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Paleomagnetic arguments for block rotations along the Arakapas fault (Cyprus)

N. Bonhommet
Laboratoire de Géophysique Interne, Centre Armoricain d'Etude Structurale des Socles
Institut de Géologie, Université de Rennes I, 35042 Rennes, France
P. Roperch
Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM)
Département TOA, 213, rue La Fayette, 75480 Paris, France
F. Calza
Laboratoire de Géophysique Interne, Centre Armoricain d'Etude Structurale des Socles
Institut de Géologie, Université de Rennes I, 35042 Rennes, France

ABSTRACT

Paleomagnetic data from the sheeted dike complex north of the Arakapas fault reveal significant internal rotations. The north-south-trending dikes have remanent magnetization directions close to the well-known westerly paleomagnetic direction of the Troodos massif, whereas the east-west-trending dikes near the Arakapas fault have northerly remanent magnetization directions. The paleomagnetic data are in agreement with the apparent clockwise rotation of the dikes. Contrary to recent geological analyses which postulate that the pattern of dike trends is due to dike injection into a sigmoidal stress field along a sinistral transform fault, the paleomagnetic results indicate clockwise rotations about vertical axes in response to a dextral shear. In addition to the rotations around vertical axes, small rotations around subhorizontal axes are inferred from the paleomagnetic data for tilted dikes. Thus, these data reinforce the vertical intrusion hypothesis.

INTRODUCTION

Sheeted dike complexes are among the most convincing items of evidence for origin of ophiolites in an oceanic spreading context. Among all ophiolite sequences, the Troodos massif provides one of the best developed sheeted dike systems with a general north-south orientation. This unity, however, is disrupted to the south adjacent to the Arakapas fault, which trends approximately perpendicular to the general dike trend of the massif (Fig. 1). From this characteristic, it has been argued that this fault might be a remnant of a fossil transform fault. If so, it would provide an interesting on-land study of one of the major oceanic structures. The progressive change in dike orientations from north-south to east-west near the Arakapas fault has been and still is the subject of controversies regarding the origins of the fault and the sense of movement along it. Interpretations of the apparent change in dike trend generally correspond to two alternative processes (Fig. 2): (1) dike injection into a sigmoidal stress field and (2) clockwise block rotations due to horizontal drag produced by a dextral movement along the fault.

Simonian and Gass (1978) were in favor of the first hypothesis because of the broad deviation zone. Comparison with recent analyses of oceanic transform-fault structures (Fox and Gallo, 1984) has led to the proposition that the Arakapas fault belt is a sinistral fossil transform fault (Varga and Moores, 1985; Murton and Gass, 1986; Murton, 1986). However, structural data from near the Tjornes fracture zone in Iceland are in agreement with clockwise rotation along that dextral transform fault (Young et al., 1985). Therefore, it seems that the present knowledge of deformations that occur along transform faults might not be sufficient to constrain the sense of movement along the Arakapas fault. On the other hand, a dextral shear was postulated by Moores et al. (1984) in their model for the origin of the Troodos massif.

The second hypothesis for the Arakapas fault zone involves a simple dextral shear. If block rotations were proven, the nature of the Arakapas fault and the age of its main activity would need to be evaluated.

In an attempt to bring new insight to this problem, we have undertaken a paleomagnetic sampling of dikes that have various orientations. Any relation between magnetization and dike strike would imply internal rotation in the sheeted dike complex related to the Arakapas fault. On the other hand, a uniform direction of magnetization independent of the obvious large deviations in strike would imply a sigmoidal stress field during cooling of the dikes.

Paleomagnetic studies of pillow lavas and sediments (Vine et al., 1973; Shelton and Gass, 1980; Lauer and Barry, 1979; Clube et al., 1985) demonstrated clearly that the ophiolitic massif underwent an anticlockwise rotation in Late Cretaceous–early Eocene time. However, preliminary results on dikes were not conclusive; Lauer (1981) argued for secondary magnetizations in the dikes. Hydrothermal metamorphism can produce secondary magnetic minerals, which may cause a complex magnetization. Therefore, we have performed detailed thermal or alternating field demagnetizations in an attempt to isolate the primary component of the natural remanent magnetism of the rock.

