Discovering the undiscovered – New ideas and technology in the mature Tennant Creek Mineral Field

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This paper details the logic behind the first application of commercial seismic reflection surveys in the Tennant Creek Mineral Field (TCMF) by Emmerson Resources Limited (ERM). It includes the interpretation and results of the deepest surface drillhole designed to test the seismic anomalies beneath known ironstones that were generated from a line of seismic reflection within the Gecko mine area (**Figure 1**). This high-risk drilling was made possible by co-funding from the Northern Territory Geological Survey (NTGS) as part of the *CORE* program and our Joint Venture partners, Evolution Mining (EVN). Encouragement from the drilling results led to a 60 km regional traverse of 2D seismic reflection extending over a large part of the northern Warramunga Province (**Figure 1**). This traverse provides the first look at the 'crustal plumbing' of this well-endowed gold-copper province and images many key ingredients of the exploration model including relationships between deep-

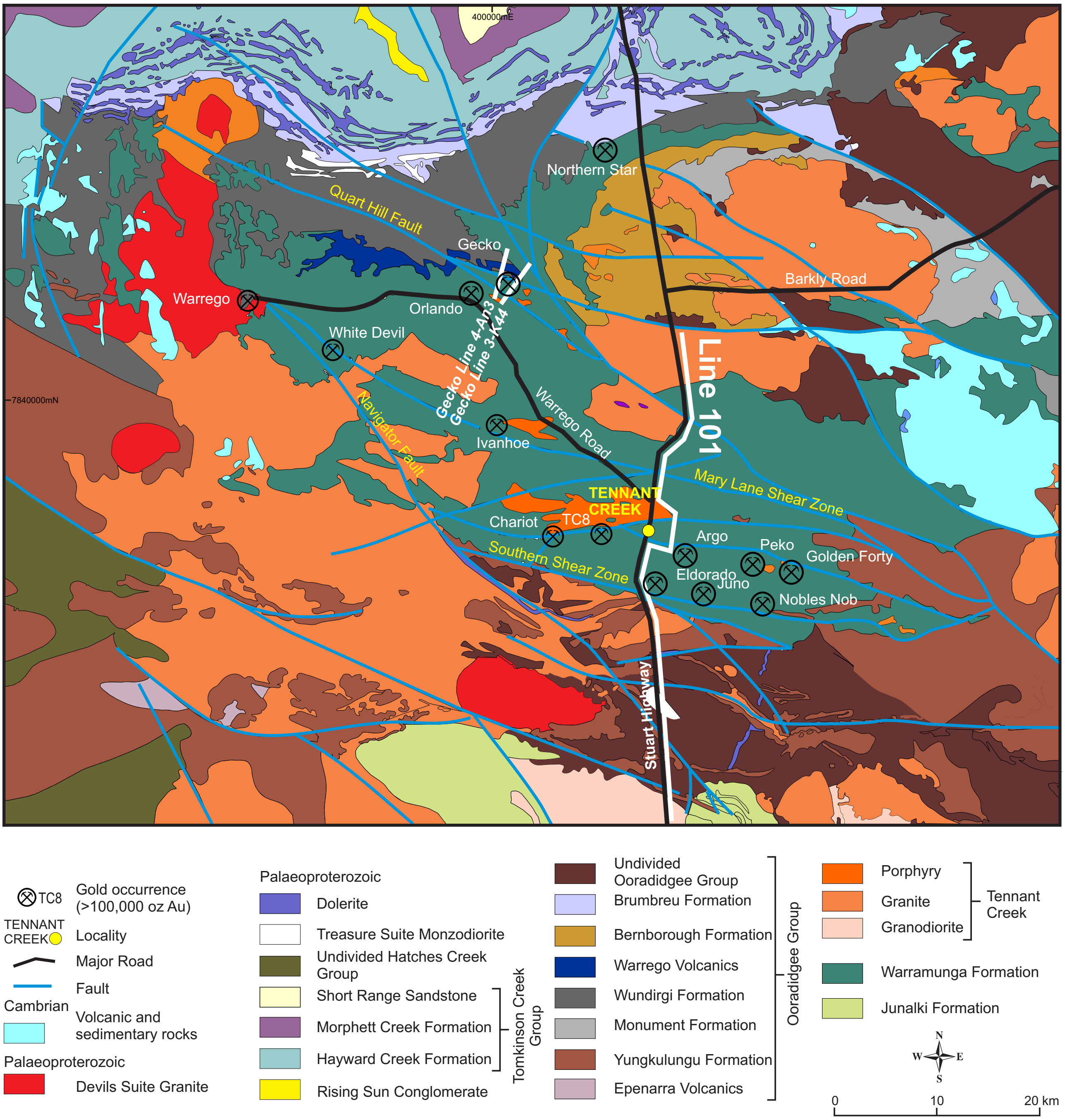

Figure 1. Geology and major gold mines (production >100 000 oz Au) of Tennant Creek Mineral Field showing location of trial shallow seismic profiles at Gecko L4-An3 and L3-K44 and regional deep seismic profile line 101 (modified after Johnstone and Donnellan 2001).

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seated structures, Warramunga Formation (WF) host rocks and intrusive rocks of the Tennant Creek Supersuite (TCS).

The TCMF was discovered in 1925 and mining has produced approximately 157 t of gold, 345 000 t of copper, 14 000 t of bismuth, 220 t of selenium and 56 t of silver from 130 mines; the majority of this production being derived from 12 deposits (Donnellan 2013). The ore occurs as free gold and Cu-Bi sulfides hosted within magnetite-haematite-chlorite-quartz bodies of hydrothermal origin locally known as ironstones. The ironstone bodies have variable dimensions, averaging 200 m long x 40 m wide x 290 m depth, extending from surface to 600 m depth, but commonly mineralised between 100 m and 400 m below the surface. The vast majority of ironstones are barren, but some are mineralised and have provided excellent economic returns as a consequence of their bonanza gold grades, despite their relatively small footprint.

Exploration success within mature provinces is dependent on a clear strategy that provides a focus and framework for exploration and funding. The strategy needs to take account of both technical and non-technical aspects; for example, fostering a discovery culture within the exploration team is as important as ensuring 'stakeholder relations' that permit the conversion of new ideas and technology into timely on-ground activities. The dimensions of a successful strategy are many but some of the more important elements relate to ensuring exploration is conducted within a business framework that avoids tracking down the path of 'diminishing returns' – often seen in times of high metal prices and 'easy' financing.

