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PALEOMAGNETIC EVIDENCE OF LARGE FAULT DISPLACEMENT AROUND THE PO BASIN — REPLY

J. VANDENBERG and A.A.H. WONDERS

Department of Structural and Applied Geology, and Paleomagnetic Laboratory, State University of Utrecht, Utrecht (The Netherlands)
Department of Stratigraphy and Micropaleontology, State University of Utrecht, Utrecht (The Netherlands)

(Received February 9, 1978)

The supposed Tuscan Autochthon (i.e. the Monticiano area) was chosen for paleomagnetic research in order to establish, whether the detailed movement pattern deduced from paleomagnetic data of NW Umbria was representative for the entire Northwestern Apennines. As it could not be excluded that the offset to the west of the Umbrian paleomagnetic data relatively to the African and Southern Alpine data was the result of a rotational décollement to its basement of the whole Umbrian sequence (VandenBerg et al., 1978; VandenBerg and Wonders, 1976).

In their comment, Kligfield and Channell question the autochthony of Tuscany, i.e. the Monticiano area, and therefore question our conclusion that the offset of the Umbrian pattern is representative for the entire Northwestern Apennines indeed. We have proposed a two phase differential movement for the Northwestern Apennines and the Southern Alpine block, Kligfield and Channell raise doubt about the second (Tertiary) phase only, stating that the Monticiano area probably is not autochthonous and therefore a rotational décollement remains to the possibilities.

The Monticiano area (about 200 km^2 large) is part of an important horst system and bounded on all sides by normal faults (Giannini and Lazzarotto, 1975). The amount of vertical uplift of this area relative to the western and eastern surroundings is about 2500 meters. It comprises Hercynian folded sediments, of Middle to Late Carboniferous age, covered discordantly by subhorizontal continental clastic sediments of Permian to Late Triassic age, 700 m total thickness (Cocozza et al., 1975; Cocozza et al., 1974a; Cocozza et al., 1974b). The Middle/Late Triassic clastic sediment is concordantly overlain by Miocene sediments. In other areas in western Tuscany, the thick-

ness of the Triassic clastics varies rapidly and in several outcrops the Paleozoic rocks are found directly overlain by Latest Triassic to early Jurassic anhydritic layers of the Mesozoic Tuscan sequence (Azzaro et al., 1976). This Mesozoic sequence forms essentially the Tuscan nappe.

REMARKS ON THE INTERPRETATION OF THE GEOLOGICAL SETTING

Kligfield and Channell assume that the slaty cleavage S1 is the result of a large recumbent fold with a flat lying axial plane, this is not supported by field observations, since no overturned strata nor the hinge of such a structure was mapped by Giannini and Lazzarotto (1975). Recumbent folds in the Tuscan nappe can be found in the "Montagnola Senese", north of the Monticiano area, and possibly in the southern and western parts of Tuscany, but there they are always related to the presence of anhydrite below the Tuscan nappe. These structures are developed in the most superfical tectonic compartment of the Tuscan nappe and cannot be extrapolated to the presently underlying compartment.

Taken into account the considerable uplift and rapid decrease to the West of the Permo-Triassic continental sediments (Azzaro et al., 1976), the presence of parautochthonous slabs at the base of drillings in more western, and therefore more internal, areas of Tuscany shows merely that directly below the Tuscan nappe a superficial tectonic compartment was reached belonging to the autochthon. That compartment, in which "rabotage" (abrading) is a common feature, was never present or has been removed together with the Mesozoic Tuscan sequence in a pre-Miocene phase from the Monticiano area.

The mineral associations related to the low grade metamorphism of the Alpi Apuane and the Monticiano area are quite different. The typical minerals for the Alpi Apuane and Monti Pisani are: quartz, albite, white-K-mica, epidote and rare biotite. This association is diagnostic for the chlorite—biotite zone of the greenschist facies (Hyndman, 1972). As for the Monticiano area the typical mineral association is: muscovite and phengite in the Hercynian folded rocks, indicating subchlorite zone, however sericite/phengite, kaolinite and possibly montmorillonite are present in the Permo-Triassic rocks, indicating for the later the zeolite facies (Hyndman, 1972; Azzaro et al., 1976). For the Alpi Apuane and Monti Pisani only compressive phases and a high geothermal gradient can account for these conditions (Carmignani et al., in press), in contrast for the Monticiano area the very low metamorphic conditions point to a burial metamorphism with a low geothermal gradient. It is more likely that during the burial of the Monticiano section the slaty cleavage was formed, parallel to the bedding of the Permo-Triassic sediments, as a reaction to the sedimentary pile (Tuscan sequence?) and not necessarily during a deformation phase. The presence of a crenulation cleavage was only observed in the Paleozoic sediments (Azzaro et al., 1976; personal observation) and was assumed to be related to the tight

Hercynian folding, axial planar to the isoclinal folds. The later metamorphism (zeolite facies) was not able to reopen the previous Hercynian system, because the temperature was too low (Azzaro et al., 1976).

