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Magmatic origin of ‘Kiruna-type’ apatite-iron-oxide ores revealed by Fe-O isotope correlations

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Apatite-iron oxide ore is by far the biggest source of iron in Europe and one of the main iron sources worldwide. Apatite-iron-oxide ore in Europe has been sourced from two principal areas, the Bergslagen region in Central Sweden and the Kiruna-Malmberget region in northern Sweden. The apatite-iron oxide ores from these localities are internationally renowned and ores of similar composition elsewhere are traditionally also referred to as ’’Kiruna-type’’. While the Grängesberg and Kiruna deposits are Paleoproterozoic in age similar, apatite-iron-oxide deposits occur along the American Cordilleras, particularly in Chile, and which range in age from Jurrasic to Quarternary (most notably the just a few Ma old El Laco deposit). Apatite-iron oxide ores of Palaeozoic ages from Iran, Turkey and China fill this age span**,** thus showing repeated formation of apatite-iron-oxide ores throughout geological time.

The main iron sources for the Kiruna-type apatite-iron-oxide ores remain enigmatic and a range from hydrothermal to magmatic formation processes have been widely discussed. Here we report on oxygen and iron isotope ratios from magnetites of Kiruna-type apatite-iron-oxide ores from Sweden, Chile and Iran and comparative data from five ortho-magmatic layered igneous intrusions, three recent volcanic provinces, and from established low-temperature hydrothermal ore deposits from Sweden and Chile. Almost 80 % of massive magnetite from apatite-iron-oxide ores exhibit $\delta^{18}O$ and $\delta^{56}Fe$ ratios that overlap with the magnetites in the layered intrusions and recent volcanic provinces. In contrast, vein and disseminated magnetites from the ore deposits correspond dominantly with our reference suite of hydrothermal magnetites and appear in equilibrium with hydrothermal fluids at temperatures ≤400 °C. The iconic Kiruna-type ores are therefore essentially of magmatic derivation, but are frequently associated with late-stage hydrothermal processes that on cooling will produce associated low-temperature magnetite as well.