PGC PUBLISHING

Skirrow, R.G. 2000 - Gold-Copper-Bismuth Deposits of the Tennant Creek District, Australia: A Reappraisal of Diverse High Grade Systems; *in* Porter, T.M. (Ed.), Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A Global Perspective, Volume 1; *PGC Publishing, Adelaide*, pp 149-160.

GOLD-COPPER-BISMUTH DEPOSITS OF THE TENNANT CREEK DISTRICT, AUSTRALIA: A REAPPRAISAL OF DIVERSE HIGH-GRADE SYSTEMS

Roger G. Skirrow

Minerals Division, Australian Geological Survey Organisation, Canberra, Australia

Abstract – Gold-copper-bismuth deposits of the Tennant Creek district, Northern Territory, Australia, are distinctive as some of the highest grade deposits within the Fe-oxide Cu-Au global family. They are unified by an association with epigenetic magnetite ± hematite-rich 'ironstones' that are hosted by a sequence ~1860 Ma, low metamorphic grade, Fe-oxide rich greywacke, siltstone and shale. While many of the high grade gold orebodies are dominated by magnetite – chlorite ± minor hematite, muscovite and pyrite, there are significant variations representing a spectrum of styles from reduced (pyrrhotite-bearing) Cu-Au-Bi deposits to oxidised hematitic Au-Bi(Cu) deposits. Shear-hosted Au-Cu mineralisation outside ironstones further adds to the diversity of styles present in the district. Ironstones predated syn- to late-deformational ~1825-1830 Ma introduction of Au, Cu and Bi in ~300-350ºC, acidic, low-moderate salinity or hypersaline fluids, which were in places carbonic and nitrogenous. The very wide range of oxidation-reduction conditions during ore deposition across the district is interpreted as the product of both reduced (magnetite ± pyrrhotite stable, $H_2S > SO_4^{=}$) and oxidised (hematite stable, $SO_4^{=} > H_2S$) fluids reacting with ironstones and/or mixing. Oxygen and hydrogen isotope data point to an hybrid ore fluid source with input of evolved surficial or formation waters, whereas Sm-Nd reconnaissance data and sulphur isotope compositions are consistent with contributions from igneous sources.

Introduction

Among the major Proterozoic Fe-oxide Cu-Au districts of Australia, the Tennant Creek Inlier hosts some of the highest grade gold and copper deposits, which are unusually rich in bismuth. The district ranks as one of Australia's larger gold producers, having yielded in excess of 160 tonnes of gold since mining began in the 1930s, although no single deposit qualifies as world-class in size. Of enduring interest have been the hundreds of magnetite- and/or hematite-rich 'ironstone' bodies that characterise the Tennant Creek Inlier, and with which all of the major exploited deposits are spatially associated. Conversely, not all ironstones are mineralised – only ~25% contained Au, Cu or Bi of ore grade (LeMessurier *et al.*, 1990; Wedekind *et al.*, 1989). Most of the larger producers were discovered beneath cover in the 1960s and 1970s following drilling of magnetic targets, and discoveries continue to be made (e.g. Chariot, 0.34 Mt @ 18 g/t inferred resource, Normandy Mining Ltd., 2000). Recent exploration programs have targeted a diversity of mineralisation styles, including traditional magnetic targets, non-magnetic ironstone-hosted Au-Cu, and non-ironstone hosted mineralisation.

Several key features of the major Tennant Creek deposits unite them as a descriptive group:

1. Gold, copper and bismuth occur either within or adjacent to massive magnetite and/or hematite–quartz–chlorite ironstones
2. All significant known deposits are hosted by the Paleoproterozoic Warramunga Formation.
3. Ore assemblages are dominated by combinations of chalcopyrite, bismuth sulphides/sulphosalts, gold, magnetite, hematite, chlorite, pyrite, muscovite and pyrrhotite.
4. Syn- to late-deformational timing of sulphide-gold mineralisation at or before ~1825 to 1830 Ma (Compston and McDougall, 1994), overprinting ironstone-stage iron oxides.

There is a consensus that the ironstones and economic mineralisation are epigenetic. Numerous studies have documented the characteristics of individual deposits and their settings, and several reviews and models for the Tennant Creek Au-Cu-Bi deposits have been presented (Large, 1975; Wedekind *et al.*, 1989; Wall and Valenta, 1990; Huston *et al.*, 1993; Skirrow, 1993; Davidson and Large, 1998; Ahmad *et al.*, 1999). A recurring theme among Proterozoic Cu-Au-Fe districts in Australia is that, despite the many shared characteristics of deposits in each district, there is a broad range of styles and mineral assemblages representing a spectrum of hydrothermal conditions (Davidson and Large, 1998; Skirrow, 1999; Skirrow and Walshe, 2002; Williams and Skirrow, 2000). This diversity of mineralisation in the Tennant Creek district, and its implications for exploration and for understanding Fe-oxide Cu-Au ore formation, are highlighted in the present review.

