CONFERENCE REPORTS

Iron Oxide Copper-Gold Deposits: Separating Fact from Fantasy Short Course

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INTRODUCTION

The Vancouver Mining Exploration Group (MEG), in conjunction with the British Columbia and Yukon Chamber of Mines, held its second annual workshop/ short course with the above title on 16 November 2000 at the downtown Vancouver campus of Simon Fraser University. Last year's meeting was a workshop on subaqueous hot-spring deposits of Eskay Creek-type (Schroeter, 2000). Equity Engineering Ltd. and Hunter Dickinson Inc. sponsored the short course, and Atna Resources Ltd., Western Keltic Mines, Phelps Dodge Exploration Canada Ltd., and the British Columbia and Yukon Chamber of Mines contributed people and helped with the facilities. The short course consisted of 9 talks, and was accompanied by the display of many iron oxide rock specimens from around the world. Approximately 90 people attended the event, including members of the local mining industry, The University of British Columbia, the British Columbia and Yukon Chamber of Mines, and the British Columbia Geological Survey Branch.

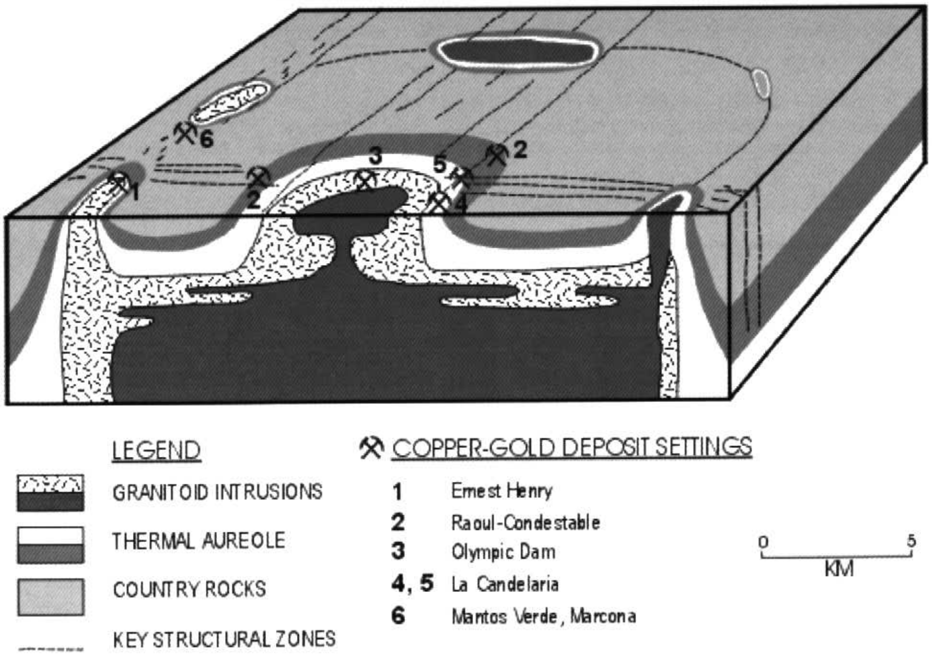

Figure 1 Cartoon placing a number of the world's best-known iron oxide copper-gold deposits in position relative to magmatic bodies, shown here as granitoid intrusions. Note that deposits range from close to distant with respect to a controlling magma body. After Wall, 2000.

OVERVIEW OF GEOLOGY AND GEOCHEMISTRY, IRON OXIDE COPPER-GOLD DEPOSITS

Vic Wall of Taylor, Wall and Associates, Australia, provided a framework for the talks to follow by giving a comprehensive review of the geology and geochemistry of iron oxide copper-gold deposits. This class of deposit is responsible for the global production of more than 800,000 tonnes of copper and 700,000 ounces of gold per year, in addition to significant volumes of iron ore, apatite, uranium, and rare earth elements (REE). Examples of iron oxide Cu-Au-U-REE systems can be found in many different areas of the world, including the Olympic Dam and Ernest Henry deposits in Australia, La Candelaria in Chile, and Kiruna in Sweden. There are three principal styles of Cu-Au iron oxide deposits:

- high temperature; oxidized; magnetite-rich, *e.g.,* Ernest Henry
- high temperature; reduced; magnetite poor; *e.g.,* Mount Roseby, and
- low temperature; oxidized; hematite dominant, *e.g.,* Olympic Dam, Mantos Verde.

