NIEDERSÄCHSISCHE STAATS- UND
UNIVERSITÄTSBIBLIOTHEK GÖTTINGEN

Werk

Jahr: 1975
Kollektion: fid.geo
Signatur: 8 Z NAT 2148:41
Digitalisiert: Niedersächsische Staats- und Universitätsbibliothek Göttingen
Werk Id: PPN1015067948_0041
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948_0041

LOG Id: LOG_0061
LOG Titel: The palaeomagnetism of age dated Tertiary volcanites of the Monti Lessini (Northern Italy) and its implication to the rotation of Northern Italy
LOG Typ: article

Übergeordnetes Werk

Werk Id: PPN1015067948
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948
OPAC: http://opac.sub.uni-goettingen.de/DB=1/PPN?PPN=1015067948

Terms and Conditions

The Goettingen State and University Library provides access to digitized documents strictly for noncommercial educational, research and private purposes and makes no warranty with regard to their use for other purposes. Some of our collections are protected by copyright. Publication and/or broadcast in any form (including electronic) requires prior written permission from the Goettingen State- and University Library.
Each copy of any part of this document must contain there Terms and Conditions. With the usage of the library's online system to access or download a digitized document you accept the Terms and Conditions.
Reproductions of material on the web site may not be made for or donated to other repositories, nor may be further reproduced without written permission from the Goettingen State- and University Library.

For reproduction requests and permissions, please contact us. If citing materials, please give proper attribution of the source.

Contact

Niedersächsische Staats- und Universitätsbibliothek Göttingen
Georg-August-Universität Göttingen
Platz der Göttinger Sieben 1
37073 Göttingen
Germany
Email: gdz@sub.uni-goettingen.de

J. Geophys. 41, 385—400, 1975

The Palaeomagnetism of Age Dated Tertiary Volcanites of the Monti Lessini (Northern Italy) and Its Implication to the Rotation of Northern Italy

H. Soffel

Institut für Allgemeine und Angewandte Geophysik der Universität München

Received January 30, 1975

Abstract. In the Monti Lessini and Monte Berici in Northern Italy ($\lambda = 11.5$ °E, $\varphi = 45.5$ °N) 37 lava flows of Oligocene to Eocene age have been sampled for palaeomagnetic measurements. For some of the flows radiometric ages between 33.0 and 47.2 m.y. have been determined. Alternating field demagnetization in fields up to 500 Oe were necessary for the removal of unstable secondary magnetization components. Rock magnetic and ore microscopic studies (Soffel, 1975) showed that the characteristic remanence is a primary one acquired by the rocks at the time of their formation. 15 lava flows of Oligocene age gave the following mean direction of characteristic remanence: $D = 204.1°$, $I = -34.8°$, with $N = 15$, $k = 17.6$, $\alpha_{95} = 8.6°$. The corresponding values of 18 lava flows of Eocene age are: $D = 156.5°$, $I = -38.1°$, $N = 18$, $k = 13.6$, $\alpha_{95} = 9.0°$. The difference in declination between the two groups is 47.6°. The pole position of the Oligocene lavas is at $\lambda = 146.4$ °E, $\varphi = 56.9$ °N. Its longitude is in good agreement with Lower to Middle Tertiary pole positions for Central Europe, while the latitude is about 20° too small. The pole position of the Eocene lavas is at $\lambda = 237.9$ °E, $\varphi = 59.1$ °N and is in the vicinity of the Eocene pole position of the Colli Euganei and of other Triassic and Permian rocks from the Southern Alps. The palaeomagnetic data of the Monti Lessini therefore confirm the result obtained by Soffel (1972, 1974a) for the Colli Euganei volcanites. They indicate that the anticlockwise rotation of Northern Italy of about 50° started in Upper Eocene (45 to 40 m.y.) and came to an end in Middle Oligocene (35 m.y.). The too low latitude which has been determined for the Oligocene rocks from the Southern Alps suggests that this area has drifted towards the North in times later than Middle Oligocene. There are also indications that the Colli Euganei have suffered an anticlockwise rotation of about 10° with respect to the Monti Lessini after Middle Oligocene.

Key words: Palaeomagnetism — Geodynamics in the Mediterranean — Italy.

1. Introduction

The time of rotation of Northern Italy has been determined by Soffel (1972, 1974a) by studying the palaeomagnetism of the Colli Euganei volcanites. According to these measurements the rotation through about 50° in an anticlockwise sense happened between 45 m.y. (Upper Eocene) and 35 m.y. (Middle Oligocene). The absolute time of rotation could be linked to radiometric age determinations carried out by Borsi, Ferrara and Piccoli (1969) and to biostratigraphic age determinations (Schiavinato 1950, Riedel 1950, Piccoli 1966) on some Colli Euganei volcanites.

Most radiometric age determinations by Borsi *et al.* (1969) refer to rocks of the younger volcanic cycle in the Colli Euganei which happened in Middle Oligocene and for which an average age of 33 m.y. was determined. Most of the informations about

Table 1. Site number, locality name, description of the site and age of the volcanic units which have been sampled in the Monti Lessini and Monte Berici. The radiometric ages have been provided by Piccoli (private communication, 1973). The other ages were taken from the Carta Geologica d'Italia (scale: 1:100000) and from Piccoli (1964)

