THE AUSTRALASIAN INSTITUTE OF MINING AND METALLURGY

Proceedings of the PNG Geology, Exploration and Mining Conference 1994, Lae. Rogerson, R. (Ed.)

Porphyry-related carbonate-base metal gold systems in the southwest Pacific: characteristics

T.M. Leach and G.J. Corbett

Abstract

Comparisons between individual SW Pacific Rim gold deposits have facilitated proposal of a new classification of porphyry-related mesothermal gold deposit types. Carbonate base-metal gold systems form at relatively high crustal levels, peripheral to porphyry intrusions. There is a spatial association with major structures which focus fluids from degassing porphyries at depth. Milled matrix intrusive breccias and extrusive maar volcano/diatreme breccias form as a result of pre-mineralisation phreatomagmatic eruptions. These focus degassing magmatic fluids by the provision of fracture ground preparation, typically within competent host rocks, adjacent to the breccia bodies. Local dilational structures control the form of individual deposits which may contain bonanza gold grades at sites of fluid quenching and/or repeated mineral deposition.

Early quartz veining and porphyry-related alteration is common and later gold mineralisation typically occurs in association with carbonate veining and Fe and base metal sulphides as Zn > Pb > Cu. The progressive cooling by mixing of the upwelling mineralised magmatic fluid with descending bicarbonate waters, produces characteristic zonations in carbonate compositions. These vary with distance from the porphyry source, from Ca through Mg, Mn and distal Fe types. Gold mineralisation is preferentially distributed within the Mn/Mg carbonates.

In magmatic arc environments, carbonate-base metal gold systems grade at shallower levels to fine quartz ± chlorite ± illite systems which occur in some banded quartz-adularia Au-Ag systems, and at deeper levels grade down to, and in places overprint, quartz-sulphide Au/Cu vein systems. Vectors provided by alteration zonation, mineral paragenesis and structure can be used to define fluid flow models, which aid in the identification of zones of mineralisation, of higher grade gold, and of copper-gold mineralisation, related to the porphyry source.

INTRODUCTION

A class of porphyry-related gold mineralisation, associated with carbonate-base metal veining, forms intermediate between SW Pacific Rim porphyry and epithermal environments. Sillitoe (1989) and Handley and Bradshaw (1986) alluded to the existence of this class of deposits in emphasising the magmatic association and noting an overlap between epithermal and porphyry environments, especially in relation to the Porgera gold deposit. Most deposits within this class have hitherto been categorised as adularia-sericite epithermal, and yet many lack adularia which, where present, is not related to the gold mineralising events. In addition, many form at levels transitional between epithermal and porphyry environments. This more detailed classification is possible following the upsurge in gold exploration during the 1980's.

Classic low sulphidation (adularia-sericite) epithermal deposits, eg. Hishikari and Sado, Japan; Waihi and Golden Cross, New Zealand, are dominated by quartz and adularia within fissure veins. However much of the gold is not associated with quartz-adularia, but occurs in sulphide bands (*ginguro ore* in the Japanese literature). These are locally characterised by chlorite, eg. Cracow Queensland, or illite eg. Tolukuma, Papua New Guinea (PNG). These deposits generally do not display any obvious spatial or fluid relationship to porphyry intrusions. Although carbonate base metal deposits may also form as fissure veins, the base metal and common high level porphyry associations confirm the setting as transitional between the epithermal and porphyry environments and so, with additional data, these deposits are now classified in a group of their own (Corbett and Leach, 1994). An understanding of the anatomy and fluid flow paths from the alteration zonation and structure, may point towards high gold grade portions of carbonate-base metal gold systems or the porphyry source rocks.

DEFINITION OF CARBONATE-BASE METAL SYSTEMS

Carbonate-base metal gold systems develop distal to porphyry intrusives from the mixing of a magmatically derived fluid with surficial bicarbonate gas condensate waters (Figure 1). Mineralisation varies from higher grade vein/breccia lode mineralisation to bulk low grade fracture or breccia infill styles. Major structures localise hydrothermal systems, and by movement create dilational ore hosting environments in subsidiary structures. High level porphyry intrusions are commonly spatially associated with ores and may represent competent host rocks. Milled-matrix intrusive breccias and extrusive maar volcano/diatreme breccia complexes commonly occur as pre-mineralisation phreatomagmatic explosive events which focus fluids degassing from porphyry bodies at depth.