Since inception in 2007, ERM has been solely focused on its 2500 km^2 Tennant Creek Project. The technical strategy relies on applying the best science and technology to unlock a new generation of gold and copper discoveries. To date ERM has discovered the *Goanna*, *Monitor* and most recently, *Mauretania* mineralisation by utilising a combination of new exploration models and detection technologies. Detailed gravity, induced polarisation and airborne electromagnetics were used to refine the models and provide drill targets, but despite advances, these techniques are still limited to ~300 m effective depth penetration. Although historically the largest deposits in the TCMF extend to 600 m depth and existing drilling indicates they do not persist to greater depths, the question of possible 'structural repeats' at depth (as suggested in our exploration models) remains unanswered.

Seismic exploration techniques have long been the tool of choice in the hydrocarbon industry, but they are only now being applied to mineral exploration. The advantage of such techniques lies in their great depth penetration, but when weighed up against order-of-magnitude higher acquisition and data processing costs, as well as the specialist skills needed to interpret the data, the easier decision is typically to assign such surveys to the 'too hard/too expensive' basket.

The TCMF has a long association with seismic techniques. A reconnaissance seismic refraction survey was undertaken by the Bureau of Mineral Resources (BMR) in 1979 to investigate the use of seismic methods to determine geological structures in areas where younger cover rocks prevent direct examination of rocks of potential economic importance (Finlayson 1981). Finlayson proposed a simple layered model for the thickness of the Warramunga Group with values of about 2.6 km near Nobles Nob mine, thinning to about 1.2 km near Warrego mine. He noted that the nature of the change between the surface and 'basement' rocks is likely to be complex, resulting in a velocity transition zone rather than a simple boundary and therefore the estimated depths to 'basement' were considered to be minimum estimates (Finlayson 1981).

GeoPeko Ltd trialled the use of seismic reflection in the Tennant Creek region in 1988. Two short N–S lines were conducted: one over the One-Oh-Two ironstone located 1.3 km east of the Orlando mine (line length 800 m), and the other over the R54 ironstone at Gecko [100 m east of the K44 ironstone, line length 1 km (Root 1989)]. Root concluded the main use of shallow seismic techniques in mineral exploration was as a supplement to drilling, and that some knowledge of the subsurface geology was required for a meaningful interpretation of seismic sections in complex terrains.

