PALEOMAGNETIC STUDY OF THE TERTIARY VOLCANICS IN CHIOS ISLAND (GREECE)

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A B S T R A C T

The calcalkaline volcanic activity which characterizes the Central Aegea is manifested in Chios by Miocene products (14-17 Ma) mostly outcropping in the S-SE part of the island.

Paleomagnetic results previously published for the broader area show a complex pattern with coexisting clockwise and counterclockwise rotations. In order to further investigate this pattern, a paleomagnetic study of the above volcanics has been undertaken at seven sites distributed in the Emporios area (SE of the island). In most cases a stable component with normal polarity could be isolated. The obtained directions indicate an important counterclockwise rotation. This is in agreement with directions already obtained in sediments of the same age in the area, which are of mainly reversed polarity. The above results are discussed, together with new structural data, in the geodynamic frame of the region.

ΠΑΛΑΙΟΜΑΓΝΗΤΙΚΗ ΜΕΛΕΤΗ ΤΩΝ ΤΡΙΤΟΓΕΝΩΝ ΗΦΑΙΣΤΕΙΑΚΩΝ ΠΕΤΡΩΜΑΤΩΝ ΤΗΣ ΝΗΣΟΥ ΧΙΟΥ (ΕΛΛΑΔΑ)

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Π Ε Ρ Ι Λ Η Ψ Η

Η ασβεσταλκαλική ηφαιστειακή δραστηριότητα που χαρακτηρίζει το Κεντρικό Αιγαίο εκδηλώνεται στη Χίο με Μειοκαινικά προϊόντα (14-17 Μα) που κυρίως εμφανίζονται στο Ν-ΝΑ τμήμα του νησιού.

Παλαιομαγνητικά αποτελέσματα δημοσιευμένα για την περιοχή δείχνουν ένα περίπλοκο σύστημα με συνυπάρχουσες δεξιόστροφες και αριστερόστροφες περιστροφές. Για να διερευνηθεί αυτό, επιχειρήθηκε μια παλαιομαγνητική μελέτη των ηφαιστειακών του Εμποριού σε επτά τοποθεσίες. Στις περισσότερες περιπτώσεις απομονώθηκε μια σταθερή συνιστώσα με κανονική πολικότητα. Οι διευθύνσεις δείχνουν μια σημαντική αριστερόστροφη περιστροφή. Αυτό είναι σε συμφωνία με διευθύνσεις που προκύψανε από ιζήματα της ίδιας ηλικίας. Τα αποτελέσματα αυτά μαζί με νέα τεκτονικά δεδομένα σχολιάζονται μέσα στο γεωδυναμικό πλαίσιο της ευρύτερης περιοχής.

INTRODUCTION

The Aegean Sea is an area of thinned continental crust behind the active South Aegean arc and has experienced subduction - related igneous activity throughout the Neogene (Fytikas et al., 1984; Pe-Piper and Piper, 1989). The subducted plate has been traced by seismic tomography to a depth of 500Km beneath the northern Aegean Sea (Spakman et al., 1988). The widespread back-arc volcanism has been extensively studied and various theories proposed for its origin. For instance, Bocaletti et al. (1974) suggested that Paleogene arc volcanism in the northern Aegean region was related to an earlier subduction zone. Fytikas et al. (1984) regarded this scattered back-arc volcanism as related to the "extensional tectonic regime". Furthermore, Pe-Piper and Piper (1989) suggest that the subducted slab rather than extension is the most significant controlling factor on magmatism and that the current extensional regime with rotations and strike-slip motions provides pathways for the magma to reach the surface.

The distribution of volcanism in the Aegean can be divided into four groups according to Fytikas et al. (1984). The third of these groups with sodic alkaline basalts and hawaite has affected the central and southeast Aegean and adjacent areas of Turkey.

It is well known that since at least the late Miocene the westward motion of Turkey has been accompanied by N-S extension in the Aegean, with simultaneous E-W shortening (Dewey and Sengor, 1979; Le Pichon and Angelier, 1981; Mercier et al., 1987). Previous paleomagnetic data reported for the area showed that significant rotations in opposite senses of adjacent blocks have occurred there since 20 Ma (Kondopoulou and Lauer, 1984; Kissel et al., 1987; Zanchi et al., 1990). Because of the incompleteness and the large scatter of these data a paleomagnetic study of the Chios island volcanics was undertaken in summer 1991. We summarize here our first results.

