

THE ROTATION OF ITALY: PRELIMINARY PALAEOMAGNETIC DATA FROM THE UMBRIAN SEQUENCE, NORTHERN APENNINES

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A preliminary collection of 43 palaeomagnetic samples (10 sites) from the miogeosynclinal and supposedly autochthonous Umbrian sequence in the Northern Apennines, Italy, was analysed by means of alternating magnetic fields and thermal demagnetization studies. The older group of samples, taken from the upper part of the Calcarei Diaspri (Malm), the Fucoid Marls (Albian/Cenomanian) and from the basal part of the Scaglia Bianca (Early Late Cretaceous), all showed normal polarity directions and resulted in a mean site direction: $D = 290.5^\circ$, $I = +51.5^\circ$, $\alpha_{95} = 11^\circ$, $k = 74$, $N = 4$.

The younger group of samples, taken throughout the Scaglia Rossa sequence (Latest Cretaceous/Middle Eocene) showed normal and reversed polarity directions. In contrast to the older group, the magnetic analysis of these samples resulted in a considerably less dense grouping of site mean directions. This presumably is due to inaccuracies introduced with the very large bedding tilt corrections that had to be applied to the samples of some sites. A tentative mean site direction for these Scaglia Rossa samples was computed as: $D = 351^\circ$, $I = +52.5^\circ$, $\alpha_{95} = 23.5^\circ$, $k = 11.5$, $N = 5$.

Despite the low precision of the Scaglia Rossa result, the significant deviation between this Latest Cretaceous/Early Tertiary direction and the Late Jurassic/Early Late Cretaceous direction indicates a counterclockwise rotation of more than forty degrees. This rotation can be dated as Late Cretaceous.

How far these data from the Northern Apennines apply to other parts of the Italian Peninsula has yet to be established. The timing of this rotation is not at variance with the data from other parts of Mediterranean Europe (Southern Alps, Iberian Peninsula) and from Africa. However, taking into account the preliminary nature of the results, the amount of rotation of the Northern Apennines seems to surpass the rotation angle which is deduced from the palaeomagnetic data for Africa.

1. Introduction

In a review of Mediterranean palaeomagnetic data, Zijdeveld and Van der Voo [1] discuss the systematic deviations between palaeomagnetic data from landmasses and peninsulas of Mediterranean Europe and those from "Stable Europe". These "Tethys" directions proved to fit reasonably well with the African palaeomagnetic pattern. This led them to the tentative conclusion that the landmasses south of the Pyrenean–Alpine mountain belt (i.e. Iberian Peninsula, Sardinia, Corsica, Italy including the Southern Alps) belonged to the African plate.

A rotation of these landmasses as part of the African plate implies synchronicity in rotation. It is

well known that the African plate rotated counterclockwise between Early Cretaceous and Eocene times. The "Tethys" data seem in general not at variance with this timing of rotation. However, Sardinia's Early Miocene [2] or perhaps slightly earlier [3,4] rotation presents a notable exception. The rotation of the Iberian Peninsula could be placed between Late Jurassic and Eocene times and the rotation of the Southern Alps occurred sometime between the Triassic and the Eocene [1]. In contrast, Soffel [5] tentatively concluded from data of the Colli Euganei (South of Padova, Northern Italy), that Italy rotated between the Eocene and Miocene, but his interpretation seems not completely unambiguous as noted previously by Storetvedt [6]. It is evident

that palaeomagnetic data from the Italian Peninsula proper, might be worthwhile in order to pinpoint the timing of Italy's rotation. Therefore, a palaeomagnetic study of the Umbrian sequence in the Northern Apennines has been undertaken. The present paper reports preliminary data from rocks of Late Jurassic to Early Tertiary age.

2. Geological setting, sampling and laboratory treatment

The lack of palaeomagnetic data from the Italian Peninsula is partly due to the largely allochthonous nature of most rock units. In the Northern Apennines the miogeosynclinal Umbrian sequence is the only one supposed to be autochthonous [7,8]. Preliminary palaeomagnetic sample collections were taken by one of us (C.T.K.) during the summer of 1973 from Upper Jurassic to Lower Tertiary deposits in the Umbrian sequence near Cagli (43°33'N, 12°41'E); this is the region where field mapping courses are given for undergraduate students from the State University of Utrecht.

