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Reinterpretation of Palaeomagnetism of the Colli Euganei and Monti Lessini (Italy)

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Abstract. New information on the age of the volcanics from the Colli Euganei and Monti Lessini (Northern Italy) collected by Channell et al. (1978) show that the divisions made by Soffel (1972, 1974, 1975a) of palaeomagnetic directions from the two areas into Eocene and Oligocene groups had to be modified. From the data of both sampling areas alone an anticlockwise rotation of the area between Eocene and Oligocene can no longer be clearly demonstrated. However, a combination of the predominantly Oligocene data from the Colli Euganei with the predominently Eocene data from the Monti Lessini as well as their comparison with corresponding palaeomagnetic data from Stable Europe brings enough statistical evidence for an anticlockwise rotation of the area of at least 20–30° between Upper Eocene and Lower to Middle Oligocene.

Key words: Palaeomagnetism – Age of Volcanism – Rotation of Italy.

1. Introduction

Channell, De Zanche and Sedea (1978) have presented valuable new information about the ages of many volcanic units which have been studied with respect to their palaeomagnetic and rock magnetic properties by Soffel (1972, 1974) in the Colli Euganei and later (Soffel, 1975a and b) in the Monti Lessini in Northern Italy. In the area of the Colli Euganei with two cycles of volcanic activities (one in Eocene, a second in Oligocene) Soffel (1972, 1974) interpreted an extremely non-Fisherian distribution of remanence directions ($225.5° > D > 122.3°$) in terms of two groups of remanence directions setting a dividing line at about $D = 180°$. All volcanic units (some of them with radiometric ages around 33 m.y.) with a declination $D > 180°$ were classified as Oligocene, all with $D < 180°$ as Eocene. A declination difference of about 50° was found between the two groups.

With this working hypothesis, additional sampling was made in the nearby Monti Lessini, where many volcanics of Eocene age crop out, some of them

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radiometrically dated as around 47 m.y. old. Also in this region an extremely non-Fisherian distribution of remanence directions was found ($239.9° > D > 131.9°$). Like in the Colli Euganei, two groups of remanence directions were postulated setting again the dividing line at about $D = 180°$. All radiometrically dated volcanic units of Eocene age and others which could be classified as Eocene from the available geological maps had in general declinations smaller than 180°. Some of the volcanites with $D > 180°$ could clearly be identified as Oligocene. However, some units could not attributed to one of the two age groups because of lack of detailed geological information available at that time.

The ages of some volcanic units from both sampling areas are still uncertain, even after the study of Channell et al. (1978). In order to avoid further confusion, their palaeomagnetic data have been left out from the following discussion.

Simply because of lack of a sufficient number of unambiguous Eocene remanence directions in the Colli Euganei area, I agree with Channell et al. (1978) and their statement, that "a 50° anticlockwise rotation of the area between Eocene and Oligocene can no more be substantiated". However, this does not devalue the remanence directions of the "clearly" Oligocene volcanic units of the Colli Euganei for any further comparison with the remanence directions of "clearly" Eocene volcanics from the Monti Lessini and with corresponding palaeomagnetic data from Stable Europe. "Clearly" in this context means that the critical revision of the ages of volcanism by Channell et al. (1978) is fully accepted at the moment, although, as has been mentioned previously, it may be difficult in some places to state whether a certain volcanic unit is still uppermost Late Eocene or already youngest Lower Oligocene from biostratigraphy or purely petrological evidence alone.

