J. Geophys. 42, 59–71, 1976

Journal of Geophysics

Postulated Rotation of Corsica not Confirmed by New Palaeomagnetic Data

K.M. Storetvedt and N. Petersen

Department of Geophysics, University of Bergen, Allégt. 70, N-5014 Bergen, Norway and Institut für Angewandte Geophysik, Universität München, Theresienstraße 41, D-8000 München, Federal Republic of Germany

Abstract. Magneto-mineralogical studies of Corsican rhyolitic/andesitic rocks of late Carboniferous-Permian age have revealed an extensive low temperature (weathering) alteration of the primary oxides. In line with this observation analysis of the palaeomagnetic record suggests that at least a substantial part of the "stable" remanence is of chemical origin, probably dating back to the early Tertiary when the West Mediterranean region was subjected to marked uplift and erosion. The relatively stable bulk remanence is composite, constituting both normal and reverse components of magnetization. However, careful demagnetization does not support previous suggestions (based on the same rock formations) of a stable component of magnetization with south-southeasterly declination. Therefore, the idea of a certain anti-clockwise rotation of Corsica, detectable by palaeomagnetic means, does not seem to have a firm basis.

Key words: Palaeomagnetism – Rock magnetism – Possible rotation of Corsica.

1. Introduction

The origin of small ocean basins like those of the West Mediterranean have been a matter of speculation among earth scientists for a long time. Such basins which to a large extent seem to be located between the compressional boundaries of larger crustal blocks may have developed through two entirely different processes: a) by subsidence of previous continental areas (Klemme, 1958; Van Bemmelen, 1969) which subsequently have been turned into a "transitional" type of crust (Menard, 1967) through vertical assimilation by the upper mantle, or b) by crustal separation through the mechanism of sea floor spreading (Vogt *et al.*, 1971; Le Pichon *et al.*, 1971). Theoretically, these mechanisms seem equally plausible and they may both have taken part in the development of at least some of the smaller ocean basins.

Table 1. Rock collection details

Site no.	Sample nos.	Locality	Rock type	Strike and dip	Other remarks
1	1 – 3	Col de Palmarella	rhyolite dike		
2	4 – 6	Near Col de Palamarella	rhyolite flow	uncertain	
3	7 – 10	The rhyolite dikes, site 1	rhyolite dike	The rhyolite dikes are	
4	11 – 14	and 3–8, have been collected		about vertical and there	
5	15 – 17	along road N 199 from		is no information about	
6	18 – 20	Col de Palmarella to		any post-emplacement	
7	21 – 25	Cöl de la Croix		tilting	
8	26 – 30				
9	31 – 36	Sites 9 – 12 collected	andesite flow	160°, 30°W	
10	37 – 40	west/southwest of		uncertain	
11	41	Osani village		uncertain	
12	42 – 44			035°, 27°NW	
13	45 – 49	On the footpath from Col de la Croix to Tuara	rhyolite dike		
14	50 – 51	Near Col de Palmarella	rhyolite flow		

As an apparent strong support of a sea floor spreading origin of the Western Mediterranean palaeomagnetic data have suggested anticlockwise rotations of Corsica/Sardinia and of Italy (Nairn and Westphal, 1968; Zijderveld *et al.*, 1970; Soffel, 1974) in the manner predicted by Carey (1958). It has been noted, however, (Storetvedt, 1970) that many of these results exhibit abnormal smeared distributions in the direction of declination suggesting that there may be something wrong with the fundamentals upon which the rotational estimates have been based. In order to look into this problem some Permo-Carboniferous rocks from NW-Corsica have been re-investigated. The considered rocks which are andesitic/rhyolitic lavas and rhyolitic dikes are those previously studied by Nairn and Westphal (1968) and it is referred to that contribution for a general account of the regional geology. Details of the new rock collection which comprises 51 hand samples, collected by application of standard geological orientation procedures, are given in Table 1.

2. Magnetic Mineralogy

Rhyolites. The original oxide mineralogy generally found in rhyolitic rocks is magnetite (with low Ti content) in coexistence with haemoilmenites (15–50 mol % haematite), but the Corsican rhyolites only occasionally show relics of such phases (in some grains), in general there are no identifiable traces of the supposed primary components. Some grains, for example in sample Co 50 (Fig. 1), show signs of high temperature oxidation by lamellae formation, but this structure is completely overprinted by subsequent disintegration. Microscopic analysis suggests that haematite and goethite (α-FeOOH) constitute the predominant iron oxide mineralogy present, an observation which fits in with the generally reddish colour of these rocks. Rutile may be present as another

