Intrusion Related Gold Deposits

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Examples

(Breccia)-porphyry: Kidston (Qld),
Skarn-porphyry: Red Dome (Qld);
Disseminated granite hosted: Timbarra (NSW);
Non-carbonate skarn: Lucky Draw (NSW),
Vein, disseminated and alluvial: Majors Creek (NSW),
Mineralised veins: central Victorian gold province (Vic).

Target

- Disseminations, greisens, veins, breccias and skarns associated with middle- to high-level felsic, intermediate to fractionated I-type granites and rhyolite complexes.
- Meso-level skarns, disseminations and veins in an around granite plutons and related dykes.
- Distal quartz veins (1 - 3 km from granite contacts).
- Target grade: >1-2 g/t in disseminated systems, higher in vein systems.
- Deposit size ranges from small (veins) and disseminated (e.g. Timbarra 700 koz Au contained in ~24 Mt at ~1 g/t Au of proven and probable resources; Mustard et al., 1998). Larger systems (Kidston: 140 t Au; Morrison et al., 1996). Many systems overseas typically contain greater than 3 Moz. High-grade examples include Pogo (9.98 Mt at 17.8 g/t Au; Lang et al., 2000).

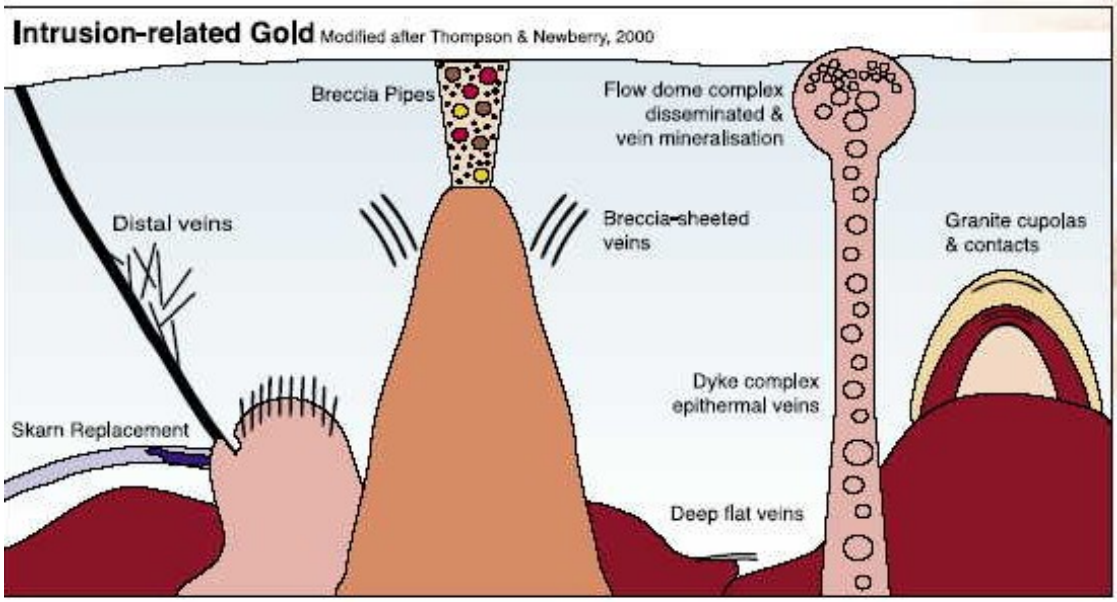

Figure 1. Generalised model for IRG systems. Modified from Thompson & Newberry (2000), to include breccia pipe (Kidston, Qld: Baker & Andrew 1981) and granite carapace (Timbarra, NSW: Mustard 2001) styles.

Mining and treatment

- Disseminated styles, greisens and skarns usually best suited to open pit mining or selective underground mining. Veins can be selectively mined underground.
- Ore grades are typically low but are usually metallurgically simple and sulfide-poor, being low in Cu and other base metals. The gold is fine-grained. Higher As contents, complex Bi mineral associations, and "refractory" Au in arsenopyrite may be present in some cases.
- Most ores can be amenable to cyanide heap leach treatment.
- Production is typically for Au only. Metallurgical credits can include Ag, Cu and Zn (e.g. Red Dome).

Regional Geological Criteria

- Orogenic belts, (collisional to postcollisonal) convergent plate margin settings, extensional back-arc environments.
- Presence of weakly reduced to moderately oxidised, intermediate to felsic fractionated I-type magmatism.
- Historically recorded association of hard rock Au deposits in granites and their aureoles, or alluvial placers apparently shed from granites. There may be a regional association with orogenic lode Au deposits (Alaska/Yukon, Central Victoria).
- Granites with historically recorded molybdenite occurrences associated in areas of known W-Mo and W-Sn mineralisation.