SAMPLING

We sampled 15 sites in the sheeted dike complex north of the Arakapas fault, and reliable paleomagnetic results were obtained for 13 sites (Fig. 1). The thickness of most dikes ranges between 0.5 and 2 m. Most sites are almost vertical or have steep attitudes. Site Y has been part of a detailed structural and geochemical study of the sheeted dike complex (Baragar et al., 1987). At this site, the chilled margin distribution did not show any clear evidence for a preferential sense of spreading. Each site consisted of a few dikes, and one or two standard cylindrical samples

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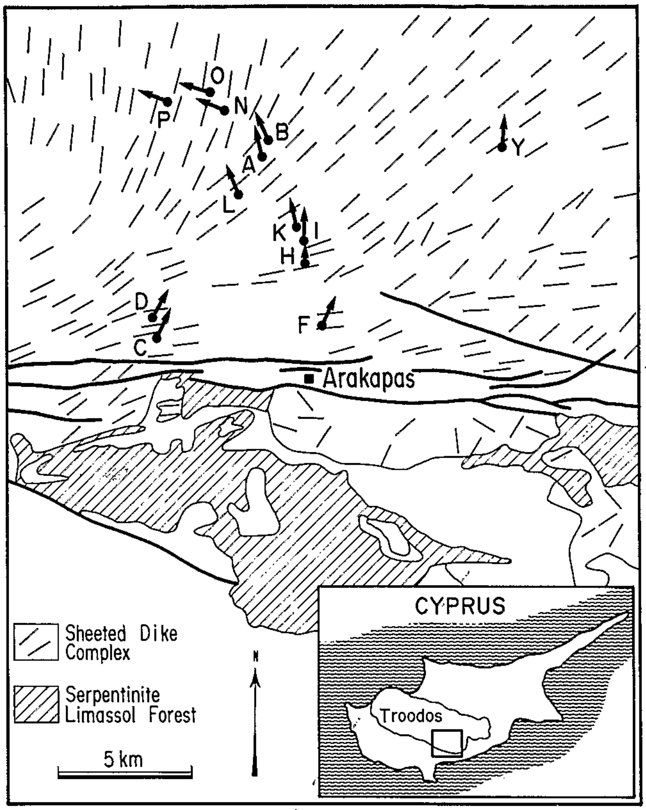

Figure 1. Simplified geologic map (from Simonian and Gass, 1978, Fig. 2) showing sheeted dike trend and sampling sites and paleomagnetic declinations obtained after tilt correction (assuming that dikes were intruded vertically).

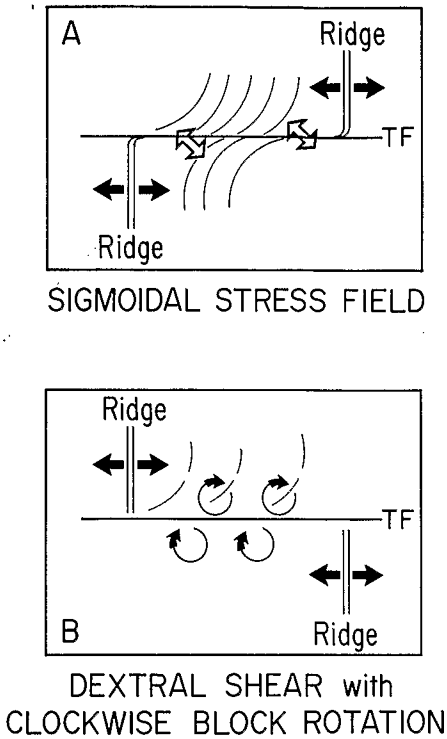

Figure 2. Simple sketch explaining two models for origin of deviation of dikes. A: Dike injection in sigmoidal stress field with relative sinistral displacement along transform fault (TF). B: Block rotation during dextral displacement along fault.

were drilled per dike. The magnetic measurements were carried out with Schonstedt equipment.

