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A revision of the stratigraphy for the Middle Pleistocene continental deposits of Rome (Central Italy): palaeomagnetic data

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Abstract
An improved knowledge of the stratigraphy of the Rome area has been achieved from the interpretation and correlation of a large number of stratigraphic logs from drillings, stored in a data bank by the Istituto Nazionale di Geofisica which allowed the authors to identify a succession of «unconformity-bounded stratigraphic units». The possibility of correlating these stratigraphic units with the oxygen isotope time scale is suggested leading to a substantial revision of the Quaternary stratigraphy of the Rome area. This paper presents the results of a magnetostratigraphic study on a *repere* layer in Rome, demonstrating that this layer cannot be correlated with the basal members of the formation outcropping in the type-site (*Helicella clays*, «Ponte Galeria Formation»), as recently proposed as a result of morpho-stratigraphical studies with important implications concerning the interpretation of the recent sedimentary and tectonic evolution of this area.

Key words *magnetostratigraphy – Middle Pleistocene – neotectonics – sea level changes – stratigraphy*

1. Introduction

The main difficulty hindering the study of the Pleistocene sedimentary sequences in the area of Rome is the paucity of significant outcrops, due to the extensive pyroclastic and extensive antropic cover, together with the lack of stratigraphic markers. The stratigraphy of the Early and Middle Pleistocene in the Roman area was recently reviewed after an extensive field survey and the analysis of stratigraphic logs from a large number of boreholes (Marra, 1993; Marra *et al.*, 1995).

In this paper we direct our attention to the Middle Pleistocene sedimentary deposits in the Ponte Galeria area and in the urban area of Rome (fig. 1a,b). The homogeneity of either the lithology and/or the palaeo-environmental facies, induced previous authors (Ambrosetti and Bonadonna, 1967; Conato *et al.*, 1980) to consider the Middle Pleistocene deposits in the whole area between Rome and the Tyrrhenian margin as a single depositional sequence, following the Cassia erosional phase *Auct.* (~1.0 Ma, Ambrosetti *et al.*, 1972), without significant gaps in sedimentation up to the emplacement of the first pyroclastic products related to the Latium volcanoes (0.6 Ma, Barberi *et al.*, 1994). The different altitudes of the basal surfaces of the two areas considered isochronous, were attributed to the subsequent tectonic activity. Recently, Marra *et al.* (1995) suggested that the subsequent outcropping in the south-western area («Ponte Galeria Formation» *Auct.*) was not continuous and that the development of the sedimentary palaeo-environments between Ponte Galeria (PG) and Rome was diachronous. The distribution of these palaeo-environments was mainly controlled by the different tectonic evolution of the studied areas. The reconstruction of the subsurface structural and geological features allowed the authors to identify several «unconformity-bounded stratigraphic units» which could represent different depositional sequences related to the sea level changes and tectonics. A partition of the PG succession into two depositional sequences of the fourth order and a tentative correlation with the oxygen isotope time scale (after Shackleton *et al.*, 1990) was suggested by Marra *et al.* (1995). This proposal was based on a previous palaeomagnetic study that located the Matuyama-Brunhes boundary (1n-1r.1r chrons, according to the Cande and Kent, 1992 nomenclature) between two members of this formation (fig. 2). In fact, after a thermal demagnetisation treatment on representative specimens, the *Helicella clays* (HC) revealed a reverse polarity of the characteristic remanent magnetisation (ChRM) ascribed to the 1r.1r chron, whilst the upper *Venerupis senescens clays* (VSC) was shown to have a normal polarity ascribed to the 1n chron (E. Tric, personal communication, unpublished data; Kotsakis *et al.*, 1992).