GEOLOGICAL SETTING AND SAMPLING - RADIOMETRIC DATA

A group of sodic mafic rocks, of Miocene age, outcrops in Psathoura, Kalogeri, Samos, Urla, Foca and Chios. These magmas have several features close to ocean-island basalts and resemble subduction-related rocks (Pe-Piper and Piper, 1989).

In the island of Chios the volcanic centers are small and occur both within Neogene basins and on alpine basement (Besenecker et al., 1968). The alkalic - basalt and calc-alkali andesite composition, suggest a transitional (spatially and temporally) process from arc to back-arc volcanism (Pe-Piper et al., 1992).

Seven sites were sampled in the S-SE part of the island, distributed in the following areas:

a) Vroulidia Bay: Rhyolite outcrops in one main body and several smaller ones.

b) Mavra Votsala: Andesitic outcrops in the form of several columnar jointed flows.

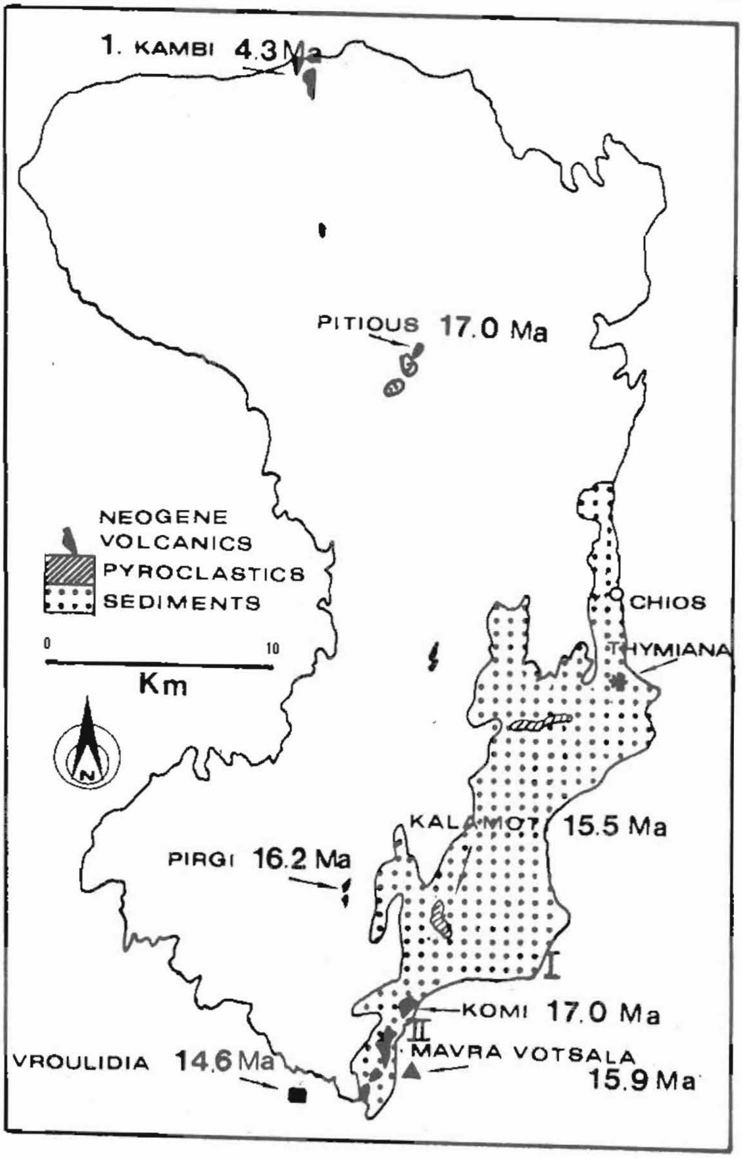


Fig.1. Simplified map of Chios (from Pe-Piper et al., 1992) and sampling sites. I,II localities of the neotectonic study.
* sediments of Thymiana
▲ andesites (sites 1-2-3-7)
■ rhyolites (sites 4-5-6)

