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Paleomagnetic results from the Pindos, Paxos, and Ionian zones of Greece

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ABSTRACT

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Maastrichtian to Miocene sediments were sampled at 12 sites in central Greece (Meso-Hellenic basin, Pindos zone and Western Thessaly unit) and four sites on Lefkas island (Paxos and Ionian zones). The samples were subjected in the laboratory to thermal and alternating field (AF) cleaning. As a result, characteristic remanent magnetizations (ChRMs) were obtained for 11 sites. In comparing these paleomagnetic directions with others already obtained for the external Hellenides, the following points are noteworthy.

(1) In post-Alpine times a slight clockwise rotation seems to be common to the zones of the external Hellenides in Western Greece;

(2) independent movement of the Pindos flysch and the Ionian Paleogene sediments is plausible as the sampled sites from the former exhibit large counter-clockwise declination rotation with respect to the latter;

(3) the net rotation of the Mesozoic sediments of both Pindos and Ionian zones is similar.

These observations may indicate that the two zones rotated independently as 'blocks' before the Miocene, for the detachment of the Paleogene from the Mesozoic sediments is opposed on geological grounds. Thus the similar declinations observed for the Mesozoic sediments of the Pindos and Ionian zones must be regarded as coincidence.

1. Introduction

In the course of a short field trip in 1986, oriented hand-samples for paleomagnetic measurement were collected from the external zones of the Hellenides (Fig. 1). Of the 16 sedimentary sites (112 samples), 12 sites represent the central part of continental Greece (Pindos zone, Western Thessaly unit and Meso-Hellenic basin) and four sites the Paxos and Ionian zones in Lefkas (Fig. 2).

A 45° Cenozoic clockwise rotation has been established for the Ionian zone by two independent studies (Horner and Freeman, 1983; Kissel et al., 1985). A smaller rotation, but again clockwise, was observed for sediments of 1–13 Ma on the Ionian islands, covering both the Paxos and Ionian zones. This rotation started 5 Ma ago and its total amplitude amounted to 26° (Laj et al., 1982). From the internal zones of the Hellenides a few paleomagnetic directions which indicated moderate clockwise rotation were reported for the Eocene sediments of Chalkidiki (Kondopoulou and Lauer, 1985). Paleomagnetic results for the Jurassic and Cretaceous sediments of the Ionian zone remained unpublished (Horner, 1983) despite their high quality. These results suggest an apparent counter-clockwise rotation of the pre-Cenozoic with respect to the Paleogene sediments.

By sampling late Cretaceous sediments in the Pindos (sites GR 11-15, GR 25-39 and GR 59-67) and Paxos (site GR 77-80) zones, and Paleocene deposits in the Western Thessaly unit (sites GR 40-43 and GR 53-58), it was intended to compare

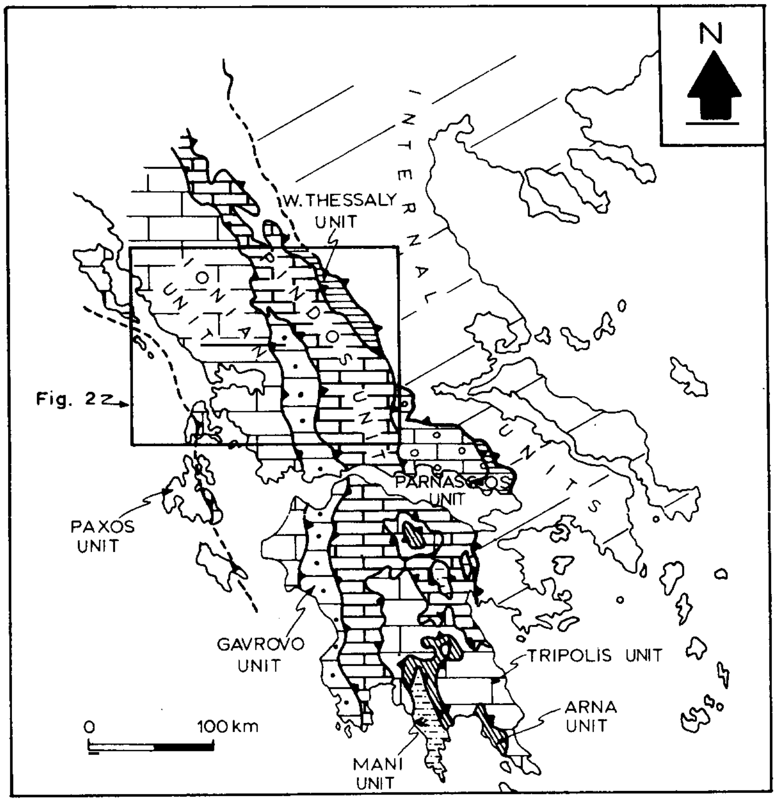

Fig. 1. Simplified geotectonic map of Western Greece showing the location of the area of interest.

the paleomagnetic directions of sediments deposited before the major orogenic events with those from the Ionian zone. On the other hand, the molasse of the Meso-Hellenic basin, which covers transgressively the Alpine Formations of the Pindos and Western Thessaly units (Papanikolaou and Sideris, 1977; Papanikolaou et al., 1986) was tested (sites GR 16-20, GR 21-24 and GR 44-52) to obtain a 'reference direction' relative to which the nappe emplacement in the more external zones (Ionian and Paxos) could be described.

