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THE GEOLOGY AND GENESIS OF IRON OXIDE-COPPER-GOLD MINERALISATION ASSOCIATED WITH WERNECKE BRECCIA, YUKON, CANADA

VOLUME I

Thesis submitted by
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"It is precisely for this that I love geology. It is infinite and ill defined: like poetry, it immerses itself in mysteries and floats among them without drowning. It does not manage to lay bare the unknown, but it flaps the surrounding veils to and fro; and every so often gleams of light escape and dazzle one's vision."

R. Topfler

Frontispiece: Bonnet Plume River valley, Wernecke Mountains, Yukon, Canada

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ABSTRACT

The large scale Wernecke Breccia system occurs throughout the 13 km-thick Early Proterozoic Wernecke Supergroup (WSG) and is spatially associated with regional-scale faults. Breccia emplacement made use of pre-existing crustal weaknesses and permeable zones; metaevaporitic rocks in the lower WSG may be intimately related to breccia formation. The breccia bodies host vein and disseminated iron oxide-copper-gold ± uranium ± cobalt mineralisation and are associated with extensive sodic and/or potassic metasomatic alteration overprinted by pervasive carbonate alteration. Multiple phases of brecciation, alteration and mineralisation are evident. Six widely spaced breccia bodies that occur in different part of the WSG were examined in this study (i.e. Slab, Hoover, Slats-Frosty, Slats-Wallbanger, Igor and Olympic). New information includes geological, paragenetic, geochronological, isotopic, fluid inclusion thermometric and compositional data.

Re-Os analyses of molybdenite from a late-stage vein that cross-cuts breccia gave model ages of 1601 ± 6 and 1609 ± 6 Ma. These ages range from older than to within error of the *ca.* 1594.8 ± 4.6 Ma published U-Pb (titanite) date for breccia in the same area. A second molybdenite sample from a late-stage vein gave a Re-Os model age of 1648 ± 5.97 Ma. This date is considered analytically sound but the significance of it is not clear as it is believed to cut the *ca.* 1595 Ma breccia. Step heating ^{40}Ar-^{39}Ar analyses carried out on muscovite from Wernecke Breccia matrix, a syn-breccia vein and two late-stage veins yielded dates of 1178.0 ± 6.1, 1135.0 ± 5.5, 1052 ± 10 and 996.7 ± 8 Ma respectively. These dates are significantly younger than the minimum age (*ca.* 1380 Ma) of Wernecke Breccia indicated by cross-cutting relationships and must have been reset. Samples submitted for U-Pb and Pb-Pb analyses gave discordant results that cannot be used to constrain the age of Wernecke Breccia or Wernecke Supergroup.

Fluids that formed Wernecke Breccia were hot (185-350 ^{o}C), saline (24-42 wt. % NaCl eq.) NaCl-$CaCl_2$ brines. Isotopic compositions for hydrothermal minerals range from: $\delta^{13}C_{carbonate} \approx -7$ to +1 ‰ (PDB), $\delta^{18}O_{carbonate} \approx -2$ and 20 ‰ (SMOW), $\delta^{34}S_{pyrite/chalcopyrite} \approx -13$ to +14 ‰ (CDT) and $\delta^{34}S_{barite} \approx 7$ to 18 ‰. Calculated $\delta^{18}O_{fluid} \approx$ -8 to +14 ‰ The isotopic compositions indicate fluids were likely derived from formation/metamorphic water mixed with variable amounts of organic water ± evolved meteoric and/or evolved seawater. Metals and sulphur were probably derived from host strata and fluids circulated via tectonic (and/or gravity) processes. Magmatic waters are considered less likely as a fluid source because the isotopic data do not have a magmatic signature and mafic to igneous rocks spatially associated with the breccia are significantly older (i.e. *ca*. 1710 vs. 1600 Ma) thus ruling out a genetic connection. This suggests IOCG mineralisation can occur in non-magmatic environments and a division of the broad IOCG class into magmatic and non-magmatic end-members, with hybrid types in between, is suggested that reflects the involvement of magmatic and non-magmatic fluids. Wernecke Breccia and Redbank are representative of non-magmatic end-members, Lightning Creek is a magmatic end-member and hybrid types include Ernest Henry and Olympic Dam.

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Reaction used	**Equation**	**Log K**
Pyrite-Magnetite:	$3\ FeS_2 + 2\ O_{2(g)} = Fe_3O_4 + 3\ S_{2(g)}$	-4.6
Pyrite-Hematite:	$4\ FeS_2 + 3\ O_{2(g)} = 2\ Fe_2O_3 + 4\ S_{2\ (g)}$	33.88
Pyrrhotite-Magnetite:	$6\ FeS + 4\ O_{2(g)} = 2\ Fe_3O_4 + 3\ S_2$	55.34
Bornite-Chalcopyrite:	$Cu_5FeS_4 + 4\ FeS_2 = 5\ CuFeS_2 + S_2$	83.64
Graphite-CO2(g):	$C + O_{2(g)} = CO_{2(g)}$	-6.93
Calcite-gypsum:	$2\ CaCO_3 + S_{2(g)} + 3\ O_{2(g)} + 4\ H_2O = 2\ CaSO_4 + 2\ CO_{2(g)}$	36.13

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$\delta S^{34}{}_{\Sigma S}$ = 18 ‰(left side). The shaded oval shows approximate fluid conditions at Slab. The position of sulphur isotope contours were calculated using the method of Ohmoto (1972) and the following conditions: temperature = 300 °C, pressure = 2.5 kb, ionic strength = 3.2 (based on fluid inclusion data). Molality of species was calculated using the programme "The Geochemists Workbench"® release 4.0.2; the following species were most abundant.

Species	**Molality**	**Mole Fraction**
$NaSO_4^-$	0.6985	0.497
$CaSO_4$(aq)	0.3741	0.266
KSO_4^-	0.165	0.117
SO_4^{--}	0.1623	0.115
H_2S(aq)	2.51E-03	0.002
HSO_4^-	1.54E-03	0.001
HS^-	1.30E-03	0.001

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