Site No.	Locality name	Description of the site	Age	
1	Valle	vent, 1 km N of Valle	37.0	m.y.
2	Sarego	road cut, 1 km N of Sarego	Ol.	
3	Montebello	1,5 km NW of M., Villa Crosara	Ol.	
4	Sorio	0,5 km E of S., road cut	Ol.	
5	Brentone	road cut, 1 km W of B.	46.8	m.y.
6/1	M. Calvarina/1	road cut, 1 km W of M. C.	46.8	m.y.
6/2	M. Calvarina/2	road cut, 1 km W of M. C.	46.8	m.y.
7	Fazzi	1 km W of M. C., hamlet Fazzi	46.8	m.y.
8	Cortivo	1 km W of M. C., hamlet Cortivo	46.8	m.y.
9	S. Bortolo	road cut, leaving S. B. to Ronca	Eo.	
10	Vittori	1 km E of Ronca, hamlet Vittori	Ol.	
11	Cracchi	churchyard, hamlet of Cracchi	47.2	m.y.
12	S. Giovanni/1	0,5 km N of S. G.	Ol.	
13	Castelcerino	road intersection, 0,5 km S of C.	Eo.	
14	C. Tribbia	2 km E of Chiuppano	Eo.	
15	Togarelli	road cut, hamlet of Togarelli	Ol.	
16	Galvari	road cut, 1,5 km S of Salcedo	Ol.	
17	Arzignano	Arzignano, exit to Tezze	Eo	
18	Brognolio	road to Fitta, 0,5 km W of B.	Eo.	
19	M. Castellaro	0,5 km W of site No. 18	Eo.	
20	Fitta	0,5 km E of Fitta	Eo.	
21	S. Valentino	4 km SW of Bretonico	Eo.	
22	Torbole	1 km NE of Torbole	Ol.	
23	Besagno	road cut, 0,5 km N of Besagno	Ol.	
24/1	S. Briccio/1	old quarry, 0,5 km S of S.B.	Ol.	
24/2	S. Briccio/2	old quarry, 0,5 km S of S. B.	Ol.	
25	Colognola	0,5 km SE of Colognola ai Colli	Eo.	
26	Portinari/1	1 km NE hamlet of Portinari	Eo.	
27	Portinari/2	0,5 km NE hamlet of Portinari	Ol.	
28	Bolca	Purga di Bolca	36.2	m.y.
29	Vestananuova	0,5 km S of Vestananuova	Eo.	
30	S. Giovanni/2	0,5 km NW S. G., W of F. Alpone	Eo.	
31/1	S. Giovanni/3	1 km S of S. G., hamlet Salgaroli	Ol.	
31/2	S. Giovanni/4	1 km S of S. G., hamlet Salgaroli	Ol.	
32/1	Gambellara/1	0,5 km S of Gambellara	Eo.	
32/2	Gambellara/2	0,5 km S of Gambellara	Eo.	
33	Grancona	road cut, 2,5 km NE of Sarego	Ol.	
	Marolla	SW of Caltrano, no outcrop, not sampled	33.0	m.y.
	Fiume Famollo	between Laverda and Lavarda no outcrop, not sampled	33.5	m.y.

the age of the older cycle of volcanic activity come from palaeontological investigations yielding a Priabonian or Lutetian (Middle to Upper Eocene) age.

However a number of new radiometrically determined ages from the Monti Lessini and Monte Berici have been made available to the author by Prof. Piccoli (private communication 1973) from the Geological Institute of the University of

Padova (Italy). These two volcanic areas are situated about 50 km northwest of the Colli Euganei on the southern edge of Southern Alps. The radiometrically determined ages in these two areas vary between 33.0 and 47.2 m.y. thus covering a time span which has been considered by Soffel (1972, 1974a) for the time of rotation of Northern Italy.

2. *Geology and Radiometric Ages of the Monti Lessini and Monte Berici Volcanites*

Among the many papers about the geology and petrography of the Monti Lessini and Monte Berici only a few publications by Piccoli (1964, 1966, 1969) shall be mentioned. They summarize his own results as well as those obtained by others. The K/Ar ages (33.0, 33.5, 36.2, 37.0, 46.8, 47.2 m.y., see Table 1) are unpublished data provided to the author by Piccoli in 1973.

According to Piccoli (1964) volcanism in the Monti Lessini and Monte Berici lasted from about Middle Cretaceous to Miocene with a main activity in Eocene and Oligocene. This has been confirmed by the radiometric age determinations. All sites with known radiometric age have also been sampled for a palaeomagnetic study. However two radiometric ages (33.0 and 33.5 m.y.) originate from sites without suitable outcrops for such kind of research.

Fig. 1 is a simplified geological map of the investigated area showing the places of outcropping Tertiary volcanism. The places where the samples for this study have been taken are shown in Fig. 2. Numbers refer to site numbers. Table 1 contains the site number, locality name and description of the site, radiometrically determined age (if available) and/or biostratigraphic age either according to the geological map of the area (Carta Geologica d'Italia) or according to Piccoli (1964).

37 different volcanic units have been sampled, in most cases 8—12 cores have been drilled from each unit.

According to Piccoli (1966) most of the basic eruptions on the Monti Lessini and Monte Berici took place under marine environment. In these cases the flows are intercalated between limestones thus facilitating tectonic corrections. Others have been extruded under subaerial conditions and some are large intrusive bodies which have cooled slowly forming large masses of columnar basalts.

According to the kind of deposition of the basalts, subaqueous, subaerial und intrusive units show distinct rockmagnetic properties which are discussed in a different paper (Soffel, 1975) in this volume.

3. *Palaeomagnetic Measurements*

3.1. Natural Remanent Magnetization (NRM)

All measurements of remanent magnetization have been made with a DIGICO spinner magnetometer. The NRM of the individual sites showing sample means are plotted in Fig. 3 in equal area projection. Open symbols: negative inclinations, closed symbols: positive inclinations. The mean NRM data of the individual sites are listed in Table 2 a together with the parameters chracterizing their scatter. Some sites show extremely small scatter already for the NRM irrespective of their polarity (site number 1, 12, 14, 19, 20, 21, 24/2, 29, 31/1, 31/2, 32/1, 32/2, 33), others have considerable

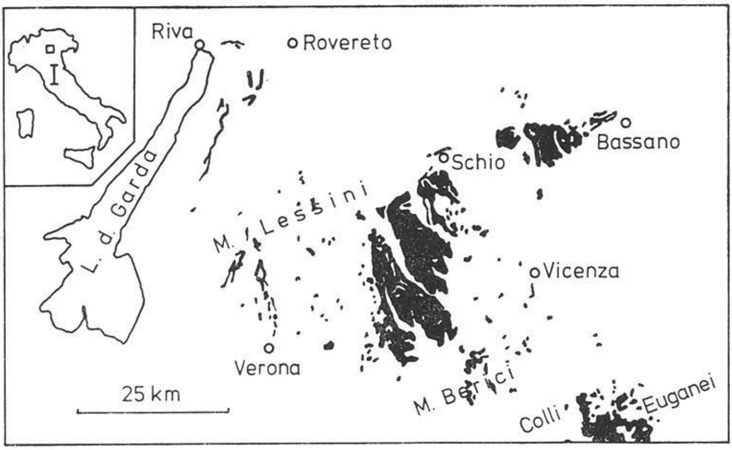

Fig. 1. Areas (in black) of Tertiary volcanism in the Monti Lessini in Northern Italy. (Redrawn from the geological map of Austria, issued by H. Vetters (1968))