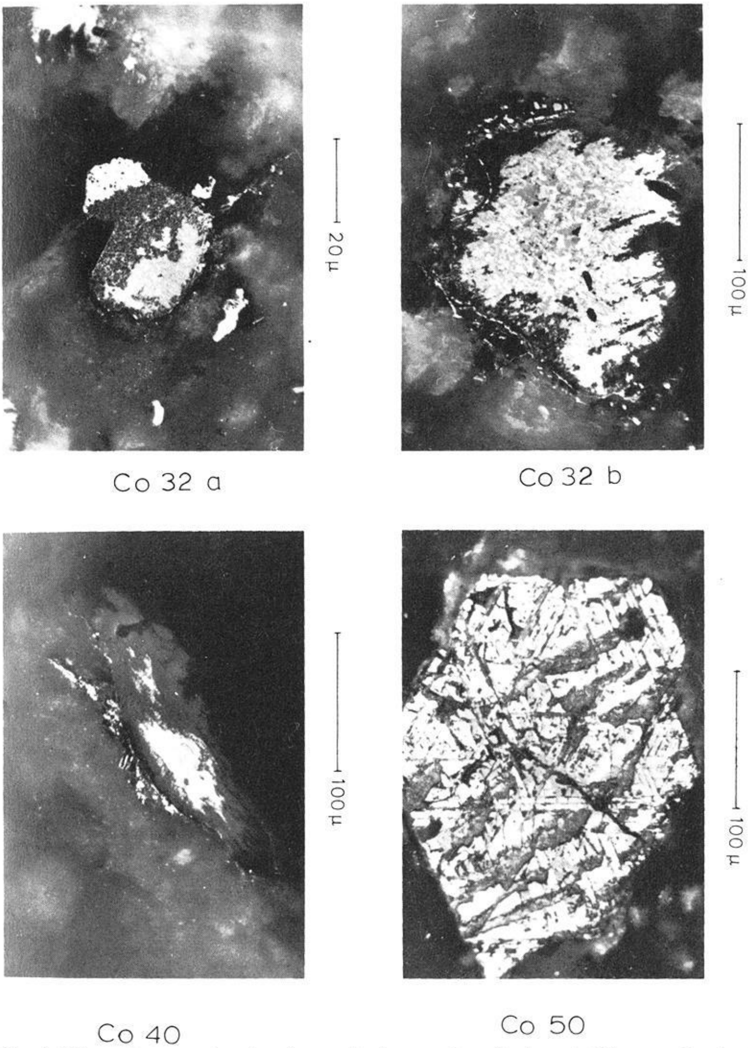

Fig. 1. Microphotographs showing typical examples of mineral disintegration in Corsican volcanics. Co 32: (a) The larger part of the ore grain has been transformed by granulation (dark grey), consisting of a very intimate mixture of presumably haematite, rutile, perowskite and/or sphene. (b) Complete transformation of the titanomagnetite grain into mainly haematite (light grey) and rutil (medium grey). Granulation of the marginal parts of the ore grain (dark grey). Co 40: Almost complete disintegration of an ore grain. Co 50: Original titanomagnetite grain with exsolution lamellae of probably ilmenite (indicating high temperature deuteric oxidation) have been replaced by an assemblage of haematite and rutile (pseudomorphism after magnetite and ilmenite)

alteration product. The microscopic evidence is in part confirmed by measurements of saturation magnetization versus temperature ($J_s - T$). The presence of magnetite (Curie temperature 580 °C) may be suggested in 2 or 3 specimens (cf. Co 50, Fig. 2) but on a whole the high field magnetization decays steadily to zero at temperatures of around 650 °C or more (cf. Co 26, Fig. 2). Another

