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1995 BOLDY AWARDS

The **Julian Boldy Award** is presented to the author(s) of the paper(s) presented at the annual GAC/MAC meeting that are judged to best describe significant and pragmatic advances in mineral deposit research or exploration. One of the aims is to encourage high standards in the communication of geological ideas.

Because of a generous increase in the endowment funding from Placer Dome, judging was expanded at the Victoria '95 meeting to include both MDD-sponsored and other economic geology sessions: A total of 77 papers in 5 day-long sessions. Three papers are being recognized with awards in 1995. These are, in alphabetical order by presenters name:

Childe, F. and **Thompson, J.**; Mineral Deposits Research Unit, UBC, Vancouver

U-Pb Age Constraints and Pb Isotopic Signatures of the Kutcho VMS Deposit: Implications for the Terrane Affiliation of the Kutcho Formation, North Central B.C.

Penczak, R.S. and **Mason, R.**; Dept of Geological Sciences, Queens Univ., Kingston, Ontario

Hydrothermal Alteration Associated with a Metamorphosed Epithermal Gold Deposit at Red Lake, Ontario

Turner, R.J.W. and **Leitch, C.H.B.**, Geological Survey of Canada, Vancouver, and **Höy, T.**, B.C. Geological Survey Branch, Victoria, B.C.

Proterozoic Graben-controlled Hydrothermal Field Associated with the Sullivan Stratiform Zn-Pb-Ag Deposit, B.C.

(each of the co-authors of this last paper also presented fine papers as part of an outstanding session entitled *Continental Rifting and the Formation of SEDEX Deposits: Sullivan and Other Giants*)

Following the Boldy Award tradition, expanded abstracts of each paper appear in this issue of The Gangue for the benefit of those unable to attend the sessions. Each co-author will receive a wall certificate, a book plate, and a small cash prize.

The Mineral Deposits Division extends its gratitude to the following, who served as judges at the Victoria '95 meeting: Nathalie Prud'homme and Lucy St Croix (Placer Dome, Val D'or), Paul Wojdak (BCGS, Smithers), Robert Pinsent (BCGS, Vancouver), Mike Cathro (BCGS, Kamloops), Gary Wells (Inmet, Vancouver), Grant Abbott (Canada/Yukon Geoscience Office, Whitehorse), and two consultants who worked with Julian Boldy for Giant Yellowknife in Keewatin in the early 1960s - Mo Kaufman (Spokane, Wash.) and Hugh Squair (Toronto).

Bob Cathro
Treasurer, MDD

U-Pb AGE CONSTRAINTS & Pb ISOTOPIC SIGNATURE OF THE KUTCHO VMS DEPOSIT:

IMPLICATIONS FOR THE TERRANE AFFILIATION OF THE KUTCHO FORMATION, NORTH CENTRAL BRITISH COLUMBIA

by Fiona Childe and John Thompson
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The Kutcho Formation is host to the Kutcho Creek VMS deposit, with reserves of 17 Mt of 1.6% copper, 2.3% zinc, 29 g/t silver and 0.3 g/t gold (Bridge *et al.*, 1986).

The predominantly volcanic Kutcho Formation forms the basal unit to the King Salmon allochthon, a discrete thrust and fault-bounded block within the Cry Lake Map Area (NTS 104-I). The Kutcho Formation is overlain by lenses of limestone which have been correlated with the Upper Triassic Sinwa Formation (Monger and Thorstad, 1978) and argillites and siltstones which have been correlated with the Inklin Formation of the Lower Jurassic Laberge Group (Gabrielse, 1962). The allochthon was tectonically emplaced onto the Cache Creek terrane and is in fault contact with the Stikine terrane (Fig. 1).

Lack of analogous stratigraphy in, and primary contact relationships with, adjacent terranes has left the terrane affiliation of the Kutcho Formation ambiguous.

Previously the Kutcho Formation has been correlated with the Lower Permian Asitka Group of the Stikine terrane (Panteleyev and Pearson, 1976; Monger, 1977), the Upper Triassic Takla Group of the Quesnell terrane (Thorstad and Gabrielse, 1986), the Cache Creek terrane (Thorstad and Gabrielse, 1986, Gabrielse, 1990a), and Upper Triassic rocks of the Stikine terrane (Höy, 1991). Prior to this study the Kutcho Formation was assigned a Late Triassic age based on a Rb-Sr whole rock age of 210±10 Ma (Thorstad and Gabrielse, 1986). A Late Triassic age designation would imply that Kutcho mineralization formed in the same time interval as several other significant VMS deposits in the North American Cordillera, including the Windy Craggy (Orchard, 1986), Greens Creek (Newberry *et al.*, 1990) and Granduc (Childe *et al.*, 1994) deposits.