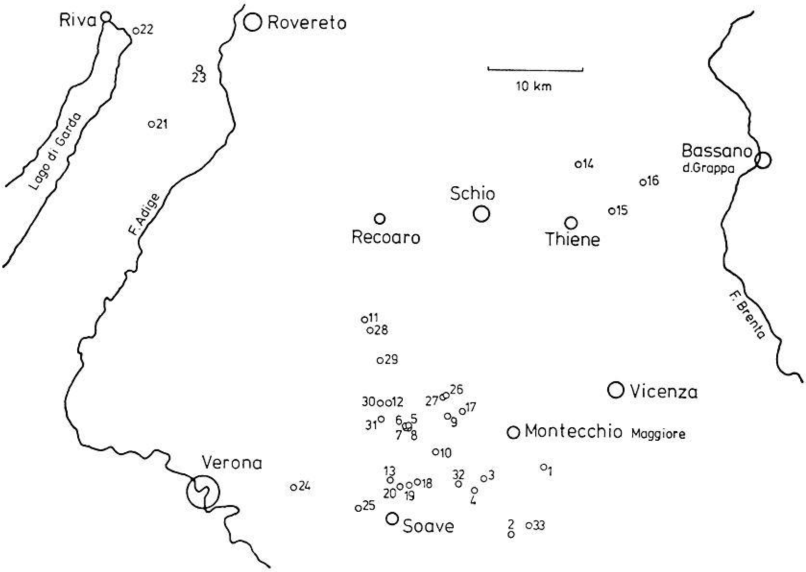

Fig. 2. Map of the sampling localities. Numbers refer to site numbers

scatter (site numbers 2—5, 15—18, 27, 28). The computation of a mean NRM direction of all sites (Fig. 4) does not seem to be reasonable. The mean intensities of NRM of the sites are also listed in Table 2a. The values vary between 600 and $26000 \cdot 10^{-6}$ Gauss. They are normal for basic volcanic rocks.

3.2. Alternating Field Demagnetization

The large scatter of the mean NRM directions of many sites suggests the presence of considerably large components of secondary magnetization in these rocks. Only

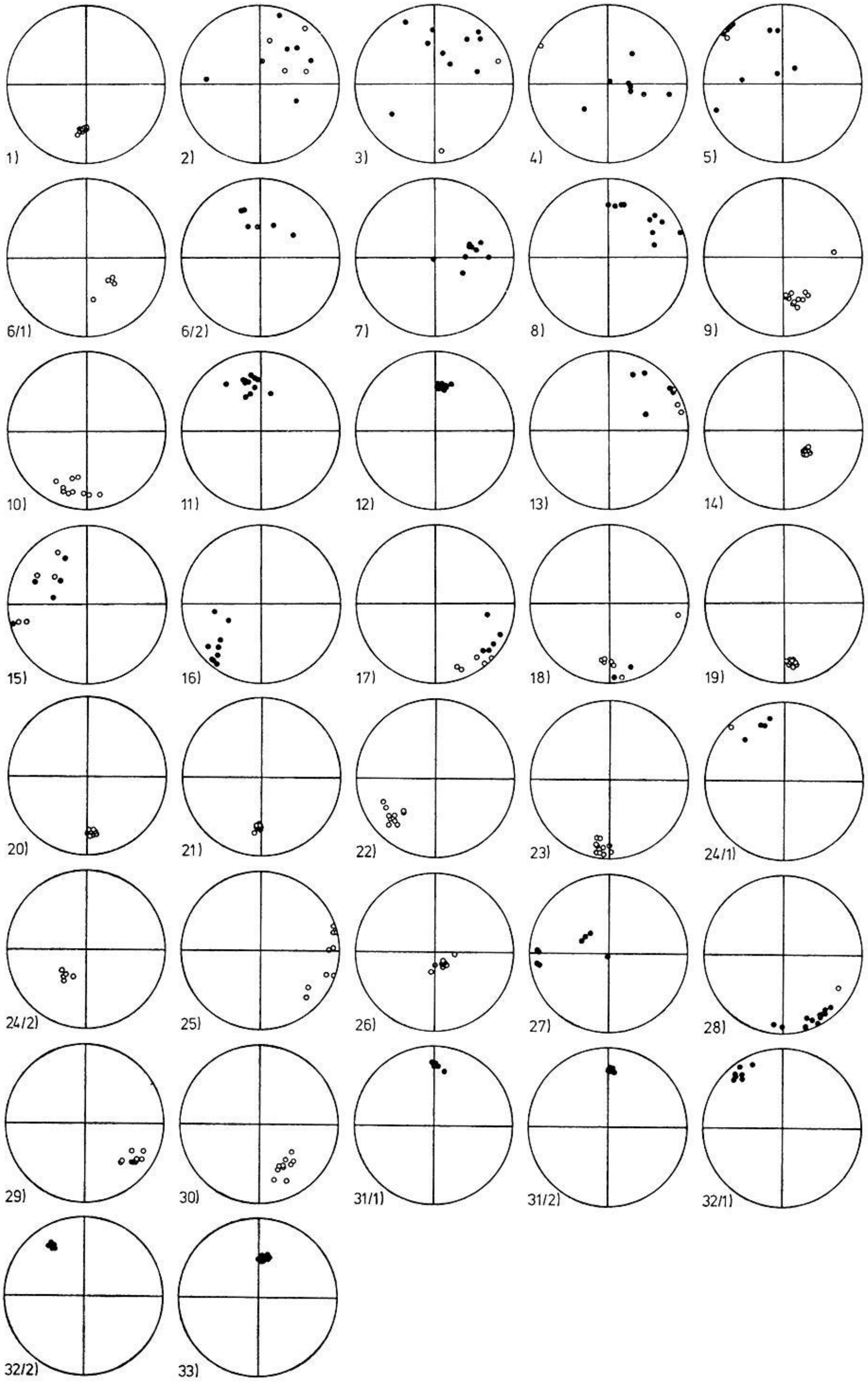

Fig. 3. Mean directions of natural remanent magnetization (sample means) of all sites. Open symbols: negative inclination, closed symbols: positive inclinations. Equal area projection

Table 2. Palaeomagnetic data for the Natural remanent magnetization (a) and for the Characteristic magnetization (b). Meaning of the different columns:

1: site number, 2: number of samples (*N*) and specimens (*n*), 3: mean declination of NRM, 4: mean inclination of NRM, 5: α_{95} value of NRM, 6: precision parameter of NRM, 7:

a) Natural remanent magnetization (NRM)

1 Nr.	2 N/n	3 $D(°)$	4 $I(°)$	5 $\alpha_{95}(°)$	6 k	7 NRM(μG)
1	10/30	185.5	−41.5	2.3	416.6	2309
2	11/24	41.6	+16.5	43.1	2.0	796
3	12/27	32.7	+44.4	37.2	2.3	2029
4	9/18	77.6	+74.6	32.4	3.4	1093
5	13/25	316.0	+37.6	26.6	3.3	5000
6/1	5/7	141.7	−54.3	9.3	45.7	1081
6/2	6/11	359.2	+51.7	15.8	13.0	1621
7	10/19	84.9	+51.7	11.6	18.0	1565
8	10/22	42.1	+31.4	14.0	10.1	3513
9	13/30	159.0	−45.7	8.5	21.1	2944
10	10/26	193.5	−26.8	7.6	33.6	1962
11	12/23	347.7	+38.6	6.2	42.5	1947
12	12/37	10.1	+42.1	2.3	299.0	23011
13	9/19	56.2	+ 9.4	13.8	11.4	8205
14	9/22	133.6	−58.3	1.6	832.2	2761
15	10/20	292.2	+ 4.4	24.6	3.2	922
16	9/24	229.9	+22.5	13.1	16.3	5146
17	10/32	136.1	+ 3.4	14.4	12.0	2699
18	9/25	171.8	−16.3	20.9	7.0	921
19	12/32	175.2	−24.6	1.8	546.6	2539
20	11/33	175.2	−30.3	1.8	636.9	2260
21	11/22	183.4	−37.1	1.8	626.1	600
22	11/22	230.1	−29.7	5.4	72.1	864
23	10/21	188.4	−15.4	5.1	89.7	774
24/1	5/10	332.6	+19.5	18.8	17.4	2129
24/2	6/11	219.2	−56.1	5.5	193.4	2598
25	10/21	97.8	−10.8	14.0	12.7	3983
26	13/23	151.9	−75.6	3.5	137.7	863
27	8/14	277.5	+39.3	25.8	5.5	5909
28	15/22	154.8	+ 8.8	8.7	20.0	26200
29	10/30	128.0	−25.1	5.2	86.1	3220
30	10/20	150.0	−37.3	6.3	58.0	2385
31/1	6/12	3.8	+26.4	4.1	263.7	1964
31/2	7/14	4.3	+29.2	1.6	1367.7	785
32/1	7/15	322.9	+13.9	5.7	110.9	3014
32/2	6/12	327.9	+27.4	3.0	472.0	1864
33	10/19	8.5	+49.6	2.7	301.1	4736

mean intensity of NRM in μG($1 \mu G = 10^{-6}$ Gauss), 8: peak field for alternating field demagnetization in Oe, 9: mean declination of CARM, 10: mean inclination of CARM, 11: α_{95} value of CARM, 12: precision parameter of CARM, 13: mean intensity of CARM in μG ($1 \mu G = 10^{-6}$ Gauss), 14: type of demagnetization curve according to Fig. 5

b) Characteristic remanent magnetization (CARM)

1 Nr.	8 H_{peak}	9 D(°)	10 I(°)	11 α_{95}(°)	12 k	13 CARM (μG)	14 Demagn.
1	150	184.1	−45.6	2.8	282.3	1287	c
2	—	unstable remanence					b
3	350	180.9	−41.2	6.7	42.2	739	h
4	300	209.4	−26.8	8.9	39.2	88	e
5	10	322.2	+27.3	29.0	4.1	3605	b
6/1	200	130.5	−55.1	4.7	380.6	961	c
6/2	50	3.8	+46.4	26.9	2.5	1498	b
7	300	80.9	+34.0	9.7	25.4	506	e
8	500	353.7	+38.1	4.2	129.5	278	a
9	200	175.6	−50.4	1.7	538.0	3752	f
10	200	192.4	−34.6	4.2	112.2	2468	f
11	50	351.5	+40.0	4.5	90.1	1366	e
12	50	12.4	+39.0	2.8	225.1	6390	a
13	200	135.1	−43.5	7.0	63.4	1344	a
14	100	134.1	−57.7	1.9	712.7	2446	c
15	500	228.6	−40.1	7.2	59.5	163	g
16	400	265.7	+59.0	13.3	15.7	1451	a
17	200	149.9	− 7.7	5.2	86.3	450	a
18	100	180.2	−29.7	3.9	173.0	856	c
19	200	175.8	−24.6	2.0	436.2	1980	c
20	200	174.0	−29.7	1.7	694.4	1676	c
21	300	175.9	−21.5	1.8	579.1	332	c
22	200	211.1	−31.2	3.7	149.5	606	f
23	200	190.2	−11.7	4.7	104.9	255	c
24/1	200	215.7	−60.9	6.5	136.6	497	b
24/2	200	196.3	−46.5	5.9	126.6	1502	e
25	150	139.7	−37.0	8.8	30.6	803	a
26	200	151.6	−73.2	1.6	657.0	801	c
27	200	239.9	−21.2	16.0	15.0	369	a
28	200	227.5	− 4.2	4.5	70.7	5126	a
29	200	131.9	−41.5	2.7	340.4	1428	b
30	100	174.5	−50.0	2.3	417.6	1850	b
31/1	100	4.3	+25.9	4.3	242.9	1771	d
31/2	100	5.7	+28.6	1.4	1649.0	767	d
32/1	100	322.5	+12.3	5.5	117.8	3046	c
32/2	100	324.3	+22.3	1.5	1867.4	1657	c
33	100	6.1	+49.6	3.6	172.6	3424	e

