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PALEOMAGNETISM AND THE ALPINE TECTONICS OF EURASIA II

THE MAGNETISM OF THE PERMIAN PORPHYRIES NEAR LUGANO (NORTHERN ITALY, SWITZERLAND)¹

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SUMMARY

The magnetic properties of 25 oriented samples of the Permian porphyries from the Lugano district are investigated. After a.c. demagnetization (up to 900 Oe peak value) eleven samples produce a characteristic direction of magnetization, declination (D) = N 143.5°E, inclination (I) = -17°. The other samples show streaking towards the direction of the present-day geomagnetic field; their recent magnetic components are very hard and could not be removed by our a.c. demagnetization procedures.

The paleomagnetic pole derived from the Lugano rocks is situated at 41.5°N 119.5°W, and is equally divergent from the other Permian poles from extra-Alpine European rocks as are the ones traced in other parts of the Alps. This divergency is best explained by assuming large-scale tectonic displacements of the south Alpine unit before and during the Alpine orogenesis.

INTRODUCTION

During the last few years it has been realised that the paleomagnetic directions obtained from rocks in the Alpine belts of Europe are deviating from those measured on coeval rocks from extra-Alpine regions in Europe. The present investigation of the Lugano porphyries forms part of a larger program that envisages analysing suitable rocks in the Alpine belts of Eurasia on their magnetic properties in order to trace thus their divergent behaviour. We expect that some fundamental conclusions on Alpine tectonics may be drawn from the ultimate result.

The Permian porphyries near Lugano looked very promising for an investigation as volcanic rocks produce usually more reliable paleomagnetic results than sediments; furthermore, an impressive number of paleomagnetic directions derived from Permian rocks is available now - both from Alpine and extra-Alpine areas in Europe - with which the result can be compared.

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GEOLOGY AND PETROGRAPHY OF THE LUGANO PORPHYRIES

The area under investigation is situated in the tectonic unit that is usually referred to as the southern Alps (It.: Alpi meridionali). It lies some 25 km south of the east-west running Insubric fault-line, that separates the central Alps from these southern Alps. The Lugano porphyries rest unconformably on a mighty complex of crystalline basement rocks that have been folded and metamorphosed during the Hercynian orogeny. On top of the volcanic series a thick Triassic sedimentary series has been deposited, starting with the Lower Triassic. This stratigraphic position makes a Permian age for the volcanics plausible. Analogous situations in the southern Alps are found farther to the east where volcanic deposits are intercalated in sedimentary formations of Permian age (Bergamasco Alps) and in the well-known volcanic Permian province around Bolzano (western Dolomites).

Outcrops of the Lugano porphyries extend over an area of some 200 km² at both sides of the Swiss-Italian border (see Fig.1). During the Alpine orogeny, the area was gently folded into two synclines and an anticline that trend west-southwest-east-northeast; additional faulting complicated the picture. The deformational stresses were rather moderate for Alpine measures as the internal structure of the volcanic rocks has not been disturbed: no traces of schistosity were found, and quartz phenocrysts only occasionally show a moderately developed wavy extinction. Earlier investigators of this region (De Sitter, 1925 and 1939; Rode, 1941) concluded that the porphyries are products of one or more Permian volcanoes. De Sitter (1939) distinguishes the following five phases in the eruptions:

Lower Triassic

- (5) Granophyre
- (4) Upper quartz-porphyries
- (3) Pyroxene-bearing porphyrites, with tufts and agglomerates
- (2) Piambello Series (tufts, porphyritic lavas and quartz porphyries)
- (1) Basal tuffaceous series
 (Local basal conglomerate)

Crystalline basement

After a period of erosion the Werfenian (Lower Triassic) sedimentation starts with the deposition of - locally fossiliferous - sandstones and conglomerates. For more complete information on the geology, petrography and chemistry of the Lugano porphyries the reader is referred to the publications by De Sitter (1925, 1939) and Rode (1941); the latter author confined his studies to the Morcote Peninsula.

SAMPLING, MEASUREMENTS AND A.C. DEMAGNETIZATION

Sampling in the Lugano area was carried out during the summer of 1963. Five of the samples (no. 35-39) have been collected by students of the Geological Institute of Utrecht during an excursion in that region in 1959. The locations where the oriented samples were taken are shown in Fig.1.