These deposits have strong structural control, and commonly occur in the roof zones of intrusives to which they are spatially or genetically related (Fig.1). They are associated with both mafic-intermediate and intermediate-felsic, high-temperature and hydrous intrusive complexes, and commonly show evidence of crystal fractionation. Abundant fluid flow and pressure results in reactivation of existing structures and widespread metasomatic alteration of both the granitoids and the host country rocks. Characteristic alteration patterns of the high-temperature systems include early high Na/K ratio metasomatism (albite+amphibole+magnetite+quartz) and later low, commonly quartz-poor Na/K ratio metasomatism (biotite+kspar+magnetite+pyrite+chalcopyrite). Mineralization is associated with the later alteration, and it is not uncommon to see both styles of alteration together. Mineralization occurs within veins and breccias and also as replacements in reactive host rocks. The low-temperature hematite systems reflect lower-temperature alteration assemblages that typically overprint the earlier magnetite event. This alteration is commonly observed in reactivated magnetite stage structures.

Included in the review were more detailed discussions on deposits from Northwest Queensland such as Ernest Henry, Eloise and Mount Roseby, and deposits of the South American Coastal Batholith such as La Candelaria and the Punta del Cobre belt.

SOURCES OF IRON OXIDE SYSTEMS

Mark Barton from the Center for Mineral Resources at the University of Arizona presented his thoughts on alternative brine sources for iron oxide systems. He proposed that in iron oxide deposits two end-members can be observed, one a product of magmatically derived fluids, with high-temperature mineralization and high K/Na ratio and Si/Fe ratio alteration. The other end-member consists of non-magmatic fluids (*i.e.,* fluids derived from the surrounding host rocks) with oxide-rich, sulphide-poor mineralization, a low Si/Fe ratio and spatially extensive alkali-rich alteration (Na>K). Barton also contends that there are hybrid examples in which there is an overlap of the two styles of hydrothermal alteration and mineralization.

Using conceptual modelling techniques, Barton was able to reproduce the observed characteristic alteration styles of both systems as summarized above. Quantitatively, he was able to show that both systems could move large amounts of metal. Using an intrusion of 1000 km^3, mass and energy balance models indicate that magmatically sourced fluids could produce 2500 Mt of 0.5 wt% copper and 0.5 ppm gold with 4 wt% magnetite. Using the same sized intrusion but with fluids derived externally rather than from the magma, it was found that these fluids could produce 2000 Mt of 0.06-0.18 wt% copper with 50% magnetite (no gold grades given), depending on the alteration of the copper source rock.

The results show that both end-member systems are able to generate large amounts of metal; however, the magmatically sourced fluids can be trapped in structures related to the intrusion whereas externally sourced fluids would require the presence a pre-existing structure that could serve to concentrate the metal.

EXAMPLES OF IRON OXIDE COPPER-GOLD DEPOSITS

Olympic Dam Cu-U-Au-Ag-REE Deposit, South Australia

Tim Craske of Western Mining Corporation (WMC) opened the deposit-oriented talks with plenty of photographs of rocks

