New constraints on the chemistry of magmas and fluids associated with intrusion-related gold deposits

T. Baker

Economic Geology Research Unit, School of Earth Sciences, James Cook University, Townsville, Queensland 4811, Australia; Tel: 61-7-47814756; Timothy.Baker@jcu.edu.au

Abstract

In the past decade several significant intrusion-related gold deposits have been discovered in terranes historically exploited for tin-tungsten mineralization (e.g., Tintina Gold Province, Yukon and Alaska, Tasman Fold Belt, Australia and the Altaid orogenic collage in central Eurasia). This paper presents new data on the geological and geochemical characteristics of these deposits that links them to magmatic-hydrothermal processes and highlights their implications for exploration. New data from several intrusion-related gold provinces suggest that these deposits are found in areas that contain granodiorite to granite, but with a locally significant mafic component, have Rb/Sr ratios ranging between 0.1 and 1.0, and are moderately reduced (Fe_2O_3/FeO ~ 0.1 to 0.6) ilmenite series, metaluminous, I-types. The intrusions are distinct from porphyry copper intrusions and tin granites, but are more akin to tungsten granites. Hydrothermal fluid types vary with depth of emplacement in intrusion-related gold deposits and new proton induced x-ray emission (PIXE) data from syn-ore fluid inclusions in shallow and deep deposits provide fascinating insight into the variation in metal content between the different settings consistent with observed deposit metal associations. Exploration for intrusion-related gold deposits in tin-tungsten terranes should focus on regions that contain both mafic and felsic intrusion that are moderately reduced, metaluminous, I-type granites rather than terranes with dominantly highly fractionated, strongly reduced, peraluminous S-types. Intrusion-related gold systems occur in variety of deposit styles (in part controlled by host rock, proximity to granite, and depth of emplacement) and exploration geologists need to be aware of the variety of target types in and around the intrusive environment, and be able to recognize whether they are exploring a shallow or deep intrusion-related gold setting.

Keywords: *Intrusion-related gold deposits, granite, fluid inclusions, PIXE*

Introduction

Intrusion-related gold deposits have become significant exploration targets in granite belts that host tungsten and tin deposits over the past decade (Fig. 1). Examples of these terranes include the Tintina Gold Province, Yukon and Alaska, with major deposits such as Donlin Creek (28 M.oz.), Fort Knox (5 M.oz.), Pogo (5 M.oz.), Dublin Gulch (2 M.oz.), Shotgun (1 M.oz.) and Brewery Creek (1 M.oz.), the Tasman Fold Belt, Australia (e.g., Kidston 5 M.oz.; Timbarra 0.5 M.oz.), and deposits in the Altaid orogenic collage in central Eurasia (e.g., Vasilkovskoye 9 M.oz; Zarmitan 11 M.oz; Jilau 2 M.oz.). This paper presents new data on the geological and geochemical characteristics of these deposits that links them to magmatic-hydrothermal processes and highlights their implications for exploration.

