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Release Variation and Enrichment Mechanism of Mantle-Derived Helium in Hot Spring Gases, Eastern China

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Deep fluids serve as a critical link between deep Earth geodynamic processes and the surficial geological environment. Against the backdrop of Pacific plate subduction and lithospheric thinning, Eastern China exhibits pronounced geothermal anomalies and active deep degassing. Due to its unique physicochemical properties and the stark contrast between crustal and mantle isotopic signatures, helium is the most sensitive tracer for mantle-derived contributions. By systematically analyzing the geochemical characteristics of helium and its associated carrier gases in hot spring volatiles from representative geothermal areas across Eastern China, this study explores the migration patterns and enrichment mechanisms of mantle-derived helium. Our findings reveal significant spatial heterogeneity in helium isotopic compositions, with mantle-derived contributions varying drastically across different tectonic units; specifically, the Late Cenozoic volcanic zones in Northeast China exhibit exceptionally high mantle helium fractions due to direct asthenospheric degassing, while deep-seated fault systems like the Tan-Lu Fault Zone facilitate the advective transport of deep volatiles despite the absence of recent volcanism. In contrast, the Southeastern Coastal Extension Belt displays distinctive crust-mantle fluid mixing under high heat flow, with significant mantle input observed near NE-striking faults. Furthermore, the negative correlation between $CO_2/^3He$ ratios and total helium concentrations observed across almost all sampled sites. This trend indicates that the preferential removal of CO_2 through mineral carbonation during hydrothermal circulation, acts as a fundamental driver for the secondary enrichment of helium. As CO_2 is stripped from the ascending fluid phase, the relatively inert helium becomes progressively concentrated, particularly along long-distance migration pathways in fault-controlled systems. In conclusion, this study demonstrates that the geochemical signatures of mantle-derived helium in Eastern China are synergistically controlled by the intensity of lithospheric thinning, the permeability of crustal-scale faults, geothermal anomalies and the coupling processes between helium and its carrier gases. These insights provide a quantitative framework for evaluating the formation of high-concentration helium resources in tectonically active regions.



