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TASMANIDES ARC-STYLE Au-Cu MINERALISATION, IN A PACIFIC RIM CONTEXT

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ABSTRACT

Prospecting in eastern Australia might be aided by comparisons between the setting and nature of Tasmanides (in the definition of Glen, 2013) arc-style Cu-Au mineralisation with the controls to varying styles of similar ore systems in younger less deformed Pacific rim arcs. Recent reconstructions of the Tasmanides suggest considerable rollback-related extension resulted in the deposition of extensive Ordovician Macquarie turbidites rather than previously considered proximal magmatic arc rocks (Glen, 2013), and so more emphasis should now be placed upon regional structures as loci for development of (island or magmatic) arc style porphyry Cu-Au and epithermal Au-Ag mineralisation. Three major structure types which localise intrusions and associated mineralisation include:

- Arc parallel faults which might also represent terrain boundaries and may have been mineralised during transient changes to oblique convergence.
- Transfer structures which accommodate changes across the arc such as the dramatic increase in width towards the southern portion of the Tasmanides.
- Conjugate fractures formed in settings of orthogonal convergence.

Porphyry Cu-Au as well as low and high sulphidation epithermal Au-Ag ore systems, formed from different ore fluids, occupy varying positions within arc and back arc environments, although linked in time and space. These linkages and zonations in mineralisation and alteration provide features which may be used to prospect for hidden ore systems. Lithocap zonations only provide vectors to porphyry mineralisation if the elements which make up an individual alteration zone are correctly understood.

INTRODUCTION

Although the science of porphyry Cu mineralisation began to evolve in the 1960's, as the development of appropriate earth moving equipment facilitated mining of bulk tonnage low metal grade ores, it is now some 30 years since a rise in Au price prompted more intensive studies of epithermal Au mineralisation. As both form in arc-back arc settings (SW Pacific island arcs floored by oceanic crust and magmatic arcs floored by continental crust in Latin America), mineral exploration has partly driven a need to better understand tectonic processes. In eastern Australia, the recent analysis of the Tasmanides tectonic setting by Glen (2013) suggests considerable rollback-related extension provided an environment for deposition of laterally extensive Ordovician turbidites in the hanging wall to a SW dipping subduction zone located in the New England region, rather than a traditional view of NS trending linear (Macquarie) magmatic arcs, as the environment for porphyry Cu and deep epithermal Au-Ag formation. Exploitation of geothermal energy has provided modern analogies to aid in the understanding of mineralisation processes, herein with an emphasis upon the work by the late Terry Leach on the Philippine island arc geothermal systems as analogies for a greater proportion of Cu-Au mineralisation styles, than the more widely published New Zealand back arc geothermal examples (Corbett 2008). Exploration might be aided by a better understanding of the controls to the varied styles of Cu-Au mineralisation derived from comparisons of the redefined (Glen, 2013) Tasmanides to younger less deformed Pacific rim ore environments and ore systems (Corbett, in prep.).

ORIGIN OF TASMANIDES ARC PORPHYRY-EPITHERMAL ORE SYSTEMS

Arc and back arc hosted Cu-Au mineralisation (with Mo and Ag where appropriate) under consideration within the Pacific rim (including the Tasmanides) displays variable relationships to intrusion source rocks which have been ultimately derived from subduction related melting. Buoyant magmas rise to elevated crustal settings and erupt as typically andesitic volcanic arcs, or cool at depth to form buried porphyry Cu-Au intrusions, interpreted to overlie deeper magmatic source rocks for metals. At higher crustal levels the interplay of evolving magmatic fluids and circulating meteoric waters within dilatant structures, facilitates the formation of high and low sulphidation epithermal Au-Ag mineralisation derived from quite different fluids. Felsic subvolcanic intrusions and breccias display relationships to mineralisation in extensional settings. The original west Pacific exploration models (Titley, 1982; Sillitoe, 1973) that placed porphyry Cu deposits in the root zones of stratovolcanoes continue to evolve to cater for differences recognised in the SW Pacific rim such as porphyry systems emplaced into basement rocks without associated volcanic sequences (Grasberg, Indonesia; Porgera, Golpu at Wafi, Papua New Guinea). The Tasmanide Cadia Valley porphyry systems which are hosted within a turbidite sequence (Wilson et a., 2007), were derived from a distal magmatic source, considered from the alkaline character to mantle-derived (Glen and Walsh, 1999) and emplaced via deep crustal structures. Consequently, in the absence of proximal magmatic arcs for much of the Tasmanides, major structures which control the Tasmanide architecture such as the widening to the south, should be prospected as sites for the emplacement of porphyry and intrusion-related epithermal Cu-Au mineralisation.

