# Rare Earth Element trends in basalts and plagiogranites from the Troodos Ophiolite, Cyprus

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## INTRODUCTION

Basaltic rocks in the upper parts of the sheeted dike section of the Troodos ophiolite have been hydrothermally altered. Some have even been altered to epidosites, which are composed mainly of quartz and epidote. Several models (Bettison-Varga et. al., 1995) have suggested that huge quantities of heated seawater flowed through these rocks during the alteration process (Bettison-Varga et. al., 1995).

Recently, geologists have been using REE data to show genetic relations between magmas. Rare earth elements are believed to be useful because of their presumed immobility during alteration of the host rock. However, I have postulated that with hydrothermal alteration involving large volumes of seawater some of these 'immobile' elements may indeed be mobile. This would mean that the removal of REE's can be correlated with the intensity of the alteration of basaltic dikes. This study examines trends that are evident from rare earth elemental analyses of samples representing various degrees of alteration. In addition to the basaltic rocks, I have also included a study of plagiogranites of varying degrees of alteration.

## METHODS

**Field work.** Samples of the sheeted dike section and the "plagiogranite" section were collected from various levels in the Troodos ophiolite in Cyprus in an attempt to get representative samples of different lithologies and degrees of alterations. Sampled areas included upper parts of the sheeted dike complex, as well as outcrops of plagiogranite. Care was taken to collect pairs of altered and relatively unaltered basaltic dikes and plagiogranites at selected sites.

**Lab work.** Polished thin sections and powdered splits were made of selected specimens. The splits were sent to Oregon State University for INAA (neutron activation analysis) of REE's and other trace elements. Splits were also sent to the University of Houston for whole rock analysis and L.O.I. The thin sections were examined with a petrographic microscope, and representative thin sections were examined by SEM for mineral identification, and semi-quantitative elemental analyses.

## DATA

**Basaltic dikes.** The three basic categories of altered basaltic dikes are greenschist, intermediate, and epidosite. Those samples classified as greenschist exhibit relict igneous textures and their general mineralogy consists of chlorite, actinolite, epidote, quartz, and plagioclase of varying composition. Samples considered to be intermediate have no relict igneous texture, and contain amphiboles (actinolite), epidote, and secondary quartz. Accessory minerals of the greenschist altered basaltic dikes and intermediates include titanite, magnetite, ilmenite, and apatite. Epidosites are composed almost completely of quartz and epidote, with accessory titanite, ilmenite, and magnetite.

REE concentrations and trace element concentrations were normalized to an average of basaltic glasses from Rautenschlein *et. al.*(1985), or the ACBG (average Cyprus basalt glass). Figure 1 is a spider diagram of basaltic dikes that had a $SiO_2$ weight percent comparable to that of the ACBG. Figures 3a, 3b, and 3c display all of the analyzed basaltic dikes normalized to the ACBG.

The REE analyses exhibit several broad trends. All the analyzed basalt samples have low Cr concentrations compared with abundances of other trace elements. Most of the basaltic dikes had higher amounts of Nd than other REE's (Fig. 1). Other elements such as Co, Hf, Ta, Th, Sr, and Ba exhibit erratic trends when normalized to the ACBG The trends of the greenschist altered basaltic dikes, the intermediates, and the epidosites all exhibit very similar trends in the REE (Figs.

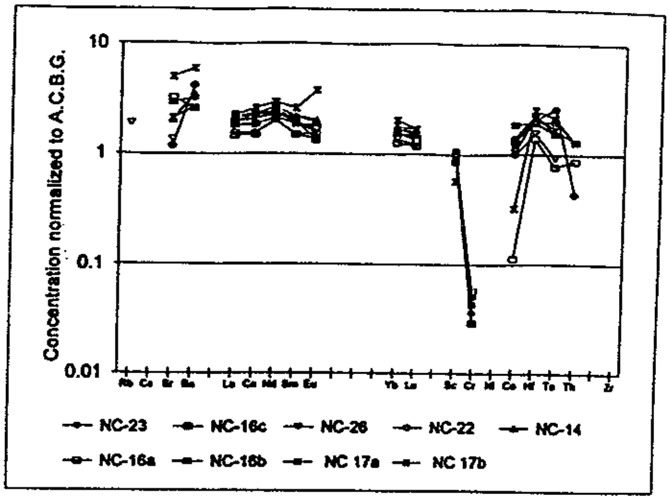


Figure 1. This diagram shows a consistent trend in the REE's (La-Lu). The epidosite, NC 17b, is enriched in Eu.

