Structural and paleomagnetic constraints on the origin of foliated gabbro, Troodos ophiolite, Cyprus

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INTRODUCTION

Foliation planes defined by an alignment of plagioclase phenocrysts are evident in gabbro outcrops in the Troodos ophiolite northeast of Khandria and in the town of Kato Amiandos. The foliation has been interpreted either as the result of plastic deformation, possibly related to extension along a detachment fault near the gabbro-dike contact (Malpas *et al.*, 1987; Hurst *et al.*, 1994) or as a phenomenon related to the deformation of a partially-crystalline "mush" (Benn and Allard, 1989). Pilot studies of the petrology, anisotropy of magnetic susceptibility (AMS), and paleomagnetic character of these outcrops, along with detailed field mapping, indicate that the foliation is a fine-scale igneous lamination, related to flow within a partially-crystalline magma chamber.

FIELD RELATIONSHIPS

The primary field area for this study is an approximately 0.25 km^2 region northeast of the town of Khandria, Cyprus (Figs. 1 and 2). This area lies structurally between the Solea and the Mitsero grabens and covers the contact between the sheeted dike complex and a plutonic complex composed mainly of gabbro and ultramafic rocks. Oriented samples and cores for paleomagnetic study were taken at this site, and detailed maps and cross-sections were made.

The structurally lowest lithologic unit of the section consists of a series of layered mafic and ultramafic rocks, mainly gabbro-norites and wehrlites. Ultramafic rocks grade upward into layers of gabbro.

A gabbroic unit structurally overlies the layered rocks. The base of the unit is a fine-grained, foliated gabbro which immediately overlies the layered mafic and ultramafic rocks. The basal foliated gabbro grades upward into a massive, coarse-grained to pegmatitic gabbro. Both of these units are cut by near-vertical diabase and fine-grained gabbro dikes and high-angle faults (Fig. 2).

The intrusive contact with the sheeted diabase dike complex runs roughly east-west along the northern part of the field area. The dikes immediately north of the contact are near-vertical.

A secondary field area, an outcrop in the town of Kato Amiandos, was also sampled, but not mapped. The dip of foliation in gabbro both at Kato Amiandos and near Khandria is moderate, with an average of approximately 38°.

PETROGRAPHY AND MICROSTRUCTURE

The foliated gabbro is an amphibole-bearing, two-pyroxene gabbro. Epidote and chlorite are present although not common, and much of the clinopyroxene and primary amphibole have been altered to a secondary amphibole (uralite). Most plagioclase is euhedral to subhedral with what appear to be adcumulate overgrowths. Foliation is defined by a shape-preferred orientation of plagioclase.

Microstructures indicative of penetrative ductile flow are not present. Subgrains and grains with undulose extinction comprise a very small part of any of the samples. Crenulate grain boundaries and recrystallized "tails" on feldspar crystals are nonexistent; bent twin lamellae and deformation lamellae are very rare.

A weak lineation was found in only one sample. In general, samples contain laths of plagioclase oriented randomly within the plane of foliation (Fig. 3). Analyses of crystallographic and shape orientations of plagioclase will quantify this observation.

