The Natural Enrichment of Phosphatic Sediments: Insights from the Moroccan High Atlas Phosphate Series

Radouan El Bamiki[1], Michel Séranne[2], Fleurice Parat[2], Jérémie Aubineau[2], El Hassane Chellai[3], Mohamed Marzoqi[3], Jean-Louis Bodinier[1, 2]
1. Mohammed VI Polytechnic University, Benguerir, Morocco, 2. University of Montpellier, Montpellier, France, 3. Cadi Ayyad University, Marrakesh, Morocco

Sedimentary phosphates are the major source of phosphorus and a potential source of critical metals such as rare earth elements (REEs). Sedimentary phosphates are non-renewable resources and witness an extremely increasing global demand. It is, therefore, critical to focus a lens on exploring new phosphate ores as part of many other proactive strategies to tackle a possible phosphate scarcity. In this study, we combine sedimentology, sequence stratigraphy, and geochemistry to explore the Upper Cretaceous-Paleogene sedimentary series of the High Atlas in Morocco. The sedimentological investigation revealed the occurrence of four genetically-linked lithofacies derived from a pristine phosphate by storm waves and bottom currents hydrodynamic differentiation, giving rise to winnowed phosphate, phosphatic lags, and karst-filling phosphate. The main phosphatic mineral in all lithofacies is carbonate fluorapatite (CFA), with 8.40 ± 0.37 wt % CO_3^{2-}. The sequence stratigraphic analysis indicated that the phosphate series of the High Atlas deposited during a second-order relative sea-level cycle, and phosphate layers preferentially accumulated at the base of the high stand systems tract and the base of the transgressive systems tract. Although some lithofacies have experienced a polyphase evolution, by winnowing, submarine reworking, transport, and subaerial weathering, CFA has resisted chemical changes and preserved its original geochemical signature, specifically an REE signal that reflects oxic seawater conditions. However, the differentiation processes triggered the oxidation of organic matter and sulfides, removing associated uranium and cadmium. Conclusively, the combination of winnowing/reworking and subaerial weathering is the most effective way of the natural beneficiation of phosphate, turning low-grade pristine phosphate (P_2O_5 <12 wt %) into a high-grade granular phosphate (up to 24 wt % P_2O_5) and reducing the content of chemical elements with environmental concern. Furthermore, points of sequence stratigraphic turnarounds are primary exploration targets of phosphate-rich sediments.