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Molybdenum Enrichment and Redox Dynamics in Carboniferous Black Shales: Insights from the Fethiye-Muğla Area (western Taurides of Turkiye)

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The element molybdenum (Mo) has a significant economic value with a low supply risk and has been increasingly utilized in various industrial applications such as high-strength steel alloys, petroleum refining catalysts, and aerospace in recent years. This study investigates the enrichment mechanism, geochemical behavior, and characterizing the depositional processes of Mo within the Carboniferous black shales in the Fethiye-Muğla area (western Taurides of Turkiye). The geochemical analysis were conducted on outcrop black shale samples using X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS). The Mo concentrations in these shales have a wide range, varying from 35 to 115 ppm. Redox-sensitive trace element ratios, including V/Ni, V/Sc, Mo/Mn, Ni/Co, and U/Th, suggest deposition occurred in a shallow marine environment on a continental slope under suboxic conditions. In such environments, Mo remains in solution but interacts with Fe-Mn oxides and organic matter. In suboxic marine settings, Mo predominantly exists as the soluble molybdate ion (MoO_4^{2-}). However, in the presence of hydrogen sulfide (H_2S), typical of euxinic conditions, molybdate transforms into thiomolybdate species (MoS_4^{2-}), facilitating its precipitation and incorporation into sediments, often associated with pyrite formation. This transformation underscores the sensitivity of Mo to redox fluctuations. In the study area, even minor variations in oxygen levels had a significant impact on organic matter preservation and the behavior of redox-sensitive elements. In addition, the moderate to high positive correlation of Mo vs. total organic carbon (TOC) (R^2=0.54), Ni (R^2=0.55), V (R^2=0.62), and U (R^2=0.70) crossplots and the lack of correlation of Mo vs. Al, Fe, Mn mean that Mo enrichment and elevated organic matter flux were controlled by oxygen drawdown in depositional setting. These findings indicate that Mo enrichment is closely linked to organic matter flux and is primarily controlled by oxygen depletion in the depositional environment. Based on these observations, a geochemical model elucidating the redox-controlled mechanisms governing Mo behavior in these shales has been developed. This model enhances our understanding of Mo cycling in ancient marine environments and provides insights into the conditions that favor Mo enrichment in sedimentary records.