Synorogenic flysch of Paleocene–Eocene age (Pindos zone: sites GR 1-5, GR 6-10, GR 68-72 and GR 73-76), Eocene limestone (Ionian zone: sites GR 93-98 and GR 99-112) and Eocene–Oligocene limestone (Paxos zone: site GR 81-92) were expected to yield paleomagnetic directions which would match in age those already found for the Ionian zone.

2. Results

The natural remanent magnetizations (NRM) of standard size cores drilled from oriented hand-samples were studied in the laboratory. The remanence was measured on JR-4 spinner magnetometers, and the susceptibility on a KLY-2 susceptibility bridge. Pilot samples, i.e. practically half of the collection, were subjected to stepwise thermal demagnetization in a Schoenstedt oven or to progressive alternating field (AF) cleaning in either a Schoenstedt or a non-commercial AF demagnetizer.

Molasse from the Meso-Hellenic basin was efficiently demagnetized by both methods (Fig. 3),

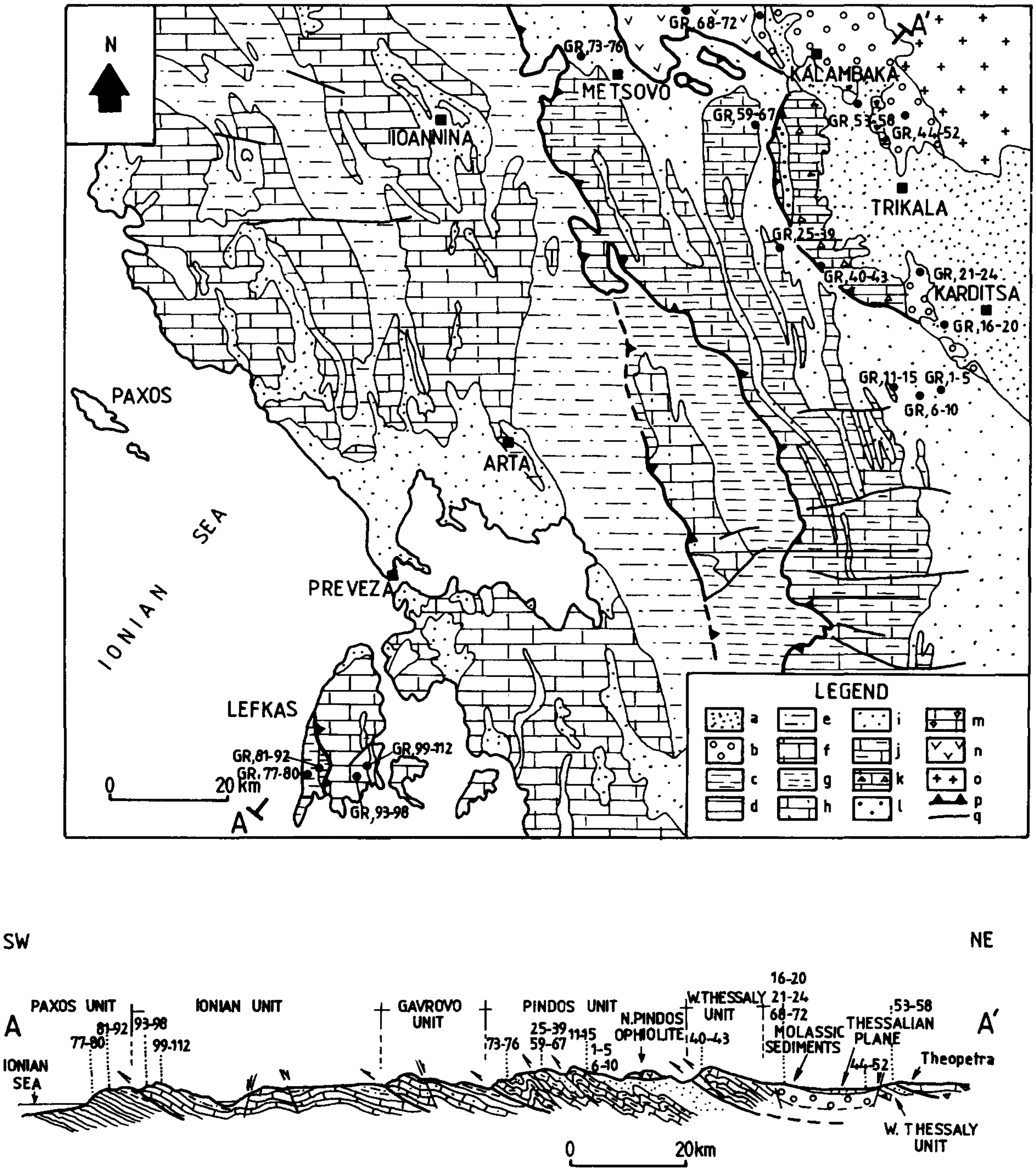

Fig. 2. Simplified geological map of Central–Western Greece (upper) and schematic SW–NE tectonic profile (lower), both showing the sampling sites (GR 1-5–GR 99-112). a, Quaternary formations; b, Oligocene–Miocene molassic formations of the Meso-Hellenic basin: c, Miocene