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Sedimentary trends in rare earth element enrichment in Cretaceous coal-bearing strata, Utah and Colorado, U.S.A.: geochemical processes and assessment methods

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Rare earth elements (REE) are used in technology products and are necessary for global development and the energy transition. Coal deposits and coal-related material have been identified as a prospective REE and critical mineral mining source. However, the geologic trends and controls on REE-enrichment in coal-bearing strata remain largely unquantified. A comprehensive geochemical and stratigraphic study of Cretaceous bituminous coal-bearing strata in central Utah and western Colorado was performed to evaluate geologic trends in REE-enrichment, as well as elucidate enrichment mechanisms. Portable X-ray fluorescence (pXRF) (n = 6424 analyses) was combined with Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (n = 222 analyses) to quantify REE enrichment. Sampling and geochemical analyses from 32 mine, cored exploration wells, and outcrop localities from the Ferron Sandstone and Blackhawk Formation in Utah and the Mesaverde Group of Colorado were performed with an emphasis on lithologic, stratigraphic, and geographic context. A systematic assessment of precision of REE quantification using pXRF and ICP-MS on a subset of 230 samples was performed, based on statistical similarity tests applied to various methodological approaches. Precision between pXRF and ICP-MS-based REE quantification is encouraging. REE-enrichment (> 200 ppm) is most commonly found in mudstone units overlying, underlying or within coal zones, with a strong preference of REEs in claystone sublithologies. Coal lithologies are generally not REE-enriched, with notable exceptions. Coals that are REE-enriched exhibit lower coal quality (i.e., dull and brown colored bituminous coals). Additional petrography combined with scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) reveal silt-size detrital monazite grains, as well as clay-size REE-enriched domains in the matrix and organic matter. REE-enrichment results from a combination of paleo-depositional and diagenetic mechanisms. These geologic trends can be used as a REE resource prediction tool, particularly in bituminous coal-bearing successions worldwide. We also provide recommended coupled pXRF and ICP-MS approaches for quantifying REE in sedimentary systems broadly.