ERM's joint venture partner, EVN, is a strong proponent of deploying seismic reflection surveys to define fertile structures and mineralisation at many of its operating mines in Australia; thus a trial program comprising 4 lines of 4 km length was executed over the Chariot East, Goanna, Gecko K44 and Gecko An3 ironstones using a weight drop source. The most encouraging line (prior to reprocessing based on downhole logging) was over the Gecko K44 ironstone, located at the geographic centre of the Gecko Au-Cu camp. This prompted the *CORE* submission for a co-funded deep drillhole designed to test beneath the known ironstones for structural repeats, provide further data on the 3D mineralisation and alteration, and to ascertain the efficacy of seismic as an exploration tool.

A single hole, GODD032, was drilled at the Gecko K44 Deeps target on ML23969 to a total depth of 1279 m. The hole was a great success, intersecting shallow copper mineralisation (in the pre-collar) and encouraging components of the exploration and structural model at depth (**Figure 2**). Specifically, the intersected mineralisation can be categorised into two zones: shallow copper-rich and deep ironstone.

Drilling through the copper zone intersected multiple quartz-chalcopyrite veins analogous to the recently discovered Goanna mineralisation that lies ca 800 m to the east. **Figure 2** shows the significant assay results that include 7 m at an average grade of 5.98% Cu and 0.46% Bi from 123 m (*including* 3 m at 10.4% Cu and 1.01% Bi from 126 m and 1 m at 15.48 % Cu and 1.16% Bi from 127 m), 1 m at 1.00% Cu and 969 ppm Bi from 134 m, 1 m at 2.08% Cu and 1759 ppm Bi from 138 m and 3 m at 4.75% Cu, 694 ppm Bi from 162 m (*including* 1 m at 10.6% Cu and 654 ppm Bi from 163 m).

The deep ironstone zone was intersected in the footwall of a major fault within the Gecko Corridor (a 300–400 m wide zone that hosts the Gecko ironstones and extends ESE to the Quartz Hill Fault), some 1 km below the surface;

it is the deepest ironstone discovered to date within the TCMF. This ironstone comprises 4.2 m of hematite-quartz-jasper, locally exhibiting ptygmatic to colloform/crustifom textures, but failed to return significant economic mineralisation. However, the associated and extensive alteration assemblages of chlorite-sericite-quartz proximal to the Gecko fault, varying to chlorite-sericite-quartz; chlorite-quartz and finally distal, quartz-chlorite, are highly encouraging as they are commonly associated with Au-Cu mineralisation.

Mineralised intermediate dykes were intersected from 968–998.2 m (900 m below surface) and have been dated at 1854 ± 13 Ma (U/Pb zircon) confirming they belong within the TCS. Also of great interest was the intersection of 10 m of pervasive quartz-dolomite alteration (intersected at 1175 m depth) above the haematite ironstone; this alteration is typically associated with distal hydrothermal fluids or 'near miss' situations.

Subsequent reprocessing of the seismic line over the Gecko An3 ironstone located ca 800 m to the west (**Figure 1**) has revealed a stronger reflector at depth in a similar position to the ironstone intersected in GODD032.

In terms of the regional picture, it was postulated as early as 1989 that the ironstones in the TCMF are related to, and perhaps even emplaced in thrust faults developed during basin inversion. The idea, first documented by Etheridge (1989), was further developed by Rattenbury (1990, 1994) and then linked to mineralisation by Skirrow and Walshe (2002). The concept includes reactivation of major thrust faults developed during basin inversion that serve as loci for development of iron oxide bodies (ironstones). These faults are subsequently mineralised during brittle transcurrent or transpressional events, with the fault planes acting as conduits for the mineralised fluids, driven by felsic intrusive rocks of the TCS.

One 60 km 2D seismic reflection line was acquired by HiSeis Pty Ltd (HiSeis) along the Stuart Highway, 30 km to the north and south of Tennant Creek (**Figure 1**). The aim of this 2D survey was to image the upper crust, pinpoint major thrust faults and better understand specific elements of our structural and exploration model – specifically the spatial distribution of the TCS and its relationship to structure.