Base metal contents typically occur as Zn > Pb > Cu, while carbonates exhibit a wide range in chemistry from Fe- to Mn-, Mg- and Ca-carbonates, and display distinct spatial zonations. Gold mineralisation preferentially occurs in association with the Mn/Mg carbonates. There is a progression in

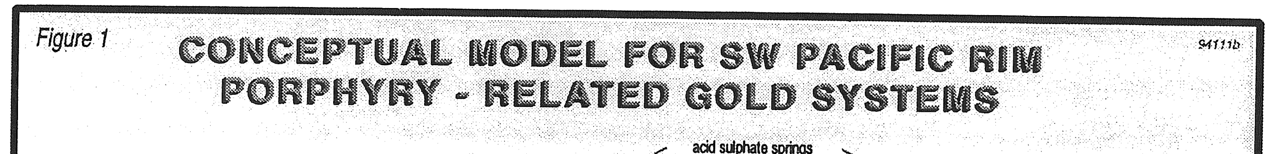

Figure 1. Conceptual model for carbonate-base metal deposits.

time and space (crustal level) from porphyry to epithermal environments. Carbonate-base mineralisation is commonly preceded by porphyry-related quartz stockwork veining, or meso-thermal to epithermal quartz-sulphide veining, depending on the depth of the system. Mineralising fluids are transitional between those of dilute circulating meteoric waters and high temperature saline porphyry systems.

DISTRIBUTION

Some significant SW Pacific Rim carbonate-base metal gold systems are: in Indonesia, Kelian (>4 and possibly 6-7M oz Au; van Leeuwen et al., 1990) and Cikotok (>2M oz Au); in PNG, Porgera mineralisation types A, B and E (>6M oz), Mt Kare, the Morobe Goldfield group of deposits (past production with alluvial 3.7M oz Au; Lowenstein, 1982), including Upper Ridges, Golden Ridges and Golden Peaks at Wau, Edie Creek, Kerimenge (1.8M oz Au, Hutton et al., 1990) and Hidden Valley (2.4M oz Au; Nelson et al., 1990), as well as Busai and Kulumadau on Woodlark Island and Maniape at Kainantu; in the Solomon Islands, Gold Ridge; in the Philippines, Acupan (4M oz Au; Mitchell and Leach, 1991); in eastern Australia, Mt Terrible in NSW (Teale, 1992).

Some epithermal Au/Ag quartz-adularia-sericite deposits are now recognised to exhibit affinities with these systems (eg. Tolukuma, PNG and Cracow, Queensland). Carbonate-base metal gold mineralisation at the Acupan Mine, Baguio District, overprints uplifted porphyry Cu/Au style mineral-isation and is the second largest gold producer in the Philippines (Mitchell and Leach, 1990).

STRUCTURAL SETTING

Carbonate-base metal hydrothermal systems form at elevated crustal levels above porphyry Cu/Au deposits and so tend to be associated with higher level, possibly differentiated porphyry intrusions. Thus, the accretionary prism of moderately eroded island arc terranes is a primary setting for these deposits. Intra arc rifts such as the Bulolo Graben (Corbett, 1994), may represent a locus of high level porphyry intrusion resulting from crustal thinning. Other intrusion centres such as Porgera (Corbett, 1994), Kelian (van Leeuwen et al., 1990), and Kulumadau (Corbett et al., 1994) are localised by major structures.