clastic formations of the Paxos unit; d, Middle Jurassic–Oligocene formations of the Paxos unit; e, Upper Eocene–Oligocene flysch of the Ionian unit; f, Pre-flysch formations of the Ionian unit; g, Upper Eocene–Oligocene flysch of the Gavrovo unit; h, Pre-flysch formations of the Gavrovo unit; i, Maastrichtian–Eocene flysch of the Pindos unit; j, Pre-flysch formations of the Pindos unit; k, Pre-flysch formations of the Western Thessaly unit; l, Maastrichtian–Eocene flysch of the Western Thessaly unit; m, Cretaceous limestones; n, North Pindos Ophiolite; o, Pelagonian metamorphic; p, overthrust; q, fault.

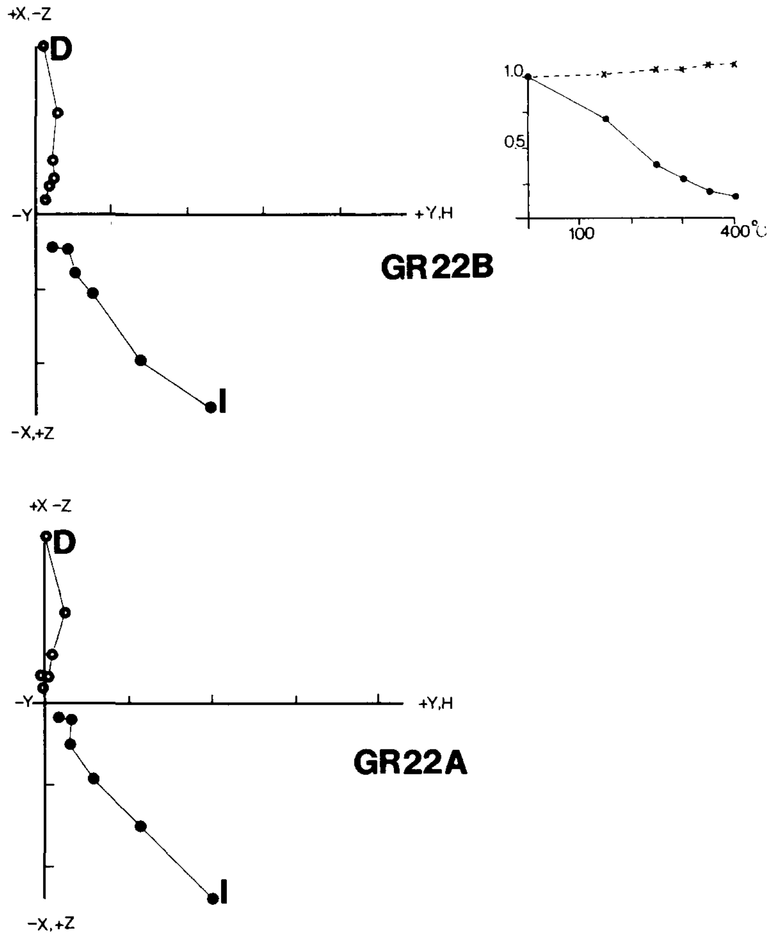

Fig. 3. Typical demagnetization diagrams for the molasse from the Meso-Hellenic basin. Left: modified Zijderveld projections of the remanence vector of sister specimens. Unit = 1.6*E* − 3 A m^{-1}. GR22B: thermal demagnetization, six steps: NRM–400 °C GR22A: AF demagnetization, six steps: NRM–50 mT. Right: normalized intensity (dot) and susceptibility (cross) as a function of cleaning temperature: specimen GR22B.

and a single component was isolated above 150 ° or 10 mT. This component permitted the definition of the characteristic remanent magnetization (ChRM) for three sites (Table 1).