REMARKS ON OUR PALEOMAGNETIC STUDY

During our first visit to the area (VandenBerg and Wonders, 1976) we collected handsamples throughout the Monticiano area from six localities all with different bedding tilts and widely dispersed. During a second party in October 1977, we cored 60 samples with an electric drill in a 100 meter section only. Kligfield and Channell refer abusively in their comment to this particular locality, since drillholes were the only traces they found. The results of this 100 meter section (VandenBerg, in prep.) support our previous findings in more than one way. The characteristic paleomagnetic directions, after thermal cleaning, are in excellent agreement with the earlier result. Besides in this section two levels were found that have complete opposite directions, proving the existence of at least two reversals in the section. The presence of reversals is a common feature in Middle-Triassic times (McElhinny and Burek, 1971), the period in which this sediment was formed (Cocozza et al., 1975). The paleomagnetic directions of the geographically distributed sites showed a positive fold test (VandenBerg and Wonders, 1976) and the presence of reversals within the section practically excludes the possibility of remagnetization during the very low grade metamorphism (Pullaiah et al., 1975; Dunlop and Buchan, 1977).

PALEOMAGNETIC DATA FROM SOUTHEAST ITALY

Paleomagnetic data are available for comparison not only from the Northwestern Apennines and outside the Southern Alps, but also from the autochthonous platforme in Southeast Italy: Campania and Gargano/Apulia (Channell and Tarling, 1975; Channel, 1977). The platforme sediments belong to the stable Adriatic block and form the backbone of the Adriatic plate (Channell and Horvath, 1976). The Umbrian sequence is the lateral equivalent of these autochthonous platform sediments, and a transitional facies can be observed. Comparison of paleomagnetic data from Umbria with those from the platforme sequences is possible, providing the quality (accuracy) is corresponding. Such a condition is common use in statistics. Channell (1977) was very generous to his new data from Gargano/Apulia and used all site mean results with an α_{95} smaller or equal 33° (sic) to compute a mean value. One should realize that we are dealing with rotations of 15°—30° at maximum. The values of α_{95} for the site mean results from the Umbrian and Southern Alpine paleomagnetic data practically never exceeded the 16° (VandenBerg and Wonders, 1976; VandenBerg et al., 1978; Lowrie and Alvarez, 1974; Channell and Tarling, 1975).

In Fig. 1 we have plotted the site mean results from Campania and Gar-

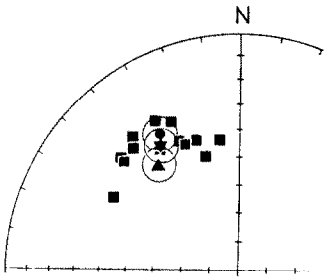

Fig. 1. Comparison of Turonian to Maastrichtian paleomagnetic data from Northwest Umbria and Southeast Italy. Full squares indicate site mean directions from Campania and Gargano/Apulia (Channell and Tarling, 1975; Channell, 1977). The full star is the mean value for these areas. Full dot indicates the mean value of the Northwestern Umbrian data according to Channell and Tarling (1975). Full triangle indicates the mean value of the Northwest Umbrian data according to Lowrie and Alvarez (1974). Circles indicate the cones of confidence on the probability level of 95% for the mean values. All directions downward pointing in lower hemisphere projection.

gano (Channell and Tarling, 1975) as well as the newly available data from the platforme carbonates in Gargano/Apulia (Channell, 1977) as full squares, using only those data which had an α_{95} that did not exceed 15°. These directions and the mean value for the platforms (dec. 327.1°, inc. +37.5°, α_{95} = 5.9°) were computed for the site of Cagli (43°33′ 12°41′) in Umbria. These paleomagnetic data cover the timespan Turonian to Maastrichtian, and can directly be compared with the Umbrian data in Fig. 1. The mean value for this timespan from our data (VandenBerg et al., 1978) (dec. 322°, inc. +42°, α_{95} = 6°) was not plotted to avoid overcrowding.

The elongated site mean distribution (squares) is in good accordance with the Umbrian pattern for this interval (VandenBerg and Wonders, 1976), and the overall mean values show no significant statistical difference, as can easily be seen in Fig. 1.

CONCLUSIONS

Kligfield and Channell's simple extrapolation of the tectonic development of the Alpi Apuane and Monti Pisani to the Monticiano area seems highly speculative.

There is no reason to assume that the paleomagnetic directions from the Monticiano area are not the result of primary magnetizations.

If at all the Umbrian sequence was detached from its basement during a décollement, than that movement was not rotational relatively to the Monticiano area nor to the Southeast Italian platform, since paleomagnetic data with an acceptable accuracy from those areas do not differ and are in excellent agreement to each other. Since especially the Southeast Italian platform

(Gargano/Apulia) is considered to represent the backbone of autochthonous Italy, the conclusion seems justified that the detailed movement pattern deduced from paleomagnetic studies in NW Apennines are representative not only for the Northwestern Apennines (VandenBerg et al., 1978), but for all peninsular Italy.

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