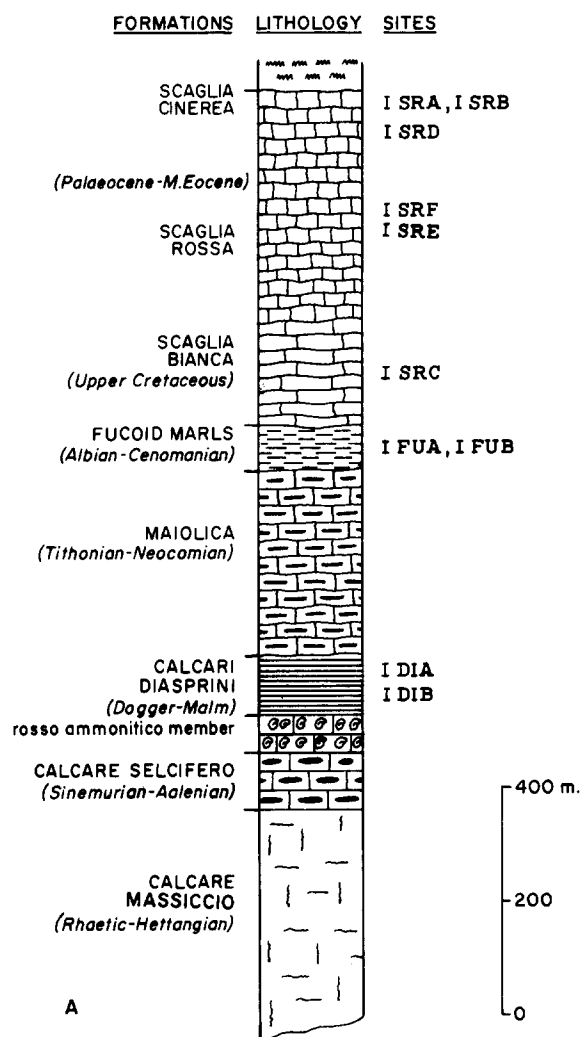
The stratigraphy of the outcropping autochthonous sequence in this area is represented in the ideal stratigraphic column (Fig. 1A) and is described in detail by Bortolotti et al. [8].

The Upper Cretaceous/Lower Tertiary Scaglia sequence especially of this area constitutes a classic stratigraphic profile and its biostratigraphy has been studied in detail [9–11], not in the least because of the observation of an abrupt microfaunal change, which has been associated with the Cretaceous/Tertiary boundary.

Around Cagli, the outcropping rocks grade from a limestone and siliceous limestone basal sequence with some marly intercalations (Calcare Massiccio, Calcare Selcifero including the Rosso Ammonitico member, Calcari Diasprini and Maiolica) into marly limestones of the Fucoïd Marl formation. These marly beds are well exposed at the base of huge escarpments formed by the younger Scaglia sequence which is made up by limestones and marlstones (Scaglia Bianca, Scaglia Rossa, Scaglia Variegata Cinerea – Fig. 1A).

In the Cagli area, this sequence is exposed in a wide NW–SE aligned anticlinal structure (Fig. 1B). The NE limb of this anticlinal structure is locally overturned.

From both limbs of this anticlinal structure altogether 43 handsamples (10 sites) were taken (Table 1). The sampling sites are indicated in Fig. 1B; i.e. 2 sites (IDIA, IDIB) from deeply red-coloured cherty limestones of the uppermost member of the Calcari Diasprini (Malm), 2 sites (IFUA, IFUB) from reddish marly limestones of the Fucoïd Marls (Albian/Cenomanian), 1 site (ISRC) from reddish limestone horizons in the lower part of the Scaglia Bianca (Upper Cretaceous) and 5 sites (ISRA, ISRB, ISRD, ISRE, ISRF) in reddish limestones throughout the Scaglia Rossa (Latest Cretaceous/Middle Eocene). The Scaglia Rossa sites were sampled both in the moderately southward-dipping



