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Paleozoic Sedimentary Rocks in the Red Dog Zn-Pb-Ag District and Vicinity, Western Brooks Range, Alaska: Provenance, Deposition, and Metallogenic Significance

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Abstract

Geochemical analyses of Paleozoic sedimentary rocks in the western Brooks Range reveal a complex evolutionary history for strata surrounding the large Zn-Pb-Ag deposits of the Red Dog district. Data for major elements, trace elements, and rare earth elements (REE) were obtained on 220 samples of unaltered and unmineralized siliciclastic rocks from the Upper Devonian-Lower Mississippian Endicott Group (Hunt Fork Shale, Noatak Sandstone, Kanayut Conglomerate, Kayak Shale), the overlying Carboniferous Lisburne Group (Kuna Formation, unnamed drowned shelf facies), and the Pennsylvanian-Permian Siksikpuk Formation. Major base metal sulfide deposits of the region are present only in the Kuna Formation, which in the Red Dog district comprises siliceous black shale and black chert, minor limestone (calcareous radiolarite), and sparse lithic turbidite and bedded siliceous rock. Gray and rare black shales of the Kayak Shale and common black shales of the Kuna Formation are anomalously low in iron (avg Fe/Ti = 6.25 and 6.34, respectively) relative to other Paleozoic shales in the region (9.58–10.6) and to average shales worldwide (10.1–10.5). In contrast, the bedded siliceous rocks contain appreciable hematite (avg Fe/Ti = 35.0) and high U/Ti and REE/Ti ratios that are interpreted to reflect low amounts of detrital material and a major Fe-rich eolian component.

Geochemical data (e.g., MnO <0.01 wt %; avg Cr = 317 ppm), sizes of framboidal pyrite grains, and limited bioturbation suggest anoxic and denitrifying depositional conditions for most black shales of the Kuna Formation; low Mo/Ti ratios argue against euxinic (sulfate-reducing) conditions. Organic-rich black shales of the Kuna Formation with up to 8.4 wt percent $C_{organic}$ and gray to black shales of the Kayak Shale with up to 4.1 wt percent $C_{organic}$ typically have only sparse pyrite (<1 wt % S) and very low iron-limited S/C ratios (mostly <0.2). Immobile element plots (e.g., Th-Zr/10-Sc) suggest that source terranes for all of the formations were dominated by one or more felsic-rich continental arcs; a small proportion of recycled sediments is present locally. A minor mafic igneous component also occurs in several shales of the Kuna and Siksikpuk Formations. High average values for the chemical index of alteration $[Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O)] \times 100$ for shales of the Endicott Group (76.4–81.5) imply moderate to intense chemical weathering in source areas of these sediments. A lower average for black shales of the Kuna Formation (73.7) does not require such weathering.

Textural and geochemical data record the effects of diagenetic and/or hydrothermal fluid flow in some of the Paleozoic rocks. Mobility of P, F, U, and light REE is documented in black shales of the Kuna Formation by phosphate replacements of carbonate clasts and of matrix material surrounding the clasts. A relatively low average Ce/Ce* value of 0.73 for P-poor black shales of the Kuna Formation (≤0.05 wt % P_2O_5) and a similar Ce/Ce* value of 0.78 for a siderite concretion in Kayak Shale suggest that these diagenetic fluids were oxidizing. Many shales of the Kuna Formation have high $(K_2O \times 100)/(K_2O + Al_2O_3)$ ratios of 21.0 to 23.0, which contrast with low ratios of generally <18.0 for shales of the underlying Endicott Group. The high ratios in shales of the Kuna Formation reflect preferential reaction of smectite to illite during the Jurassic-Cretaceous Brookian orogeny, owing to high silica activities in pore fluids that were generated by the dissolution of abundant biogenic silica.

The distribution and composition of Paleozoic strata in the western Brooks Range may have played a fundamental role in Zn-Pb mineralization of the Red Dog district. In our model, deposition and early lithification of biogenic chert and bedded siliceous rocks in the upper part of the Kuna Formation served as a regional

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hydrologic seal, acting as a cap rock to heat and hydrothermal fluids during Late Mississippian base-metal mineralization. Equally important was the iron-poor composition of black shales of the Kuna Formation (i.e., low Fe/Ti ratios), which limited synsedimentary pyrite formation in precursor sediments, resulting in significant H_2S production in pore waters through the interaction of aqueous sulfate with abundant organic matter. This H_2S may have been critical to the subsurface deposition of the huge quantities of Zn and Pb in the district. On the basis of this model, we propose that low Fe/Ti and S/C ratios in black shale sequences are potential basin-scale exploration guides for giant sediment-hosted, stratiform Zn-Pb-Ag deposits.