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Time of the evaporite involvement in the ore formation of the iron oxide-apatite deposit: insights from S and Sr isotopes of magmatic apatite and hydrothermal pyrite

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Iron oxide-apatite (IOA) deposits are an important source of Fe ores, characterized by large amounts of Fe oxide ores and byproducts of considerable critical mineral resources. Recent studies reveal that evaporites play a crucial role in the formation of IOA ores. However, the timing of evaporite involvement in the ore formation system is poorly understood.

The Ningwu ore district is a well-defined IOA district in eastern China, containing more than 30 IOA deposits. Four volcanic activities occurred over approximately 10 Ma (134–126 Ma) at Ningwu, and the IOA ore mineralization is associated with the second one (DWS volcanic cycle). In this study, in situ LA-MC-ICP-MS Sr and S isotopes and LA-ICP-MS trace element analysis were performed on magmatic apatite collected from IOA-related and barren volcanic cycles, and in situ LA-MC-ICP-MS S isotope analysis was performed on pyrites from different mineralization stages of the Washan large-scale IOA deposit. The elemental features of apatites imply that the volcanic cycles associated with Fe deposit formation underwent significant fluid exsolution. All four volcanic cycles have relatively high S isotope values and mantle-sourced Sr isotope values. These S and Sr isotopes in apatite, as well as the oxygen fugacity characteristics (as reflected in apatite S content, etc.), do not show a positive correlation, indicating that the high S values in apatite are not primarily due to contamination from the evaporites. The evaporites have not involved in the stage of magmatic fluid differentiation. The pyrite at each stage of the Washan deposit does not show obvious growth zonation or superimposed generations. Still, the S isotopes at different positions of the same pyrite grain vary significantly, as in the middle of the pyrite are relatively low, ranging from -0.2‰ to 3‰ in the middle part, while ranging from 8‰ to 13‰ at the edge. These indicate that evaporites were incorporated into the mineralization system at the initial stage and remained continuously involved throughout the ore-forming process.