Local geological Criteria

- Current depth exhumation of magmatic systems is important as deposit targets will vary from high level porphyries and breccias, through disseminated and vein systems in the apical portions of granite plutons (Kidston, Timbarra) to deeper skarn and vein systems.
- Carbonate or other reactive units (basalts) are amenable for skarn formation (e.g. Red Dome, Lucky Draw)
- Reduced host rocks can provide reductant traps for hydrothermal fluids. Reduced host rocks can also cause widespread reduction of granite intrusions (e.g. reduced I-types in the Melbourne Province of central Victoria).
- Existing structures may be reactivated during granite emplacement.
- Structural controls on localisation of pluton emplacement and fluid egress. Interplay of reactivated older structures and evolving magmatic-hydrothermal system can be important.

Mineralisation Features

- Gold ± Bi, As, W, Mo, Sb, Te occurs in: single, planar, sheeted and stockwork quartz veins; disseminations in granites and skarns; and as infill in breccias.
- Base metal contents are highly variable from almost absent to assemblages of Cu-Zn-Pb-As. Bi minerals may be well developed.
- Alteration is variable in both style and intensity.

- Zonation from intrusion proximal/high temperature W-Mo to distal lower temperature/later Au-As-Bi assemblages is present in vertically zoned porphyry systems (Kidston) and longitudinally along vein systems (central Victoria). Zonation on a pluton to district scale can be apparent. Distal examples can mimic mesothermal orogenic Au mineralisation styles.

Alteration styles

- Potassic (K-feldspar), sodic (albite), sericitic, greisen, skarn. Tourmalinisation is rarely developed.
- Distal veins may have only narrow alteration selvedges.
- Carbonate alteration accompanying Au mineralisation may be locally well developed.
- Skarns may be carbonate (Red Dome) or non-carbonate (after mafic rocks, e.g. Lucky Draw). Carbonate skarns at Red Dome comprise hedenbergite, andradite-diopside-calcite, and wollastonite dominated assemblages; and chlorite-quartz-calcite-epidote-sulfide retrograde alteration. At Lucky Draw, a mineralised chlorite-almandine-biotite assemblage overprints earlier gedrite-biotite-cordierite-staurolite-hercynite-quartz-albite-ilmenite alteration of non-carbonate metasedimentary rocks and mafic volcanics.

Deposit geochemical criteria

- Two types of igneous associations are apparent: intermediate (i.e. granodiorite) I-types (SiO_2 = 60 to 70%), and felsic (SiO_2 = 70 to 76%), high-K, I-type and fractionated. The latter are enriched in incompatible elements (Y, REE, Th, U, Nb) and depleted in compatible elements (Ti, P, Sr, Fe, Mg, Ni, Cr).
- IRGD are metaluminous to weakly peraluminous (A/CNK = 1.0 to 1.1) in the more felsic examples. A/CNK can be higher in some peraluminous I-type granites (e.g. Burraga), where muscovite and high-Mn garnet are present.
- The granites have subequal quartz, plagioclase and alkali feldspar with minor, usually biotite>amphibole, and minor apatite. Magnetite is rare or absent (due to low relative Fe content and/or weak oxidation state).
- High level rhyolites are strongly porphyritic (sparse to crowded). Granites are equigranular to porphyritic. Both are typically texturally variable and have well developed Unidirectional Solidification Textures (USTs), Interconnected Miarolitic Textures (IMTs), pegmatites, vein dykes etc indicative of volatile saturation during crystallisation at mid to high crustal levels.
- Magmas are weakly reduced to moderately oxidised (FMQ to NNO). Late crystallizing primary titanite may be present. Alkali feldspars may be pinkish, but commonly white to greenish due to phyllic alteration proximal to mineralisation. Magnetite contents are low to absent because of relatively low magmatic oxidation states and Fe contents. Intrusion-Related Gold Deposit (IRGD) granites generally fall into the field between ilmenite- and magnetite-series granites. High SiO_2 late stage phases, sub volcanic intrusions and those with abundant volatile related textures may have higher Fe_2O_3/FeO ratios on account of oxidative effects of volatile exsolution and loss.
- The ore element of economic interest is usually Au. Base metals can be present, or absent. Mineralisation elsewhere in the granite suite includes Mo

and Mo-W±Bi in earlier, higher temperature mineralisation stages, and associated granite suites may elsewhere be associated with Sn-W and W-Mo-Bi-(Sn) mineralisation.
- Trace elements in alteration associated with fractionated granites can include F, B, Cs, Rb, and Li. Yttrium-, Th- and REE-bearing minerals such as xenotime can be present in associated greisens and veins.

Surficial geochemical criteria

- Chemical and petrographic characterisation of granites is a key guide to prospectivity and area selection.
- Known association with W-Sn, and Mo-W-Bi, and Mo mineralisation, especially where historical hard rock or alluvial Au is also recorded.
- Stream and soil surveys (e.g. BLEG) for Au, As, Bi, Sb or Mo shed from intrusion centres.
- Base metal contents are highly variable and cannot be used as a reliable guide for all systems.