LOCALISATION

Three classes of major structures (figure 1) which localise porphyry-epithermal ore systems are relevant to the Tasmanides:

Arc parallel structures, commonly characterised as terrain boundaries with general reverse senses of movement in orthogonal arcs (Domeyko Fault-West Fissure, Chile) or lateral movement in oblique arcs (Philippine Fault), may host ore systems within dilational segments. In conditions of oblique movement, negative flower structures host stacked dilatant sites characterised with decreased depth as: most deeply buried splay faults, fault jogs or link structures, and surficial pull-apart basins (Corbett and Leach, 1998). Splay faults localise porphyry Cu deposits at the Chuquicamata mine in the West Fault, Chile (Boric et al., 1990), and the Far South East porphyry Cu-Au in the segmented Philippine fault, Philippines

(Corbett and Leach, 1998). The La Escondida porphyry Cu, Chile occurs in a link between Domeyko fault segments (Corbett, unpubl. data), and the Frieda porphyry-Nena high sulphidation epithermal system are also localised by a splay in the arc parallel Fiak-Leonard Schultz Fault, Papua New Guinea (Corbett, 1994). The West Fault-Domeyko Fault system is interpreted to have changed from reverse to regional dextral movement during the emplacement of Chuquicamata and La Escondida porphyry Cu deposits, which is also apparent at the higher crustal level El Indio and La Coipa high sulphidation Au and El Peñón low sulphidation Au-Ag epithermal deposits, Chile.

In the Tasmanides, the Gilmore suture localises Cu-Au mineralisation with many ore systems discernible as having formed under conditions of sinistral strike-slip deformation (Mt Adra, Gidginbung, West Wylong). The Gympie and Cowal deposits lie within pull-apart basins (20 km long for Gympie) in which basin forming growth faults are reactivated as vein hosts, also in conditions of sinistral movement on the roughly NS structural grain. From comparisons with other arcs, it has previously been suggested (Corbett and Leach, 1998) this orogen-wide tendency for sinistral oblique movement discernible in the kinematics of individual Tasmanide ore systems, apparently through protracted time (Browns Creek skarn, Mineral Hill, Cobar district [in Glen 1987]), results from transient changes on the nature of convergence which provide triggers for the forceful emplacement of spine-like porphyry intrusions and evolution of ore fluids to form higher crustal level epithermal deposits. However, these transient changes in convergence might only be discernible in the geological record as the divergence between the kinematics of individual ore systems and the overall arc.

Orthogonal extension on arc parallel structures also localises epithermal mineralisation in many Pacific rim epithermal districts (200% Basin and Range district of SW USA-Mexico; Bulolo Graben, Papua New Guinea), which may be apparent in the localisation of Drummond Basin low sulphidation epithermal Au deposits.

Transfer structures (termed transform by some workers) cut arcs at high angles and facilitate segmentation of the subduction-arc complex characterised by variations in strike of the arc, dip of the subducting plate or rate of subduction, commonly with protracted histories of activity. Transfer structures have long been recognised with a regular spacing across the island of New Guinea (Corbett, 1994) as deep fundamental breaks which may tap mantle-related magmas (Porgera, Papua New Guinea), or focus overprinting intrusion events (Wafi-Golpu, Papua New Guinea). The giant Yanacocha high sulphidation epithermal-porphyry district lies in such a structure which facilitates bending of the Peruvian Andes (Teal and Benavides et a., 2010; Longo et al., 2010). The Lachlan Transverse Zone (Glen and Walshe, 1999) localises the Cadia district where analysis of mine data demonstrates the Ridgeway and Cadia East ore systems lie within pull-apart basin scenarios at the intersection of NS fractures with sinistral senses of movement, while sheeted quartz veins are aligned with the dilatant WNW fractures here and Cadia Hill. The dilatant fractures have acted as growth faults during volacanism (Wilson et al., 2997) and also splay faults to localise porphyry emplacement. While the recognition of a relationship between Lachlan Transverse Zone NW structures and

Cu-Au mineralisation is not new, (Scheibner and Stevens, 1974), the pronounced thickening of the Tasmanides from Queensland to NSW (Glen, 2013) is no doubt accounted for by transfer structures which now represent high priority exploration targets, especially at the intersection of the NS structural grain.