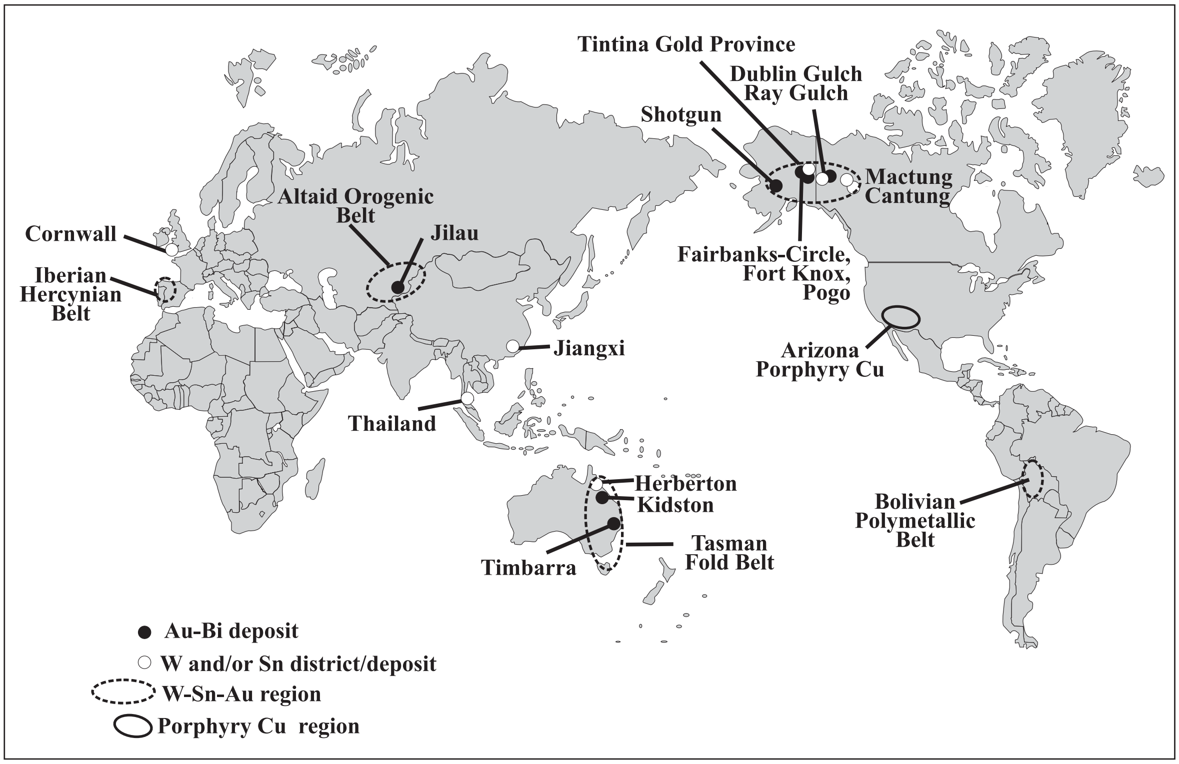


Figure 1. World map showing locations of selected major Cu, Sn, W, and Au regions and deposits (modified from Baker et al., 2005).

Granite metallogeny

Different magma-types have broad associations with different metal types (Blevin and Chappell, 1992). This is illustrated by data compiled by Baker et al. (2005) and this study that are presented in Table 1 and Fig. 2, and include examples of intrusion related gold deposits from the Tintina Gold Province (TGP) in addition to granite geochemistry from tin and tungsten systems in Alaska and Yukon. The Tasman Fold Belt in eastern Australia also includes intrusion related gold deposit examples such as Kidston and Timbarra in addition to major tin and tungsten districts associated with the Kennedy Igneous Province (KIP) granites. Another region renowned for intrusion related gold is the Altaid orogen which includes examples such as the Jilau sheeted vein and skarn hosted gold-bismuth-tungsten deposit in Tajikistan (Cole et al., 2000) as well as significant granite related tungsten-molybdenum deposits (e.g., Late Paleozoic granites of central Kazakstan; Heinhorst et al., 1996; Yakubuchuk et al., 2002). Other regions are known for their tin and tungsten deposits but lack significant gold. These include Cornwall, England (Manning and Hill, 1990), the Jiangxi province, southeast China (Yan et al., 1980), and granite-related tin and tungsten deposits of Thailand (Ishihara et al., 1980). Also added to this compilation for comparison are data from SW Arizona porphyry copper deposits (Lang and Titley, 1998).