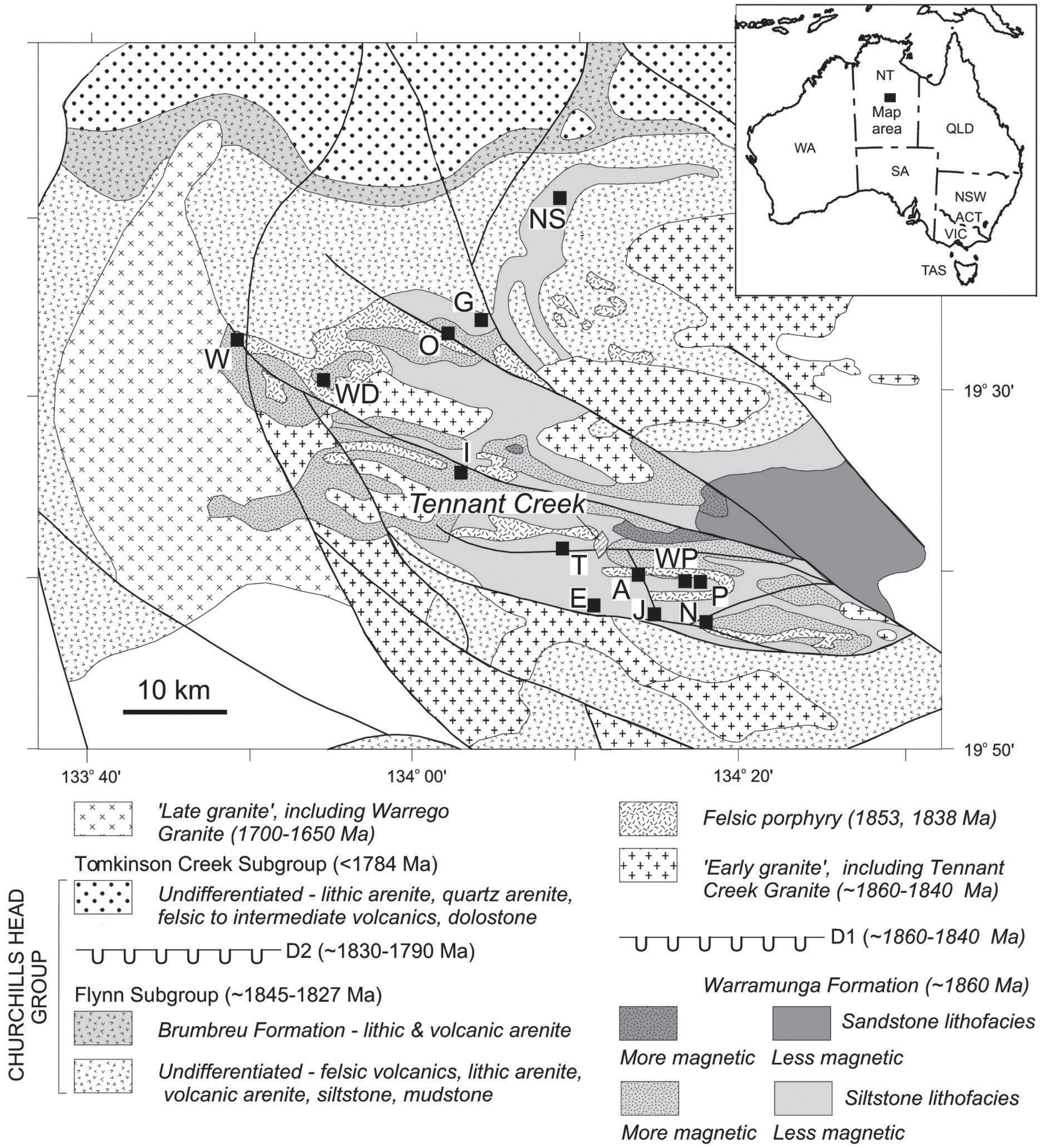


Figure 1: Regional geology of the Tennant Creek district within the central part of the Tennant Creek Inlier, and location of significant Au-Cu-Bi deposits (modified after Donnellan *et al.*, 1995). A – Argo, E – Eldorado, G – Gecko, I – Ivanhoe, J – Juno, N – Nobles Nob, NS – North Star, O – Orlando and Orlando East, P – Peko, T – TC8, W – Warrego, WD – White Devil, WP – West Peko.

Regional Geology of the Tennant Creek Au-Cu-Bi district

The Tennant Creek goldfield (Fig. 1) is situated in the central province of the Tennant Creek Inlier which includes the Davenport province to the south and Tomkinson Creek province to the north. Greywacke, siltstone and shale of the Warramunga Formation were deposited around 1860 Ma (Donnellan *et al.*, 1994; Compston, 1995). The Warramunga Formation is notabley iron-rich, containing abundant disseminated detrital and metamorphic magnetite and numerous thin hematitic ± carbonate-bearing siltstones and shales. Carbonaceous matter and evaporitic strata are evidently lacking. This succession is interpreted to have formed as flysch in an ensialic, transtensional (failed) rift (Donnellan, 1994). The Warramunga Formation was deformed, metamorphosed in the greenschist facies, and intruded by I-type Tennant Creek Suite granitoids, quartz-feldspar porphyry and minor mafic bodies at ~1850 Ma during the Barramundi Orogeny of northern Australia (Stolz and Morrison, 1994; Compston, 1995; Etheridge *et al.*, 1987).

Felsic volcanics of the Flynn Subgroup overlie the Warramunga Formation, and along with a second suite of felsic porphyry sills and possibly monzodiorite, were emplaced between 1845±4 and 1827±9 Ma (Compston, 1995) within a continental rift setting (Hussey *et al.*, 1994). The overlying Tomkinson Creek Subgroup is a siliciclastic molasse-like sequence with minor carbonates and basalt.

A second deformation event at ~1830 to 1790 Ma overprinted the Flynn Subgroup and equivalents elsewhere in the Tennant Creek Inlier (Donnellan *et al.*, 1994; 1998), although its effects in the Warramunga Formation were generally partitioned into domains of more intense deformation (e.g. shear zones). Other later deformation events were relatively minor. A suite of fractionated S-type granites (including Warrego Granite) with a poorly defined emplacement age of ~1700 to 1650 Ma intruded the Warramunga Formation and Flynn Subgroup, and post-dated Au-Cu-Bi mineralisation (Stolz and Morrison, 1994; Compston, 1995; Wedekind, 1990).

Ironstones

In excess of 600 ironstones have been documented in the Tennant Creek district, ranging in size from a few tonnes to tens of millions of tonnes. Ellipsoidal, lens, cigar-like and irregular geometries are characteristic. Ironstones lacking Au-Cu-Bi mineralisation are composed of dominantly magnetite and/or hematite with variable quantities of quartz, chlorite, dolomite and talc. Mineralised ironstones contain, in addition to these minerals, sulphides, sulphosalts, and minor muscovite (see below). Textural variations include massive intergrowths of fine to medium grained Fe-oxide, diffuse-banded to mottled Fe-oxide – quartz – chlorite, colloform-banded fine-grained Fe-oxide-quartz, and skeletal and growth-zoned magnetite. Both replacement and infill processes were involved (Wall and Valenta, 1990; Davidson and Large, 1998). Microtextures suggest that the earliest assemblages involved hematite or hydrated Fe-oxides, and were overprinted by magnetite (Large, 1975). Zoning is well developed in both barren and mineralised ironstones. The lower margins of massive ironstones grade into vein and replacement networks of magnetite – quartz ± hematite (‘stringer zones’), extending as footwall ‘pipes’ for several hundreds of metres in some cases. Both the massive ironstones and vein networks are enveloped by chloritic alteration zones ranging from a few centimetres to metres in width. Chlorite compositions increase in Fe/(Mg+Fe) towards the ironstones but tend to be of intermediate Fe/(Mg+Fe) within ironstones (Large, 1975; Skirrow, 1993). Talc and dolomite occur in discrete zones adjacent to both mineralised and ‘barren’ ironstones (commonly lateral to, or above ironstones), and in places are associated with hematitic alteration of magnetite and magnesian chlorite. Dolomite occurs a banded masses and vein infills, whereas talc typically forms extension-fibre infill between boudinaged sheared magnetite masses, locally known as ‘spewstone’.

Ironstones are transgressive to bedding in many cases, and were localised in a variety of structural settings including antiformal fold closures, shears and faults, and contacts of felsic porphyry intrusions (Ivanac, 1954). Dilational zones developed across contacts between rheologically contrasting units appear to have been favoured sites of Fe-oxide - quartz deposition (Edwards *et al.*, 1990; Wall and Valenta, 1990). A strong structural control is evident in the concentration of ironstones within several dominantly east-west regional ‘lines’ or trends (Wedekind *et al.*, 1989; Rattenbury, 1992). Some ironstones are spatially associated with hematitic siltstone/shale strata. These oxidised and locally calcite-bearing rocks may have acted to chemically trigger iron-oxide deposition where they were encountered by channelised magnetite-stable fluids (Large, 1975; Wedekind *et al.*, 1989). Well developed foliation in the chloritic alteration aureoles of ironstones parallels the regional S1 foliation, and ironstones generally have long dimensions within this foliation, suggesting early- to syn-D1 timing. The absolute timing of ironstone formation remains unknown, but is inferred to be ~1850 Ma.

The conditions of ironstone formation have been debated. Colloform-like textures and early hematite and/or hydrated Fe-oxide deposition (Large, 1975) are consistent with relatively low temperature initial formation, as supported by fluid inclusion homogenisation temperatures of 120 to 180ºC (not pressure-corrected; Khin Zaw *et al.*, 1994a; Huston *et al.*, 1993; Skirrow, 1993). Huston *et al.* (1993) suggested ironstones formed at ~250ºC. Calculated temperatures of chlorite formation and oxygen isotope geothermometry on quartz-magnetite pairs in both barren and mineralised ironstones indicate, however, that magnetite-chlorite that replaced the early assemblage may have formed at ~300 to 400ºC (Skirrow, 1993), consistent with formation during lower greenschist facies regional metamorphism (Wall and Valenta, 1990). There is general agreement that the ironstone-forming fluids were calcic brines with 10 to 20 equivalent weight percent NaCl (Khin Zaw *et al.*, 1994a; Huston *et al.*, 1993; Skirrow, 1993; Skirrow and Walshe, 1994). Based on oxygen-hydrogen isotope compositions of ironstone-related minerals (chlorite, magnetite, quartz) in barren and mineralised ironstones, fluids in equilibrium with these minerals isotopically resemble formation waters (Wedekind *et al.*, 1989; Wedekind, 1990; Huston, 1991; Skirrow, 1993). The actual source and flow paths of ironstone-forming brines remains unknown. Reconnaissance Sm-Nd isotopic results point to REE input in barren ironstones from sources external to the Warramunga Formation and that are unlike granite sources, possibly from material with Archean-like Sm-Nd characteristics (Skirrow, 1999). These data do not rule out contributions of components such as iron from the Warramunga Formation.

