The Role of Iron-Rich Hydrosaline Liquids in the Formation of Kiruna-Type Iron Oxide–Apatite Deposits: Evidence from Fluid Inclusions

Li-Ping Zeng[1], Xin-Fu Zhao[1], Carl Spandler[2]
[1]State Key Laboratory of Geological Processes and Mineral Resources, and School of Earth Resources, China University of Geosciences, Wuhan, China, [2]Department of Earth Sciences, The University of Adelaide, Adelaide, Australia

Kiruna-type iron oxide-apatite (IOA) deposits, an important source of iron, show close associations with andesitic subvolcanic intrusions. However, the processes of ore formation and the mechanism controlling iron concentration remain uncertain. Several genetic models have been proposed, including iron oxide or sulfate (- carbonate) melts formed via magma immiscibility, flotation of igneous magnetite micro-aggregates, and replacement by magmatic hydrothermal fluids. Recent studies have focused on high-temperature melt/fluid inclusions, as these provide critical clues for understanding the nature and origin of the initial ore-forming fluids/liquids or iron-rich melts.

Here, we report the widespread presence of high-temperature, water-poor, multi-phase hydrosaline liquid inclusions in pre- and syn-ore minerals (including albitized zircon, garnet, diopside, and magnetite) from representative IOA deposits in eastern China. These inclusions consistently homogenize to a liquid phase upon vapor disappearance during heating at temperatures ranging from 787 to 928°C (average 865°C). These homogenization temperatures roughly represent the entrapment temperatures of the hydrosaline liquids, supported by other independent geothermometric data. Additionally, the hydrosaline liquids can be stable at temperatures and pressures of subvolcanic settings in the simplified H2O-NaCl phase diagram. LA-ICP-MS analyses show these inclusions predominantly contain 3 to 10 wt.% Fe, highlighting their significant iron transport capacity. Furthermore, elemental ratios (e.g., K/Na and Ca/K) of the hydrosaline liquids and B-Sr-O isotopic data from associated minerals suggest that such hydrosaline liquids were likely immiscible from the dioritic magmas with high Cl/H2O in subvolcanic settings, typically at depths ≤2.5 km.

Therefore, we propose a novel genetic model in which high-temperature alteration and magnetite ores were formed simultaneously through host-rock interaction with, and/or decompression and cooling of, the hydrosaline liquids. This model provides important insights into the distinctive characteristics of IOA deposits in shallow magmatic-hydrothermal systems.