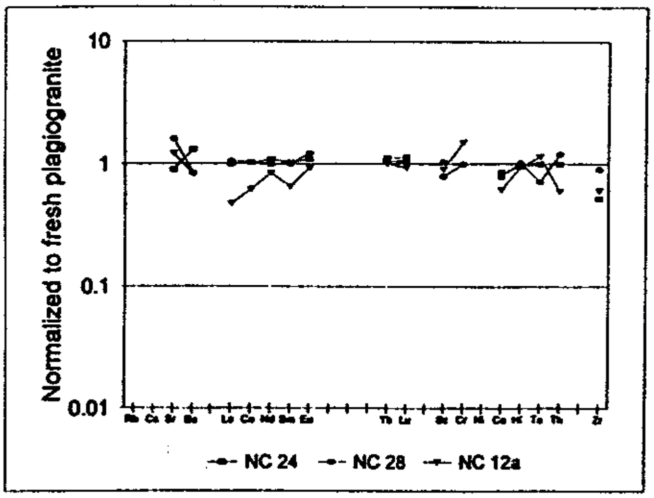


Figure 2.a. These are the plagiogranites of this study normalized to a sample of a "fresh" plagiogranite.

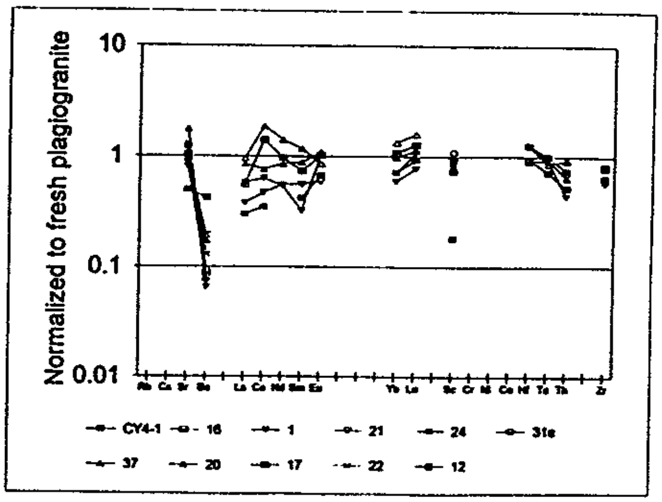


Figure 2.b. These are Twinning's plagiogranites normalized to this study's "fresh" plagiogranite. The REE trends are erratic, but there are some consistencies in the Yb, Lu, and Sc trends.

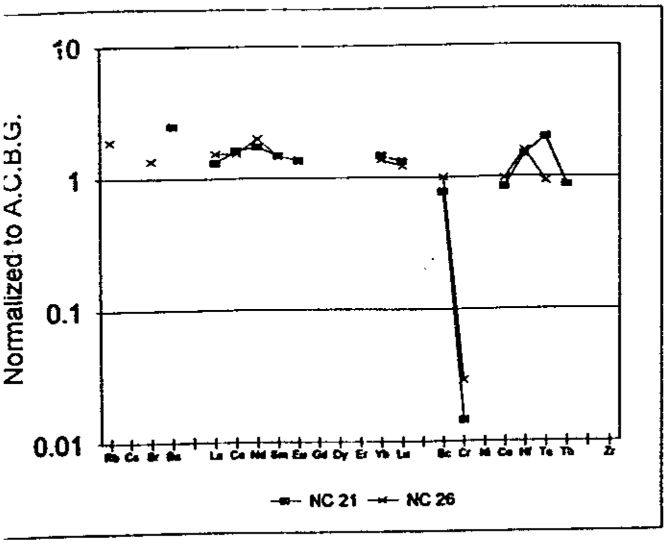


**Figure 3.a.** These are the greenschist altered basalts.

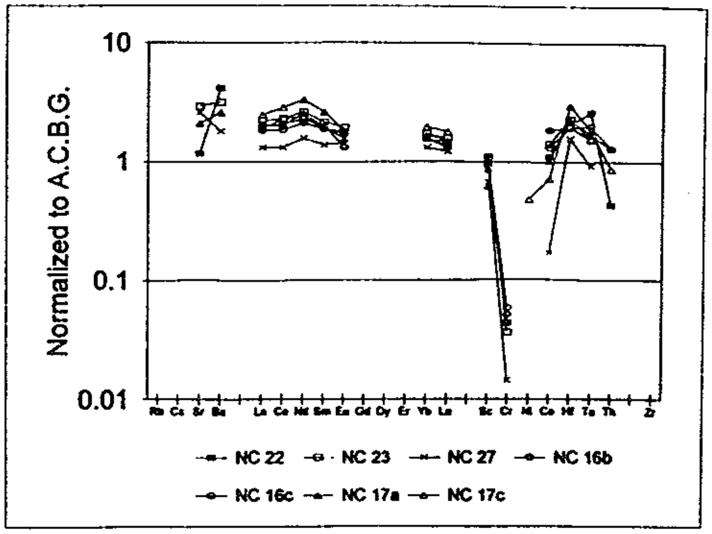


**Figure 3.b.** These are the intermediates. Note the consistent trends in the La through Lu. NC 22 and NC 23 are an altered pair. (NC 23 is the more altered basalt.) Sample NC 17c is the sample with the allanite.