Mineralisation and Alteration

Descriptive features of Au-Cu-Bi deposits in the Tennant Creek district are summarised in Table 1, and cross sections of the major variants are depicted in Fig. 2. Although sharing a number of key characteristics, noted above, deposits across the district vary widely in Au/Cu ratios, magnetite/hematite ratios, Fe-sulphide mineralogy, and sulphur isotope composition (Wedekind *et al.*, 1989; Wall and Valenta, 1990; Huston *et al.*, 1993; Skirrow, 1993; Davidson and Large, 1998). The spectrum of ironstone-related styles exhibit systematic variations that can be described in terms of two compositional end-members: *reduced* (magnetite–pyrrhotite), Cu-rich deposits with narrow ranges of $\delta^{34}S$ sulphide values (e.g. Peko, West Peko, Fig. 2), and *oxidised* (hematite - magnetite ± pyrite), Au-rich deposits with wide ranges of $\delta^{34}S$ sulphide values (e.g. Eldorado, Fig. 2, Skirrow and Walshe, 2002). Between these compositional extremes lie many of the larger, high grade Au deposits which are characterised by minerals of intermediate oxidation-reduction state within their gold-sulphide/sulphosalt zones (magnetite – chlorite ± minor pyrite, e.g. Juno, Fig. 2, White Devil). The largest deposit, Warrego (Fig. 2), contains both high-grade gold and copper in association with magnetite – chlorite and minor pyrite and pyrrhotite (replaced by marcasite; Wedekind, 1990; Wedekind and Love, 1990), and probably represents a transitional style between the reduced and intermediate redox members. The Gecko Cu-Au K44 ore body is unusual within the compositional spectrum, because high grade copper is associated with high hematite/magnetite ratios, although a gold hematite association is also present (Huston *et al.*, 1993).

Variants in this spectrum display distinctive magnetic signatures reflecting the relative proportions of hematite, magnetite and pyrrhotite. Dominantly hematitic versus magnetite ± pyrrhotite-rich deposits will clearly require differing magnetic targeting models in exploration, although both styles would be expected to produce localised gravity anomalies. Less well known in the Tennant Creek district is Au and Cu mineralisation hosted in country rocks 10s to 100s of metres or more from ironstones lacking significant iron oxides (Crohn, 1965). Examples include the 'satellite orebodies' at the Gecko K44 deposit (Fig. 2; Main *et al.*, 1990), Orlando East prospect (Skirrow, 1993), Bishop Creek prospect (G. Edwards, pers. comm., 1993), and gold mineralised zones peripheral to the West Peko ironstones (Fig. 2, Skirrow, 1993). Gold ± chalcopyrite ± bismuth minerals are disseminated in shear-hosted quartz – chlorite ± pyrite vein networks and associated chloritic alteration. This style of mineralisation illustrates that non-traditional targets await further exploration in the Tennant Creek district, and the style is also significant as a possible genetic link between the ironstone-hosted deposits and syn-deformational Au ± base metal mineralisation in other terranes (e.g., Pine Creek Inlier, Tanami-Granites district, Cobar, Telfer).

Table 1: (below and facing page) Characteristics of selected Au-Cu-Bi deposits and prospects of the Tennant Creek district.

Deposit/ Prospect	Au, Cu tonnage-grade[1]	Host-rock geology	Ore-associated assemblages
Warrego	4.75 Mt @ 8 g/t Au, 2% Cu, 0.3% Bi	Variably chloritised Qtz-Ms schist; Qtz porphyry in hangingwall; Warrego Granite to west	Au zones: Mag-Chl-Ms-Bism-Au; Cu zones: Ccp-Mag-Chl-Qtz-Py-Po(Mar) ±Sid
Nobles Nob	2.1 Mt @ 17 g/t Au	Greywacke, siltstone, shale, Hem-shale; locally brecciated, silicified	Hypogene Mag-Chl-Ms-Ccp-Py-Au-Bism; supergene Hem-Qtz-Ser-Au-Mal-native Cu
Juno	0.45 Mt @ 57 g/t Au, 0.4% Cu, 0.6% Bi, 7 g/t Ag	Greywacke, siltstone, shale, Hem-shale, lamprophyre	Mag-Chl-Ms-Bism-Au±Hem±Qtz
White Devil	2.1 Mt @ 12 g/t Au (1987-1999)[2]	Greywacke, sandstone, shale, Qtz-Fs porphyry	Mag-Chl-Hem-Bism-Au-Ccp-Ms; minor Aspy; Hem replaces Mag
Peko	3.2 Mt @ 3.5 g/t Au, 4% Cu, 0.2% Bi, 14 g/t Ag	Greywacke, siltstone, shale, Qtz-Chl porphyroid	Hypogene Mag-Py-Ccp-Po±Qtz±Chl±Ms
Argo	0.29 Mt @ 8.6 g/t Au, 0.8% Cu, 0.6% Bi[3]	Greywacke, siltstone, Hem-shale, chloritised Qtz porphyry, lamprophyre	Mag-Py-Chl-Dol-Ccp-Bism-Au; Py-Mag-Dol-Au; Dol-Au; Hem in supergene upper zone
Gecko K44	3.0 Mt @ 1.2 g/t Au, 4.9% Cu	Hematitic siltstone, Hem-shale, greywacke, conglomerate; dolerite in district	Hem-Mag-Chl-Qtz-Ccp-Py-Bism-Au-Ms
Eldorado	0.21 Mt @ 20 g/t Au	Greywacke, siltstone, Hem-shale	Hem-Chl-Au-Bism
TC8	0.04 Mt @ 67 g/t Au, 1.2% Cu, 0.5% Bi[4]	Siltstone, shale, arkose, Hem-shale	Chl-Mag-Ms-Au-Bism-Ccp; Bn-Ta-Dol
West Peko prospect	15 m @ 3.5 g/t Au, 6% Cu (intersection)[5]	Greywacke, siltstone, shale, Hem-shale, Qtz-Chl porphyry	Mag-Chl-Sti-Po-Py-Ccp-Bism-Au; minor Ga, Sp, Bi; Au-Bi outside iron-stone in Qtz-Chl veinlets
Orlando East	0.15 Mt @ 4.1 g/t Au[6]	Siltstone, shale, greywacke, Qtz-Chl porphyroid	Qtz-Chl-Py-Ccp-Bism-Au

Mineral abbreviations: Aspy - arsenopyrite, Bism - bismuthinite and sulphosalts, Carb - carbonate, Chl - chlorite, Ccp - chalcopyrite, Dol - dolomite, Gal - galena, Hem - hematite, Mag - magnetite, Mal - malachite, Mar - marcasite, Min - minnesotaite, Ms - muscovite, Po – pyrrhotite, Py – pyrite, Qtz – quartz, Ser – sericite, Sid – siderite, Sp – sphalerite, Sti – stilpnomelane, Ta- talc.

Ore and alteration mineral assemblages are distributed systematically both in their paragenetic sequence and spatially within the ironstone-associated deposits. It has long been recognised that the Cu and Fe sulphides, bismuth minerals (including bismuthinite and a range of seleniferous Bi±Pb sulphosalts, Large, 1975), and gold overprint magnetite-rich ironstones as cross-cutting veinlets and replacements, although interpretations vary as to the time separation between these events (see below). Veinlets commonly occur as en echelon arrays of subhorizontal gashes, and internal features such as crack-seal and fibre textures indicate that at least some sulphidic veinlets were syn-deformational in origin, although some chlorite is randomly oriented. Ore-related (alteration) assemblages have been described as magnetite-muscovite-Mg chlorite (Large, 1975; Wedekind *et al.*, 1989), or hematite-muscovite-Mg chlorite (Wall and Valenta, 1990; and at Gecko K44 and White Devil deposits – Huston *et al.*, 1993). Not only are both these assemblages present within the spectrum of deposit styles described above, but an important additonal assemblage occurs in the reduced end-member style. These are characterised by new magnetite – pyrrhotite ± pyrite – chalcopyrite – bismuthinite ± bismuth sulphosalts, Fe-chlorite, and less common minnesotaite and stilpnomelane in outer zones (Fig. 2, Skirrow and Walshe, 2002). Magnesian alteration, hematite and muscovite are inconspicuous and/or postdate ore-related assemblages in these deposits.