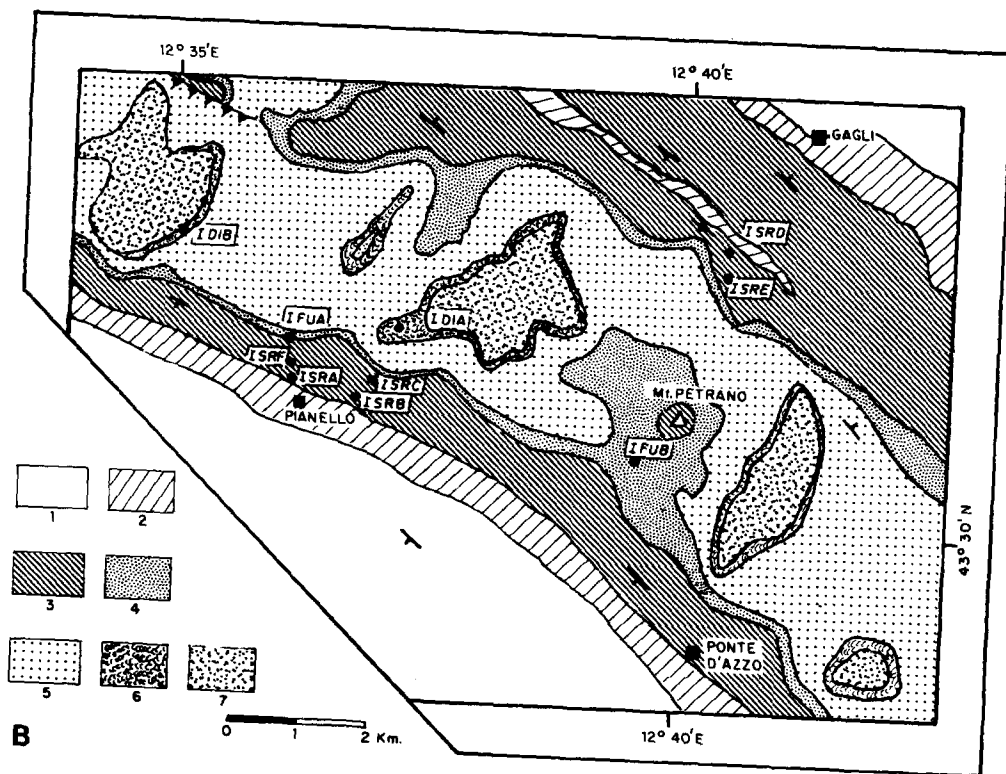


Fig. 1A. Ideal stratigraphic column of the Umbrian sequence in the sampling area (according to Bortolotti et al. [8], p. 354). B. Geological sketchmap of the sampling area with the sampling sites indicated. 1 = Marnoso Arenacea, 2 = Scaglia Cinerea – Scaglia Variegata sequence, 3 = Scaglia Rossa – Scaglia Bianca sequence, 4 = Fucoid Marls, 5 = Maiolica, 6 = Calcari Diasprini, 7 = Calcare Selcifero, including the Ammonitico Rosso member, – Calcare Massiccio sequence.

southern limb (ISRA, ISRB, ISRF) and in the steeply dipping (ISRE) to locally overturned (ISRD) northern limb of the anticline. The samples from each site were taken usually from a stratigraphic sequence several meters in thickness. However, the samples from the Scaglia Rossa sites ISRA and ISRF were taken over the whole stratigraphic sequence of this formation.

The limits between the Scaglia Bianca and the Scaglia Rossa formations are lithologic and not chronological. It is plausible that in the sample area the basal part of the Scaglia Rossa formation covers the uppermost Cretaceous. Foraminiferal studies in order to data a more extensive palaeomagnetic sample collection, are in progress.

Orientation in the field was done by means of a magnetic compass. In the palaeomagnetic laboratory of the State University of Utrecht "Fort Hoofddijk", the samples were analysed by means of alternating field and thermal demagnetization studies. At least 3

specimens, 2.2 cm height and 2.5 cm diameter, were drilled from each sample (116 in all). Because of the low NRM intensity, the astatic magnetometer appeared to be a marginal instrument. Therefore, all measurements were performed with the very sensitive Czechoslovakian JR-3 spinner [12]. Site IFUB samples disintegrated upon drilling, so these hand samples (3) were cast in paraffin wax and had to be measured with an astatic magnetometer.

After initial NRM measurements two specimens from each site were selected for progressive demagnetization by means of alternating fields in 15 to 24 steps up to 3200 Oe peak value. In addition, at least 2 specimens from each site were selected for progressive demagnetization by thermal methods in 11 to 15 steps up to zero intensity. The remaining specimens were partially and progressively demagnetized in alternating fields (6 to 9 steps).

Directional analysis of the data was made according

to Zijdeveld [13] by means of orthogonal projection figures, which are very suitable for interpretation of successive changes in the total magnetization vector upon demagnetization treatment. In the statistical analysis, unit weight was given to the sample direction, computed as the mean of each of 3 specimen directions. For data processing the CDC-6500 of the Academic Computer Centre Utrecht was programmed in Algol-60 [14].

3. Results

The intensity of initial remanent magnetization of the specimens was very low. Intensities ranged from 2×10^{-7} to 5×10^{-6} gauss in the Scaglia Rossa limestones, the Fucoid Marls and the siliceous limestones of the Calcarei Diasprini. Intensities in the redish limestones from the Scaglia Bianca were somewhat higher, between 2×10^{-6} and 2×10^{-5} gauss.

The initial specimen directions from all sites together were distributed over the lower hemisphere (Fig. 2A), with a tendency for concentration towards the northern quadrants. Such a wide dispersion of initial specimen directions was to be expected because the tectonic positions of the sites were widely different (Fig. 1B, Table 1). The concentration tendency of initial specimen directions towards the northern quadrants of the lower hemisphere is mainly caused by a secondary local field component (local field direction in the sampling area: $D = 359^\circ$, $I = +59^\circ$) of appreciable intensity which was removed by means of alternating field and thermal demagnetization treatment (Figs. 2B1, 4).

In the Scaglia Rossa specimens (ISRA, ISRB, ISRD, ISRE, ISRF) the large "present field component", constituting about 25–80% of the initial intensity, was removed upon demagnetization treatment at 100–200 Oe peak value (Fig. 4A,C,D) or 200°C to 300°C (Fig. 4G). In all Scaglia Rossa sites well concentrating characteristic directions were removed generally between 200 and 1000 Oe (ISRB, ISRD, ISRE – Fig. 4A,C,E) to 2000 Oe (ISRA, Fig. 5A) or 300°C to 600°C (Figs. 4E,G,H,5B).

