# Intrusion-Related Gold Systems in the New England Fold Belt – The Tooloom Example

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#### Intrusion-related Gold Systems

Intrusion-related gold systems (IRGS) are a relatively newly defined class of economically important gold deposits based largely on well-studied examples in the Tintina Gold Belt of Yukon/Alaska (eg. Thompson et al., 1999, Thompson & Newberry 2000, Lang et al., 2000). Whilst some debate and confusion has surrounded the nomenclature of these systems since initial recognition, a generally widely accepted set of geologic and geochemical criteria have now been established to define this model. General characteristics, according to Thompson et al. (1999) and Lang & Baker (2001) include:

- a metal assemblage variably combining Au with Bi, Te, W, Mo, As, Sb with a low sulphide content (<5%) and reduced ore mineral assemblage typically comprising arsenopyrite, pyrrhotite and pyrite and lacking magnetite or hematite;
- common metal and deposit style zoning centred on a central mineralising intrusion (Figure 1);
- spatial and/or temporal relationship with moderately reduced, I-type, intermediate to felsic intrusions;
- carbonic to rarely saline hydrothermal fluids;
- restricted zones of hydrothermal alteration;
- a continental tectonic setting inboard of inferred convergent plate margins;
- located in provinces best known for W and/or Sn.

Furthermore, IRGS systems are characterised by a range of mineralisation styles, both proximal and distal to the mineralising intrusion, as illustrated on Figures 1 and 2. These include:

- sheeted veins and stockworks;
- breccias;
- disseminated deposits;
- skarns;
- replacements; and
- distal base metal bearing fissure veins.

Vertical metal zoning is common and tends to differ from shallow to deeper systems with W±Mo at depth and Au-Bi at shallower levels (Figure 2). Shallower systems are often expressed as breccias with sericite-carbonate alteration more abundant at these depths. Furthermore, stibnite is more common in distal and high-level deposits, with Bi often characteristic of deposits in or close to plutons (Thompson & Newberry, 2000). However, some distal deposits locally contain elevated Bi. These criteria contrast significantly with geologic models for Cu-Au porphyry deposits, although some overlap is apparent with orogenic gold deposits.

Intrusion-related gold systems have been documented in relatively few districts around the world, however, the model is increasingly being applied to known gold systems with some success. The main documented IRGS provinces, according to Lang & Baker (2001), are the Tintina Gold Belt of Yukon/Alaska (Donlin Ck, Fort Knox, Pogo, Shotgun), the Bolivian

Polymetallic Belt (Kori Kollo), the Palaeo-Tethys Closure (encompassing deposits in China, Kazakstan, Czech Republic, Spain and Portugal) and the somewhat isolated occurrences of Eastern Australia in North Qld (Kidston, Red Dome) and north-eastern New South Wales (Timbarra in the New England Fold Belt). Of particular interest to this paper is the occurrence of IRGS in the New England Fold Belt (NEFB) and how the Tooloom Gold Project could represent a large, previously unrecognised IRGS in Eastern Australia.

## The Tooloom Example

The Tooloom Gold Project is located within the NEFB in far northeastern NSW, approximately 130 km south southwest of Brisbane (Figure 3). Alluvial gold was first discovered in 1857 and within a few years up to 10,000 people were mining predominantly alluvial gold from the Tooloom valley. Alluvial and small-scale hardrock mining operations continued into the late 1860's until the Gympie gold field was discovered, resulting in the majority of miners leaving Tooloom. Apart from some small-scale alluvial mining which has ceased only in recent years, Tooloom largely remained forgotten as a gold field until the involvement of Malachite Resources, which has re-discovered the Tooloom district in recent years. The Tooloom goldfield was first published on Government geological maps only in 2001, four years after Malachite began work in the area.

