Effects of degree of weathering, host rocks and rock ages on the formation of ion-adsorption type deposits (IAD) of rare-earth elements

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Background
Today, demand for new technologies such as renewable energy and electric vehicles is increasing, but the production of rare earth elements (REE) needed for these technologies is localized in a few regions, which still poses a supply risk. Ion-adsorption type deposits (IAD) are a type of terrestrial REE deposits, which are characterized by easy extraction of REEs with electrolyte solutions. In IADs, REEs are weakly adsorbed onto clay minerals as outer-sphere complexes, and since such clay minerals tend to be formed in temperate regions with moderate weathering, IADs are likely to exist in temperate zones such as Japan. In this study, we examined the conditions for the formation of IADs using weathered granite samples collected in various parts of Japan.

Purpose
From previous studies, it is considered that the following conditions are necessary for IAD formation: (1) high REE concentration in the source rock, and (2) the presence of clay minerals that can be adsorbed as an outer-sphere complex. In addition, based on an example of low extraction concentration of REE in Proterozoic weathered granite layer in Sri Lanka, we examined whether the age of the source rock was appropriate as a necessary condition for IAD formation. The age of the source rock was estimated by simulating the downward migration of REE using a Reactive Transport Model, and the necessary conditions for the age were discussed by comparing the weathering and erosion ages.

Results and Discussion
The concentrations of total REE and extracted REE in the enrichment area of the samples in this study are lower than those of the IADs explored in the past, which is not necessarily promising as an IAD. On the other hand, even in such samples with low REE level, enrichment of REE were observed within the layer, and the REE species determined by EXAFS spectroscopy were easily extractable outer-sphere complexes. In addition, from the comparison of the age of the sample and the concentration, it was found that the older the age of the sample, the larger the concentration range if the concentration of REE in the source rock is similar. This may be due to the downward migration of REE continues for a longer period of time in older samples. The relationship between the adsorption capacity and the amount of extracted REEs was examined, and some cases of low amount of extracted REEs were found even in samples with large adsorption capacity. From this result, age was considered as a new factor for the necessary condition. In order to account for the age of IAD formation, we simulated the downward migration of REEs by using an advection-diffusion equation that takes into account adsorption reactions based on Kd model. From the simulation, the downward migration rate of REE is 1-8 m per million years. This result is significantly faster than expected based on the depth profile of REE and age, but this is probably because the effects of weathering and erosion are not taken into account. In actual samples, downward migration and adsorption of REE must occur after weathering, and the downward migration must be faster than erosion for enrichment to occur. In other words, the erosion rate E < the migration rate R < the weathering rate W is required. In fact, the weathering and erosion rate of granite is 5-10 m per million years from literature values, and R < W can be sufficiently satisfied; E < R depends on the topography at each site, and high

concentration IADs can be formed if these and (1) and (2) are also satisfied.

Conclusions
The following four points can be pointed out as the required conditions and characteristics for the IAD formation expected by this study.
(1) High REE concentration in the source granite
(2) Presence of clay minerals that can adsorb REE as an outer-sphere complex
(3) Erosion rate E < migration rate R < weathering rate W
(4) The older the age of the source granite, the higher the total amount of REE in the IAD is expected to be.

Keywords: REE