Phreatomagmatic explosions which form maar volcanoes/diatreme breccias result from the sudden heating of groundwaters in contact with a porphyry heat source (Sillitoe et al., 1985). Pre-mineralisation intrusive breccias characterised by milled, fluidised or muddy matrices may exploit pre-existing structures and provide plumbing systems used by subsequent mineralising fluids. Major structures commonly allow downward migration of groundwaters to heat sources promoting diatreme breccia eruption. Magmatic fluids which continue to degas from the magma chamber may be focused by the brecciation associated with the diatreme/maar volcano eruption and, beyond the magma chamber, utilise the plumbing system provided by fractured basement rocks surrounding the pipe-like diatreme margin. At Wau, the now allochthonous deposits of Upper Ridges and Golden Ridges are diatreme-related (Sillitoe et al., 1984), as are also Edie Creek (Corbett, 1994) and Kerimenge (Akiro, 1986). Similarly, the Gold Ridge deposit occurs within a diatreme localised at a splay in a major thorough-going structure.

STRUCTURE

Mineral deposition is promoted by fluid cooling and varies according to the structural environment. High gold grades result from quenching in feeder structures (eg. the lodes mined in the old workings at Ivanhoe and Busai, Woodlark Island). The term lode is applied to mineralised structures. Lower grade ores form as fracture/vein filling (eg. Porgera), tension gash (eg. Kelian and Woodlark Island) and open space breccia infill (eg. Kelian), or dilational fissure veins (eg. Edie Creek), commonly formed as subsidiary features to major structures (eg. Wau and Acupan). While bonanza gold grades are common in lode mineralisation, elevated gold grades may also form by repeated deposition in dilational structures (eg. Acupan, Upper Ridges), especially if proximal to fluid upflow zones. Hangingwall splits are ideal settings for fluid mixing and hence mineral deposition (eg. Kerimenge, Hidden Valley, Upper Ridges). Strike slip deformation in these regimes may create dilation features which host locally higher gold grades (eg. Mt

Terrible, Plumridge).

Pre-mineralisation structures control fluid flow and fracturing surrounding the margins of breccia bodies, such as maar volcano/diatreme breccias, which then represent ideal loci for fluid flow and hence mineralisation. Thus an ideal setting for carbonate-base metal gold mineralisation might be fracturing near the intersection of major through-going structures and diatreme/maar complexes (eg. Upper Ridges and Kerimenge), or at the contact of veins with diatreme pipe margins (eg. Acupan GW ore bodies). Pre-mineralisation breccias controlled by regional structures are exploited by carbonate-base metal veins at Busai.

Rock competency is a critical factor in fracture development and hence mineral deposition. At Porgera, intrusive stocks are inferred from the aeromagnetic data (Henry, 1988) to cap a much larger intrusive system at depth. Host rocks are the incompetent Chim Formation shales. Degassing fluids from depth are preferentially focused into the fractured margins of high level stocks and competent thermally metamorphosed sediments. The structural tapping of degassing fluids is most evident in the relationship of the later roscoelite mineralisation to the Roamane Fault, a bounding structure to the intrusive complex. Similarly, at Kelian, brecciated intrusive margins within incompetent "muddy breccias" (van Leeuwen et al., 1990) host gold mineralisation.

Maar volcano/diatreme breccias are gas driven and so are clay altered, and do not fracture well in the upper and low temperature clay portions. Thus the margins of pipe-like breccia bodies are the locus of fluid flow. Only in deeper portions of diatreme breccias where higher temperature clay alteration is more competent, do maar volcanos host gold mineralisation (eg. Montana Tunnels, Sillitoe et al., 1985).

ALTERATION, VEINING AND MINERALISATION

A generalised paragenetic sequence of veining, alteration and mineralisation for carbonate-base metal veining is presented in Figure 2. Initial regional propylitic alteration of host rocks probably formed in response to thermal gradients set up by the emplacement of intrusives at depth, and is commonly followed by extrusion