The NRM of the flysch proved to be more varied in behaviour than that of the Miocene sediments. Although at site GR 6-10, for example, it was as simple as the NRM of the molasse, at site GR 1-5 AF cleaning failed to give any result. On thermal demagnetization the overprint was removed (Fig. 4). However, full demagnetization was not achieved, because of the newly formed magnetic phase on heating above 400 ° C.

ChRM could be isolated for two sites only (Table 1). However, for site GR 73-76 the tendency to shift towards the site mean directions determined for GR 1-5 and GR 6-10 may be recognized (Fig. 5). Samples from site GR 68-72 had to be rejected because of highly unstable behaviour of the NRM on both AF and thermal cleaning.

Weak NRM characterized the Cretaceous and

TABLE 1

Paleomagnetic results from central Greece and Lefkas island

Sampling site long E, lat N	Rock type	N/N_0	D	I	k	α_{95}	D_c	I_c	k	α_{95}	Polarity
Meso-Hellenic basin, Miocene											
GR 16-20 21.82, 39.41	Molasse	5/5	9	48	18	18	20	30	19	18	Normal
GR 21-24 21.82, 39.41	Molasse	4/4	19	56	27	18	32	40	27	18	Normal
GR 44-52	Limestone	8/9	350	44	13	16	352	38	19	13	Normal
Pindos zone, Paleocene–Eocene											
GR 1-5 21.78, 39.32	Flysch	4/5	150	−47	27	18	174	−23	27	18	Reversed
GR 6-10 21.78, 39.32	Flysch	5/5	311	0	6	32	311	42	11	24	Normal
Pindos and Western Thessaly units, late Cretaceous and Paleocene											
GR 11-15 21.75, 39.24	Limestone	4/5	342	67	57	12	20	−2	57	12	Mixed
GR 25-39 21.61, 39.39	Limestone	5/15	312	51	12	23	22	50	102	8	Normal
GR 53-58	Limestone	3/6	219	−43	17	30	30	47	23	26	Reversed
GR 59-67 21.50, 39.67	Limestone	7/9	22	48	32	11	76	48	60	8	Normal
Ionian zone, Lefkas island, Eocene											
GR 99-112 21.71 38.66	Limestone	9/14	268	75	15	13	90	43	17	13	Mixed
Paxos zone, Lefkas island, Eocene–Oligocene											
GR 81-92	Limestone	13/13	6	50	18	10	23	32	6	16	Normal

N/N_0 = number of samples evaluated/collected. D, I and Dc, Ic = mean declination and inclination before and after tilt correction. k, α_{95} = statistical parameters (Fischer, 1953).

Paleocene limestones from the Pindos and Western Thessaly units. Nevertheless, at least some of the samples at each site yielded a reasonably well-defined component (Fig. 6). Even samples from site GR 11-15, with extremely weak remanence, yielded meaningful magnetic signals with normal and reversed magnetizations 180° apart (Fig. 7). Characteristic remanences for four Cretaceous sites are tabulated (Table 1).

From Lefkas island, sites GR 81-92 (Paxos zone) and GR 99-112 (Ionian zone) yielded characteristic magnetization (Table 1) as a result of thermal cleaning (Fig. 8), although sites GR 77-80 and GR 93-98 had to be rejected, the first because of extremely weak NRM, the second because of high within-site scatter.

3. Discussion

Post-Alpine sediments of Miocene age for the Meso-Hellenic basin are characterized by an overall mean magnetic direction of $D = 4°$, $I = 50°$, $k = 51$, $\alpha_{95} = 17°$ before, and $D_c = 15°$, $I_c = 37°$, $k = 23$, $\alpha_{95} = 26°$ after tilt correction. Increasing scatter on tilt correction suggests that the magnetization was acquired in the present position of the Miocene strata.

For the same basin, Oligocene detrital sediments from seven sites yielded an overall mean of $D = 27°$, $I = 47°$, $k = 25$, $\alpha_{95} = 10.4°$, after tectonic correction (Kissel and Laj, 1988). Based on these data we may assume that the Ionian islands, the Meso-Hellenic basin, and probably

