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Magnetic stratigraphy of the Villafranchian type-section (Villafranca d'Asti, Italy)

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Abstract

A detailed magnetostratigraphic investigation has been carried out along the section of the Fornace RDB quarry (Villafranca d'Asti, NW Italy), which is the type-section of the Villafranchian and has provided many of the land mammal remains used by Azzaroli (1977) to define the Val Triversa faunal unit (zone MN16a). Poorly consolidated clay and clayey silt are the prevailing lithologies and samples were collected with plastic boxes. Isothermal remanent magnetization measurements showed that haematite is the main ferromagnetic mineral and occurs through the section, whereas iron sulphide is subordinate and only occurs in the lower part. Alternating field demagnetization usually succeeded in isolating a stable component and was used to derive the characteristic remanence by demagnetizing the specimens at 4 to 7 steps in the range 15 to 80 mT. The magnetic fabric was investigated by measuring the anisotropy of the magnetic susceptibility. It was always well defined and characterized by a horizontal foliation matching the bedding plane. The anisotropy of isothermal remanent magnetization was measured on some specimens and yielded fully comparable results. This consistency shows that detrital haematite carries the primary magnetization in these sediments and explains the 20° inclination shallowing of the site mean palaeomagnetic direction. Only one reverse to normal polarity transition has been detected and a direct correlation with the GPTS reference scale of Cande and Kent (1992, 1995) is thus not possible. The age of the Triversa fauna has been much debated in recent literature. Some authors have recently suggested that it is transitional between Ruscinian and Villafranchian, *i.e.* a little older than previously assumed. According to this hypothesis, the lower part of the RDB section would correlate to the chron C2Ar (upper Gilbert) and the upper part to the chron C2An.3n (lower Gauss), whereas according to the traditional interpretation correlation is to one of the polarity inversions within the middle Gauss (Kaena and Mammoth). An independent age constraint based on magnetostratigraphy will only be possible when other Ruscinian and Villafranchian sections are investigated in the same detail and a correlation between palaeosecular variation is established.

Key words *detrital remanence – magnetic fabric – magnetostratigraphy – Villafranchian*

1. Introduction

Villafranchian sediments cover the whole of the Piedmontese flatlands and much of the hills (fig. 1a,b), where they crop out as erosion relicts that vary in both deposits and age from one area to another (Carraro, 1996). The zone around Villafranca d'Asti, some 40 km south-east of Turin, was studied for the first time by Pareto (1865) and is considered as the type-zone. It consists of a sequence of Plio-Pleistocene continental sediments conformably deposited on Zanclean-Piacenzian marine sands. Some of its outcrops contain large quantities of palaeontological material, mainly continental vertebrate and molluscs, plant macrofossils and pollens. From the vertebrate remains, Azzaroli (1977) defined the Val Triversa unit, the oldest of the Villafranchian mammal faunas (MN16a, De Bruijn *et al.*, 1992).

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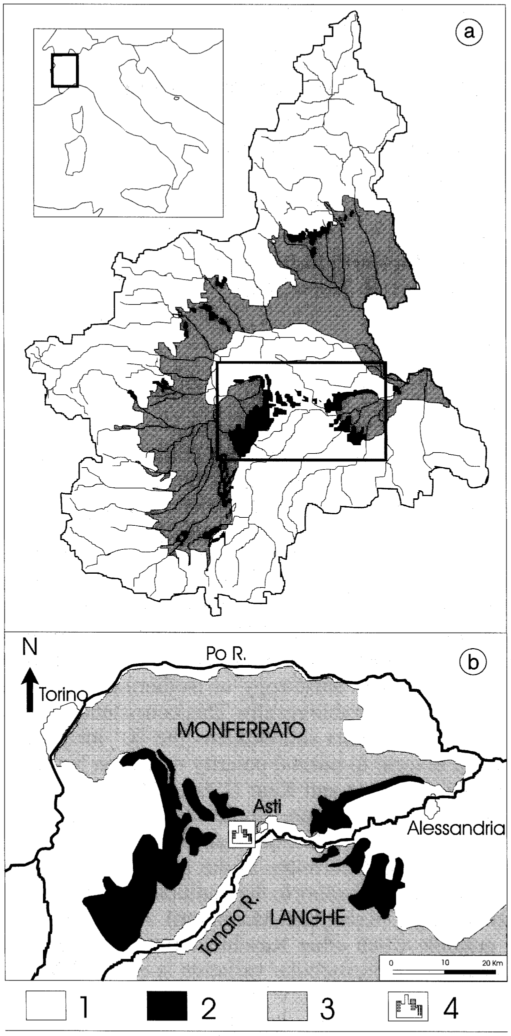

Fig. 1a,b. a) Areal distribution of the Villafranchian in Piedmont (from Carraro, 1996). Symbols: black/ grey = cropping out / buried deposits. b) Simplified geological sketch map of the type-area near Villafranca d'Asti. Symbols: 1 = Pleistocene to Holocene; 2 = Villafranchian; 3 = Palaeocene to Pliocene; 4 = Fornace RDB quarry.