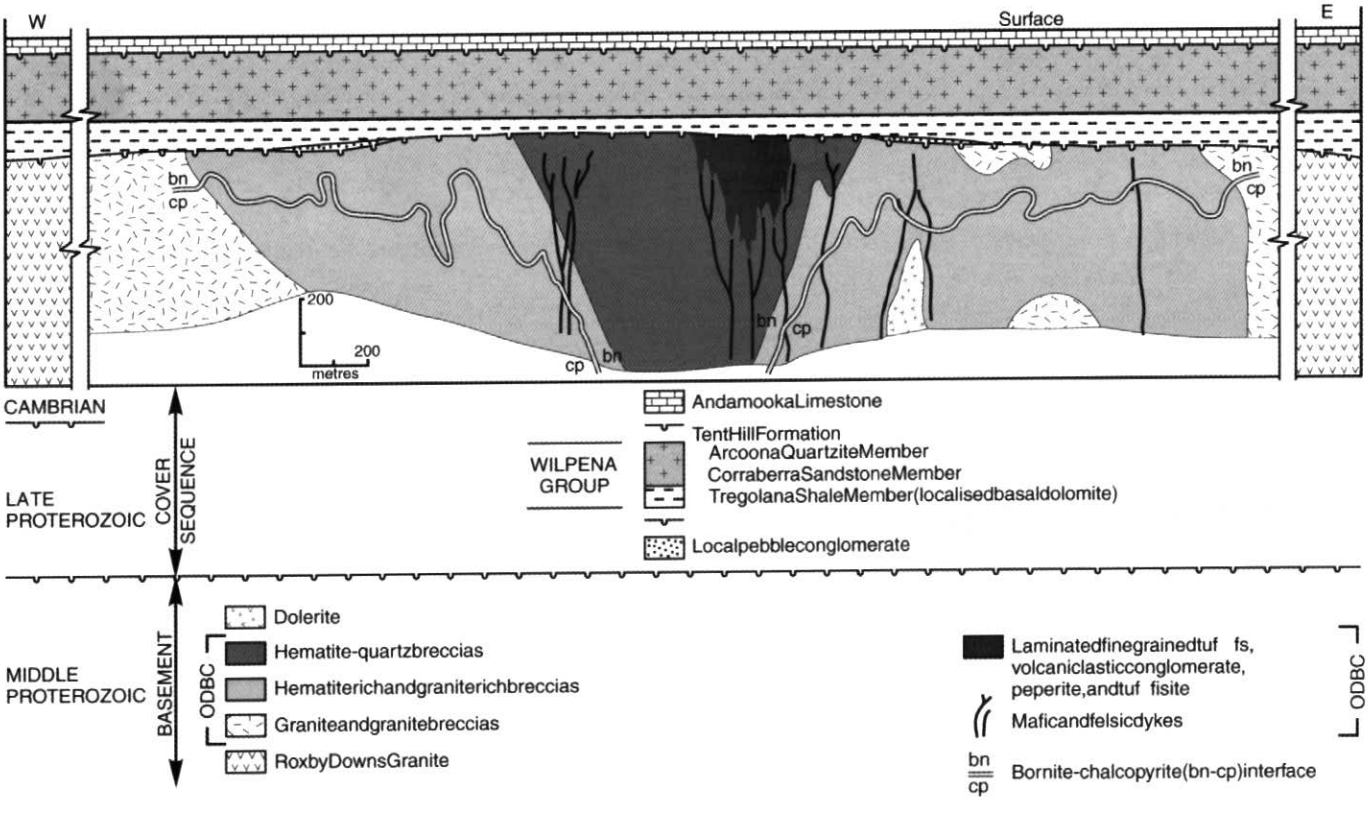

Figure 2 Schematic west-east section through the Olympic Dam Breccia Complex (ODBC). Sericite occurs within all zones except the hematitie-quartz core. Chlorite and siderite alteration occur more abundantly at depth and on the periphery of the breccia zones. Discrete, irregular zones of intense alteration occur around the margins of the hematite-quartz breccias, and are prospective zones for higher-grade gold mineralization. Modified from a diagram prepared by Tim Craske, Western Mining Corporation.

and an excellent discussion on the Olympic Dam deposit. He provided some deposit history, worked through the geological specifics, and outlined the evolving genetic model of this giant mineralizing system.

