



A fluid inclusion and stable isotope study of the Pebble porphyry copper-gold-molybdenum deposit, Alaska



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ABSTRACT

The hydrothermal fluid evolution in the supergiant Pebble porphyry Cu-Au-Mo deposit in southwest Alaska has been constrained using fluid inclusion and light stable isotope data. The deposit is related to ~90 Ma granodiorite porphyry intrusions and mineralization occurs primarily in sodic-potassic, potassic, and advanced argillic alteration zones.

Throughout the deposit vein quartz hosts intermediate-density fluid inclusion assemblages with an average salinity of 9.5 wt% NaCl equivalent and homogenization temperatures of 377 to 506 °C. Pressure corrections result in trapping temperatures with a maximum of 610 °C. This early fluid exsolved from a crystallizing magma at depth and underwent phase separation under varying conditions during cooling and depressurization forming two distinct fluid compositions. The two fluids formed two hydrothermal alteration assemblages which have different metal signatures. In the hydrothermal core in the eastern part of the system, high-density quartz veins, potassic alteration and the most economically significant mineralization are related to ~52 wt% NaCl equivalent brines that coexist with very low-density vapor. In the western part of the system peripheral to the hydrothermal core, lower quartz vein densities accompanied by sodic-potassic alteration and lower grade mineralization are associated with ~38 wt% NaCl equivalent brines and low-density vapor. Sulfide mineralization precipitated late in this early alteration event at temperatures between 375 and 330 °C.

Fluids related to sodic-potassic alteration minerals have $\delta^{18}\text{O}$ signatures from +6.0 to +10.5‰ VSMOW and δD values from -70 to -41‰ VSMOW, which are consistent with a magmatic fluid source. Fluids related to potassic alteration assemblages have $\delta^{18}\text{O}$ of -1.7 to +2.3‰ VSMOW and δD of -68 to -59‰ VSMOW, which suggests that the magmatic fluids evolved to lighter oxygen isotope signatures due to quartz precipitation during alteration.

Lower temperature (~280 °C) sericite and illite alteration followed the high-temperature magmatic stage and formed from the rising vapor plume as it mixed with varying amounts of meteoric fluid. Sericite in quartz-sericite-pyrite alteration on the periphery of the deposit and illite from areas of illite \pm kaolinite alteration which overprints sodic-potassic alteration and forms quartz-illite-pyrite alteration within the deposit are related to low-salinity aqueous fluids that have a significant magmatic component (+2.1 to +4.1‰ $\delta^{18}\text{O}$ and -76 to -67‰ δD). Illite alteration which overprints both potassic alteration and quartz-sericite-pyrite alteration formed from fluids with a large meteoric component (-9.1 to -4.8‰ $\delta^{18}\text{O}$ and -101 to -90‰ δD). The higher vein density and therefore higher permeability in the core of the deposit facilitated ingress of larger amounts of meteoric fluid compared with the more peripheral region.

Advanced argillic alteration and associated high-grade mineralization are related to a second pulse of magmatic fluid which did not intersect the two phase field during cooling and depressurization. The fluid contracted to form a 3 wt% NaCl equivalent aqueous fluid that resulted in a sericite-pyrite-bornite-digenite bearing assemblage with a magmatic signature (4.6 to 6.5‰ $\delta^{18}\text{O}$ and -108 to -102‰ δD) at 340 °C. Cooling and mixing of this fluid with meteoric water resulted in a fluid that formed a pyrophyllite-quartz-sericite-chalcocopyrite bearing assemblage (-8.9 to -0.6‰ $\delta^{18}\text{O}$ and -110 to -96‰ δD) at 300 °C. Compared to older potassic and sodic-potassic alteration, the advanced argillic alteration has a highly depleted δD signature which is attributed to degassing of a crystallizing intrusive fluid source.

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1. Introduction

The Pebble porphyry Cu-Au-Mo deposit is located in southwest Alaska (Fig. 1A) and is one of the world's largest concentrations of