The remanent magnetizations of the samples were determined at the

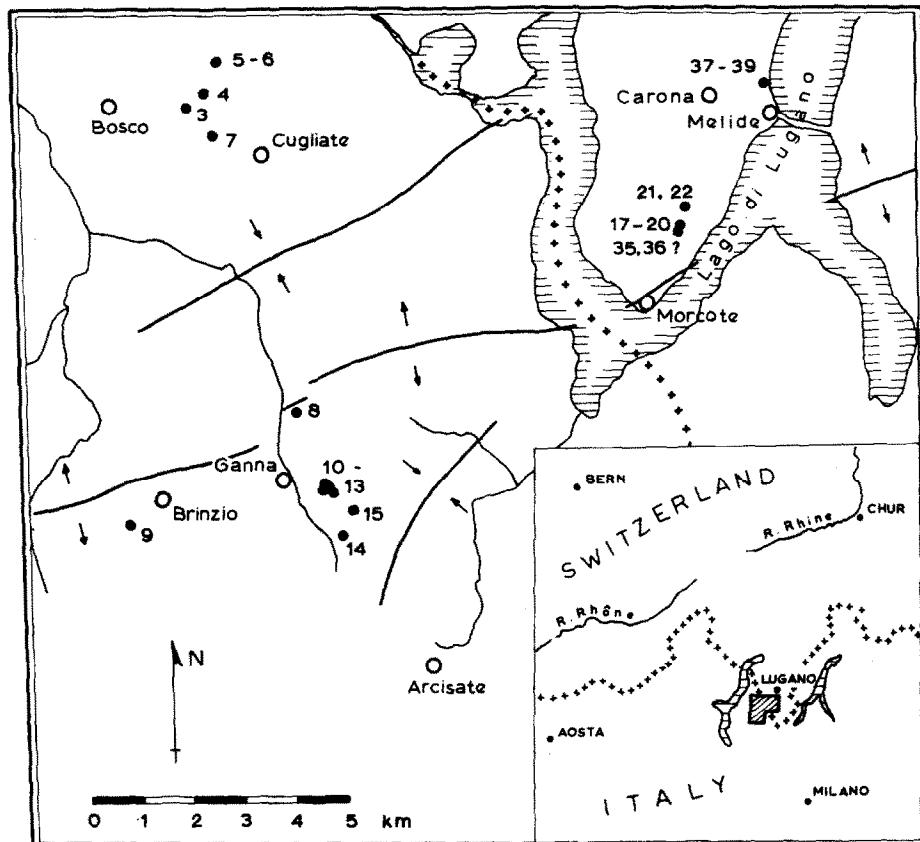
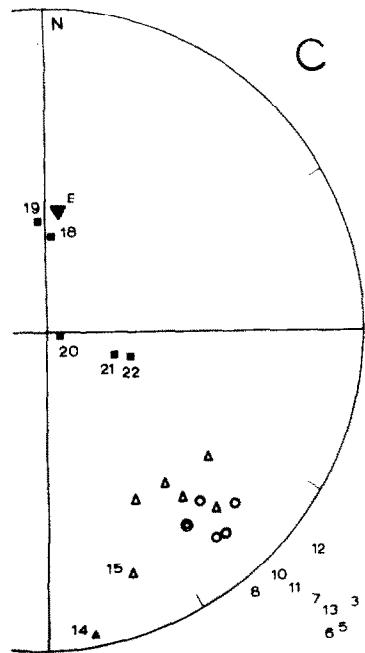
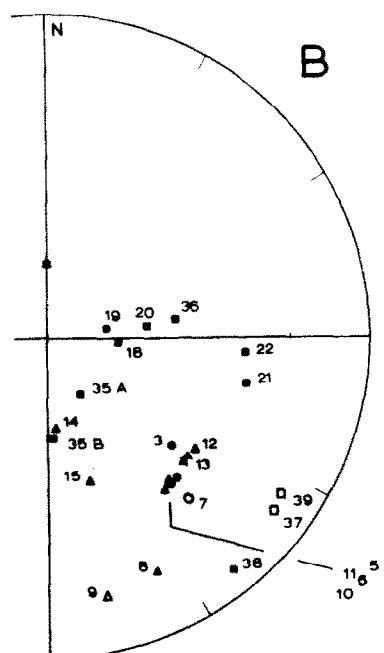
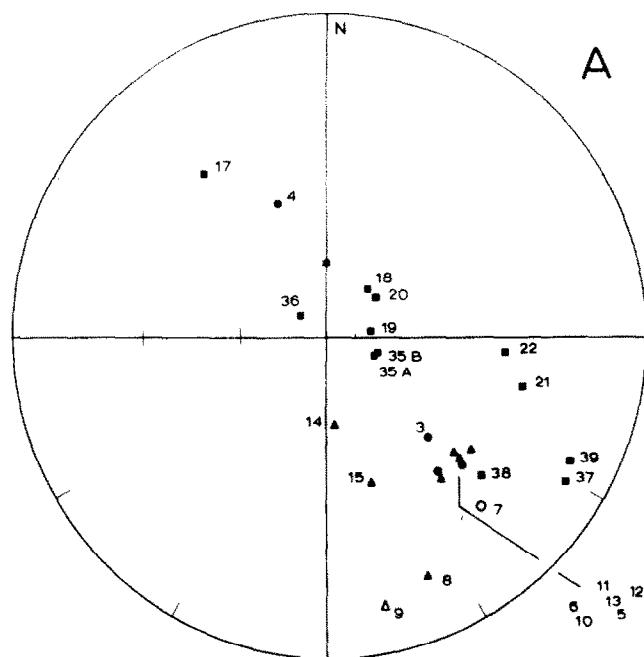


Fig.1. Location map of sampling sites in the Lugano area. Simplified structural trends after De Sitter (1939, pl.I).

Paleomagnetic Laboratory of the Utrecht State University. There the roughly equidimensional samples (volume from 100 to 300 cm³) were cast with paraffin to cubes with 10 cm edges and measured with astatic magnetometers. The remanence of all samples was analysed with demagnetizing a.c. magnetic fields of increasing intensity (step by step up to 900 Oe peak value; 50 c/sec); after each demagnetizing step the sample was remeasured. These measuring and demagnetization procedures and their apparatus have been described extensively by As (1960), As and Zijderveld (1958), and Gregor and Zijderveld (1965). This method of progressive demagnetization is very successful for the separation of components of different hardnesses that constitute the total natural remanent magnetization of the investigated rocks. In many instances it enables us to distinguish between the original direction of magnetization of the lavas, TRM., and the components that have entered the rocks at later times.

Fig.2A shows the directions of the total natural remanent magnetization, without correction for tectonical tilt, of all 24 samples of the Permian volcanics of the Lugano area. These directions are grouped in the southeastern



quadrant of the stereographic projection. Some numerical data on the rocks are given in Table I where the high Q values of most of the samples are remarkable.

The intensity of two porphyry samples (no.4 and 17) is very weak and much lower than that of the majority. Both samples have an altered appearance which is in contrast to the rest of the collection. During their demagnetization the intensity of the samples 4 and 17 became even lower, going thus beyond the sensitivity of our measuring apparatus. For this reason these two samples are discarded.