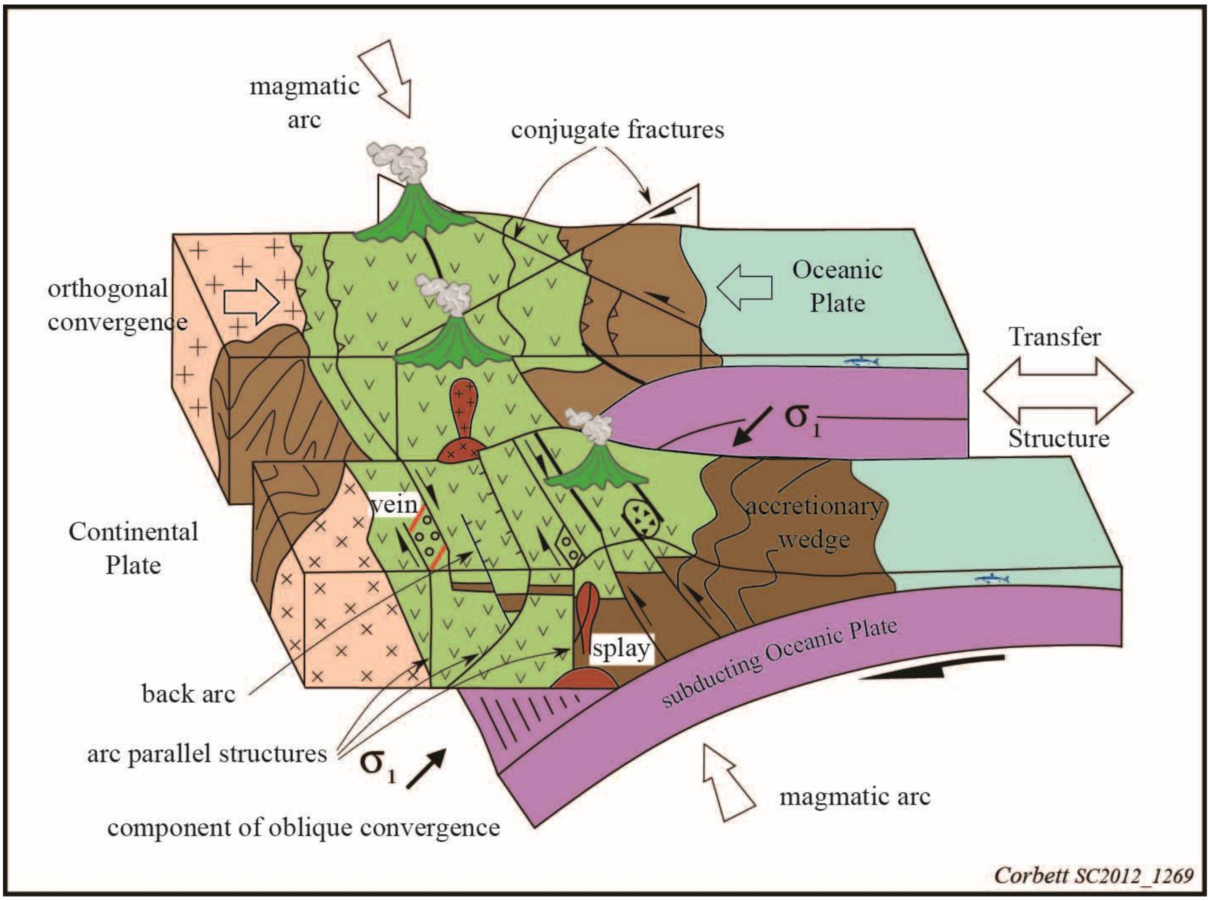

Figure 1. Conceptual magmatic arc formed at an ocean-continent collision with oblique and orthogonal convergence segments showing the three types of structures classed as arc parallel, transfer structures and conjugate fractures (from Corbett in prep., modified from Corbett and Leach, 1998 and Corbett, 1994).

Conjugate fractures with a regular spacing (Corbett, unpubl. data) localise ore systems in orthogonal magmatic arcs (northern Chile-Argentina; Argentine Patagonia; NE Sulawesi, Indonesia), in conditions of compression or extension, commonly at intersections with arc parallel fractures where regular changes in kinematics (above) create dilatant settings. Modest sized low sulphidation epithermal veins in Patagonia are localised by NE and NW conjugates in mostly compressional regimes. Larger high sulphidation epithermal systems are localised on conjugates during extension (Pascua-Lama, Veladero, Chile-Argentina) than those formed in compression settings (El Guanaco, Chile and Quevar, Argentina). In the Northern Tasmanides intersecting conjugates localise the Kidston breccia pipe by tapping the underlying magma source (Corbett and Leach, 1998).

MINERALISATION STYLES

The mineralisation styles (figure 2) recognised in the Tasmanides are broadly similar to those recognised in Pacific rim arcs (Corbett, 2009 and references therein; Corbett, in prep.) although typically older and more deeply eroded.