2. Reinterpretation of the Palaeomagnetic Data

Figure 1a shows the mean remanence directions of the "clearly" Oligocene volcanic units of the Colli Euganei (C) and Monti Lessini (M). The numbers refer to the site numbers in the corresponding papers (Soffel, 1972, 1974, 1975a). There is a fairly well and closely grouped Fisherian distribution of Oligocene remanence directions from both sampling areas with the following mean (open square): $N = 17$, $R = 16.43$, $D = 200.2°$, $I = -52.5°$, $k = 28.3$, $\alpha_{95} = 6.4°$. This group is surrounded by 8 "satellite" remanence directions, which are in general about 30° apart from the marginal directions of the closer group. The mean also including these 8 remanence directions is (open diamond): $N = 25$, $R = 22.16$, $D = 189.5°$, $I = -46.7°$, $k = 8.5$, $\alpha_{95} = 9.6°$. It must be noted here that the inclusion of the 8 "satellite" remanence directions reduces the precision parameter k from 28.3 (an average value of k for a group of volcanic rocks of the same age) to a very low value of only 8.5. This may be due to lack of sufficient tectonic control implying undetected tilts up to about 60°. The absence of almost any tilts in the Monti Lessini area and the presence of only small tilts in the Colli Euganei call this in question. Eventually older (Eocene) ages may be the reason for the directions with D around 150°, although part of them

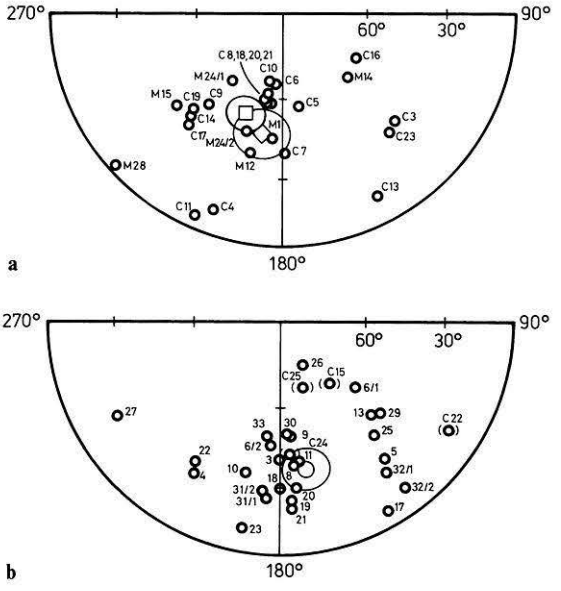

Fig. 1 a and b. Site mean directions of stable remanence of the Colli Euganei **(C)** and Monti Lessini **(M)** area. Only reversed directions are shown. Numbers refer to site numbers. The circles of 95% confidence are also shown. **a** Oligocene directions. Mean of all sites: open diamond. Mean of the closely grouped directions: open square. **b** Eocene directions. Mean of all sites from the Monti Lessini, excluding M27 and those in brackets of uncertain age from the Colli Euganei: open circle

were classified as "clearly". Oligocene by Channell et al. (1978). Some intermediate geomagnetic field directions may also contribute to the scatter of the 8 "satellite" remanence directions.

Figure 1 b shows the mean remanence directions of the "clearly" Eocene volcanic units. They come entirely from the Monti Lessini (M) area. Numbers refer to the site numbers according to Soffel (1975 a). The remanence directions of 4 sites from the Colli Euganei (C15, C22, C24, C25) are also plotted in brackets. There is no direct evidence for their age according to Channell et al. (1978). They have been regarded as Eocene by Soffel (1972, 1974). Considering only the data from the Monti Lessini (discarding M27 because of too large deviation from the remaining group) the following mean is obtained and plotted in Figure 1 b as an open circle: $N=26$, $R=23.89$, $D=169.9°$, $I=-36.7°$, $k=11.8$, $\alpha_{95}=8.0°$. Including also M27 we get the following mean: $N=27$, $R=24.38$, $D=172.5°$, $I=-36.9°$, $k=9.9$, $\alpha_{95}=8.6°$. An exclusion of one site out of 27 sites, which reduces the precision parameter k by about 20%, seems to be justified. Tentatively including besides M27 also the 4 directions of the eventually Late Eocene sites from the Colli Euganei yields the following mean: $N=31$, $R=27.77$, $D=169.8°$, $I=-38.8°$, $k=9.3$, $\alpha_{95}=8.3°$. All three means for Eocene differ only by less than 3°. Site numbers M5, M6/1, M6/2, M8, M9, and M12 have radiometric ages of around 47 m.y. (see Soffel, 1975 a). Their mean is: $N=6$, $R=5.76$, $D=163.2°$, $I=-44.0°$, $k=20.7$, $\alpha_{95}=15.0°$. This also indicates that the mean Eocene remanence direction is situated rather in the second than in the third quadrant.

