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Paleomagnetism of the tertiary intrusives from Chalkidiki (northern Greece)

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Abstract. Paleomagnetic measurements made on Eocene-Oligocene intrusives of Chalkidiki (northern Greece) have given normal and reversed directions. The mean direction is $D=37°$, $I=30°$, $\alpha_{95}=9°$ and the pole is 50°N, 140°E. This direction indicates a clockwise rotation of about 25° for Chalkidiki, similar to the rotations observed in western Greece but different from Bulgarian results.

Key words: Paleomagnetism – Northern Greece – Chalkidiki – Oligocene – Rotation

Introduction

Paleomagnetic results from western Greece (Epirus, Ionian islands), in the external zones of the Hellenides, have shown major clockwise rotations of 50°–60° (Laj et al., 1982; Horner and Freeman, 1983; Kissel et al., 1985). It was interesting to check if the core of the Dinaric-Hellenic chain had also suffered any rotations. We studied paleomagnetically the widespread Tertiary intrusives of Chalkidiki.

Geological setting

The Chalkidiki peninsula is part of the innermost zones of the Dinaric-Hellenic fold system. From east to west these "internal Hellenides" are constituted by:

a) The Rhodope massif. It is formed of old Proterozoic and Paleozoic rocks, mainly metamorphosed into amphibolites in Paleozoic times. This massif was the backbone of the Serbomacedonian and Vardar zones (Fig. 1).

b) The Serbomacedonian massif represents a crystalline complex, mainly constituted of Paleozoic and Precambrian rocks, as well as Hercynian and Alpine intrusives. During the Mesozoic it is considered to have acted as a continental margin (Mercier, 1966).

c) The Vardar zone has been separated into three subzones by Mercier (1966) which are, from east to west: the Peonias trough, the Paikon ridge and the Almopias trough; constituted by Jurassic limestones, a metamorphic Trias-Jurassic basement, an ophiolitic sequence, upper Paleocene flysch and Miocene volcanism. Recent geological studies have distinguished a circum-Rhodopian zone between the Serbomacedonian massif and the Vardar zone (Kauffman et al. 1976). This zone extends towards Sithonia and near Mt. Athos gulf. It turns to the E–NE and appears again in the SE Rhodope.

The Serbomacedonian zone is cut by several granitic and granodioritic bodies whose ages were poorly known until recently. The Sithonia peninsula is mainly formed by several plutons of granodiorites and monzonites (Soldatos et al., 1976). In the main Chalkidiki body we find the Arnea and the Gomati intrusives. The Arnea body is a schistosed, medium-grained granite similar to the Sithonia plutonites. The Gomati complex is a hornblende diorite. More to the east, two other granitic complexes are found; one near Ouranopolis, at the beginning of Mount Athos, intruded in metasediments. The other one is the Stratoni-Olymbias complex with a granodioritic to calcalkaline granite.

There is only little stratigraphic evidence for the age of these intrusives. But two age determinations by the K-Ar method on biotites have been obtained. One by Montigny (personal communication) on Sithonia peninsula (paleomagnetic sampling site SA) with an age of 40.5 ± 1.5 Ma and the second one near sites STR and MDL by Papadakis (1971) with an age of 30.5 ± 1.5 Ma. We can thus estimate that these intrusives are Upper Eocene to Lower Oligocene in age.

Sampling and measurements

Oriented hand-samples were collected at several sites in Sithonia eight sites), Arnea (one site), Ouranopolis (one site) and Stratoni-Olymbias (two sites). At each site, three–seven samples separated by several metres were taken. The samples were then drilled in standard 25-mm cores and measured with a Digico spinner magnetometer. The samples were stepwise demagnetized, either by alternating field or thermally.