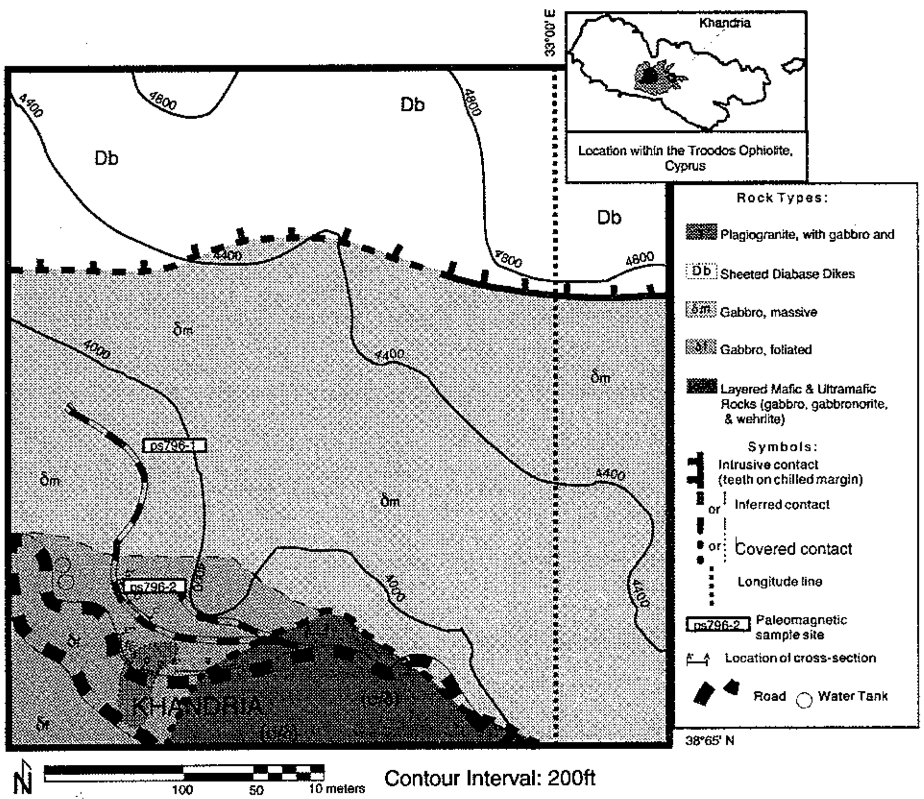
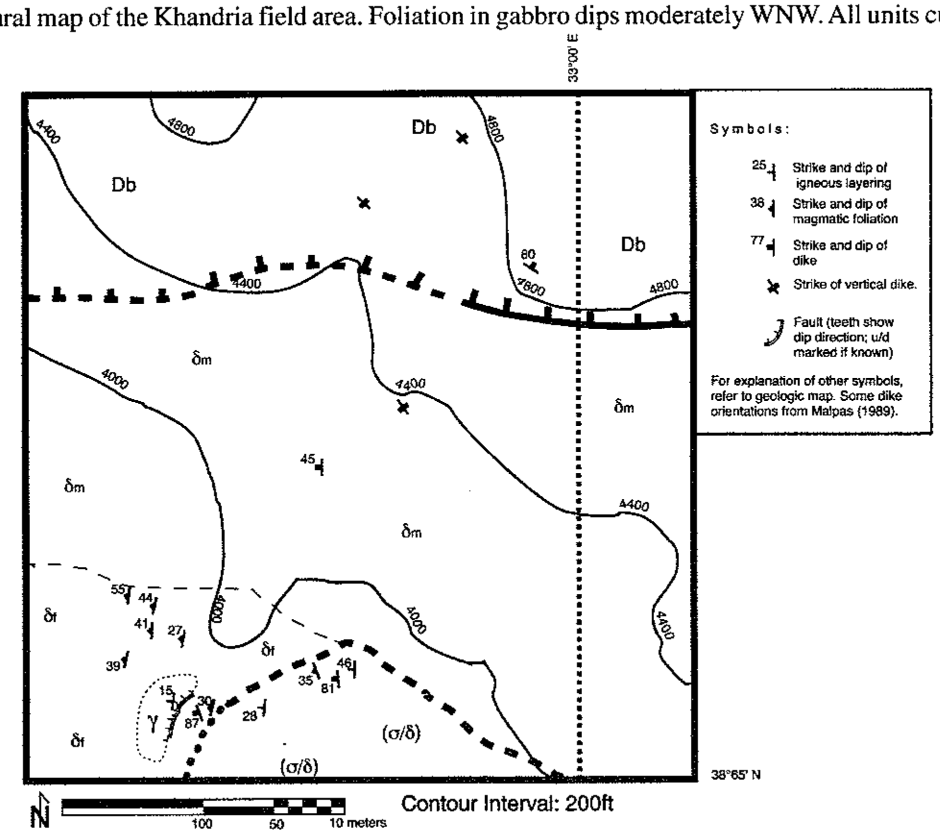


Figure 1 (above): Khandria field area. Massive gabbro overlies foliated gabbro. Massive and foliated gabbro were sampled for paleomagnetic study.

Figure 2 (below): Structural map of the Khandria field area. Foliation in gabbro dips moderately WNW. All units cut by near-vertical dikes.