A hiatus of sedimentation between the top of the pre-volcanic succession and the emplacement of the first pyroclastic deposits («pisolitic tuffs» *Auct.*, 1st Pyroclastic Flow Unit p.p. from the Colli Albani Volcanic District, De Rita *et al.*, 1988), corresponding to the continental deposition in the urban area of Rome, was also proposed. The suggested older age of the first Ponte Galeria depositional sequence (PG1), including the *Helicella clays*, with respect to the homologous Middle Pleistocene continental sequence in the urban area of Rome is tested in this paper by means of palaeomagnetic analysis.

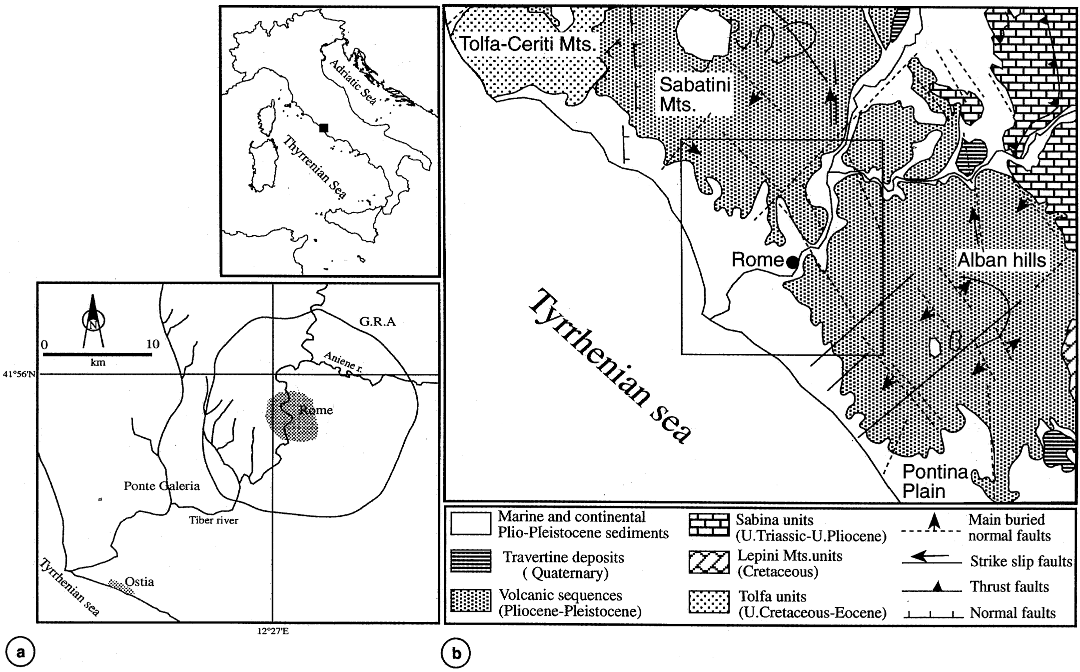

Fig. 1a,b. Geographical (a) and geological (b) sketch map of the sampling site.