A new geological mapping of the type-zone (Boano and Forno, 1996) has enabled a distinction to be drawn between two complexes separated by an erosion surface. The Lower Complex is a middle-upper Pliocene regressive sequence which rests in sedimentary continuity on the littoral marine Asti sands. It is composed of cross-stratified sandy and sandy-gravelly sediments typical of a delta front environment (Ferrere unit) followed by horizontally stratified clays and silts with subordinate cross-stratified sandy intercalations typical of a delta plain environment (San Martino unit). The top of this complex is shorn by an erosion surface bearing the discordant lower Pleistocene fluvial deposits of the Upper Complex. Most of the vertebrate remains from the type-area described in the literature come from the Lower Complex. The limited outcropping of the Upper Complex and the coarse to medium grain size of the sediments of the Ferrere unit mean that magnetostratigraphic studies can only be carried out in the San Martino unit. The type-section of this unit is the Fornace RDB quarry (lat. 44°55′N, long. 8°10′E) a few hundred metres west of Villafranca d'Asti. A preliminary magnetostratigraphic investigation (Lindsay *et al.*, 1980) showed that all but the fourth of the five levels sampled on a 13-m front of the quarry were of reverse polarity. These authors tentatively interpreted the normal polarity level as the short interval between the Mammoth and Kaena reverse polarity events and suggested that the section was correlated with the central part of the Gauss epoch.

Many European localities with mammal faunas consist of thin discontinuous outcrops. Their stratigraphic correlations are hard to establish and their magnetostratigraphic sections cannot be unequivocally referred to the reference timescales, but just provide a means to check conclusions drawn from the palaeontological evidence. Higher magnetostratigraphic resolution requires much more detailed sampling than usual. This paper describes the results of a detailed magnetostratigraphic investigation of the RDB quarry as part of a review on the Villafranchian type-area (Carraro, 1996).

2. Geological setting and sampling

The Fornace RDB quarry is situated in the central part of the Villafranchian type-area, which forms the hinge of a gentle synclinal fold whose axis plunges 5°-10° towards the east, and lies at the base of a hill composed of San Martino unit sediments topped by those of the Upper Complex. The dominant lithofacies consists of clay and clayey silt (Carraro, 1996) made up of horizontal parallel laminae. Their mean thickness of 1 mm and notable lateral continuity give evidence for deposition from still water, whereas high-energy flows laid down the subordinate, often cross-stratified, medium to fine sand intercalations. As already mentioned, these sediments are typical of a delta plain: clays and silts were deposited in flooded areas between one channel and the next, whereas sands are the expression of major overbank flooding episodes. The clay fraction consists of predominant illite with subordinate smectite and small quantities of chlorite (Carraro, 1996). Its vertical uniformity is indicative of a virtually constant depositional environment. The mineralogy of the sands, too, is very uniform and typical of a derivation from granitoid rocks: 30% quartz, 30% white mica, 5-10% potassic feldspar, carbonates, biotite and plagioclase, and subordinate opaque minerals. The abundant palaeontological material has been extensively described in the literature: Vertebrata (Azzaroli, 1977; De Bruijn *et al.*, 1992; Azzaroli *et al.*, 1998), Gasteropoda (Esu *et al.*, 1993), pollens (Bertoldi, 1990), Ostracoda, Foraminifera and plant macrofossils (see references in Carraro, 1996).

The quarry has penetrated some 40 m into the San Martino sediments over the course of the years. Our samples were taken from the quarry front about 18 m high that existed in 1994-1995. The rocks exploited are poorly consolidated and a 30-50 cm thick layer of loose material had to be removed to bring fresh rock to light and to cut even clean faces. Coring proved impossible and the specimens were collected with commercial plastic boxes (inner volume = 2 × 2 × 2 cm) gently pushed into the soft rock keeping the front face vertical, at 5 cm intervals through most of the section, with the exception of some completely loose sandy beds, and oriented with bubble level and compass. The sampled section was 16.1 m high and 207 specimens were taken. Twelve hand-samples were also collected from the most coherent beds, consolidated and cut to standard cylinders.