The Tooloom Gold Project lies within the Emu Creek Block of the southern NEFB. The oldest rock unit exposed in the project area is the Late Carboniferous – Early Permian Emu Creek Formation, comprising gently folded, uncleaved, interbedded, terrestrial to shallow marine sedimentary sequences and minor volcanic rocks (Brown et al., 2001). Massive, medium-grained, magnetic, calc-alkaline, intermediate to felsic, I-type intrusions of the Late Permian to Early Triassic Clarence River Supersuite intrude the Emu Creek Formation within the project area. These include the Jenny Lind Granite and a number of previously unrecorded diorite, granodiorite, tonalite, dolerite and gabbro intrusions. Monzogranite and leucogranite intrusions of the Early Triassic Moonbi Supersuite intrude the Emu Creek Formation and Clarence River Supersuite (Thompson, 1976; Bryant et al., 1997; Mustard, 2004) in the vicinity of the project. These are generally weakly magnetic, high-K, calc-alkaline, I-type intrusions associated with vein and disseminated gold (Timbarra; Mustard, 2001), molybdenum (Glen Eden; Soumarin & Ashley, 2004) and tin (Taronga; Suppel et al., 1998) mineralisation in the southern NEFB.

Four main intrusive centres (Phoenix, Cullens, Joes Gully and Frasers) have been defined at Tooloom, each of which is associated with a number of significant gold occurrences, both within and adjacent to the intrusive complexes. At the Joes Gully, Cullens and Frasers intrusive centres, gold resides in narrow, sheeted quartz veins and stockworks within Emu Creek Formation sedimentary rocks and adjacent to doleritic dykes. Alteration associated with the veins is weakly expressed as a narrow centimetre-scale selvage. Visible gold can be seen in outcropping quartz veins at prospects surrounding the Frasers intrusive centre, with gold values up to 100 g/t. More work is required to unequivocally link the mineralised systems at Joes Gully, Cullens and Frasers to the IRGS model. However, the style of mineralisation and close spatial association to intrusive phases at these prospects suggests the formation of a magmatic hydrothermal system related to these intrusives.

The Phoenix intrusive centre is the most significant IRGS discovered to date within the Tooloom project area. Phoenix was discovered by following up multiple, anomalous gold (+20 ppb) BLEG stream sediment samples collected as part of a regional exploration program. Mapping and prospecting up these creeks discovered outcropping hydrothermal breccia, named the Phoenix Breccia. Initial gold values from rock chip samples of the breccia were low (0.2 - 0.4 g/t Au), and subsequent soil sampling showed that gold in soil values over the breccia were anomalous but patchy and of low tenor. These factors are presumably the main reason why this system lay undiscovered for so long! The Phoenix Breccia lies on the northern side of an annular, moderately strong IP-chargeability anomaly and a coincident gold-arsenic-antimony-bismuth-copper soil geochemical anomaly measuring 1 km in diameter, as illustrated on Figure 4. The IP anomaly extends to at least 400 m depth, equating to at least one billion tonnes of mineralised rock. The coincident IP and geochemical

anomaly reflects a diffuse stockwork of quartz-carbonate-sulphide veinlets in patchy sericiticaltered, quartz-biotite-hornfelsed clastic sedimentary rocks of the Emu Creek Formation carrying low-grade gold-sulphide mineralisation (0.1-0.5 g/t Au). A 2 km diameter aeromagnetic low overlaps the mineralised system at Phoenix (Figure 4). Mapping defined the surface expression of the breccia to have a lensoid shape with a strong northeast – southwest structural orientation.

A zone of intense crackle brecciation/fracturing extends to the southwest of the breccia and includes a second significant Au-Bi-As-Cu soil geochemical anomaly. This zone, known as the Creek Zone, lies within a northeast striking structural corridor which encloses the Phoenix Breccia. Future work is planned to further define this mineralised zone.