Geophysical criteria

- Granites are weakly to moderately oxidized and have low Fe contents: magnetite contents may be low or absent. The granites may appear as magnetic lows although some magnetic granodiorites occur (e.g., Braidwood).
- Highly fractionated granites will have elevated K and U and, in the case of metaluminous I-types, will also have high Th. These will appear white on composite K-Th-U radiometric images. Greisen zones may be high in Th and K.
- Gravity will be low over large batholithic masses. Combined geophysics and magnetics can delineate concealed granites.

Fluid chemistry and source

- High temperature saline fluids are present during pre-Au mineralisation stages.
- Gold mineralisation is typically associated with lower temperature, lower salinity fluids which are commonly CO_2 bearing. Melt inclusions contain Au strongly suggesting (but not proving) a direct magmatic origin for the gold (Mustard et al., 2004).
- High temperature early fluids, and those in intrusion-proximal settings, are magmatic or highly exchanged. Gold mineralisation stage fluids range from magmatic to dominantly magmatic with variable amounts of external or unexchanged waters, probably introduced into the hydrothermal system during cooling.

Comments on genesis

Although still regarded as controversial, Intrusion Related Gold Deposits (IRGD) represents a new class of mineral deposit (Sillitoe, 1991; Thompson et al., 1999). The consistent association of IRGDs with certain magma types, their consistent polymetallic metal associations (Au, Bi, W, As, Mo, Te and/or Sb; Lang et al., 2000), metal zonation patterns, and the presence of Au in high temperature melt inclusions

associated with intrusion proximal examples strongly suggest a magmatic origin for IRGD (Mustard et al., 2004). The importance of the geochemical inheritance of anomalous Au in felsic magmas (e.g. Tomkins and Mavrogenes, 2003) is unclear but is probably not required, and does not explain the consistent associations between IRGD and certain granite types. Gold must be preserved in the melt fraction of crystallizing plutons and be available to the fluid phase during exsolution. Low S magmas of intermediate to felsic compositions with intermediate oxidation states favour neither early sulfide or magnetite precipitation, or early SO_2 formation. The absence of these conditions should be conducive to the preservation of Au in the melt fraction of granite magmas (Blevin, 2004).

DISCUSSION

Examples of IRGDs in Eastern Australia.

IRGD occur in a range of deposit types (Fig. 1). Deposit types in general mirror the range of deposit types typical of lithophile mineralisation (Sn, W, Mo) associated with intermediate to felsic granitic plutonism to high level rhyolitic magmatism. The deposits have a close spatial relationship with either the apical regions or margins of granite plutons (Timbarra, Burraga), or high level to sub-volcanic rhyolite intrusions, sills and dykes (Red Dome, Kidston). Deposit types range from disseminated styles and greisens contained within the apical portions of granites (Timbarra), skarns ± endoskarn in contact with granites (Lucky Draw) and rhyolite complexes (Red Dome). Deeper styles include veins and skarns (Fig. 1).

Timbarra

The mineralisation at Timbarra comprises gold disseminated in the roof zone of a highly fractionated granite. Mineralisation and alteration are capped by microgranite, aplite and fossil crystallisation fronts close to the top of the granite, with negligible quartz veining and with minimal sulfides. Each of the four deposits (Poverty Point, RMT, Hortons and Surface Hill) exhibits a unique morphology controlled by the size of the host intrusive body; granite facies associations; and variable structural controls such as cooling joints, veins, sills, dykes and faults. The four deposits have a total identified mineral resource of 13.65 Mt at 0.95 g/t gold (417 000 oz of contained gold) and a proved and probable reserve of 10.06 Mt at 1.01 g/t gold (327 000 oz of contained gold; Mustard, et al., 1988).

The Timbarra granites evolved in an essentially closed system in which chilled carapaces were formed and the late stage microgranite or aplite was intruded as dykes and sills in cooling joints and cracks. Altering and mineralising fluids moved up from below and "pooled" in the partially or totally crystalline granite underneath the chilled carapaces resulting in sericitisation and corrosion of feldspars and the chloritisation of biotite (Simmons, 1993). Gold deposition occurred in corroded cavities in feldspar and along crystal boundaries and joints. The introduction of gold was associated with molybdenum, bismuth, antimony and arsenic (Simmons *et a*l, 1996). The granites are part of the extensive Moonbi Supersuite (Blevin and Chappell, 1996).

Kidston (QLD)

Kidston (140t contained Au) comprises a zoned polymetallic porphyry system centred on a cylindrical hydrothermal breccia pipe (Morrison et al., 1996). The alteration system and breccia pipe is at least 1300m deep.