3. Magnetic measurements

Magnetic Susceptibility and its Anisotropy (AMS) were first measured on all specimens with a KLY-2 bridge. All measurements were corrected for the effect of the box, which proved to be isotropic. The bulk susceptibility varied in the range $30 < k < 200 \times 10^{-6}$ SI units, and was systematically higher in the lower part of the section (0-7.8 m) than in the upper (7.8-16.1 m): typical values were 90-100 and $60\text{-}70 \times 10^{-6}$ SI respectively. The magnetic fabric was well developed and the anisotropy degree $P = k_1/k_3$ ($k_1 > k_2 > k_3$) (Tarling and Hrouda, 1993) mostly ranged from 1.015 to 1.070. The magnetic foliation always prevailed over lineation and was close to the horizontal bedding plane. Fabric was not altered by the sampling procedure, since no systematic relation was found between the AMS directions and the box orientation (Copons *et al.*, 1997). The site mean foliation was truly horizontal (fig. 2) and the single specimen lineations were dispersed within the bedding plane with a prevalent E-W direction. The mean

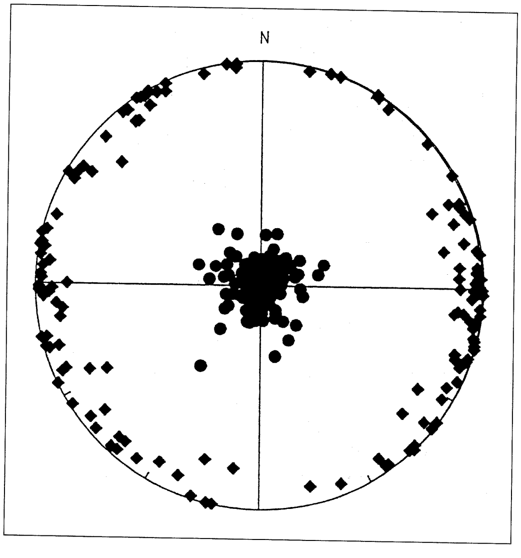

Fig. 2. Equal-area projection of the magnetic susceptibility principal directions. Symbols: squares = maximum axis, k_1; dots = minimum axis, k_3.

value of the shape parameter q, expressed as $(k_1 - k_2)/((k_1 + k_2)/2 - k_3)$ was very low ($q = 0.13$) and, according to resedimentation experiments (Rees and Woodall, 1975), typical of deposition from still water. These results are consistent with the deltaic alluvial plain environment characteristic of the RDB quarry sediments, which have thus retained their primary, depositional fabric.

Measurements of the Isothermal Remanent Magnetization (IRM) unambiguously showed that the higher susceptibility in the lower part of the section was due to the presence of different ferromagnetic minerals. A pulse magnet was used to give the rock an IRM up to a maximum field of 1.5 T. As preliminary measurements had shown that some boxes carried a Natural Remanent Magnetization (NRM) even after having been washed, a first run was done on an empty box to assess its effect on IRM acquisition. The box with the highest measured NRM intensity (5×10^{-4} A/m) was used and its IRM intensity proved two orders of magnitude lower than that of the rocks. The box effect was therefore negligible. Fifteen specimens were investigated and their properties varied as a function of their stratigraphic position. Those from the lower part of the section (0-6.0 m) either reached or acquired 95% of the saturation remanence at field values of 0.1 to 0.3 T (fig. 3a). In the second case, the IRM intensity slowly increased at higher fields and approached saturation at the maximum available field. The remanent coercive force varied from 70 to 110 mT. In the upper part of the section (7.8-16.1 m), the maximum field was not enough to saturate the specimens (fig. 3b) and the remanent coercive force was always higher than 200 mT. The middle part of the section (6.0-7.8 m) presented an intermediate picture. IRM was further investigated by thermal demagnetization according to the Lowrie method (1990). The high-coercivity component always decreased very slowly with increasing temperature, and was removed between 630 and 670 °C (fig. 4a,b). The trend of the intermediate- and low-coercivity components was similar to that of the high-coercivity component in the upper part, whereas in the lower part they decreased to 10-20% of the initial value within 400 °C and were then completely removed in the range 630-670 °C.