The data show that porphyry copper deposits are associated with less fractionated (Rb/Sr ~ 0.01 to 1.0; 48-79 wt % SiO_2), metaluminous, oxidised (Fe_2O_3/FeO ~ 0.5 to 5) intrusions whereas granites related to tungsten deposits are associated with fractionated (Rb/Sr ~ 0.1 to 10; 56-77 wt % SiO_2) intrusions of intermediate oxidation state (Fe_2O_3/FeO ~ 0.1 to 2.0) that are peraluminous to metaluminous in composition (Fig. 2 and Table 1). Tin deposits, however, are associated with the most fractionated (Rb/Sr ~ 1 to 100; 70-77 wt % SiO_2) and reduced (Fe_2O_3/FeO ~ 0.01 to 0.5) peraluminous granite types. Porphyry copper deposits are associated with I-type intrusions, whereas tungsten deposits are associated with both S- and I-type granites, and tin deposits primarily with S-type. New data from several intrusion-related gold provinces suggest that these deposits are found in areas that contain granodiorite to granite, but with a locally significant mafic component (49-78 wt % SiO_2), have Rb/Sr ratios ranging between 0.1 and 1.0,

Metallogenic Association	Region/Deposit	Country	Granite type	SiO2 wt %	Granitoid Series	Alumina saturation	Accessory minerals*	References
Sn-W-Bi	Cornwall	UK	S	71-74	Ilmenite	peraluminous	ilmenite, monazite, andalusite, topaz, fluorite	Manning and Hill, 1990
Sn-W-Bi	Herberton	Australia	I	73-77	Ilmenite	peraluminous	ilmenite, monazite, topaz, fluorite	Pollard, 1988; Champion and Chappell, 1992
Sn-W-Bi	Fairbanks-Circle	USA	I	71-77	Ilmenite	peraluminous	ilmenite, titanite, monazite, tourmaline, topaz	Newberry et al., 1990
Sn-W	Western Thailand	Thailand	I/S	70-74	Ilmenite	peraluminous	ilmenite, andalusite, pyrrhotite	Ishihara et al., 1980; Linnen, 1998
W-Sn-Mo	Jiangxi	China	S	66-76	Magnetite	peraluminous	magnetite, ilmenite, garnet, monazite, tourmaline, fluorite	Yan et al., 1980
W-Cu-Mo	E Yukon	Canada	I	67-77	Ilmenite	metaluminous to peraluminous	ilmenite, monazite, garnet, andalusite, allanite, tourmaline	Gordey and Anderson, 1993
W-Mo-Sn-Bi	Altaid orogenic belt	Kazakhstan	I	63-77	Magnetite	metaluminous to peraluminous	magnetite, titanite, monazite, allanite, ilmenite	Heinhorst et al., 1996; Serykh, 1996
W-Mo-Bi-Sn	Herberton	Australia	I	56-72	Magnetite	metaluminous	allanite, fluorite, ilmenite	Champion and Chappell, 1992
W-Sn-Au	Iberia	Spain/Portugal	I/S	62-76	Ilmenite	metaluminous to peraluminous	cordierite, garnet, titanite, andalusite, sillimanite, tourmaline, topaz	Neiva and Gomes, 1991; Fernandez-Suarez, 1998
Au-Bi-W	Tintina Gold Province	USA & Canada	I	50-74	Ilmenite	metaluminous to peraluminous	ilmenite, titanite, allanite	Lang et al., 2000
Au-Bi-W	Jilau	Tajikistan	I	57-72	Ilmenite	metaluminous to peraluminous		Cole et al., 2000; Cole, 2000
Au-Bi-Mo	Timbarra	Australia	I	49-78	Magnetite/Ilmenite	metaluminous to peraluminous	magnetite, ilmenite, titanite, fluorite	Mustard, 2001
Au-Bi-Cu-Mo-W	Kidston	Australia	I	50-76	Magnetite/Ilmenite	metaluminous to peraluminous	titanite, fluorite, magnetite, ilmenite, xenotime	Baker and Andrew, 1991; Blevin, 2004
Cu-Au-Mo	SW Arizona	USA	I	48-79	Magnetite	metaluminous	magneitite, titanite	Lang and Titley, 1998
Bold - principal commodity(ies)							*In addition to zircon and apatite	

Table 1. Classification and characterization of granites associated with Cu, Sn, W, and Au deposits.