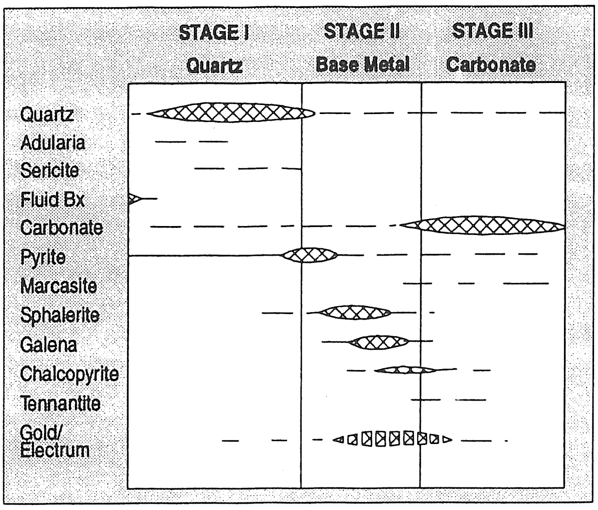

Figure 2. Generalised paragenetic sequence for carbonate-base metal deposits.

of typically polyphasal diatreme and/or fluid breccias.

Stage I veining is dominated by quartz and post-dates the breccia event, and in some deposits contains either early adularia and/or late sericite/illitic clay. The quartz veining ranges from porphyry-related quartz stockwork (eg. Copper Hill, NSW; Porgera, Richards, 1992) at deep levels, to quartz-sulphide veining at intermediate levels (eg. Kelian, Morobe Goldfield, Woodlark, Maniape), and to crustiform-banded quartz-adularia at shallow levels (eg. Tolukuma; Corbett et al., 1994). Fluid inclusion data indicate that the early quartz veining in many deposits (Figure 3) was deposited from relatively hot (250-350°C) but dilute (<2-4 wt% NaCl) fluids.

Stage II-III base metal sulphide-carbonate veining typically overgrows and/or crosscuts the earlier quartz veining. The base metal sulphides commonly pre-date carbonate veining with early pyrite, then sphalerite and galena being overgrown by later copper phases (mainly chalcopyrite followed by late tennantite). In places the base metal sulphide mineralisation extends into the Stage III carbonate event.

The carbonates in places occur as fine crustiform banded veins, locally alternating with thin quartz-rich carbonate bands. Fluid inclusion data indicate that the carbonate and sphalerite in many systems were deposited from a fluid significantly more saline (<4-6 wt% NaCl; exceeding 20 wt% in sphalerite at Kelian), but at