In 1975, Western Mining Corporation undertook a multidisciplinary study that targeted deep-seated horst structures that had the potential to serve as conduits for copper-rich fluids exsolved from basalts and channeled to overlying, reduced strata. Serendipity played a role in the ensuing exploration, as they did not locate sedimentary exhalative mineralization but were fortunate enough to find an elephant nonetheless. WMC drilling intersected copper mineralization in the first hole and had continued success, culminating with a very thick intersection in the tenth hole.

The Olympic Dam deposit contains a resource of 30 Mt of Cu, 930,000 t of U_3O_8, 1200 t of Au and 6700 t of Ag, and 10 Mt of REE's, with an average iron content of approximately 26% Fe. Ore reserves total in excess of 600 Mt averaging 1.8% Cu, 0.5 kg/t U_3O_8, 0.5g/t Au, and 3.6 g/t Ag (Western Mining Corporation Limited Annual Report, 1999).

The deposit is hosted within rocks of the Middle Proterozoic Roxby Downs Granite, a member of Proterozoic granites and sediments of the Gawler Craton (Fig. 2). The granite is unconformably overlain by approximately 300 m of Late Proterozoic to Cambrian age flat-lying sedimentary rocks. The Olympic Dam Breccia Complex (ODBC), dated as 1588±4 Ma, consists of a funnel-shaped core of hematite-quartz breccias with a peripheral silicified-gold zone passing into hematite-rich and granite-rich breccias. Hydrothermal alteration is dominated by hematite and sericite with lesser chlorite, siderite and quartz. The breccia bodies have a NW to NNW trend, aligned to an overall WNW axis. A complex multi-stage vein sequence exists within the breccia zones and extends outward into the surrounding sediments. The veins typically reflect the dominant mineralization and alteration phases seen within the ODBC (Fig. 2). It is hypothesized that a breccia complex formed in a high-level volcanic environment, then subsequent intrusion by mafic and felsic dykes produced local diatreme structures. Hydrothermal activity, thought to have formed from two evolving magmatic hydrothermal systems, was localized by structures, and progressive development of the ODBC occurred through repeated physical and chemical brecciation mechanisms.

La Candelaria Cu-Au (Zn-Ag) Deposit, Chile

Discovered in 1987 by a subsidiary of Phelps Dodge Corporation, La Candelaria is the largest of the iron oxide copper-gold deposits that constitute the Punta del Cobre belt, with reserves of 470 Mt grading 0.95% Cu, 0.22g/t Au, and 3.1 g/t Ag.

The Punta del Cobre belt is situated in an Early Cretaceous continental volcanic arc and marine back-arc basin terrane that is overlain by carbonate rocks and has been intruded by Early Cretaceous granitoid plutons of the Chilean Coastal Batholith. La Candelaria is located near the center of the Tierra Amarilla Anticlinorium on an elevated block that is bounded to the west and east by NNW trending faults. In most instances, mineralization is controlled by faults of this orientation, and occurs where they intersect the contact between the upper volcaniclastic unit and the underlying massive volcanic rocks of the Punta del Cobre Formation. Alteration patterns show a pervasive albite-chlorite-calcite-hematite assemblage in the dacitic volcanic rocks that grades downsection into pervasive K-feldspar-quartz-chlorite/biotite and/or biotite-quartz-Na-plagioclase-K-feldspar plus magnetite± hematite alteration (Fig. 3). Hypogene ore mineralogy consists of magnetite and/or hematite with chalcopyrite and pyrite, occurring as massive veins, veinlets and stringers that cut the altered host rocks or magnetite replacement bodies, as breccia fillings, and as mantos. Magnetite is the predominant iron oxide phase at La Candelaria, and it is commonly seen as pseudomorphs of specularite in veinlets and veins in most of the deposits in the Punta del Cobre belt.

