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Palaeomagnetic Data from the Western Lepontine Area (Central Alps) *)

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Abstract

Preliminary palaeomagnetic measurements in the Valle Antigorio (northern Italy) show the presence of Upper Tertiary magnetization caused by cooling during uplift of the Lepontine area which followed the young Tertiary period of high temperature metamorphism. During the high temperature period temperatures of around 600°C must have been reached, as the critical blocking temperatures of stable remanent magnetization range between 580°C and 590°C. The direction of stable remanence deviates from contemporaneous directions of stable Europe. Possible mechanisms are discussed which may have caused the post-magnetization deformation.

INTRODUCTION

Within mobile orogenic belts like the Alps palaeomagnetic investigations are still rare because of the complicated tectonic state and history of those regions. Simple block rotations which in the past have been inferred from palaeomagnetism in many tectonically consolidated regions, usually do not yield promising results. Recent investigations in the central Alps (Lepontine area) have shown that young alpidic metamorphism due to deep burial postdates the large tectonic horizontal displacements and main folding events in this area (Niggli, 1970). Temperatures of 600°C to 650°C have been reached in the central part of the Lepontine area (Frey et al., 1974) and concordant monazite ages indicating the high temperature period of metamorphism vary regionally between 20 to 30 m.y. (Köppel and Grünenfelder, 1975). As the metamorphic temperatures exceed the Curie temperatures of most rock-forming ferromagnetic minerals, a preliminary palaeomagnetic study has been conducted in the Valle Antigorio, northern Italy. Its purpose was to check if the metamorphic rocks (mainly gneisses of the Antigorio nappe)

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possess magnetic properties suitable for a palaeomagnetic investigation, to find out if the gneisses were indeed remagnetized during the Miocene and finally to verify how the palaeomagnetic directions measured in these rocks correlate with contemporaneous directions from stable Europe north of the Alpine belt.

PALAEOMAGNETISM

a) Sampling area

35 oriented cores have been drilled at six sites in the Valle Antigorio about 10 to 20 km to the north of Domodossola (Fig. 1). One site is situated in the deepest unit of the Penninic nappes, the Verampio granite-gneiss which crops out around Baceno due to the Toce culmination. The other sites were chosen to the north of this tectonic window in the gneisses of the Antigorio nappe.