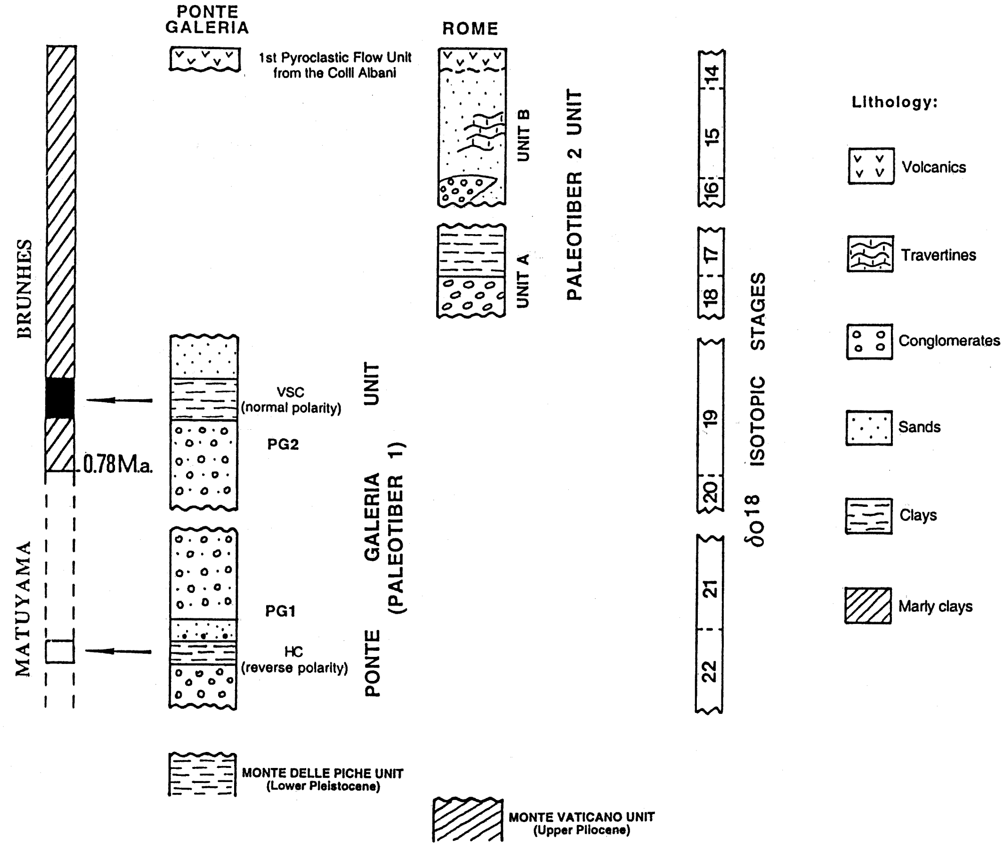

Fig. 2. Correlation of the Ponte Galeria and Rome depositional sequences with the Oxygen isotope time scale (Shackleton *et al.*, 1990), inferred from the presence of the Matuyama-Brunhes boundary (0.78 Ma, Spell and McDougall, 1992) within the PG sedimentary sequence.

2. Geological setting

The studied area represents the landward extent of the Tyrrhenian extensional margin of Italy, in which post-orogen rifting processes have taken place since the Late Tortonian, having developed at the back of a synchronous eastward migrating Apennines chain-foredeep system (*e.g.* Elter *et al.*, 1975; Patacca *et al.*, 1990). The extensional processes generated «graben» and «half graben» depressions filled by thick continental-brackish and marine Messinian-Pleistocene depositional sequences, controlled by tectonic movements and sea level changes.

Figure 3 shows the isobaths of the top of the Plio-Pleistocene marine units, which constitute the base of Middle Pleistocene continental deposits in the Rome area. A well defined drainage network with a main NW-SE, structurally controlled valley is clearly recognisable in the north-eastern sector. In the south-western area, a younger substratum looks faintly eroded and shows a flat sector corresponding to the Ponte Galeria area. The distribution of the basal conglomerates of the Ponte Galeria