In sites ISRD and ISRE an additional hard third component was removed between 1000 and 3000 Oe (Fig. 4C,D). This latter component could not be distinguished with thermal demagnetization. In case

of site ISRE this component seems to represent another "present local field" component residing in grains with higher coercive forces (Fig. 2B2), which was separately removed upon AF treatment above ca. 1000 Oe peak value. However, in site ISRD above 1000 Oe peak value such a very hard "present local field" component apparently was removed simultaneously with the remaining part of the characteristic magnetization, thus leading to aberrant directions (Fig. 3B2). Similar effects were noted before in Silurian volcanics from the Spanish Meseta ([15], Fig. 8).

For the computation of site mean directions the results of some samples had to be rejected, either because they only contained a "present local field" component (ISRB 2 samples) or because they yielded aberrant directions (ISRF 2 samples, ISRD 1 sample). A field reversal was observed in the Scaglia Rossa sequence, which is covered by the ISRA and ISRF samples (Fig. 1A), so possibly the aberrant directions might be interpreted in terms of "intermediate" directions. In addition the basal sample from site ISRF was not included in the site mean computation. Its direction was aberrant from the other ISRF directions, but evidently tended towards the direction of the stratigraphically underlying Scaglia Bianca site (ISRC).

In samples from the Scaglia Bianca site (ISRC), a "present local field" component of about 25–60% of the initial intensity was removed at 150 Oe peak value (Fig. 5A) or 200°C (Figs. 4F,5B). Well grouping characteristic directions were removed between 200 to 3000 Oe peak value or 300°C to 600°C (Fig. 4B,F).

In the Fucoid Marls (IFUA, IFUB), a "present local field" component of about 30–50% of the initial intensity was removed at 150 Oe peak value or 200°C (Figs. 4K,I,5A,B). Well grouping characteristic directions were removed between 250 to 3000 Oe peak value or 200°C to 600°C (Fig. 4K,I). Also in samples from the Calcarei Diasprini (IDIA, IDIB) a "present local field" component of about 15–40% of the initial intensity could be removed at 80–200 Oe peak value or 130°C to 200°C (Figs 4I,J,5A,B). In site IDIA well concentrating characteristic directions were removed between 200 and 3000 Oe peak value or 200°C to 500°C (Fig. 4I,J). Upon alternating fields treatment of site IDIB samples only uninterpretable components with widely dispersed directions could be recognized. Therefore the results from this particular site were abandoned.

TABLE 1

Natural remanent magnetization

Site	Samples	Specimens	Init. intens. ($\times 10^8$ gauss)	Samples	AC(TH)*	Mean direction (deg.)	α_{95} (deg.)	k	Pole position (deg.)	dp (deg.)	dm (deg.)
<i>After alternating fields or thermal demagnetization</i>											
ISRA	2	6	20-115	2	5(1)	165.5 + 37.5	—	—			
ISRB	4	12	44-69	2	9(3)	197.5 + 29.5	—	—			
ISRD	5	15	139-297	4	12(3)	67 + 7	2.5	1158			
ISRE	5	16	28-137	5	13(3)	277 + 24.5	11	51			
ISRF	5	15	47-533	2	13(2)	2 + 21	—	—			
ISRC	4	12	162-1846	4	9(3)	341 + 11	15	38			
IFUA	4	12	70-431	4	10(2)	336.5 + 36	11	74			
IFUB	3	3	20-70	3	3	286 + 45	18	48			
IDIA	5	13	128-299	4	11(2)	328 + 44	14.5	42			
IDIB	6	12	173-303	—	10(2)	—	—	—			
<i>After dip correction</i>											
ISRA						171.5 - 24	—	—	58 N 151.5 W	—	—
ISRB						196.5 - 42.5	—	—	66.5 N 151.5 E	—	—
ISRD						145.5 - 75.5	7	170	62.5 N 21.5 W	12	13
ISRE						347.5 + 45.5	11	51	70.5 N 131.5 W	8.5	14
ISRF						325 + 67.5	—	—	65.5 N 49 W	—	—
ISRC						305.5 + 47	15.5	36	44 N 78 W	13	20
IFUA						286 + 55.5	11	73.5	34.5 N 58 W	11	15.5
IFUB						273 + 51	18	48	23.5 N 55 W	16.5	24.5
IDIA						295.5 + 50.5	10	82	38.5 N 68.5 W	9	13.5
IDIB						—	—	—	—	—	—
<i>Mean site directions</i>											
ISRA, B, D, E, F						351 + 52.5	23.5	11.5	(77.5 N 131.5 W	22	32)
ISRC, IDIA, IFUA, B						290.5 + 51.5	11	74	35.5 N 64.5 W	10	15

* AC: specimens treated by means of alternating fields; TH: specimens treated by thermal methods.