MAGNETIC PROPERTIES

The frequency distribution of the natural remanent magnetization intensities shows a broad spectrum (Fig. 3a). Nevertheless, most of the samples have intensities around 1 A/m and corresponding susceptibilities around 0.003 Gs/Oe (Fig. 3b). These values can be compared with recent results from Deep Sea Drilling Project (DSDP) Leg 83, which penetrated an oceanic sheeted dike complex; these results indicate that the magnetization of this layer is higher than previously estimated (Smith, 1985). The 1 A/m intensity value found in the Troodos sheeted dike complex is directly comparable with the Leg 83 value obtained at a drilling depth of 200–1300 m in the sheeted dikes under the transition zone.

Most of the samples from Troodos have a Curie point of magnetite. Some samples have irreversible saturation magnetization (Js) vs. temperature (T) curves with a Curie point around 300 °C indicative of titanomaghemite in the sample. This magnetic phase is destroyed during heating; however, original magnetites are responsible for the high Curie point found in all experiments.

Previous studies on the magnetic properties of ophiolite in Cyprus and around the world (Banerjee, 1980; Swift and Johnson, 1984) show that magnetites are common in dikes and result from greenschist metamorphism. Two issues to be dealt with are (1) timing of this metamorphism and (2) the primary nature of the remanence for these samples.

The greenschist metamorphism is contemporaneous with the accretion, as indicated by isochron dating (Desmet et al., 1978). The time duration was estimated by Staudigel et al. (1986) to have been less than 15 m.y. The age of the ophiolite itself is about 90 Ma. Because paleomagnetic results on sediments (Clube et al., 1985) date the rotation of Cyprus as Late Cretaceous–early Eocene time, the magnetization carried by the sheeted dike complex, even if it is of chemical origin, should have recorded this rotation.

Viscous remanences were interpreted by Clube et al. (1985) to explain dispersion of the results from the sheeted dikes. It is certain that viscous remanent magnetizations (VRM) may be acquired by oceanic basalts or ophiolites (Beske-Diehl and Banerjee, 1980). Our experience with the Troodos samples is not conclusive. A viscous test during 10 days in the laboratory was not indicative of large VRM acquisition.

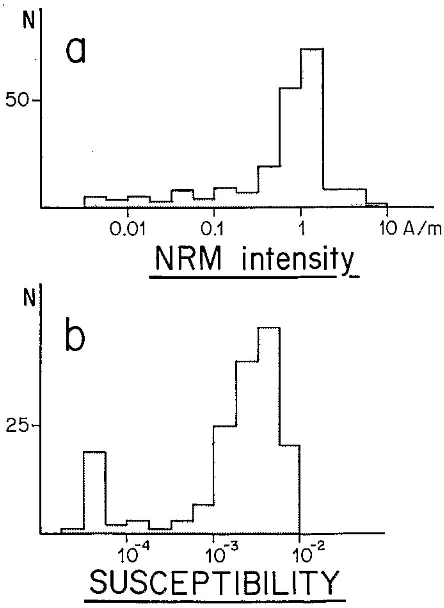

Figure 3. a: Frequency distribution of intensities of natural remanent magnetization (NRM). b: Frequency distribution of magnetic susceptibility.

Alternating-field (AF) demagnetizations were generally not as efficient in isolating the characteristic magnetization as was thermal demagnetization. A complete cleaning of the samples was not effective at 100 mT, which is the maximum peak field obtained with our Schonstedt GSD1 demagnetizer. It was observed that the magnetic directions carried by the pure magnetite phase were not always identified by AF, whereas thermal demagnetization generally enables a good separation of remanence components (Fig. 4). This is easily understood by the behavior of the samples during Js-*T* experiments. The magnetic phase having a Curie point around 300 °C is destroyed during heating, leaving the samples with a single magnetic phase of magnetite. Therefore, we have decided to use, preferentially, the high-temperature components. Detailed demagnetization data have been analyzed by means of graphical interpretation of Zijderveld diagrams and fitting a straight line upon the last points of the demagnetization diagram through the origin. A mean direction per site was determined by using Fisher statistics (Table 1).