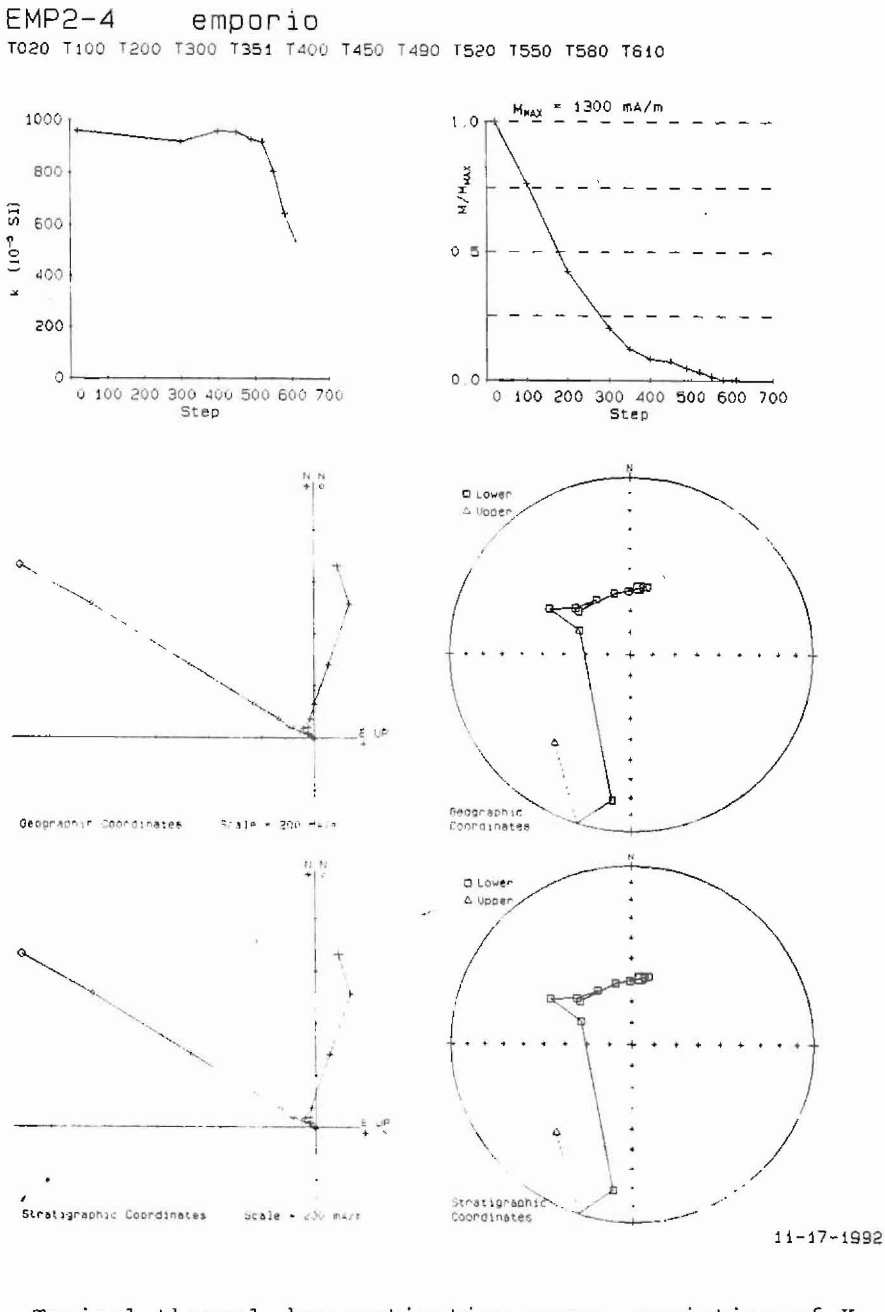


Fig.2a. Typical thermal demagnetization curve, variation of K, Zijderveld diagrams, stereographic projections.

K/Ar radiometric dating on whole rock samples indicates a single period of volcanic activity between 17 and 14 Ma (Bellon et al., 1979). The precise ages of our sites are

14.6 ± 0.8 for cape Oura - Vroulidia (a)

15.9 ± 0.8 for Emporios - Mavra Votsala (b)

At each site drilled cores were obtained over at least a few tens of meters and were oriented with both a magnetic and a sun compass.

A total of about 80 cores were sampled and cut in standard cylindrical specimens.

The studied area and the location of the sampling sites are shown in Fig.1.

LABORATORY METHODS AND RESULTS

Measurements of the NRM have been performed using either a spinner magnetometer (Univ. of Thessaloniki) or a three-axis cryogenic magnetometer (Univ. of Paris VI).

Intensities of NRM vary between 3.0×10^{-4} A/m to 1.5 A/m. At least one specimen per core has been stepwise demagnetized either by AF (Univ. of Thessaloniki) or thermally (Univ. of Paris VI) However the AF treatment yielded overall more consistent results. The mean destructive field is in the order of 70mT and blocking temperatures were around 580°. These observations suggest that the main magnetic carrier is fine grained magnetite. The low-field magnetic susceptibility for pilot samples was measured after each heating step. No significant change is shown up to 400°C but after this step a regular and progressive decrease is seen in almost all samples. This change can explain the unsatisfactory response of the samples to the thermal cleaning.

