Petrogenetic implications of the geochemistry of sheeted dikes in Phterykhoudi Canyon, Troodos ophiolite, Cyprus

Kalsoum Abbasi
Department of Geology, The Colorado College, 14 E. Cache La Poudre, Colorado Springs, CO 80903
Faculty sponsors: Bruce Loeffler and Jeffrey B. Noblett, The Colorado College
Diane R. Smith, Trinity University

INTRODUCTION

The Troodos ophiolite on the island of Cyprus is a largely intact, well-exposed structure that is thought to exemplify oceanic crust and therefore has been the subject of numerous studies. Presence of a well-developed sheeted dike complex (less than 2-5% host rock) within Troodos is an important piece of evidence that led to the suggestion that the ophiolite formed in an accretion zone (Desmet et al., 1978). Ophiolite dikes are generally rooted in the underlying mafic cumulate sequence and extend into the overlying pillow lavas, linking them together. The sheeted dike complex thus contains a nearly complete representation of magma compositions that were available during generation of the oceanic lithosphere. Furthermore, different magma compositions appear to have been extruded sequentially as an upper depleted and a lower non-depleted suite in the pillow lavas, but show no preferred age relationship within the dikes. Therefore, the entire range of compositions was available contemporaneously (Baragar et al., 1987). If geochemistry can be correlated with the direction of local dike injection, it may be possible to create a model that explains the nature of the original magma chamber(s) (*see* Adams, Hitchens, Rance, this volume). The primary goal of this project is to characterize and compare variations in dike petrography and geochemistry within a section of the central sheeted dike complex. The tectonic setting of the ophiolite in terms of its geochemistry is also examined.

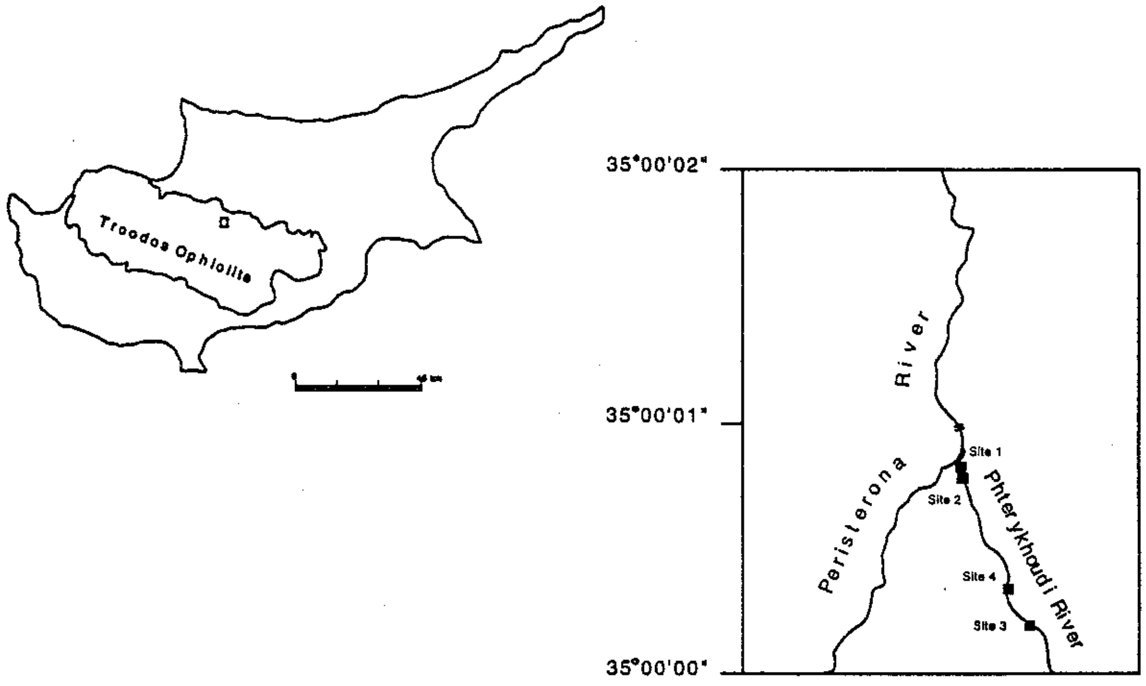


Figure 1. Map of Cyprus with field area detailed.