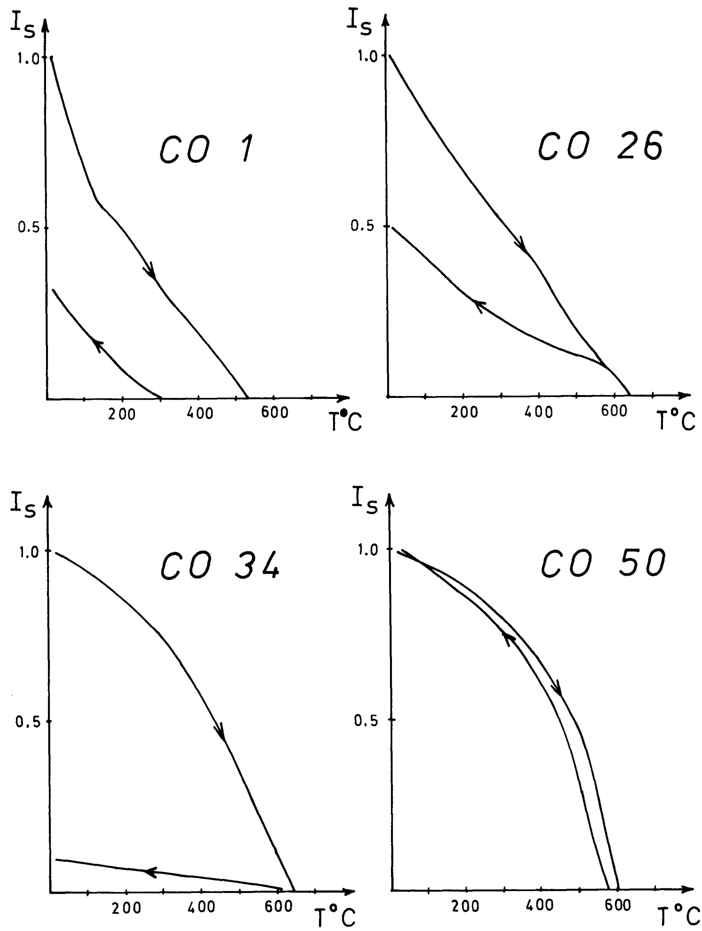

Fig. 2. Representative selection of strong field (4–6 kG) magnetization versus temperature during heating and subsequent cooling

pronounced feature of the $J_s - T$ measurements is the generally strong irreversibility between heating and cooling curves. In general, the magnetization is considerably lower after heating than before heating and in some cases this behaviour is associated with a pronounced lowering of the "Curie point" (cf. Co 1, Fig. 2). Some of these results may be interpreted in terms of a maghaemite/haematite transformation.

Andesites. Similarly as for the rhyolites the primary oxide mineralogy is severely altered—only some small relics of the assumed original phases (titanomagnetite with 30–40 mol% ulvospinel, in coexistence with haemoilmenite) are still present. With very few exceptions the Fe-Ti oxides have been transformed into a mixture of haematite and rutile. In several respects the situation resembles that one encountered in a previous study by the present authors (Storetvedt and Petersen, 1970) involving a practically complete alteration of the magnetite host as well as the exsolved lamellas (Ti-rich) into haematite and rutile. However, in the present case the disintegration has sometimes proceeded further, producing perowskite and/or sphene. The J_s-T measurements of the andesites are very similar to those of the rhyolites.

On a whole, the original Fe-Ti oxide mineralogy of the Corsican rhyolitic/andesitic rocks undoubtedly has suffered an extensive alteration. Low temperature oxidation probably as a result of weathering and/or moderate reheating, is the dominating form of alteration. Unless these processes took place over a short interval of time or while the geomagnetic field had a constant direction (for example in Kiaman time) these alterations are likely to have imposed a complex build-up of the palaeomagnetic record.

3. The Palaeomagnetic Record

About one hundred specimens were treated by progressive thermal or alternating field analysis, the remanence parameters after each demagnetization step being measured on various astatic magnetometers. In agreement with the previous study (Nairn and Westphal, 1968) the NRM intensity varied widely—from approximately 5.10^{-3} emu/cm^3 to $1 \cdot 10^{-6}$ emu/cm^3. No general difference in the total remanence properties between lavas and dikes was found but except for one site (no. 13) the intensity of magnetization of the dikes proved to be less resistant against demagnetization than that of the lavas. The relatively large component of low-stability magnetization in the rhyolite dikes may account for the experimental problems found in the majority of these rocks—the underlying "stable" magnetization in general became unsatisfactorily determined due to scatter in the magnetic parameters at a certain stage of demagnetization. On the other hand, many lava specimens were successfully thermally demagnetized up to temperatures of $\geqq 600$ °C but stable end points were not reached in any of these rocks. The most important blocking temperature range of the lavas is between 500 °C and 550 °C but in several specimens 20–70 per cent of the natural intensity had its decay at temperatures above 600 °C. This is in line with the high oxidation state of the magnetic minerals—haematite then being a major magnetic constituent—as inferred from microscopy and J_s-T measurements. Some examples of the intensity decay pattern versus temperature are shown in Fig. 3.