Heterogeneous rhyolite plugs cut early barren "felsite" dykes. The plugs show strong phyllic alteration, have zones of brain rock and micropegmatites, are associated with tourmaline breccias and contain quartz-magnetite veins and quartz-molybdenite stockworks. Adjacent basement rocks have base metal-bearing quartz-epidote veins with propylitic alteration. The intrusion of normal-textured porphyries is associated with the subsequent main breccia stage. This is succeeded by phenocryst-rich (crowded) porphyries and the mainstage Au-base metal mineralisation. Post-mineralisation crowded porphyries and andesite dykes are also present. Gold-base metal mineralisation comprises sheeted veins and cavity infill and occurs near the top of prominent vertical metal zonation extending down through Zn-Pb-Cu-As, Cu-Zn, to Mo(W-Cu) at depth (Morrison et al., 1996). Phyllic alteration (quartz-sericite-pyrite-carbonate ± fluorite) is widespread while patchy remnants of pink quartz-albite-hematite and green-grey propylitic (sericite-chlorite-carbonate ± epidote) alteration is present in the deeper parts of the intrusive bodies. Early, pre-breccia fluids were high temperature and saline with the breccia diatreme having formed from overpressuring. Post-breccia CO_2-bearing Au-ore fluids have lower salinities and lower $\delta^{18}O$ and δD values and represent condensate from a boiling and cooling dominantly magmatic fluid (Baker and Andrew, 1991).

The Kidston intrusions are fractionated, high-K, weakly to moderately oxidised I-types that are chemically indistinguishable from the locally associated dyke swarm and the plutonic rocks of the Lochaber-Bagstowe Complex immediately to the south. They are very similar to other fractionated I-type Carboniferous suites elsewhere in North Queensland (Champion and Chappell, 1992), in particular, the Ootann Supersuite.

Red Dome (Qld)

The Red Dome open cut mine produced 12.8 Mt at 2 g/t gold and 0.5% copper between 1986 to 1996, closing a few years later (Nethery and Barr, 1998). Two main Carboniferous porphyry phases are present: an early quartz veined porphyry, and a later crowded porphyry, which appears to have intruded along faults within the earlier intrusion. Blevin (1995) concluded that the porphyries were fractionated members of the Carboniferous I-type Ootann Supersuite.

Early minor Sn-W-Mo occurs as disseminations and veinlet stockwork in the apical portions of a microgranite plug and in the surrounding prograde skarn halo. This is overprinted by pervasive and vein-related hydrous retrograde alteration with associated quartz-arsenopyrite-Au-Mo veining, which is in turn crosscut by a second andradite-magnetite-bornite-chalcocite skarn phase (Torrey, 1986; Ewers et al., 1990). Later retrograde overprinting is associated with carbonate-quartz-chalcopyrite-sphalerite-galena veining. A late stage association of minor colloform quartz-adularia veining, massive sulfide-sulfosalt, breccia pipes, and highly oxidised hydrothermal eruption breccias is also present.

Early fluids in crenulate quartz rocks yielded fluid inclusion homogenisation temperatures up to 520°C. Trapping temperatures of the main alteration and mineralisation fluids range from 300 to 380°C or 400 to 500°C depending on pressure estimates (0.4 to 1 kb, or 1.6 kb; Torrey et al., 1986; Ewers and Sun, 1998; Solomon and Groves, 2000). Early fluids were uniformly saline (up to 30-55 equiv. wt% NaCl) while later fluids had lower salinities with CO_2 and CH_4 also being present.

Lucky Draw (NSW)

The Lucky Draw deposit (Shepherd et al., 1995) comprises disseminated Au-Bi-Te>As skarn-hosted mineralisation introduced during chlorite-almandine-biotite development which overprinted earlier gedrite-biotite-cordierite-staurolite-hercynite-quartz-albite-ilmenite alteration. The initial alteration stage resulted from the metasomatism of non-carbonate metasedimentary rocks and mafic volcanics. Bismuth minerals and native gold were introduced during the second alteration (T ~ 550°C; P ~ 2 to 3 kb; Shepherd et al., op. cit.). The low melting temperature of the various Bi ore minerals indicates that they were introduced as a melt and deposited interstitial to chlorite grains and along chlorite cleavages.

The associated Carboniferous Burraga Granite is a highly fractionated, mildly peraluminous I-type granite. Garnet has been stabilised due to high Mn/(Mn+Fe+Mg) and elevated A/CNK ratios in the magma, and pegmatites are well developed at the margin of the pluton closest to the mine. Magnetite is described as being present in the granite by Shepherd et al. (1995) and Fe_2O_3/FeO ratios of the granite and associated plutons are consistent with a moderate oxidation state. Some similar aged granites of the Oberon region also show decreasing Y and increasing Mn/(Mn+Fe+Mg) with increasing SiO_2 and are also mildly peraluminous. This suggests that this is a local feature in common with spatially-associated Carboniferous I-types, and is not unique to the Burraga Granite. The K/Rb ratios for these granites are low and their Rb/Sr ratios are high indicating evolved origins and strong fractionation trends.

