

## U-Pb, Hf, O, and Nd constraints for the Kiruna apatite iron oxide deposits, Sweden

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The world-class iron deposits in the Norrbotten region of northern Sweden (e.g., Kiirunavaara) are considered the type locality of apatite iron oxide (IOA) deposits, but whose origin has been debated for several decades. Two contrasting theories for their formation suggest that these iron ores were emplaced through either: (1) immiscible silicate liquid–iron oxide melts; or (2) that the iron was transported and emplaced by hydrothermal fluids. Similarities with the iron oxide–copper–gold (IOCG) class of deposits have been proposed based on the latter. Here, for the first time using spatially well constrained samples, detailed in situ U–Pb dating of accessory minerals and tracer isotope geochemistry on the mineral and whole-rock scale are combined to provide a better understanding of the ore genesis of these ore deposits.

Our U–Pb dates of zircon agree with previously reported dates (1900 to 1880 Ma), but our data provide a more accurate time frame of 1884 to 1880 Ma for the emplacement of the metavolcanic country rocks that host the main ore body at Kiirunavaara. Syenite and granite that intruded the footwall of the deposit have been dated at ca. 1880 and ca. 1874 Ma, respectively. Zircon crystals that were dated from the ore main body are similar to the granite intrusion (ca. 1874 Ma).

The oxygen and Hf isotopic composition has also been determined in situ on the zircon grains that were previously dated in these samples. Zircon grains from metavolcanic host rocks and the granite and syenite intrusions have  $\delta^{18}\text{O} \sim 3\text{‰}$ , and  $\epsilon\text{Hf}_i = -6$  to  $-10$ , whereas the zircon grains from the ore samples have  $\delta^{18}\text{O} \sim 7\text{‰}$ , and  $\epsilon\text{Hf}_i = -5$  to  $+3$ ) and are distinctly different. Whole-rock Sm-Nd data shows a similar contrast with  $\epsilon\text{Nd}$  of  $\sim -6$  for host rocks and  $\epsilon\text{Nd} \sim -3$  for the ore.

The U–Pb data suggests that the ore formed a few million years after the metavolcanic host rocks were emplaced, but close to the emplacement of the granite intrusion. The differences observed in all isotopic systems points towards an origin for the iron ore distinct from its magmatic host rocks. Furthermore, the low oxygen isotopic values strongly indicate the involvement of high-temperature hydrothermal fluids. Therefore, a magmatic-hydrothermal fluid system, driven by the heat produced by the intrusions, seems most likely to have mobilised iron and concentrated it in these massive iron oxide deposits.