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Radiogenic isotope systematics in iron-smelting experiment products: Toward the provenance study of ancient iron artifacts

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The invention of iron smelting by ancient societies had a significant impact on the development of human civilization. Researchers have analyzed iron artifacts, slags, and ores from archaeological contexts to understand the origins of iron metallurgy, suggesting that iron smelting began in Anatolia and the Near East during the Early to Middle Bronze Age [1]. Radiogenic isotope systematics are powerful geochemical tools for investigating the provenance of iron objects and provide important information on the spread of iron-smelting technology. A major challenge in applying isotopic methods in this field is the potential modification of isotopic compositions during smelting, making it difficult to clarify the relationships among iron products, slag, and ore. Isotopic compositions of slags reflect interaction and mixing with furnace wall clay and, if present, with any added flux material [2].

In this study, we conducted iron-smelting experiments to examine potential changes in isotopic compositions during smelting. Following Nagata et al. (2023) [3], experiments were performed in a refractory-brick furnace using limonite iron ore and charcoal. Three experiments were conducted: (1) smelting using only iron ore and charcoal; (2) smelting with the furnace walls lined with clay; and (3) smelting with limestone as a flux. The radiogenic Sr, Nd, and Pb isotopic compositions of the recovered slag and metal were compared with those of raw ore, furnace wall clay, and limestone flux. In the first experiment, the slag accumulated at the furnace base, resulting in the formation of a large single bloom. In contrast, in the second and third experiments, a portion of the slag was discharged through the tapping hole. Preliminary results suggest that the geochemical compositions of the “tapping slags” were significantly modified, likely due to interactions with wall clay or flux. Further analyses clarify which portions of the slag and metal most faithfully preserve the isotopic signature of the raw ore, providing important insights for developing strategies for the provenance analysis of ancient iron artifacts.

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