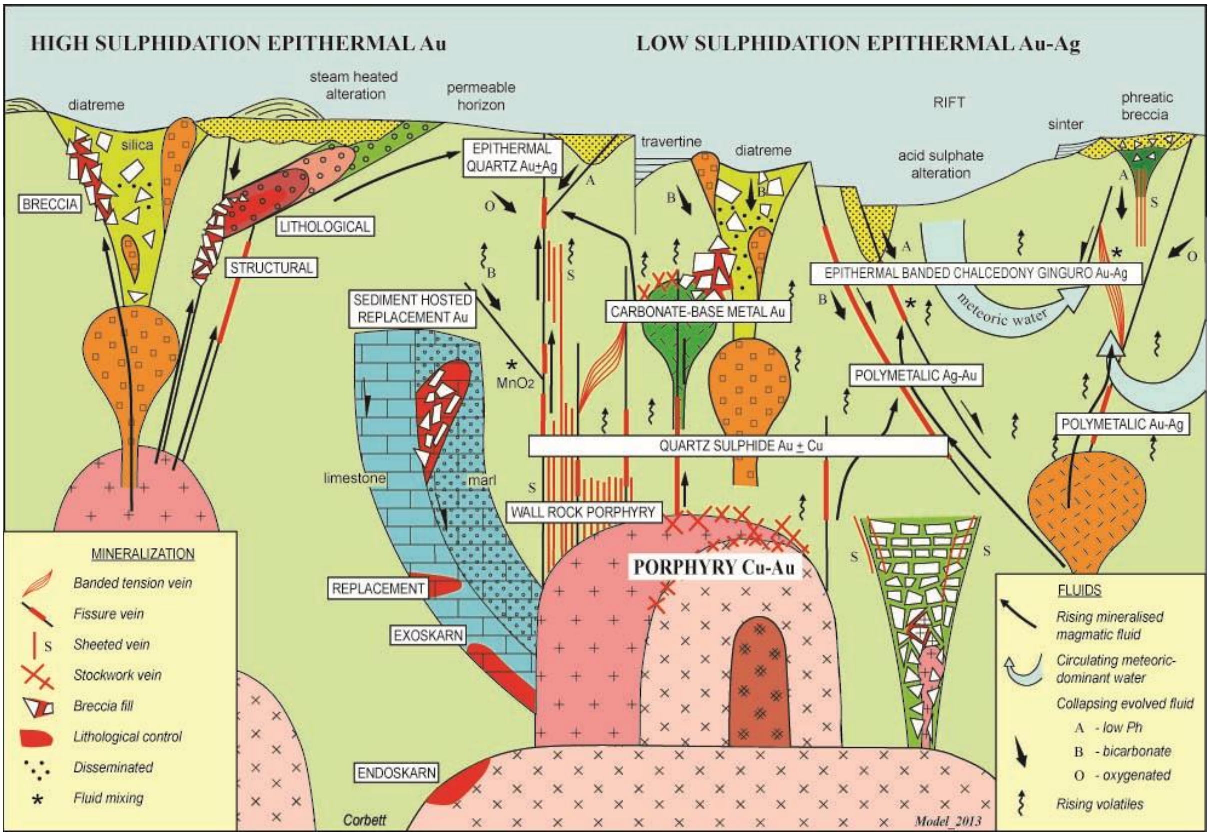

Figure 2. Conceptual model illustrating the linkages between porphyry with high and low sulpidation epithermal mineralisation (from Corbett in prep., modified from Corbett, 2009).

Porphyry Cu-Au intrusion rise as locally vertically attenuated spine-like forms to within a km of the palaeo surface above deeper magmatic source rocks for much of the metals and provide economic ore systems in settings of repeated intrusion emplacement and mineralisation, provided barren post-mineral intrusions do not stope-out ore. Intact buried porphyry systems (Ridgeway, Australia; Golpu, Papua New Guinea; Oyu Tolgai, Mongolia) represent attractive targets as significant metal contents lie in the overlying wall rocks. Some vectors which might aid in discovery of these hidden buried intact ore systems include:

- Structure described above as a basic targeting tool.
- Zoned prograde potassic-propylitic hydrothermal alteration (Corbett, 2008, 2009 and references therein; Corbett, in prep.) in which the presence of inner propylitic actinolite represents a good indicator of nearby porphyry systems, although epidote may provide a larger alteration footprint (see the Terry Leach zoned alteration pH vs temperature figure in Corbett and Leach, 1998). At Wafi-Golpu, the first appearance of actinolite alteration correlates with the first appearance of chalcopyrite and is coincident with the 0.1% Cu shell (Menzies et al., 2013).
- D veins (in the terminology of Gustafson and Hunt, 1975) characterised by quartz, pyrite, chalcopyrite, galena, sphalerite and carbonate form marginal to porphyry systems and zonations in mineralogy such as sphalerite composition (colour), may

provide some indication of distance to the buried source intrusion (Corbett, in prep.). Consequently, broad Zn anomalies may rim porphyry systems and provide vectors to the central porphyry mineralisation (e.g., Wafi-Golpu in Menzies et al., 2013).

- Careful analysis of down hole and surface Cu-Mo geochemistry provides vectors to porphyry mineralisation (Menzies, pers. commun.). Cadia Hill is rimmed by >250ppm Cu (Wood, 2012) and Golpu >150ppm Cu (Menzies et al., 2013) while the Gulpu advanced argillic alteration host >40ppm immobile Mo. Elsewhere, the Bajo de la Alumbrera porphyry, Argentina is rimmed by >43ppm Mo (Sillitoe, 1995) and Batu Hijau >30ppm Mo (Meldrum et al., 1994).
- Higher temperature end members of the barren shoulder continuum (Corbett, 2008), described below may vector towards source intrusions (below).
- Geophysical signatures in settings obscured by cover will include spot magnetic highs for intact prograde potassic alteration, although destroyed by later retrograde phyllic-argillic alteration. Donut shapes prevail for preserved prograde alteration at deeper erosional levels. Chargeability anomalies vary to significantly higher levels within retrograde phyllic silica-sericite-pyrite-carbonate alteration which collapses upon prograde alteration, causing magnetite destruction. Caution is urged in the use of geophysical prospecting as chargeable phyllic alteration does not equal porphyry Cu-Au mineralisation but is part of the overall porphyry system (Corbett, 2008, 2009).
- Careful attention to the style of breccias may also aid explorationists in the identification of porphyry targets (Corbett, in prep.).