Results

For most of the formation sampled, the intensity of natural remanent magnetization is between 1 and 100 mA/m. Some sites, for instance BO, CR, SA, LIN had very stable monocomponent magnetizations with high blocking temperatures and high coercive forces. Other sites (ZIB, MDL) had much softer magnetizations with a strong secondary component eliminated at 25 mT and with a median destructive field

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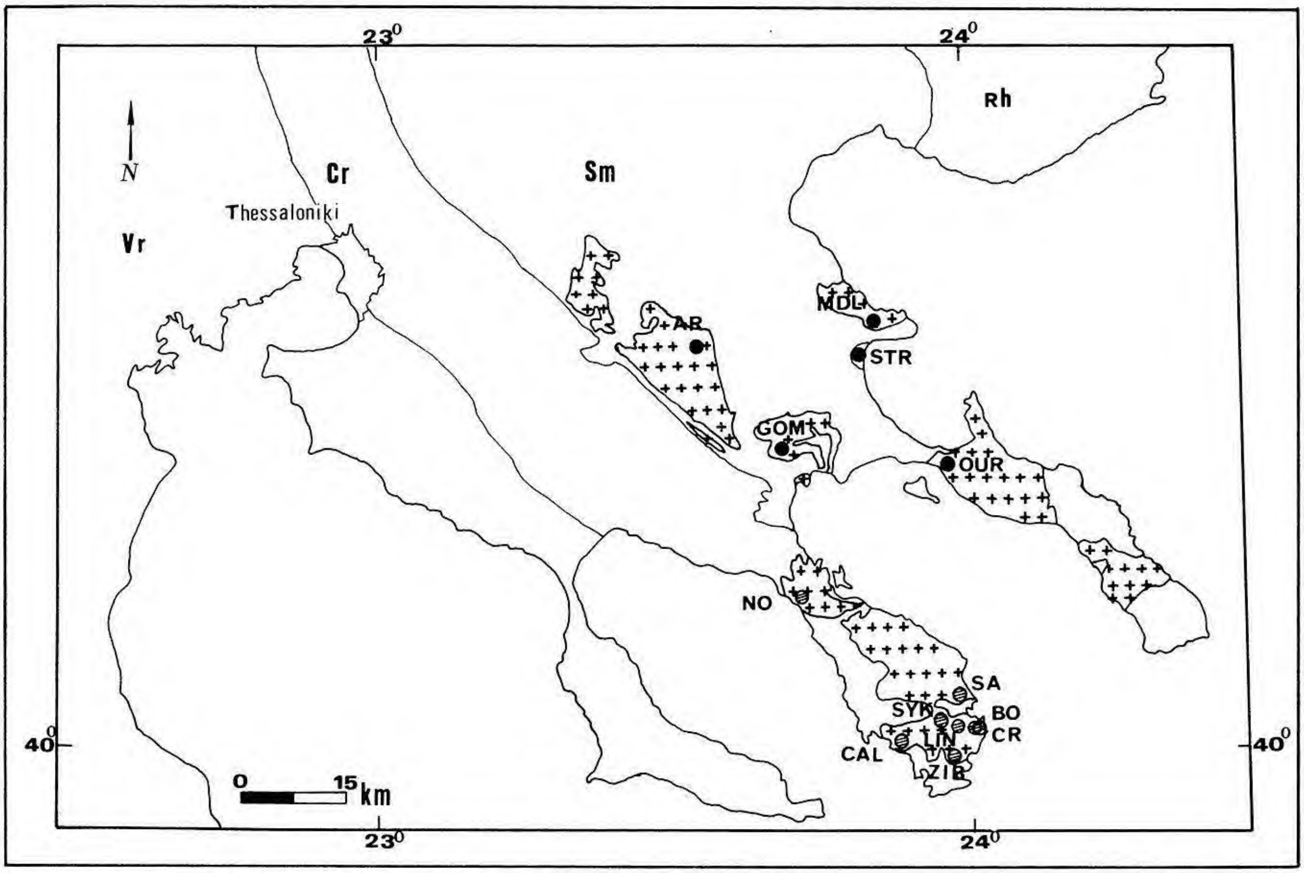

Fig. 1. Outline of Chalkidiki with sampling sites (and sites names) and granitic and granodioritic intrusives. *Rh* Rhodope massif, *Sm* Serbomacedonian zone, *Cr* Circum Rhodope zone, *Vr* Vardar zone