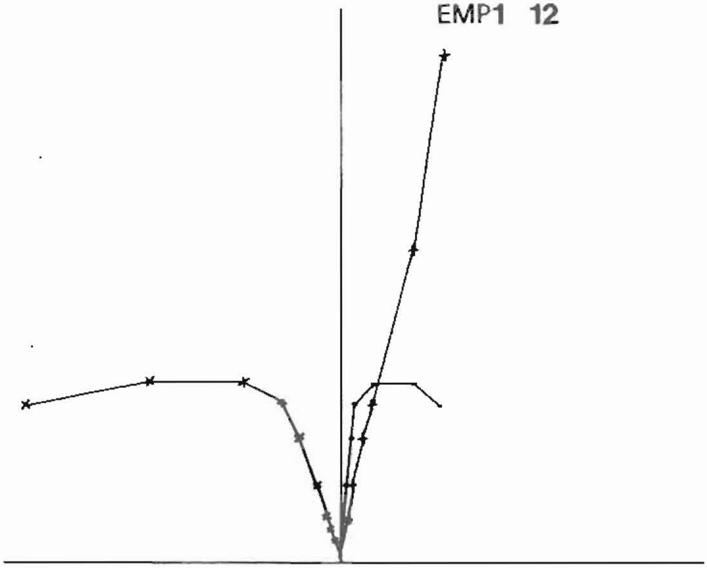


Fig.2b. Example of an AF demagnetization curve in Zijderveld projection.

Typical demagnetization diagrams are shown on Fig.2. In most cases the primary component could be calculated by using the best fit towards the origin. Nevertheless some samples submitted to thermal treatment show totally aberrant demagnetization curves and have been rejected from the calculation of mean direction. The reason for this phenomenon is not fully understood.

All sample directions are plotted in Fig. 3a and reliable site mean directions ($k \geq 15$) are reported in Table I. We notice that all the obtained directions are normal. We will discuss this in the last section together with directions obtained in sediments from a neighbouring area.

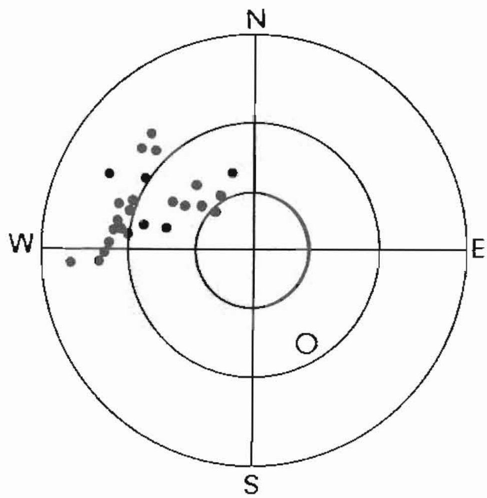


Fig.3a. Sample directions obtained from 27 samples in the lavas
○ Mean direction obtained in Thymiana sediments. (Kondopoulou et al., this volume)

STRUCTURAL ANALYSIS

A detailed study with microtectonic measurements and observations of the faults in SE Chios has been performed by one of us (C.S.). The studied localities are shown in Fig. 1. The microtectonic analysis, the histogramm and the statistical analysis of the obtained measurements are shown in Fig. 4.

The occurence of active faults in the area has also been mentioned by Besenecker (1973). An analogous estimations of major tectonic accidents in the area has been observed by Bellon et al. (1979).

Table I. Site mean directions obtained in the present study.

	N(samples)	Dec°	Inc°	K	a_{95}
EMP1	4	283.7	38.8	142	10
EMP2	5	296.5	31.1	31	14
EMP3	5	276.7	25.0	74	9
EMP4	4	321.5	54.6	30	17
EMP5	3	321.5	50.2	176	9
EMP6	4	309.6	26.5	60	16
EMP7	4	270.3	24.6	52	12

Mean direction A (1,2,3,7) N=4, D=281.5, I=30.2, K=47.1, a=13.5
Mean direction B (4,5,6) N=3, D=316.5, I=44.0, K=25.9, a=24.7