Skarn deposits develop by the reaction of porphyry-related hydrothermal fluids with reactive carbonate wall rocks and may form attractive Cu-Au ore systems within porphyry districts (Browns Creek, NSW; Mungana, Queensland), and host distinctive prograde and retrograde mineralogy including magnetite, identified in regional magnetic surveys. In each of the above examples, highest grade ores overprint the skarns as porphyry-like sheeted quartz veins at Browns Creek and as Ag-rich tennantite veins at Mungana, and so the skarn in part represents a favourable host rock connected to the magmatic source. A most important aspect of Tasmanide magnetite skarns is as a vector towards nearby porphyry mineralisation (e.g., Big Cadia skarn), just as many Pacific rim porphyry systems developed from magnetite skarn discoveries (Ok Tedi & Nena, Papua New Guinea; Grasberg, Indonesia).

Wallrock porphyry systems (Cadia Hill, Tooloom, Australia; Gaby, Ecuador; Maricunga Belt, Chile) characterised by sheeted Au>Cu bearing quartz-sulphide veins represent the transition between porphyry and (deep) low sulphidation epithermal regimes (figure 2). Most display marginal metal grades, although Cadia Hill economics were assisted by the presence within a mineralised district (Ridgeway).

Epithermal Au-Ag deposits are divided between high and low sulphidation styles, most easily considered by explorationists as derived from distinctly different hydrothermal fluids which provide characteristic ore and gangue mineralogy and wall rock alteration (Corbett and Leach, 1998; Corbett, in prep.).

Low sulphidation epithermal ore systems (figure 2) are deposited from near neutral fluids characterised by varying mixes of meteoric and magmatic waters and display two fluid flow trends from deeper crustal level intrusion metal sources to near surficial settings (Corbett and Leach, 1998; Corbett, 2001, 2009; Corbett, in prep.). The controls of dilatant structures, competent host rocks and efficient mechanisms of Au deposition (Leach and Corbett, 2008) provide higher Au grades in deposits further from the intrusion source. Styles include:

Quartz-sulphide Au ± Cu mineralisation comprises quartz with auriferous pyrite and varies with depth to include chalcopyrite, pyrrhotite and specular haematite and at higher crustal levels, marcasite and opal, or quenched arsenian pyrite. The modest Au grades deposited from a cooling magmatic-rich ore fluid (Hamata, Papua New Guinea) are compensated by the good metallurgy of coarser grained ores which are readily treated as heap leach operations, especially where oxidised (Round Mountain & Sleeper, Nevada, USA). However, fine grained commonly arsenian pyrite ores deposited from quenched ore fluids display refractory metallurgy (Lihir & Kerimenge, Papua New Guinea). Many systems display elevated Au grades where overprinted by epithermal quartz-Au-Ag mineralisation (Emperor, Fiji; Round Mountain, Sleeper) or in settings of improved mechanisms of Au deposition (Leach and Corbett, 2008). Ore fluids have mixed with oxygenated groundwaters at Kencana at Gosowong, Indonesia, as evidenced by hypogene haematie, and bicarbonate waters in the Link Zone at Wafi, Papua New Guinea, evidenced by rhodochrosite. Quartz-sulphide systems are common ores in deeply eroded arcs such as the Tasmanides (Nolans, Mt Wright, London-Victoria, Mineral Hill, McKinnons, Adelong, Mt Adra, Drake). Caution is urged as quartz-sulphide mineralisation commonly displays near surface supergene Au enrichment with resultant disappointing drill results from testing attractive soil and rock chip anomalies.

Carbonate-base metal Au mineralisation coined by Leach and Corbett (1993) to describe some of the most prolific Au producers in the SW Pacific rim (Porgera, Misima, Hidden Valley in Papua New Guinea; Chatree, Thailand; Antamok, Acupan, Victoria in the Philippines; Kelian, Mt Muro, Cikotok District in Indonesia; Gold Ridge in the Solomon Islands, and others) characterised by early pyrite (of the quartz-sulphide stage) followed by sphalerite>galena and later variable but dominantly Mn carbonate. Ores typically occur as breccia fill, stockwork and lesser fissure veins and may display an association with felsic intrusions and breccias. The mixing of rising magmatic ore fluids with oxidising bicarbonate waters provides higher Au grades than the quartz-sulphide systems (Corbett and Leach, 1998; Leach and Corbett, 2008), although many deposits display highly variable internal metallurgy. These deposits exhibit pronounced vertical zonation as well as variations in time from earlier quartz-sulphide to later epithermal quartz Au ± Ag ores (below). Tasmanide examples include Cowal, Kidston, Mt Leyshon and Mt Rawdon and as parts of many other deposits such as Mineral Hill, London-Victoria and Drake (although Ag-rich). This style of mineralisation, commonly discernible in weathered exposures by the MnO stain after Mn carbonate, are highly attractive bulk low grade mining operations (Cowal, Porgera).