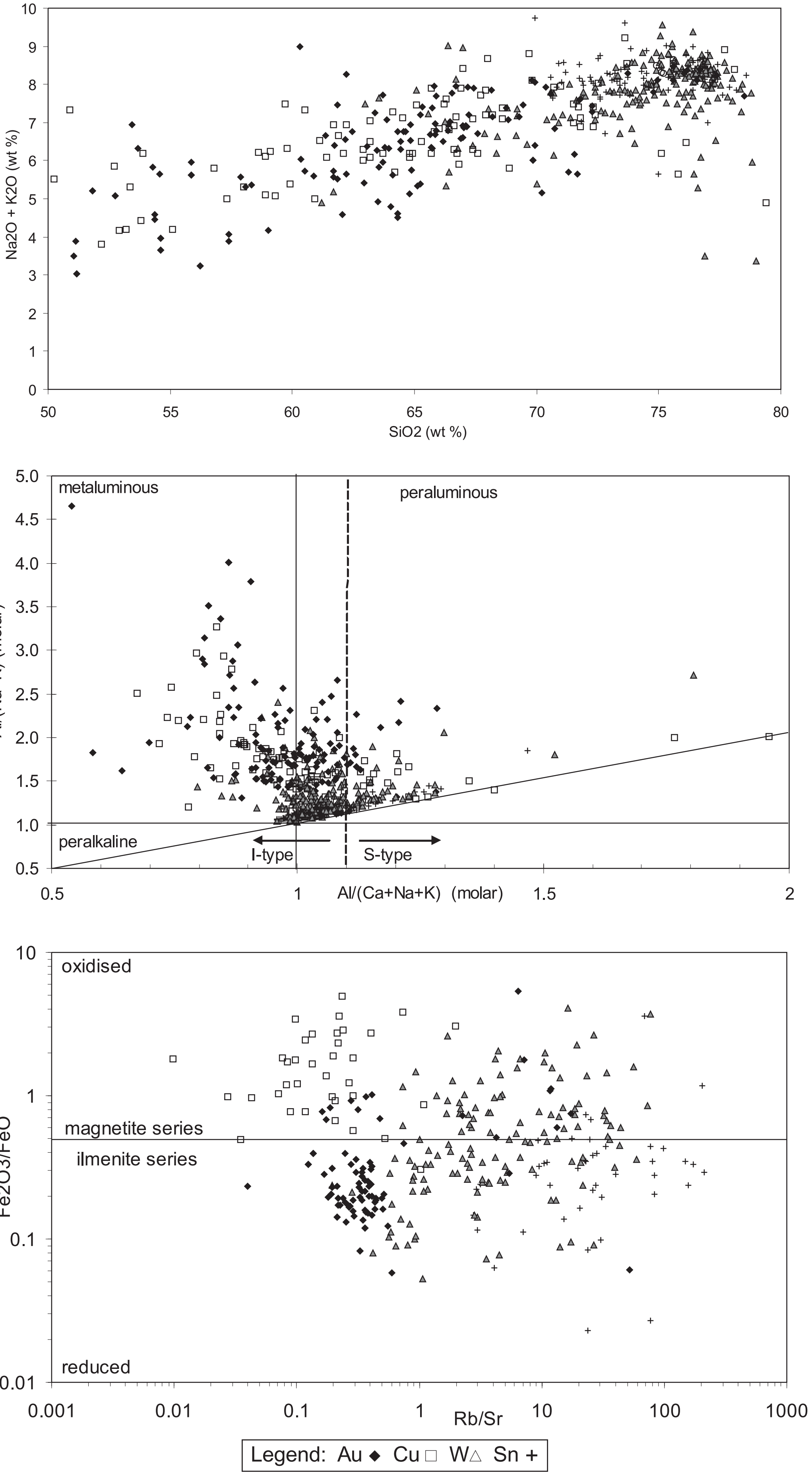


Figure 2. Geochemical plots of (a) total alkalis versus silica (Le Maitre, 1989); (b) Shand's peraluminosity index (Maniar and Piccoli, 1989); (c) Rb/Sr versus Fe_2O_3/FeO (Blevin and Chappel, 1995).