As one might suggest on basis of the advanced alteration state of the primary oxides the magnetic remanence shows a fairly complex structure. On a whole the data have led us to an entirely different conclusion than that of the previous authors and it seems absolutely necessary therefore to present a fair amount of directional information. Thus, Figs. 4–7 give the direction data as a function of demagnetization of a total of 36 specimens. Effort has been made to give an adequate presentation of within-sample as well as within-site behaviour. In all the examples given, the associated remanence intensity performs a smooth variation (decay) versus increasing field or temperature. This is one of the necessary requirements if directional changes are to be evaluated in a realistic manner. Also, when the intensities initiate an irregular behaviour (at some

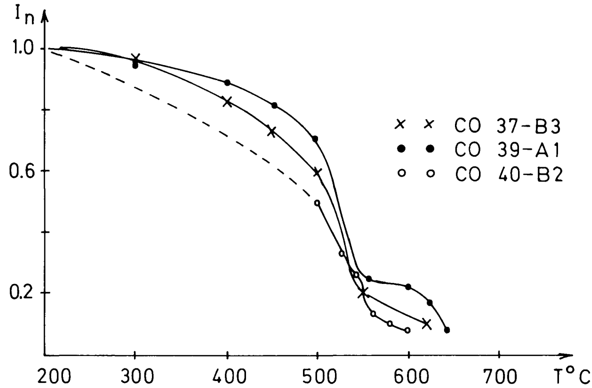

Fig. 3. Decay of remanence intensity during progressive demagnetization of Corsican lavas

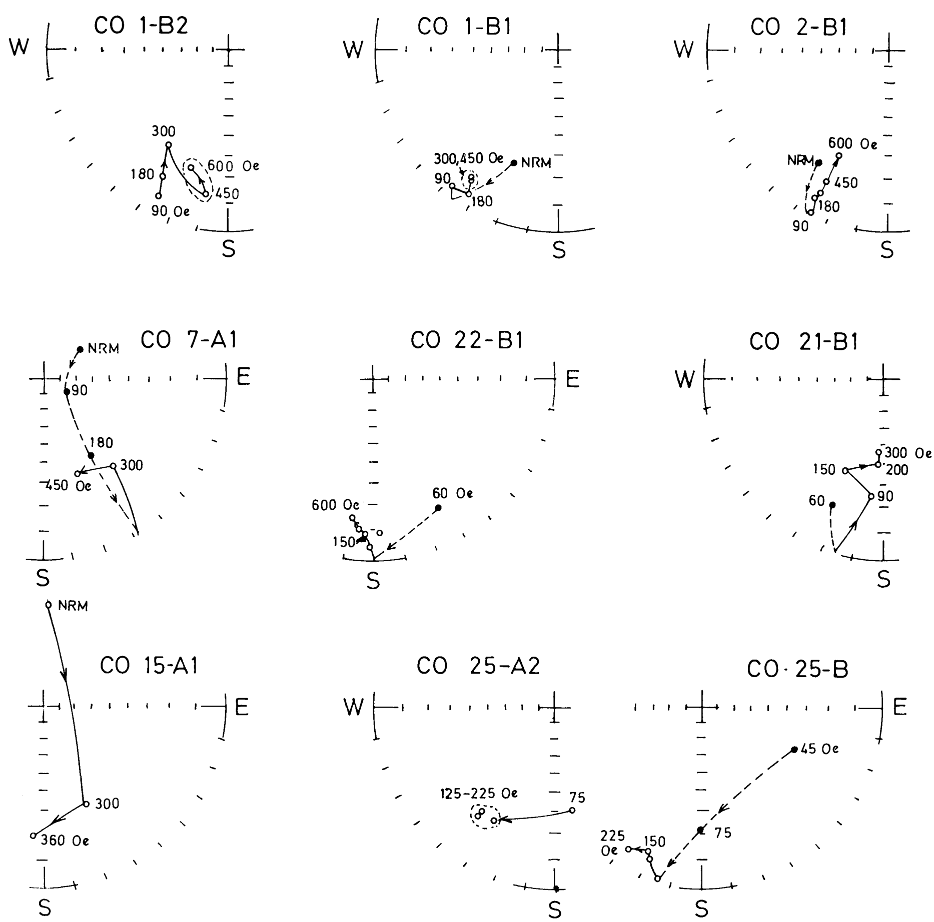

Fig. 4. Stereograms showing directional behaviour as a function of progressive demagnetization. Full circles are downward seeking magnetism while open circles represent upward pointing magnetization vectors. See text for further details