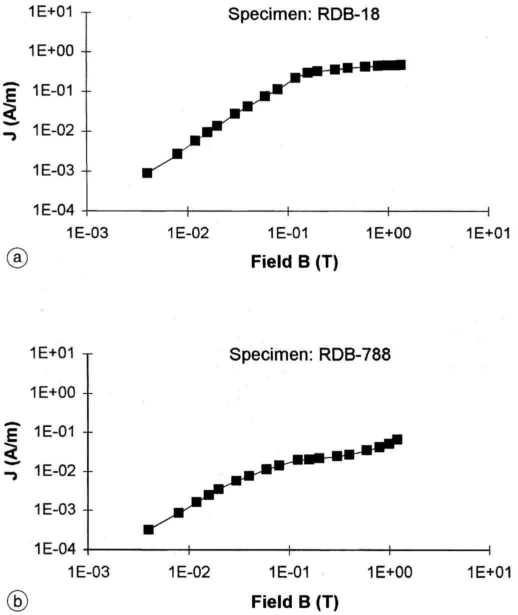

Fig. 3a,b. Isothermal Remanent Magnetization (IRM) acquisition curves for the lower (a) and upper (b) part of the RDB quarry section.

These results show that haematite with its high coercivity and Néel point of ≈ 670 °C is the main ferromagnetic mineral and occurs throughout the section. In the lower part, the low-coercivity magnetization and the less than 400 °C Curie temperature are consistent with the occurrence of an iron sulphide. This hypothesis is further substantiated by the susceptibility values, which are higher than in the upper part and increase after heating above ≈ 350 °C. In conclusion, the RDB quarry section may be divided into three zones: lower (LZ, 0-6.0 m), middle (MZ, 6.0-7.8 m) and upper (UZ, 7.8-16.1 m). The LZ zone is characterized by the occurrence of haematite + iron sulphide, the MZ by the gradual disappearance of the iron sulphide and the UZ by haematite alone.

The NRM was measured with a JR-5 spinner. Intensity was of the order of 10^{-3} to 10^{-4} A/m and directions fell under two groups: mainly southwards declination and negative inclination

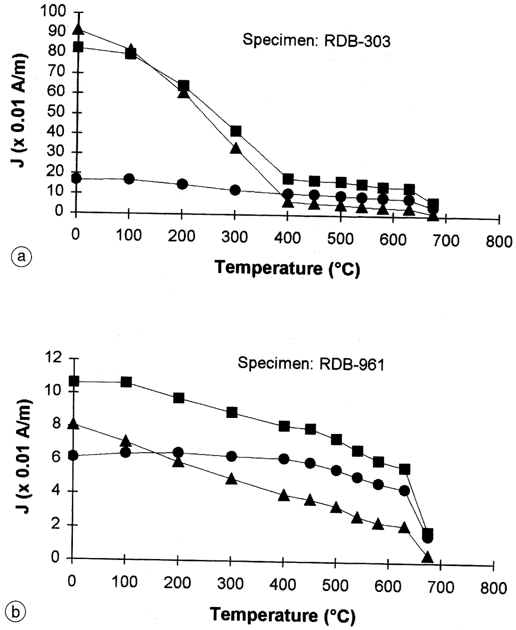

Fig. 4a,b. IRM thermal demagnetization curves for the lower (a) and upper (b) part of the RDB quarry section. Symbols: dots = high-; triangles = intermediate-; squares = low-coercivity component.

up to about 12.0 m, northwards declination and positive inclination above. Stepwise Alternating Field (AF) demagnetization on pilot specimens showed secondary components usually removed at peak-field within 10-20 mT, and then a stable component (fig. 5a). At 100 mT peak-field, most of the NRM was removed in the LZ and some 40% to 60% was left in the UZ specimens. Thermal demagnetization was done on the few cylinders from the most coherent sediments. Secondary components were removed within 200-250 °C. At higher temperatures, remanence direction was substantially stable up to values close to the Néel point of haematite (fig. 5b). Thermal demagnetization proved more effective than AF, as expected for haematite bearing sediments. However, it could not be applied as a routine procedure, because the rock cropping out at RDB quarry is poorly consolidated and specimens were collected with plastic boxes.

Comparison of AF and thermal curves (fig. 5a,b) shows that the results are alike as far as direction is concerned, even though AF demagnetization does not completely remove the NRM. The direction isolated at peak field higher than 20 mT may be confidently regarded as the Characteristic Magnetization (ChRM), since it remained stable in the pilot specimens demagnetized up to a peak field of 220 mT (fig. 5c). All specimens were thus demagnetized at 4 to 7 steps between 15 and 60-80 mT (fig. 5d). A stable ChRM direction was isolated from about 75% of the specimens and calculated by interpolation. Most of the remainder showed an unambiguous polarity, even if the direction was not well defined and only a few yielded erratic results.

