

Rare earth elements in Icelandic hydrothermal fluids

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Introduction

Until recently the *REE* were considered to be immobile in the hydrosphere. However, studies of hydrothermal fluids from mid-ocean ridges and subaerial hydrothermal systems has shown that the *REE* are mobilised during water-rock interactions. In submarine hydrothermal systems, where the host rocks are basaltic and therefore containing relatively low *REE* concentrations, appreciable concentrations of the *REE* are observed in the fluids, (Michard 1989). The *REE* have also been studied in subaerial hydrothermal systems. Only where either the pH is low or the host rock is highly evolved, are there significant concentrations of the *REE*, (Michard 1989). In Icelandic geothermal systems, where the rocks are typically tholeiitic in composition, and the geothermal waters are neutral to alkaline, the *REE* have been investigated in order to understand their mobility in this geochemically very different environment.

Method

Water samples were collected from geothermal wells and springs in Iceland. The Nesjavellir 11 sample was collected from a geothermal well in the Nesjavellir high temperature, geothermal field near to the Hengill volcano. Hallkesholar and Hamrar lie within the Southern Lowlands, low-temperature geothermal field adjacent to Hvervellir. Cool carbonate rich waters at Heggastadir and Olkelda were also sampled. The waters were filtered and acidified at collection prior to analysis. The *REE* were preconcentrated using an organic extraction process, (Aggarwal *et al.* 1994). Briefly, the sample is contacted with an ester mix of alkyl hydrogen phosphates. The *REE* are extracted back from this phosphate mix using hydrochloric acid. *REE* measurements were carried by Flow Injection coupled to an ICP-MS as detailed in Aggarwal *et al.* (1994).

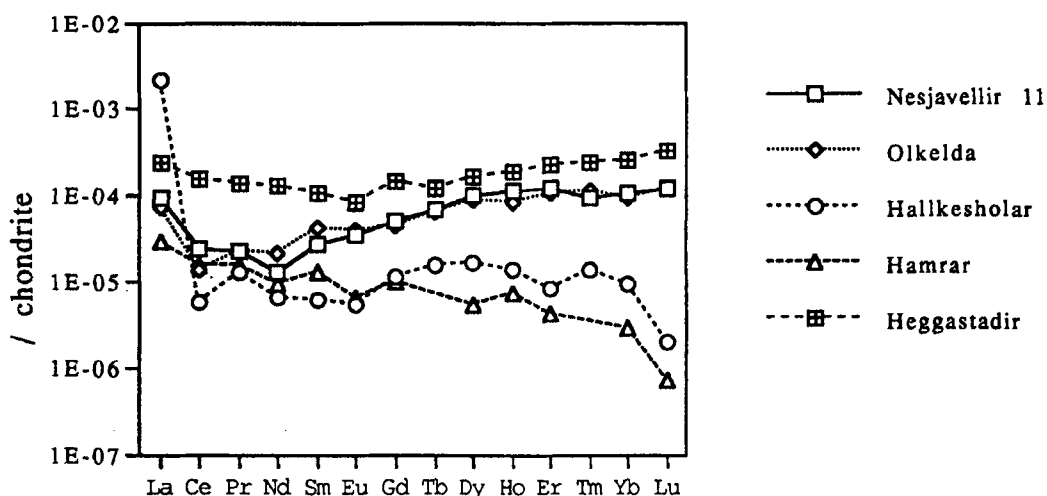


FIG. 1. Normalised *REE* plots for selected geothermal water samples in Iceland.

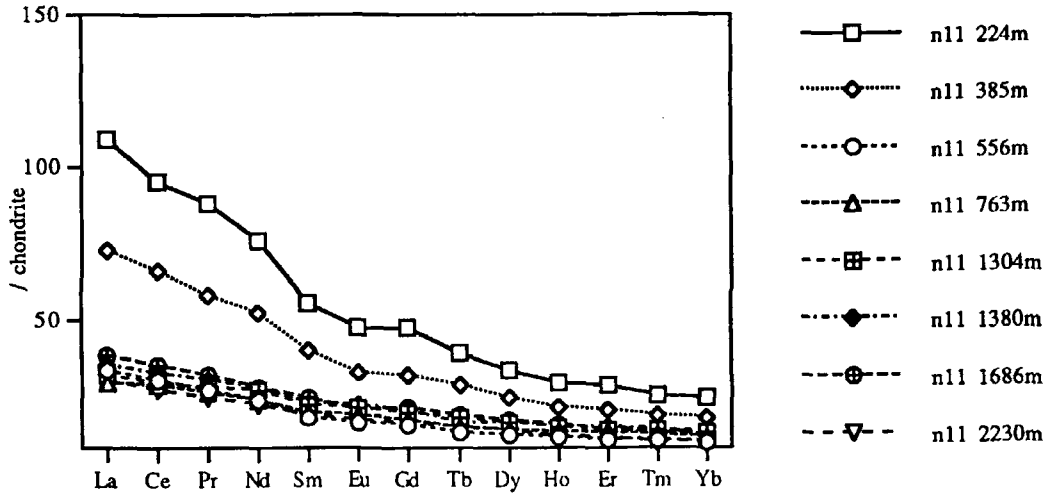


FIG. 2. Normalised REE plots for drill cutting material from the Nesjavellir 11 well.

Discussion

The results of a few of the analyses are shown normalised to chondrite in fig 1. The figure shows the REE patterns for the most acidic low temperature geothermal systems sampled. The pH's of these waters reach range from 6 to 11. At these relatively high pH's there are generally very low REE concentrations as compared to more acidic waters which can contain REE at three or more orders of magnitude higher (as observed in sub-marine hydrothermal systems). Typically the sum of all of the REE concentrations in the water samples illustrated is of the order of about 1nmolkg^{-1} . Of the samples shown, Nesjavellir 11, Olkelda and Heggastadir all show a heavy REE enrichment. Heggastadir and Olkelda are both carbonate rich springs, with the concentrations of dissolved CO_2 are 500ppm and 1000ppm, respectively. Such heavy REE enrichment is typical in waters rich in CO_2 , (Cantrell and Byrne 1987). Nesjavellir 11, however, shows a very low CO_2 concentration (74ppm), and the heavy REE enrichment can not be simply attributed to carbonate complexation of the REE.

The relatively flat or slight light REE enriched profile of the water samples collected at Hamrar and Hallkesholar are similar to the REE profile of the unaltered rocks. Nesjavellir on the other hand, exhibits a heavy REE enrichment. The host rocks

of the Nesjavellir, Hamrar and Hallkesholar systems all show similar REE profiles. In the Nesjavellir system, the cause of the light REE enrichment is due to the incorporation of the light REE into secondary minerals (such as zeolites and clays) which have been found towards the top of the wells. Altered rocks from Nesjavellir well 11, at 385m and 224m depth, show an abundance of zeolites. These zeolites show a very strong light REE enrichment (fig 2). It is therefore the zeolites that fractionation the REE to produce the heavy REE enrichment in the emerging geothermal fluids. The Olkelda well does not show the presence of zeolites at depth, partly due to very cool nature of the geothermal system.

In conclusion, the REE profile of geothermal waters in Iceland, reflects the complexation of the REE in waters, the REE profile of the host rock and may be altered by the secondary phases.

References

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