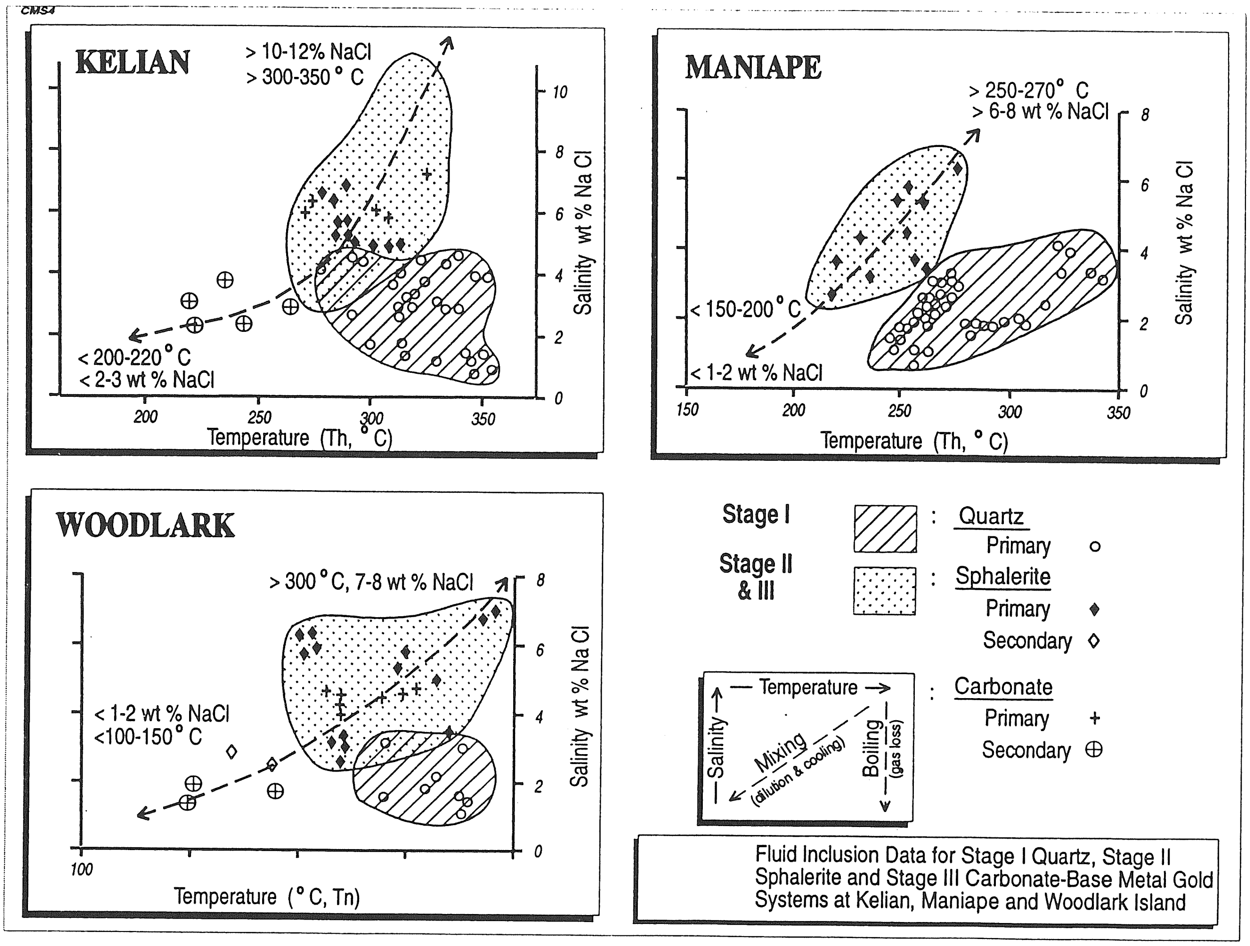

Figure 3. Fluid inclusion data, carbonate-base metal deposits.

similar or slightly lower temperatures to the earlier quartz. The high salinity inclusions in carbonate-sphalerite is interpreted to indicate an influx of a fluid with a significant magmatic component during Stage II-III activity.

Gold mineralisation predominantly occurs during base metal sulphide deposition but extends into the carbonate event. Gold typically occurs in the native state, either as inclusions in pyrite or base metal sulphides, intergrown with carbonate, or infilling fractures and vuggs in earlier quartz. Some gold mineralisation also occurs within late stage quartz veining, especially where abundant pyrite/arsenopyrite is present (eg. at Kerimenge, Syka and Bloom, 1990; and Porgera, Richards, 1992). The average fineness of gold in carbonate-base metal systems typically lies within the range of 700-850 (Figure 4), intermediate between epithermal Au-Ag systems and quartz-sulphide veining marginal to porphyry systems.

Late stage activity is either dominated by surficial fluids with kaolin, interlayered clay, gypsum, quartz deposition; or deep fluids characterised by calcite deposition. Gold mineralisation may locally persist into the initial stages of this late event.

ZONATIONS IN VEINING AND MINERALISATION

Carbonate-base metal gold deposits exhibit a distinctive zonation in their style of veining and mineralisation from areas proximal to a porphyry source or hot conditions, to distal or cooler environments (Figure 5). The carbonate species vary moving towards the porphyry source from Fe-rich (siderite) and Mn-rich (rhodochrosite) at shallow or distal environments, to Ca-rich and Mg-rich species (calcite, Mg-calcite, dolomite) at depth or proximal to an inferred