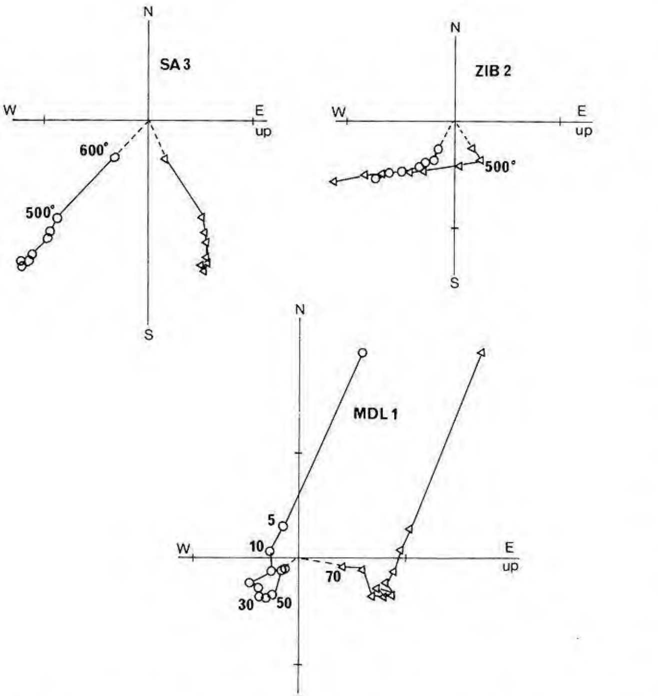

Fig. 2. Examples of demagnetization; thermal and by alternating fields. *Circles*: projection of the vector in the horizontal plane. *Triangles*: projection in the vertical, north-south plane. Numbers indicate temperatures (° C) or field (in mT)

for the main component of about 50 mT (Fig. 2). After demagnetization three groups of characteristic remanent magnetization directions were found:

- reversed directions with $D = 216°$, $I = -32°$ corresponding to sites NO, CAL, ZIB, SA, MDL and OUR
- normal directions nearly antiparallel to the first group: $D = 38°$, $I = 29°$ corresponding to sites LIN, SYK, BO and CR
- normal directions close to the present dipole field: sites GOM and AR.

At site STR the scatter of directions was too large even after demagnetization and no characteristic remanent magnetization could be defined. We could only observe that a few samples had normal or reversed components close the characteristic directions of the first two groups.

Differences in behaviour between different sites were also found in IRM acquisition curves. Two extreme cases are shown in Fig. 3. MLD 4 shows a very quick increase in magnetization, and saturation is reached at about 0.1 T. This is probably due to multidomain magnetite grains and may explain the strong and soft secondary components (see Fig. 2). The other extreme is shown by OUR 6. It is a metasediment intruded and reheated by granitic sills. The IRM aquisition curve grows slowly and saturation is reached only above 0.5 T. Most of the NRM is destroyed only at high temperature above 600° C showing that a great part of the magnetization is carried by fine-grained haematite. Other sites show intermediate curves. The characteristic magnetization is probably carried by fine-grained haematite

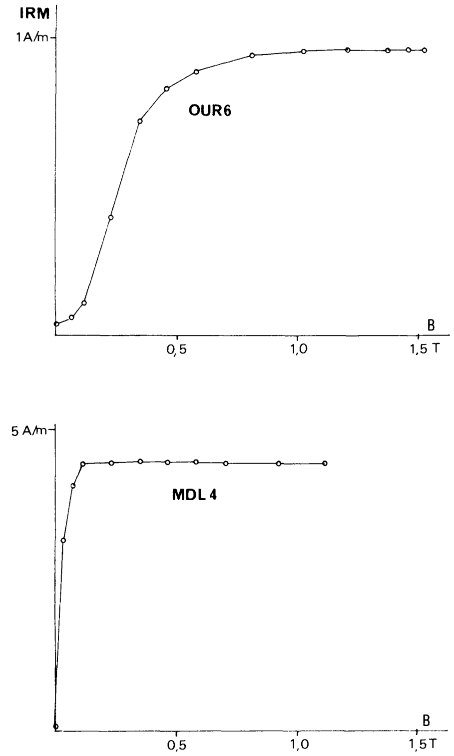

Fig. 3. Isothermal remanent magnetization acquisition curves for two samples. B: field in Tesla. Magnetization is in A/m

and secondary components, when present, by multidomain magnetite.