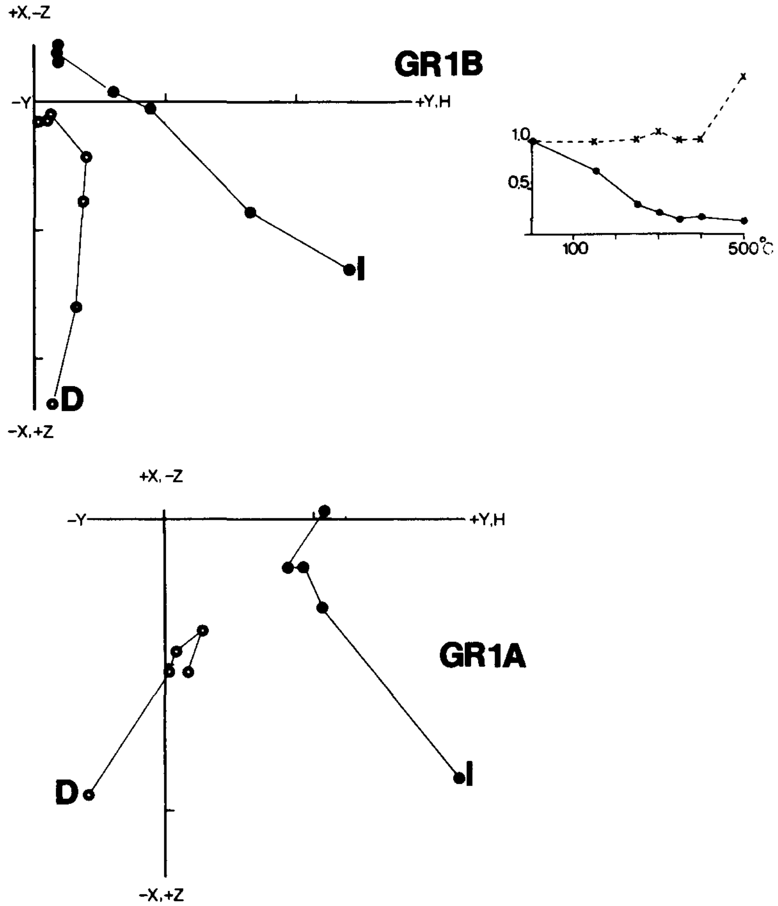

Fig. 4. An example of the behaviour of the flysch from the Pindos zone during progressive demagnetization. Left: modified Zijderveld projection of the remanence vector of sister specimens. Unit = $4.5E-4$ A m^{-1}. GR1B: thermal cleaning, seven steps: NRM–500 °C. At 500 °C cleaning was repeated with X and Z in opposite directions in the oven, and identical directions were obtained. Further demagnetization did not seem practicable. GR1A: AF cleaning, five steps: NRM–40 mT. Instability prevented the isolation of a ChRM. Right: normalized intensity (dot) and susceptibility (cross) as a function of cleaning temperature: specimen 1B.

the area between, rotated slightly in the clockwise sense in post-Oligocene times (Fig. 9).

The flysch sampled from the Pindos zone, in contrast, rotated in the opposite sense. The counter-clockwise rotation shown by two sites with well-defined site mean direction geographically close to each other (GR 1-5 and GR 6-10) and indicated by a third site (GR 73-76) nearly 100 km from the first two (Fig. 5) is moderate with respect to the present orientation. However, it is large compared with the clockwise rotation found for the Oligocene flysch and Eocene limestone in the Ionian zone. Comparison cannot be made with the Paxos unit, for the result shown in Table 1 must be a secondary magnetization.

The observations so far discussed are not difficult to explain with the help of a schematic paleogeographic reconstruction of the external Hellenides (Fig. 10). This reconstruction shows the Ionian and Pindos zones as two unconnected basins in the late Cretaceous. The sediments of these basins were independently overthrust on neighbouring platforms—the sediments of the Ionian zone over the Paxos units, and those of the

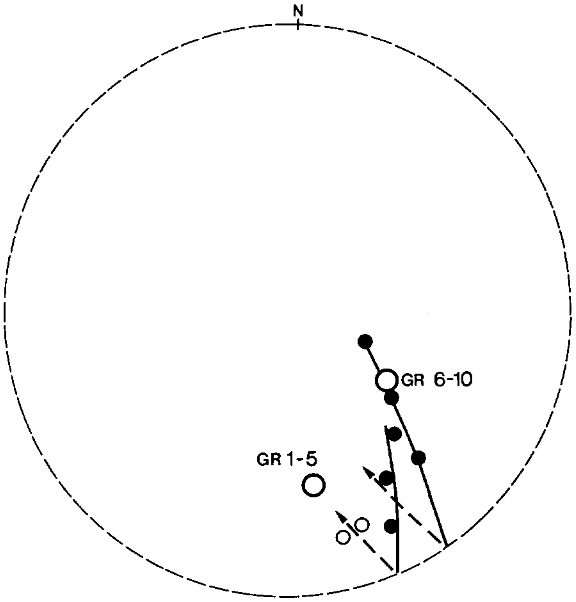

Fig. 5. Pindos zone, flysch. Tendency shown by NRM vectors (smaller dot and circle) for site GR 73-76 to move towards the site mean directions (larger circle) of GR 1-5 and GR 6-10 during progressive AF and thermal demagnetization. Stereographic projection, tectonic system. Dot: positive, circle: negative inclination.