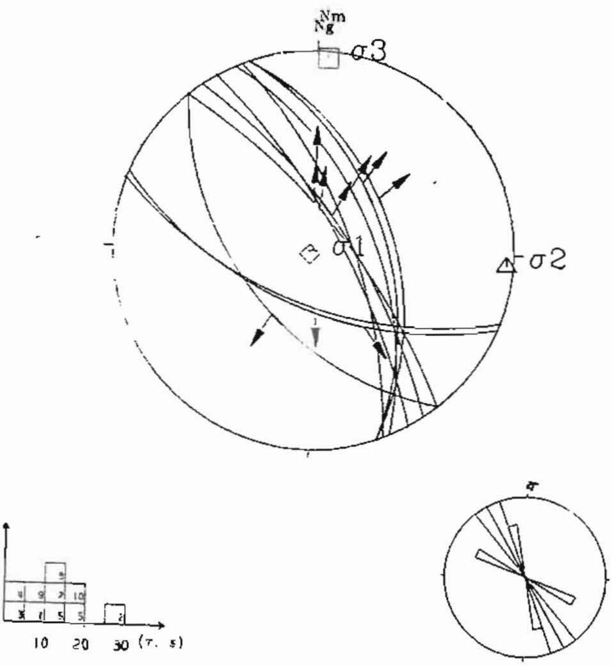


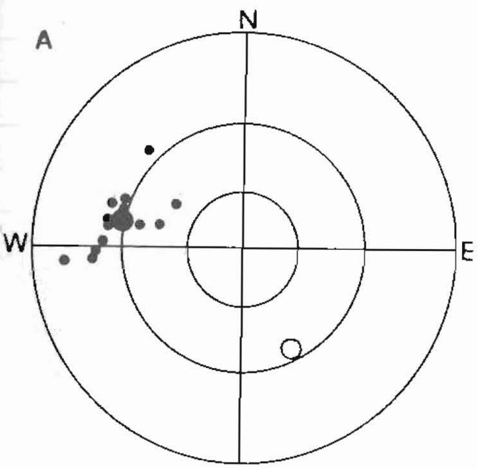
Fig.4. Microtectonic analysis histogramm and statistical analysis of neotectonic measurements in the study area.

From the configuration of the paleomagnetic directions we can observe two distinct groups, A and B.
A. with sites 1-2-3-7 near Vroulidia-cape Oura (14.6±0.8) Ma
B. with sites 4-5-6 near Emporio (15.9±0.8) Ma.

The two mean directions differ by an angle of N25° which cannot be fully explained by their difference in age (1.3 Ma). As group B is almost antipodal to directions obtained in sediments of the same age (Fig. 3a.), we can safely assume that this is the rigid rotation that Chios has suffered since 15Ma. The directions in group A could be due either to secular variation effects or, most probably, to an important sinistral movement on a stystem of parallel faults directed generally NNW-SSE which we can observe very close to the region of sampling. This system of faults belongs to the basement and is related to dextral normal or extentional movements but it has been reactivated during the Quaternary with a sinistral normal or extentional movement with σ_3=N3 (Fig. 4.)

DISCUSSION

The obtained mean directions in the Chios lavas have been divided into two groups according to the distribution of sites and their age (Fig. 3b). Group A (sites 1-2-3-7) belongs to Vroulidia Bay rhyolites with an age of 14.6±0.8 Ma. Group B (sites 4-5-6) is in Emporios andesites with an age of 15.9±0.8 Ma. The A direction (D=282° I=29.5°) is strongly deviated to the west whereas the B direction (D=317° I=45°) is closer to other directions obtained in the broader area. Namely, sediments of the same age from Thymiana (40 Km to the North) yield a mean direction with D=155° I=-35.3° (reverse) (Kondopoulou et al., this volume). This direction is not exactly antipodal to the B direction from the lavas but is deviated also to the west with an opposite polarity which is a good indication of a promising result.