and are moderately reduced (Fe_2O_3/FeO ~ 0.1 to 0.6) ilmenite series, metaluminous, I-types (Baker et al., 2005). Radiogenic isotopes, however, suggest a significant sedimentary crustal component to many of the magmas.

Granites and hydrothermal fluids

Textures indicative of the magmatic-hydrothermal transition are also common in intrusion-related gold systems and include features such as pegmatites, vein dykes, miarolitic cavities and unidirectional solidification textures (Fig. 3). Mineralization contains gold-bearing quartz veins that are characterized by a reduced (pyrrhotite-stable with no magnetite or hematite), low sulfide (<5 volume %) ore assemblage (Thompson et al., 1999). The deposit styles, however, vary greatly and include large flat veins (Pogo), sheeted veins (Fort Knox and Dublin Gulch), breccia and stockwork (Shotgun and Kidston), disseminated to greisen (Timbarra) and dyke-sill hosted veinlets (Brewery Creek and Donlin Creek). This variation in style has been attributed to depth of emplacement and proximity to intrusions with systems such as Donlin Creek and Brewery Creek considered to be shallow-level epithermal/epizonal deposits (< 2km), Shotgun and Kidston emplaced at typical porphyry-levels (2-5km) and Pogo, Fort Knox and Dublin Gulch emplaced in deeper plutonic environments (>5km). Shallow-level deposits are typically characterized by gold associated with arsenic and antimony and locally elevated base metals, whereas deeper systems commonly contain abundant bismuth, tungsten and arsenic.

Fluid inclusion types also vary with depth of emplacement in intrusion-related gold deposits (Baker, 2002). Deposits in shallow environments (~<5 km) contain high temperature (>350 °C), immiscible brine (>30 wt % NaCl) and low-salinity (<5 wt % NaCl) vapour that commonly contains carbon dioxide. Deposits in deeper environments (>5 km) contain abundant low-salinity, carbon dioxide±methane-rich aqueous fluids (<10 wt % NaCl). This diversity in fluid types has lead to some controversy regarding the genesis of these deposits as to whether they were derived from focused magmatic-hydrothermal systems (Thompson et al., 1999) or through large-scale metamorphic processes (Groves et al., 2003). New PIXE data from syn-ore fluid inclusion in shallow (coexisting brine and carbon dioxide-bearing vapour inclusions) and deep (low salinity carbon dioxide±methane-rich aqueous fluids) deposits have some similar characteristics including high K/Ca wt. ratios (> 1) consistent with granite-derived or granite equilibrated fluids, and low Mn/Fe wt. ratios (< 0.24) are consistent with the reduced conditions in which the ore systems formed. Fluid inclusions in the shallow level deposits are characterized by higher base metals contents due to the greater abundance of chlorine (Fig. 4a). Nonetheless, the copper contents are significantly lower (< 1000ppm) than those found in porphyry copper systems (Fig. 4b).