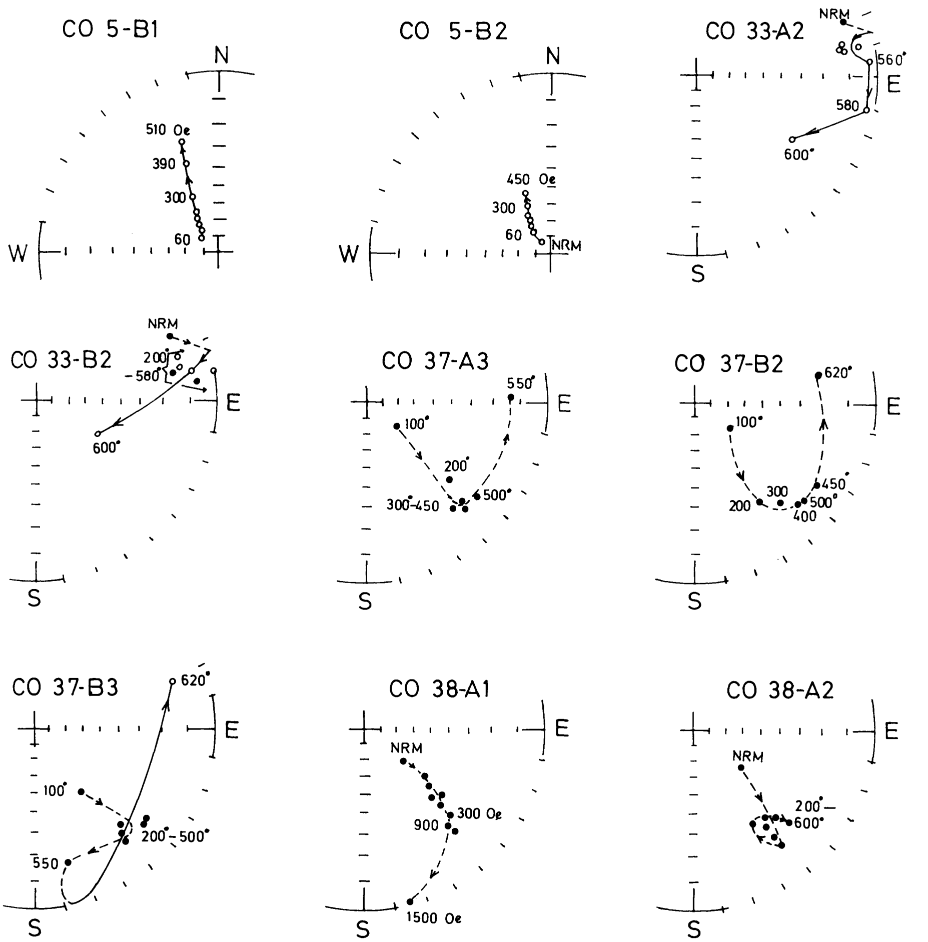

Fig. 5. Text as for Fig. 4

stage of demagnetization) the directional patterns are nearly always erratically disrupted as well. Therefore, the "erratic stage" in the analysis has not been included in the diagrams. Also, directional data associated with intensities below $5 \cdot 10^{-7}$ emu/cm^3 have systematically been disregarded.

The south-easterly stable magnetization as previously claimed for Corsican rocks (Ashworth and Nairn, 1965; Nairn and Westphal, 1968) are not verified by the present study. Only one specimen, Co 30-a2, exhibits a satisfactory stable direction in the SE-quadrant (cf. Fig. 5) but the suggested stability to progressive demagnetization in this case neither agrees with that of neighbouring specimens (within the same hand sample) nor with other specimens from the same site. In fact, the general directional behaviour of the specimens of this study consists of gradual movements into or towards the NE and SW quadrants, respectively, suggesting that south-easterly directions may be purely accidental, representing resultant magnetization vectors (consisting of at least a normal and a reversed