A combined total of 26 RC and diamond drill holes have been completed at Phoenix to date. All holes drilled have encountered anomalous gold mineralisation in the breccia body or in Emu Creek Formation sedimentary rocks. Initial drilling was based on a 'Cadia-type' porphyry model, although more recent drilling focussed on the breccia pipe once its IRGS affinities were recognised. Drilling has defined sharp, near-vertical margins to the breccia body on the southeast and northwest contacts, however this body remains largely open to the northeast and southwest and at depth. The breccia has a true width of 85 m at its widest point, an outcrop length of 300 m and a northeast elongate pipe-like geometry that extends to at least 500 m vertical depth. The breccia is characterised by polymictic, angular to subrounded clasts ranging in size from less than 1 cm to several metres. Open space accounted for 5 to 20 vol% of the breccia prior to partial or complete cementation by at least two stages of guartz-carbonate-sulphide infill. The sulphide assemblage is dominated by arsenopyrite-pyrite with stibnite at shallower levels. Stibnite and pyrite tend to become subordinate with depth, with pyrite often replaced by marcasite. Clasts show little evidence of significant vertical displacement and often exhibit a "jigsaw texture". Clast lithologies are dominated by Emu Creek Formation sandstone and siltstone, however, dolerite, quartz-feldspar porphyry, feldspar porphyry and tonalite/granodiorite (70K Tonalite) clasts are also evident, particularly at depth. Hydrothermal alteration within the breccia consists of variably developed sericitisation, most intense on the northwest side of the breccia. The increased intensity of alteration tends to correspond with increased sulphide content and better gold grades, most likely related to higher permeability due to increased open-space on this side of the breccia. This side has the most potential for higher-grade shoots. Multiple broad intersections from the breccia include 48 m @ 2.21 g/t Au and 42 m @ 1.78 g/t Au from separate holes in the most recent drilling program. There is a clear association of gold with bismuth, arsenic and antimony mineralisation throughout the breccia and the presence of stibnite, with grades up to 8.3% Sb over 1 m, adds significant extra value.

A newly defined tonalite-granodiorite intrusive, know as the 70K Tonalite, has been mapped at Phoenix. This intrusive lies directly to the northwest of the Phoenix Breccia, however the breccia pipe itself is thought to be located within the hornfelsed aureole of a deeper seated, as yet unrecognised, mineralising intrusion. The 70K Tonalite phase appears to be prebrecciation as fragments of tonalite are found within the breccia. Possible evidence for a magmatic-hydrothermal system contributing to the formation of the breccia pipe at Phoenix is provided from the modelling of aeromagnetics and IP-chargeability data over the prospect. These data show anomalous responses attributed to an annulus of moderately magnetic, sulphidic-alteration (disseminated and veinlet pyrrhotite, pyrite and arsenopyrite) within biotite-grade siliceous-hornfels of the Emu Creek Formation. This feature lies within a magnetic low that might represent a blind intrusion located below the southern margin of the Phoenix breccia pipe (Figure 4). The presence of widespread hypogene pyrite-pyrrhotite mineralisation associated with the biotite-grade hornfels, and the occurrence of locally anomalous bismuth, arsenic, antimony and copper geochemistry in soils, further supports the presence and influence of a mineralising intrusion. The actual mineralising intrusion, however, is possibly a weakly magnetic leucogranite of the Moonbi Supersuite which may intrude the Emu Creek Formation and the 70K Tonalite below the Phoenix breccia pipe. Further evidence for a magmatic-hydrothermal association is provided by analogy with the Timbarra gold deposit, located about 60 km to the south-southwest. Timbarra is hosted in the carapace of a leucogranite member of the Moonbi Supersuite. This intrusion-related gold deposit has a distinctive metal association that is very similar to that at Phoenix, and its

formation has been clearly linked to a magmatic hydrothermal system directly related to the host intrusion (Mustard, 2004).

The relatively low Au-Bi correlation (<0.5), the high Au-As correlation (>0.8), the abundance of stibnite and arsenopyrite, and the patchy distribution of Bi throughout the Phoenix system suggest the breccia pipe maybe located mid-way between the proximal and distal deposit types (i.e. <1 km from source mineralising intrusion) as classified by Thompson & Newberry, 2000 (see Figure 2). Furthermore, and in accordance with these criteria, the Phoenix gold deposit most likely formed at a high level, with significant potential implied for a range of other deposit types associated with IRGS districts. This includes the possibility of significant zones of gold mineralisation occurring beyond the breccia pipe into peripheral stockworks, other unexposed or blind breccia bodies, zones of replacement-style mineralisation in reactive metasedimentary rocks, or mineralised buried intrusions (see Figures 1 and 2).