The alternating field demagnetization showed that the samples, except those collected at the Morcote Peninsula, carry hardly any or absolutely no secondary magnetism; they have one singular hard magnetization. In all samples this magnetization has a similar direction; this is the characteristic direction for these Lugano porphyries. This hard natural remanence remains untouched by a.c. magnetic fields up to 100–200 Oe; in higher a.c. magnetic fields (up to 900 Oe) this remanence decreases only slightly in most instances. In order to facilitate their discussion the samples are divided into three groups according to their sampling areas (see Fig.1): the northern group northwest of Cuglione, the southern group around Ganna, and the eastern group sampled on the Morcote Peninsula.

The Cuglione group (samples 3–7)

The demagnetization diagrams of samples 7 and 3 respectively are shown in Fig.3 and 4; samples 5 and 6 behave in an identical way. Such a demagnetization diagram shows two orthogonal projections – one on the horizontal plane, the other on the vertical east–west plane – of the vector representing the natural remanent magnetization. The plotted points are the projections of the end of the magnetization vector after each demagnetization step. The magnetization component, removed by each demagnetization step, is given by the vector between the successive points of the curve.

The diagram of Fig.3 reveals that a very small component is removed by the lower alternating magnetic fields (up to 150 Oe); it is directed downwards with a northern declination. This direction is about parallel to the present-day geomagnetic field in northern Italy and this small component is clearly a viscous magnetization. By treatment with a.c. magnetic fields from 200 to 900 Oe the magnetization vector decreases strongly in length without changing its direction. The magnetizations, eliminated during these higher demagnetization steps, all have the same direction, which is also parallel to

Fig.2. Stereographic plot of the directions of magnetization. A. Natural remanent magnetization. B and C. Stable directions of magnetization after a.c. demagnetization. A and B before correction for geologic dip, C after correction for geologic dip. Full (open) symbols in lower (upper) hemisphere, positive (negative) inclination. Star represents the direction of the present geomagnetic dipole field in northern Italy. Circles = samples of the Cuglione group; triangles = samples of the Ganna group; squares = samples of the Morcote group; double circle = mean direction of magnetization (see Table II). E (Fig.2C) = calculated direction of European Eocene magnetic field in northern Italy.

TABLE I

Magnetization measurements on rock samples of the Lugano area¹

Sample no. and rock unit ²	Strike and dip of bedding (degrees)	Natural remanent magnetization		
		Intensity $\times 10^6$ (e.m.u./cm ³)	Q-value	direction
		D (degrees)	I (degrees)	
3 (4)	51-49 SE	185	48	133.5 +42
4 (4)	50-33 SE	0.8	1	340 +43
5 (4)	58-39 SE	57	7.1	132.5 +29.5
6 (4)	58-39 SE	27	5.7	139.5 +33
7 (3)	198-05 W	420	6.1	137 -19
8 (2)	88-45 S	90	10.3	155.5 +12.5
9 (2)	uncertain	44	5.9	167.5 -9
10 (2)	55-57 SE	145	22	140.5 +31
11 (2)	66-54 SE	230	8.4	131.5 +33.5
12 (2)	59-59 SE	380	112	127 +30
13 (2)	74-52 S	240	44	132 +31
14 (4)	77-57 S	390	158	174.5 +59
15 (4)	58-54 SE	130	9.8	162.5 +39.5
17 (2)	231-51 NW	0.2	0.3	322 +25.5
18 (2)	235-43 NW	14.5	0.3	42.5 +67.5
19 (2)	235-43 NW	90	0.3	82.5 +73
20 (2)	170-30 W	55	0.4	53 +66.5
21 (3)	187-40 W	560	42	103.5 +25
22 (3)	169-35 W	570	37	94.5 +31.5
35A (2)	unknown	29	0.4	109 +72
35B (2)	unknown	26	0.4	107 +71
36 (2)	unknown	23	0.4	311 +77.5
37 (3)	horizontal?	260	0.7	121 +8
38 (3)	horizontal?	280	0.5	132 +24
39 (3)	horizontal?	580	0.8	117 +9

¹ All measurements with respect to true north.² The numbers in brackets refer to the lithological column of p.430.

that of the magnetization remaining after 900 Oe. This indicates that the magnetization remaining after the 200 Oe step consists of only one singular component that is steadily broken down by the higher alternating fields.

The demagnetization diagram of sample 3 (Fig.4) shows that alternating magnetic fields up to 200 Oe do not affect its natural remanence: in this sample the secondary, viscous magnetization is lacking. Here too, the vector of the natural magnetization decreases along a straight line under influence of the higher magnetic fields up to 900 Oe. However, a closer examination shows that the straight trajectory between the 200 and 900 Oe steps is not pointing precisely towards the origin of the coordinate system. This situation has often been encountered in demagnetizing rocks. A satisfactory explanation is not easy to give for all instances. The fact remains however, that the magnetization broken down in the 200-900 Oe trajectory, represents clearly a single natural remanent magnetization component, whereas the magnetization remaining after the 900 Oe step is probably not the definite one. In this sample 3 the difference between these two directions amounts only to 7°. At the present stage we prefer to consider the magnetization component,

TABLE I (continued)

Stable component from a.c. demagnetization				
a.c. field (Oe)	before tectonic correction		after tectonic correction	
	D (degrees)	I (degrees)	D (degrees)	I (degrees)
500-900	130.5	+36	132	-12.5
500-900	137	+29	138	-10
500-900	139.5	+29	140.5	-10
500-900	138.5	-23	137.5	-18.5
900	155	+13	152.5	-28.5
900	167	-11		
900	142	+29	142	-28
900	139.5	+30	140.5	-22.5
900	126.5	+30.5	127.5	-25
900	132	+31	136	-15
900	175	+59	171	+2
500-900	163.5	+40.5	160	-12.5
500-900	92.5	+65	3	+57
500-900	81	+69	357.5	+52
500-900	83	+55	100	+84.5
900	102.5	+25	108.5	+64.5
900	94	+26.5	106	+59.5
400-1,000	149.5	+67.5		
500-900	176	+56.5		
500-900	82	+46.5		
500-900	127	-6.5		
500-900	141	+4		
500-900	124	-7.5		

removed between 500 and 900 Oe, as the more reliable estimate of the characteristic direction of magnetization. The same holds for the samples 5 and 6 from Cugliate.

