Paleomagnetic evidence for Late Alpine rotation of the Lepontine area

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Paleomagnetic evidence for Late Alpine rotation of the Lepontine Area[1])

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ABSTRACT

The metamorphic rocks of the Lepontine area (Central Swiss Alps) contain stable components of natural remanent magnetization *(NRM)*. They are carried by magnetite and titanohaematite. The site mean directions of *NRM* at nine stable sites dip steeply and consistently towards NNW and lead to a well-defined regional mean direction with declination $D = 332.6°$ and inclination $I = 59.3°$. Therefore it is concluded that the Lepontine rocks were remagnetized during the young Alpine event of high grade metamorphism. The declinations indicate a counterclockwise rotation of the Lepontine area by ca. 30° with respect to stable extra-Alpine Europe, whereas normal "European" *NRM* directions have been found at two stable sites in the southern Aar Massif.

ZUSAMMENFASSUNG

An insgesamt elf Probenentnahmestellen im Bereich des Lepontin und des südlichen zentralen Aarmassivs konnten stabile Richtungen der natürlichen remanenten Magnetisierung *(NRM)* isoliert werden. Sie werden von Magnetit und Titanohämatit getragen. Alle Proben sind jungtertiär während der alpinen Metamorphose remagnetisiert worden, wobei im Lepontin bei dem Ummagnetisierungsvorgang Temperaturen von 600°C überschritten wurden. Die tertiären *NRM*-Richtungen im Aarmassiv stimmen überein mit denen des extraalpinen Mitteleuropa, während diejenigen des Lepontin um etwa 30° im Gegenuhrzeigersinn gedreht sind.

Introduction

The Lepontine area underwent high grade regional metamorphism between late Eocene and early Miocene (TRÜMPY 1973, FREY et al. 1974), caused by deep burial during the formation of the Alpine nappes (NIGGLI 1970). At the same time granitoid bodies such as the Bergell were emplaced. Although tectonic style and history (MILNES 1974), and crustal structure (MÜLLER et al. 1976) are rather complex, the metamorphic zoning is simple, and the end of the metamorphic event postdates the tectonic deformation. Rapid cooling commenced later than 27 my to 21 my b.p. (KÖPPEL & GRÜNENFELDER 1975) after temperatures of 600 °C had been exceeded in the central part of the Lepontine area (WERNER et al. 1976, FREY et al. 1976). Rb-Sr ages of biotites (blocking temperature: 300 ± 50 °C) have been found to range between 25 my and 12 my (JÄGER et al. 1967).

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Until now paleomagnetic investigations in the Alps north of the Insubric line have not been very successful. The main reasons are undatable or very recent remagnetization events and tectonic complications which cannot be clearly accounted for. In this respect the magnetic properties of the Lepontine metamorphic rocks appear to be more suitable since the age relation between deformation and metamorphism is well-known.

Stable, Late Alpine magnetization directions already have been found in the Bergell granite and certain Valle Antigorio gneisses (Heller 1973, 1977). The aims of the present work are firstly to link the previous studies by incorporating new data from the Central Lepontine area, secondly to correlate the observed paleomagnetic directions with contemporaneous directions from extra-Alpine Europe and the Southern Alps, and thirdly to interpret the results in terms of currently topical tectonic models (e.g. Channell & Horvath 1976, Vandenberg 1979).

Paleomagnetism

a) Sampling

In addition to the previous rock collections in the western part (Valle Antigorio) and the eastern extension (Bergell) of the Lepontine area 13 new sites have been cored in the central part of the area in order to obtain paleomagnetic information throughout the whole zone of young Alpine metamorphism. Several sites were also drilled in the Aar Massif. The Lepontine sites coincide with localities sampled by Jäger et al. (1967), Hunziker (1974) and Köppel & Grünenfelder (1975) for age dating so that accurate age control is achieved for all sampling sites.

b) Magnetic mineralogy

Ferromagnetic minerals which carry the natural remanent magnetization *(NRM)* of rocks can be identified magnetically by their coercivity and blocking temperature spectra. Dunlop (1972) measured the acquisition curves of isothermal remanent magnetization *(IRM)* versus magnetic field and derived from these curves coercivity spectra of remanent magnetization which permit separation of the contributions of low coercivity magnetite and high coercivity haematite to the *IRM*. Progressive thermal demagnetization of *IRM* yields further information on the blocking temperature spectra of the various rockforming ferromagnetic minerals. Since the grain size distribution of ferromagnetics in metamorphic rocks usually covers both single- and multidomain grain size, maximum blocking temperatures in these rocks can be correlated closely to Curie temperatures which depend on mineral type and composition.