At site OUR only metasediments gave reliable results. A bedding plane can be seen there and if we use it as a paleohorizontal marker we see that the tectonic-corrected direction (Table 1) is in better agreement with other sites than the uncorrected direction. We have thus retained this corrected direction. Unfortunately, no paleohorizontal evidence could be seen at other sites.

Discussion

Except for sites AR and GOM, normal and reversed directions are nearly antiparallel. Thus, we can assume that almost all common secondary magnetizations have been eliminated. We feel also that the two sites AR and GOM are significantly different from other site means, although the number of sites is too low to apply statistical tests. We see at least in Table 1 that the scatter is strongly reduced when we eliminate these two sites: k increases from 15–28 for normal and reversed sites, from 13 to 152 with normal sites only. Therefore, we decided to use the mean direction calculated with ten sites: $D=37^\circ$, $I=31^\circ$, $k=28$, $\alpha_{95}=9^\circ$.

This mean CARM direction is significantly different from the axial dipole field of $D=0^\circ$, $I=50^\circ$ in the sampling area. The mean pole position for stable Europe and for about 35 Ma is 83° N and 136° E (Westphal et al., 1985). The corresponding field direction is $D=8^\circ$ and $I=57^\circ$. The direction obtained in Chalkidiki is also significantly differ-

Table 1. Characteristic remanent magnetization of Chalkidiki intrusions. Site: site name, N: number of samples used in the statistics; N_O: number of samples collected in the field; D: declination; I: inclination; k, α_{95}: Fisher statistical parameters; polarity: N-normal, R-reversed

Site	N/N_O	$D(^\circ)$	$I(^\circ)$	k	α_{95}	Polarity	
NO	3/3	240	−32	8000	1	R	
CAL	6/7	193	−19	23	14	R	
ZIB	4/4	220	−36	51	13	R	
LIN	4/4	35	20	37	17	N	
SYK	6/6	37	28	103	7	N	
BO	4/4	38	32	108	9	N	
CR	3/3	41	34	43	19	N	
SA	7/4	215	−20	30	11	R	
STR	0/6	scattered					
MDL	6/6	224	−58	176	5	R	
OUR	3/6	219	7				uncorrected
		213	−24	83	13	R	corrected
AR	3/4	1	62	142	10	N	
GOM	3/4	354	62	44	19	N	
Means							
Overall mean							
	12	33	36	15	11		
Normal sites							
	6	29	41	13	19		all sites
	4	38	29	152	7		without AR+GOM
Reversed sites							
	6	216	−32	17	16		
Retained mean							
	10	37	31	28	9		

Pole: 50° N 139° E dp = 6° dm = 10°
(mean sites coordinates: 40.2° N 23.8° E)

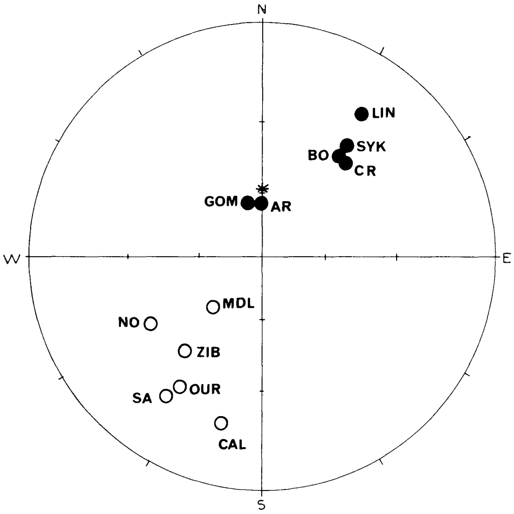

Fig. 4. Stereogram showing the mean characteristic directions for Chalkidiki. *Solid circles*: positive inclination; *open circles*: negative inclination; *star* is present-day dipole field direction