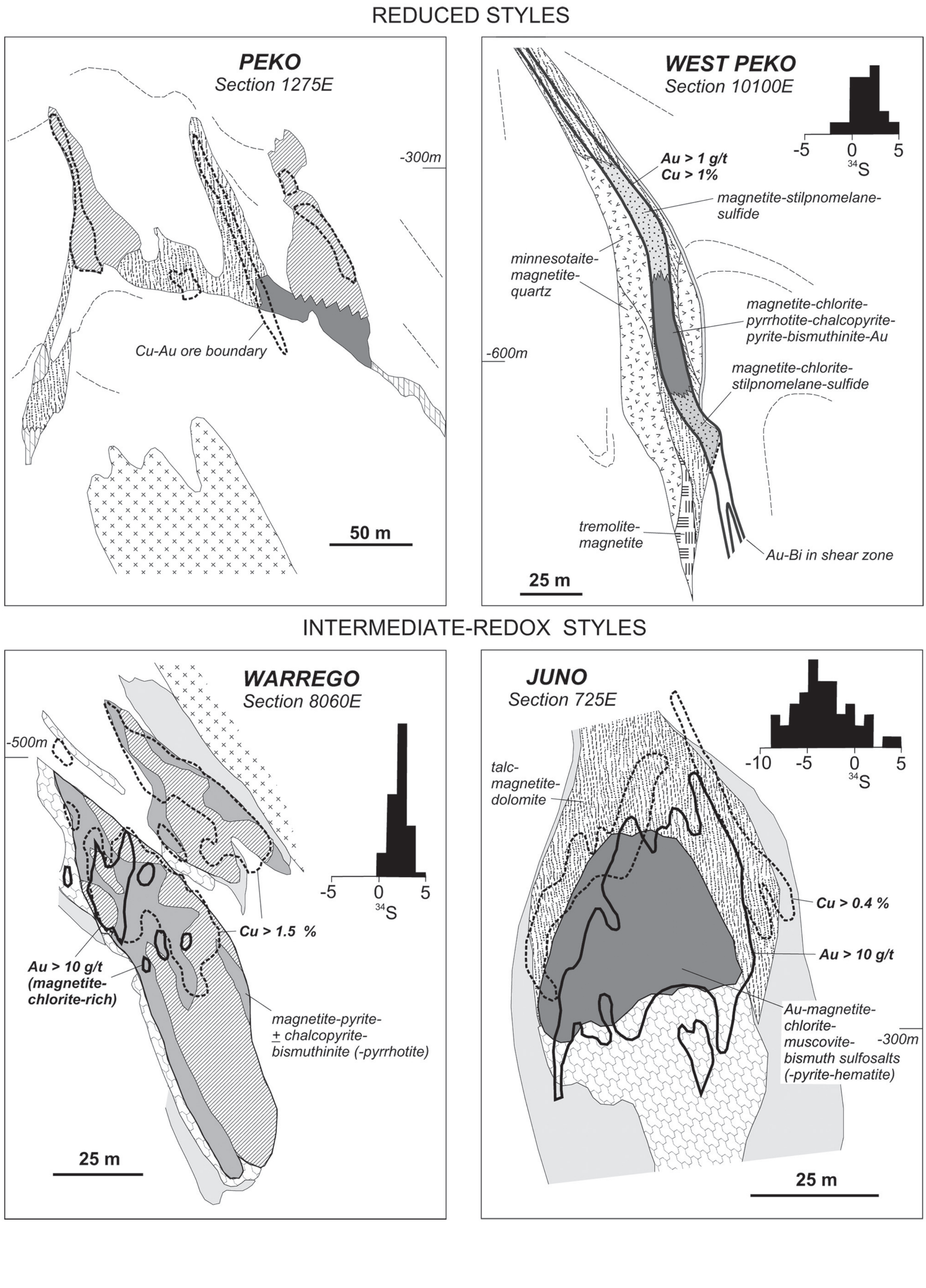
Deposits of intermediate redox style commonly show development of chlorite and muscovite associated with chalcopyrite – pyrite – gold – bismuth-mineral introduction (Large, 1975; Wedekind *et al.*, 1989). Ore-stage chlorite compositional variations are complex: a pattern of early magnesian chlorite that was replaced by Fe-chlorite during sulphide/sulphosalt –gold deposition is repeated at both Warrego and the oxidised Eldorado Au deposit (Skirrow, 1993). The interpretation of minor hematisation of magnetite in several deposits of this style has ranged from post-mineralisation (Wedekind, 1990) to syn-mineralisation (Huston *et al.*, 1993). Some but not all intermediate redox style deposits have well developed and zoned magnesian assemblages and, conversely, these are also present at some unmineralised ironstones (e.g. in Eldorado area). At the Juno and TC8 deposits talc-magnetite zones form a carapace above and adjacent to magnetite-chlorite zones,

Mineralisation textures, style	Mineral and metal zoning	Controlling Structure	References
Veinlets of Chl-Ms-sulphide-Au cutting massive Mag-Chl	West to east: Mag-Chl stringer zone, Mag-Chl-Ms(Au-Bi), Mag-Ccp-Py-Po(Cu-Bi), Qtz-Mag	Ironstone occurs at contact with Qtz porphyry; both cut by Footwall Fault	Wedekind & Love (1990), Wedekind (1990)
Fracture, fault and breccia infill within ironstones & mudstone	High grade Au in supergene zone; no Ta, Dol	Ironstones hosted by finer grained units; some bedding-parallel faults	Yates & Robinson (1990)
Veinlets of Chl-Bism-Au cutting massive Mag-Chl	Lower Mag-Ms-Hem-Chl stringer zone, massive Mag-Chl(Au-Bi), upper Ta-Mag-Py(Cu-Bi), Dol-Hem-Mag	Antiformal parasitic closure	Large (1974, 1975)
Au-Bism in vein networks, breccias; Ccp-Py in ductile zones	Lower/lateral stringer Mag-Chl(Au-Bi), massive Mag-Chl-Hem(Au-Bi); very minor Dol below	Dilational jog in shear zone	Nguyen *et al.* (1989), Edwards *et al.* (1990), Huston *et al.* (1993)
Brecciated & veined ironstone, sulphide infill	Lower Mag-Chl, upper/outer Qtz-Mag(Cu) & Ta-Mag(Cu), Dol-Mag	Limb of synform	Wright (1965)
Sulphide-Au veins & breccia infill in Mag; Py replaces Mag	Massive Mag(Au); Py-Mag(Au) zone in hangingwall; Carb envelope containing Mag-Ta-Chl-Carb	Reverse-faulted antiform	Meade (1986)
Mag replaced and veined by Hem-sulphides	Central Mag-rich(Ccp), outer Hem-rich(Ccp), peripheral breccia and Chl-Hem-Mag altered seds(Ccp)	Sheared antiformal parasitic closure on regional antiform	Main *et al.* (1990), Huston *et al.* (1993)
Mag replaced and veined by Qtz-Hem-Ms; late Au-Bism	Central Mag-Hem-Chl(Au), upper/outer Hem-Mag-Chl(Au), outermost stringer, breccia Hem-Mag-Chl(Au)	Sheared antiformal parasitic closure and jog in fault	Horvath (1988), Skirrow (1993)
Not reported	Lower Mag-Chl-Ms(Au-Bi) stringer zone, massive Mag-Chl(Au-Bi), upper Ta-Mag(Cu-Bi), Dol, Hem-Mag	Fold plunge reversal?	Hill (1990)
Sulphide-Au replacements and infill	Inner Mag-Chl(Cu-Au-Bi), outer Mag-Sti(Cu-Au-Bi), peripheral Min-Sti, Ta, Trem, Carb; Au-Bi outside ironstone	Sheared parasitic antiform on limb of regional synform	Skirrow (1993)
Vein networks in sheared chloritised seds	Mag more abund towards Orlando ironstone Cu-Au	Shear zone and attenuated fold limbs	Skirrow (1993)

[1] Data from Ahmad *et al.* (1999) (production figures); [2] Production data sourced from MinMet Australia; [3] Cu and Ag data from Wedekind *et al.* (1989), Au data from Ahmad *et al.* (1999); [4] Au, Cu and Bi data from Wedekind *et al.* (1989); [5] Data from Geopeko, 1993; [6] Orlando East data from Register of Australian Mining, 2000/01.

and zone upwards and outwards to dolomitic zones (Fig. 2, Large, 1975; Wedekind *et al.*, 1989). Metal zonation at Juno, TC8, Warrego and several other deposits shows a pattern of gold concentration near the base or directly below ironstone bodies, passing upwards and outwards through a bismuth zone into a copper zone (Fig. 2, Large, 1975; Wedekind *et al.*, 1989).