Two main types of *IRM* acquisition curves have been observed in the metamorphic rocks of the Lepontine area (Fig. 1). The *IRM* of the first type saturates in fields of 1–2 kOe and indicates the presence of low coercivity phases usually interpreted as magnetite. The second type is most clearly represented by sample *LEV 1CC* (Fig. 1) and does not reach saturation in fields up to 8 kOe. Haematite usually is thought to be the carrier of such a high coercivity *IRM*. The rocks of the second type also often

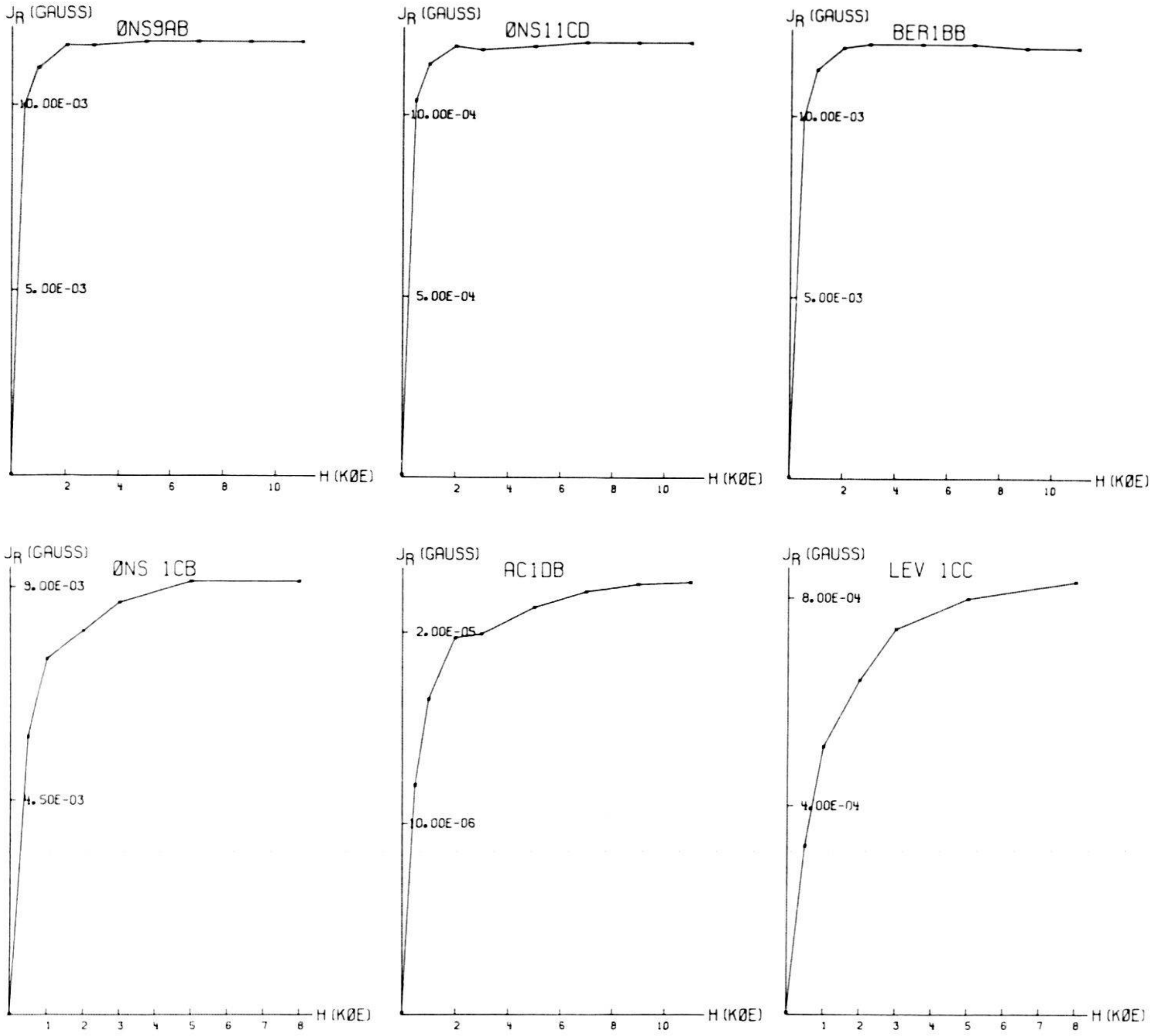

Fig. 1. Two types of *IRM* acquisition curves are observed in the Lepontine metamorphic rocks. Upper series saturates below $H=2$ kOe; lower series contains ferromagnetic minerals with coercivities greater than 2 kOe.

contain low coercivity contributions due to magnetite and possibly pyrrhotite, which result in a sharp *IRM* intensity increase at low fields, but a slow approach to eventual saturation (sample *AC1DB*).

Thermal treatment shows (Fig. 2) that rocks with high coercivity *IRM* have blocking temperatures over 600 °C (sample *LEV 1CC*), but the maximum blocking temperature of pure haematite is not reached. Thus the presence of impure, probably Ti-enriched haematite is indicated. This is confirmed by ore microscopy where haemo-ilmenite has been observed. The haemo-ilmenite consists of a groundmass of ferroilmenite in which numerous small sized exsolutions of titanohaematite are imbedded. The low coercivity rocks have maximum blocking temperatures around 550 °C which originate from comparatively pure magnetite (sample *ONS 9CC*). Sometimes the demagnetization curves are inflected (sample *AC 1EC*) between 300 °C and 400 °C, due to the presence of another ferromagnetic phase. This is probably pyrrhotite which has been observed optically in addition to magnetite.