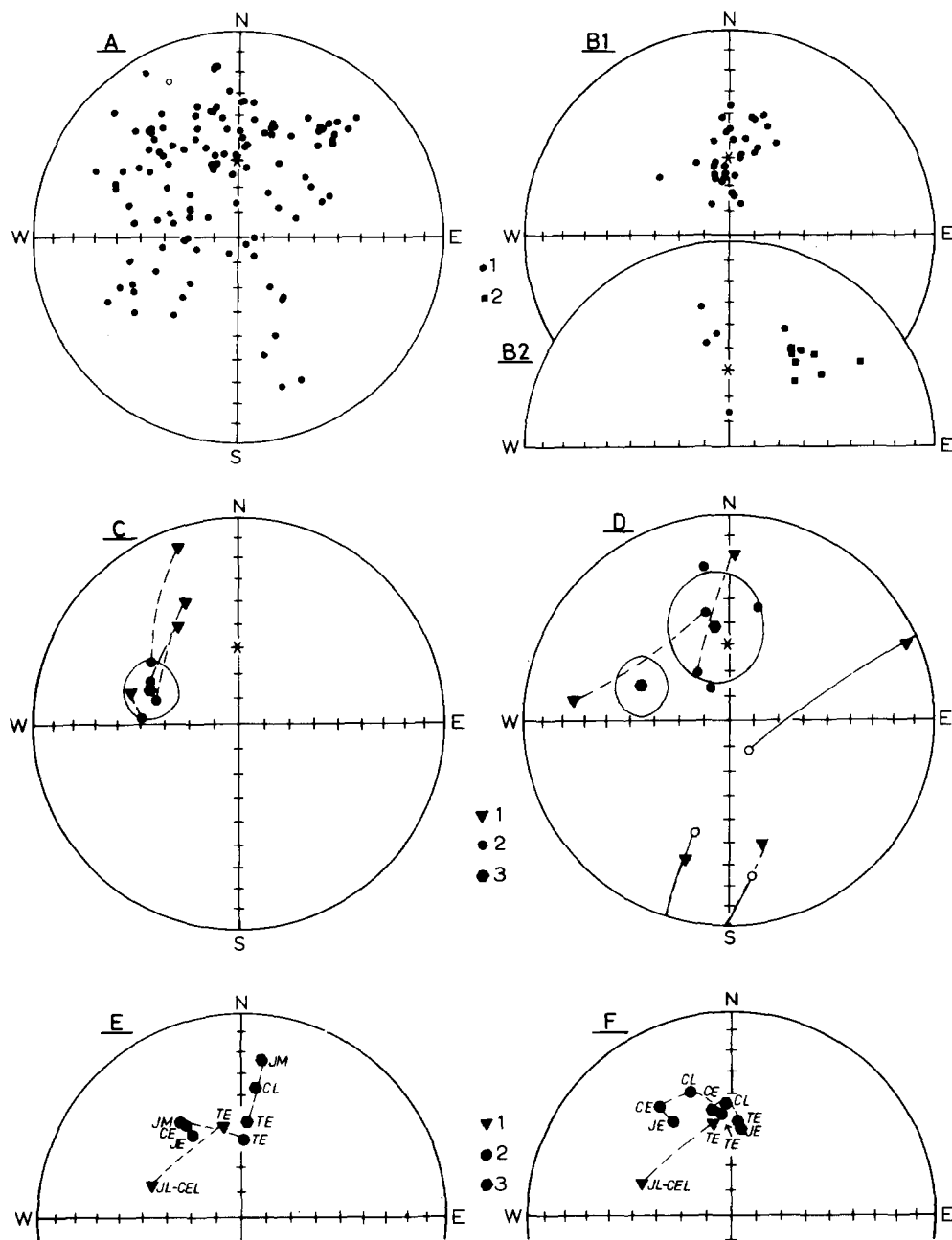


Fig. 2. Remanent magnetization directions in equal area projection. The asterisk denotes the present local field direction dipping downwards at the sampling area. Open symbols denote upward pointing directions. Full symbols denote downward pointing directions. A. Initial specimen directions. B1. Present local field components eliminated upon AF- or thermal demagnetization. B2. Hard secondary components from site ISRD (1) and site ISRE (2), eliminated upon AF-demagnetization. C. Site mean directions for the Late Jurassic to Early Late Cretaceous sites, shown before (1) and after (2) dip correction. The mean site result (3) and the corresponding cone of confidence 95% level are indicated. D. Idem, site mean directions from the Latest Cretaceous/Early Tertiary sites. For comparison the Late Jurassic to Early Late Cretaceous mean-site result is indicated also. For convenience the dip corrected reversed directions (2) are shown as normal polarity directions as well. E. Comparison of the mean directions from the Umbrian sequence (1) with African (2) and European (3) directions, the latter data (2,3) are transformed to the present sampling area according to the central axial dipole field formulae. The European and African data are based on the compilation by Zijdeveld and Van der Voo [1]. Legend: JE = Early Jurassic, JM = Middle Jurassic, JL-CEL = Late Jurassic to Early Late Cretaceous, CE = Early Cretaceous, CL = Late Cretaceous, TE = Early Tertiary (Latest Cretaceous to Early Tertiary for the Umbrian sequence). F. Idem, the European and African data are based on virtual poles, computed by Van der Voo and French [17] from sea-floor spreading data and the general palaeomagnetic pattern from the Atlantic bordering continents.