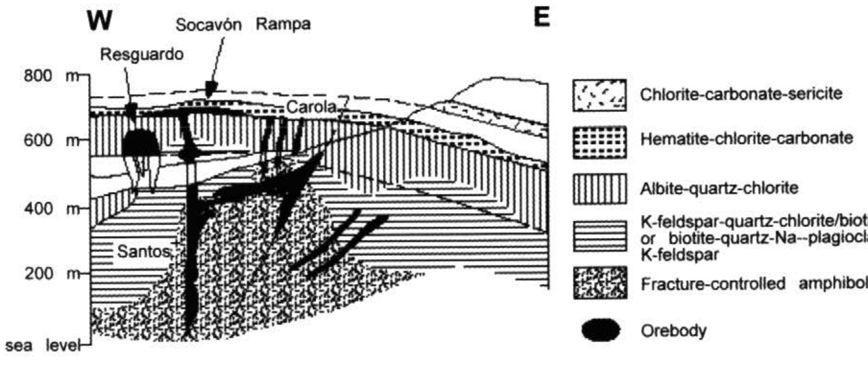

Figure 3 Schematic cross-section of the La Candelaria deposit, Chile, highlighting the distribution of alteration styles. Modified from Marschik *et al.*, 2000.

Productora Cu-Au-U-REE Property, North-central Chile

General Minerals Corporation holds the Productora property, an exploration prospect located in the Punta del Cobre belt. Iron oxide±Cu±Au±U±REE±apatite mineralization and alteration occurs within an area that measures >6km by >3km, containing more than 80 prospect pits and 12 small mining operations. Sets of N and NW trending structures related to the Atacama fault zone controlled volcanism in the Productora area, resulting in a gentle to moderately inclined package of Cretaceous (?) quartz-bearing felsic tuffs and mafic flows that contain the bulk of the iron oxide mineralization in the region. Four felsic intrusive units cut these tuffs and flows, three of which are thought to be genetically related to the hydrothermal system. The fourth intrusive unit postdates the iron oxide mineralization but is itself cross cut by NW trending Au bearing quartz±barite veins.

The 3 x 6 km zone of hydrothermal alteration is mainly focussed on the north-trending El Mollo and Cachiyuyito stocks. A pervasive albite-rich zone with veins of actinolite, magnetite and epidote occurs deepest and most proximal to the stocks. Outward from this, a second alteration assemblage is dominated by chlorite-actinolite-magnetite-calcite-apatite. A third more distal alteration is characterized by widespread K-spar and tourmaline, hematite, secondary biotite, and silica. The uppermost and lowest temperature alteration contains massive silica, specular hematite, sericite, and dumortierite. Hypogene Cu-Au mineralization is associated with the second and third alteration assemblages, and includes magnetite, specular hematite with chalcopyrite, pyrite, and native gold.

Past drilling has focussed on areas where mineralized units crop out; some encouraging intersections include 112 m grading 0.65% Cu and 0.1 g/t Au, with a high-grade intersection of 28 m grading 1.0% Cu and 0.13 g/t Au. Recent geophysical work shows that the Productora mineralization is associated with a strong I.P. anomaly that is open to the north, south, and west. In particular two alluvium-covered anomalous zones to the west of known mineralization were detected; these will be high-priority follow-up drill targets.

BRITISH COLUMBIA SETTINGS

Copper Mountain: A Possible Iron Oxide-Associated Copper-Gold Deposit?

Although the Copper Mountain deposit near Princeton, British Columbia, has been considered to be an alkalic porphyry deposit, Peter Holbek of Atna Resources, Vancouver and his co-authors Jim Lang and Steve Blower proposed that perhaps it might be a higher-level iron oxide copper-gold deposit. Exploration and mining for copper has been conducted in the area since 1884. When the mine closed in 1997, the total historical production was calculated to be in excess of 175 million tonnes grading approximately 0.46% Cu, 0.13g/t Au and 1.72g/t Ag (Stanley *et al.*, 1995).

