Of heavy metal, microbes, and phosphate: rock of the Ypresian Age (Early Eocene Climate Optimum) illustrates natural processes of metal sequestration from an ancient intermontane lake

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Organic-rich mudstone (ORM, or 'oil shale') is a fossil fuel that typically contains abundant heavy metals associated with organic matter in fine-grained sediments often deposited in lakes. When burnt it is notorious for producing copious waste that can end up polluting soil and water resources. Detailed investigation of how, when, and in what form the metal accumulated with the organic matter in ancient lakes (to produce oil shale) can provide a better understanding of (1) how industry might mitigate against producing such waste should the ORM be burnt, and (2) how naturally polluted lakes in the geologic record were able to sequester such heavy metals for millions of years, indicating ways modern polluted lakes might be effectively remediated.

The Green River Formation (GRF) of Utah and Colorado, USA, hosts the world's largest oil shale resource, which was deposited in ancient lakes during greenhouse-earth conditions of the Ypresian Age (Early Eocene). Previous analysis of ORM from the upper GRF in the Uinta Basin has recorded, in a few beds only, enrichments of numerous toxic trace metals within phosphatic intervals, including rare-earth elements (REE), W, Hg, Th, and U. In all cases the rock contains microscopic globules of Carbonate Fluor-Apatite (CFA), which can be interpreted as the fossilized remains of substrate microbes. While phosphorus (P) is essential to and present in all life, certain microbes, such as the sulfate-reducing bacteria and sulfur-oxidizing bacteria, respectively are known to utilize W in their metabolism, and store P. Environmental change triggered by earthquakes and slumps, or dropping lake levels, during or following some episodes of ORM deposition, may have resulted in mass mortality of the microbes. Microbial decay would then release P into sediment pore waters potentially to reach supersaturation and precipitate as CFA-cemented horizons in the ORM prior to significant compaction. The CFA may fossilize the microbes, incorporating any W that was present, and encapsulate other early-formed diagenetic sulfides such as HgS. The CFA crystal lattice also is sufficiently flexible to incorporate substitutions of Ca by REEs, Th, and U that diffused from reducing pore waters into the cemented horizons.

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