Although care must be taken in interpreting 2D sections because observed reflections may not originate from directly below the survey line, initial results suggest that all of the major gold-copper deposits in proximity to line 101 (Eldorado, Argo, Chariot) are associated with northward-verging thrust faults that extend down to about 10 km depth (**Figure 3**). This survey also revealed a number of newly identified thrusts that lack surface expression and known mineralisation, yet in all respects are similar to the mineralised thrusts. In addition, it appears the survey has imaged voluminous felsic intrusive rocks with a major sub-horizontal boundary visible at approximately 20 km depth. This boundary may represent the top of a different seismic

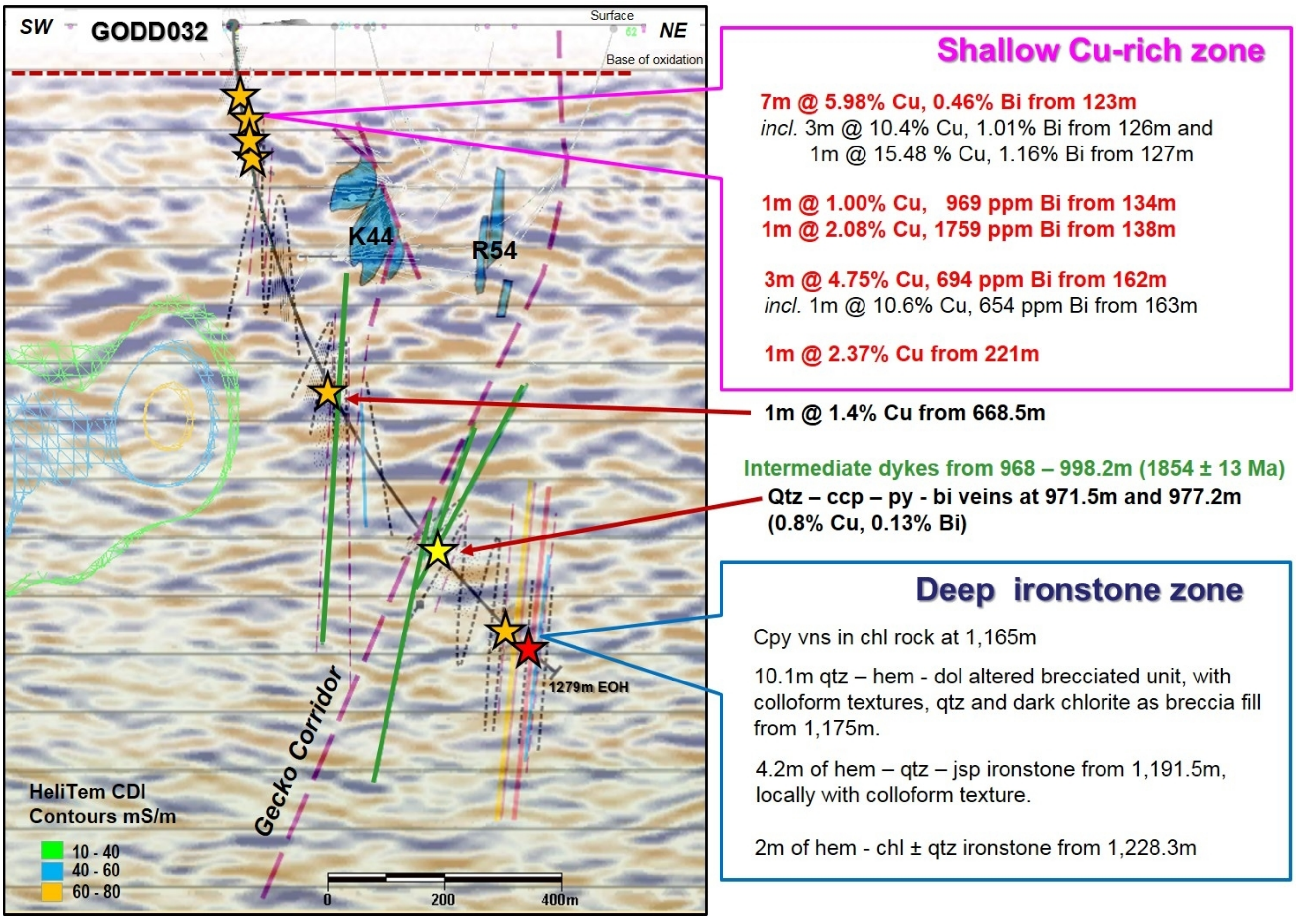

Figure 2. Cross-section of drillhole GODD032 under Gecko K44 and R54 ironstones (blue polygons) superimposed on final seismic section. Significant geological/assay intervals highlighted.