The Copper Mountain deposit is located within the Late Triassic Nicola Group island arc volcanics and sediments of the predominantly Mesozoic Quesnellia terrane. These rocks are sandwiched to the south by the Copper Mountain suite and to the north by the multi-phase Lost Horse Intrusive Complex (LHIC). Intrusion of the Copper Mountain stock produced a hornfels that is the earliest phase of alteration on the property. The next phase is a pre-mineralization sodic metasomatic event, resulting in a pervasive albite-epidote hornfels that occurs in two central areas of the camp. An extensive pervasive potassic alteration event locally overlaps or cuts zones of sodic alteration. The majority of the mineralization on the property is structurally controlled with veins and vein stockworks, with lesser breccias. The mineralization consists of a magnetite-chalcocite-bornite-chalcopyrite-pyrite-hematite assemblage, and magnetite breccias are observed.

On reviewing the characteristics of this deposit it is evident that there are some similarities with the iron oxide model. Mineralization and alteration within the deposit have a very strong structural control, both in its location and within the deposit itself, and it hosts an initial sodic alteration followed by potassic alteration. The mineralization assemblage reflects a low-sulphur, high-iron and oxygen fugacity system, and magnetite breccias occur as ore hosts in a number of areas. These features display the similarities of this system to other iron oxide copper-gold systems around the world. Although some mineral associations such as tungsten, uranium, and rare earth elements are missing, it might be that the Copper Mountain deposit is a high-level expression of an iron oxide copper-gold deposit.

Potential Iron Oxide Gold-Copper Deposits?

Gerry Ray of the British Columbia Geological Survey Branch studied iron oxide Cu-Au deposits and evaluated the potential for these systems in British Columbia, using an iron oxide model along with BC Minfile, regional geochemical surveys, aeromagnetic survey maps of British Columbia and anecdotal evidence from discussions with geologists and prospectors. He described four categories; the best examples of iron oxide copper-gold prospects include the Iron Range property, and albite-Fe oxide occurrences in Proterozoic rocks of the Cranbrook–Kimberley area. There are other prospects that have favorable iron oxide characteristics, but whose classification is uncertain, including the Mag geophysical anomaly ESE of the Sullivan mine, the Heff Fe-Cu-Au skarn on the north side of Heffley Lake near Kamloops, and the Glen Iron mine located 22 km west of Kamloops.

Based on this compilation work, it is clear that the potential for iron oxide deposits in British Columbia at both the property and the grass roots level exists, and that exploration is warranted.

YUKON

Overview of Wernecke Breccias

Derek Thorkelson of Simon Fraser University presented the regional geological setting of the Wernecke breccias. Hosted within the 13-km thick, Middle Proterozoic Wernecke Supergroup, "Wernecke Breccia" is a term used to describe numerous breccia bodies that range from 0.1 km^2 to 10 km^2 in the Wernecke, Ogilvie, and Richardson mountains in the northern Yukon Territory. The main brecciation and metasomatic event contains minor magnetite and ubiquitous matrix-filling and vein specular hematite, and occurred at circa 1.6 Ga, which is very close to the age of the Olympic Dam breccias (1588±4 Ma). Some bodies are related to faults, whereas others do not show this relationship. It is possible that these bodies are simply underexplored. Although the source of the fluids is uncertain, it is postulated that the volatile-rich fluids that shattered large volumes of the Wernecke Supergroup may be related to igneous intrusions at depth.