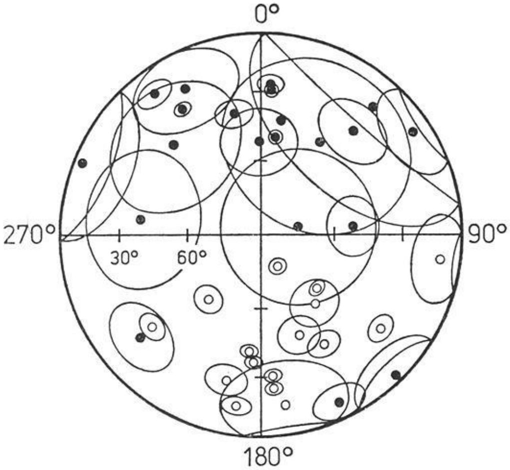

Fig. 4. Mean directions of natural remanent magnetization (NRM) together with their α_{95} cones of confidence. For legend see Fig. 3

alternating field demagnetization was applied to remove these components starting with the stepwise demagnetization of test samples from each site. The most suitable demagnetizing field for the specimens of one site was chosen according to their rock magnetic properties (Soffel, 1975) and statistical criteria (minimum of scatter). The peak fields in Oe are listed in Table 2b. The drop of intensity of remanence during alternating field demagnetization was not uniform. Eight different types could be distinguished which are shown in Fig. 5 for demagnetizing fields up to 1000 Oe. However many of the test samples have been treated with fields up to 1500 Oe. Type a) shows a large drop of intensity combined with a change in remanence direction at alternating fields between 50 and 100 Oe. The remanence remained constant up to 1000 Oe and more without essential change in direction and intensity, which was less than 10% of the NRM. Type b) showed similar behaviour as type a). However the intensity of remanence did not drop below 25% of NRM. Type c) is similar to type b), showing the drop of intensity between 200 and 400 Oe combined with a more or less sudden convergence towards a stable remanence direction. Type d) shows only a small drop of intensity in alternating fields up to 1000 Oe without a change in remanence direction. Type e) shows a slight increase of remanence in fields between 0 and 50 Oe followed by a sharp drop of intensity between 50 and 100 Oe similar to type a). Large variations of direction of remanence occur only between 0 and 150 Oe. Type f) is similar to type c), showing a slight increase of remanence combined with moderate variations of the direction of remanence between 0 and 150 Oe. A peculiar curve is type g) showing an increase of remanence between 0 and 50 Oe followed by a sharp drop between 50 and 100 Oe, a further increase between 100 and 300 Oe and a gentle decrease for still higher intensities of the alternating field. Large variations of the direction of remanence occur between 0 and 300 Oe until a final reversed direction with stable remanence is obtained. A similar behaviour (without the initial increase between 0 and 50 Oe) has the curve of type h). Rocks

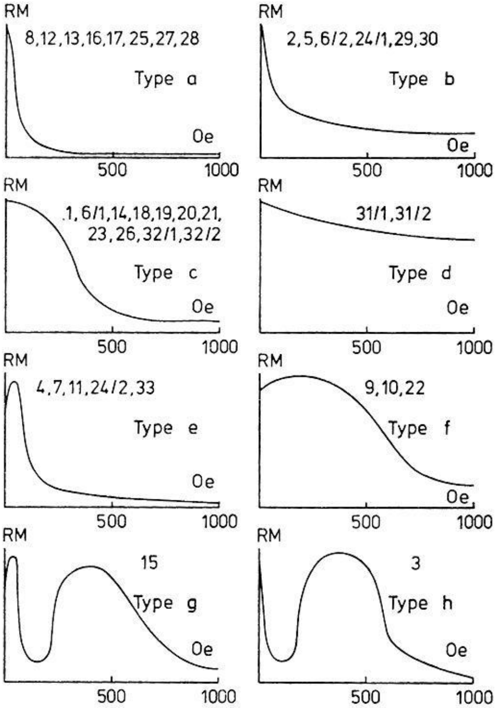

Fig. 5. Behaviour of typical test samples during alternating field demagnetization in fields up to 1000 Oe. Intensities are shown in arbitrary units. Numbers refer to site numbers

belonging to types g) and h) have unstable magnetization components more or less in the direction of the present field in the sampling area which are stronger than the primary reversed direction of remanence but (fortunately) connected with smaller coercive forces.

3.3. Characteristic Remanent Magnetization (CARM)

The directions of the stable remanence after alternating field demagnetization of all sites (sample means) are shown in Fig. 6 in equal area projection. For site number 2 no stable remanence with a grouping better than for the NRM could be obtained. The CARM data of the individual sites are also listed in Table 2b together with the parameters characterizing their scatter. The data of site 6/2 were omitted because of too large internal scatter ($\alpha_{95} = 26.9°$). Intermediate directions have been obtained for site 7 and 16. These data were also omitted for the computation of mean CARM directions.

Fig. 7 shows the mean CARM directions of all sites (minus site numbers 2, 6/2, 7 and 16) together with their cones of confidence in equal area projection. The scatter of the directions is much smaller than that for the NRM. With exception of site numbers 5 and 27 all α_{95} values are much smaller than 10°. The data plotted in Fig. 7 and listed in Table 2b already include tectonic corrections which were especially necessary in the northwestern part of the sampling area.

