Different styles of Na, K and Mg–Fe alteration and REE mobilisation in the Riddarhyttan and Norberg ore districts, Bergslagen, Sweden

Stefan S. Andersson[a], Erik Jonsson[a,b] and Martiya Sadeghi[a]

[a]Department of Mineral Resources, Geological Survey of Sweden, Uppsala, Sweden, stefan.andersson@sgu.se; [b]Department of Earth Sciences, Uppsala University, Uppsala, Sweden

The Riddarhyttan and Norberg districts in the Bergslagen ore province host the most well-known Bastnäs-type Fe-REE deposits, comprising skarn-hosted, magnetite-rich iron oxide deposits associated with localised REE-rich and polymetallic mineralisation (e.g., Cu, Co, Bi, Mo). The prevailing genetic interpretation is that these deposits formed through the replacement of carbonate interlayers by hot Fe-REE-rich magmatic fluids in a syn-volcanic, sub-seafloor setting at around 1.9 Ga. The volcano-sedimentary wall rocks to the deposits underwent variable degrees of syn-volcanic hydrothermal alteration and were subsequently affected by polyphase Svecokarelian metamorphism and deformation. To evaluate the potential for REE mobilisation by the syn-volcanic hydrothermal fluids in the districts, we have compared variably altered felsic metavolcanics and penecontemporaneous metagranites with precursor rocks showing minimal to no alteration. We utilised the lithogeochemical database of the Geological Survey of Sweden, supplemented by newly collected samples.

In the Norberg district, notable Bastnäs-type REE deposits include the Malmkärra, Östanmossa and Johanna mines. The alteration of the metavolcanic rocks varies from pervasive to localised and show K or Mg-Fe signatures. The Mg-Fe alteration is concentrated in the central parts of the district and in proximity to different iron-oxide deposits, likely representing the footwalls to the mineralised skarn horizons. Local zones with Na to Na-Mg alteration are also observed. Around the Malmkärra deposit, Mg-Fe-altered metavolcanic rocks show relative enrichment of Mg and Fe, and depletion of Na, Ca, K, Ba, Sr and LREEs. Similarly, Mg-Fe-altered rocks closer to Norberg show a relative decrease in the LREEs. Conversely, K-altered metavolcanic rocks show no to weak LREE depletion. Metagranites east of the metavolcanic sequence exhibit distinct Na-Mg alteration, characterised by the relative enrichment of Mg and Na, and depletion of Ca, Fe, K, Rb, Ba, Sr and typically the LREEs.

The Bastnäs field, including the Nya and Gamla Bastnäs deposits, is located in the Riddarhyttan district. To the west of the field, likely representing the footwall, the metavolcanic rocks are weakly to moderately Fe-Mg-altered, with relative enrichment of Fe and Mg, and depletion of Na, Ca, Li, Ba, Sr, Pb, Zn, and variable LREE depletion. Proximal to the mineralised skarn horizon(s), the metavolcanic rocks display strong Fe-Mg alteration, with variable REE and polymetallic mineralisation, and show relative addition of Fe, Mg and locally also REE, S, Cu, Mo, Bi, Se and Te, as well as the depletion of Na, K, Li, Rb, Ba and Sr. Local skarn alteration of a marble outside of the main REE-rich mineralised zone shows relative enrichment of Si, Ba, Sr, LREEs, MREEs, Cu, Co, and Mo compared to an unaltered marble. Metavolcanic rocks to the east of the skarn horizon(s) exhibit no to weak K alteration and minimal LREE depletion, and likely corresponds the hanging wall. Further east of the Riddarhyttan district, regional-scale Na, Na-Mg and Mg-Fe alteration of metavolcanic rocks have resulted in variable LREE depletion. In contrast to the Norberg district, Na-Mg altered metagranites typically display low degrees of LREE depletion.

Significant LREE depletion in both districts is related to Mg-Fe-altered metavolcanic rocks, interpreted to be the footwall of the skarn-hosted REE deposits. Variable LREE depletion is also associated with Na-(Mg) alteration of metagranites and metavolcanic rocks. This indicates that syn-volcanic hydrothermal Mg-Fe and Na-(Mg) alteration were able to mobilise the LREEs and supports a genetic relationship between alteration and primary REE mineralisation. However, textural evidence for the remobilisation of REE during metamorphism is present in both districts, and it is difficult to determine how that has affected the chemical composition of the altered rocks. Nonetheless, the extensive zones of hydrothermally altered metavolcanic rocks and penecontemporaneous metagranites found in the districts suggest that the altered rocks could be the primary sources of REE.

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