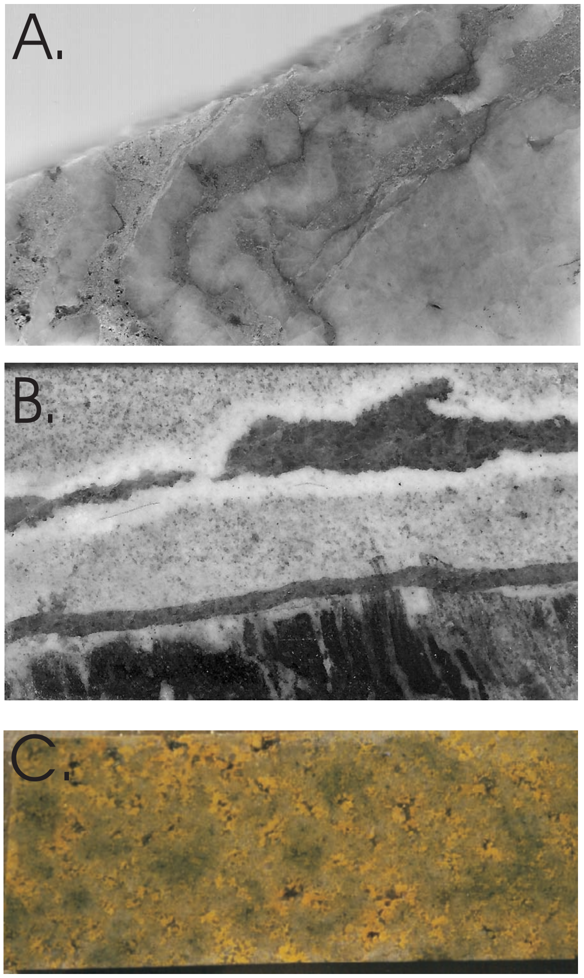


Figure 3. Magmatic-hydrothermal transition textures from intrusion related gold deposits; (a) unidirectional solidification textures at Kidston; (b) vein dyke at Dublin Gulch; (c) miarolitic cavities at Timbarra.