The dispersion of the magnetic vectors, at the site level, which is characterized by low values of the Fisher precision parameter K (Table 1) is not well understood. For instance, we are not able to relate the variations of the magnetic directions to individual structural dike attitudes. The magnetization acquisition process would need to be more thoroughly investigated.

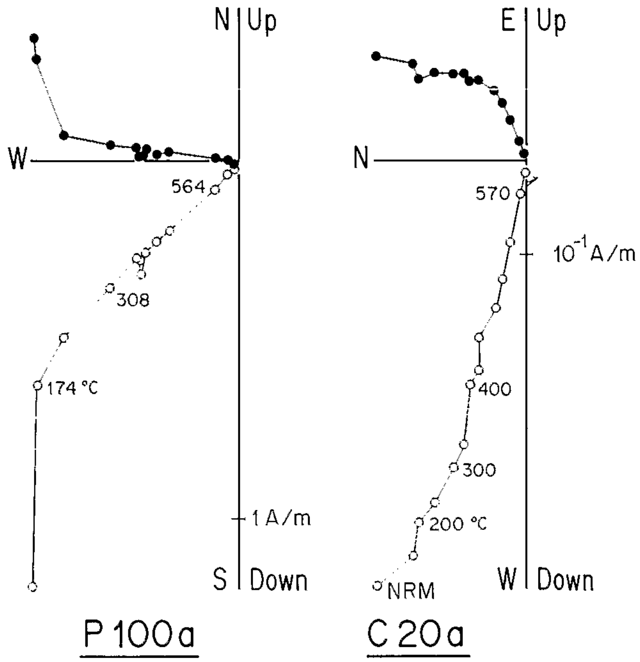

Figure 4. Examples of thermal demagnetizations on Zijderveld diagrams. Solid symbols: projection onto horizontal plane; open symbols: projection onto vertical plane.

TABLE 1. PALEOMAGNETIC RESULTS, TROODOS OPHIOLITE, CYPRUS

Site	n /N	In situ dec (°)	In situ inc (°)	K	α95	S, D (°)	Dip corr dec (°)	Dip corr inc (°)	reoriented dec (°)	reoriented inc (°)
A	4 /4	356	60	62	11.8	63, 65SE	347	36	284	36
B	7 /7	336	52	24	12.5	69, 90	336	52	267	52
C	9 /13	67	76	49	7.4	89, 61S	21	54	292	54
D	4 /5	99	65	29	17.4	90, 60S	46	55	316	55
F	4 /9	28	67	67	11.0	105, 90	28	67	283	67
H	3 /3	359	54	780	4.4	85, 90	359	54	274	54
I	6 /6	1	53	57	9.0	85, 90	1	53	276	53
K	5 /5	344	43	135	6.6	85, 90	344	43	259	43
L	7 /7	329	40	90	6.4	48, 82SE	328	32	280	32
N	8 /8	307	66	47	8.2	355, 75E	292	53	297	53
O	8 /8	282	40	126	5.0	15, 80E	282	30	267	30
P	7 /7	287	43	134	5.2	350, 90	287	43	297	43
Y	22 /26	55	66	31	5.6	67, 48SE	8	38	301	38
Mean										
In situ	13	342	64	9	14.5					
Cor/dip	13	341	53	9	14.4					
Cor/dip/N	13	283	48	29	7.9					

Note: n: number of independent samples included in site mean calculation; N: number of drilled samples per site; K: Fisher precision parameter; α95: semi angle of confidence at 95%; S, D: mean strike and dip per site; Dec, Inc: declination and inclination in situ, after dip correction (dip rotated to vertical about strike line), and after correction for dip of dike and reorienting dike to north south orientation.

RESULTS

From the results, it appears that the magnetic directions do not cluster close to the mean westerly direction expected for the Troodos complex (Fig. 5a). Results show, however, that the sites with dikes oriented north-south have the expected westerly direction, whereas sites with an east-west strike have an almost northward declination (Fig. 1). If we assume that the original structural attitude of the sheeted dike complex corresponds to vertical, north-south–oriented dikes, we propose the following corrections.