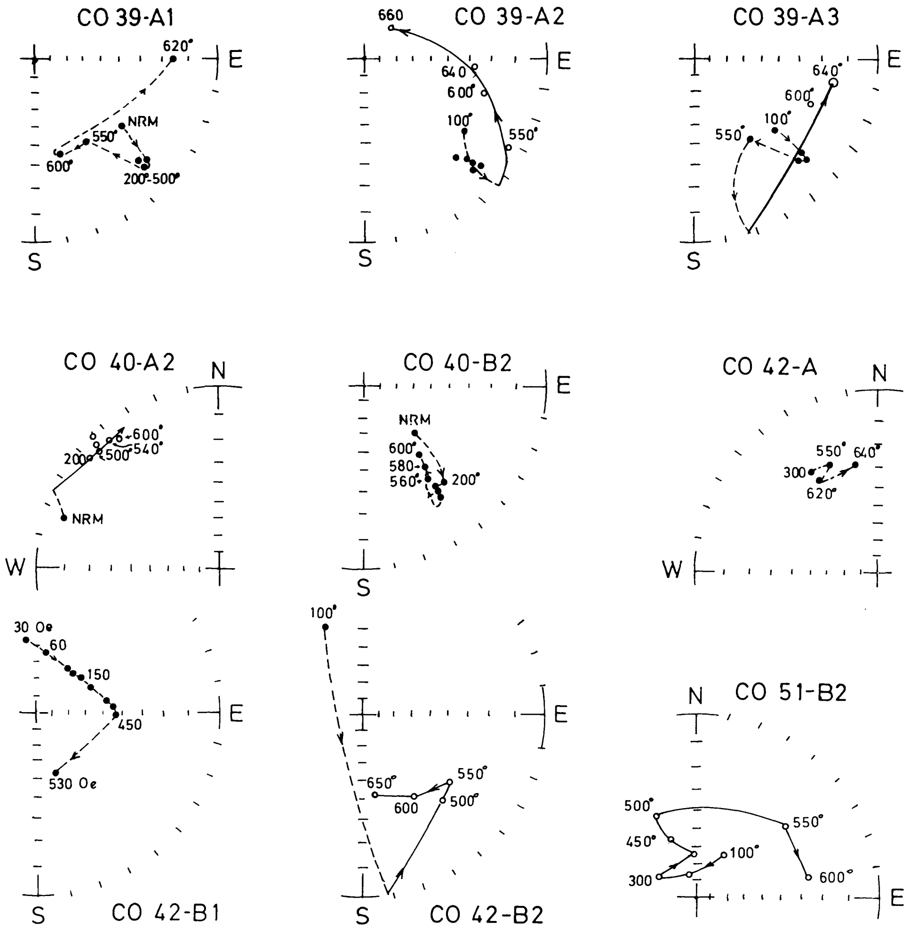

Fig. 6. Text as for Fig. 4

sub-component) having no geophysical reality. The fundamental experimental problems are that the sub-components involved in general tend to have closely similar stability spectra so that terminal directions (for one particular component) are not being achieved at the stage at which disruption of the demagnetization patterns take place. In this context, however, it is obvious that an "end-point" is not by itself a sufficient criterion that a single magnetization component has been isolated and that a field direction marker has been obtained; a composite magnetization may well exhibit high directional stability at strongly discordant and palaeomagnetically irrelevant directions (Storetvedt, 1970; Roy and Park, 1972). Thus, ancient field directions must in general be carefully evaluated through a combination of "stable points" forming one or more clustered groups, together with additional experimental data defining "areas" of directional convergence.