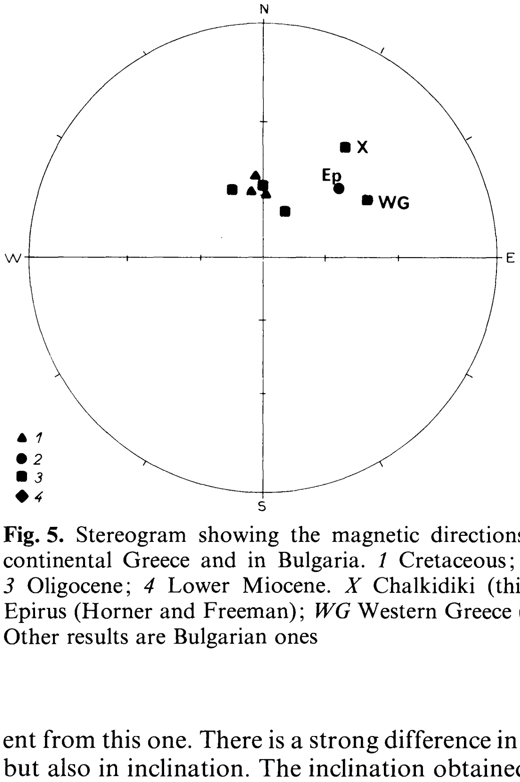

Fig. 5. Stereogram showing the magnetic directions obtained in continental Greece and in Bulgaria. *1* Cretaceous; *2* Paleocene; *3* Oligocene; *4* Lower Miocene. *X* Chalkidiki (this paper); *Ep* Epirus (Horner and Freeman); *WG* Western Greece (Kissel et al.). Other results are Bulgarian ones

ent from this one. There is a strong difference in declination, but also in inclination. The inclination obtained is too low. An average tilt toward the north may explain a part of the inclination difference of about 30°, but not all of it. Even site OUR, where a tectonic correction could be made, has too low an inclination (−24°).

Paleomagnetic results for similar periods have been obtained in western Greece (Horner and Freeman, 1983; Kissel et al., 1985), in the Rhodope massif and in the Stara Planina chain (Nozharov and Petkov, 1976a, 1976b, 1977; Nozharov et al., 1977a, 1977b). Figure 5 and Table 2 show a clear difference of directions between continental Greece and more northern parts. The Rhodope and other Bulgarian results are more or less close to a north-south declination and have an inclination of about 50°–70°. Inland Greece, mainly the external zones of the Hellenides, have an easterly declination of about 30°–50° and shallower inclinations.

Table 2. Paleomagnetic results from the Dinaric-Hellenic chain. *D*, *I*: declination, inclination, α_{95} and pole position. Ref.: 1 Nozharov et al. (1977a); 2 Nozharov et al. (1977b); 3 Nozharov and Petkov. (1976a); 4 Nozharov and Petkov. (1976b); 5 Nozharov and Petkov. (1977); 6 Horner and Freeman (1983); 7 Kissel et al. (1985); 8 This paper

	D (°)	*I* (°)	α_{95} (°)	Pole (° N)	(° E)	Ref.
Bulgaria						
Upper Cretaceous						
Sredna Gora	357	52	19	83	224	2
Srednogoriye	353	59	14	85	254	1
Maritsa	2	59	12	88	151	4
Oligocene						
Madjarovo	337	55	25	73	294	3
	27	66	9	70	85	3
Sredna Gora	high scatter					2
Lozen	355	56	24	84	245	5
Greece						
External Hellenides						
Paleocene						
Epirus	47	44	4	48	116	6
Oligocene						
Nortwestern Greece	58	39	5	38	112	7
Internal Hellenides						
Eocene-Oligocene						
Chalkidiki	37	31	9	50	141	8

The Chalkidiki results are closer to the western Greece results than those of the Rhodope and Stara Planina. But sites GOM and AR are similar to the latter. Upper Cretaceous results from Bulgaria are similar to Oligocene results and show that no rotation occurred during this period for this region. This means that, although the different tectonic zones from the Hellenides look more or less rectilinear, important rotations occurred in them. The external zones have been rotated clockwise through 60° since the Oligocene. This rotation is clearly shown by Kissel et al. (1985) and Laj et al. (1982) as a rotation in two phases: the first at about 13 Ma and the second since 5 Ma. The more internal zone in Chalkidiki has also rotated in the same direction. At the present time wo do not yet know if the different results from sites GOM and AR are due to a younger age of these intrusions or a later remagnetization. Thus, we cannot yet conclude about the location of the limit between the unrotated parts seen in Bulgaria and the rotated part of Chalkidiki. We have also to explain the discrepancy in inclination.

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