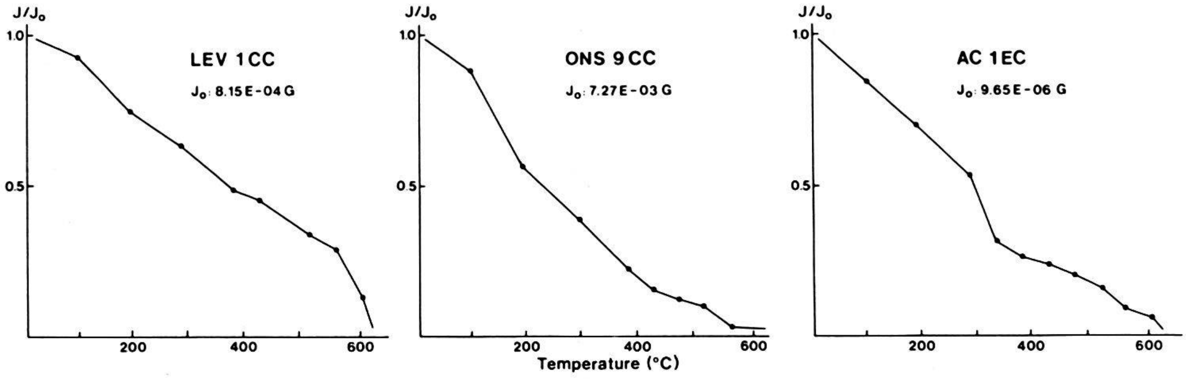

Fig. 2. Progressive thermal demagnetization of *IRM* acquired in a field $H = 8$ kOe. The different shape of the demagnetization curves and the different maximum blocking temperatures indicate the presence of several ferromagnetic minerals.

It has also been shown elsewhere that titanohaematite as well as magnetite determine the magnetic properties of the Bergell granite and the Valle Antigorio gneisses (HELLER 1971, 1977).

c) *Natural remanent magnetization (NRM)*

The *NRM* intensity of the Lepontine metamorphics varies to a large extent between 10^{-8} G and 10^{-4} G with a mean value at 2.4×10^{-5} G. The initial *NRM* directions are scattered widely and magnetic cleaning techniques were used to isolate stable magnetization directions. Usually alternating field *(AF)* demagnetization, and to a lesser extent thermal demagnetization, have been employed for this purpose.

Only seven of the 13 new Lepontine sites contain stable and consistent directions of *NRM*. The other localities had to be discarded on the basis of directional stability criteria (HELLER 1978) which in these instances showed either excessively high directional dispersion during the repeated measurement of a sample (probably due to magnetic viscosity) or large changes in *NRM* direction between each demagnetization step. The reliable sites contain rocks with magnetizations which are considered to be stable as illustrated by the examples in Figures 3 and 4. *AF* and thermal demagnetization curves of two high coercivity samples from the same core have been plotted in Figure 3. Upon *AF* cleaning a soft magnetization component is removed at first. At higher fields the *NRM* vector becomes absolutely stable with a negative inclination (i.e. antiparallel to the present earth's magnetic field) and a declination pointing towards southeast. During thermal demagnetization again the *NRM* is extremely stable (in particular the direction) and maximum blocking temperatures are reached above 600 °C. It has already been established by *IRM* experiments that titanohaematite controls the magnetic properties of these rocks. With respect to the magnetization history it is important to note that the *NRM* is unblocked at the same temperature as the saturation *IRM*. This means that the *NRM* process affected the uppermost blocking temperatures close to the Curie temperature of the titanohaematite. Therefore according to PULLAIAH et al. (1975)

the temperatures of young Alpine metamorphism must have exceeded 600 °C, in accordance with the known geological and petrological history (NIGGLI 1970, KÖPPEL & GRÜNENFELDER 1975).

The low coercivity samples are not as stable in direction or intensity as the previous example. Nevertheless, as illustrated in Figure 4, both *AF* and thermal demagnetization techniques often allow the isolation of characteristic *NRM* directions with northwestern declinations and downwards inclinations.

The characteristic *NRM* directions of the seven stable central Lepontine sites and the Valle Antigorio site obtained after optimum demagnetization have been plotted on equal area stereographic projections in Figure 5. The respective site mean directions and 95% circles of confidence (α_{95}) have been plotted for uniformity always on the lower hemisphere regardless of actually measured *NRM* polarity. The site mean declinations always point NNW, but the inclinations vary between 45° and 70°. This variation may come from a variable degree of magnetic anisotropy the main plane of which lies horizontal at many sites thus giving rise to a variable

