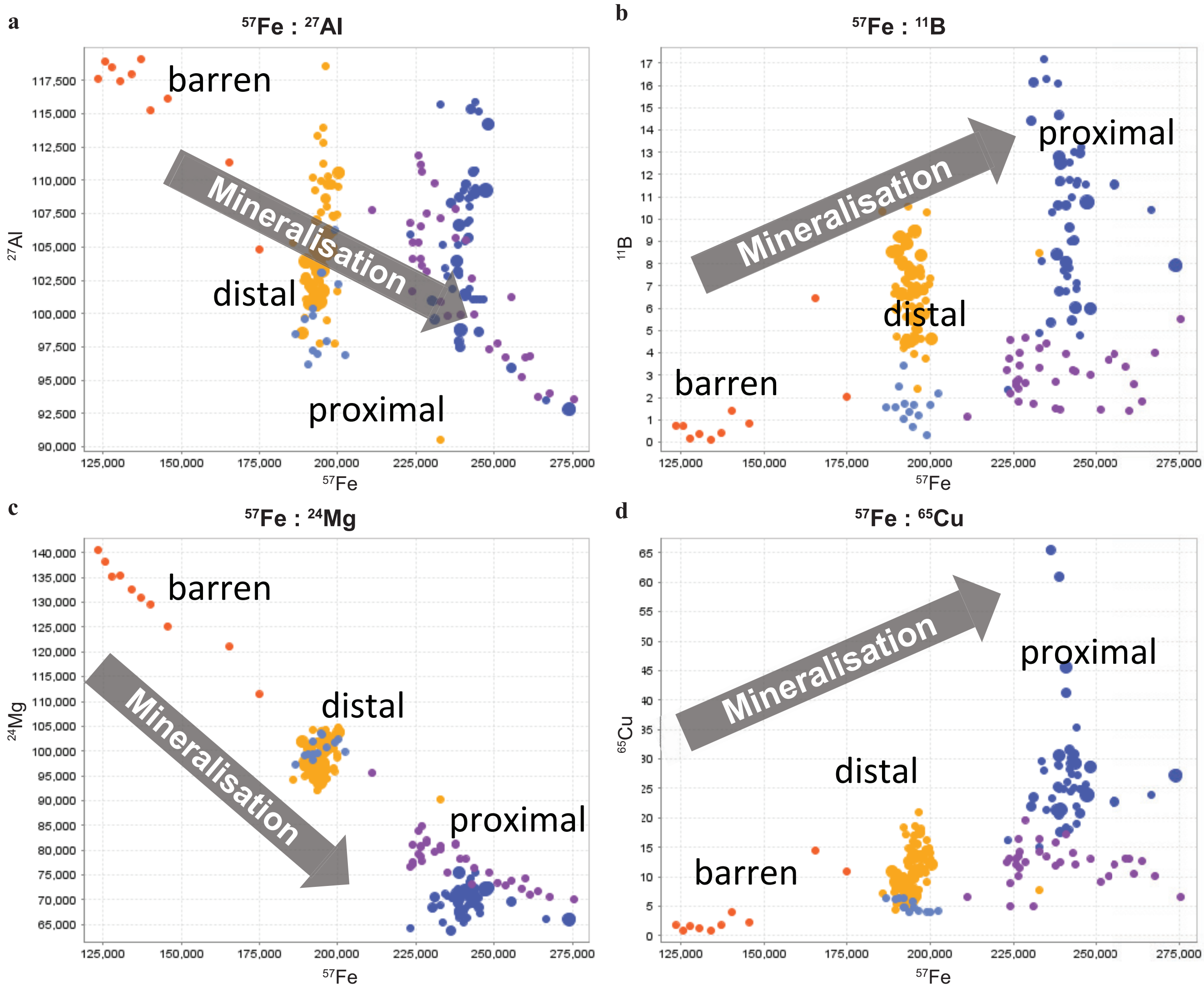

Figure 3. Element ratios in chlorite analyses from the Mauretania IOCG deposit, Tennant Creek (Meffre *et al* 2022). Dots are color-coded according to distance from the deposit, with blue representing the closest and red representing the furthest sample. (**a**) Al/Fe. (**b**) B/Fe. (**c**)Mg/Fe. (**d**) Cu/Fe.

As for geochronology, the main tool will be LA–ICP–MS, supplemented by one or more finer-scale techniques if necessary or desired, such as SHRIMP (sensitive high resolution ion microprobe) or SIMS (secondary ionization mass spectrometry).

The principal advantage of this proposal is the potential to cover most (if not all) of the Tennant Creek district with the above techniques, something that has never been done previously. If successful, it would represent a sea change in mineral exploration, not just for Tennant Creek but for other districts all across Australia and overseas. Integrating multidisciplinary techniques across multiple scales is the key to unlocking the mineral potential for any region, and it is high time for Tennant Creek to rise to the fore in this arena.

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