The directions found by demagnetization is represented in Fig.2B; from Table I it can be read what vector - removed or final - has been taken. Fig.2C shows these characteristic directions of magnetization after a correction for the geological dip of the strata has been applied to them. There are samples from differently dipping strata, so an unfolding test may be applied to the four samples collected near Cugliate. According to McElhinny (1964), who analyzed the statistics of the unfolding test, the unfolding is statistically significant on the 95% (99%) level when the k_2/k_1 ratio exceeds 4.28 (8.47) in the case of four samples, where k_2 and k_1 are the precision parameters $k = (N - 1)/(N - R)$, after and before unfolding respectively. For the case under discussion these values amount to $k_2 = 214.3$ and $k_1 = 8.00$, so that the k_2/k_1 ratio comes to 24, which is well above the critical values as calculated by McElhinny (1964).

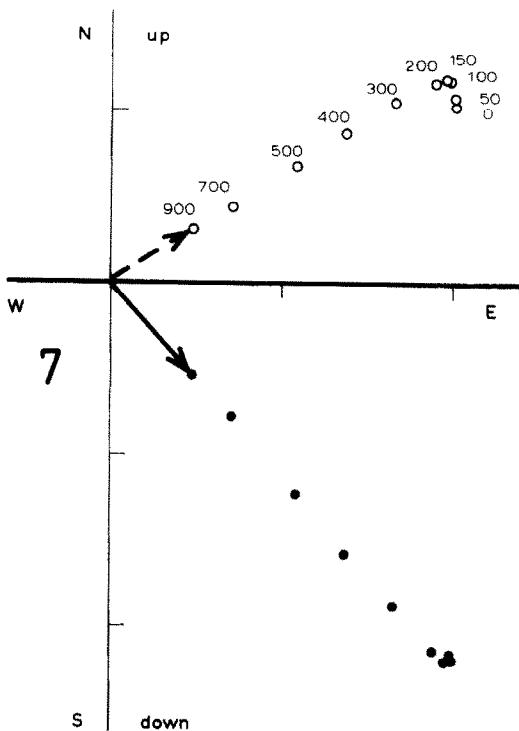


Fig. 3. Demagnetization diagram of the natural remanence of sample 7, Cuglia group, almost horizontal porphyry. Such a demagnetization diagram shows two orthogonal projections of the ends of the same magnetization vector during the progressive demagnetization. Projections of the entire magnetization vectors remaining after the final (900 Oe) step are added. Dots and full arrow represent projections on the horizontal plane to which the north-south and east-west axes refer. Open circles and dashed arrow represent projections on the east-west vertical plane, to which the east-west and up-down axes refer. Numbers denote the corresponding intensities of the alternating magnetic field (Oe). Unit on axes: $133 \cdot 10^{-6}$ e.m.u./cm³.

The Ganna group (samples 8-15)

These samples have high intensities and very high Q values. Fig. 5 shows the demagnetization diagram of sample 13, which is representative for this group. More clearly than in the Cuglia group, the very small effect was notable for the demagnetizing a.c. fields on the natural remanent magnetization of these porphyries. Viscous secondary magnetism is lacking. Neither the direction nor the intensity of the natural remanence is much altered, which may indicate a great magnetic stability.

For all other samples of this group the final direction of magnetization (after treatment with 900 Oe) is regarded as the stable one. Only sample 15 shows an appreciable decrease in intensity, and for this sample the direction

of magnetization removed between 500 and 900 Oe is taken as the characteristic one. The directions after demagnetization are shown in Fig.2B.

The geological dip of the strata from which sample 9 was taken could not be determined in the field. The position near the anticlinal axis (see Fig.1) may suggest that the dip will be small. This sample is not used for the calculation of the ultimate mean.

Somewhat aberrant directions are obtained from samples 14 and 15. One might suppose that in an ancient volcanic area such as the present one, relatively large primary dips of the flows will be encountered, from which the observed deviations might originate.

The mean direction of the remaining five samples of this group is very close to the directions measured on the rocks of the Cuglia group.

The Morcote group (samples 18-22, 35-39)

Looked upon as a whole, the Morcote group displays a pronounced "streaking", i.e. the directions of their total natural remanent magnetizations are smeared between the directions of the present and ancient local geomagnetic fields (Fig.2A). Such streaking is commonly explained by superposition of later

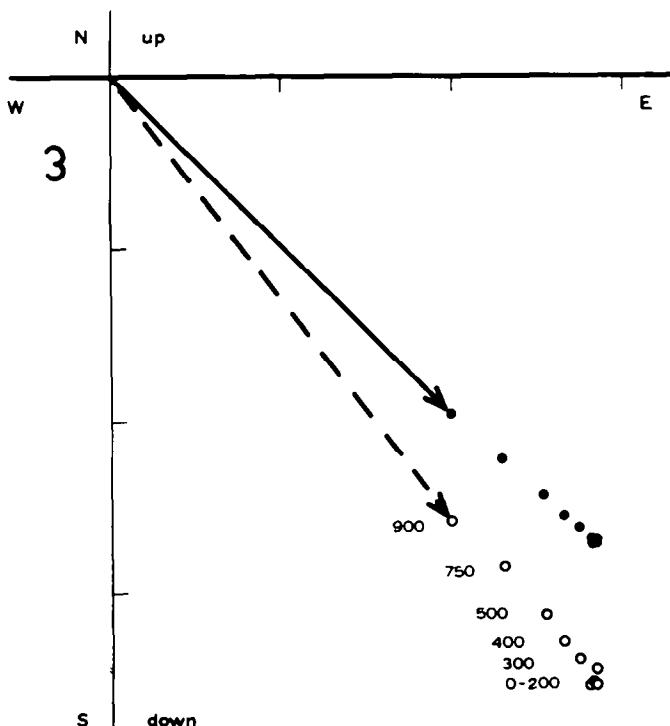


Fig.4. Demagnetization diagram of the natural remanence of sample 3, Cuglia group, southeast dipping porphyry. Unit on axes: $35.5 \cdot 10^{-6}$ e.m.u./cm³. Explanation symbols: see legend of Fig.3.