4. Palaeomagnetic results

The lithostratigraphic section and the declination and inclination of the stable ChRM are reported in fig. 6. Examination of the inclination curve shows that with a very few exceptions it is substantially lower than 63°, the value expected from the Geocentric Axial Dipole (GAD) model for the RDB quarry latitude. Fisher's statistics was used to calculate the mean ChRM directions of the normal and reverse polarity specimens. They were D = 359.5°, I = + 43.4° and D = 167.7°, I = – 42.5° respectively, with α_{95} = 3.5° in both cases. The mean inclinations are 20° less than the GAD value. At first sight, it might seem that we could ignore this discrepancy, because we are mainly interested in the ChRM polarity. Polarity, however, is established according to the Virtual Geomagnetic Pole (VGP) latitude, and this in turn depends on the ChRM inclination.

Inclination values substantially lower than those expected from the GAD model have often been found in sedimentary rocks and artificially deposited sediments and interpreted as the result of the preferred orientation of elongated and tabular grains within the horizontal bedding plane. Preferred orientation of ferromagnetic grains results in a foliated magnetic fabric and flattening of the depositional remanence direction, also known as inclination error or shallow-

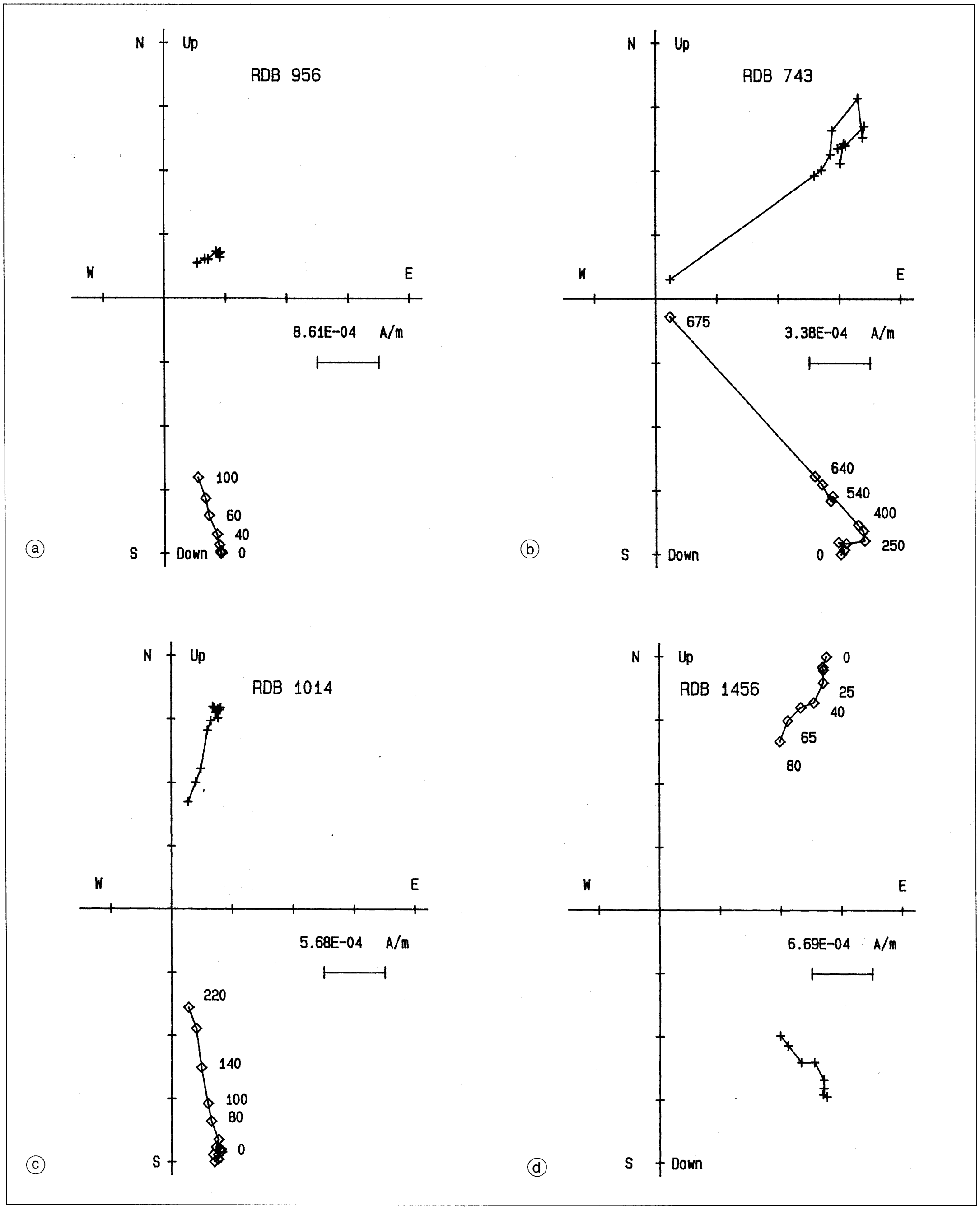

Fig. 5a-d. Zijderveld diagrams for alternating field (a, c, d) and thermal (b) demagnetization. Symbols: squares = declination; crosses = apparent inclination; figures = peak-field (mT) or temperature (°C) value.

