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Making a black shale shine: the interaction of hydrothermal fluids and diagenetic processes

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Hydrothermal fluids are important agents of mass and thermal transfer in the upper crust. This is exemplified by shale-hosted massive sulphide deposits (SHMS), which are anomalous accumulations of Zn and Pb sulphides (± barite) in sedimentary basins created by hydrothermal fluids. These deposits occur in passive margin settings and, typically, there is no direct evidence of magmatic input. Recent studies of Paleozoic deposits in the North American Cordillera (MacMillan Pass and Red Dog Districts) have shown that the deposits are formed in a sub-seafloor setting, where the potential for thermal and chemical gradients is high. Mineralization is characterized by the replacement and displacement of unconsolidated, partially lithified and lithified biosiliceous mudstones (± carbonates), and commonly the sulphide mineralization post-dates, and replaces, bedded barite units in the sediments.

The Red Dog District (Alaska, USA) contain some of the largest Zn-Pb deposits ever discovered. The host-rocks are dominantly carbonaceous mudstones, with carbonate units and some radiolarites. The ore forms massive sulphide bodies that replace pyritized mudstones, barite and carbonate units. Lithological and textural relationships provide evidence that much of the ore formed in bioturbated, biosiliceous zones that may have had high primary porosity and/or permeability. Sediment permeability may have been further modified by aging of the silica rich sediments and the dissolution/replacement of carbonate and barite beds.

At the Tom and Jason deposits (MacMillan Pass, Yukon) the fault-controlled hydrothermal upflow zone is uniquely preserved as an unequivocal vent complex. Here, the metal bearing fluids are hot (300°C), low salinity (6 wt% NaCl equiv.) and acidic (pH < 4.5). These fluids were initially in thermal and chemical disequilibrium with a partially lithified organic rich host-rock but cooled rapidly during fluid rock interaction and the input of diagenetic pore fluids.

Paragenetically-constrained sulphur isotope analyses provide evidence that at MacMillan Pass and in the Red Dog deposits, reduced sulphur was generated during open system diagenesis and euxinic conditions were not present at the time of mineralization. Furthermore, the formation of diagenetic barite provided an important mechanism of sulphur concentration into the host rock. Both features combined to produce an effective metal trap in the sub-surface.

Ultimately, interactions between hydrothermal and diagenetic fluids within a permeable, chemically reactive medium contribute to the formation of SHMS deposits. Where these factors align, it is possible to produce world-class ore deposits (e.g. in the Red Dog district). The complex textures that are commonly encountered in these systems are the result of hydrothermal fluids interacting with their host-rocks in a heterogeneous and dynamic physical and chemical environment.