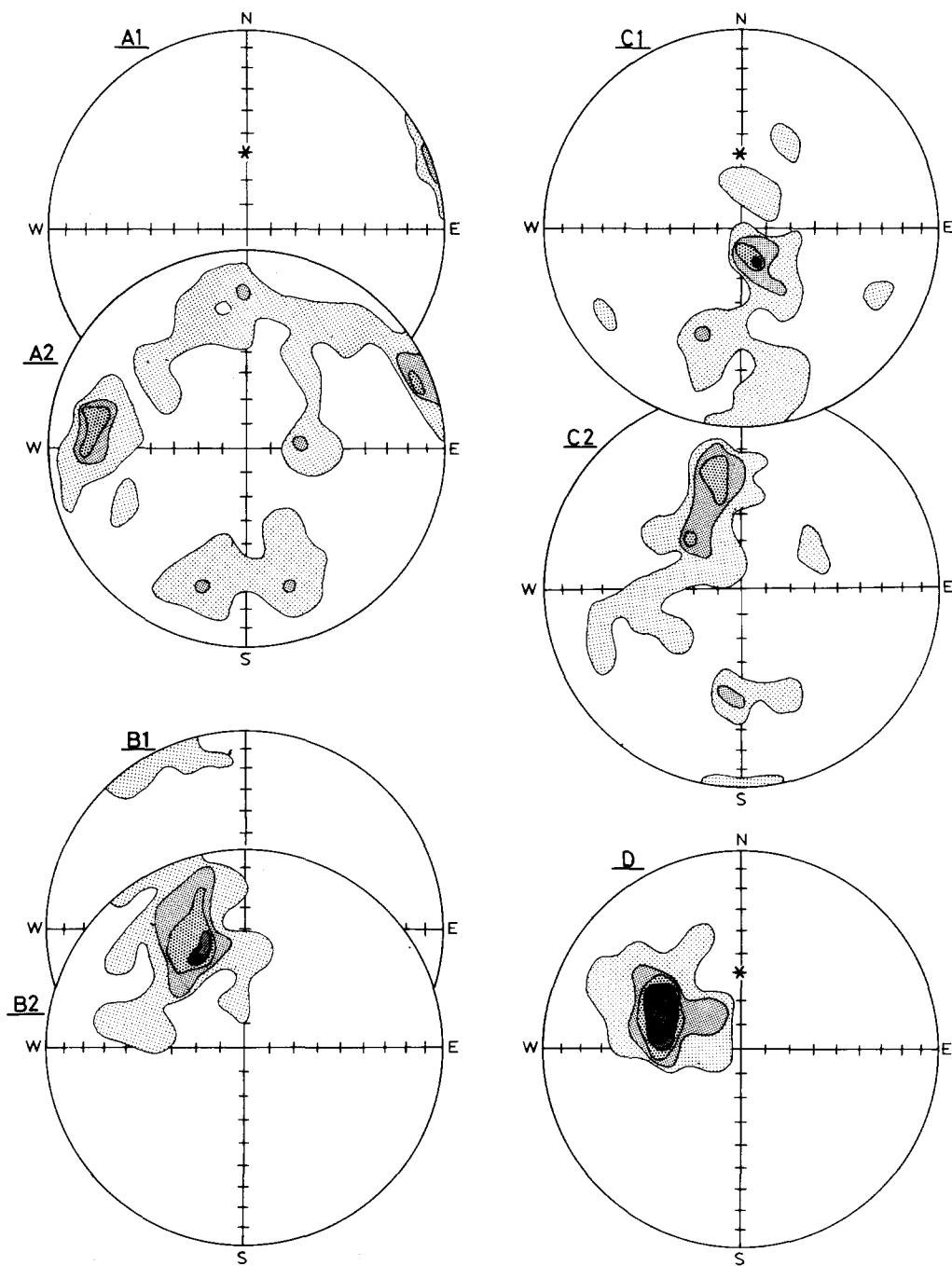


Fig. 3. Density distribution of remanent magnetization directions in equal area projection. The asterisk denotes the present local field direction at the sampling area.

Before dip correction: A1. Characteristic directions from specimens of the Scaglia Rossa sites, lower hemisphere projection only. A2. Idem, upper hemisphere projection only. B1. Characteristic directions from specimens of the Scaglia Bianca, the Fucoïd Marls and the Calcarei Diasprini sites, lower hemisphere projection only. B2. Idem, upper hemisphere projection only.

Idem, after dip correction: C1. Scaglia Rossa sites, lower hemisphere projection only. C2. Idem, upper hemisphere projection only. D. Scaglia Bianca, Fucoïd Marls and Calcarei Diasprini sites, lower hemisphere projection only.