Epithermal quartz Au ± Ag (modified from epithermal quartz Au-Ag in Corbett and Leach 1998) mineralisation is characterised by gangue-poor, high fineness, high to locally bonanza grade, free Au, which commonly overprints quartz-sulphide (Round Mountain & Sleeper; Emperor, Fiji) or carbonate-base metal ore systems (Porgera Zone VII, Mt Kare, Edie Creek in Papua New Guinea). The addition of chalcedony-adularia from circulating meteoric waters may provide banded veins with high fineness free Au in contrast the ginguro bands described below (Sleeper; Gowowong, Indonesia). Ores of this style are recognised in the Tasmanides at Mineral Hill, Twin Hills, and Mt Boppy in the Cobar region and represent particularly attractive exploration targets if preserved from erosion. Some bonanza Au deposits such as Gympie and Tick Hill may also be intrusion-related systems ultimately of this style.

Chalcedony-ginguro banded Au-Ag low sulphidation epithermal veins typically form in Pacific rim strongly extensional settings (figure 2) where there is considerable input of meteoric ground waters (Hishikari & Sado, Japan; Waihi & Golden Cross, New Zealand; Kupol & Asacha, Eastern Russia; Midas, USA; Cerro Vanguadia & Cerro Negro, Argentine Patagonia; Tolukuma, Papua New Guinea). Many western Pacific rim examples (Waihi, Kupol) terminate downwards with lower Au and higher base metal contents, although in Latin America there is a downward progression to mineralised low sulphidation epithermal **polymetallic Ag-Au** veins (Arcata & Cayollama in Peru; Palmarejo & Fresnillo in Mexico) mines as Ag-Au resources. Most Au in chalcedony-ginguro systems occurs in the sulphidic ginguro bands deposited from magmatic fluids, rather than the chalcedony and adularia deposited from meteoric waters. The polymetallic ores are likened to Ag-rich fissure vein hosted carbonate-base metal mineralisation. In the Tasmanites banded chalcedony-ginguro veins are well developed in the Drummond Basin (Vera Nancy-Pajingo) extensional environment, although individual examples display greater magmatic components (Twin Hills). Tasmanide polymetallic Ag-Au veins (Hadleigh Castle & Mungana Queensland; Conrad, NSW) are deposited from magmatic-dominated fluids.

High sulphidation epithermal Au ± Ag ore systems are deposited from a magmatic fluid which develops a hot acidic character during evolution from porphyry to epithermal crustal levels, and so there is an important physical separation between the epithermal ore system and its intrusion source (Lepanto-Far South East, Philippines in Corbett and Leach, 1998). Controls to fluid flow and hence mineralisation, include structure, alteration and breccias. This fluid breaks into a volatile rich phase which travels more quickly and produces the characteristic zoned advanced argillic alteration during progressive cooling and neutralisation by reaction with wall rocks and ground waters. This alteration which grades outwards from the feeder structure as mineral assemblages dominated by residual vughy silica, alunite, pyrophyllite-diaspore, dickite, kaolin to marginal illite, varies with crustal level (temperature) and control of fluid flow (lithology, breccias or structure). Alteration zonation and fluid flow controls are used as vectors towards hidden mineralisation. A later liquid-rich phase commonly deposits Au-Ag mineralisation with enargite, including the low temperature polymorph luzonite, and pyrite along with gangue of alunite, barite and local sulphur. SW Pacific rim examples tend to be Au dominant whereas examples in Latin America also contain Ag, while some from Ag-only deposits. Examples in the Tasmanides include the relatively small deposits of Peak Hill, Gidginbung and Dobroyd in NSW and Mt Mackenzie in Queensland, and while some important examples occur in the SW Pacific rim (Lepanto, Martabe, Indonesia; Nena & Wafi, Papua New Guinea; Mt Kasi, Fiji), the home of high sulphidation deposits is in the high Andes (Yanacocha & Pierina, Peru; Pascua-Lama, El Indio, La Coipa, Chile; Veladero, Argentina). As apparent in the mining of Gidginbung and Peak Hill, and exploration at Wafi, Papua New Guinea (Erceg et al., 1991), these deposits are commonly worked only in the oxide zone as sulphide ores display refractory metallurgy.