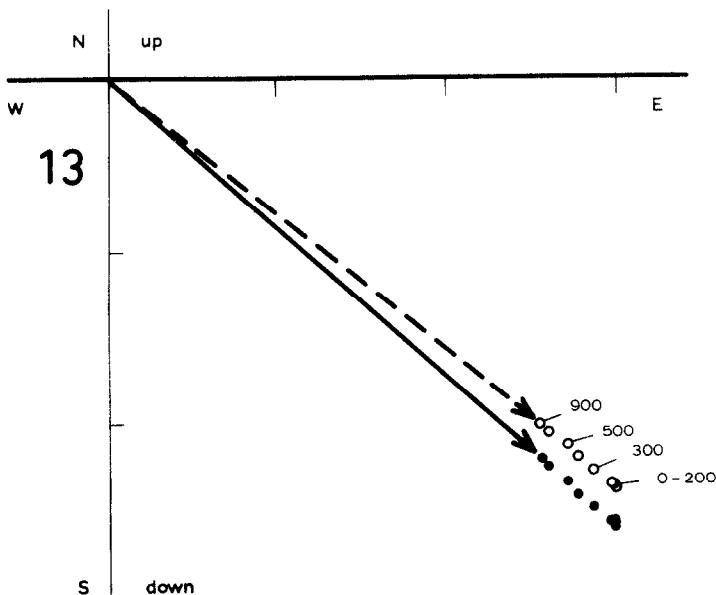


Fig.5. Demagnetization diagram of sample 13, Ganna group. Unit on axes: $52 \cdot 10^{-6}$ e.m.u./cm³. Explanation symbols: see legend of Fig.3.

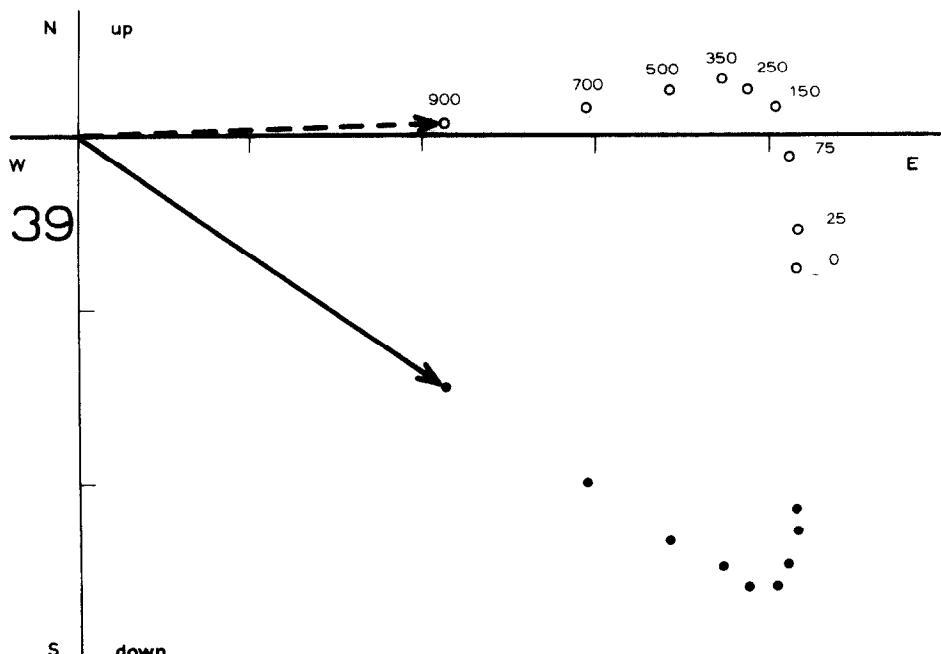


Fig.6. Demagnetization diagram of sample 39, Morcote Peninsula. Unit on axes: $123 \cdot 10^{-6}$ e.m.u./cm³. Explanation symbols: see legend of Fig.3.

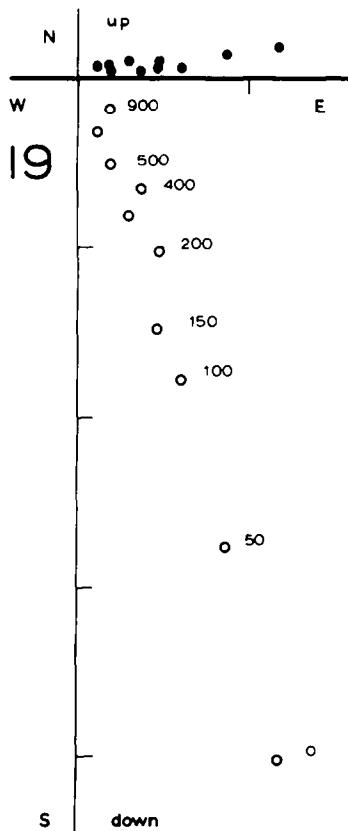


Fig.7. Demagnetization diagram of sample 19; Morcote Peninsula. Unit on axes: $21.5 \cdot 10^{-6}$ e.m.u./cm³. Explanation symbols: see legend of Fig.3.