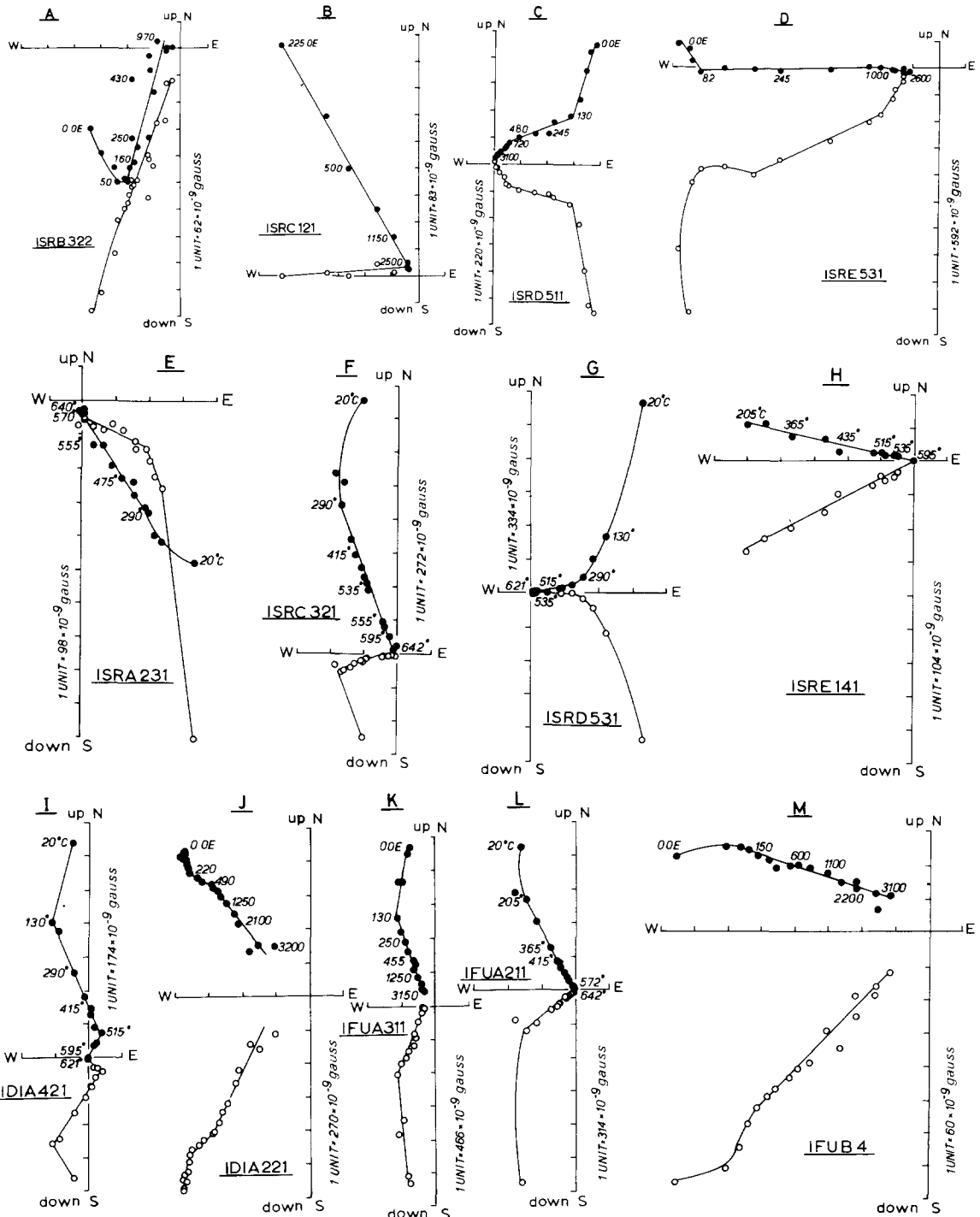


Fig. 4. Orthogonal projection figures of the vector path of the total remanent magnetization vector during AF-cleaning (A, B, C, D, J, K, N) or thermal cleaning (E, F, G, H, I, M). Circles denote projections on the vertical east–west plane, dots denote projections on the horizontal plane. Numbers denote Oe peak values of the applied alternating fields or peak values of the applied temperatures.

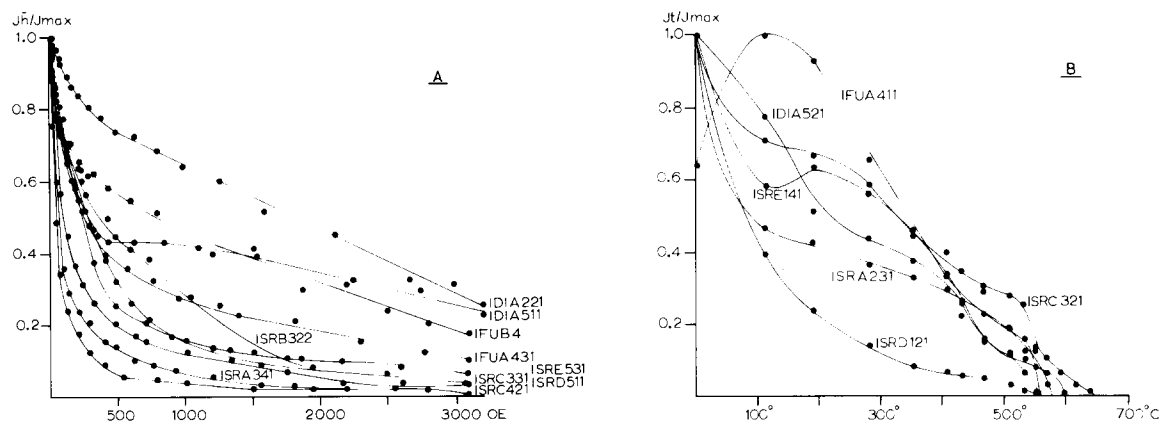


Fig. 5. Normalized curves, showing the decrease in intensity of total remanent magnetization, during AF-cleaning (A) or thermal cleaning (B).

