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Hydrodynamics zonation controls the mineralization of the ion-adsorption type rare earth element deposits

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Ion-adsorption type rare earth element (REE) deposits are the primary source of heavy REE resources worldwide, supplying over 90% of global heavy REE products. These deposits originate from intensive chemical weathering of REE-rich granitoid and volcanic rocks under warm and humid climates and low hilly terrains. Groundwater controls weathering of REE minerals and formation of clay minerals, and serves as a crucial driving force for activation, migration, and enrichment of REEs. This study integrates geophysical, geochemical, and mineralogical methods to examine hydrologic zonation in regolith and its influence on REE mineralization. Resistivity data indicate that groundwater inside the regolith has a "multi-layer structure" with varying hydrodynamic properties. Further analysis reveals a spatially coupled distribution between the REE orebody and capillary fringe. It is proposed that REEs released from the upper regolith rapidly migrate downward through the unsaturated vadose zone and are subsequently intercepted and gradually enriched in the capillary fringe where moist content progressively rises. Additionally, the hydrodynamic zonation influences the evolution of clay minerals and iron oxides. The alternating wet and dry conditions dissolve kaolinite and significantly transform it into halloysite, leading to a sharp reduction in kaolinite abundance and structural order. Meanwhile, when the capillary fringe shifts from wet to dry condition, goethite progressively dehydroxylates to form hematite, hence increasing hematite abundance. Changes in the resistivity of the regolith, as well as the abundance and structure of clay minerals and iron oxides, can be distinguished by high-density electrical resistivity tomography (ETR) and near-infrared spectroscopy (NIRS), respectively. Therefore, combining ETR and NIRS effectively identify the hydrodynamical control on REE leaching and accumulation processes in the ion-adsorption type REE deposits, thereby expediting field exploration and ore body delineation of such deposits.