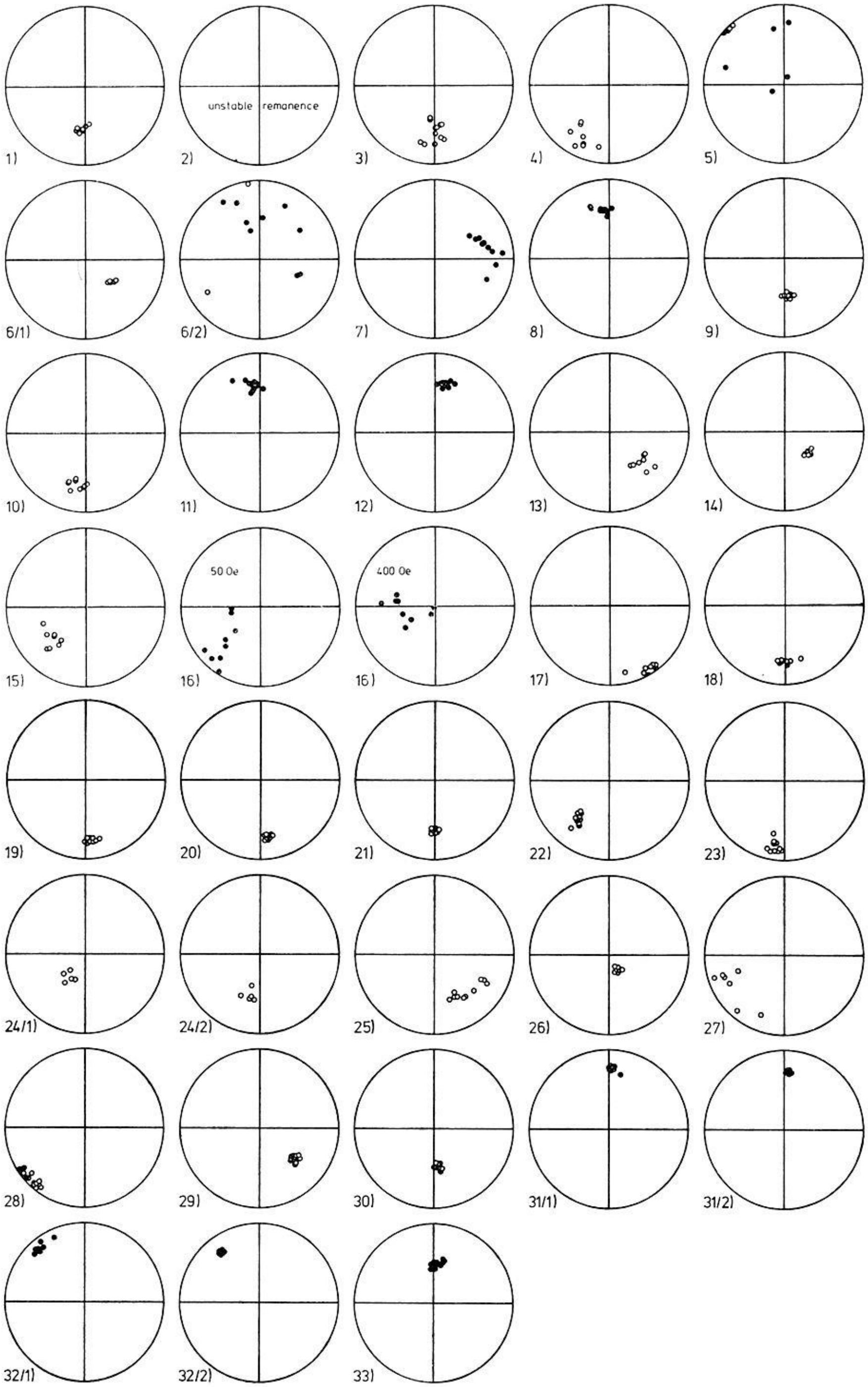

Fig. 6. Mean directions of characteristic remanent magnetization (CARM, sample means) of all sites. For legend see Fig. 3

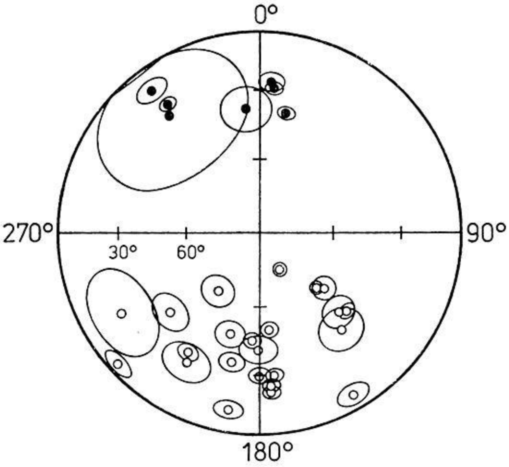

Fig. 7. Mean direction of characteristic remanent magnetization (CARM) of all sites together with their α_{95} cones of confidence. The data of site numbers 2, 6/2, 7 and 16 are not plotted

The radiometric age determinations according to Piccoli (private communication, 1973) together with data taken from the geological map of the sampling area (Carta Geologica d'Italia) and from Piccoli (1966) permitted to divide the sites into two main groups with respect to their ages. One group (group I) includes ages younger than 40 m.y. and volcanics classified as Lower and Middle Oligocene. The other group (group II) comprises rocks with ages between 40 and 50 m.y. and volcanics classified as Middle and Upper Eocene. The mean CARM directions of sites from group I (Lower and Middle Oligocene) are plotted in Fig. 8. The mean direction of this group is plotted as a square together with its α_{95} cone of confidence using equal area projection. Only reversed polarities are plotted (open symbols), the CARM direction of sites with normal polarity was projected to the other hemisphere. The mean direction of sites from group I is: $D=204.1°$, $I=-34.8°$, with $N=15$, $k=17.6$, $\alpha_{95}=8.6°$. Fig. 9 shows the mean CARM directions of sites from group II (Middle and Upper Eocene) in equal area projection together with the mean direction of all sites (square) and its α_{95} cone of confidence. Again only reversed polarities are shown, normal polarities were projected to the other hemisphere. The mean direction of sites from group II is: $D=156.5°$, $I=-38.1°$, with $N=18$, $k=13.6$, $\alpha_{95}=9.0°$. In both cases unit weight was given to each site for the computation of the mean direction. The difference in declination between the two groups is 47.6°. A declination difference of about the same amount (51.2° and 55.3° respectively, depending on the scheme of subdivision into two groups of different age) has been obtained by Soffel (1972, 1974a) from the study of the palaeomagnetism of the Tertiary Colli Euganei volcanites. As both sampling areas (Colli Euganei, Monti Lessini and Monte Berici) are only 60 km apart, their mean CARM directions of all sites can be combined for a better and more reliable determination of the mean CARM direction of Middle and Upper Eocene as well as Lower and Middle Oligocene for Northern Italy. The combined data for group I (Lower and Middle Oligocene, group I') are: $D=197.1°$, $I=-42.1°$,

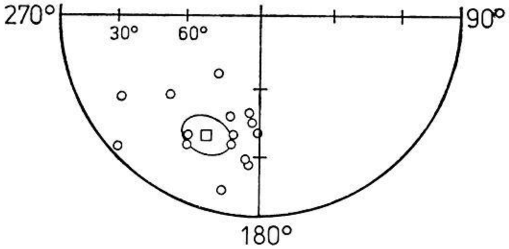

Fig. 8. Mean directions of characteristic remanent magnetization of all volcanic units of Oligocene age. Square: mean of all sites together with the α_{95} cone of confidence. Only reversed polarites are shown. The directions of sites with normal polarity were projected to the other hemisphere

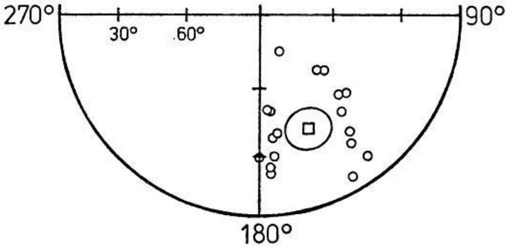

Fig. 9. Mean directions of characteristic remanent magnetization of all volcanic units of Eocene age. Square: mean of all sites together with the α_{95} cone of confidence. Only reversed polarities are shown. The directions of sites with normal polarity were projected to the other hemisphere

$N=31$, $k=13.3$, $\alpha_{95}=6.9°$, giving unit weight to each site. The combined data from both sampling areas for group II (Middle and Upper Eocene, group II') are: $D=150.3°$, $I=-37.3°$, $N=25$, $k=12.1$, $\alpha_{95}=8.0°$. The declination difference between the groups of the combined data is 46.8°.