PALEOMAGNETIC STUDIES

Samples for the paleomagnetic component of this study were taken from three sites. Six to eight cores were drilled from each location. Within the primary field area, an outcrop of massive gabbro (*ps796-1* on Fig. 1) and an outcrop of foliated gabbro (*ps796-2*) were sampled; the third site was located at the Kato Amiandos outcrop.

Four of the twenty-five cores (three from the Khandria massive gabbro and one from the Khandria foliated gabbro) were cut into two parts each. Half of the duplicate specimens were demagnetized by step heating to 200, 400, 500, 550, and 580° C; the rest of the specimens cut from the same cores were demagnetized in an alternating field, as were the rest of the specimens cut from the other cores. Two specimens from each site were subjected to twelve steps of alternating field demagnetization, from 2.5 to 80 mT. All other specimens from the massive gabbro were demagnetized at successive peak alternating fields of 2.5, 20, 25, 30, and 35 mT; the remainder of the specimens were demagnetized in fields of 20, 40, and 60 mT. IRM and J/J_0 plots are consistent with magnetite as the magnetic carrier. Magnetic susceptibilities measured before and after thermal demagnetization are similar, indicating that no new magnetic phases grew during heating. Further work will characterize grain size and occurrence of the magnetic carrier.

Stable magnetization components of all samples in each site cluster tightly around mean values (α_{95} ranges from approximately 2° to 12°). The site mean vectors are all close to each other and to the Troodos Mean Vector (274/36, Fig. 4), but only the α_{95}s of the foliated gabbro sites overlap the α_{95} of the TMV.

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS)

Anisotropy of magnetic susceptibility is a measure of the ease with which magnetization is acquired in three perpendicular directions (Kmin, Kint, and Kmax). These three vectors can be visualized as defining the three principal axes of an ellipsoid. AMS represents a shape anisotropy of or anisotropic distribution (*i.e.* a crystallographic preferred orientation) of magnetite crystals (O'Reilly, 1984). If either ductile or magmatic flow has occurred, Kmax will lie in the direction of flow, and the AMS ellipsoid will be prolate; Kmin will lie in the direction of compaction if compaction has occurred (Raposo and Ernesto, 1995).

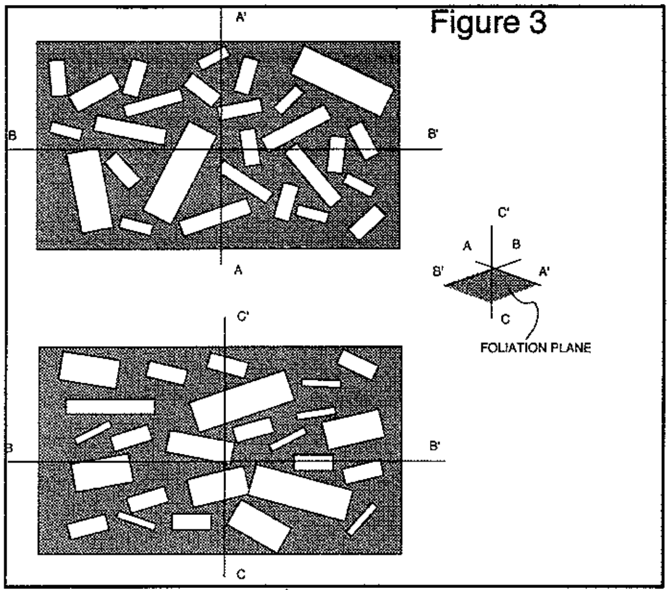
AMS was measured for all cores except those thermally demagnetized. Anisotropies range from 3.9 to 9.5% in the massive gabbro and 3.2 to 12.7% in the foliated gabbro. All ellipsoids are close to spherical, although most are slightly oblate (Kint/Kmin > Kmax/Kint). The orientation of the AMS ellipsoid is poorly-constrained in the massive gabbro, although Kint is usually the most steeply-plunging of the three axes. In the foliated gabbro, however, Kmax and one other axis (usually Kint) define planes subparallel to foliation. Clustering of Kmax toward the south is best observed in analyses of the Kato Amiandos foliated gabbro (Fig. 5), defining a weak N-S AMS lineation.