Pindos over the Gavrovo–Tripolis units. Subsequently, these zones behaved as a single unit and must have been rotated slightly in the clockwise sense.

However, the paleomagnetic observations for the late Cretaceous sediments of the Pindos and Western Thessaly units call for a more complex solution. Apart from site GR 11-15, at which the ChRM must be of post-folding age (the inclination after tectonic correction does not fit a plausible paleolatitude in either an African or a European system), the paleomagnetic directions after tilt correction indicate moderate but significant post-Cretaceous clockwise rotations in the Pindos zone. These rotations are similar in sense and magnitude to those found earlier for the Jurassic and Cretaceous sediments of the Ionian zone (Fig. 11). Assuming that the similar net rotation shown by the Mesozoic sediments of the Ionian and Pindos zones is not a coincidence, we must conclude that the rotation of the Paleogene deposits in either zone with respect to those of the Mesozoic in the same zone and relative to each other is a sign of their detachment from the Mesozoic sequence. If the possibility of detachment is excluded on geological grounds (for it is only in the northern part of the Pindos zone where the detachment is evident), we must move the Pindos and Ionian zones independently at least twice before the Miocene and must conclude that the similarity of the paleomagnetic directions for the Mesozoic sediments in the two zones is a coincidence.

Although the second model seems more plausible on geological grounds, it is not yet adequately substantiated by paleomagnetic data. Clearly, further studies are needed in the Pindos zone, for without demonstrating the regional consistency of

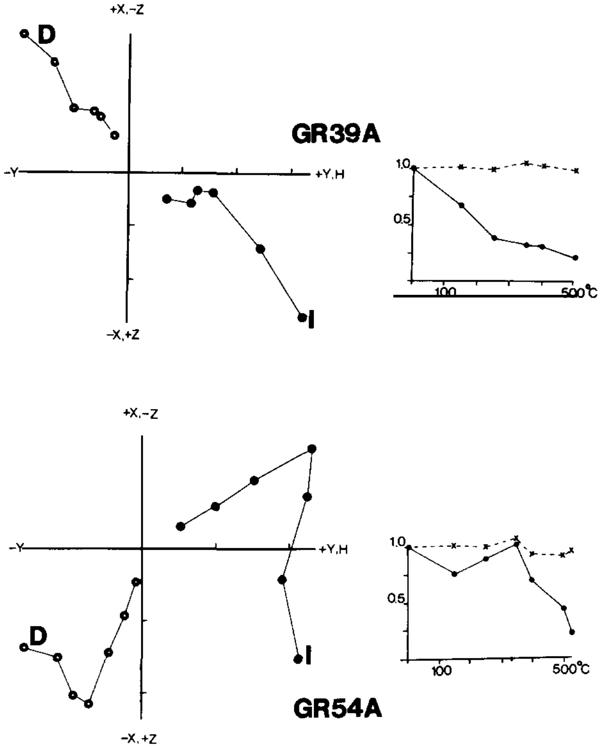

Fig. 6. Pindos and Western Thessaly units. Typical demagnetization diagrams for late Cretaceous–Paleocene limestones; progressive thermal demagnetization. Left: change in intensity and direction of the remanence vector during heating. GR39A: unit = $1.6E-4$ A m^{-1}, 6 cleaning steps: NRM–500 °C. GR54A: unit = $4.0E-4$ A m^{-1}, 7 cleaning steps: NRM–525 °C. Right: relative change in NRM intensity (dot) and susceptibility (cross) during heating.