Figure 2 shows the mean of the closely grouped (open square) Oligocene directions. The Oligocene mean including also the 8 "satellite" directions is plotted as open diamond. The open circle is the mean Eocene direction (excluding

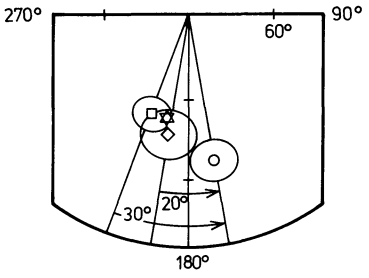

Fig. 2. Means of the Oligocene (open square and diamond) and Eocene (open circle) directions. For details see text and caption of Fig. 1. Open star: expected remanence direction for Lower Tertiary in the sampling area (see text). The amounts of anticlockwise rotation are indicated

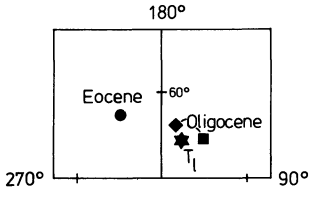

Fig. 3. Pole positions. Star: mean pole position for Lower Tertiary (T_1) after McElhinny (1973). Diamond: Oligocene (all). Square: Oligocene (closely grouped). Circle: Eocene

M27). The corresponding circles of 95% confidence are also shown. In order to test the significance of the difference between the means for Oligocene and Eocene the *F*-test after Watson (1956) was applied yielding the following values:

(a) Oligocene, closely grouped directions: $N_1=17$, $R_1=16.43$. Eocene: $N_2=26$, $R_2=23.89$. Total of both groups: $N=43$, $R=39.29$. *F*-ratio: 15.76. Critical value for the 95% confidence level: 3.20 and for the 99% confidence level: 5.15.

(b) Oligocene, including the 8 "satellite" directions: $N_1=25$, $R_1=22.16$. Eocene: $N_2=26$, $R_2=23.89$. Total of both groups: $N=51$, $R=45.50$. *F*-ratio: 4.79. Critical value for the 95% confidence level: 3.18 and for the 99% confidence level: 5.05.

According the McElhinny (1973) the mean pole position for Lower Tertiary (T_1) of Stable Europe is: $\lambda'=151°$ E, $\varphi'=75°$ N (see Fig. 3, star). For the mean sampling locality ($\lambda=11.4°$ E, $\varphi=45.4°$ N) the expected remanence direction is: $D=191.6°$, $I=-52.8°$, which is also plotted in Figure 2 has an open star. This value is in agreement within the limits of error with what has been measured for the Lower to Middle Oligocene in the Colli Euganei and Monti Lessini area. Yet its declination is at least 20° different from the Late Eocene value.

The pole positions are shown in Fig. 3 using the same (closed) symbols as for the remanence directions in Fig. 2. Star ($\lambda'=151°$ E, $\varphi'=75°$ N): Lower Tertiary of Stable Europe according to McElhinny (1973). Square ($\lambda'=133.8°$ E, $\varphi'=70.2°$ N): Oligocene, closely grouped data alone. Diamond ($\lambda'=164.8°$ E, $\varphi'=71.0°$ N): Oligocene, all data. Circle: ($\lambda'=213.1°$ E, $\varphi'=63.7°$ N): Eocene.

According to the standard criteria in palaeomagnetism, especially regarding the statistical evidence for the difference between the mean remanence directions of the "clearly" Oligocene and Eocene groups, the statement of Channell et al. (1978), that "a 50° anticlockwise rotation of this part of Northern Italy can not be substantiated" has to be modified. There seems to be sufficient statistical

evidence that an anticlockwise rotation within the short time interval between Late Eocene and Lower to Middle Oligocene of 20–30° took place. The uncertainties of some ages, which tend to bring the two groups of data together thus reducing the difference of the means and increasing their internal scatter favour an even larger amount of rotation between Eocene and Oligocene.

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