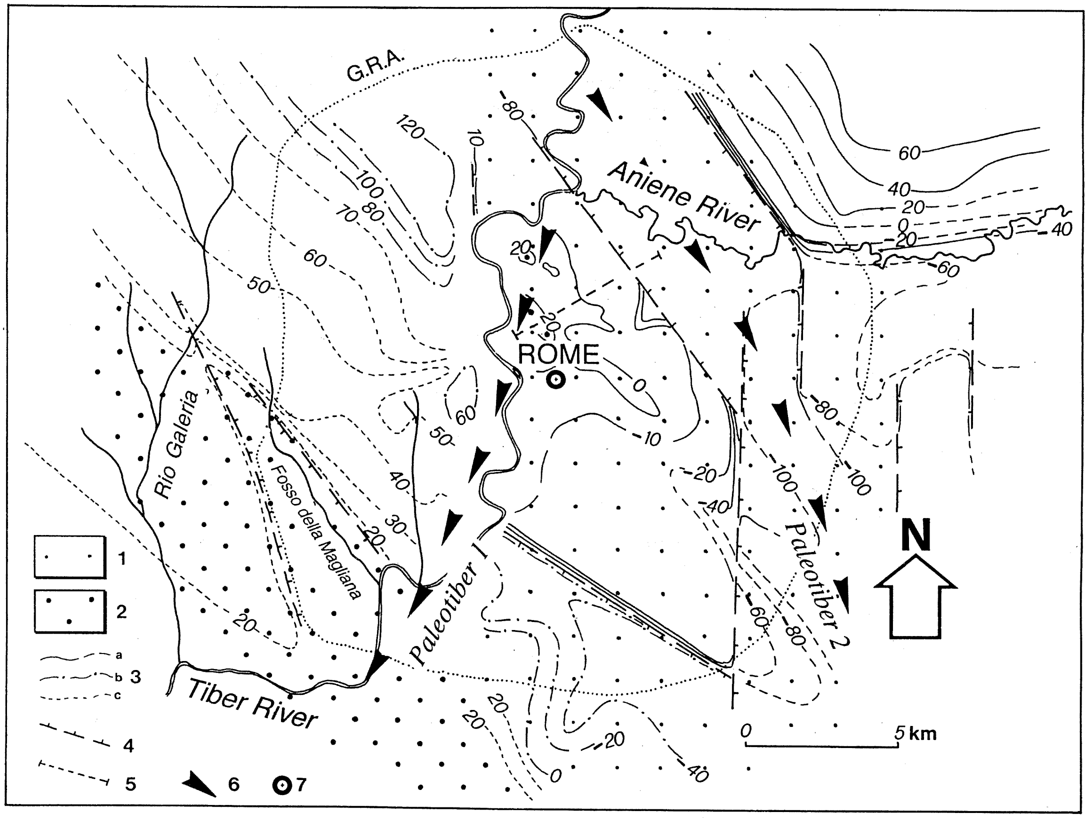

Fig. 3. Isobath map in meters of the top of the Plio-Pleistocene marine substratum (the recent Tiber Valley incision has been omitted). Legend: 1) distribution area of the basal conglomerates of the Palaeotiber 2 a Unit; 2) distribution area of the basal conglomerates of PG1 sequence; 3) isobaths relative to actual sea level of Monte Vaticano Unit (a: Upper Pliocene), Monte Mario Unit (b: Santernian, Lower Pleistocene), Monte delle Piche Unit (c: Emilian, Lower Pleistocene); 4) inferred faults; 5) track of the profile of fig. 4; 6) flow direction of ancient Palaeotiber courses; 7) Colosseum site. After Marra *et al.* (1995).

and the Rome urban area depositional sequences is also shown. The first depositional sequence of Ponte Galeria (PG1) does not extend to the north-east of the Fosso della Magliana line which marks a raising of the Lower Pleistocene marine substratum, whilst the second depositional sequence (PG2) overlaps this substratum (Marra, 1993).

Figure 4 shows a SW-NE cross-section of the urban area of Rome. Two pre-volcanic depositional sequences, resting directly on the eroded Pliocene bedrock, were identified and attributed to a later sedimentary cycle (Palaeotiber 2, Marra *et al.*, 1995) with respect to the deposits outcropping in Ponte Galeria (related to the Palaeotiber 1, see also fig. 3). The basal conglomerate in the Rome area steps down towards the north-east and is displaced by a sin-sedimentary fault-system, that allowed the accumulation of the great thickness of pebbly and clayey deposits in the north-eastern sector. The fault activity is related to a tectonic phase which should be considered the main cause for the diversion of the Palaeotiber course and the displacement of its delta from the Ponte Galeria area (Marra *et al.*, 1995).