Majors Creek-Braidwood

The Braidwood Granodiorite is located in the northern part of the Bega Batholith. It comprises two main intrusive phases. Numerous aplites, pegmatites and porphyritic phases are also present in what is interpreted to represent the westward dipping roof zone of the pluton. Over 40 tonnes of gold have been produced from alluvial placer deposits shed from the granodiorite, and extensive potential reserves remain (Middleton, 1970, McQueen, 2003). The granodiorite is high in K, Ba and Rb and is relatively oxidised. Primary Au mineralisation at Dargues Reef comprises narrow mineralised lodes of intense pyritic and seritic alteration, enclosed in zones of propylitic alteration (McQueen and Perkins, 1995). Discrete quartz and quartz-calcite veins also occur in the granodiorite and adjacent country rocks. Gold is accompanied by a base metal assemblage of Cu-As-Bi-Mo-Pb-Te. Molybdenite, pyrite and minor chalcopyrite are also disseminated through a porphyritic leucogranite phase of the granodiorite at Araluen.

Fluid inclusion data indicates CO_2-bearing fluids of low to moderate salinity (<16 equiv. wt% NaCl) and medium to low temperatures (<350°C), at pressures greater than 500 bars (Wake and Taylor, 1988; McQueen and Perkins, 1995). Carbon, sulfur and lead isotope data are consistent with a magmatic source for the mineralisation, while oxygen isotopes suggest some possible limited involvement of meteoric waters (McQueen and Perkins, 1995).

In contrast to other Au-mineralised granites, the Fe_2O_3/FeO contents of the Braidwood Granodiorite is borderline between moderately and strongly oxidized. The granodiorite is high in magnetite (typically 1 to 1.5 modal percent), which is higher than would be otherwise implied by the Fe_2O_3/FeO ratio alone. Conversely, titanite is a rare or late stage mineral. The dykes are fractionated with modestly elevated Rb/Sr, Y and Nb.

Western Victoria

Devonian IRGDs are developed in the Central Victorian gold province. Possible examples include the Wonga deposit (Stawell Granite), Maldon (Harcourt Granite and dykes), Mount Piper, Myrtle Creek, Malmsbury, and deposits associated with the Woods Point Dyke Swarm (Bierlein et al, 2001; Bierlein et al., 2003). Some of the Au deposits located in granite wallrocks have previously been interpreted as contact metamorphosed older vein Au deposits that have been overprinted by W-Mo-Bi-Te hydrothermal assemblages close to granite contacts (e.g. Phillips and Hughes, 1996).

Metal associations for the deposits are typically Au ± Bi, Mo, W, As, Te, Sb and Cu. Alteration styles range from skarn like to sericitisation, sulfidation, silicification, chloritisation and carbonisation (Bierlein et al., 2003). Fluid inclusion studies from Malmsbury indicate moderately saline CO_2-rich (± CH_4) fluids (Bierlein et al., 2003).

Associated granites are typically weakly reduced to weakly oxidized I-types. The Harcourt Granite has a mineralogy of plagioclase, orthoclase, quartz, biotite with accessory zircon, apatite, ilmenite and titanite (Bierlein et al., 2001). It is I-type, though moderately reduced. Redox (ie Fe_2O_3/FeO) data for the Stawell Granite lies in the transitional zone between reduced and oxidized conditions, consistent with its weakly magnetic to non-magnetic character. The Mafeking Granite is associated with disseminated molybdenite and quartz-pyrite veins containing traces of gold. Placers associated with that granite as well as around the McKenzie River and Epacris Granites may have been sourced from similar low grade mineralisation. A strong trend of increasing Fe_2O_3/FeO away from the oxidized-reduced transition is apparent in the more felsic members of the Mafeking Suite (which is titanite and magnetite bearing in part). In general, these granites have a range of SiO_2 from 66 to 70 % with some more felsic analyses being present in the Stawell pluton and Mafeking Suite (B. W. Chappell, unpublished data). An important observation on the oxidation state of these granites is that many I-type, particularly in central Victoria are reduced, and associated S-type even more strongly so. This indicates that the relatively reduced nature of some of these I-types is a regional characteristic.