Wernecke Breccias: Fairchild Joint Venture

Richard Gorton of Newmont Mining Corporation presented a summary of exploration by a Newmont–Westmin-Equity Engineering–Pamicon Developments joint venture on the Wernecke breccias. In 1992, Equity and Pamicon recognized that the intense K feldspar and albite metasomatism, magnetite and hematite breccias with associated Cu, Au, Co, U mineralization reported in the Werneckes compared favorably with Olympic Dam style mineralization. Work began, and exploration of the breccias accelerated with Newmont's arrival on the project in 1993. Newmont used a proprietary airborne magnetic-radiometric system and reconnaissance scale mapping, and prospecting and stream geochemical sampling to define numerous targets in the region, of which 12 prospects were eventually tested by more than 14,000 m of drilling. Some of the better drill results included over 100 m of 0.3% Cu at the Slab property, 0.41% Cu and 0.3 g/t Au over 75 m on the Hoover property (10 km to the NW of Slab) and 21 m of 2.0% Cu, 0.2% Co and 0.2 g/t in siderite veining at Gremlin.

The mountainous terrain and structural uplift in the Wernecke Mountains provides for an excellent study of the iron oxide breccias that span some 9,000 m of Wernecke Supergroup strata. As expected, magnetite-albite dominant systems are found at lower levels (Slab, Hoover) whereas the breccias reaching the highest levels in the stratigraphy are hematite-rich and characterized by abundant K feldspar.

A CONCLUDING, GLOBAL PERSPECTIVE

Following a day spent by short course attendees in digesting the many different views of the "same" family of deposits, Mike Ethridge of SRK Consulting, Sydney, Australia, returned to the global level of study. He presented, in summary form, a clear picture of a simple process model for Fe-oxide Cu-Au deposits, provided further examples, and finished by outlining key geophysical, geochemical, and geological exploration methods. Figure 4 illustrates Ethridge's simple model for the formation of iron oxide copper-gold deposits, and infers the setting for a number of globally important deposits. Ethridge's model focusses on the roof zone of a pluton, and illustrates the structural control of the two stages of alteration and mineralization, as well as the theoretical location of different styles of iron oxide copper-gold deposits. Vectoring in on targets using this model is possible by coupling an understanding of the structural regime through mapping and geophysical data, with alteration patterns. Geophysical techniques, such as magnetic and I.P. surveys, can be used both for locating prospective target areas and for further refining the location of possible structures and sulphide bodies. Further to these methods, gravity surveys can be used to identify intrusive roof zones. Geochemically, it should be possible to use radiometric surveys to locate zones of K + U enrichment. Soil and rock data may demonstrate patterns that reflect changes in alteration, and can aid in targeting cores of systems. Once an attractive target area is selected, Etheridge emphasized that rather than "massaging" the target with additional surveys, the target should be drilled, allowing the geologist to develop a better understanding of rocks and structure. This should help to further refine the target, and hopefully increase chances of success.