Rocks of the Kutcho Formation can be broadly divided into lower and upper sequences, with the lower sequence composed of interbedded bimodal, tuffaceous volcanic rocks with minor argillaceous sediments and possible basalt flows (Fig. 2). This sequence is cut by at least two types of felsic intrusions: an equigranular unit which has been interpreted to be trondhjemite (Pearson and Panteleyev, 1975); and a quartz and feldspar porphyritic subvolcanic intrusion of rhyolitic composition which is characterized by locally abundant metamorphic biotite.

The upper sequence, which hosts mineralization at Kutcho, is composed primarily of plagioclase and/or quartz porphyritic rhyolitic fragmental rocks of probable mass flow and pyroclastic origin. Felsic volcaniclastic rocks in the footwall and immediate hangingwall to mineralization show strong sericite-pyrite-carbonate alteration. The volcanic sequence is capped by argillites and siltstones, which are in turn overlain by conglomerates composed primarily of clasts derived from the underlying volcanic rocks. Coarse-grained augite±plagioclase porphyritic gabbro sills intrude the upper sequence primarily along the felsic volcanic-sediment contact; locally developed pepperitic interaction textures with the sediments indicate that the sills intruded into unlithified wet sediments.

Preliminary lithogeochemistry by Thompson *et al.* (1995) has shown that the rhyolitic and basaltic volcanics, as well as felsic intrusives of the Kutcho Formation, have a tholeiitic affinity, with very low concentrations of incompatible and rare-earth elements. In contrast, the gabbro sills near the top of the sequence have trace element signatures that are similar to alkaline arc magmas.

In the current study three units were dated using U-Pb zircon geochronology. The three samples, the rhyolitic subvolcanic intrusive (KC-GC-03), a plagioclase-quartz porphyritic mass flow from the footwall of the deposit (KC-GC-04), and a coarsely quartz porphyritic mass flow from the immediate hangingwall to mineralization (KC-GC-01) have yielded preliminary ages of 244 +5/-1 Ma, 243 +7/-1 Ma and 242 +/-5 Ma, respectively (Fig. 2). The latter two ages bracket Kutcho mineralization as forming at the Permo-Triassic boundary. This is an uncommon age for felsic volcanism within the accreted terranes of the Canadian Cordillera and represents a new age for VMS mineralization in this region.

Mineralization at Kutcho Creek consists of three subcropping, east-west striking *en echelon* massive sulphide orebodies with a predominant sulphide mineralogy of massive pyrite, chalcopyrite, bornite and sphalerite. This mineralization is locally overlain by a brecciated, laminated dolomite facies in which the brecciated areas are infilled by an assemblage of quartz-calcite-pyrite-bornite-covellite, and darker laminae within the dolomite are infilled with sulphides.

In order to examine the question of terrane affiliation of the Kutcho Formation, sulphides from both styles of mineralization were analyzed for their lead isotopic composition and compared with VMS mineralization of known age from the Stikine terrane (Childe, 1994). Within the Stikine terrane VMS deposits of Devono-Mississippian to Middle Jurassic age show a general trend from less to more radiogenic lead isotopic compositions with time. Kutcho mineralization, with lead isotopic compositions of

$^{206}Pb/^{204}Pb = 18.43\text{-}18.51$,

$^{207}Pb/^{204}Pb = 15.51\text{-}15.61$, and

$^{208}Pb/^{204}Pb = 37.87\text{-}38.04$

is less radiogenic than any of the Stikine terrane deposits.

These data, together with the distinctive chemistry of the felsic volcanic rocks which host the mineralization, suggest that the Kutcho Formation formed in a more oceanic tectonic environment than the Stikine composite island arc, perhaps as a primitive arc built directly on the Cache Creek terrane as suggested by Thorstad and Gabrielse (1986).