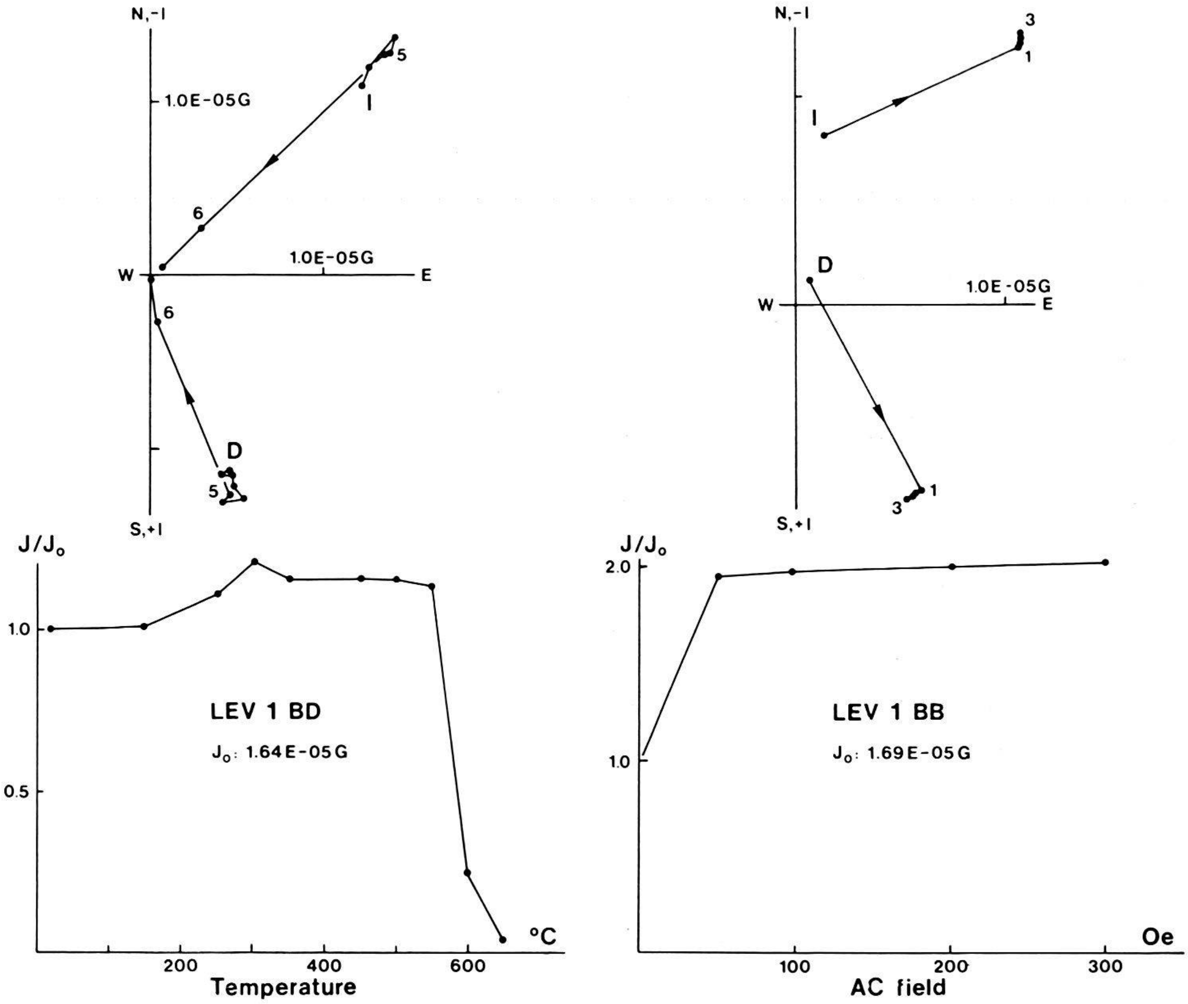

Fig. 3. Thermal and *AF* demagnetization of *NRM* of high coercivity samples. *NRM* intensity decay during demagnetization plotted on the lower two diagrams. *NRM* directional variations given as projections of the declination and inclination components of *NRM* in the upper two vector plots.

deflection of the *NRM* inclination from the paleofield direction. The declinations are not influenced by anisotropy effects because the maximum principal axes of anisotropy do not show any preferred alignment (HELLER 1977). The characteristic direction of the Bergell granite - where anisotropy effects had to be encountered when determining the characteristic declination (HELLER 1973) - coincides closely with that of the other Lepontine sites (Table). The site mean directions are regionally consistent and lead to a well grouped Lepontine mean value (Fig. 6, Table) which has a declination $D = 332.6°$ and an inclination $I = 59.3°$ with $\alpha_{95} = 6.8°$ (number of sites including Bergell: $N = 9$).

The consistency of *NRM* directions and the angle of inclination indicate that the Lepontine metamorphic rocks have been completely remagnetized during the young Alpine metamorphism. They acquired a thermoremanent magnetization during rapid cooling in lower to middle Miocene times. Since frequent reversals of the geomagnetic field occurred at that time (HEIRTZLER et al. 1968) and the uplift of the Lepontine area was not exactly coeval in the different regions (WERNER et al. 1976),