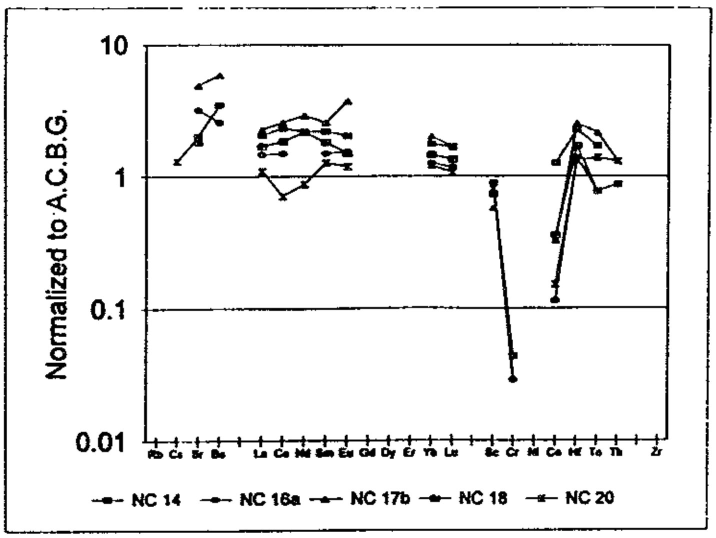


**Figure 3.c.** These are the epidosites.

3a, 3b, and 3c), despite different degrees of alteration.

Under the SEM, one of the epidote grains in an intermediate was observed to have an REE and Ce enriched allanitic core. This grain also exhibits REE zoning. Under the petrographic microscope the zoned grain was optically continuous.

**Plagiogranites.** Rocks identified as plagiogranites had significant plagioclase and quartz, and lesser amounts of amphibole and epidote. These "plagiogranites" lack potassium feldspar and are not true granites, but they are still referred to as plagiogranites in this study. As with the basaltic dikes, the relict igneous texture and the presence of epidote can be used to classify the degree of alteration of the plagiogranite. One of the four plagiogranites collected was significantly less altered than the three remaining samples of plagiogranite. The three more altered plagiogranites were normalized to the less altered plagiogranite. Altered plagiogranites from a study by Twinning (1996) were also normalized to this "fresh" plagiogranite.

The plagiogranites of this study (Fig. 2a) exhibit some anomalies in the REE's, as did the altered plagiogranites from Twinning's study (Fig. 2b). The only consistent REE trends in the plagiogranites were those of Yb and Lu. Several of Twinning's samples were enriched in Ce, and most of Twinning's samples were depleted Ba (Fig. 2b).

## DISCUSSION

The REE diagrams of the basaltic dikes do not indicate a consistent trend of decreasing concentrations of REE's that can be correlated with increasing alteration. The consistency of the REE trends in the basaltic dikes of this study seem to indicate that REE comparison in basalts is a reasonably reliable method to determine genetic relations between parental magmas. When dealing with trends in the basalts, what might appear to be deviation from the normal may be effects of fractionation. It would be interesting to recalculate fractionated materials back into the composition of the altered basaltic dikes, and then examine their REE trends. However, the difficulty with this lies in finding the correct quantities of materials to hypothetically reinsert. The depletion of Cr in the basaltic dikes of this study indicates that they may have been more fractionated than the basalts studied by Rautenschlein *et. al.* (1985). In support if this, the spider diagrams normalized to the ACBG show an REE ratio greater than one (Fig 1). The incompatibility of most of the REE's should generally result in enrichment of REE's in more fractionated basalts.

This study did not examine the relationship between the allanite and the alteration of the basalt. Although allanites are commonly found in granitic rocks, their presence in the Cyprus basaltic dikes has not yet been fully explained. The zoning present in the grain could answer some questions about REE mobility during hydrothermal alteration.

The trends that the plagiogranites exhibit are difficult to explain. If I had computed some minerals back into the more fractionated plagiogranites, some trends might have been more consistent. Perhaps isocon diagrams of the altered plagiogranites can be used to indicate the relative amount of fractional crystallization that the plagiogranites have experienced. Disfigurements in REE trends of the altered plagiogranites, as a result of removal of REE compatible minerals, could be mathematically repaired. This might reveal a more accurate picture of the REE mobility in the plagiogranites.

## REFERENCES

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