FIELD OBSERVATIONS

The field area is located west of the Mitsero graben axis, in northern Phterykhoudi Canyon between latitudes 35°0'12" and 35°0'51" (Fig. 1), approximately 11 km north of the CY-4 drill hole studied by Baragar et al. (1989). Dikes are exposed along the canyon walls and floor, but are often obscured by river deposits, debris, and dense vegetation. Intense hydrothermal alteration occurred in localized areas, destroying the original igneous texture and rock competency. Greenschist facies metamorphism is evident in outcrop as all rocks are green- to blue-gray; epidotization is seen in several areas. Four sites were chosen for study based upon their relatively low levels of alteration and weathering, the prominence of clearly visible chilled margins, the presence of cross-cutting relationships, and the number of adjacent dikes. Because this study was done in conjunction with Hitchens' paleomagnetic study, it was important to choose sites that would be beneficial to both projects. Each site was located by GPS and mapped, the dikes' chilled margins and cross-cutting relationships noted, and strikes and dips measured. Twenty-seven rock samples were collected for geochemical and petrographic analysis.

ANALYTICAL TECHNIQUES

Rock samples were shipped to The Colorado College for processing and analysis. Petrographic analysis of thin sections was limited by the altered nature of the rocks, which made determination of plagioclase composition and modal analysis by point count difficult. Geochemical analysis included x-ray fluorescence and loss on ignition of all twenty-seven samples; fifteen samples were sent to Oregon State University for instrumental neutron activation analysis. Geochemistry was analyzed using the computer modeling program Minpet.

PETROGRAPHY

All rocks are aphyric, fine-grained, and green- to blue-gray in hand sample. One sample (4-S) is slightly coarser-grained than the others, while two (1-27 and 1-25) are aphanitic, the only recognizable mineral being secondary pyrite. The latter two samples come from very narrow dikes (8-15 cm) that cooled rapidly, forming extremely fine-grained textures. Similarly, dike 4-S may have cooled slowly enough to allow for the growth of larger crystals, or they may be the result of a more hydrous melt. Eleven samples exhibit visible sulfides due to hydrothermal alteration. Sixteen samples contain plagioclase laths up to 1 mm in length, indicating that metamorphic recrystallization was not advanced enough to destroy the original igneous texture of the rocks.

Examination of thin sections confirms that most of the primary igneous minerals have been metamorphosed to a greenschist facies assemblage. Original clinopyroxene is present in six samples, but has been altered to either chlorite or actinolite in all the samples; relict crystal shapes are generally well-preserved and display a subophitic texture. An attempt to use Michel-Levy technique on the plagioclase crystals yielded sporadic results, but a Becke line test revealed that plagioclase has a higher refractive index than epoxy (1.54). Albite has refractive indices less than 1.54, so extensive alteration to albite has not taken place. Five samples contain acicular plagioclase crystals indicative of rapid cooling. Epidote occurs in three forms: fibrous, crystalline, and as a rim around a secondary quartz crystal in sample 2-5. Most quartz in the samples does appear to be secondary, as crystals are large overgrowths and often hexagonal, but some interstitial quartz is also present. Carbonate minerals are seen in most samples, either as veins or as distinct crystals. Examination of thin sections under reflected light reveals that the opaque phase is magnetite rather than ilmenite, with a small amount of associated hematite in a few samples. Titanite is seen in samples 3-6a and 7-12-96-8, which suggests that some titanomagnetite is present. Magnetite abundance ranges from 5% to 15% in the samples. Pyrite crystals are also present in eleven samples.

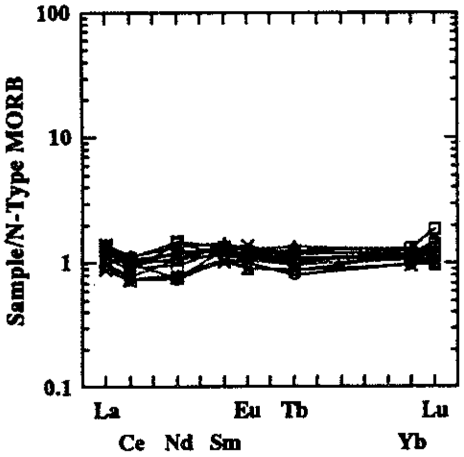
A few small vesicles (up to 2.25 mm) are present in ten samples, seven from Site 4. One sample, 4-5U, contains a vesicle lined with small quartz crystals. In addition, the fibrous epidote in sample 4-3 looks as though it formed inside a void space. The presence of vesicles may indicate gas exsolution from dikes emplaced in a relatively shallow setting. Concentration of dikes containing vesicles in Site 4 is interesting because the site is not located in the structurally highest part of the field area; in fact, it is toward the center. The cause of this possible localized gas exsolution poses an intriguing question.