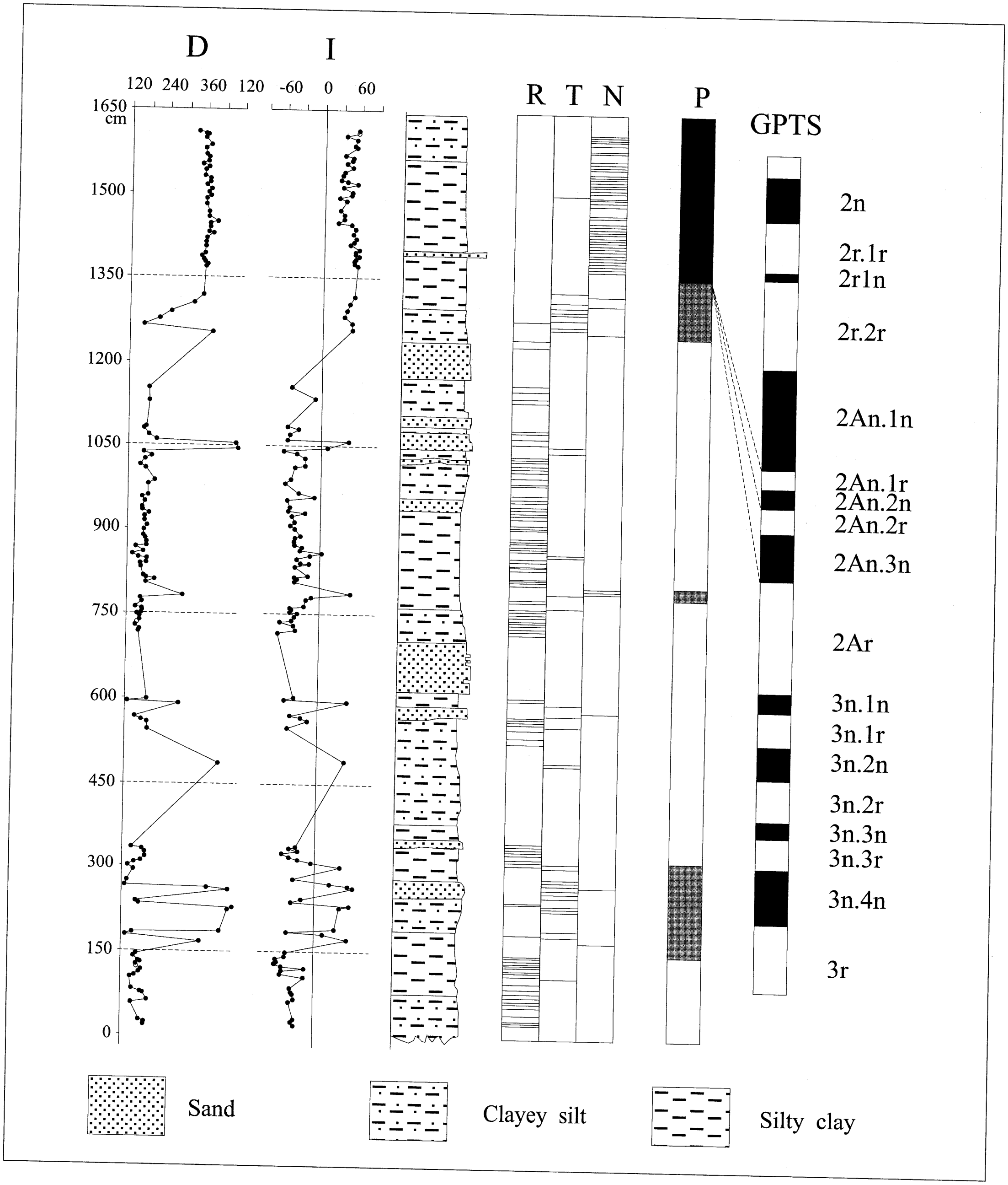

Fig. 6. Magnetic stratigraphy of the RDB quarry section. Symbols: D = Declination; I = Inclination; R, T, N = Reverse, Transitional, Normal polarity of single specimens (see text for further explanation); P = Polarity section: black = normal; white = reverse; grey = transitional or excursional; GPTS = Geomagnetic Polarity Time Scale of Cande and Kent (1992). The dashed lines show the possible correlations between the RDB polarity section and the GPTS scale.