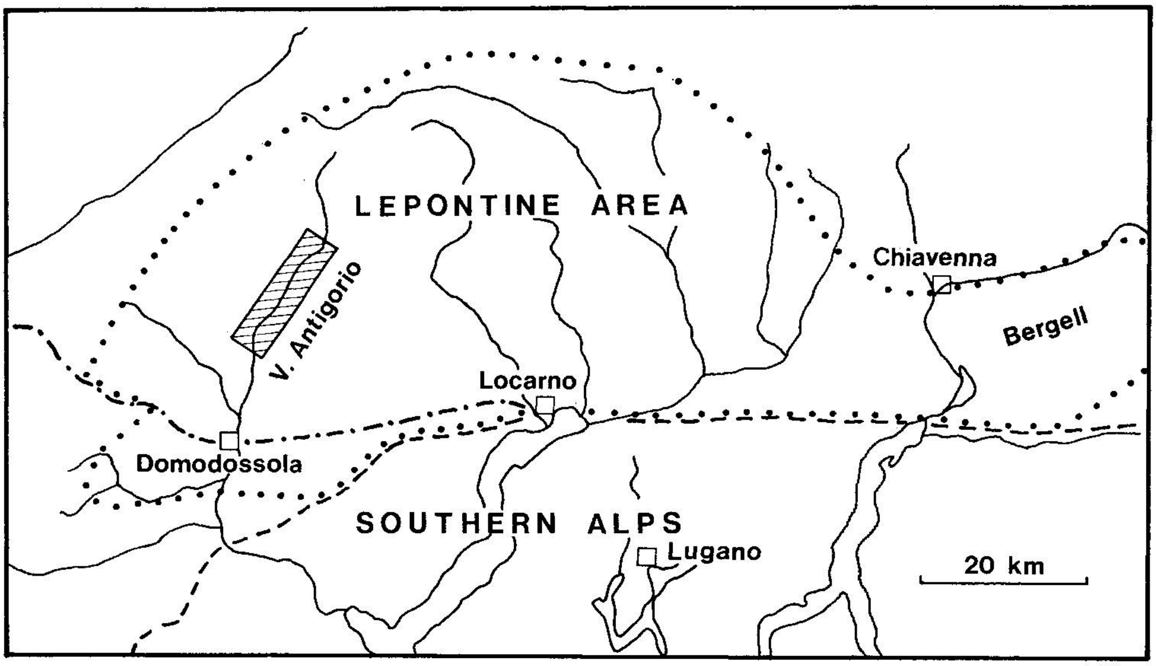

Fig. 1. Boundary of Alpine amphibolite facies metamorphism ...., Insubric line – – –, Simplon-Centovalli fault –·–·–. Dashed area covers sampling sites.

b) Natural remanent magnetization (NRM)

The initial NRM intensities varied between 1×10^{-6} Gauss and 350×10^{-6} Gauss and the initial NRM directions were scattered widely. To remove unstable magnetization components and to isolate the stable component of NRM, the samples were subjected to alternating field demagnetization techniques. Stepwise AF-cleaning up to 800 Oe peak field showed stable NRM characteristics in only 30% of the samples. The change of magnetization direction with change of amplitude of the demagnetizing field ($\Delta\vartheta/\Delta$ H) has been used as a stability criterion. If $\Delta\vartheta/\Delta$ H exceeded 0.5°/Oe during the whole demagnetization procedure, samples were regarded as useless for further palaeomagnetic considerations. Following these criteria only 22 specimens from two of six sampling sites showed stable NRM directions. These specimens also had stable NRM intensities, indicating the presence of a high-coercivity ferromagnetic mineral. The stable rocks are fine-grained granite-gneisses found at a few places within the usually coarse-grained Antigorio gneisses (Augen-gneisses) all of which proved to be unstable. The Verampio granite-gneisses also showed unstable NRM. The distribution of remanence directions (Fig. 2) becomes more tightly clustered after optimal ($\Delta\vartheta/\Delta$ H $\rightarrow$ minimum) AF demagnetization and has a mean direction given by: declination D = 153° E, inclination I = −55°, the radius (α_{95}) of the 95% circle of confidence (FISHER, 1950) is 7°.

Using a high-temperature, three component computer controlled magnetometer designed by HEINIGER and HELLER (1976) some samples were heated in air up to temperatures of about 600° C, while the remanence (partly cleaned previously by the AF treatment) was measured continuously to obtain information on the high temperature characteristics of magnetization especially on the blocking temperature range. During heating no change in direction was observed. The NRM intensity (Fig. 3) at first increases up to temperatures of about 200° C. Above this temperature the intensity decreases and vanishes at about 590° C, thus defining the highest blocking temperatures