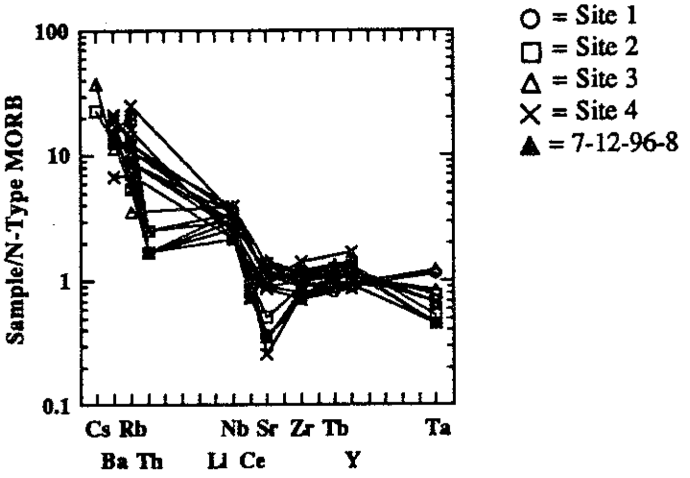
GEOCHEMISTRY

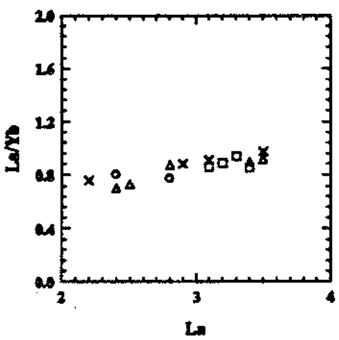
Weight percent SiO_2 ranges from 43.52% to 63.69%, indicating a basaltic to andesitic suite. The altered nature of the rocks makes major element chemistry unreliable, especially Ca, Na, and K, which are particularly mobile. However, Ti and P are not considered mobile in greenschist facies metamorphism (Rollinson, 1993). Mg is a constituent of sea water and therefore may be enriched in rocks that have been hydrothermally altered by sea water, such as the Troodos sheeted dikes. Mg content does not appear to have been significantly affected in the samples, which have fairly low Mg numbers (33.59-46.20). Immobile trace elements such as Y, Th, Zr, Hf, Nb, Ta, Co, Ni, V, and the rare earth elements are the most reliable, and therefore were used in the majority of element plots.

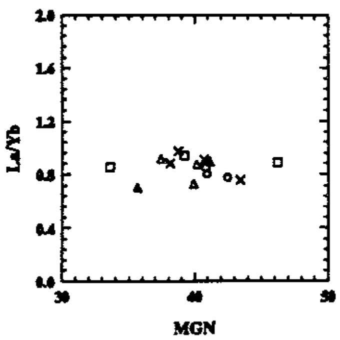
When normalized to NMORB composition, REE plot nearly at 1. LREE are slightly depleted, with a very slight negative Ce anomaly, compared to HREE, but the difference is small (Fig. 2). Spiderplots show an enrichment (up to 40 times NMORB) of LIL elements, and near-normal abundances of HFS elements (Fig. 3).

REE are both immobile and incompatible during igneous processes and most low-grade metamorphism, so a ratio of LREE/HREE plotted against either an indicator of fractionation or another immobile element will follow a straight line trend in fractionated rocks. La/Yb versus either La or Mg# fall on a line (Fig. 4, 5). These constant ratios suggest that the rocks were generated from the same source. HFS elements, which are also immobile and incompatible, are extremely helpful in determining fractionation trends. Ratios of HFS elements will remain constant, and when plotted against an indicator of fractionation, such as Ni, Mg#, or % SiO_2, will also fall on a line if fractionation did indeed occur. Th/Ta plotted against Mg# shows some scatter (Fig. 6), which could imply multiple magma sources, but is possibly a result of alteration. Cr and V plots suggest fractionation of clinopyroxene and magnetite; there are not enough data points to plot Ni as a check of olivine fractionation. The samples consistently plot on the boundary between island arc basalts and mid-ocean ridge basalts (Fig. 7, 8, 9) in discrimination diagrams for tectonic setting (Th-Ta-Hf, Cr-Ti, Ti-V, Zr-Y-Ti, Zr-Zr/Y, Zr-Ti, Mn-P-Ti).