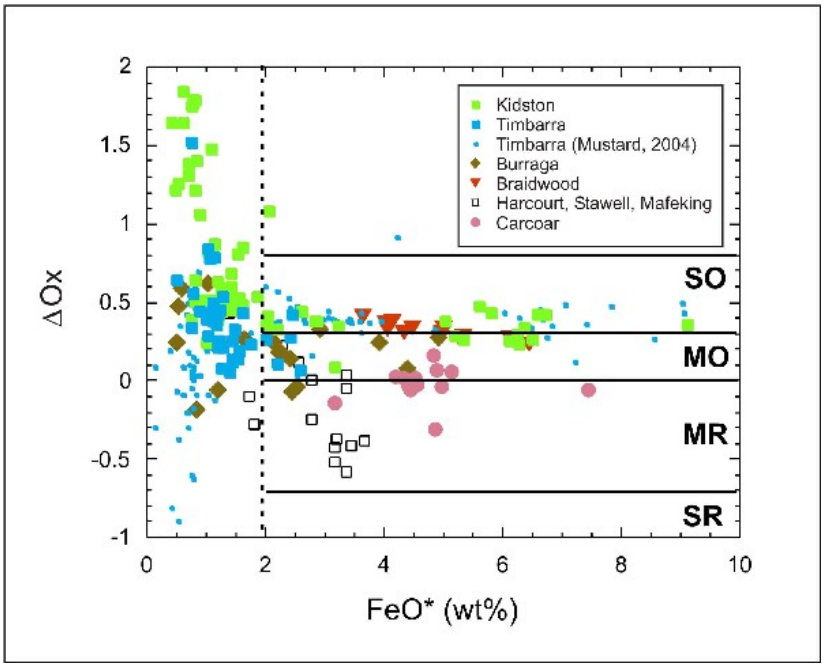

Figure 2: Relative oxidation states of IRGDs. Delta Ox (ΔOx) refers to relative oxidation state calculated using the equation Delta Ox = log(Fe2O3/FeO) + 0.3 + 0.03*FeO*, where FeO* = total Fe expressed as FeO (see Blevin, 2004). Fields marked as SO, MO, MR and SR refer to Strongly Oxidised, Moderately Oxidised, Moderately Reduced and Strongly Reduced, respectively. Delta Ox values for samples with FeO*< 2wt% are not representative of their actual oxidation state and reference to related samples with higher FeO* contents should be made. Data sources: Blevin (2004 and unpublished data); B. W. Chappell (unpublished data); Mustard (2004).

Chemistry of Associated Granites

IRGD in eastern Australia are associated with two broad granite associations:

1. Intermediate (SiO_2 = 60 to 70%), medium- to high-K I-type granodiorites to granites. They are typically moderately oxidized, but can be moderately reduced in regions where that is the dominant I-type character. They may be either amphibole-biotite or simply biotite bearing.
2. Felsic (SiO_2 = 70 to 76%), moderately to strongly fractionated high-K, granites and rhyolitic equivalents. These generally occur at higher crustal levels than the IRGD granodiorites.

The compositional properties of granites associated with IRGD provide important clues to the origin of these systems. Although Au is commonly part of a predictive relationship in the zoning of most polymetallic magmatic hydrothermal ore systems, some systems are enriched in Au with respect to other metals making them "gold deposits", economically at least, while still being fundamentally polymetallic hydrothermal ore systems. The fO_2 for the related granites, determined from mineralogy, magnetic susceptibilities and Fe_2O_3/FeO indicate that they are neither strongly reduced nor oxidized (Fig. 2). They are also metaluminous, or may be weakly peraluminous if very felsic, although this does not imply a strongly peraluminous ancestry of the granite rocks or their source rocks. Compositionally, they are too evolved and/or felsic to be associated with Cu, too oxidised to be associated with significant Sn production, and are not oxidised enough to be associated with significant Mo (Fig. 3, 4). They occur in the redox-fractionation zone

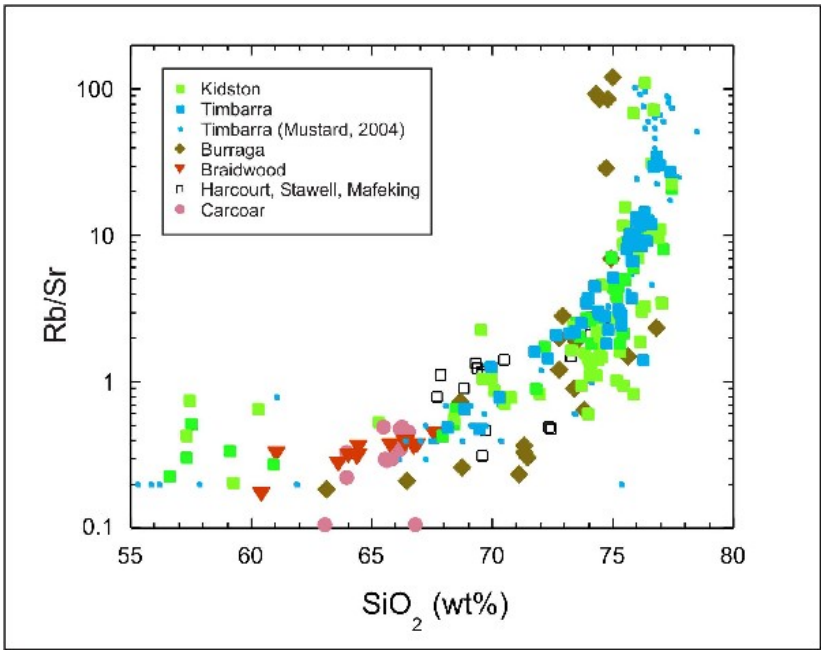

Figure 3: Rb/Sr versus SiO_2 (wt%) for granite associated with IRGDs in eastern Australia. Note the strongly fractionated nature of felsic systems (Kidston, Timbarra, Burraga). Red Dome is similar but not included due to alteration. Note the less fractionated and felsic nature of Braidwood, Carcoar (Browns Creek), and Victorian examples