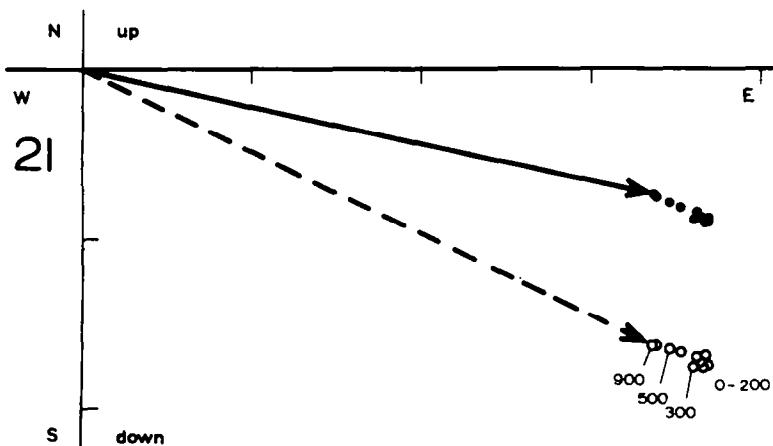


Fig.8. Demagnetization diagram of sample 21, Morcote Peninsula. Unit on axes: $134 \cdot 10^{-6}$ e.m.u./cm³. Explanation symbols: see legend of Fig.3.

(recent) components upon the original (ancient) magnetization of the rocks.

The subgroup, consisting of samples 37, 38 and 39, shows a notable change in direction during their demagnetization. Both from the projections of Fig.2 and from the example of demagnetization of sample 39 (Fig.6) it is seen that the magnetization vectors move away from the direction of the present-day local geocentric axial dipole field (0° , $+64^\circ$) so that samples 37 and 39 finally have a negative inclination and thus come close to the cluster of directions found for the samples from Cuglia and Ganna.

The natural remanent magnetization of the subgroup of samples 18–20, 35A, 35B (two specimens of the same sample 35) and 36 is entirely different. The direction of the total natural remanent magnetization had a very steep, downward inclination and the Q value of this magnetization was, contrary to the other porphyries, very low. As could be expected from this low Q value, the natural remanence was fairly soft. A characteristic demagnetization curve for this subgroup is shown in Fig.7 (demagnetization of sample 19). The magnetization vector tends to shrink rapidly towards the origin, though the measurements display some scattering. As representative direction is taken as the globally estimated direction of the component removed in the final stage of the demagnetization procedure. This direction agrees with those of samples 18, 20 and 36, before the tectonic corrections are applied (Fig.2B). After unfolding (Fig.2C), the scatter in these characteristic directions of this subgroup increases appreciably, which indicates that at least part of the magnetization entered the rocks after their (Alpine) deformation. The effect of demagnetization on samples 21 and 22 is extremely small, as is shown in Fig.8 where the demagnetization curve of sample 21 is given. As in the former subgroup, the correction for geological dip removes the directions of magnetization still further from the cluster found for the samples of Cuglia and Ganna; they come to lie near the centre of the projection, with steep positive inclinations. The strongly deviating directions of the harder magnetizations of both latter subgroups from Morcote seem to suggest that they are still complex and composed of a small ancient and a large recent component.

So this is an example of a case where the hardness of the recent magnetization component is about equal to that of the ancient one; consequently the a.c. demagnetization procedure fails to separate them (Zijderveld, 1966).

It will be remarked that the streaking displayed by the Morcote samples is very prominent in Fig.2C, where the directions are shown after correction for the tilt of the flows. This seems to indicate that part of the secondary magnetization entered the rocks when they were still lying flat, i.e., before their Tertiary deformation. We think that this possibility should not be overlooked, especially where the direction of the pre-deformational magnetic field - the European Eocene field - is in agreement with such an assumption. The direction of this Eocene field has been constructed in Fig.2C (heavy dot E) from the mean European pole situated at 170.5°E 75°N (Van Hilten, 1964, p.28).

We are aware of the fact that the magnetic properties of the samples 21 and 22 are similar to some of the samples of the Ganna group and that this similarity leads one to analogous reasoning concerning the latter samples. The parallelism of the Ganna directions to those of the Cuglia group (Fig.2C) should contradict such reasoning however, as the stability of the Cuglia directions is fairly well established by the unfolding test.

In the report of the party that collected the samples 35-39, the geological dip of their flows is not given. Samples 37-39 could therefore not be used for the calculation of the mean direction of magnetization. It will be understood that the directions of the questionable hard magnetizations of the Morcote group are also omitted from this calculation.

PRELIMINARY INTERPRETATION OF THE RESULTS

The pole position derived from the Permian rocks of the Lugano district (Table II) is quite divergent from the ones determined on rocks from stable, extra-Alpine Europe that cluster well around a mean pole position of 43°N 170.5°E . A similar divergency is displayed by the other Permian pole positions found in Alpine-disturbed areas. The pole position for the Lugano area (41.5°N 119.5°W) comes very near to that found for the Permian quartz-porphyrries near Bolzano and in the Vicentinian Alps, located at 51°N 120°W ; this latter position was determined independently by Van Hiltén (1960) and by De Boer (1963). Furthermore, the Permian pole of Africa at 48°N 111°W , a mean position calculated from the recent data of Nairn (1964) and Opdyke (1964), lies very close to these south Alpine poles.

This consistency of the extra-Alpine Permian magnetizations is demonstrated by Fig. 9 in another manner: isoclines around the mentioned mean of the cluster of European poles are shown on the map of Europe. The directions of the magnetizations, plotted where their rocks were sampled, are in agreement with these lines and the value of their inclinations come close to that of the nearby isoclines. The picture shows also convincingly that the magnetizations measured in the Alpine areas (Pyrenees, southern France, Corsica, northern Italy, the Carpathian Mountains, Turkey) do not fit the pattern of isoclines, due to divergent declinations and/or inclinations. On the map of Fig. 9, some Permian isoclines belonging to Africa are also shown. The mentioned nearness of the African and south Alpine poles is reflected in Fig. 9 by the position of the sampling sites of the southern Alps in line with the -30° African isocline, while their declinations are about perpendicular to this isocline.