3. Palaeomagnetic analyses

3.1. *Sampling, measurements and palaeomagnetic data*

A magnetostratigraphic analysis on the fluvial-lacustrine clay layer of the supposed Palaeotiber 2 cycle was performed to verify a possible correlation between those clays and the *Helicella clays* deposited during the Matuyama chron. This layer is located between the Pliocene substratum and the first Pyroclastic Flow Unit from the Colli Albani Volcanic District (fig. 5). An 8 cm diameter core, was taken from the vicinity of the Colosseum by standard rotary drilling techniques and the sections lack of azimuthal orientation. A portion of a continuous fluvial-lacustrine depositional sequence was sub-sampled. It consists of grey clays from 21.1 m to 26.5 m below the ground surface (b.g.s.), sandy-clays from 26.5 m to 27.5 m and then conglomerate from 27.5 m to 30.0 m (fig. 6). The sampling was carried out following routine palaeomagnetic procedures, using a gasoline powered portable corer with a water-cooled diamond bit. Twenty vertically oriented palaeomagnetic cores 25 mm in diameter were taken with an average spacing of approximately 28 cm, from 21.1 to 26.6 m b.g.s. The sediment from 26.6 to the top of the conglomerate, was very friable and showed pervasive diagenesis and evidence of hydrothermal alteration (fig. 6) so it was not sampled. The samples were then cut into standard specimens 22 mm high and stored inside the magnetically shielded room of the palaeomagnetic laboratory of the Istituto Nazionale di Geofisica before the measurements. At first, both the low field bulk susceptibility (k) and its anisotropy (AMS) were measured on a KLY-2 kappabridge, and the natural remanent magnetisation (NRM) was measured on a JR-4 spinner magnetometer, both instruments constructed by Geofizika Brno. The variation of these parameters as a function of the stratigraphic level was monitored (fig. 7). The anisotropy of magnetic

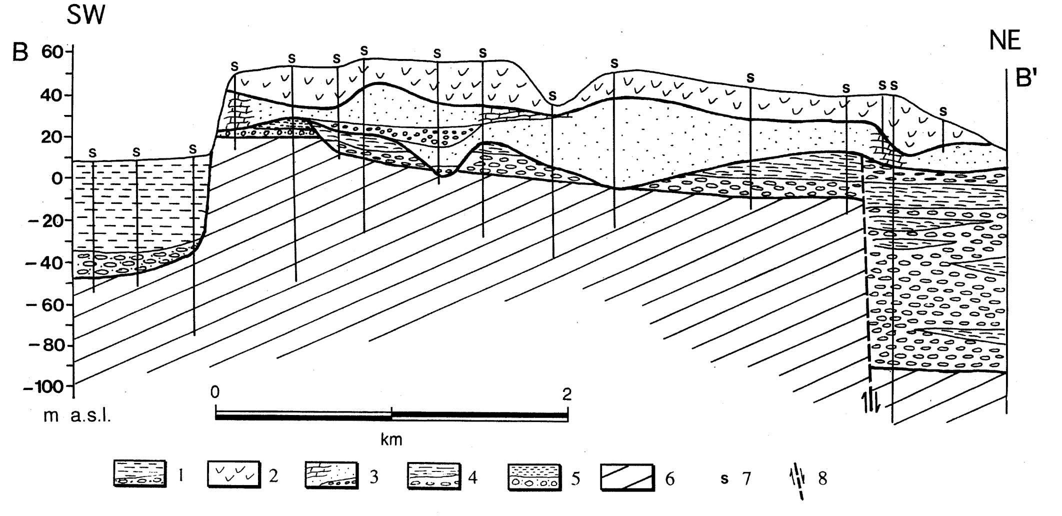

Fig. 4. SW-NE cross-section of the urban area of Rome (see fig. 3 for location). Legend: 1) Tiber Valley's recent alluvium (Holocene-present); 2) Volcanics; 3) Palaeotiber 2 b Unit; 4) Palaeotiber 2 a Unit; 5) Ponte Galeria first depositional sequence (PG1); 6) Monte Vaticano Unit (Pliocene substratum); 7) boreholes; 8) inferred faults. After Marra *et al.* (1995).

