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Genesis of polymetallic hyper-enriched black shale mineralization in the northern Canadian Cordillera

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Polymetallic (Ni-Mo-Zn-Pt-Pd-Au-Re) hyper-enriched black shale (HEBS) mineralization in the northern Cordillera of northern Yukon and northeastern British Columbia consists of thin (3–10 cm), semi-massive sulfides interbedded with black shale. High-grade mineralization contains up to 7.4 wt.% Ni, 2.7 wt.% Zn, 0.38 wt.% Mo, 400 ppb Pt, 250 ppb Pd, 160 ppb Au and 58.5 ppm Re. The HEBS in northern Yukon was studied at the Nick, Peel River, Monster River and Moss localities. Mineralization discontinuously outcrops at the regional stratigraphic contact between the black shales of the Road River Group and Canol Formation in a geographically widespread area within the Richardson and Blackstone troughs. The sulfide mineral paragenesis, similar for all localities, was protracted, initiated during syngensis to earliest diagenesis and persisted into later diagenesis. Laser ablation-inductively coupled plasma-mass spectrometric (LA-ICP-MS) analyses indicates that pyrite is the principal host of platinum group elements (PGE), Au and Re. These (and other) metals are hosted in framboidal, nodular and cryptocrystalline pyrite, and these textural varieties reflect diagenetic precipitation. Ni sulfide minerals host subordinate amounts of these metals. Rhenium-Os geochronology of HEBS at Nick and Peel River indicate the age of mineralization is 390.7 ± 5.1 and 387.3 ± 4.4 Ma, respectively. These ages overlap with biostratigraphically constrained ages of the sedimentary host rocks, indicating that mineralization and sedimentation were coeval. Together with the LA-ICP-MS data, this suggests minimal remobilization or resetting occurred after sulfide precipitation. The bulk sulfur isotope composition of HEBS is uniformly negative ($\delta^{34}\text{S} = -29$ to -10‰), indicating that bacterial sulfate reduction generated reduced sulfur to precipitate sulfide minerals. The high S contents and low negative sulfur isotope compositions of the HEBS imply long-lived sulfate reduction in an environment with ample sulfate and labile organic matter. The sulfate was most likely sourced from ambient seawater, and the organic C most likely originated from high degrees of biological productivity. The initial Os ratios at Peel River (0.25 ± 0.07) and Nick (0.32 ± 0.20) overlap with Middle Devonian seawater and continent-crust normalized PGE patterns are similar to modern seawater, and collectively these suggest that the metals were derived from seawater. Shale-normalized U and Mo ratios suggest that ferromanganese oxyhydroxide particulates scavenged metals from seawater and shuttled them to the seafloor to be deposited as a chemical sediment. Paleogeographic and eustatic sea level reconstructions suggest that this occurred in a favorable basinal environment that underwent periodic restriction. We hypothesize that this confluence of ideal paleoenvironmental conditions facilitated HEBS formation in combination with organic matter remineralization and reductive dissolution (and precipitation as sulfides) of hydrogenous ferromanganese particles supplied sulfur and metals, respectively.