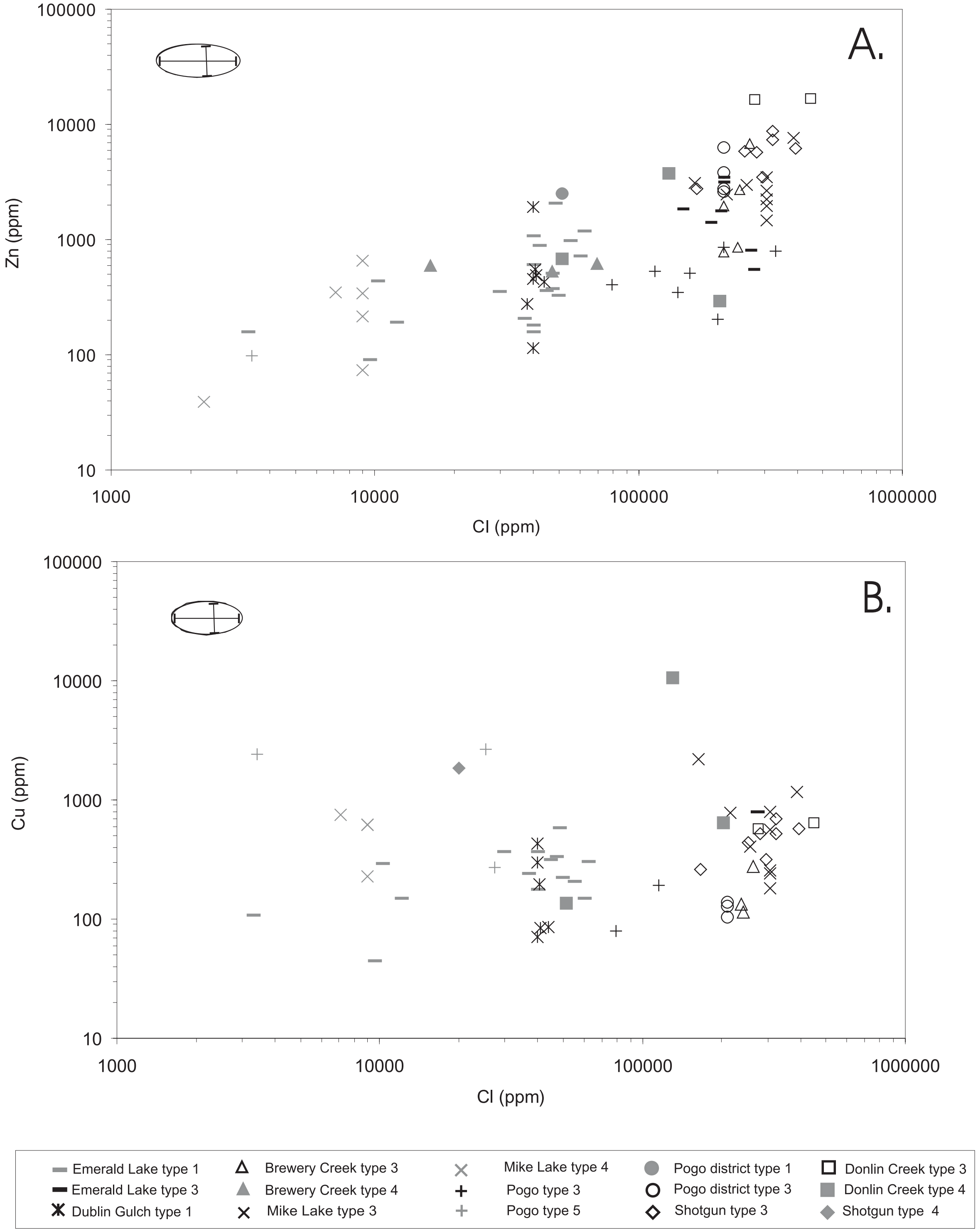
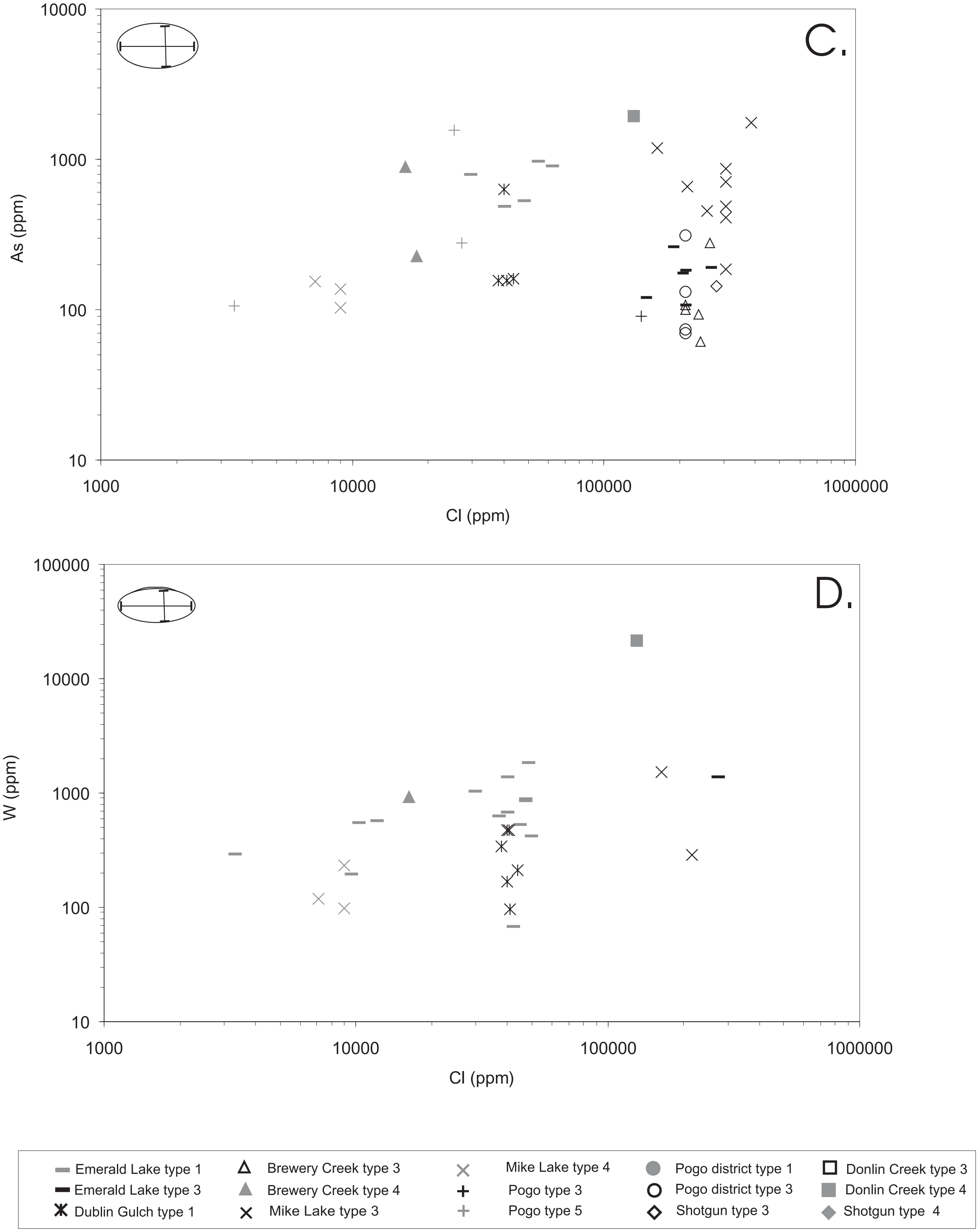