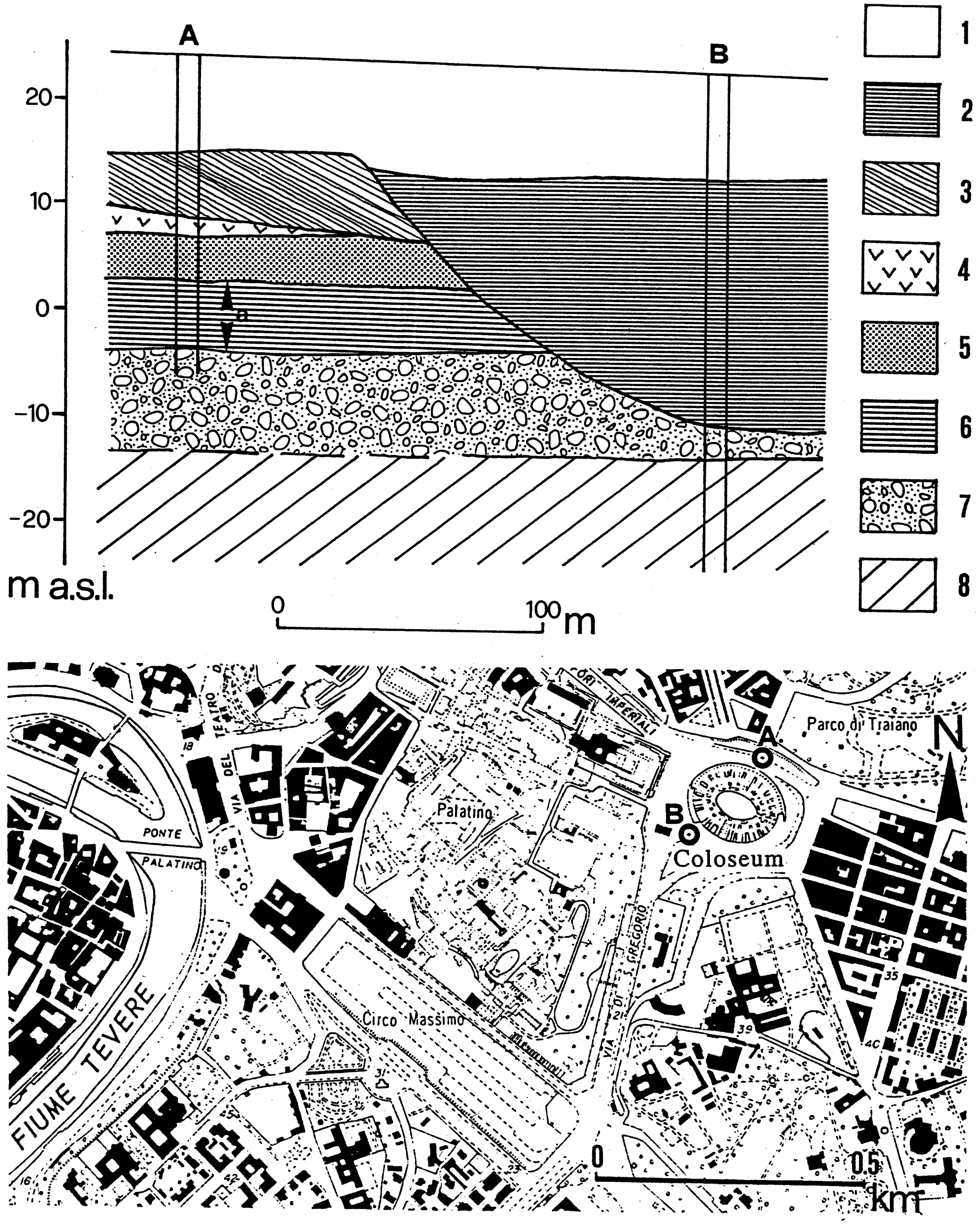

Fig. 5. Location and stratigraphy of the drillings analysed for this study. A) Core sampled for magnetostratigraphy; B) core observed for stratigraphy; a) investigated clayey layer; 1) antropic cover; 2) Holocene alluvium; 3) Middle-Upper Pleistocene lacustrine deposits; 4) 1st Pyroclastic Flow Unit from the Colli Albani; 5) Palaeotiber 2b Unit; 6) fluvial-lacustrine clayey layer of the Palaeotiber 2a Unit; 7) basal river conglomerates of the Palaeotiber 2a Unit; 8) Pliocene substratum.