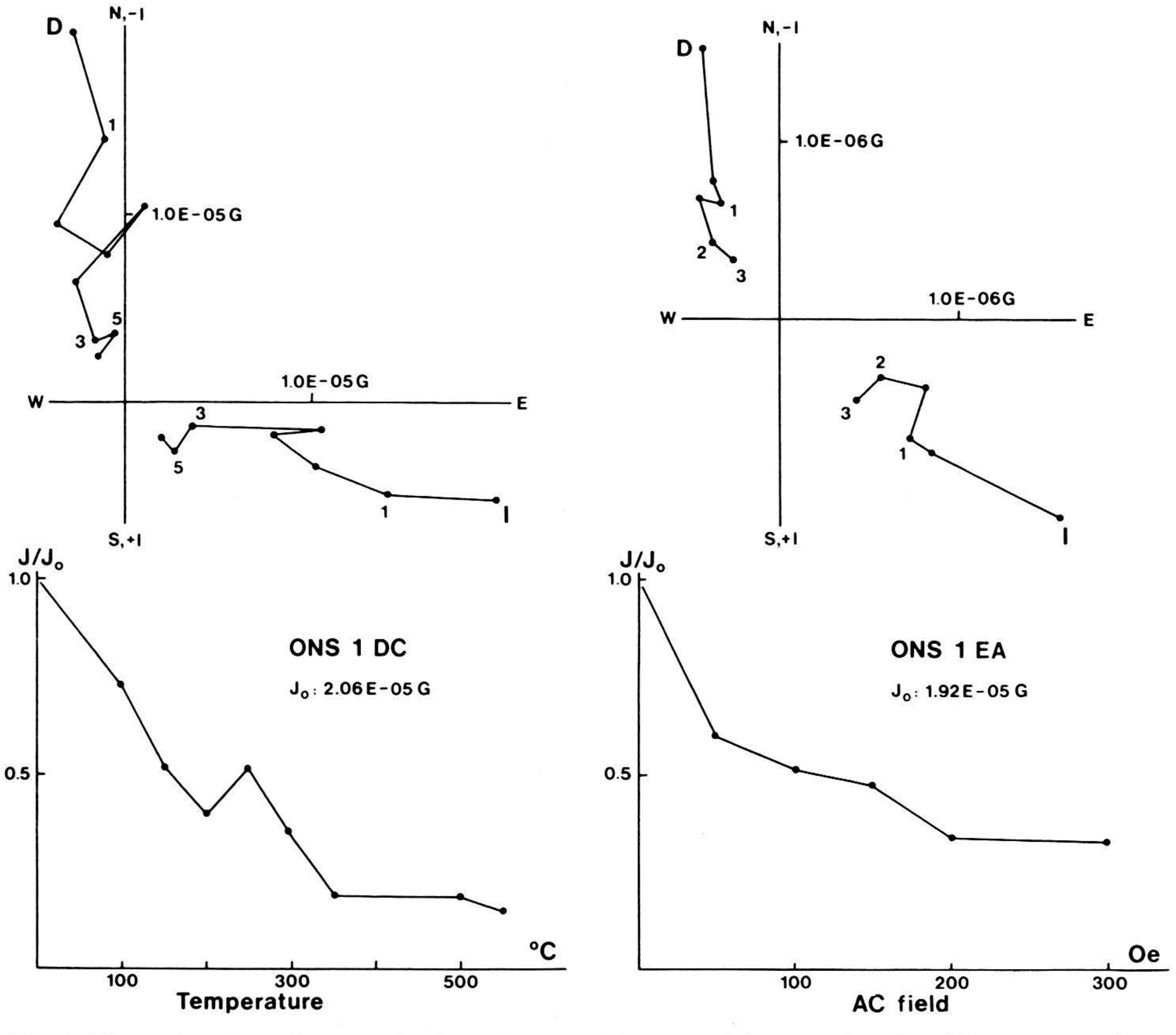

Fig. 4. Thermal and *AF* demagnetization of *NRM* of low coercivity samples. Graphic representation as in Figure 3.