Figure 4. Scatter plots illustrating the relationship between chlorine and metals as measured by PIXE in fluid inclusions from intrusion related gold deposits; (a) Zn; (b) Cu; (c) As; (d) W. Indicative error bars = 30%. Type 1 inclusions – low salinity CO_2-H_2O±CH_4; Type 3 inclusions – halite-bearing aqueous inclusions; Type 4 inclusions – CO_2-bearing vapor-rich; Type 5 - low salinity CH_4-H_2O±CO_2.



Tungsten is more elevated in the low salinity carbon dioxide-bearing fluid inclusions consistent with high tungsten contents in deeper level deposits, and likely due to tungsten's preference to form tungstate complexes rather than chloride complexes (Fig. 4d). Arsenic was found in both high and low salinity fluid inclusions, and may be explained by its ability to complex with other elements such as sulfur (e.g., thioarsenite) in addition to chlorine (Fig. 4c). Arsenic may be used as a proxy for gold due to their similar chemical behaviour and explain why both shallow and deep level deposits contain gold despite the diverse fluid types present.

Implications for exploration

The results of this study clearly show a strong connection between certain granite types and gold mineralization. Exploration for intrusion-related gold deposits in tin-tungsten terranes should focus on regions that contain moderately reduced, metaluminous, I-type granites rather than highly fractionated, strongly reduced, peraluminous S-types. Intrusion-related gold systems occur in variety of deposit styles (in part controlled by host rock, proximity to granite, and depth of emplacement) and exploration geologists need to be aware of the variety of target types in and around the intrusive environment, and be able to recognize whether they are exploring a shallow or deep intrusion-related gold setting. New fluid inclusion PIXE data suggests that the geochemical variations in metal characteristics between shallow and deep systems can explained by the different fluid types found in these different settings. The diversity of fluid types may be related to the fact that carbon dioxide degasses at much higher pressures than water and chlorine in felsic magmas and consequently, the carbon dioxide contents of deep magmatic-hydrothermal systems will be higher and of lower salinity than shallow environments, where phase separation will be common and produce higher salinity fluids (Baker, 2002).

Acknowledgements

TB wishes to thank industry support that has helped with this research, in particular two Mineral Deposit Research Unit collaborative projects, support from the Yukon Geological Survey and United States Geological Survey, and various James Cook University research grants. Tony Christie of the GNS is thanked for the invitation to present the results at the 2005 New Zealand Conference.

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