Although Kutcho has been classified as both a Besshi- (Pearson and Panteleyev, 1975) and Kuroko-type (Thorstad and Gabrielse, 1986) deposit it does not appear to have the fundamental characteristics of either, and may in fact represent a previously unrecognized style of VMS mineralization; the major characteristics of which include copper and zinc-rich mineralization, a predominance of proximal felsic volcanic rocks, a bimodal tholeiitic chemistry, and a possible primitive oceanic arc environment.

The new age and isotopic constraints determined in this study can now be used to examine possible correlatives of the Kutcho Formation. Previous workers (Monger *et al.*, 1978; Thorstad and Gabrielse, 1986; J. Marr, pers. comm., 1994) have noted strong similarities in the stratigraphy and structural styles between the Kutcho Formation and the Sitlika Assemblage. Gabrielse (1990b) has suggested that the fault-bounded volcano-sedimentary Sitlika Assemblage (NTS 93-N), which lies directly east of Takla Lake, between the Takla and Vital faults is a dextrally displaced portion of the Kutcho Formation.

If this correlation is valid the Sitlika Assemblage, which is already known to host several base metal volcanic-associated occurrences has the potential to host significant Kutcho-equivalent mineralization.

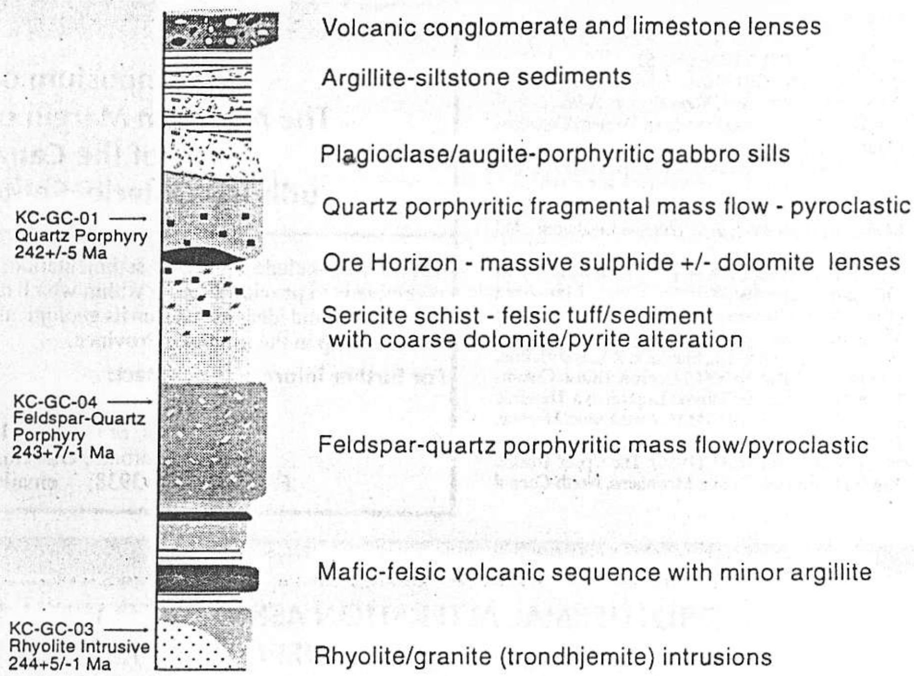

Figure 1. Regional setting of the Kutcho Formation (after Thorstad and Gabrielse, 1986).

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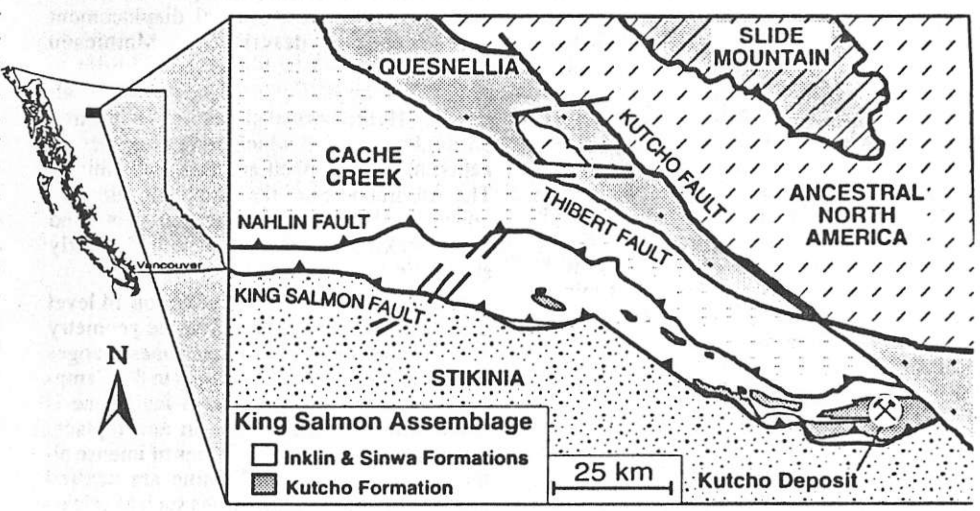