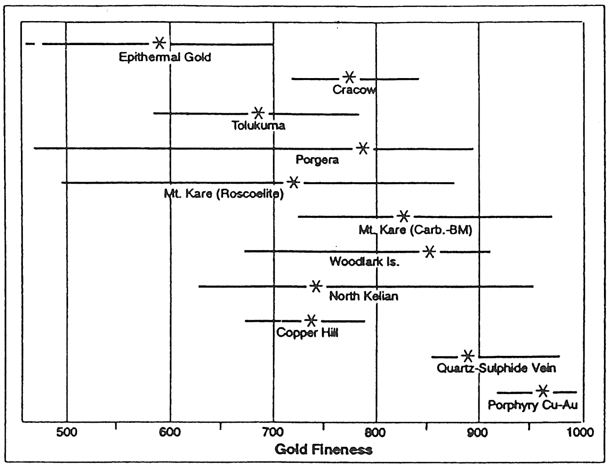

Figure 4. Comparison of gold fineness in carbonate-base metal vein systems with gold fineness in Porphyry Cu/Au, Quarz-sulphhide Au/Cu and Epithermal Au/Ag systems. ✱ denotes average

porphyry source. Intermediate between these carbonate types, are the mixed (Mn-Mg-Fe-Ca) carbonate species, ankerite and kutnahorite. Limited oxygen and carbon isotope analyses on Kelian carbonates (Van Leeuwen et al., 1990), indicated that the Ca-rich carbonates have strong magmatic fluid signatures, whereas the Mn-Fe carbonates were more likely to develop from a surficial fluid origin, and the kutnahorite and dolomite demonstrate a mixing of the two fluid sources. This zonation in carbonate chemistry is therefore interpreted to represent the descent and heating of cool, low pH condensate fluids, and simultaneous mixing of these fluids with upwelling hot magmatic dominated fluids. A similar zonation in carbonate species and modes of formation has been

Distal to porphyry source or Cool

Vein Type	Carbonate Type	Base Metals	Sphalerite	Fe-sulphides
quartz>carbonate				
carbonate>quartz	Fe(siderite)			pyrite -marcasite
	Mn(rhodochrosite)			
carbonate	MnMg(kutnahorite)	Zn≥Pb>Cu	Zn > Fe	
	MgCaFe(ankerite)			pyrite
	MgCa(dolomite)			
	CaMg(Mg-calcite)		Fe>Zn	
	Ca(calcite)			pyrite
sulphides		Cu>Zn,Pb		-pyrrhotite (magnetite)

Proximal to porphyry source or Hot

Figure 5. Zonations in vein mineralogy and styles of mineralisation in carbonate-base metal deposits.

documented for active porphyry-related hydrothermal systems in the Philippines (Leach et al., 1985).

Bulk low grade gold mineralisation is usually encountered in the mixed carbonate, kutnahorite/ankerite to rhodochrosite zones, where progressive mixing between descending bicarbonate and upflowing mineralised fluids has taken place, commonly within dilational structural environments. High grade mineralisation is encountered in restricted feeder structures where sudden quenching of upwelling fluids has occurred close to the inferred porphyry source.

Veining is dominated by sulphides at depth and becomes more carbonate-rich at the expense of sulphides at progressively shallower levels. In outflow zones, quartz locally dominates over carbonate.

Pyrite is the dominant sulphide throughout most systems. However in some deposits, pyrrhotite becomes more abundant at depth, in places intergrown with magnetite (eg. Kelian). Marcasite occurs as shallow levels in many systems and pyrite locally forms colloform bands (melnicovite), and in rare instances is amorphous.

Base metal sulphides (Zn commonly > Pb) dominate over copper phases in most systems. However, copper contents may increase proximal to inferred porphyry sources. Sphalerite typically contains chalcopyrite blebs and stringers, and varies from colourless to yellow (Fe-poor) in cool distal environments, to dark red-brown to opaque (Fe-rich; marmatite) under hotter conditions.

FLUID FLOW MODEL

Hot mineralised fluids evolve from cooling shallow level porphyry intrusives and rise along permeable zones provided by regional structures, diatreme margins or other lithological contacts such as feeder dykes to domes, or basement plutons (Figure 1). At depth, these fluids mix with circulating meteoric waters within splays or dilational structures and form gold mineralisation within quartz-pyrite/arsenopyrite vein systems in which copper phases dominate over lead-zinc sulphides.

Gases evolving from these upwelling fluids form gas condensate zones at surficial levels which are dominated by bicarbonate waters, with a minor acid sulphate component.