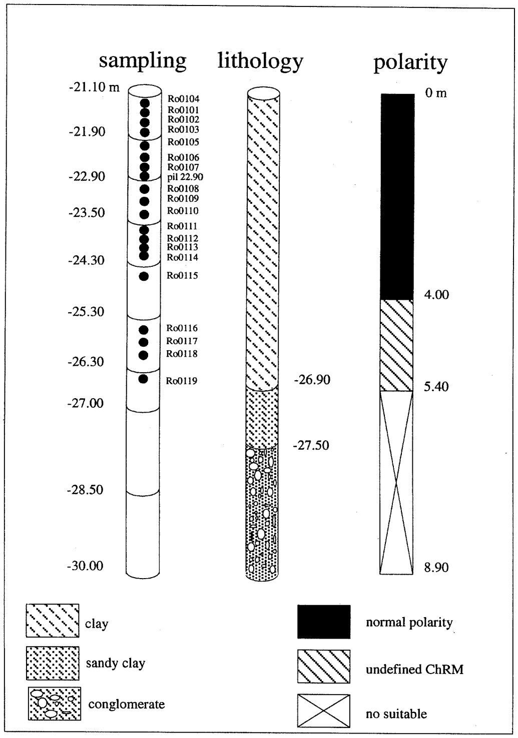

Fig. 6. Profile of sampling distribution (the samples code are also shown), lithology and magnetic polarity of the studied core.

susceptibility (AMS) was also determined for nine specimens. The degree of anisotropy was measured by means of the p and p′ parameters (degree of anisotropy and corrected degree of anisotropy, respectively) (Hrouda, 1982). In the studied specimens, the values of these parameters ranged from 1036 (0.006 st. dev.) to 1040 (0.008 st. dev.). Furthermore, the analysed lithology is characterised by a triaxial susceptibility ellipsoid with the k_{min} directions clustered parallel to the vertical. These AMS features suggested a primary sedimentary magnetic fabric (fig. 8, table I). Representative pilot specimens were progressively thermally demagnetised in a nearly-zero-field oven built in our laboratory. Temperature steps of 50 °C were applied, but these were reduced within about 100 °C of the Curie temperatures of the main known magnetic phases to identify the higher blocking temperatures more precisely. The bulk susceptibility was also measured at each heating step, to monitor possible new thermally induced mineralogical phases; other pilot samples were stepwise AF demagnetised with a Molspin tumbler demagnetizer applying a log-normal distribution in peak field demagnetisation steps. The directions of the characteristic magnetisation component cannot be reliably determined, because for the lower interval of the core, from 25.3 to 26.5, the secondary NRM is carried by higher coercive grains and AF demagnetisation is ineffective in separating this from the highest-stability component (ChRM). These pilot samples are likely to be of normal polarity.

Progressively thermal demagnetisation was applied to pilot samples with a minimum of 9 steps from room temperature up to the limit of reproducible results which were plotted on both Zijderveld diagrams and stereographic projections. Best fit lines and planes to progressive demagnetisation data were evaluated by the Principal Component Analysis (PCA) (Kirschvink, 1980). The maximum angular deviation (MAD) was calculated to provide an estimate of the precision related to each best-fit line and plane and data with MAD greater than 10° were considered poorly defined. Orthogonal projections of thermal demagnetisation data from 21.1 to 25.0 m indicate that the magnetisation is dominated by a single, normal component that can be resolved at demagnetisation temperatures above 400 °C (fig. 9).