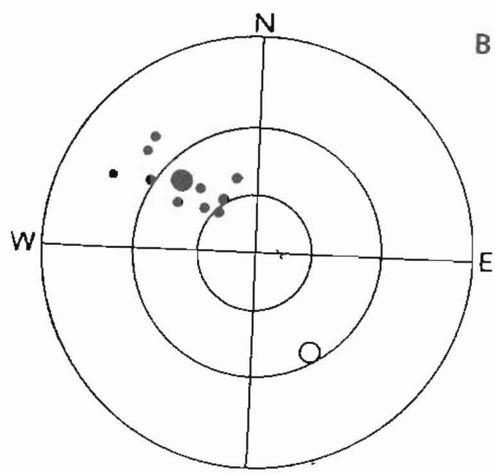


Fig. 3bi Group A
● Mean direction in lavas
○ Mean direction in sediments

Fig. 3bii Group B
● Mean direction in lavas

In order to evaluate this result we have compared it to data obtained in neighbouring areas (Table II). In Samos and Lesbos in lavas of 6.5 Ma and 15-18 Ma respectively no rotation or a slight counterclockwise (CCW) one is demonstrated (Samos). In western Turkey, opposite to Chios, the pattern is quite complex. A closer examination of directions, nevertheless, reveals that the only reliable ones (Izmir area) correspond to a CCW rotation of about 30° since 17 Ma. The two other regions, showing CW rotations, display bad or even unacceptable statistics. We can thus conclude quite safely that in the broader area the dominating pattern as deduced from reliable paleomagnetic data favours either no rotations (Samos, Lesbos) or counterclockwise ones (Western Turkey, Chios) (Fig. 5.)

This conclusion is consistent with the pattern of rotations suggested by several independent tectonic models for the area. For instance Sonder and England (1989) propose clockwise rotations for the western part of central Aegean and counterclockwise ones for the eastern part. According to Jackson et al. (1992) in the eastern part of central Aegean both CW and CCW rotations can occur but the preferable ones are CCW. Westaway (1990 a,b) suggests that most of the domains in W.Turkey rotate counterclockwise. Finally, Jolivet et al. (1992) define a rotation pole A in the eastern part of the Aegean and claim that extension in this area proceeds through counterclockwise rotations about this pole.

Table II. Paleomagnetic results obtained in the broader area.

Area	Age Ma	N sites	D	I	K	a_{95}	Ref.
Cannakkale	-	4	6	54	254	4.3	(1)
Lesbos 1	15.5-18	10	12.4	48.9	11.4	14.8	(2)
Lesbos 2	15.5-18	17	6	49	25	6.8	(1)
Izmir- Bergama	7-18	13	327	52	20	8.7	(1)
South of Bergama	17.5	3	22	39	16	20.2	(1)
Karaburun - Cesme	17-21	8	49	51	9	16.4	(1)
Samos	6.5	-	353	51.2	18.4	4	(3)

(1) Kissel et al., 1987.
(2) Kondopoulou, 1982.
(3) Sen and Valet, 1986

The regional setting of the Neogene volcanics in Chios and in the broader area has been extensively studied by Pe-Piper et al. (1992). In the proposed model it is suggested that changes in subduction rates will produce changes in the distribution and type of igneous products. Such a change in the relative motion of Africa and the Aegean plate probably occurred in the Middle Miocene where a significant decrease in the rates of convergence of these plates is assumed. More precisely, subduction was relatively rapid from late Oligocene to about 17 Ma and was followed by a slow phase from 17 to 11 Ma. The Chios volcanics would belong to this last phase. At the present state of knowledge we cannot definetely conclude that this change corresponds to the important CCW rotation (between 30°-45°) measured in the area. Furthermore the youngest site which recorded this rotation is in the Izmir area (7.0 Ma) and allows us to suppose that this westward motion is probably related to a bulk rotation of the region (Zanchi et al., 1990).

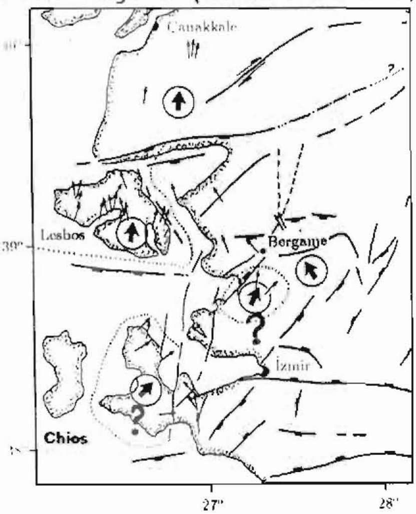


Fig.5. Mean paleomagnetic declinations in the broader area (from Kissel et al., 1987) (Arrows in circles). The CW directions with? indicate the poorly defined ones.

From all the above we conclude that our results enlighten the complex rotational pattern in W.Turkey by pointing out that counterclockwise rotations prevail in the area and that the clockwise ones need further clarification. At the same time the obtained sense of rotation agrees with the general pattern of deformation from independent models. A lot of supplementary paleomagnetic data in the broader area are needed to support either a lithospheric or a block-rotational movement.

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