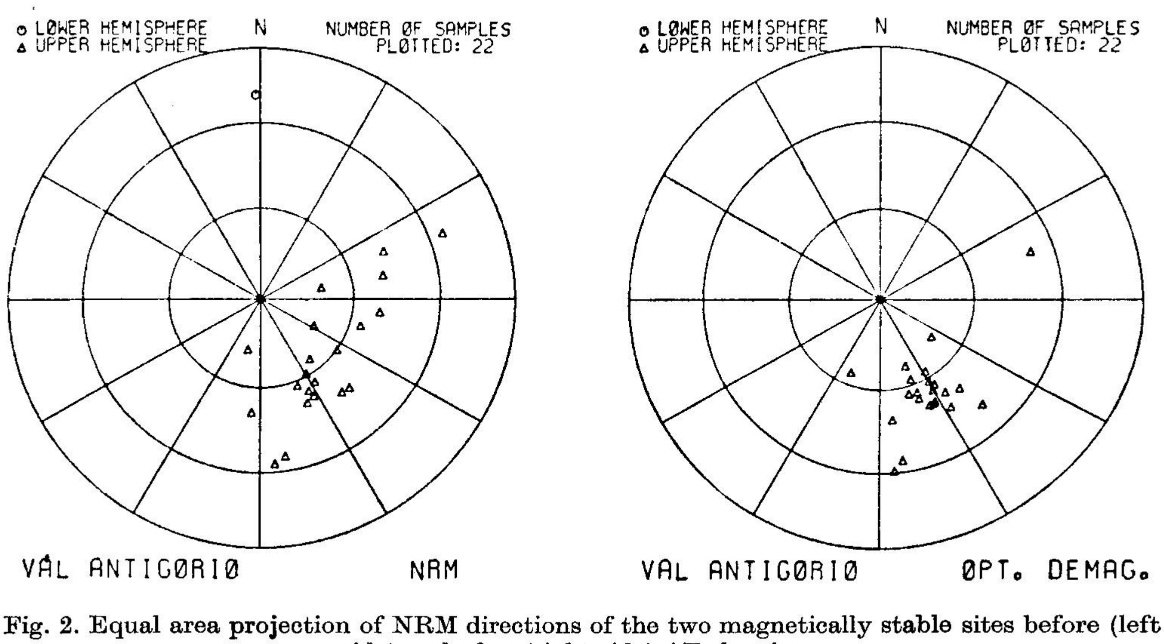

Fig. 2. Equal area projection of NRM directions of the two magnetically stable sites before (left side) and after (right side) AF-cleaning.

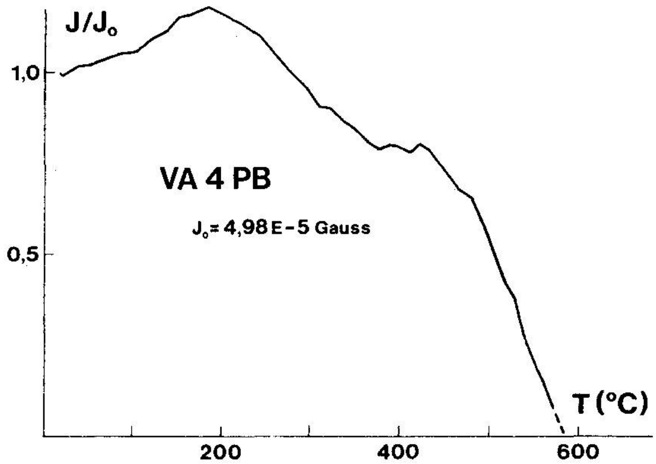

Fig. 3. Continuous thermal demagnetization of AF-cleaned stable NRM.

at this level. This type of thermal demagnetization curve is very similar to that found in the titanohematites of the Bergell granite (HELLER and EGLOFF, 1974). The increase of NRM intensity with temperature up to 200°C may therefore by analogy with the Bergell ferromagnetic minerals be attributed to the presence of a second magnetic phase in the titanohematite (see below) which shows negative interaction with the high blocking temperature phase. The range of blocking temperatures of the latter phase is – again by analogy with the Bergell titanohematites – very small and restricted to the temperature interval from 580°C to 590°C.

c) Optical examination of ferromagnetic minerals

According to ore microscopic observations two ferromagnetic minerals are present in the Antigorio rocks. Magnetite – probably Ti poor – of various grain size is the only ferrimagnetic mineral identified in the magnetically unstable coarse-grained gneisses. The stable rocks contain hemo-ilmenite which is exsolved to a large extent. Its groundmass consists of titanohematite; the exsolutions of ferroilmenite are aligned within the basal plane. The grain size varies from a few μm to about 100 μm. Usually the grains are elongated with the major axis lying in the plane of macroscopically visible schistosity. The optically established presence of exsolved hemoilmenite is consistent with the thermal demagnetization characteristics as well as the stable NRM intensity found in the fine-grained gneisses during AF-cleaning.

d) Anisotropy of magnetic susceptibility

The results of anisotropy measurements are shown in Fig. 4. The directions of intermediate and maximum susceptibility axes (k_2, k_1) are widely scattered, but distributed along a great circle representing the trace of the magnetic