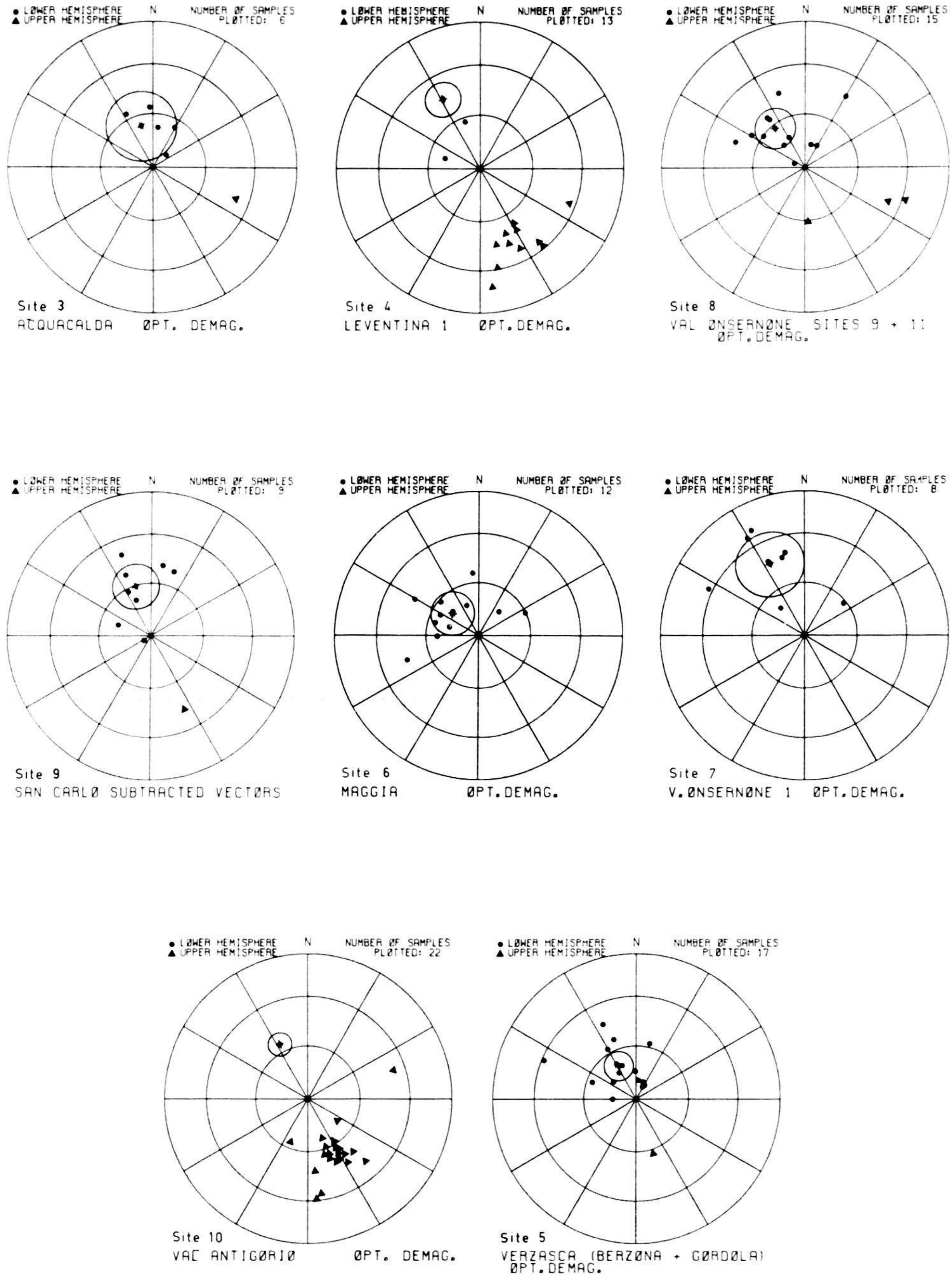

Fig. 5. Paleomagnetically stable Lepontine sites: *NRM* directions of individual samples together with site mean directions. The latter always are plotted on lower hemisphere together with 95% circles of confidence regardless of the actually measured *NRM* polarity. Site numbers 3–10 correspond to site numbers used in the Table and Figure 8.

Table: *Site mean directions and paleomagnetic pole positions for two sites from the Aar Massif and nine sites from the Lepontine area. Locality numbers refer to those given in Figure 8.*

Locality	Number of stable samples	Site mean direction Declination	Inclination	α_{95}	Pole position Long. E	Lat. N	Polarity (%) +	-	ΔD
Aar Massif:									
Schöllenen (1)	21	186.7	-70.1	8.1	34.7	81.0	48	52	±23.8
Grimsel (2)	6	195.3	-74.2	8.1	35.3	73.1	-	100	±29.7
Lepontine Area:									
Acquacalda (3)	6	343.8	66.1	19.9	296.0	78.8	83	17	±49.1
Leventina (4)	13	331.1	45.3	10.2	248.4	60.0	15	85	±14.5
Verzasca (5)	17	331.6	69.0	8.3	308.0	70.6	94	6	±23.2
Maggia (6)	12	309.7	70.8	12.3	313.4	57.7	100	-	±37.4
Onsernone E(7)	8	334.0	44.2	19.5	243.2	61.0	100	-	±27.2
Onsernone W(8)	15	321.6	62.2	11.4	286.9	62.9	80	20	±24.4
San Carlo (9)	9	342.5	60.5	13.2	264.4	76.6	100	-	±26.8
V.Antigorio(10)	22	152.7	-55.2	6.8	261.3	67.0	-	100	±11.9
Bergell (11)	405	338.7	57.4	1.2	258.7	72.3	50	50	± 2.2
Lepontine Mean (N = 9):		332.6	59.3	6.8	271.4	69.2			±13.3

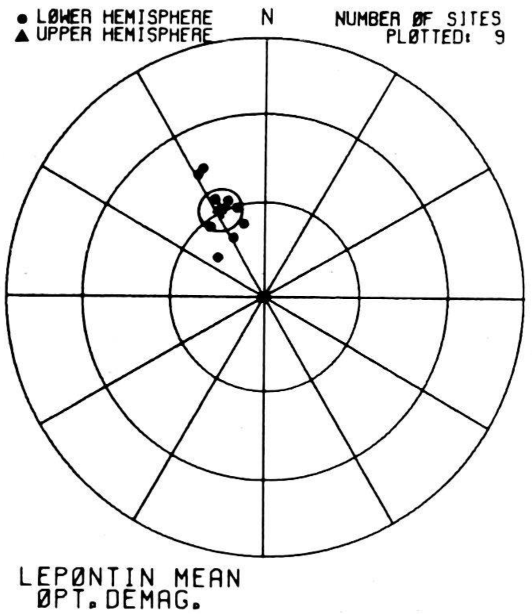

Fig. 6. Regional mean *NRM* direction of the Lepontine area.

different *NRM* polarities have been found at different sites. Probably due to varying blocking temperatures of *NRM* negative and positive polarities have been observed even within some sites (Fig. 5).