As can be seen from Fig. 10 there seems to be a systematic difference between the mean directions of remanence of the Monti Lessini (squares) and Colli Euganei (circles) for both Eocene and Oligocene rocks. The declinations obtained for the Colli Euganei rocks are in average about 10° smaller than those obtained for the Monti Lessini rocks while the inclinations are in better agreement. This suggests an anticlockwise rotation of the Colli Euganei with respect to the Monti Lessini of about 10° since Middle Oligocene. However this conclusion is not very reliable as the mean directions of the two sampling areas, though being different systematically to some extent, are in general agreement within the possible limits of error. The eventual anticlockwise rotation of the Colli Euganei with respect to the Monti Lessini could possibly be related to the post Oligocene rotation of the Corso-Sardinian block (De Jong *et al.*, 1973) and its tectonic consequences in the area of the Apennine and Po basin.

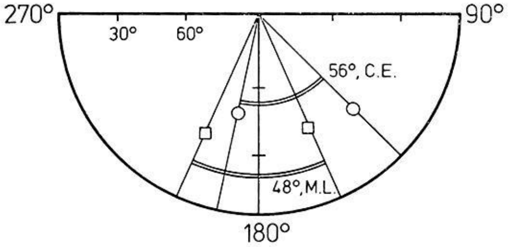

Fig. 10. Mean directions of characteristic remanent magnetization of both Oligocene and Eocene age according to Fig. 8 and Fig. 9 for the Monti Lessini (squares) and for the Colli Euganei (circles) according to Soffel (1974a). The angles of rotation are shown (48° and 56° respectively) as well as the systematic difference in declination between the two areas

3.4. Virtual Geomagnetic Pole Positions (VGP)

The mean geographic coordinates of the sampling area are: $\lambda = 11.5°$ E, $\varphi = 45.5$ °N. Within a few tenth of a degree these values are correct for both Monti Lessini and Colli Euganei area. For the group I of the Monti Lessini (Lower and Middle Oligocene) the following VGP position is obtained: $\lambda = 146.4$ °E, $\varphi = 56.9$ °N. The corresponding VGP position for the group II of the Monti Lessini (Middle and Upper Eocene) is: $\lambda = 237.9$ °E, $\varphi = 59.1$ °N. The pole positions for the combined data of the Monti Lessini and Colli Euganei are for group I′ (Lower and Middle Oligocene): $\lambda = 152.6$ °E, $\varphi = 64.7$ °N and for group II′ (Middle and Upper Eocene): $\lambda = 246.0$ °E, $\varphi = 55.3$ °N. These VGP positions are plotted in Fig. 11 in equal area projection. Fig. 11 also contains mean pole positions for Lower Tertiary (T_l) and Upper Tertiary (T_u) for Stable Europe according to the latest data compiled by McElhinny (1973). Fig. 11 shows that there is good agreement between the VGP positions of group I and group I′ (Lower and Middle Oligocene of the Monti Lessini and Monti Lessini combined with the Colli Euganei respectively) with the Lower Tertiary pole positions determined on rocks from Central Europe. The VGP positions of group II and group II′ (Middle and Upper Eocene of the Monti Lessini and Monti Lessini combined with the Colli Euganei respectively) are far apart from the Tertiary pole positions for Central Europe and in the vicinity of pole positions of Permian and Triassic rocks from the Southern Alps according to Zijderveld and Van der Voo (1973) and Manzoni (1970). These pole positions are marked with P and Tr respectively in Fig. 11. Fig. 11 also contains the pole position of paleozoic dykes from within the Ötztal Massive according to Förster, Soffel and Zinsser (1975), the pole position of Permian quartz porphyries in Vorarlberg (Austria, Va) according to Soffel (1975a) and the pole position (Tosc.) determined by Lowrie and Alvarez (1975) for the Upper Cretaceous to Lower Tertiary Scaglia Rossa formation in the Toscana in Central Italy. The data suggest an anticlockwise rotation of Northern Italy (and eventually also the remaining part of Italy) with respect to Central through an angle of rougly 50°. At least for the Southern Alps it can be assumed that the rotation took place between 45 m.y. and 35 m.y. This time interval seems to be sufficiently well confirmed by the latest radiometric age determinations by Piccoli (private communication, 1973).

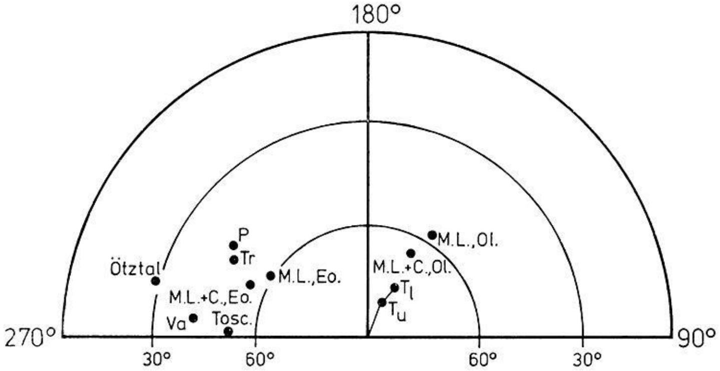

Fig. 11. Virtual geomagnetic pole positions in equal area projection. T_u and T_l: mean pole positions of Upper and Lower Tertiary respectively according to McElhinny (1973) for Central Europe. M. L., Ol. and M. L. + C., Ol.: Oligocene pole positions for the Monti Lessini area and a combined pole position for the Monti Lessini and Colli Euganei areas respectively. M. L., Eo. and M. L. + C., Eo.: same meaning, but refering to rocks of Eocene age from both sampling areas. P.: Permian pole position of the Southern Alps according to Zijderveld and Van der Voo (1973) and Tr: Triassic pole position of the same area according to Manzoni (1970). Va: Pole position of the Permian quartz porphyries in Vorarlberg according to Soffel (1975a). Ötztal: pole position of paleozoic dykes from the Ötztal massive according to Förster, Soffel and Zinsser (1975). Tosc.: Cretaceous to Lower Eocene pole position of Central Italy according to Lowrie and Alvarez (1974)