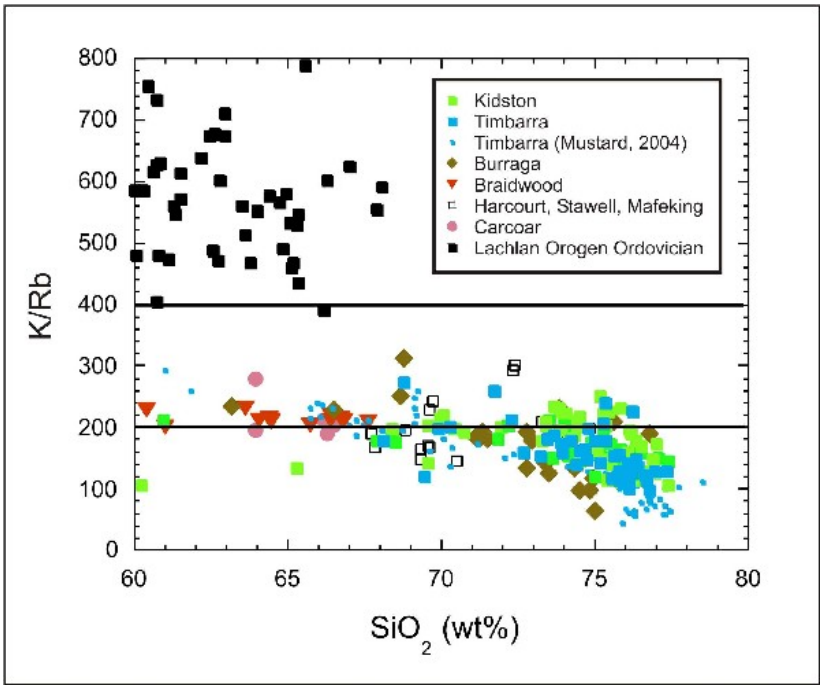

Figure 4: K/Rb versus SiO_2 for granites suites associated with IRGDs in eastern Australia. Black solid squares show porphyry Cu-Au related intrusions from the Ordovician of NSW for comparison.

normally associated with minor W-Mo +/- Sn occurrences and W-scheelite mineralisation (Blevin and Chappell, 1995; Blevin et al., 1996).

Metal Zonation and Associations

In oxidised porphyry Cu systems Au occurs with the Cu in the high temperature proximal core of the systems. In more felsic and evolved systems, (e.g., Kidston, Red Dome), economic Au mineralisation is located distally (spatially and paragenetically) from the higher temperature W-Mo cores of the systems (Fig. 5). At Kidston deep drilling indicated that metal zoning separated the higher temperature W-Mo portion of the system from the Au-rich zone by 1400m (Morrison et al., 1996). The location of economic gold mineralisation within these hydrothermal systems changes from proximal in Cu-Au centred systems (e.g. Cadia, Australia), to the more distal base-metal zone in W-Mo-Bi centred systems (e.g. Kidston, Australia). At Timbarra, minor, early high temperature quartz-molybdenite veining is overprinted at lower temperatures by disseminated Au mineralisation (Mustard et al., 1998).

These zonation relationships, if superimposed on a redox-fractionation plot of core element assemblages suggest that the location of economic Au in granite related mineral deposits occurs paragenetically more distal from the higher temperature core element association in deposits associated with progressively more felsic and evolved (and less oxidised) systems (Fig. 5). This indicates that the Au-rich portion of granite related mineral deposits may be locally distant from the higher temperature parts of the hydrothermal system, and that obvious genetic links between the Au-rich portions of these deposits and their related granites may be more difficult to establish. The element assemblages associated with the lower temperature, more distal deposits (Au ± As, Bi, Te, Sb) also resembles those of mesothermal deposits.