The total directional information from the present rocks suggests that the

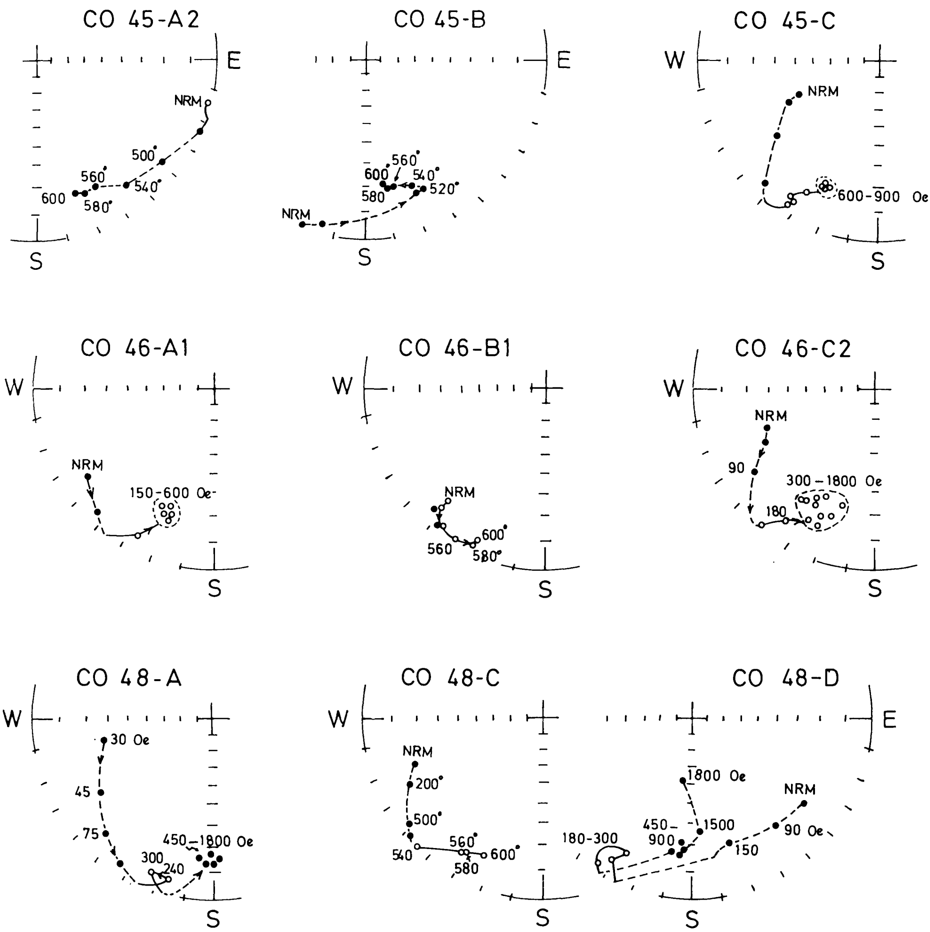

Fig. 7. Text as for Fig. 4

magnetization process (which, based on the extensive low temperature mineral alteration, is most likely chemical in this case) spanned a time interval long enough to cover one or more field inversions. The relative abundance of normal and reversed magnetism varies greatly, resulting in scattered within-sample and within-site distribution of "stable" bulk magnetization, but on a whole the reversed magnetism tends to provide the largest contribution to the resultant. It is important to recognize, however, that specimens from sample Co 50, which had the most strongly developed high temperature oxidation features of the entire collection, possessed a fairly stable northerly directed bulk magnetization ($D \sim 350°$, $J \sim -60°$) in complete disagreement with the relative field for the Kiaman epoch in which these rocks must have acquired their original magnetization.

The only consistent group which can be reasonably inferred from the present study has a direction striking slightly west of south and with a shallow upward

Table 2. Palaeomagnetic data from Permo/Carboniferous dikes, NW. Corsica

Specimen	N	Dec.	Inc.	*R*	*k*	α_{95}	Pole
Co 1 – B1		214	–10				
Co 1 – B2		192	–19				
Co25 – A2		212	–18				
Co45 – C		203	–18				
Co46 – A1		200	–16				
Co46 – B1		204	– 4				
Co46 – C2		204	–17				
All specimens combined	7	201.8	–14.8	6.93	86	6.5	154E, 50N
Eocene volcanics, Lisbon							
(1) tilt-corr. data							158E, 47N
(2) without tilt corr.							160E, 54N
Permian of Europe							~160E, ~42N

inclination. The seven specimens which tend to define this suggested palaeomagnetic direction are all from the rhyolite intrusives. Further details are given in Table 2. Each of these directions represents the mean of two or more demagnetization steps as having been encircled in Figs. 4 and 7. Upon demagnetization other specimens obtained directions in general agreement with the latter group, but as the terminal directions have not been confirmed in these cases the specimens concerned are not included in the paleaomagnetic figure. Nevertheless, the latter information gives further support in favour of a geomagnetic reality of the shallow, upward inclined, SSW-striking magnetization. No final normal direction has been achieved.

In site no. 13 (Fig. 7) three or four specimens are showing a certain indication of a reversed direction with a downward dip of around 15–20 degrees (cf. Co 48-A). However, the results from other specimens from the same sample, for example Co 48-D, suggest that these downward pointing directions are probably not true palaeomagnetic field markers.

4. Geophysical Interpretation of the Results

Based on some floral evidence the formations concerned are thought to date back to Westphalian/Stephanian times or in part perhaps to the Permian (cf. Nairn and Westphal, 1968). However, all the observational results of this study seem to establish beyond doubt that the original TRM, if not completely, at least to a major extent, has been replaced by magnetizations of chemical origin. A fundamental question is therefore the timing of these latter components. There is very strong evidence that the geomagnetic field was consistently reversed in late Palaeozoic times: the so-called Kiaman magnetic interval seems to have existed from around 300 Ma B.P. to the end of the Permian, i.e. for about 70 Ma (McElhinny, 1969; Thompson and Mitchell, 1972). Therefore, the relatively strong normal magnetization contribution suggests that a considerable mineral alteration (and associated remagnetization) must have occurred in the rocks in post-Permian times. Also, Nairn and Westphal (1968) were puzzled about the relatively strong normal component, which they tentatively suggested might have become imposed sometime in the early Mesozoic, but they seem to have disregarded this important observation in their final interpretation. A question of ultimate importance is in fact to which extent also a major part of the present reversed magnetization post-dates the Permian.