4. *Conclusions*

The characteristic remanent magnetization of 37 volcanic units has been investigated with standard measuring and alternating field demagnetization techniques. For two out of 37 volcanic units no stable characteristic remanence could be determined, the data of 2 other lava flows had to be omitted because of intermediate remanence directions. The mean declination of 15 Oligocene lava flows is 47.6° greater than the mean declination of 18 Eocene lava flows, while the inclinations of both groups are the same within the limits of error. The mean remanence directions of the Oligocene as well as the Eocene lava flows in the Monti Lessini are quite close to the corresponding data of the Oligocene and Eocene rocks of the Colli Euganei (Soffel, 1972, 1974a). The pole positions derived from the palaeomagnetic data are shown in Fig. 11 in comparison with the pole positions obtained for rocks of corresponding age in Central Europe. The Oligocene pole positions of both the Monti Lessini and the Colli Euganei rocks are in quite good agreement with the Lower Tertiary pole position of Central Europe. However their latitudes are somewhat lower. The Eocene pole positions of both areas are in the vicinity of the Triassic and Permian pole positions of the Southern Alps. This confirms the result obtained by Soffel (1972, 1974a) indicating that the rotation of Northern Italy in an anticlockwise sense of about 50° took place between Eocene and Oligocene.

The radiometric age determinations in the Monti Lessini (Piccoli, private communication, 1973) suggest that the rotation started between 45 and 40 m.y. and has come to an end at around 35 m.y. The too low latitude for the Oligocene pole positions of the Monti Lessini and the Colli Euganei compared with Central Europe suggests a drift of the Southern Alps to the North in times after Middle Oligocene. A small but systematic difference between the declinations of rocks from the Monti Lessini and Colli Euganei (Fig. 10) suggests an anticlockwise rotation of the Colli Euganei with respect to the Monti Lessini after Middle Oligocene. This could eventually be related to the post Oligocene rotation of the Corso-Sardinian block and its tectonic consequences in the area of the Apennine and the Po basin.

Acknowledgement. The investigations have been made in the Institut für Angewandte Geophysik, University of Munich. Thanks are due to Prof. Dr. G. Angenheister and Dr. N. Petersen for their interest and support. Dr. Bögel from the Geological Institute of the Technical University in Munich suggested the measurements in the Monti Lessini as a check for the previously obtained Colli Euganei results. His current interest in the work is gratefully acknowledged. Prof. Piccoli from the Geological Institute of the University of Padova kindly provided some unpublished radiometric age determinations and gave valuable hints for suitable sampling localities. Dipl. Geophys. H. Becker kindly helped to collect part of the samples. Special thanks are due to the two refereees for their help to improve the manuscript.

The financial support of the Deutsche Forschungsgemeinschaft is gratefully acknowledged.

References

Borsi, S., Ferrara, G., Piccoli, G.: Determinazione col metodo K/Ar dell'età delle eruzioni Euganee. Rend. Soc. Ital. Mineral. Petr. *25*, 3—10, 1969

De Jong, K. A., Manzoni, M., Stavenga, T., Van Dijk, F., Van der Voo, R., Zijderveld, J. D. A.: Palaeomagnetic evidence for rotation of Sardinia during Early Miocene. Nature *243*, 281—283, 1973

Förster, H., Soffel, H., Zinsser, H.: Palaeomagnetism of rocks from the Eastern Alps from north and south of the Insubrian line. N. Jb. Geol. Palaeont., in press, 1975

Lowrie, W., Alvarez, W.: Rotation of the Italian peninsula. Nature *251*, 285—288, 1974

Manzoni, M.: Paleomagnetic data of Middle and Upper Triassic age from the Dolomites (Eastern Alps, Italy). Tectonophysics *10*, 411—424, 1970

McElhinny, M. W.: Palaeomagnetism and plate tectonics. Cambridge: The University Press 1973

Piccoli, G.: Tettonica e attività vulcanica nel paleogene dei Lessini (Alpi meridionali, Italia). Proc. Intern. Geol. Congr. India, Part *11*, 497—513, 1964

Piccoli, G.: Subaqueous and subaerial basic volcanic eruptions in the Paleogene of the Lessinian Alps (Southern Alps, Italy). Bull. Volcanol. *29*, 253—270, 1966

Piccoli, G.: Le conoscenze attuali sulle manifestazioni eruttive neogeniche nel Veneto. Giorn. Geol. *35*, 359—366, 1969

Riedel, A.: Geologia degli Euganei nord-occidentali. Mem. Museo Civico St. Nat. Verona *2*, 107—124, 1950

Schiavinato, G.: La provincia magmatica del Veneto sud-occidentale Mem. Ist. Geol. Mineral. Univ. Padova *17*, 1—38, 1950

Soffel, H.: Anticlockwise rotation of Italy between the Eocene and Miocene: palaeomagnetic evidence from the Colli Euganei, Italy. Earth Planet. Sci. Lett. *17*, 207—210, 1972

Soffel, H.: Palaeomagnetism and rock magnetism of the Colli Euganei volcanites and the rotation of Northern Italy between Eocene and Oligocene. Boll. Geofis. Teor. Appl. *16*, 333—355, 1974a

Soffel, H.: The palaeomagnetism of the Permian effusives near St. Anton, Vorarlberg (Austria) and the anticlockwise rotation of the Northern Calcareous Alps through 60°. Jb. Geol. Palaeont., in press, 1975a

Soffel, H.: Rock magnetism of the Monti Lessini and Monte Berici Volcanites and age of volcanism deduced from the Heirtzler polarity time scale. J. Geophys. *41*, 401—411, 1975

Zijderveld, J. D. A., Van der Voo, R.: Palaeomagnetism in the Mediterranean area. Implications of continental drift to the Earth Sciences. Vol. 1. New York: Academic Press 1973

Prof. Dr. Heinrich Soffel
Institut für Allgemeine und
Angewandte Geophysik der Universität
D - 8000 München 2, Theresienstraße 41
Federal Republic of Germany