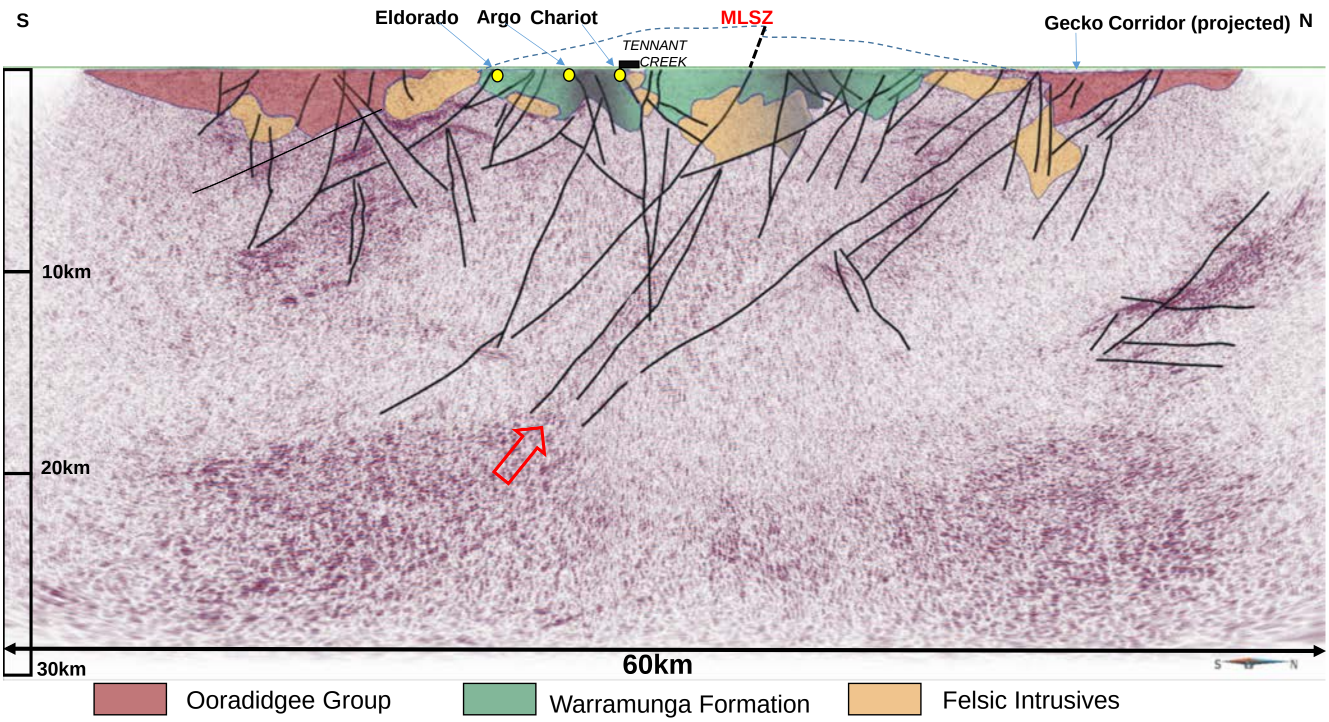

Figure 3. Preliminary geological interpretation of upper portion of regional seismic profile 101. Arrow indicates where Mary Lane Shear Zone (MLSZ) nucleates off major sub-horizontal boundary representing the top of a different seismic domain of strong reflectivity at approximately 20 km depth. Dashed blue line marks postulated unconformity between Warramunga Formation and Ooradidgee Group, now domed.

domain, possibly analogous to the top of the Ooratippra Seismic Province defined in line 09GA-GA1 (Georgina Basin-Arunta Region), located 210 km to the southeast (Korsch *et al* 2011). One of the key structures in the TCMF is the Mary Lane Shear Zone which is clearly visible above and nucleating from the top of this zone (**Figure 3**).

This regional, 60 km long, deep seismic reflection traverse has provided some further insights into the subsurface geology of the TCMF; it has also revealed some tantalising new structures that remain unexplored.

Additional details of the Gecko K44 drillhole and regional seismic traverse can be found in the respective reports submitted as part of the *CORE* program.

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