Figure 2. Stratigraphic section for the Kutcho Formation, showing relative position of samples dated by U-Pb geochronology.

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HYDROTHERMAL ALTERATION ASSOCIATED WITH A METAMORPHOSED EPITHERMAL GOLD DEPOSIT AT RED LAKE, ONTARIO

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The Campbell mine occurs within the Red Lake greenstone belt which is situated in the western part of the Uchi Subprovince of the Superior Province in northwestern Ontario. The sequence of events which is outlined in Table 1 illustrates the complex geologic history of the Red Lake greenstone belt. Figure 1 is a simplified geology map of the Red Lake greenstone belt showing the distribution of significant past and presently producing gold mines.

The Red Lake greenstone belt is a collage of volcanic, intrusive and sedimentary rocks which formed between 3000-2730 Ma (Stott and Corfu, 1991). The lithologic units at the Campbell mine and the adjacent Red Lake mine (formerly known as the Arthur W. White and Dickenson mines) consist of metabasalts (which host most of the mineralization), ultramafic volcanic and intrusive units, rhyolites, dioritic rocks, minor iron formation and a variety of mafic and felsic intrusive dikes. Rhyolite from the 20th level of Campbell mine has been dated at 2989±3 Ma (Corfu and Andrews, 1987). The stratigraphic sequence was folded, thrusted and intruded by granodiorite intrusions. The McKenzie Stock (2720±2 Ma; Corfu and Andrews, 1987) and the Dome Stock (2718±1 Ma; Corfu and Wallace, 1986) host past-producing gold mines. At the Campbell Mine the sequence of events related to alteration and mineralization have been subdivided into four main phases; early strike-slip faulting, early alteration phase, main stage vein phase, and mineralization phase. This was followed by the emplacement of felsic dikes ("minette lamprophyre"). A post-mineral QFP dike cuts across ore zones at the Red Lake mine and has been dated at 2714±4 Ma (Corfu and Andrews, 1987) which provides a minimum age for gold mineralization. The marginal (latest) phase of the Trout Lake Batholith (Walsh Lake Pluton) has been dated at 2699±1 Ma (Noble *et al.*, 1989) and thus post-dates gold mineralization. Hydrothermal alteration and mineralization were deformed and recrystallized during crustal shortening and regional metamorphism associated with the Kenoran orogeny. Blocking dates for micas at the minesite are similar to those across the Superior Province (York *et al.* 1991) and are related to uplift and cooling following peak Kenoran metamorphism at about 2650 Ma.

The W to WNW striking, and S to SW steeply dipping volcanic strata in the Balmertown area is offset by two sub-parallel WNW striking, SW steeply dipping strike-slip faults, the Campbell fault zone to the north which has a sinistral sense of movement, and the Dickenson fault zone to the south which has a dextral sense of movement (Fig. 2). Relative fault movements on the principal displacement zones were first described by Mathieson (1982). Strike-slip faulting occurred prior to or early in the initiation of hydrothermal alteration. Hydrothermal alteration was centred on the fault system which controls mineralization at the Campbell and Red Lake mines. The Au orebodies at the Campbell mine are hosted by high-level epithermal veins and vein stockworks associated with the early strike-slip fault system.