The thermal intensity decay curves are mainly characterized by a thermally distributed blocking temperature spectrum (Fig. 5B) which partially can be attributed to a "present local field" component. After a fast initial decrease, the intensity drops rather regularly. An evidently sharper intensity decrease is visible in the later part of the curves, generally between 500°C and 600°C, whereas in some specimens the magnetization is completely destroyed only at temperatures in excess of 600°C.

Isothermal remanent magnetization measurements revealed that in all samples saturation was not yet reached at 20,000 Oe. All measured coercivities of maximum remanence (H_{cr}) were in excess of 500 Oe (Scaglia Rossa 500–1700 Oe, Scaglia Bianca about 600 Oe, Fucoid Marls about 2000 Oe, Calcari Diasprini about 3600 Oe). These IRM data clearly indicate the presence of hematite. However, the thermal data show Curie temperatures indicative for magnetite as well. So it might be concluded that both are present.

4. Interpretation

Because the sites were sampled both in the moderately dipping southern limb and in the steeply dipping or locally overturned northern limb of the anticlinal structure, the fold test could be applied. The positive result of the fold test (Figs. 2C,D,3C,D) clearly shows a concentration into two distinct groups and indicates that the characteristic magnetization component is

of pre-tectonic, i.e. pre-Pliocene origin. We interpret this characteristic component as the primary magnetization of the rocks.

The first group of directions is made up by data from the Calcari Diasprini, the Fucoid Marls and the basal part of the Scaglia Bianca, which are all of normal polarity and concentrate around a mean site direction: $D = 290.5^\circ$, $I = +51.1^\circ$, $\alpha_{95} = 11^\circ$, $k = 74$, $N = 4$.

The second group of directions comprises all Scaglia Rossa data. The samples taken from the upper part of the Scaglia Rossa sequence (the upper 30 m at least) are of reversed polarity, whereas the samples taken from the more basal part of the Scaglia Rossa sequence reveal normal polarity directions. As shown in Fig. 2D the normal polarity site mean directions have northern declinations, whereas the reversed polarity site mean directions have southern declinations. However, there is a considerable dispersion in directions which most probably might be due to local tectonic complications in some sites.

Extensive development of drag folds is typical for the Scaglia formations [16]. We avoided sampling in strongly tectonized localities, but especially the samples from the steeply northwards dipping to locally overturned northern limb (sites ISRD and ISRE) of the anticline (Fig. 1B) had to be collected from localities with considerable minor folding in the near surroundings. In view of this dispersion, the mean site direction of the Scaglia Rossa sequence: $D = 351^\circ$, $I = +52.5^\circ$, $\alpha_{95} = 23.5^\circ$, $k = 11.5$, $N = 5$ can be presented as a preliminary result only.

5. Conclusion

Despite the low precision of the mean Scaglia Rossa result, the data (Table 1, Fig. 2C,D) evidently reveal an appreciable difference in declination between both mean directions. This difference can be explained by a counterclockwise rotation of the sampling area through an angle of more than forty degrees. The exact amount however, taking into account the preliminary nature of the Scaglia Rossa result, is liable to refinement.

The group with westward declinations is made up by data from the Calcarei Diaspri (Malm), the Fucoid Marls (Albian/Cenomanian) and a single result from the basal part of the Scaglia Bianca sequence. So this mean site result can be regarded as representative for the Late Jurassic/Early Late Cretaceous timespan. On the other hand, the group with dispersed northward (normal polarity) and southward (reversed polarity) declinations is made up by data from the Scaglia Rossa sequence. So this mean site result tentatively represents the Latest Cretaceous/Early Tertiary direction. Therefore, the counterclockwise rotation of the Umbrian autochthon and probably also of the Northern Apennines must have occurred during the Late Cretaceous.

Important transverse structures like the Anzio–Ancona line divide the Apennines, so it remains to be tested whether the present data are applicable to the Italian Peninsula as a single unit. However, the present evidence for a Late Cretaceous counterclockwise rotation of the Northern Apennines is not at variance with data from the Southern Alps, which indicate a similar counterclockwise rotation that occurred sometime between the Triassic and the Eocene [1].

The well-known general affinity of the “Tethys” palaeomagnetic data with the African data, holds also for the present data from the Northern Apennines (Fig. 2E,F). The Late Cretaceous dating of the Northern Apennines rotation supports Zijderfeld and Van der Voo’s suggestion for a contemporaneous counterclockwise rotation of major parts of Mediterranean Europe and Africa. However, the present data reveal a larger rotation angle for the Northern Apennines than shown by the African data (Fig. 2E,F), noting that the latter data are admittedly rather scanty. A possible conclusion can be that the Northern Apennines and may be the rest of the Italian Peninsula have rotated as a separate entity.

More detailed palaeomagnetic research on the Umbrian sequence is in progress.

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