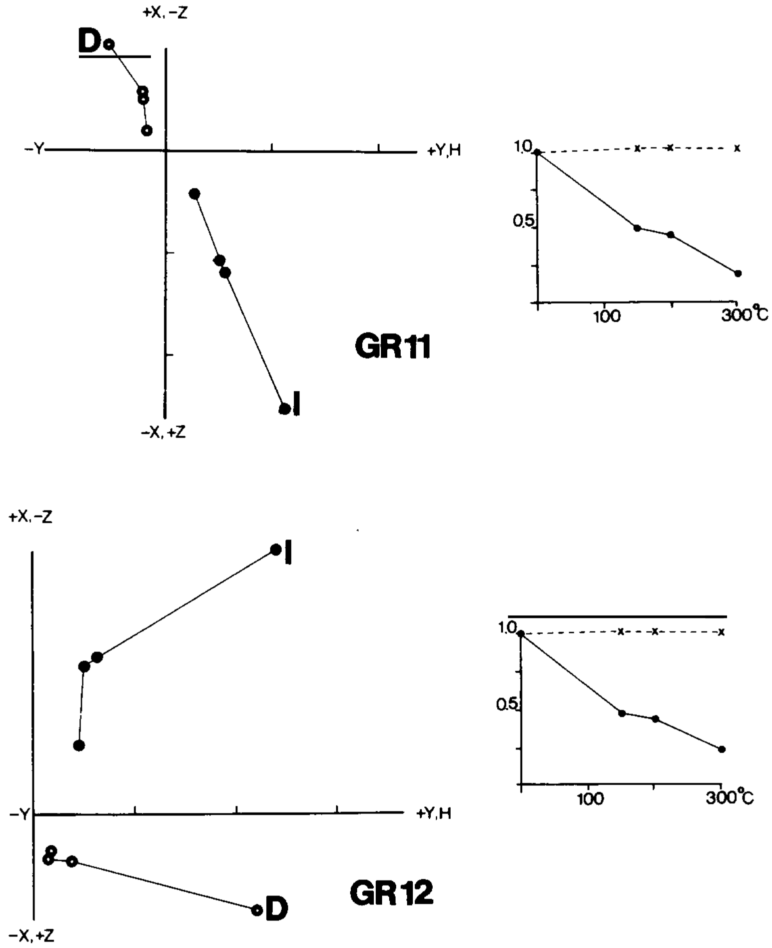

Fig. 7. Pindos zone. Site GR 11-15, late Cretaceous limestone. Demagnetization diagrams for two samples with ChRM 180° apart. Left: change in intensity and direction of the remanence vector during thermal demagnetization. Unit $= 1.6E-5$ A m^{-1}, four steps: NRM–300°C. Right: relative change in NRM intensity (dot) and susceptibility (cross) during heating.

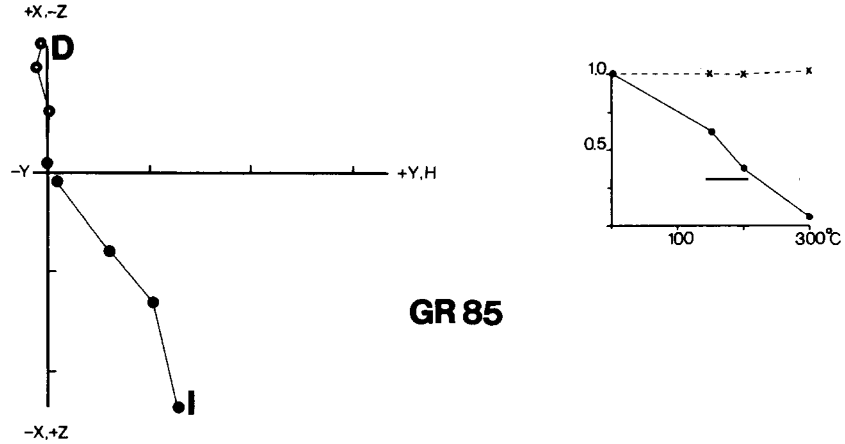

Fig. 8. Paxos zone, Lefkas island. Typical demagnetization diagram for Eocene limestone (sample GR 85). Left: modified Zijderveld projection of the remanence vector. Unit $= 8.0E-5$ A m^{-1}, four demagnetization steps, NRM–300°C. Right: relative change in NRM intensity (dot) and susceptibility (cross) during heating.