The distribution of ore zones on 14 level is shown in Figure 2, however, the geometry as well as the distribution of ore zones changes vertically in the mine. Compared to the Campbell fault zone, the Dickenson fault zone is straight and hosts fissure vein and replacement type mineralization. Zones of intense alteration at the Campbell mine are centred around structural complexities such as releasing bends and horsetail splays on the principal displacement zone (PDZ) of the Campbell fault, as well as complexities caused by fault splays and delaminated lithological contacts associated with the PDZ. The Campbell fault zone is relatively straight at the Red Lake mine whereas on Campbell it forms a releasing bend resulting in the formation of high quality ore zones in main stage vein sites within secondary fractures associated with the releasing bend (Fig. 2). The L zone formed in a horsetail splay off the hanging wall side of the Campbell fault zone. The G zone formed in a splay near the basalt-ultramafic rock contact. Interactions between the Campbell fault and adjacent subsidiary fault structures as well as lithological contacts change the geometry of the G zone forming a cymoid loop in the deeper levels.

Widespread early hydrothermal alteration occurred prior to the emplacement of main stage veins and mineralization. This early alteration phase has been previously described as "feldspar destructive alteration" by MacGeehan and Hodgson (1982). The early alteration was controlled by fault and fracture zones and zones of primary permeability such as pillows, lithological contacts and flow contacts. Christie (1986) suggested that the early alteration is related to primary features formed in the volcanic environment which could have only remained permeable prior to the development of a metamorphic-tectonite fabric. This phase of alteration was important for sealing primary structures from later alteration phases which were more structurally controlled. The ultramafic, and to a lesser extent mafic volcanic rocks, are the most intensely altered mine lithologies. Most of the wall-rock carbonatization was early, but continued throughout the alteration sequence resulting in complex overprinting relationships between carbonate and various other phases of wall-rock alteration.

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Palabora Igneous Complex South Africa

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Palabora Mining Company, a a member of the international RTZ Group, is situated near the town of Phalaborwa in the remote part of the north-eastern Northern Province, Republic of South Africa (Fig. 1). It is a mine unique amongst the world's major copper operations in its geology and mineralogy, diversity of by-products, technical innovation and performance efficiencies, financial performance and its dedication to social development and environmental care. It is also one of the largest open cast mining operations in the world and is the largest in Africa.

The exploitation of the orebody by Palabora Mining Company started in 1956, although artifacts found in the area prove that copper of remarkable purity was produced in the Phalaborwa area as early as the 8th century AD. In 1963, construction began on site, and two years later, mining operations began. In February 1966, the first Cu anodes were cast.

The mine operates as a high tonnage, low copper grade (average of 0.5% Cu) venture producing about 100 000 tons of broken rock per day on a 7-day week basis to feed a milling operation continually at a nominal rate of 82000 tons per day. The average stripping ratio is approximately 0.173:1 where waste material includes dolerite and material below 0.1% Cu.

The current pit dimensions are 1800m E-W, 1400m N-S and 450m deep. The pit is designed to achieve a final depth of 762m below average surface elevation in the year 2002 with final pit dimensions of 388.69m E-W and 143.88m N-S at bench 58. The ore is, however, known to extend far deeper than the final pit depth and feasibility studies are being conducted into underground mining to extend the life of the mine well into the next century.

At present, Palabora mines three pipelike bodies in the Palabora Igneous Complex, those being the northern and southern pipes for its vermiculite and apatite (apatite goes to Foskor) and the central, or Loolekop pipe for its copper. Mining does however alternate between the two vermiculite deposits, depending on the market requirements.

By-products of the copper mining venture include, magnetite, baddeleyite (ZrO_2), uranium, nickel sulphate and sulphuric acid and account for approximately 20% of the total revenue. The ultramafic rocks of the complex are host to economic deposits of vermiculite, and Palabora supplies approximately 30% of the world's requirements.

PALABORA IGNEOUS COMPLEX

The Palabora Igneous Complex is in Archean Shield and covers an elongated, kidney-shaped area roughly 6.5km north-south and 2.5km east-west in extent. The Complex resulted from an alkaline intrusive cycle, which emplaced, in successive stages, a suite of rocks ranging from ultramafic to peralkaline in character. (geological and mineralogical staff, 1976). The geology of the Complex is shown in Figure 2 (modified after Hanekom *et. al.* 1965). According to Hanekom *et. al.* three successive stages in the intrusive cycle are distinguishable.

PHASE I

The first phase of the intrusive cycle resulted in the emplacement into the Archean granite gneisses of a massive ultramafic, vertical, pipelike body consisting mainly of pyroxenite, consisting of variable proportions of phlogopite, diopside and apatite. A corona of feldspathic pyroxenite around the pyroxenite, formed as a result of the interaction of the pyroxenite with the Archean granite gneisses.