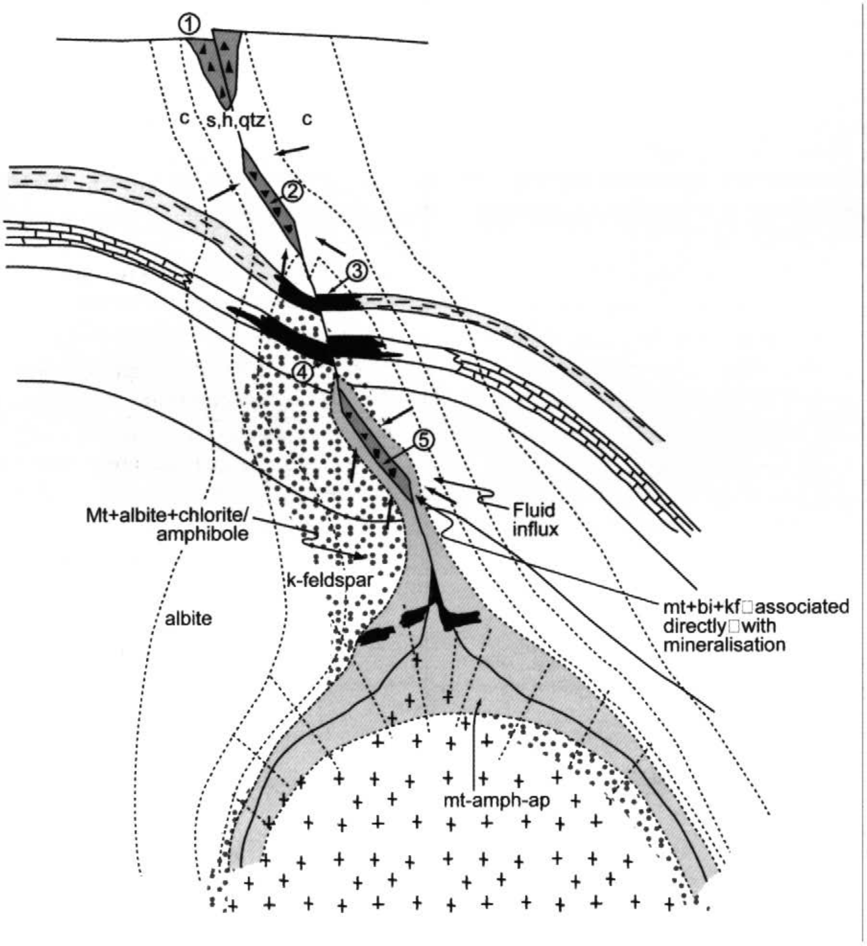

Figure 4 A simple process model for iron oxide copper-gold deposits, highlighting the location of the different styles of deposits. **Metal source(s)**: mafic-intermediate plutons, +/- albitized country rock. **Fluids**: Hot (300-600 °C), highly saline, 9 >30 wt% NaCl, CaCl). Variable fO_2 + xO_2 mostly magmatic. **Hosts**: Variable, breccias generally in more competent rock units, but this depends on the structural and dilational controls. **Numbered examples on diagram**: (1) Possible Olympic Dam setting, diatreme and hematitie breccia. Lower Cu-Au ratios, low to moderate grade, large tonnage. (2) Starra type setting. Hematite breccia (h, s, kf, cb, +/- cp, py, ab). Lower Cu-Au ratios, high grade, small to medium tonnage. (3) Cu sulphide-rich reduced deposits in graphitic hosts (cp, po, py, +/- cp, ab, qtz). Higher Cu-Au ratio, higher grade, small to medium tonnage. (4) Replacement/skarn in carbonate or quartz-mica host (mt, b, am, ap, f, to). Lower Cu-Au ratios. (5) Ernest Henry setting. Magnetite breccia (mt, h, am, ap, gt, kf). Lower Cu-Au ratios, low to moderate grade, medium to large tonnage. Modified from material provided by Mike Etheridge of SRK Consulting, 2000.

ACKNOWLEDGMENTS

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FURTHER INFORMATION

The full title of the notes is: Iron Oxide Copper-Gold Deposits: Separating Fact from Fantasy; The Short Course; unpaginated, divided into sections A-H: A – Background Information; B – Keynote Session – What You Need to Know; C- Some Theory on Origins; D – Olympic Dam and Information from Down Under; E – Examples of Fe-Oxide Cu-Au Deposits from South America; F – Potential for Fe-Oxide Cu-Au Deposits in the Northern Cordillera; G - Olympic Dam and Kiruna style mineralization, NWT, Canada; and H – Exploration Guides: A Global Perspective.

Copies of the Short Course Notes are available from the British Columbia and Yukon Chamber of Mines, 840 West Hastings Street, Vancouver, BC V6C 1C8; Chamber Web site is www.chamberofmines.bc.ca. Cost is $35.00 including taxes and postage; cash or cheques (payable to the Vancouver Mining Exploration Group) only. For further information or to order, please contact Sally Howson at ssh@istar.ca or by telephone at 604-689-5271, ext. 104.

The new (November 2000) 350-page monograph *Hydrothermal Iron Oxide Copper-Gold and Related Deposits – A Global Perspective*, published by the Australian Mineral Foundation Inc., is another excellent source of information. Their Web site is: www.amf.com.au/amf/

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