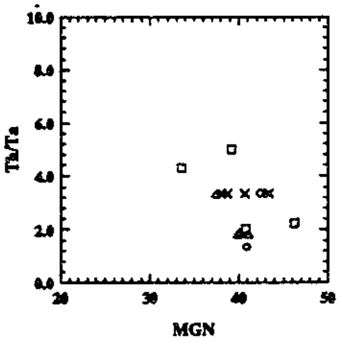
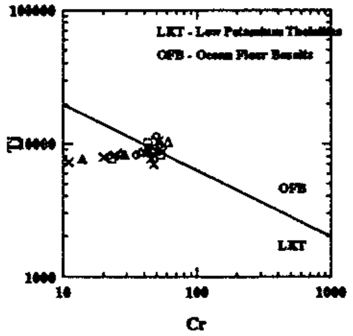


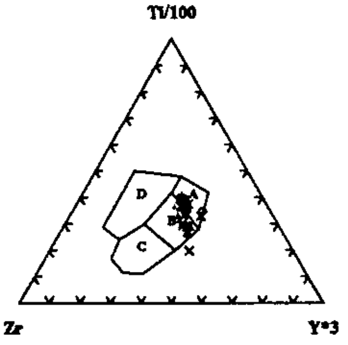
Figure 2 NMORB-normalized REE plot.
Figure 3 NMORB-normalized incompatible element spiderplot.
Figure 4 La/Yb vs. La plot. Straight line indicates fractionation.
Figure 5 La/Yb vs. Mg# plot. Straight line indicates fractionation.
Figure 6 Th/Ta vs. Mg# plot. Scatter possibly due to alteration.

DISCUSSION AND CONCLUSIONS

Several trace element plots demonstrate one distinct fractionation trend within the sheeted dikes sampled. Data were plotted by number of chilled margins as well as by site in an attempt to pick out either spatial or temporal differentiation, but none was evident. Some plots do show scatter rather than a linear relationship, which could indicate more than one magma source, but this is probably the result of element mobility due to alteration; the evidence is not conclusive. None of the plots show more than one distinct fractionation trend. It appears as though all the dikes in this confined section of the sheeted dike complex evolved from one fractionating magma chamber.

While a marginal basin setting for the formation of the Troodos ophiolite is generally agreed upon by those who have studied its geology and geochemistry, specifics of the tectonic environment are not. Data plotted on discrimination diagrams show chemistry transitional between ocean ridge tholeiite and island-arc basalt, which is characteristic of many back-arc basin basalts. Enrichment of LIL elements relative to HFS elements and the negative Ce anomaly are evidence of contamination by a subduction component (Saunders and Tarney, 1984). Crystallization of clinopyroxene before plagioclase, demonstrated by subophitic texture in the thin sections, is typical of basalts formed in a supra-subduction zone (SSZ) environment. While geochemistry and petrology indicate an SSZ setting, presence of the sheeted dike complex, the pelagic nature of existing volcanics, and lack of significant arc volcanics in the overlying sediments are contradictory. Reconciling geochemistry and geology therefore requires a model of seafloor spreading above a subduction zone prior to arc formation (Pearce et al., 1984).





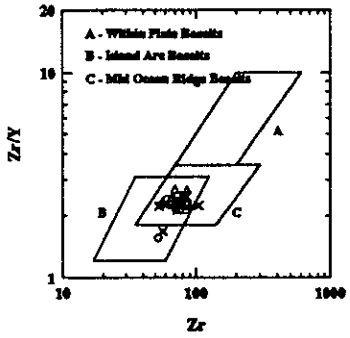


Figure 7 Ti vs. Cr discrimination diagram for tectonic setting.
Figure 8 Zr-Y*3-Ti/100 discrimination diagram for tectonic setting. A,B=LKT; B=OFB; C=calc-alkaline basalt
Figure 9 Zr/Y vs. Zr discrimination diagram for tectonic setting. All three diagrams show overlap indicative of a back-arc setting.

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