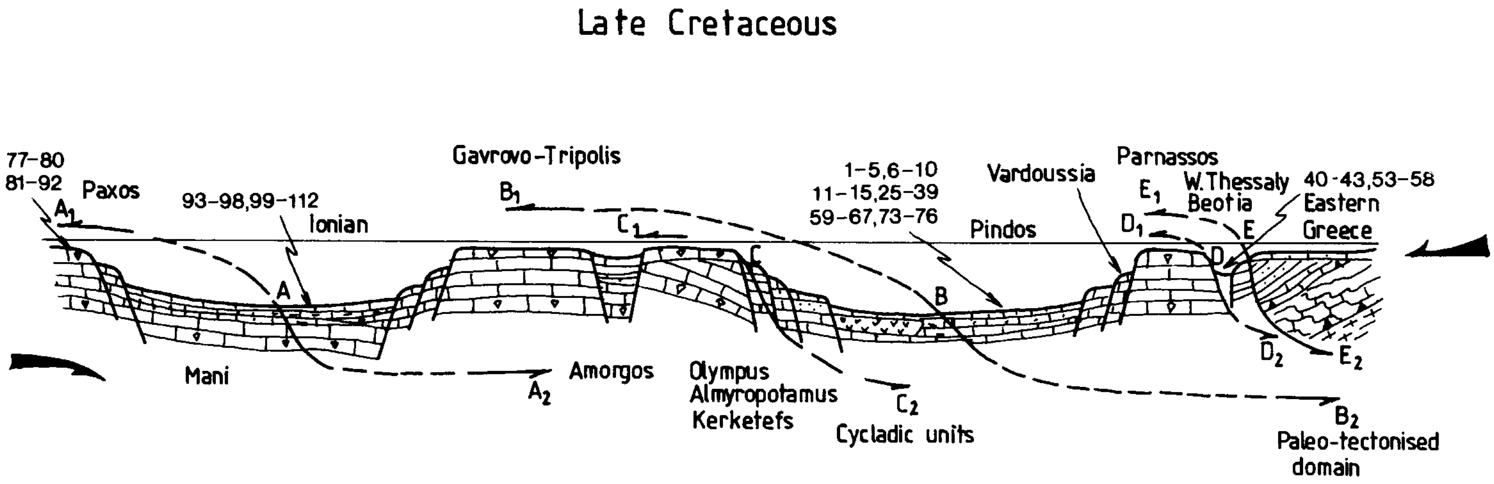

Fig. 10. Schematic paleographic reconstruction for the late Cretaceous of the external Hellenides (Papanikolaou, 1986). Symbols are as in Fig. 2. (for technical reasons, Fig. 9 appears on p. 69.)

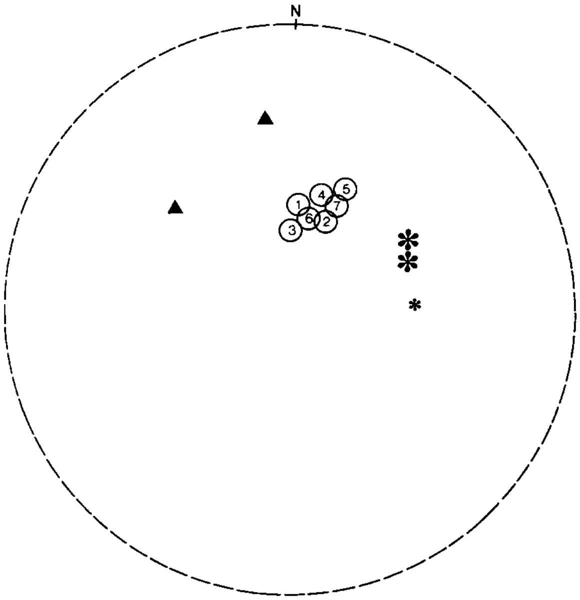

Fig. 9. Post-Cretaceous paleomagnetic directions for the external Hellenides on a stereographic projection. Numbered directions are overall means for post-Alpine sediments:

Meso-Hellenic basin: 1 present study
2 Kissel and Laj (1988).
Ionian zone: 3–5 Laj et al. (1982)
Paxos zone: 6–7: Laj et al. (1982).

Larger stars, overall mean directions for the Eocene (Horner and Freeman, 1983) and Oligocene (Kissel et al., 1985) sediments of the Ionian zone. Small star, Lefkas island, Ionian zone, present study. Triangles, site mean directions for flysch from the Pindos zone, present study.

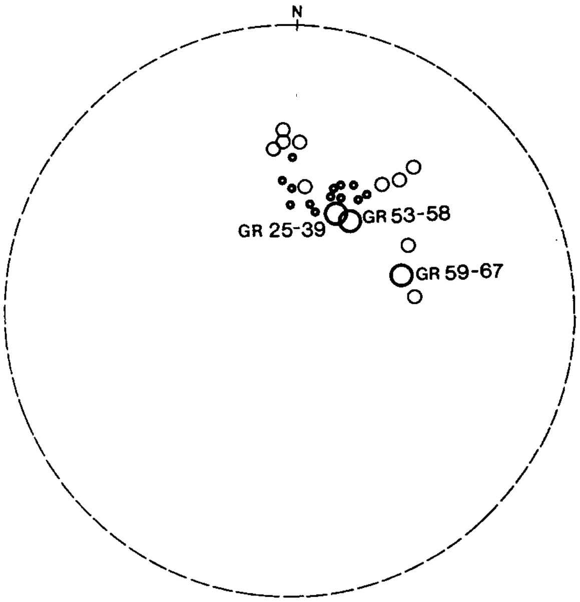

Fig. 11. Mesozoic paleomagnetic directions for the external Hellenides on a stereographic projection. The inclinations are positive. Large circles, Pindos zone, present study. Medium circles, Ionian zone, late Cretaceous (Horner, 1983). Small circles, Ionian zone, Jurassic (Horner, 1983).

the paleomagnetic directions throughout the zone, 'block rotation' may be considered as indicated but not proved.

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