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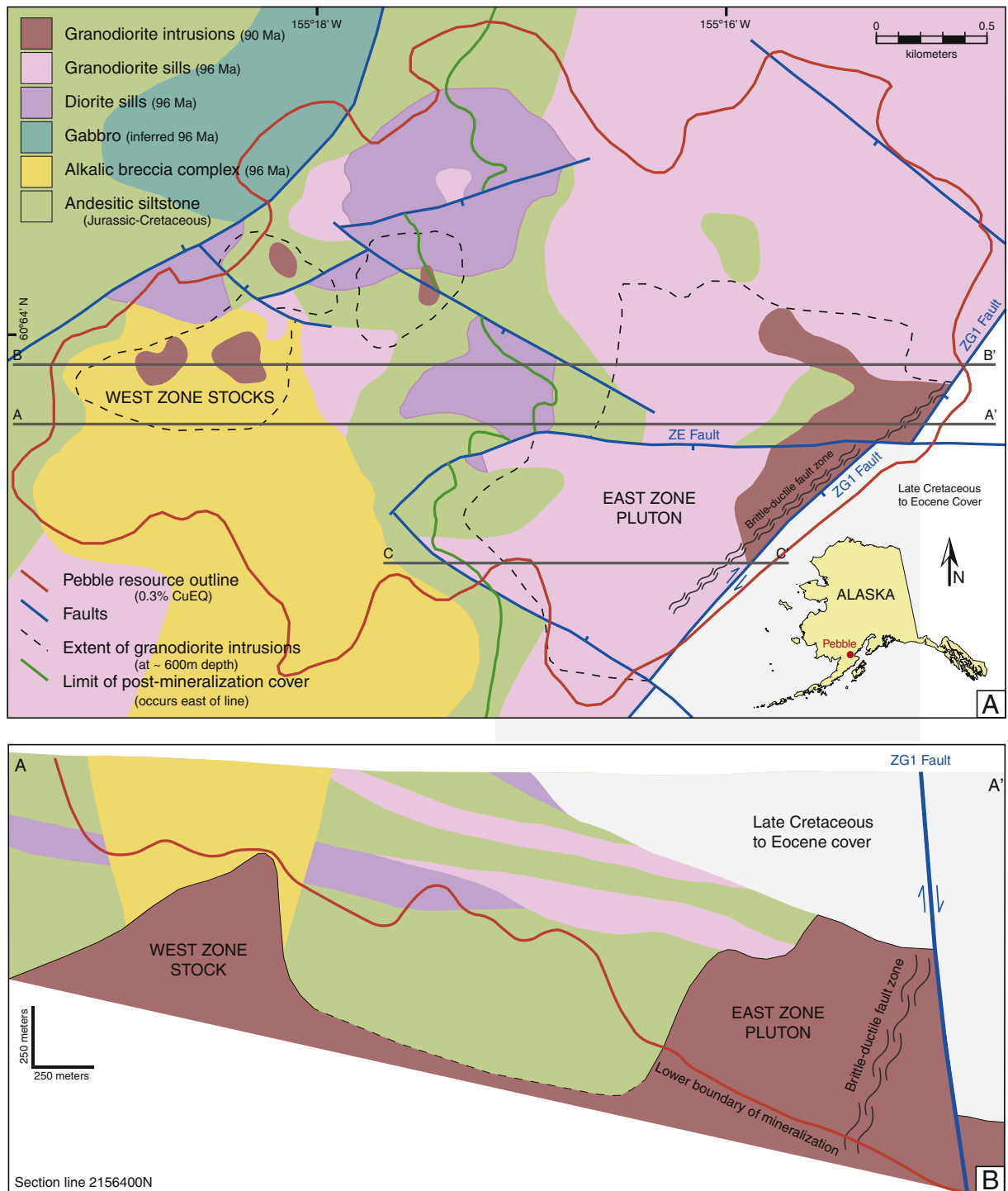


Fig. 1. Geology of the Pebble porphyry Cu-Au-Mo deposit. A. Simplified Cretaceous geology map of the deposit area based on drilling. Glacial deposits and post-mineralization rocks units have been removed. B. Geological cross section along line A–A'. CuEQ expresses the combined copper, gold and molybdenum grade as a copper grade based on the dollar value of all the metals (Cu - US\$1.85/lb., Au - US\$902/oz., Mo - US\$12.50/lb.; Pebble Limited Partnership, 2010).

metals. The deposit contains 36.6 million tonnes of copper, 3341 tonnes of gold and 2.5 million tonnes of molybdenum (Pebble Limited Partnership, 2010). Its gold endowment alone is among the largest of all deposits on earth (Sebag, 2012). The deposit is genetically related to ca. 90 Ma granodiorite intrusions and mineralization is hosted by diverse types of hydrothermal alteration assemblages that include sodic-potassic, potassic, illite ± kaolinite, quartz-illite-pyrite, quartz-sericite-pyrite, and advanced argillic assemblages (Lang and Gregory, 2012; Gregory et al., 2013; Lang et al., 2013).

This study uses fluid inclusion and stable isotope data to unravel the fluid history of the Pebble deposit. A particular focus of the study is the relationship of advanced argillic alteration, which is associated with the highest grades of copper and gold in the deposit, to other alteration types and their fluid sources. There is an increasing recognition that advanced argillic alteration and associated mineralization occur in the deeper parts of porphyry deposits (e.g., Oyu Tolgoi, Khashgerel et al., 2009) in addition to longer-recognized occurrences in the epithermal or lithocap environment (e.g., Hedenquist et al., 1998). Advanced

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