Additional exploration at Phoenix will be focussed on deeper drilling to better define the gold deposit hosted by the breccia body along strike and at depth, and ideally to discover the source mineralising intrusion. Additional targets ready for drill testing include a 40 m wide shear zone located adjacent to the Phoenix Breccia which exhibits stibnite occurring as "paint" and "rosettes" of needles on fractures, which could have behaved as a second conduit for mineralising fluids. Identical forms of stibnite have been observed within fertile structures at the Hillgrove Au-Sb mine located 220 km south of Tooloom.

### **IRGS in the New England Fold Belt**

The metallogeny of the NEFB is characterised by hundreds of occurrences of gold, tungsten, antimony, tin, molybdenum and base metals, particularly in the southern NEFB (see Figure 5). A strong spatial and temporal association exists between various styles of mineralisation and a suite of post-orogenic, Mid-Permian to Early Triassic, I-type, calc-alkaline, reduced, low-magnetic, felsic- to intermediate intrusives (Stroud et al., 1999; Stroud, 1999; Gilligan & Barnes, 1990). Some examples of these intrusive phases in the NEFB are the Moonbi Supersuite, the Clarence River Supersuite, the Uralla Supersuite, the Nundle Supersuite, the Gundle Belt, the Coastal Belt and various unnamed leucogranite intrusives. Deposit styles associated with these intrusives include veins, stockworks, pipes, disseminations, greisens and skarns (Gilligan & Barnes, 1990). Examples include the Timbarra gold deposit (disseminations), the Kingsgate Mo-Bi deposit (pipes, veins and disseminations), the Glen Eden Mo-W-Sn deposit (breccia pipes and stockworks) and Taronga Sn deposit (sheeted veins) (Gilligan & Barnes, 1990). The combination of favourable granite geochemistry, the widespread occurrence of IRGS-affiliated mineral deposits and the presence of gold systems with IRGS affinity (Timbarra and Tooloom), highlights the IRGS prospectivity of the NEFB.

To put this into a 'fold-belt' scale exploration perspective, compare the history of discovery in the neighbouring Lachlan Fold Belt (LFB). Companies such as Kennecott, Anaconda and Phelps Dodge intensively explored the LFB in the1960's and 1970's for porphyry copper deposits using the "Arizona light-bulb" model. The failure of these companies to discover any significant porphyry copper deposits ultimately led to NSW being declared unprospective for porphyry deposits. Success came later with the recognition of a new model related to Ordovician shoshonitic intrusives, leading to the discovery of significant deposits at Northparkes, Cadia and Lake Cowal. By comparison, the NEFB has had very little exploration, especially through the direct application of a wide-ranging geological model. The NEFB in Queensland hosts significant gold deposits, such as Cracow, Gympie and Mt Morgan (see Figure 3). In spite of that, the NSW part of the NEFB seems to be widely regarded as unprospective for large gold deposits. The application of the IRGS model will no doubt help to reinvent the NEFB as highly prospective for large gold deposits. Phoenix could do for the NEFB what Northparkes did for the LFB!

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Figure 1 – General plan model of intrusion-related gold systems illustrating various mineralisation styles, locations and outward metal zoning. (Modified from Hart et al., 2002)



**Figure 2** – Schematic model for intrusion-related gold systems showing lateral and vertical zonation in mineralisation styles, and interpreted position of the Phoenix Breccia. (Modified from Lang et al, 2000)





Figure 3 – Location of major gold deposits within the New England Fold Belt.

**Figure 4** – Phoenix prospect plan map illustrating gold-in-soil and IP anomalies, location of the Phoenix Breccia and enhanced helimag response (lighter grey = low).



**Figure 5** – New England Fold Belt showing mineral occurrences and location of the Tooloom Gold Project (Mineral occurrences map reproduced with permission from NSW Department of Mineral Resources Minfo Magazine).