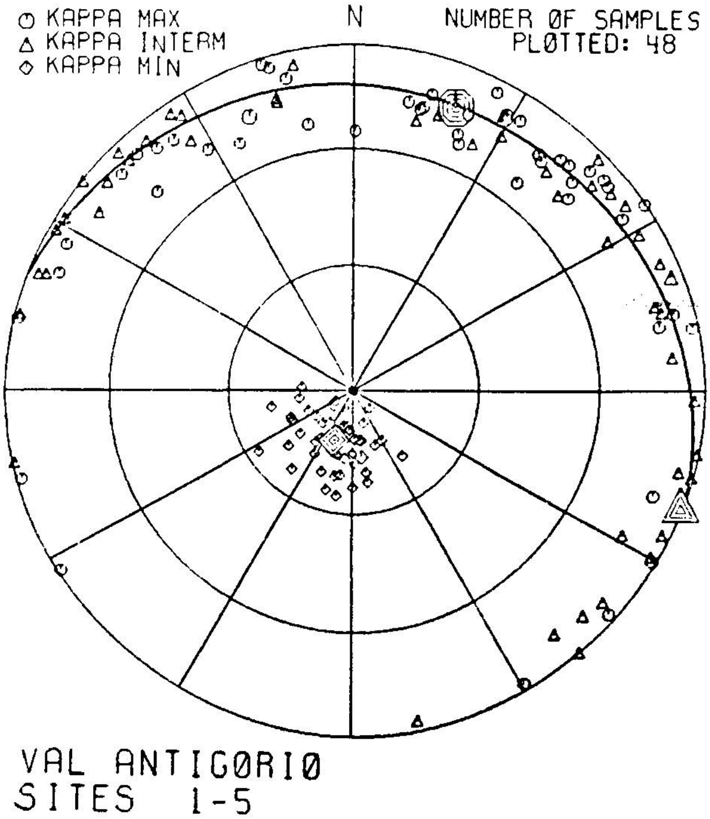

Fig. 4. Lower hemisphere equal area plot of principal axes (kappa max = k_1, kappa interm = k_2, kappa min = k_3) of magnetic anisotropy.

foliation plane. The axes of minimum susceptibility (k_3) are very closely grouped with a mean direction dipping very steeply to the south (bearing B = 200°E, dip D = 77°, angular standard deviation $\psi_{63} = 9°$, number of samples N = 48). There is no difference in the orientation of the anisotropy ellipsoids between stable and unstable rocks. The average oblateness OB which is defined by $OB = \frac{1}{N}\sum_i (k_2-k_3)_i/)k_1-k_2)_i$ has a value of OB = 4.9. This indicates dominant planar alignment of the ferromagnetic minerals within the major anisotropy plane which strikes roughly E-W and dips gently to the N (perpendicular to k_3). Thus the magnetic fabric is consistent with the optical data and is in good agreement with the regional schistosity orientation observed in the Valle Antigorio. Linear magnetic alignment which would be represented by close grouping of k_1 directions is not found.

DISCUSSION

There is no doubt that the stable NRM is a thermoremanent magnetization, i.e. the magnetization was blocked during a cooling process when the critical blocking temperature was reached. Radiometric age determinations point to two events during which the rocks in the Valle Antigorio possibly became magnetized. Firstly, the occurrence of concordant monazite ages of 250 to 270 m.y. has been proved by KÖPPEL and GRÜNENFELDER (in preparation) for certain rock types of the central part of the Lepontine area. Secondly, regionally varying concordant monazite ages of 20 to 30 m.y. (KÖPPEL and GRÜNENFELDER, 1975) indicate the young Tertiary high temperature period of metamorphism in the Lepontine area which was followed by rapid cooling (WERNER et al., 1976).