Strongly oxidised deposits are dominated by hematite – chlorite – muscovite ± pyrite in the Au ore zones. Ore mineralisation at Eldorado consists of gold and bismuth sulphosalts, with only traces of chalcopyrite. Hematite in the Eldorado Au deposit occurs as bladed crystals in quartz – Mg-chlorite veins and breccias cutting magnetite ironstone and in Fe-chlorite veinlets with gold and



bismuth sulphosalts, and also as martite replacements of magnetite. Vughy hematitic zones in upper levels of the Eldorado, Warrego and other deposits are of late-stage, low temperature origin (Wedekind and Love, 1990; Skirrow, 1993). Deep weathering at the Nobles Nob deposit resulted in hematitic ore assemblages; the hypogene ore and alteration assemblages are not known with certainty, but included magnetite, chlorite and muscovite (Yates and Robinson, 1990), and thus the deposit may be akin to either the intermediate-redox or oxidised styles of deposits.

Age of Mineralisation

Muscovite associated with gold mineralisation in several Tennant Creek deposits has yielded $^{40}Ar/^{39}Ar$ plateau ages of ~1825 to 1830 Ma, representing a minimum age of Au-Cu-Bi mineralisation (Compston and McDougall, 1994). This result is consistent with Pb model ages of 1819 to 1856±15 Ma for four of the major deposits (Warren *et al.*, 1995). Magmatism of the Flynn Subgroup (Tennant Creek Province) and Hatches Creek Group (Davenport Province) spanned this period (Compston, 1995; Blake and Page, 1988), although it should be noted that no 'causative' intrusions have been identified in relation to Au-Cu-Bi mineralisation. Relative timing of Au-Cu-Bi introduction is post-D1 and probably syn-D2 (Edwards *et al.*, 1990).

Fluid Properties and Origins

Considerable research effort has been applied to determining fluid properties and origins and ore formation conditions of the Tennant Creek Au-Cu-Bi deposits. There are nevertheless some fundamental unresolved questions concerning the temperature-salinity properties of the fluids, redox characteristics, and interpretations of stable isotopic data. Fluid inclusion studies have revealed the presence of several fluid compositional groups ranging from low salinity to multiphase inclusions of high salinity

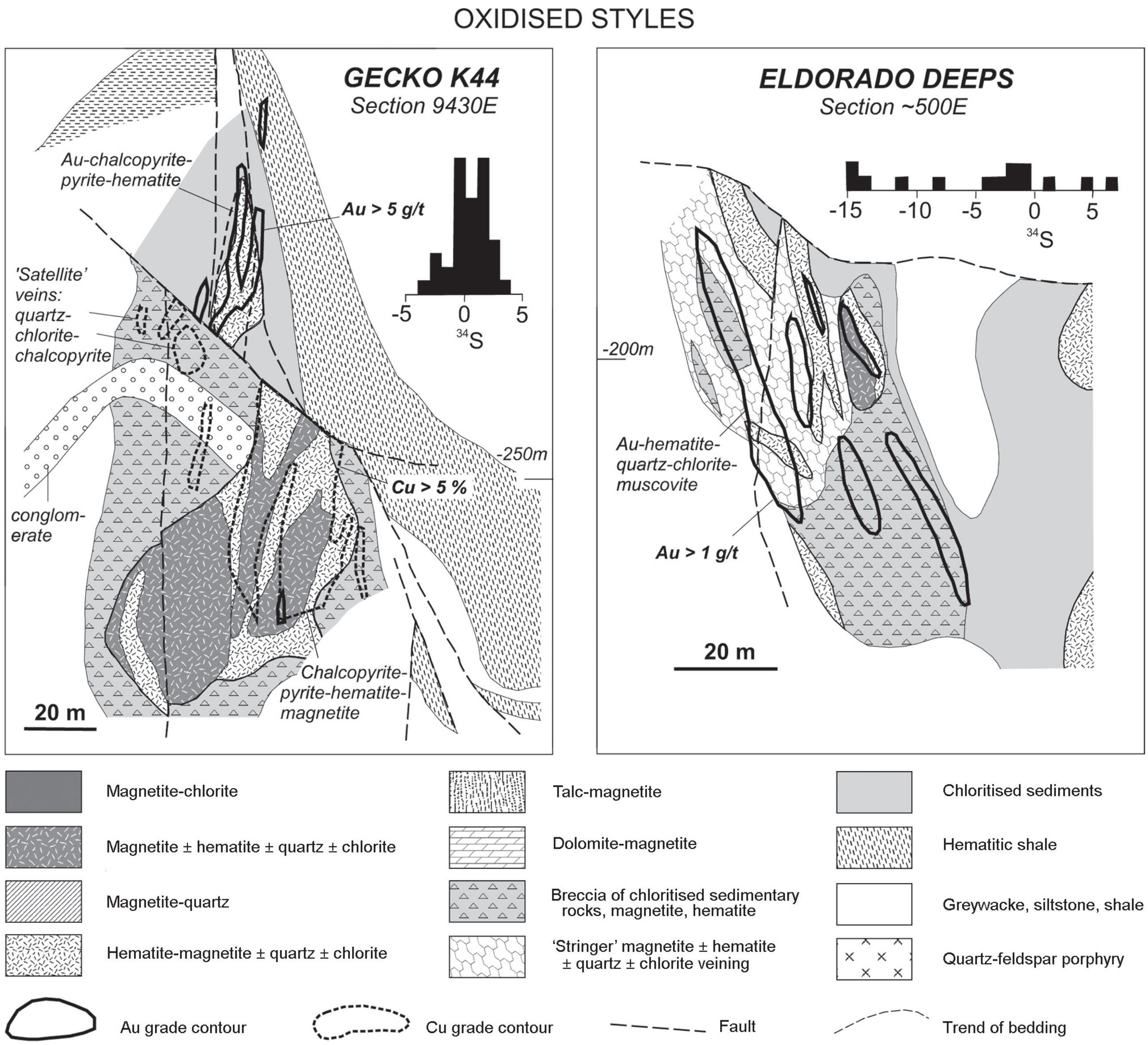


Figure 2: (above and facing page) Representative cross sections of reduced, intermediate-redox and oxidised deposit styles in the Tennant Creek district. Sources of data are listed in Table 1.