If a high sulphidation fluid is sufficiently cooled and neutralised by reaction with wall rocks or ground waters, it may evolve to lower sulphidation mineralogy, characterised by higher Au grades and improved metallurgy. The bonanza Au grade direct shipping ore at El Indio, Chile is interpreted by many workers as of a low sulphidation epithermal quartz Au-Ag style (Corbett and Leach unpubl reports; Heberlein, 2008). Mt Carlton in Queensland displays initial zoned advanced argillic alteration and lower precious metal grade pyrite-enargite ore, but is overprinted by high Ag grade lower sulphidation mineralisation containing yellow Fe-poor sphalerite and Ag sulphosalts. The recent term "intermediate sulphidation" (Einaudi et al., 2003) used by some workers to describe carbonate-base metal Au and polymetallic Ag-Au ores (Sillitoe and Hedenquist, 2003) applies to only low temperature end members of carbonate-base metal Au and polymetallic Ag-Au systems characterised by yellow Fe-poor sphalerite, and lacks the zonation in time and space of those deposits. Although rare intermediate sulphidation mineralisation develops in the transition between high and low sulphidation (Mt Carlton, above), no significant intermediate sulphidation fluid exists of the same calibre as high and low sulphidation and so the original terminology of Leach and Corbett (1993-1998) should be maintained.

LITHOCAPS

The symposium run by the AIG to honour the late Terry Leach represented an opportunity (at the request of Kaylene Camuti, current AIG President) to begin to unravel lithocaps which contain a number of distinctly different (advanced argillic-argillic) alteration styles which display profoundly variable relationships to mineralisation, commonly lumped together by explorationists (figure 3; Corbett, 2008). The structurally controlled deeper crustal level locally high temperature advanced argillic alteration categorised as barren shoulders (Corbett and Leach, 1998) provide vectors to some Pacific rim porphyry Cu-Au systems (Lookout Rocks barren shoulder - Ohio Creek porphyry, New Zealand; Ekwai Debom barren shoulder - Horse Ivaal porphyry at Frieda River, Papua New Guinea) and may be used as exploration targeting tools. However, higher crustal level permeability controlled advanced argillic lithocaps (in the restricted use of the term herein; figure 3) are more challenging exploration targets throughout less eroded Pacific rim arcs than the Tasmanides, although alteration at Bulahdelah and Pambula and a number in the Esk Trough represent local examples. Two recently published porphyry-lithocap scenarios (Wafi-Golpu, Papua New Guinea; Menzies et al, 2013; Caspiche, Chile, Sillitoe et al., 2013) represent younger high sulphidation epithermal Au deposits related to younger deep unseen porphyry systems superimposed upon existing porphyries. At Golpu the later acid fluid upgrades Cu in the earlier porphyry (Menzies et al., 2013). Explorationists must distinguish initially barren zoned advanced argillic alteration from zoned advanced argillic alteration associated with high sulphidation epithermal Au deposits. (They display rare overprinting mineralisation). High sulphidation epithermal Au deposits represent difficult porphyry targets at depth. Acid sulphate and steam heated alteration caps to low and high epithermal deposits respectively (Corbett, 2008) are not likely to be preserved in the deeply eroded Tasmanides although resources have been identified below the former at Guadalupe at Palmarejo, Mexico and the latter at Quimsacocha, Ecuador, and so these alteration zones remain quality exploration targets in younger less eroded arcs.