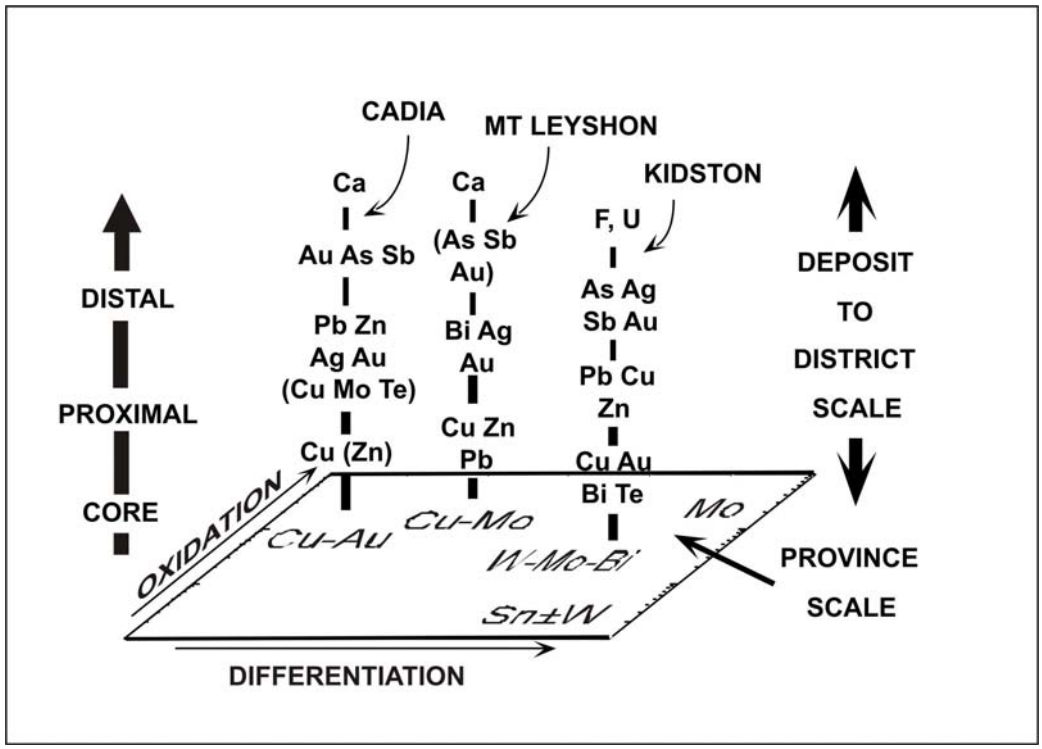

Figure 5. Relationships between metal zonation at the deposit or district scale and how they relate back to higher temperature, proximal igneous centred systems (Cu-Au, Cu-Mo, W-Mo, Sn-W, Mo). These correspond to the main porphyry deposit types. Examples of economic gold systems of diverse metallogeny are shown (e.g. Cadia - porphyry Cu-Au; and Mount Leyshon). Note that for Kidston (and felsic IRGD systems), economic Au mineralisation tends to be located further from the proximal core of the hydrothermal system.

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FIGURE CAPTIONS

Figure 1: Examples of IRGD deposit types in eastern Australia.

Figure 2: Relative oxidation states of IRGDs. Delta Ox (ΔOx) refers to relative oxidation state calculated using the equation Delta Ox = log(Fe2O3/FeO) + 0.3 + 0.03*FeO*, where FeO* = total Fe expressed as FeO (see Blevin, 2004). Fields marked as SO, MO, MR and SR refer to Strongly Oxidised, Moderately Oxidised, Moderately Reduced and Strongly Reduced respectively. Delta Ox values for samples with FeO*< 2wt% are not representative of their actual oxidation state and reference to related samples with higher FeO* contents should be made. Legend: Green squares - Kidston; blue squares – Timbarra; brown diamond – Burraga; orange triangle – Braidwood; open black square – Mafeking, Harcourt and Stawell (Victoria); purple filled circles – Carcoar (Browns Creek). Data sources: Blevin, 2004 and unpublished data; B. W. Chappell (unpublished data); Mustard, 2004.

Figure 3: Rb/Sr versus SiO_2 (wt%) for granite associated with IRGDs in eastern Australia. Note the strongly fractionated nature of felsic systems (Kidston, Timbarra, Burraga). Red Dome is similar but not included due to alteration. Note the less fractionated and felsic nature of Braidwood, Carcoar (Browns Creek), and Victorian examples. See Figure 2 for symbols.

Figure 4: K/Rb versus SiO_2 for granites suites associated with IRGDs in eastern Australia. Symbols are the same as that for figure 2. Black solid squares show porphyry Cu-Au related intrusions from the Ordovician of NSW for comparison.

Figure 5. Relationships between metal zonation at the deposit or district scale and how they relate back to higher temperature, proximal igneous centred systems (Cu-Au, Cu-Mo, W-Mo, Sn-W, Mo). These correspond to the main porphyry deposit types. Examples of economic gold systems of diverse metallogeny is shown (e.g. Cadia - porphyry Cu-Au; and Mount Leyshon). Note that for Kidston (and felsic IRGD systems), economic Au mineralisation tends to be located further from the proximal core of the hydrothermal system.