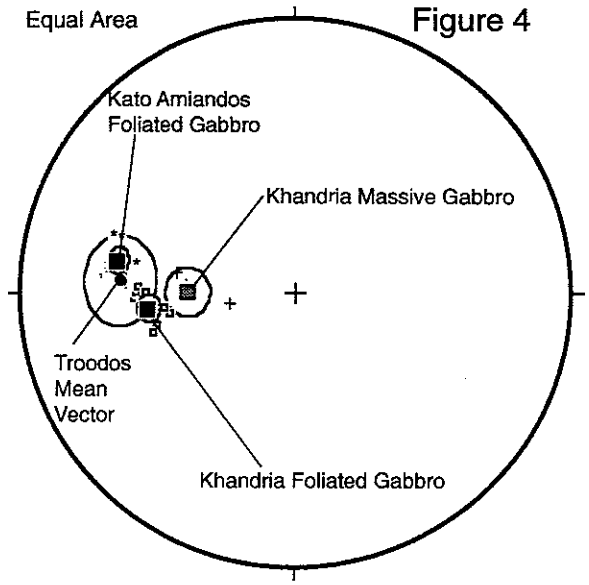
DISCUSSION OF RESULTS

The presence of a weak, N-S, dike-parallel anisotropy of magnetic susceptibilities and of euhedral, undeformed plagioclase laths suggest that viscous flow within the magma chamber was at least partly responsible for the generation of the foliation in the Troodos gabbro. The flattened character of most of the foliated gabbro AMS ellipsoids, the orientation of many of those ellipsoids with Kmin perpendicular to the foliation, and the plagioclase "mats" which define the foliation suggest that compaction of a crystal mush may have contributed to the development of foliation (see Raposo and Ernesto, 1995, for an analogue).

Small deviations in the paleomagnetic data from the Troodos Mean Vector could result from tectonic rotation or from secular variation of the earth's magnetic field. Paleomagnetic data is consistent with a minor rotation about a subhorizontal N-S axis. However, the tight clustering and small α_{95} values suggest that deviation from the TMV may be due to secular variation.

The lack of grain-scale plastic deformation features, the lack of strong field and paleomagnetic evidence for rotation, and the presence of a N-S AMS lineation both suggest that the foliation was not the result of plastic deformation in a detachment fault zone. This indicates that a detachment, if it exists in this area, is probably deeper within the ophiolite pseudostratigraphy, and may be located at or below the paleo-Moho.





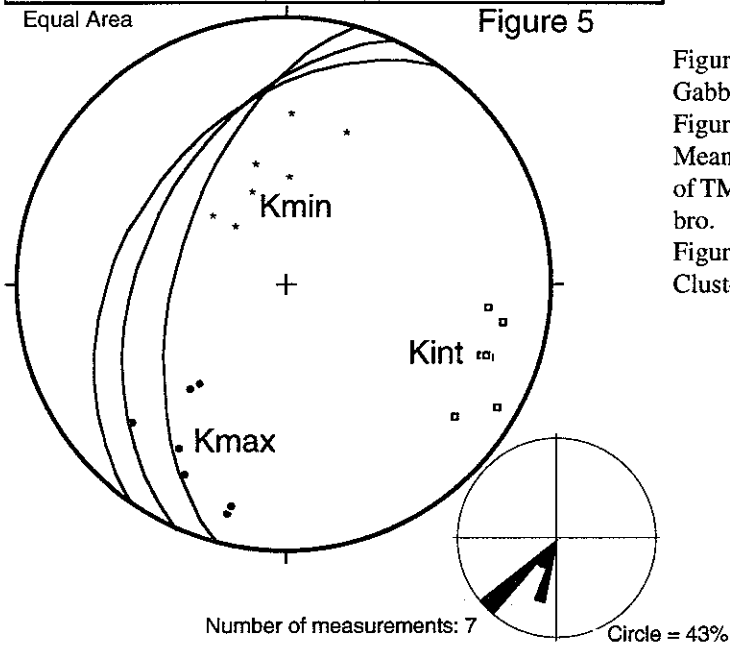


Figure 3: Foliation in Khandria and Kato Amiandos Gabbros is defined by matted plagioclase laths.

Figure 4: Site mean paleomagnetic vectors and Troodos Mean Vector. A_{95} circles for foliated gabbro overlap α_{95} of TMV. No α_{95} circle overlaps with α_{95} of massive gabbro.

Figure 5: AMS foliation lies in mineralogical foliation. Clustering of Kmax suggests N-S, dike-parallel flow.

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