The apparent polar wander path for stable Europe is reasonably established since the Upper Carboniferous (Fig. 5). Therefore magnetization directions corresponding to the above time intervals can be derived for the Lepontine area assuming that it is part of stable Europe. For the older possible magnetization event a declination of $D = 20°E$ and an inclination of $I = 10°$ corresponding to the Permian palaeomagnetic pole position is calculated and for the younger event $D = 7°E$ and $I = 59°$ corresponding to the Upper Tertiary pole position McELHINNEYS (1973) is evaluated.

The inclination values are compared at first. They give direct evidence for the palaeomagnetic co-latitude. Neglecting the negative sign of the Antigorio inclination ($I = -55°$), which probably indicates reversed polarity of the ambient palaeofield, close coincidence between the Upper Tertiary European inclination and the Antigorio inclination is observed. This suggests that the Antigorio rocks indeed were remagnetized during the rapid cooling process (WERNER et al., 1976) following the period of Tertiary high temperature metamorphism. As the blocking of magnetization certainly took place at temperatures around 600°C we also can conclude that during the metamorphism period at least this temperature was reached in the western part of the Lepontine area. An earlier origin of magnetization cannot be excluded definitely, but having in mind the very complex folding history between Cretaceous and Eocene (MILNES, 1974) it would be an unlikely coincidence if a pre-Tertiary distorted inclination was closely aligned to the Upper Tertiary European inclination at the two stable sites in Valle Antigorio.

However, there is still a large gap between the Antigorio VGP position and the Upper Tertiary pole position for stable Europe (Fig. 5). This is due to an anti-clockwise deviation of the Antigorio declination ($D = 333°E$, disregarding the reversed polarity) of about 35° of arc with respect to the above calculated European declination ($D = 7°E$). As the magnetic foliation of our rocks is more or less horizontal and as the direction of k_1 does not show preferred alignment, the observed deflection of declination is not influenced by anisotropy. We rather have to assume a post-magnetization rotation of the Antigorio sites to align both magnetization directions parallel.

