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Nature of Hydrothermal Fluids at the Shale-Hosted Red Dog Zn-Pb-Ag Deposits, Brooks Range, Alaska

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Abstract

The Red Dog Zn-Pb-Ag district in the western Brooks Range, northern Alaska, contains numerous shale-hosted Zn-Pb sulfide and barite deposits in organic-rich siliceous mudstone and shale, chert, and carbonate rocks of the Carboniferous Kuna Formation. The giant Red Dog shale-hosted deposits consist of a cluster of four orebodies (Main, Qanaiyaq, Aqqaluk, and Paalaaq) that lie within distinct thrust panels that offset a single ore deposit during the Mesozoic Brookian orogeny. These Zn-Pb-Ag-barite orebodies contain one of the world's largest reserves and resources of zinc.

Fluid inclusions in samples of vein sphalerite, which accounts for about 20 percent of the ore in the Main deposit, and quartz that composes the bulk of the extensive silicification in the ore deposit, were studied by microthermometry, Raman spectrometry, and ion chromatography. The study of fluid inclusions in the vein sphalerite was limited by the intense postore deformation of the ore deposits. However, four primary aqueous fluid inclusion assemblages in vein sphalerite yield temperatures of homogenization of 115° to 120°C, 123° to 127°C, 110° to 120°C and 175° to 180°C. More abundant final-melting temperatures indicate that the fluid inclusions in sphalerite have salinities of about 14 to 19 wt percent NaCl equiv. The fluid inclusion electrolyte data show that the ore fluid responsible for the vein sphalerite derived its salinity from the evaporation of seawater. Considering the salinity of the fluid inclusions together with the electrolyte data, it is possible that the evaporative brine was initially about 30 wt percent saline fluid and that it mixed with a more dilute fluid somewhere along its flow path. The temperature, salinity, and electrolyte composition of vein sphalerite in the Red Dog deposits are remarkably similar to those characteristics in sphalerite veins near the Century zinc deposit, Australia. Together, these data compose the majority of information on the temperature and composition of sphalerite in deposits of this type.

On the basis of data describing fluid inclusions in sphalerite and the geologic setting of the ore deposits, a "reflux brine" model is suggested for the Red Dog deposits. In this model, brines were produced in evaporative environments in supratidal carbonate facies of the Lisburne Group less than 100 km from the Red Dog deposits. These reflux brines may have infiltrated the underlying rocks of Endicott Group or fractured metasedimentary basement rocks. In the absence of a local heat source at the Red Dog deposits, the temperature of the ore fluids (~100° to <200°C) requires that the fluids circulated at depths between ~ 2.4 and 7.4 km.

In the Red Dog area, the metalliferous fluids ascended into the organic-rich rocks of the Kuna Formation, probably along zones of active extensional faults or breaches in the shale aquitards overlying the aquifers in the Endicott Group. Fluid inclusions were also studied in the abundant quartz that constitutes the majority of the silica rock in the ore deposits. This postore quartz extensively replaced barite and was traditionally thought to be part of the main ore event. Primary fluid inclusion assemblages contain two-phase aqueous inclusions, single-phase inclusions of dense methane, or both. Primary assemblages that contain single-phase, dense-methane inclusions together with two-phase aqueous inclusions yield consistent homogenization temperatures that provide unequivocal evidence for the coeval trapping of immiscible gas and aqueous fluids.

The densities of the methane inclusions, together with the temperature of homogenization of coexisting aqueous fluid inclusions, show that these fluid inclusions were trapped between pressures of 800 and 3,400 bars and temperatures between 187° and 214°C. The pressures obtained provide unequivocal evidence that the quartz formed after ore deposition in the Carboniferous because such high fluid pressures could only have been produced from thrust loading during the Mesozoic Brookian orogeny. The observed large variation in pressure is best explained by transient fluid pressures from hydrostatic to lithostatic conditions during thrust loading. The 3,400 bars pressure corresponds with about 12 km of lithostatic burial, whereas the lower pressures (800 bars) correspond with about 8 km of hydrostatic pressure. Because of their low salinity (0–5 wt % NaCl equiv) the electrolyte compositions of the quartz fluid inclusions do not constrain their origin.

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