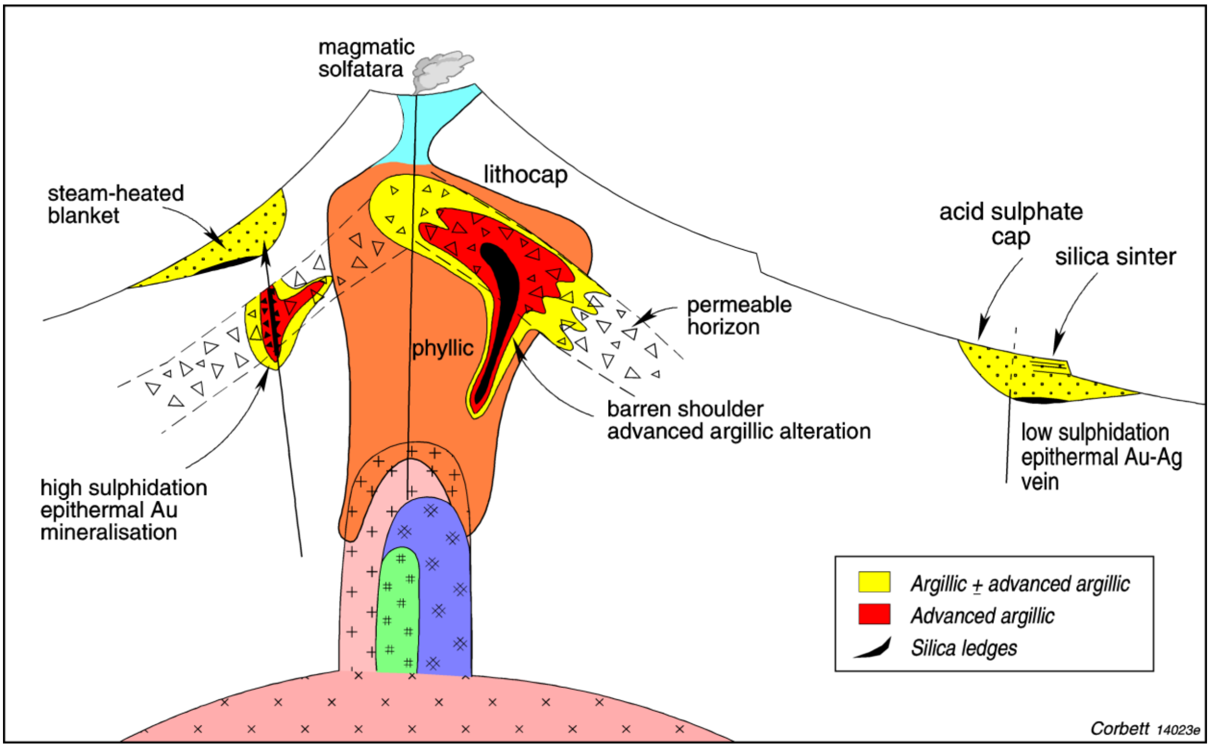

Figure 3. Styles of argillic-advanced argillic alteration included within the commonly regarded lithocap classification (from Corbett in prep., modified from Corbett, 2008).

EXPLORATION IMPLICATIONS

Analysis of more youthful Pacific rim ore systems without post-mineral deformation may aid in Tasmanide targeting as:

- WNW-NW trending transfer structures which may account for the great change in width between the southern and northern Tasmanides (Glen, 2013), could host intrusion-related mineralisation, particularly where the intersections of NS facture systems (with sinistral senses of movement) provide dilatant sites. Prospecting in NSW should consider these structures which display regular spacing and localise porphyry-epithermal mineralisation in Pacific rim arcs (Papua New Guinea; Peru).
- Arc parallel structures might host intrusion-related mineralisation in dilatant sites such as pull-apart/link/splay faults, as recognised in the Pacific rim. The orogeny-wide tendency for sinistral oblique movement on NS structures to localise ore systems allows rapid targeting by rapid examination of data bases for left stepping perturbations in throughgoing structures and links within fracture corridors.

- Structural intersections such as the arc parallel structures with conjugate fractures or transfer structures remain prospecting sites, and are not just local sites, but through oblique convergence represent larger dilatant settings such as pull-apart basins.
- Magnetite skarns derived from porphyry intrusion source rocks may, as recognised elsewhere, act as vectors towards porphyry mineralisation, if combined with other data such as geophysical interpretations.
- Mo and Zn anomalism may vector to porphyry Cu-Au mineralisation.
- The variety of low sulphidation epithermal Au deposits display controls dominated by structure, competent host rocks and efficient mechanisms of Au deposition as well as linkages that might in prospecting. Some low sulphidation epithermal systems display particular characteristics discernible during prospecting such as: boxworks after pyrite for commonly supergene enriched lower hypogene Au grade quartz-sulphide systems, or MnO as an indicator of weathered carbonate-base metal Au ores.
- Lithocaps represent prospecting sites for porphyry mineralisation elsewhere in the Pacific rim but require careful analysis as only some types of advanced argillic alteration might vector towards porphyry deposits. Acid alteration overlies epithermal ores in less eroded terrains than the Tasmanides.
- Exploration for porphyry Cu sources to high sulphidation epithermal Au deposits may be inhibited by the considerable physical separation between them, although some porphyry deposits are overlain by younger high sulphidation epithermal Au systems (Wafi-Golpu, Papua New Guinea; Caspiche, Chile). At Golpu the later acid fluids have upgraded the Cu content of the earlier porphyry.

CONCLUSIONS

Changes in the overall tectonic character of the Tasmanides (Glen, 2013) decrees that greater use of regional structure should be employed in prospecting for porphyry systems and analyses of deposit-scale structure might aid in the discovery of epithermal ores. WNW-NW transfer structures which account for the southward thickening of Tasmanides are prime targets, especially at the intersections of NS fractures. Prospecting in the southern Tasmanides may investigate left stepping perturbations in NS regional structures as sites of ore formation. In both northern Chile and the Tasmanides many ore systems are interpreted to have formed in conditions of oblique convergence (dextral in Chile, sinistral in NSW), although the arcs are considered to display overall orthogonal convergence. In this interpretation (Corbett and Leach, 1998), transient changes in the nature of convergence act as triggers for the forceful emplacement of spine-like porphyry intrusions or higher crustal level epithermal deposits. Further work might more carefully investigate whether oblique convergence discernible from ore system kinematics is long lived.

Styles of alteration and mineralisation and linkages between them provide vectors to aid explorationists when prospecting for porphyry and epithermal ore systems, including the likely distance to ore as well as viability of lithocaps as exploration tools, and consequently contribute towards the estimation of target priority in any exploration program.

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