ing. In our case, the rock's bulk susceptibility is very low ($k < 200 \times 10^{-6}$ SI) and the AMS measurements alone (fig. 2) are not enough to draw conclusions about remanence, because they are affected by the orientation of both ferro- and paramagnetic minerals. The difficulty was circumvented by measuring the anisotropy of the IRM, which is a remanence and only characterizes the ferromagnetic grains. The measurements were done on specimens from the UZ, where only haematite occurs. They were demagnetized at a 100 mT peak-field and then magnetized with a PUM-1 pulse magnet in a 20 mT direct field, according to the procedure suggested by Jelinek (1994). The results (fig. 7a,b) show that the remanence and susceptibility fabrics do coincide. Foliations are both horizontal and lineations are dispersed in the foliation plane, with some E-W clustering for the susceptibility fabric and NE-SW for the IRM. The easy magnetization axis of the haematite grains lies thus in the bedding plane and their ChRM direction deviates towards the horizontal.

At this point we can summarize our palaeomagnetic results:

1) The ChRM is a primary remanence carried by detrital haematite.

2) The ChRM flattening of 20° is the result of inclination shallowing; this value is similar to those found in other detrital haematite bearing sediments (Tauxe and Kent, 1984; Collombat *et al.*, 1993; Rösler *et al.*, 1997) and in good agreement with the results of redeposition experiments (Tauxe and Kent, 1984).

3) This shallowing lowers the VGP latitude ϕ. It does not bias the definition of normal and reverse polarity ($\phi > 45°$), whereas transitional polarities ($\phi < 45°$) must be dealt with cautiously, because the low VGP latitude might result from ChRM flattening. The single specimen VGPs were therefore computed from the ChRM direction; when they were transitional, they were recalculated after increasing their inclination by 20° and their polarity was defined according to the corrected value of the VGP latitude.

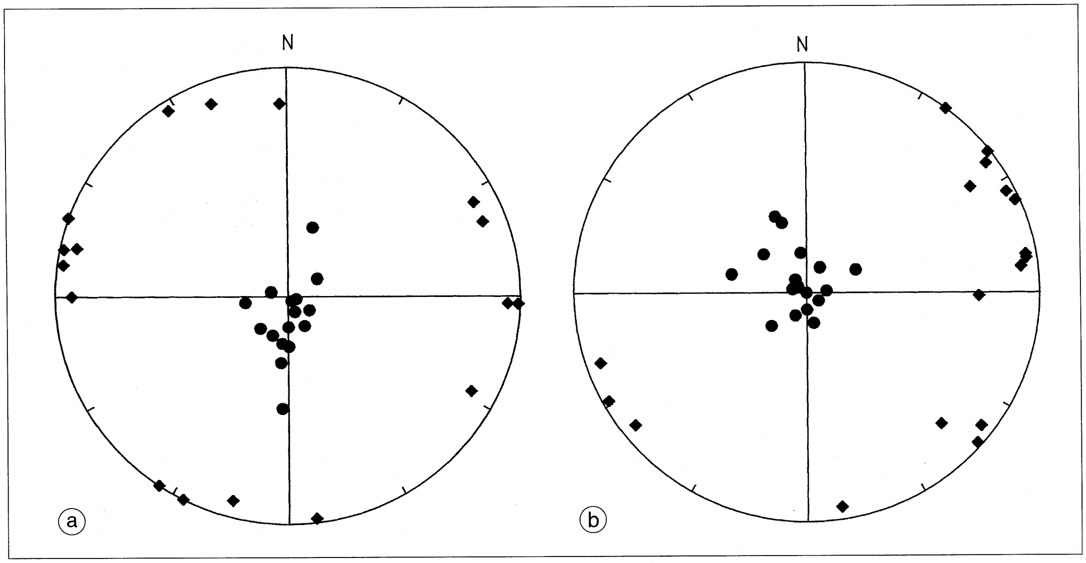

Fig. 7a,b. Equal-area projection of susceptibility (a) and isothermal remanent magnetization (b) principal directions of haematite-bearing sediments from RDB quarry. Symbols: squares = maximum axes, k_1 and I_1; dots = minimum axes, k_3 and I_3.

The magnetostratigraphic results are shown in fig. 6. The declination and inclination columns only report results from specimens (about 75%) which yielded a well-defined ChRM direction. The two curves, owing to the high sampling rate, represent the palaeosecular variation recorded by the RDB sediments. The corresponding polarity data are shown in the fourth column. They have been integrated with those from the specimens (about 20%) which provided an unambiguous ChRM polarity but a poorly defined direction. The interpretative polarity sequence is shown in the fifth column: polarity is mainly reverse from the base of the section up to 12.50 m, transitional from 12.50 to 13.50 m and normal from 13.50 m up to the top. The reverse zone is interrupted by two intervals (1.5 to 3.0 m and 7.70 to 8.00 m) with mixed polarities, which could correspond to geomagnetic excursions. The sixth column shows the GPTS reference scale of Cande and Kent (1992).