Only two of several sites sampled from the Aar Massif had stable directions. Their characteristic directions differ from those of the Lepontine; they dip more steeply and point towards north (Fig. 7, Table).

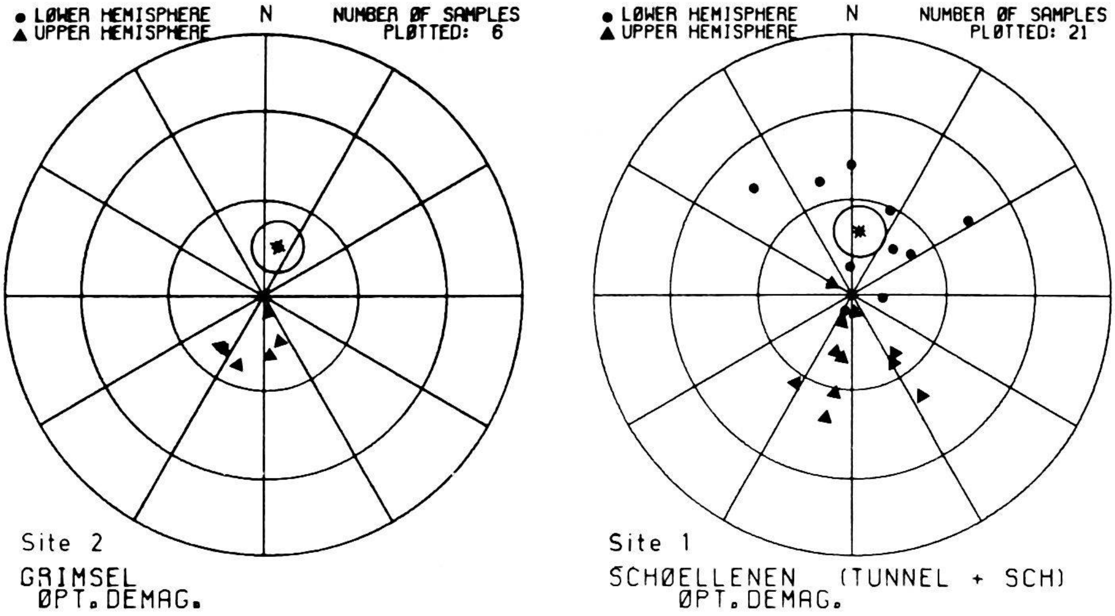

Fig. 7. Characteristic *NRM* directions at the two stable sites from the Aar Massif.

Discussion

IRVING'S (1977) Eurasian paleomagnetic data indicate that a 20 m.y. old magnetization in the Central Swiss Alps should have a direction with $D = 359°$ and $I = 60°$, if the Lepontine area as one tectonic block belonged to stable Europe at the time of *NRM* formation. The same direction should also be observed if the Lepontine block like the Southern Alps was part of a northern extension of the African plate (Adriatic subplate: CHANNELL & HORVATH 1976), since for the time span under consideration the African and European paleomagnetic pole positions coincide closely (VANDENBERG 1979).

The inclinations of the Lepontine site mean directions fit the predicted value very closely whereas the mean declinations (Fig. 6, 8) are deflected anticlockwise by $27° \pm 13°$ (Table). This suggests independent rotational movements of the region which may be connected with the uplift of the area and the "Neo-Alpine" phase of Alpine orogeny (TRÜMPY 1973).

VANDENBERG (1979) proposes that the Adriatic subplate was detached from Africa and has been rotated in a counterclockwise sense by 20° with respect to Europe and Africa since the early Tertiary. This interpretation would suggest that the Adriatic block and the Lepontine unit experienced the same rotation after middle Miocene. However, VANDENBERG'S (1979) Tertiary paleomagnetic data either come from possibly allochthonous rock units which may be decoupled from the basement, or require further subdivision of the Adriatic plate, if DE BOER'S (1963) directions from the Vicentinian Alps are not omitted. VANDENBERG also incorporates into the Southern Alpine block the earlier Bergell data (HELLER 1973), and also the Biella andesites (LANZA 1977) where the declination direction heavily depends on a proper and exact tectonic dip correction. This may be invalid since the