(up to 50 wt.% $NaCl_{equiv.}$), as well as vapour-rich inclusions rich in CO_2±N_2 or CH_4-N_2 (Nguyen *et al.*, 1989; Huston *et al.*, 1993; Khin Zaw *et al.*, 1994a; Skirrow and Walshe, 1994). A major difficulty encountered in fluid inclusion studies of the Tennant Creek deposits has been the paucity of suitable quartz or other minerals with sufficiently large fluid inclusions that can be demonstrated to have formed synchronously with the sulphide-gold mineralisation. Nguyen *et al.* (1989) and Skirrow and Walshe (1994) suggested that Au ore fluids at the White Devil, West Peko and Eldorado deposits were of low to moderate salinity (up to ~10 eq. wt. % NaCl) and with homogenisation temperatures (Th) reaching ~300ºC. Huston *et al.* (1993) and Khin Zaw *et al.* (1994a), in contrast, proposed ore fluids of >35 wt. % $NaCl_{equiv.}$ and with Th of >350ºC, based on studies at Juno, White Devil, TC8, Gecko and Eldorado. High salinity calcic inclusions at West Peko are late- to post-mineralisation, with Th <160ºC, whereas at Eldorado the calcic brine inclusions associated with quartz – hematite – chlorite alteration have Th up to ~240ºC but predate or are synchronous with Au-Bi deposition (Skirrow, 1993). PIXE ion probe analysis of high salinity inclusions from Juno revealed Ca-Fe-Mn-Pb-Zn rich compositions (Khin Zaw *et al.*, 1994b), whereas low-moderate salinity inclusions associated with Au-Bi deposition at West Peko yielded low but detectable Cu and Bi concentrations (PIXE analysis, R. Skirrow and C. Ryan, unpubl. data). These reconnaissance PIXE results are consistent with ore fluids of low-moderate salinity, which also contained CH_4-N_2, but further detailed work is required.

Evidence for phase separation of CO_2±N_2 or CH_4-N_2 fluids was presented by Huston *et al.* (1993), Skirrow (1993) and Khin Zaw *et al.* (1994a). This process may have contributed to formation of dolomitic zones within dilational sites adjacent to some Au-Cu-Bi mineralised ironstones as well as some barren ironstones.

The origins of fluids have been investigated through a number of oxygen, hydrogen, carbon and sulphur isotope studies of the Tennant Creek deposits. The first reported oxygen and hydrogen isotope results suggested involvement of fluids similar to sedimentary brines (Wedekind *et al.*, 1988). Subsequent work on silicates has shown that, depending on assumed temperatures of formation and choice of fractionation factors, both ironstone-related and ore-related fluids have overlapping compositional ranges, with most data in the range $\delta^{18}O_{fluid}$ = 0 to 6‰ and δD_{fluid} = -40 to -10‰ (Wedekind, 1990; Huston, 1991; Skirrow, 1993). Discrimination between mineralised and barren ironstones, and identification of magmatic fluid input from oxygen and hydrogen isotope data (Wedekind, 1990), are problematic. With the exception of several data from West Peko, all oxygen-hydrogen isotopic compositions of fluids lie outside and above the generally accepted field for magmatic waters. Input of evolved surficial waters (e.g. formation waters or their higher temperature equivalents) appears necessary to generate the oxygen-hydrogen isotopic compositions, but contributions of magmatic or metamorphic waters cannot be ruled out.

Sulphur isotope compositions have been analysed for seven of the major deposits and several prospects, and vary systematically between and within some deposits (see inset histograms, Fig. 2). The reduced end-member deposits are characterised by relatively narrow ranges of $\delta^{34}S_{sulphide}$ from approximately 0 to +4‰ (e.g. West Peko), whereas oxidised deposits such as Eldorado yield a spread of $\delta^{34}S_{sulphide}$ values from approximately -15 to +7‰ (Skirrow, 1993). The ranges for intermediate-redox deposits are between these extremes (e.g. Juno, -9 to +5‰, Large, 1975; White Devil, -4 to +6‰, Huston *et al.*, 1993). In keeping with its reduced to intermediate-redox sulphide-bearing assemblages, Warrego $\delta^{34}S_{sulphide}$ values cluster tightly from approximately 0 to +4‰ (Wedekind, 1990). An important feature at Warrego, Juno, White Devil and Gecko is the zoning of $\delta^{34}S_{sulphide}$ values from lower values in Au-rich and/or footwall zones to higher values in upper/distal zones (Large, 1975; Wedekind, 1990; Huston *et al.*, 1993). Based on pyrrhotite and chalcopyrite $\delta^{34}S$ values at West Peko and Warrego, ore fluid $\delta^{34}S$ values were approximately 0 to +4‰ (Wedekind *et al.*, 1988; Wedekind, 1990; Skirrow, 1993). Magmatic sulphur may or may not have been involved. Lower values in intermediate-redox and oxidised deposits are interpreted to have resulted from isotopic fractionation during oxidation-reduction reactions near conditions of $SO_4^{=}/H_2S$ equal activity (Large, 1975; Wedekind, 1990; Huston *et al.*, 1993; Skirrow, 1993).

Reconnaissance Sm-Nd isotope studies of the West Peko prospect have yielded $\varepsilon_{(Nd)}$ values that are significantly higher in Cu-Au-Bi mineralised samples than in lesser mineralised or barren parts of the same ironstones (Skirrow, 1999). The results are suggestive of input of REE to Cu-Au-Bi zones from a relatively primitive source that differs from sources of ironstone-forming materials. Follow-up Sm-Nd work is warranted on mafic and other igneous rocks that may have been emplaced around the time of Au-Cu-Bi mineralisation (~1850 to 1825 Ma).

Ore Depositional Processes and Models

Different interpretations have been placed on the genetic relationship between ironstones and Au-Cu-Bi, oxidation-reduction characteristics of the ore fluids, sulphur isotope patterns, and Fe-O-S mineral assemblages, with consequent major implications for ore genesis models. Proposals have been advanced for single-stage evolving ironstone-Au-Cu-Bi systems (Large, 1975), a continuous two-stage process within a single evolving system (Wedekind *et al.*, 1989; Huston *et al.*, 1993), and two stages separated by a time break of tens of millions of years (Edwards *et al.*, 1990; Wall and Valenta, 1990). More accurate dating of the major hydrothermal events may resolve this problem. Separate stages for ironstone formation and Au-Cu-Bi mineralisation, representing two fluid regimes that probably operated independantly except at the ironstone depositional sites, is a variant of the two-stage theme (Skirrow, 1993).

This view is supported by the following observations:

(1) only a small proportion of ironstones are mineralised,
(2) occurrences of Au-Cu are known to occur separately from ironstones,
(3) the kinematics of deformation during Au deposition differed from those during earlier ironstone development (Edwards *et al.*, 1990),
(4) fluid inclusion properties are distinct for the two hydrothermal stages,
(5) Sm-Nd signatures of barren ironstones differ from those of Au-Cu-Bi ores.

Building on the model of Large (1975), Wedekind *et al.* (1989) advanced a model in which magnetite-stable acidic ore fluids reacted with pre-existing Fe-chlorite in ironstone to produce gold, Mg-chlorite, muscovite and new magnetite via pH increase and fO_2 decrease of the fluid. Huston *et al.* (1993) proposed highly oxidised ($SO_4^= >> H_2S$, hematite-stable) magmatic hydrothermal ore fluids for some deposits, in part based on the metal and sulphur isotopic zonation patterns, presence of hematite in ores, and interpreted high salinity of ore fluids. Sulphur isotope compositional variations in sulphides at White Devil and Gecko K44 were claimed to be the result of isotopic fractionation of a fluid with $\delta^{34}S$ of ~12‰ as fluid fO_2 decreased and pH increased.

Wall and Valenta (1990) also suggested oxidised ore fluid reaction with pre-existing ironstone, and advocated a descending flow path for such fluids. An alternative model that accounts for the range of assemblages from reduced to oxidised, sulphur isotopic compositions of sulphides and fluid (~0-4‰), and fluid inclusion observations, involves deep-sourced relatively reduced ($H_2S > SO_4^=$, magnetite ± pyrrhotite – stable) low-moderate salinity fluids carrying Au-Bi ± Cu, reaction with pre-existing magnetite-hematite ironstone, and variable input of a second fluid of oxidised saline character late within or post-dating ore formation (Skirrow, 1993; Skirrow and Walshe, 2002). Increases in ore fluid pH, oxidation, reduction, desulphidation, fluid mixing, and phase separation all may have contributed to sulphide-gold deposition to different extents in deposits of the Tennant Creek district.