Again the invariable divergency of the paleomagnetic observations from the Alps (s.l.) is stressed here. The only sensible conclusion that can be drawn from this behaviour is to make the Alpine orogenic movements

TABLE II

Summary of data

Mean site position	$45^{\circ}55'\text{N}$ $8^{\circ}50'\text{E}$ of Greenwich
Mean direction of magnetization	$D = \text{N } 143.5^{\circ}\text{E}$ $I = -17^{\circ}$
No. of samples (N) used for calculation of mean	11
k	27.9
a ₉₅	$8^{\circ}40'$
Pole, position	41.5°N 119.5°W
dp	$4^{\circ}38'$
dm	$8^{\circ}57'$
Samples used for the calculation	3, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15

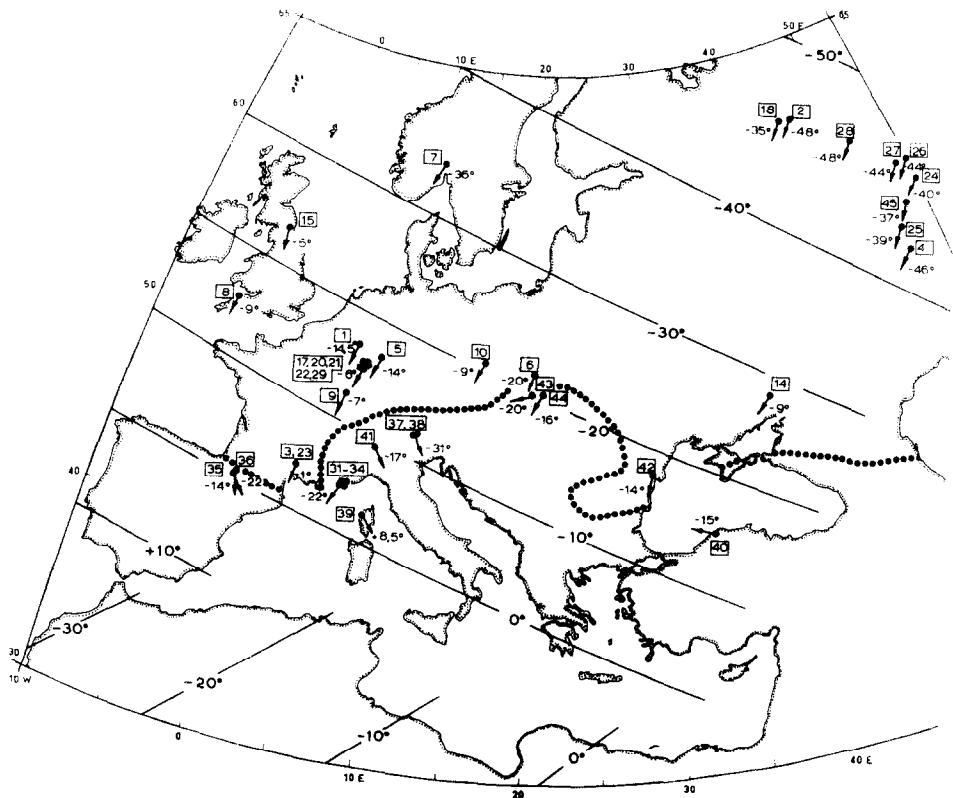


Fig. 9. Permian isocline map of Europe and Africa, with sampling sites and directions of magnetization. European isoclines drawn about the mean Permian pole for stable (extra-Alpine) Europe, 165.5°E 46.5°N^* . African isoclines about the pole 111°W 48°N , the mean of the investigations by Nairn (1964) and Opdyke (1964).

Directions of magnetization from sampling sites in the Alpine chains (south of the dotted line) are not in agreement with the European isocline pattern: declination not perpendicular to isoclines, and/or value of inclination aberrant. Site numbers (in frame) 1–38** refer to Van Hilten's (1964, Appendix I, pp.67–68) list. Site 39 on Corsica: Ashworth and Nairn (1965); site 40 in northern Turkey: Gregor and Zijderveld (1964); site 41 refers to the present investigation; site 42 in Rumania: Patrascu et al. (1964); sites 43 and 44 in Czechoslovakia: Kotásek and Krs (1965); site 45 in Russia: Kramov and Andreyeva (1964).

* This pole has been calculated from the investigations of which the samples were successfully subjected to a.c. demagnetizations: site 7 (Van Everdingen, 1960), site 5 (Nijenhuis, 1961), sites 3 and 23 (Kruseman, 1962), and site 29 (Roche et al., 1962). The results from these sites were weighted: 2, 2, 1, 1, and 2 respectively.

** Sites 12, 13, and 16 in Scotland are not shown on the map as the age of these rocks might well be Carboniferous instead of Permian (Mykura, 1965; Wagner, 1966).

responsible for it. This implies that these movements must have been far greater than is commonly thought in the classical orogenic theories.

The direction of magnetization of the Lugano area is almost parallel to that found for the Permian of the Bolzano area (Fig. 9); as a result, the two pole positions of these areas come close to one another. The agreement becomes still better, if the two divergent samples 14 and 15 were not taken into account: the mean declination and inclination would come to $D = N 138.5^\circ E$ and $I = -19^\circ$. It is reasonable to assume, therefore, that this consistency of data reveals a similar tectonic history for both regions, though they are some 220 km apart. Such an identical history for the Lugano and Bolzano areas agrees with the concepts on Alpine orogenesis, in which they both are regarded as parts of the southern Alpine tectonic unit. So, for the moment, the same hypothetical movements that have been proposed for the Bolzano unit may be extended to the area under consideration, and, as has become more likely by this investigation, possibly to the entire southern Alpine realm.