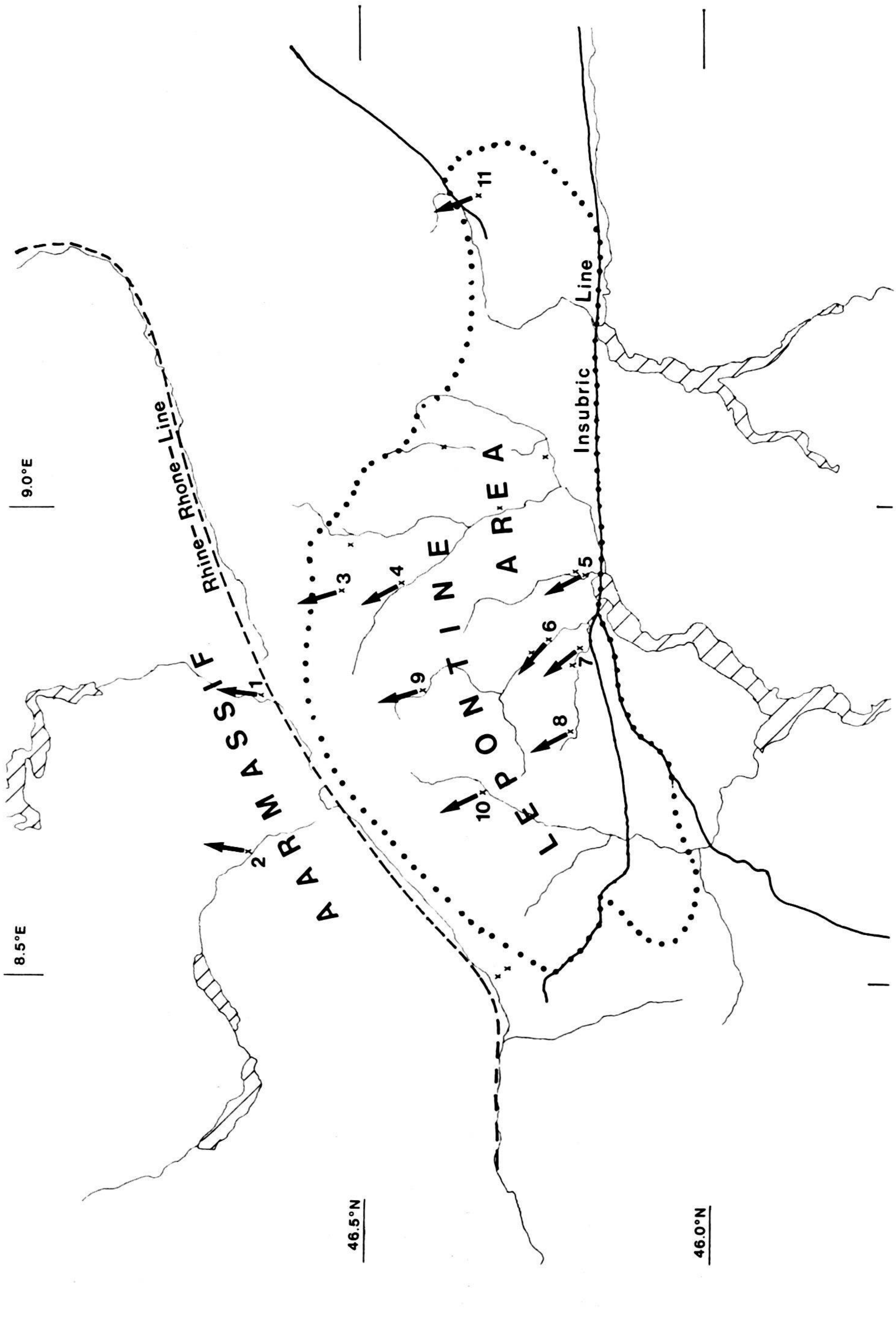

Fig. 8. Regional distribution of NRM site mean declinations in the Aar Massif and the Lepontine area.

Insubric fault zone with its important post-Oligocene displacements, both horizontal and vertical (LAUBSCHER 1971, TRÜMPY 1973) clearly separates the Southern Alps from the Central Alpine tectonic unit. Therefore a joint rotation of these two blocks seems unlikely.

Also on the basis of paleomagnetic evidence CHANNELL & HORVATH (1976) keep the Adriatic subplate always in close contact to African movements since the Jurassic. These authors have demonstrated that the deformation history of the Alps responds to movements of the Adriatic block as part of the African plate. Their work implies that the Lepontine area only has been rotated since the beginning of uplift of the Central Alps. This interpretation requires a frame of tectonic elements where movements occurred along the boundaries of this block. The southern boundary is formed by the Insubric line where large vertical movement (TRÜMPY 1973) as well as minor dextral horizontal displacement of a few kilometers (FUMASOLI 1974) has been observed. The northern boundary must be sought along the Rhine-Rhone-line since *NRM* declinations in the Aar Massif (Table, Fig. 7, 8) are found to be aligned parallel to contemporaneous directions in stable Europe. Dextral shear movements along this fault zone are connected with the formation of the Helvetic nappes which originate from the belt between Aar Massif and Gotthard "Massif". There is as yet no direct geological evidence for dextral displacement along the Rhine-Rhone-line, but focal mechanisms of recent earthquakes (PAVONI 1976) may be indicative of dextral E-W movements in the Rhone valley.

Thus we conclude that the Lepontine area is a tectonic block unit with consistent, Miocene *NRM* directions. They are deflected counterclockwise by $27° \pm 13°$ from European and African directions due to dextral movement along two major fault zones in the Alps, the Insubric and the Rhine-Rhone-lines (Fig. 8).

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