At the latitudes of southern Europe the original (late Palaeozoic) field must have had an approximately zero inclination. It is well known that in tropical environment mineral changes due to surface weathering may penetrate very deeply. Owing to the long time span of the Kiaman interval (reversed) one would suggest therefore that if the considered rocks (first of all the lavas) had been subjected to "surface" conditions throughout the Permian the possibility for further surface alterations of the magnetic oxides should be extremely limited in post-Permian time. For this reason the relatively strong normal magnetization in the lavas suggests that something must have prevented a rapid oxidation of these strata in their earliest history. A clue to this problem may lie in the fact that in the Upper Palaeozoic and throughout the Mesozoic the West Mediterranean formed part of the extensive Tethyan geosyncline – it appears quite likely that Corsica was covered by sediments during an extensive length of time from Permian onwards. A sediment cover may well have provided the postulated slowing down of the oxidation processes first of all in the underlying Permo-Carboniferous lavas. It was not until the end of the Cretaceous or the beginning of the Tertiary that the Alpine folding and upheaval became of importance in the Mediterranean region (Debelmas and Lemoine, 1970). Most likely the area of Corsica participated in this uplift, becoming subsequently the site of extensive erosion and weathering. As a result of the orogenic movement (and erosion) the late Palaeozoic dikes may for the first time in their history have become exposed to surface conditions. In fact, one may suggest that oxidation processes which had been suppressed in the earlier history of the rocks advanced rather quickly during the Lower Tertiary. Because of the excessive alteration of the primary magnetic minerals any remaining Permian magnetization component in the rhyolite dikes, is pobably to be associated with hydrothermal alteration during the cooling stage.

With reference to Table 2 there are only 7 specimen directions in this study for which there is reasonable laboratory evidence that palaeomagnetic directions have been obtained. As the chemical processes at ambient temperatures probably encompassed a long time span (compared with the "time constant" of the geomagnetic secular variation) it seems reasonable to suggest that the scatter of the final results is basically due to the difficulty of obtaining completely clean single-component magnetizations rather than being caused by geomagnetic secular variation. Therefore, because of the geomagnetic integration effect most likely following a chemical remanence, it is thought that at least the overall mean direction approximates to that of an ancient axial dipole field relative to Corsica. In Table 2 the estimated palaeomagnetic pole of the considered Corsican rocks is shown in conjunction with the Upper Carboniferous/Permian pole for Europe and with poles for the Lower Tertiary based on recent data from the Lisbon volcanics (Storetvedt, 1973a). The latter information is referred to Iberia in its pre-drift position in that the rotation and displacement of this continental fragment seem to have occurred as late as early Oligocene (Storetvedt, 1972). The Lisbon data have been given both with and without tectonic correction as the magnetic history of this formation makes it difficult at present to choose adequately between the two alternatives. The relatively low palaeolatitude inferred from the Eocene Lisbon volcanics represents a revision of the early Tertiary geomagnetic dipole axis for Europe originally suggested from a study of the Antrim basalts of Northern Ireland (Løvlie *et al.*, 1972). Recent results from the Faeroe Islands (Løvlie, 1975; Løvlie and Kvingedal, 1975) have given further support for the new early Tertiary pole position. The relative Upper Palaeozoic pole is based on information from minor intrusives from Norway and England (Halvorsen, 1970, 1972; Storetvedt and Gidskehaug, 1969) as the palaeomagnetism of European lavas of Kiaman age seems to have become slightly upset by a certain Mesozoic magnetization overprint (Storetvedt, 1970; Storetvedt and Petersen, 1970). However, the Upper Carboniferous-Permian pole here accepted is very close to the overall late Palaeozoic pole for Europe as well as nearly identical to the one used by Larson and LaFountain (1970).

As one can infer from Table 2 the overall palaeomagnetic pole of the Corsican dikes are in better agreement with the suggested Lower Tertiary pole than with that of the late Palaeozoic. By also taking into account the fact that the considered rocks have a two-polarity magnetization build-up, it seems reasonable to conclude that at least the major component of "stable" remanence was impressed in post-Permian time, probably in connection with the Lower Tertiary uplift of the West Mediterranean domain.

The new evidence casts doubt about the postulated rotation of Corsica. As such a movement would most likely be of Tertiary age the present data may indicate that a rotation detectable by palaeomagnetic methods has not taken place. On the other hand, it is possible that the inferred remagnetization in the early Tertiary has obscured the palaeomagnetic evidence for a rotation which may have occurred either at the time of remagnetization (as a results of the same geodynamic processes causing uplift) or during the Mesozoic. However, based on available information it seems more reasonable to conclude at present that the crust beneath the Ligurian Sea formed through continental subsidence (and subsequent oceanization in situ) rather than through crustal separation by sea-floor spreading (Storetvedt, 1973b).

Acknowledgement. Parts of the work described in this paper were carried out in the Department of Geophysics of the University of Bergen, while one of us (N.P.) was invited to give a lecture course there.

The financial support by "L. Meltzers Høyskolefond" is greatly acknowledged.

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Received September 24, 1975