Cycling of the hydrothermal system facilitates periodic descent of these cool, oxygenated, moderately low pH bicarbonate fluids deep into the hydrothermal system. Pulses of hot, rising, mineralised fluids mix with these bicarbonate fluids and deposit gold-bearing mineralisation within carbonate-base metal sulphide vein/ breccia systems at various crustal levels, depending on available permeability.

Vectors provided by alteration zonation, the paragenetic sequence, and structure may be used to chart the flow of both upwelling, magmatic-dominated mineralised fluids and descending bicarbonate fluids in order to target:

1. high grade gold zones resulting from fluid quenching within feeder structures;
2. mixing within the progressive cooling environments producing low grade bulk gold mineralisation and in which higher gold grades may develop in settings of repeated mineral deposition; and
3. possible Cu/Au mineralisation associated with the porphyry source.

In near surface outflow zones, repeated boiling and cooling of mineralised fluids results in formation of commonly colloform banded quartz-adularia veining. Gold mineralisation preferentially occurs in thin sulphide-rich bands or breccia zones where hot magmatic fluids have been quenched by cool, oxygenated waters (eg. Tolukuma, PNG; Cracow, Queensland).

DISCUSSION

While carbonate-base metal gold mineralisation displays characteristics of both epithermal and porphyry deposits, systems of this type should be distinguished and treated differently during exploration and evaluation. Both bulk-mineable low grade fracture/breccia ores and higher grade, lode-style ore types are recognised. However, the former are more appropriate to open pit mining methods. The nature of fracture-controlled mineralisation will be governed by the local structural environment and should therefore be considered in the planning of the orientation of any drilling programme, and the evaluation of that data. Dilational ore zones form at differing orientations to the controlling structures, which may be only weakly mineralised. Drilling directions should take these angular relationships into consideration. Features such as maar volcano/diatreme breccias will have a pronounced influence in any fluid flow models. Of great interest is that it is possible to map out the anatomy of these hydrothermal systems, and then use the vectors described above to define fluid flow models which aid in targeting zones of high grade gold mineralisation.

Acknowledgements

Theo van Leeuwen inspired the early work by TML on Kelian and John Baldwin of Kelian Equatorial Mining is thanked for permission to include an update of that work. R. Sillitoe has assisted GJC in the understanding of diatreme breccias and Max Baker provided information on Gold Ridge. Highlands Gold are thanked for permission to publish data concerning Maniape and Woodlark Island, although much of this interpretation post-dates the collection of that data.

REFERENCES

Akiro, K., 1986. The geology and mineralisation of the Kerimenge gold prospect, Wau District, Morobe Province, *in* Papua New Guinea Mineral Development Symposium, Madang, p. 59-62. The Australasian Institute of Mining and Metallurgy, Melbourne.

Corbett, G.J., 1994. Regional structural control to the setting of selected Cu/Au occurrences in Papua New Guinea, *in* Rogerson, R. (Ed.), Proceedings of the PNG Geology, Exploration and Mining Conference, Lae. The Australasian Institute of Mining and Metallurgy, Melbourne. This volume.

Corbett, G.J., and Leach, T.M., 1994. Southwest Pacific Rim Cu/Au systems: structure, alteration and mineralisation. Manual prepared for the Mineral Exploration Workshop, University of Papua New Guinea, Port Moresby, June 1994.

Corbett, G.J., Leach, T.M., Shatwell, D.O., and Hayward, S.B., 1994. Gold mineralisation on Woodlark Island, Papua New Guinea, *in* Rogerson, R. (Ed.), Proceedings of the PNG Geology, Exploration and Mining Conference, Lae. The Australasian Institute of Mining and Metallurgy, Melbourne. This volume.

Corbett, G.J., Semple, D.G., and Leach, T.M. 1994. The Tolukuma Au/Ag vein system, Papua New Guinea, *in* Rogerson, R. (Ed.), Proceedings of the PNG Geology, Exploration and Mining Conference, Lae. The Australasian Institute of Mining and Metallurgy, Melbourne. This volume.