Either of two critical rotations may be considered to account for this

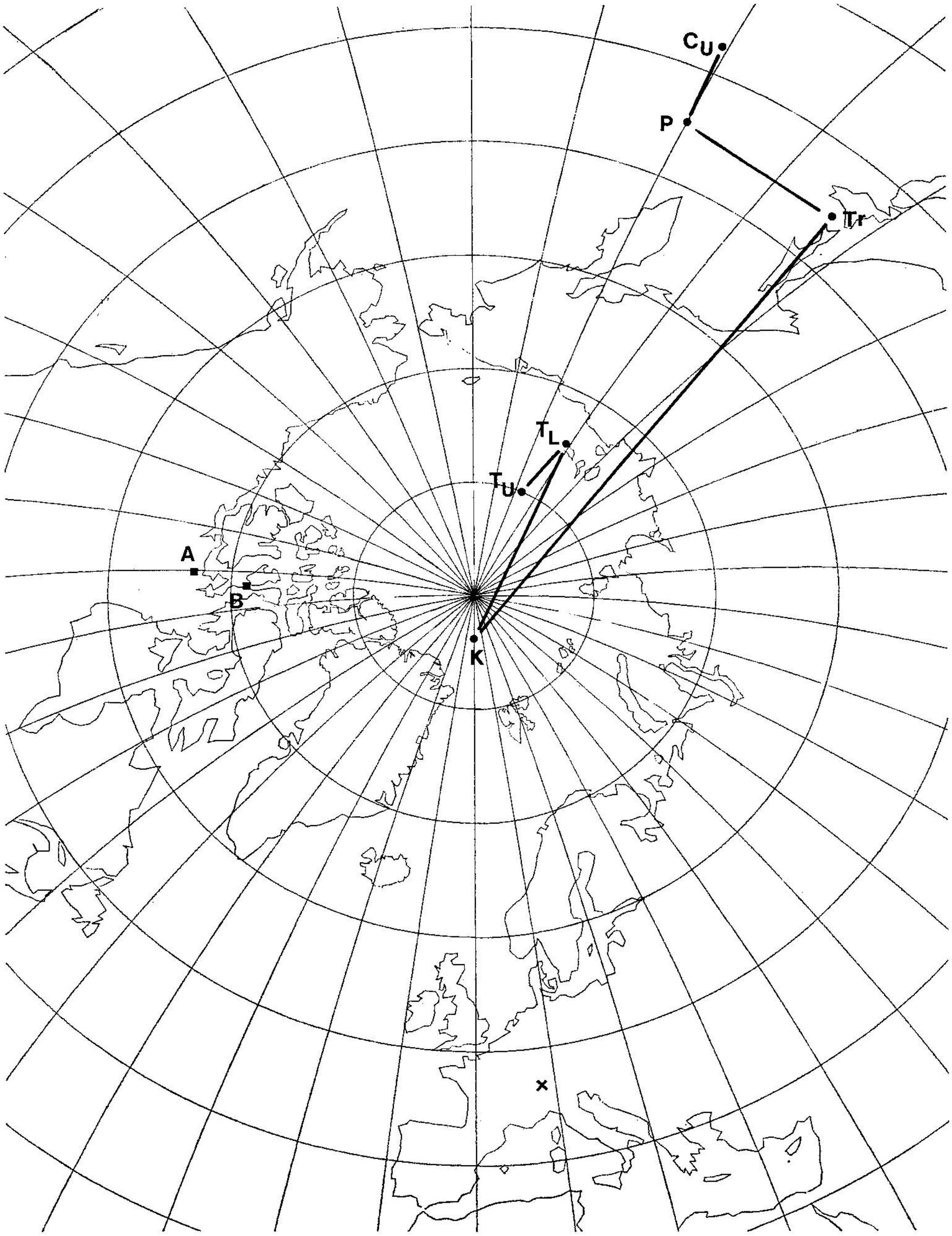

Fig. 5. Apparent polar wander path for stable Europe (Upper Carboniferous C_U to Upper Tertiary T_U) according to McElhinney (1973). Squared VGP's result from the stable NRM mean directions of Valle Antigorio (A) and Bergell massif (B).

difference although, of course, intermediate motions are not excluded: (a) a rotation about a horizontal axis or (b) a rotation about a vertical axis.

During the uplift of the Lepontine area which in different regions did not occur at the same time (WERNER et al., 1976), bending and tilting of different tectonic blocks might have happened. The size of these blocks cannot be estimated at present. Thus a rotation of the Antigorio region as a block of uncertain size about a horizontal north-trending axis by about 22° of arc would align the magnetization direction of the Antigorio rocks into the stable European position with the block dipping 22° to the east now. As the Bergell granitic rocks show the same magnetization direction (HELLER, 1972), a tilt correction may be applied in the same sense to explain their deviation from the European direction. But here such a solution is rather improbable, as the western part of the Bergell intrusion is surrounded by a broad contact metamorphism aureole in contrast to the eastern part, thus suggesting that the Bergell block dips rather to the west than to the east assuming no change of the sense of rotation between the times of contact metamorphism and uplift. It seems therefore that tilt rotation may not be used generally as a solution for the rotations observed in the Lepontine area.

In the Southern Alps anti-clockwise rotations about a vertical axis have been established by palaeomagnetic workers (e.g. ZIJDERVELD and VAN DER VOO, 1973). These rotations have been attributed to huge dextral E-W striking horizontal displacements between Eurasia and Africa (DE BOER, 1965). Although those large displacements are no longer considered, the counterclockwise rotation of the Valle Antigorio and of the Bergell massif – again the block sizes are uncertain – possibly is due to horizontal dextral motions along the Insubric line s.l., which according to LAUBSCHER (1971) began to set in during the Oligocene. As an alternative to tilt-rotations these dextral rotations in combination with the Alpine N-S compression may have caused the observed counterclockwise rotation of the Antigorio and the Bergell declinations.

Both motions seem to be possible and at present we cannot positively favour one over the other. To give a definite answer to the rotation problem, more detailed palaeomagnetic sampling in the Lepontine area is necessary. Then we may also be able to find evidence for the size of rotated blocks which may comprise either minor segments of the Lepontine area or may consist of this area as a whole.

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