5. Discussion and conclusions

The reverse to normal polarity transition provided by the RDB quarry section cannot be directly correlated with the GPTS scale (Cande and Kent, 1992, 1995), as indeed is the case in most European localities with upper Pliocene to Pleistocene mammal faunas, where only one or two polarity zones occur (Lindsay *et al.*, 1997; Opdyke *et al.*, 1997 and references therein). Reference must thus be made to the palaeontological data. The Triversa fauna comprises fossils from the RDB quarry and nearby localities in the San Martino unit, and has been assigned (Azzaroli, 1977; Azzaroli *et al.*, 1988) to the lower part of the Villafranchian, which corresponds to the mammal age MN16a. On the grounds of multivariate analysis of upper Miocene to Pleistocene mammal faunas from numerous localities of Western Europe, however, Alberdi *et al.* (1997) regard this fauna as transitional between the Ruscinian MN15 and the Villafranchian MN16a. It is, in fact, included in the Ruscinian cluster (Montpellier, Perpignan, Triversa, La Calera, La Gloria and Layna), and also shares a certain number of species with faunas that belong to the Villafranchian cluster, particularly Villaroya and Les Etouaires. A magnetostratigraphic study of the Galera section in the Betic ranges of Southeastern Spain led Garcés *et al.* (1997) to set the Ruscinian/Villanyan (= Villafranchian) boundary in chron C2An.3n, corresponding to the lower part of the Gauss.

In the light of their comparison of the faunas and magnetostratigraphic data of Valensole, Triversa and Hajnaka, Lindsay *et al.* (1997) propose that the Triversa fauna corresponds to the MN15 age and correlates with the upper part of the Gilbert, chron C2Ar, on the basis of their own palaeomagnetic data from the RDB quarry (Lindsay *et al.*, 1980) and our preliminary data (Carraro, 1996). In their opinion, it is hardly likely that their (see Section 1) and our normal polarity zone represent the same chron or subchron. They therefore suggest that the two sections only partially overlap. This would mean that the RDB quarry covers the upper part of the Gilbert and the lower part of the Gauss, and that their normal magnetozone corresponds to chron C3n.1n (Cochiti), ours to C2An.3n. The two sampling areas may thus be supposed to have involved older and younger strata respectively. No direct comparison can be made between the two magnetostratigraphic sections because the quarry front has moved in the intervening fifteen years. However, since the stratification is horizontal, according to the new interpretation our section should be at least 3-4 m higher than that of Lindsay *et al.* (1980), *i.e.* greater than the difference between the thicknesses of the reverse polarity zones. This higher position is plausible according to the quarry's overseer. The base of its front, in fact, has been gradually raised, because the clay level worked from the end of the 1970s to the beginning of the 1980s ran laterally to sands of little commercial value (Faravelli, personal communication). The actual amount of this rise cannot be established, because there is unfortunately no graphic evidence of the position of the front before 1986. Lastly, the mixed polarity intervals within the reverse magnetozone (fig. 6) cannot help in correlation, since they could have been missed by Lindsay *et al.* (1980), whose sampling was much more spaced than ours.

Gliozzi *et al.* (1997), on the other hand, in their review of mammals, molluscs and ostracods remains from selected Italian localities maintain the traditional age assignment of the Triversa fauna and correlate it to subchrons Kaena and Mammoth (C2An.1r and C2An.2r) within the Gauss epoch.

We may conclude by observing that identification of the main reverse to normal polarity inversion of the RDB quarry section with either the transition from C2Ar to C2An.3n or the upper transition of one of the two subchrons C2An.2r and C2An.1r results in an age difference of ± 0.25 Ma (Cande and Kent, 1995) for the Triversa fauna. The order of magnitude of this uncertainty is comparable to the length of the polarity subchrons during the Pliocene. It is thus very difficult for magnetic stratigraphy based solely on polarity inversions to improve the precision of the present chronology. Progress could probably be made by investigating the palaeosecular variation, *i.e.* a signal with a much higher frequency and hence greater resolution. Its characteristics vary from one region of the Earth to another, yet remain substantially similar on the subcontinental scale, such as that of western European regions. Correlations of this kind, however, would require a much closer sample spacing than usual, which has so far only been adopted in investigation of the RDB quarry section.

Acknowledgements

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