Handley, G.A., and Bradshaw, P.M.D., 1986. The Porgera Gold Deposit, Papua New Guinea, *in* MacDonald, A.J. (Ed.), GOLD '86. An International Symposium on the Geology of Gold Deposits, Toronto, p. 416-424.

Handley, G.A., and Henry D.D., 1990. Porgera Gold Deposit, *in* Hughes, F.E. (Ed.), GEOLOGY OF THE MINERAL DEPOSITS OF AUSTRALIA AND PAPUA NEW GUINEA, p. 1717-1724. The Australasian Institute of Mining and Metallurgy, Melbourne.

Henry, D., 1988. Porgera - the first fifty years, *in* Bicentennial Gold '88 Abstracts, p. 144-149. Geological Society of Australia, Sydney.

Hutton, M.J., Akiro, A.K., Cannard, C.J., and Syka, M.C., 1990. Kerimenge gold prospect *in* Hughes, F.E. (Ed.), GEOLOGY OF THE MINERAL DEPOSITS OF AUSTRALIA AND PAPUA NEW GUINEA, p. 1769-1772. The Australasian Institute of Mining and Metallurgy, Melbourne.

Leach, T.M., Umali, D.U., and del Rosario, R.C., 1985. Epithermal mineral zonation in an active island arc; The Bacon-Manito Geothermal system, Philippines, *in* Proceedings of the 7th New Zealand Geothermal Workshop, Auckland, p. 39-44.

Lowenstein, P.L., 1982, ECONOMIC GEOLOGY OF THE MOROBE GOLDFIELD. Papua New Guinea Geological Survey Memoir 9.

Mitchell, A.H.G., and Leach, T.M., 1991. EPITHERMAL GOLD DEPOSITS IN THE PHILIPPINES. Academic Press, London.

Nelson, R.W., Bartram, J.A., and Christie, M.H., 1990. Hidden Valley gold-silver deposit, *in* Hughes, F.E. (Ed.), GEOLOGY OF THE MINERAL DEPOSITS OF AUSTRALIA AND PAPUA NEW GUINEA, p. 1773-1776. The Australasian Institute of Mining and Metallurgy, Melbourne.

Richards, J.P., 1992. Magmatic epithermal transitions in alkalic systems: Porgera gold deposit, Papua New Guinea. Geology 20, p. 547-550.

Sillitoe, R.H., 1989. Gold deposits in western Pacific island arcs: The magmatic connection, *in* THE GEOLOGY OF GOLD DEPOSITS: THE PERSPECTIVE IN 1988, p. 274-290. Economic Geology Monograph 6.

Sillitoe, R.H., Baker, E.M., and Brook, W.A., 1984. Gold deposits and hydrothermal eruption breccias associated with a maar volcano at Wau, Papua New Guinea. Economic Geology 79, p. 638-655.

Sillitoe, R.H., Grauberger, G.L., and Elliott, J.S., 1985. A diatreme-hosted gold deposit at Montana Tunnels, Montana. Economic Geology 80, p. 1707-1721.

Syka, M.M., and Bloom, M.S., 1990. The geology and paragenesis of epithermal gold mineralisation at the Kerimenge Prospect, Papua New Guinea, *in* Proceedings of the Pacific Rim 90 Congress, Gold Coast, p. 293-299. The Australasian Institute of Mining and Metallurgy, Melbourne.

Teale, G.S., 1992. Gold mineralisation associated with the Warrigundi Igneous Complex, Currabubula NSW, *in* Furney-Greig, T. (Ed.), Twenty five years of geology at Macquarie, p. 36-37. Macquarie University Geological Society, Sydney.

van Leeuwen, T., Leach, T.M., Hawke, A.A., and Hawke, M.M., 1990. The Kelian disseminated gold deposit, East Kalimantan, Indonesia, *in* Hedenquist, J.W., White, N.C., and Siddeley, G. (Eds), Epithermal gold mineralisation of the Circum Pacific. Volume I. Journal of Geochemical Exploration 35, p. 1-61.

T.M. Leach
CMS New Zealand Ltd
11 Blake St
Ponsonby
New Zealand.