Tennant Creek Au-Cu-Bi Deposits in Perspective

The unusually high grade of Au-Cu-Bi mineralisation in the Tennant Creek deposits makes this style of deposit a particularly attractive exploration target, despite their generally small tonnages. Chemical mass transfer modelling of the Tennant Creek systems demonstrates that very high gold grades are possible because of the efficiency of massive magnetite ± hematite – chlorite to act as a desulphidant, and also either as an oxidant for reduced fluid reaction, or as a reductant for oxidised fluid reaction (Skirrow, 1993; Skirrow and Walshe, 2002). Simulated mixing of the reduced and oxidised fluids documented in the district also results in very high gold grades, which potentially may occur outside ironstones. The abundance of bismuth and selenium in deposits of the Tennant Creek district is also somewhat unusual. Estimates of the thermodynamic stability of aqueous gold-selenide complexes suggests these could have contributed to unusually high gold concentrations in the ore fluids. The association of bismuth with gold in the Tennant Creek district may result in part from their similarities in complexing behaviour as predicted for bismuth aqueous complexes (Skirrow, 1993).

As observed in many other districts of Fe-oxide associated Cu-Au deposits, ore metal deposition was paragenetically late with respect to the bulk of magnetite at Tennant Creek. The switch from apparently sulphur-poor to sulphidic ± seleniferous fluids that were out of equilibrium with pre-existing magnetite ± hematite – chlorite – quartz ironstone probably required a shift in fluid flow paths, reservoirs, and metal/ligand sources. Identification of the new pathways at regional, district and deposit scales through alteration and structural mapping will assist in defining exploration targets.

The Tennant Creek district lacks the prominent albitic Na-Ca-Fe regional alteration that characterises the Cloncurry Cu-Au, Olary Cu-Au-Mo, Moonta-Wallaroo Cu-Au districts, and many other Fe-oxide Cu-Au districts worldwide (Hitzman *et al.*, 1992). However, ironstones may be considered a variant on the regional alteration theme, representing widely distributed but locally focussed Fe ± Mg ± Ca metasomatism. The lack of alkali feldspathic alteration in the Tennant Creek district may reflect the dominance of relatively low-pH fluids buffered by clay/mica rich strata of the Warramunga Formation. The ore fluids were of sufficiently low pH to stablise muscovite in the Tennant Creek ores, in comparison with presumably higher pH fluids producing K-feldspar in some Cu-Au ores of the Cloncurry and Olary districts (Williams and Skirrow, 2000).

The role of magmas in Au-Cu-Bi ore systems of the Tennant Creek district remains problematic. The close spatial and temporal association of magnetite with igneous rocks that has been documented in several other Fe-oxide Cu-Au districts (e.g. Cloncurry district, Perring *et al.*, 2000) is not evident in currently available datasets at Tennant Creek. Nor is Au-Cu-Bi mineralisation intimately associated with any known igneous rocks, although altered quartz porphyritic dykes and sills are present in drilling at many prospects (Table 1), and several major deposits lie broadly within or near a regional gravity gradient that may represent a deep-seated contact with low-density (granitic?) material. Oxygen and hydrogen isotopic signatures point to hybrid sources of fluid components rather than a dominant magmatic hydrothermal component. Further elemental analysis of inclusion fluids may assist in identifying any magmatic input, and help resolve whether highly saline or low-moderate salinity fluids carried the ore metals.

Acknowledgements

Staff of Geopeko and Normandy Mining are thanked for support. Special thanks go to John Walshe for his enthusiastic interest, advice and discussions on all aspects of this work. Numerous discussions over many years with staff from Geopeko, WMC, ANU, AGSO and CODES have contributed valuably. Published by permission of the Chief Executive Officer, AGSO.

References

Ahmad, M., Wygralak, A.S. and Ferenczi, P.A., 1999 – Gold deposits of the Northern Territory; *Northern Territory Geological Survey*, Report 11., v.

Blake, D.H. and Page, R.W., 1988 - The Proterozoic Davenport Province, central Australia: regional geology and geochronology; *Precambrian Research*, v. 40/41, pp. 329-340.

Compston, D.M. and McDougall, I., 1994 - ^{40}Ar-^{39}Ar and K-Ar age constraints on the Early Proterozoic Tennant Creek Block, northern Australia and the age of its gold deposits; *Australian Journal of Earth Sciences*, v. 41, pp. 609-616.

Compston, D.M., 1995 - Time constraints on the evolution of the Tennant Creek Block, northern Australia; *Precambrian Research*, v. 71, pp. 107-129.

Crohn, P.W., 1965 - Tennant Creek gold and copper field; *in* McAndrew, J. and Madigan, R.J. (eds.), Geology of Australian Ore Deposits; 8th Commonwealth Mining and Metallurgy Congress, *Australasian Institute of Mining and Metallurgy, Melbourne*, v. 1, pp. 176-182.

Davidson, G.J. and Large, R.R., 1998 - Proterozoic copper-gold deposits; *Journal of Australian Geology and Geophysics*, v. 17(4), pp. 105-113.

Donnellan, N., 1994 - The Paleoproterozoic Warramunga Formation, Tennant Creek Block, central Australia: sedimentology, geochemistry and provenance; *in* Proceedings, Annual AusIMM Conference, Darwin, 5-9 August 1994, *Australasian Institute of Mining and Metallurgy, Melbourne*, pp. 179-184.

Donnellan, N., Morrison, R.S. and Hussey, K.J, 1998 - Tennant Creek Province: a strike-slip orogenic terrain; *Geological Society of Australia,* Abstracts, v. 49, p. 120.

Donnellan, N., Morrison, R.S. and Hussey, K.J., 1994 - A brief summary of stratigraphy and structure of the Tennant Creek Block, central Australia; *in* Proceedings, Annual AusIMM Conference, Darwin, 5-9 August 1994, *Australasian Institute of Mining and Metallurgy, Melbourne*, pp. pp. 161-164.

Donnellan, N., Hussey, K.J. and Morrison, R.S., 1995 - Tennant Creek, Northern Territory - 1:100 000 geological map series; *Northern Territory Geological Survey* Explanatory Notes, SE/53-14, 5758.

Edwards, G. C., Booth, S. A. and Cozens, G. J., 1990 - White Devil gold deposit; *in* Hughes, F. E., (ed.), Geology of the Mineral Deposits of Australia and Papua New Guinea, *The Australasian Institute of Mining and Metallurgy, Melbourne*, Monograph 14, v. 1, pp. 849-856.

Etheridge, M.A., Rutland, R.W.R. and Wyborn, L.A.I., 1987 - Orogenesis and tectonic process in the early to middle Proterozoic of northern Australia; *in* Kroner, A., (ed.), Proterozoic Lithospheric Evolution, Geodynamic Series, 17, *American Geophysical Union*, pp. 115-130.

Hill, J.H., 1990 - TC8 gold deposit; *in* Hughes, F. E. (ed.), Geology of the Mineral Deposits of Australia and Papua New Guinea, *The Australasian Institute of Mining and Metallurgy*, Monograph 14, v. 1. pp. 857-859.

Hitzman, M., Oreskes, N. and Einaudi, M. 1992 - Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits; *Precambrian Research*, v. 58, pp. 214-287.

Horvath, H.S., 1988 - The geology and genesis of the Eldorado Au-bearing lode, Tennant Creek, N.T., Australia; Unpublished B.Sc. (Hons.) thesis, *University of Tasmania, Hobart*.

Hussey, K.J., Morrison, R.J. and Donnellan, N., 1994 - Stratigraphy and geochemistry of the Flynn Subgroup volcanic rocks; ; *in* Proceedings, Annual AusIMM Conference, Darwin, 5-9 August 1994, *Australasian Institute of Mining and Metallurgy, Melbourne*, pp. 165-169.