1. We assume that the dikes are intruded vertically. Although it is difficult to determine the amount of tilting without knowing the paleohorizontal, it seems that tilting is common and may account for the steep inclination of the magnetizations. Despite this difficulty, we have performed a tilt correction by assuming that the dikes have been rotated around the horizontal strike and that the dikes were originally vertical. This correction does not yield a distribution of directions around the expected western direction (Fig. 5b), but it does decrease the inclination toward that observed in the sedimentary rocks of the Troodos complex. An example is given by site Y (Table 1). This procedure may find some support if listric faults perpendicular to the direction of extension are present in the accreting zone (Verosub and Moores, 1981). A paleomagnetic investigation in the Solea graben in the northern part of the massif (Allerton and Vine, 1987) has confirmed this interpretation.

2. We assume that the dikes all had the same original orientation and make a strike correction involving the alignment of the dikes into a north-south direction. The complexity in the tangle of the dikes results from successive families of dikes (Desmet et al., 1978) or from the accreting process (Baragar et al., 1987). Thus, we determine a mean structural correction by averaging dike attitudes at each site. Application of this strike correction significantly decreases the dispersion of the data and shows the significant relation between the magnetic vector and

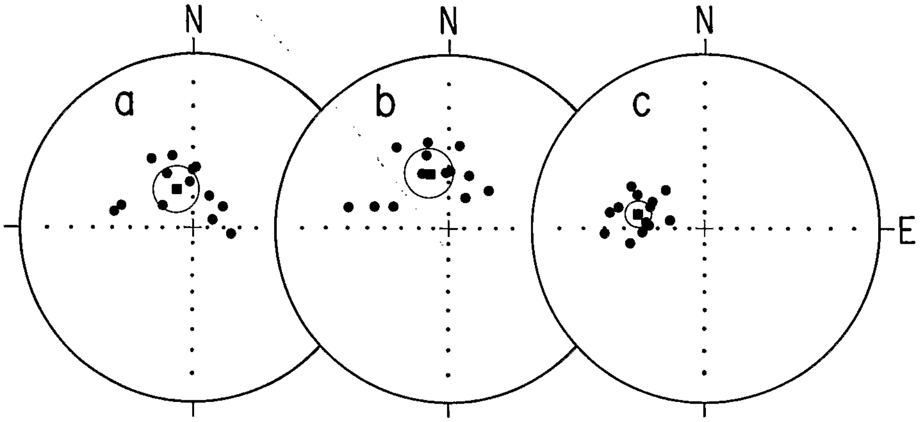

Figure 5. Stereographic projection of mean paleomagnetic results: (a) in situ; (b) after bedding correction, assuming that dikes were intruded vertically; (c) after bedding correction and reorientation of strike of dikes in north-south direction. Circles are site-mean directions from Table 1; and squares with circle of confidence are their respective means.

the orientation of the dikes (Fig. 5c). Moreover, the mean direction (283°, 48°) is not far from the characteristic direction from pillows and sediments given by Clube et al. (1985; 274°, 36°).

CONCLUSIONS

1. A reliable magnetization is carried by the sheeted dike complex. The magnetic carrier is mainly pure magnetite.

2. The simplest interpretation of the data indicates that tilting and rotation in the sheeted dike complex occurred after the acquisition of the magnetization.

3. The clockwise rotation of paleomagnetic vectors observed in the north part of the Arakapas fault shows that dike injection in a sigmoidal stress field is not an appropriate model.

4. Our data indicate that rigid rotations may occur along transform faults. An alternative interpretation would be that the Arakapas fault results from a simple dextral shear, and such rotations are well known in regions of strike-slip faulting (Ron et al., 1984; Nur et al., 1986). Simonian and Gass (1978) were impressed by the lack of fracturing of individual dikes in the deviation zone. Therefore, small blocks bounded by faults, without internal deformation, are needed to accommodate the observed rotations.

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