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Characteristics and Evolution of the Hydrothermal Fluid in the North Zone High-Grade Area, Porgera Gold Deposit, Papua New Guinea

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Abstract

The ~20-million-ounce (Moz) Porgera gold deposit, Papua New Guinea, is hosted by 6-m.y.-old alkalic intrusions and Cretaceous sedimentary rocks in which the intrusions were emplaced. Gold-bearing veins occur in three stages: (1) magnetite-sulfide-carbonate ± quartz veins with minor gold (prestage I), (2) base metal-sulfide-carbonate ± quartz ± Au veins (stage I), and (3) quartz-roscoelite-pyrite-gold veins and breccias (stage II). Stage II veins are economically the most significant.

Quartz-roscoelite-pyrite-gold veins form high-grade zones associated with the Roamane fault (a late normal fault that crosscuts the intrusive complex) and in the footwall to the fault (the North zone). The North zone mineralization is the main focus of this study. The quartz-roscoelite-pyrite-gold assemblage occurs in three texturally distinct styles: (1) thin (1–5 mm) veinlets in which roscoelite-pyrite-gold are more abundant than quartz and in which roscoelite and gold also occur in the wall rock; (2) veins (5 mm to 10 cm) in which roscoelite-pyrite-gold with minor quartz form a band at the vein edges, followed by coarse-grained quartz and the vein centers commonly filled with anhydrite and carbonate; and (3) breccia veins and breccias in which wall-rock fragments are rimmed by roscoelite-pyrite-gold and minor quartz, followed by vuggy quartz infilling.

Fluid inclusions from quartz in these veins and breccias are mostly liquid rich, and average salinities in individual samples range from 7.5 ± 1.0 to 9.6 ± 0.2 wt percent NaCl equiv. In five of 27 samples, an additional cluster of salinities between 4.4 and 6.2 wt percent NaCl equiv was observed. These relatively low salinity inclusions occur toward the vein center and are less abundant than high-salinity inclusions that occur toward the vein margins. Three samples exhibit a continuous salinity trend from 4.5 to 10.2 wt percent NaCl equiv. For samples where CO₂ analyses were available average corrected salinities range from 5.1 to 8.0 wt percent NaCl equiv. Average homogenization temperatures (T_h) of individual samples range from $127^\circ \pm 12^\circ$ to $167^\circ \pm 25^\circ$ C. The average T_h of the low-salinity inclusions ($145^\circ \pm 9^\circ$ C) is marginally lower but overlaps with that of all high-salinity inclusions ($152^\circ \pm 17^\circ$ C).

Gas chromatographic analyses showed that the high-salinity fluid contains up to 2 mol percent CO₂, 0.11 mol percent CH₄, 0.065 mol percent N₂, and traces of C₂H₄, C₂H₆, and COS. Concentrations of Cl⁻ (310–609 mM/l), Br⁻ (0.28–0.75 mM/l), Li⁺ (1.25–8.80 mM/l), Na⁺ (462–1126 mM/l), K⁺ (0–81 mM/l), Mg²⁺ (0–7.0 mM/l), and Ca²⁺ (0–185 mM/l) were determined by ion chromatography.

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The $\delta^{18}\text{O}$ values of quartz range from 13.9 to 18.3 per mil, and calculated $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ values range from -1.2 to 4.1 per mil. The $\delta\text{D}_{\text{H}_2\text{O}}$ values lie between -77 and -52 per mil. The calculated isotopic composition of the hydrothermal fluid lies between that of magmatic and that of meteoric water. The $\delta^{18}\text{O}$ values of carbonates range from 15.2 to 16.6 per mil. Carbon isotopes were analyzed on carbonates ($\delta^{13}\text{C} = -3.3$ to -2.4‰), altered and unaltered sedimentary rocks (-5.4 to -4.0 and -1.5 to 0.0‰ , respectively), and organic carbon in shales (-23.6 to -16.8‰). The $\delta^{34}\text{S}_{\text{pyrite}}$ values range from -9.4 to 6.1 per mil, and $\delta^{34}\text{S}_{\text{anhydrite}}$ values range from 12.4 to 17.5 per mil.

The petrographic and analytical results suggest that an ascending fluid interacted with the sedimentary rocks and/or fluid hosted by the sedimentary rocks at depth (rather than at the site of ore deposition). This interaction is suggested by the presence of organic-derived volatiles and high NH_4^+ concentrations in inclusion fluid. In some samples, two fluids were involved in stage II vein formation. Vapor-rich fluid inclusions indicate that the hydrothermal fluid boiled locally, and continuous salinity trends suggest that fluid mixing occurred in some stage II veins.

The analytical data and paragenetic information were used to estimate element concentrations in the Porgera hydrothermal fluid that were used for thermodynamic reaction path modeling using the software CHILLER. This fluid was subjected to boiling, mixing with sedimentary formation water, cooling, and fluid-rock reaction. During boiling, quartz, pyrite, gold, and K-feldspar formed; mixing resulted in the deposition of pyrite, gold, and mica; reaction with diorite produced the observed wall-rock alteration assemblage; and cooling formed quartz plus minor mica, pyrite, gold, and kaolinite.

Observations, analytical data, and modeling results suggest that more than one process was involved in stage II vein formation in different locations and at different times. Boiling, mixing, and fluid-rock reaction, all accompanied by cooling, occurred intermittently over the entire depth extent of the North zone, and the size of Porgera may be a result of all of these processes occurring at the deposit.