A brief summary of the ideas on the hypothetical movements performed by this unit of the Alps follows here. When the first paleomagnetic data from the Bolzano porphyries became known (Van Hiltén, 1960) it was tried to keep the movements, required to make them suit the rest of the European paleomagnetic data, as small as possible. For this purpose two assumptions were made that had to be abandoned in later years, when more data became available:

(1) The Bolzano porphyries acquired their magnetizations during a reversal period of the Permian geomagnetic field. We know now that such a period occurred only near the end of the Permian, and it is not realistic to assume that all Permian rocks sampled later in the Alps would belong to that relatively short period of reversal, against which the stratigraphic relations are also witness. The assumption became untenable since De Boer (1963) actually traced the reversal period in his rocks of Upper Permian age in the Camparmo and Staro areas of the Vicentinian Alps.

(2) Taking the various tectonical hypotheses on Alpine orogenesis into account, it is desirable to limit the movements of Africa relative to Europe to some hundreds of kilometers since the Permian.

Based on these two preliminary assumptions, it seemed possible to fit the Bolzano unit to Africa, either on its north coast, near Algeria (Van Hiltén, 1960, 1962), or off its northwest coast as has been proposed by Raven (1960). From a geological point of view it is attractive to link the south Alpine realm to Africa, as is often put forward in the Alpine orogenic theories, wherein this unit is regarded as the northern extremity of Africa that compresses and thrusts the central Alps from the south. Overlooking the entire Mediterranean Basin, the continuity of structures and lithology from North Africa to southern Italy is evident (Glangeaud, 1962; Caire, 1965), and it is difficult to draw a borderline there between what should be reckoned to Africa and what to Europe.

De Boer (1963) established a paleomagnetic stratigraphy for the southern Alps, by which it became clear that the divergent character of the magnetizations in this part of the Alps is not restricted to the Permian. His findings that the Permian magnetizations, as found earlier in the Bolzano area, could not possibly be acquired during a reversal of the Permian geomagnetic field, forced him to increase enormously the trajectory along which the tectonic

unit should have travelled since the Permian. De Boer (1963) estimates that during the Permian the south Alpine tectonic unit must be situated somewhere near the present Himalaya region, some 4,800 km away. This region is situated where the Permian -30° isoclinal leaves the Eurasian continent, so this is the nearest place where the south Alpine unit, with its paleomagnetic inclination of -30°, might have been situated at that time. De Boer (1963) gives no suggestions as to what mechanism might be held responsible for the transport of the tectonic unit over that distance.

Since the paleomagnetic investigations of Nairn (1964) and Opdyke (1964) on Permian rocks of Africa, it is realised that the Late Paleozoic relation between Europe and Africa must have been quite different from the present one: their data show that a large part of the African continent, its northern and northwestern portion, was situated on the Permian Northern Hemisphere (see African isoclines in Fig.9), while the paleomagnetic observations from stable Europe indicate (Fig.9) that the Permian equator ran across the latter continent. These paleomagnetic requirements cannot be met with Europe and Africa in their present positions, and the only way is offered by accepting a huge east-west translation of one of these continents with respect to the other (Nairn, 1964). The presence of a series of large dextral (clockwise) strike-slip faults in between these continental blocks (see Van Hilten, 1964; since then another dextral fault system was found in Cyprus by Bagnall, 1964) gives preference to a westward moving of Africa with respect to Europe during the Mesozoic and Tertiary. Van Hilten (1964) thinks that this wrenching between Europe and Africa is a part of a greater event, the movement between entire Laurasia and Gondwanaland which took place in the belt that is formed now by the Alpine chains of the Caribbean, the European Alps, the Middle East and Indonesia: the ancient Tethys. Whence his naming this wrenching movement the "Tethys-Twist". It has been pointed out (Van Hilten, 1964, plate II, and p.50) that the paleomagnetic data as found by De Boer (1963) for the differently aged rocks of the southern Alps agree astonishingly well with those of the African mainland, so that it seems possible again to have the southern Alps connected to the northern coast of Africa, but now with quite other arguments: the paleomagnetic requirement that both north Africa and the south Alpine unit occupied a position well on the Permian Northern Hemisphere, corresponding to their values of inclination of -30° (see also Fig.9). Together they perform the Tethys-Twist till in Tertiary times when the southern Alps seem to be "smeared off" against Europe at the moment that Africa has about finished its movements with respect to Europe. This preliminary synthesis offers various advantages: (1) the structural and lithological connections between southern Alps and Africa are maintained; (2) the paleomagnetic requirements of Europe, southern Alps, Turkey (Gregor and Zijderveld, 1964), and Africa are satisfied; (3) the mechanical problem as put by the individual travelling or drifting of a small tectonic unit over enormous distances is reduced to that of the continental drift of Africa by attaching the southern Alps to that continent; (4) the Tethys-Twist might perhaps be held responsible for the characteristic bending of Alpine structures that is encountered only in this Tethys belt (Caribbean Arc, the arc formed by the western Alps in Europe, the Carpathian Arc, the south Italian Arc, the bending of the Middle East Alpine trends, the Banda and Celebes Arcs).

In his later paper, De Boer (1965) reaches similar conclusions as to

the mechanism and the connection of the southern Alps to Africa in pre-Tertiary time.

Van Bemmelen (1966) is also strongly in favour of the Tethys-Twist; he came to this view along a different line of approach, a synthesis of the structures found in the Tethys belt and in the former boundaries of Gondwanaland.

Finally, by way of circumstantial evidence, we want to put forward a number of analogous investigations outside Europe in which deviations of paleomagnetic directions have been explained in terms of megatectonic movements - geologists have the habit of believing in certain processes rather than they occur at the other end of the globe: (1) The Alpine bending of Japan's main island Honshu (Kawai et al., 1961); (2) the Devonian rotation of the Island of Newfoundland with respect to the Canadian mainland (Black, 1964); (3) the orocline-like bending of the northern Appalachians (Irving and Opdyke, 1965); and (4) the modelling of the orocline in the western United States, as evidenced by the investigations of Cox (1957) and Watkins (1965).

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