Huston, D. L., Bolger, C. and Cozens, G., 1993 - A comparison of mineral deposits at the Gecko and White Devil deposits: implications for ore genesis in the Tennant Creek District, Northern Territory Australia; *Economic Geology*, v. 88, pp. 1198-1225.

Huston, D.L., 1991 - Follow-up studies of C-O-H isotopes in the Tennant Creek district, Northern Territory. University of Tasmania; CODES-AMIRA Workshop, Proterozoic Gold-copper Project, June 1991, Manual No. 5, pp. 31-42.

Ivanac, J. F., 1954 - The geology and mineral deposits of the Tennant Creek Goldfield, N.T., Australia; *Bureau of Mineral Resources, Canberra,* Bulletin 22, 164p.

Khin Zaw, Huston, D.L., Large, R.R., Mernagh, T. and Ryan, C.G., 1994a - Geothermometry and compositional variation of fluid inclusions from the Tennant Creek gold-copper deposits: implications for ore deposition and exploration; *Mineralium Deposita*, v. 29, pp. 288-300.

Khin Zaw, Huston, D.L., Large, R.R., Mernagh, T. and Hoffman, C., 1994b - Microthermometry and geochemistry of fluid inclusions from the Tennant Creek gold-copper deposits, Northern Territory: implications for exploration of auriferous ironstones; *in* Proceedings, Annual AusIMM Conference, Darwin, 5-9 August 1994, *Australasian Institute of Mining and Metallurgy, Melbourne*, pp. 185-188.

Large, R.R., 1974 - Gold-bismuth-copper mineralisation in the Tennant Creek district, Northern Territory, Australia; Unpublished Ph.D. thesis, *University of New England, Armidale*.

Large, R.R., 1975 - Zonation of hydrothermal minerals at the Juno Mine, Tennant Creek goldfield, Central Australia; *Economic Geology*, v. 70, pp. 1387-1413.

Le Messurier, P., Williams, B.T. and Blake, D.H., 1990 - Tennant Creek Inlier - regional geology and mineralisation; *in* Hughes, F.E., (ed.), Geology of the Mineral Deposits of Australia and Papua New Guinea, *Australasian Institute of Mining and Metallurgy, Melbourne*, Monograph 14, v. 1, pp. 829-838.

Main, J.V., Nicholson, P.M. and O'Neill, W.J., 1990 - K44 ironstone copper-gold deposit, Gecko Mine; *in* Hughes, F.E. (ed.), Geology of the Mineral Deposits of Australia and Papua New Guinea, *Australasian Institute of Mining and Metallurgy, Melbourne*, Monograph 14, v. 1, pp. 845-848.

Meade, R.A., 1986 - The geology and genesis of the Argo gold-bismuth-copper deposit, Tennant Creek, Northern Territory, Australia; Unpublished Honours thesis, *Monash University, Melbourne*.

Nguyen, P.T., Booth, S.A., Both, R.A. and James, P.R., 1989 - The White Devil gold deposit, Tennant Creek, Northern Territory, Australia; *in* Keays, R.R., Ramsay, W.R.H. and Groves D.I., (eds.) The Geology of Gold Deposits: the Perspective in 1988, *Economic Geology*, Monograph 6, pp. 180-192.

Perring, C.S., Pollard, P.J., Dong, G., Nunn, A.J. and Blake, K.L., 2000 - The Lightening Creek sill complex, Cloncurry district, northwest Queensland: A source of fluids for Fe-oxide Cu-Au mineralisation and sodic-calcic alteration; *Economic Geology*, v. 95, pp. 1067-1090.

Rattenbury, M. S., 1992 - Stratigraphic and structural controls on ironstone mineralization in the Tennant Creek goldfield, Northern Territory, Australia; *Australian Journal of Earth Sciences*, v. 39, pp. 591-602.

Skirrow, R.G. and Walshe, J.L., 2002 - Reduced and Oxidized Au-Cu-Bi Iron Oxide Deposits of the Tennant Creek Inlier, Australia: An Integrated Geologic and Chemical Model; *Economic Geology*, v. 97, pp. 1167 - 1202.

Skirrow, R.G. and Walshe, J.W., 1994 - Transport and deposition of ore metals in the Tennant Creek gold-copper-bismuth deposits: evidence for involvement of oxidizing and reducing fluids; *Geological Society of Australia*, Abstracts, v. 37, p.410.

Skirrow, R.G., 1993 - The genesis of gold-copper-bismuth deposits, Tennant Creek, Northern Territory. Unpublished Ph.D. thesis, *Australian National University, Canberra, Australia*.

Skirrow, R.G., 1999 - Proterozoic Cu-Au-Fe mineral systems in Australia: Filtering key components in exploration models; *in* Stanley, C.J. (ed.), Mineral Deposits: Processes to Processing, Proceedings of SGA-IAGOD Joint International Meeting, London, 22-25 August 1999, *Balkema, Rotterdam*, pp. 1361-1364

Stolz, A.J. and Morrison, R.S., 1994 - Proterozoic igneous activity in the Tennant Creek region, Northern Territory, Australia, and its relationship to Cu-Au-Bi mineralization; *Mineralium Deposita*, v. 29, pp. 261-274.

Wall, V.J. and Valenta, R.K., 1990 - Ironstone-related gold-copper mineralisation: Tennant Creek and elsewhere; *Pacific Rim 90 Congress, Gold Coast, Queensland,* Abstracts, pp. 855-864.

Warren, R.G., Thorpe, R.I., Dean, J.A. and Mortensen, J.K., 1995 - Pb-isotope data from base-metal deposits in central Australia: implications for Proterozoic stratigraphic corrrelations; *Journal of Australian Geology and Geophysics*, v. 15, pp. 501-509.

Wedekind, M. R., 1990 - Geology and chemistry of the Warrego Au-Cu-Bi Mine, Tennant Creek, N.T. Australia; Unpublished Ph.D. thesis, *University of Tasmania, Hobart*.

Wedekind, M.R., Large, R.R. and Williams, B.T., 1989 - Controls on high-grade gold mineralization at Tennant Creek, Northern Territory, Australia; *in* Keays, R.R., Ramsay, W.R.H. and Groves D.I., (eds.) The Geology of Gold Deposits: the Perspective in 1988, *Economic Geology*, Monograph 6, pp. 168-179.

Wedekind, M.R. and Love, R.J., 1990 - Warrego gold-copper-bismuth deposit; *in* Hughes, F.E. (ed.), Geology of the Mineral Deposits of Australia and Papua New Guinea, *Australasian Institute of Mining and Metallurgy, Melbourne*, Monograph 14, v. 1, pp. 839-843.

Wedekind, M.R., Large, R.R., Khin Zaw, Horvath, H.S. and Gulson, B., 1988 - The composition and source of ore depositing fluids in the Tennant Creek goldfield; *in* Goode, A.D.T. and Bosma, L.I., (eds.), Bicentennial Gold 88, Melbourne, May 1988, *Geological Society of Australia*, Abstracts, v. 23, pp. 492-494.

Williams, P.J. and Skirrow, R.G., 2000 - Overview of iron-oxide copper-gold deposits in the Curnamona Province and Cloncurry district (eastern Mount Isa Block), Australia; *in* Porter, T.M., (ed.), Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A Global Perspective, *PGC Publishing, Adelaide*, v. 1, pp. 105-122.

Wright, K., 1965 - Copper ore deposit of the Peko Mine, Tennant Creek; *in* McAndrew, J. and Madigan, R.J. (eds.), Geology of Australian Ore Deposits; 8th Commonwealth Mining and Metallurgy Congress, *Australasian Institute of Mining and Metallurgy, Melbourne*, v. 1, pp. 183-185.,

Yates, K.R. and Robinson, P., 1990 - Nobles Nob gold deposit; *in* Hughes, F.E. (ed.), Geology of the Mineral Deposits of Australia and Papua New Guinea, *Australasian Institute of Mining and Metallurgy, Melbourne*, Monograph 14, v. 1. pp. 861-865.