3.2. *Rock-magnetic data*

Magnetic mineralogy was also investigated on representative specimens. We analysed:

– isothermal remanent magnetisation (IRM) acquisition curves up to 1.6 Tesla (T);

– remanence coercive force (H_{cr}), determined by back-field application to the saturation IRM;

– thermal demagnetisation on three components IRMs produced by magnetising speci-

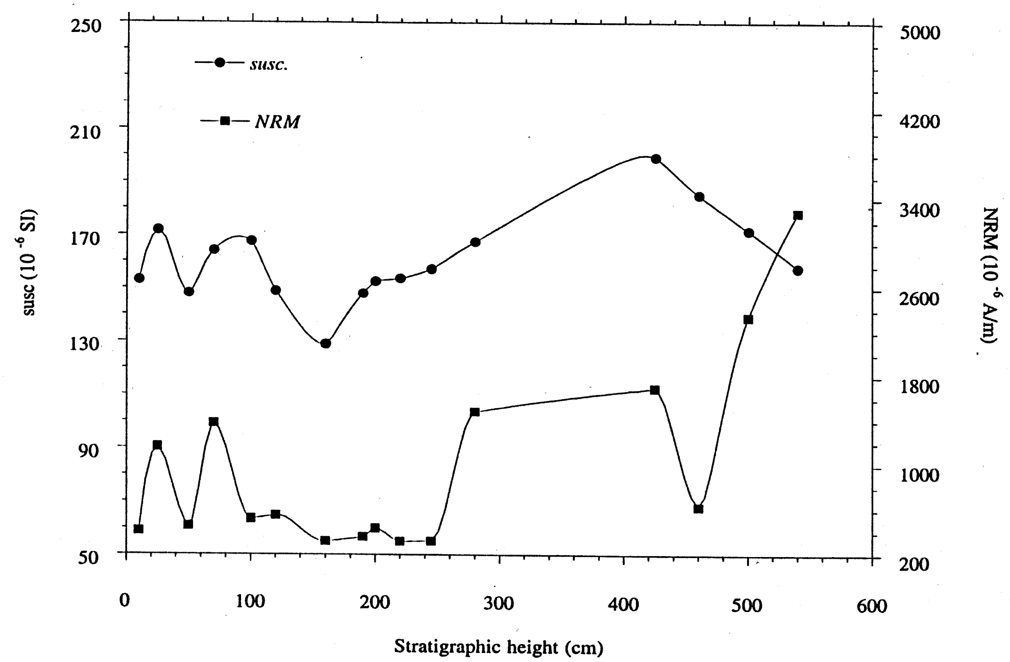

Fig. 7. Stratigraphic plot of the Natural Remanent Magnetization (NRM) and low field bulk susceptibility.

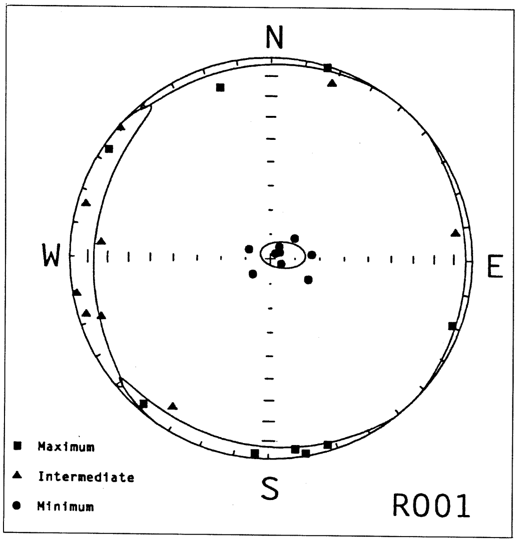

Fig. 8. Equal area projection of principal susceptibility axes. All symbols are for lower hemisphere: ■ = k_{max}; ▲ = k_{int}; ● = k_{min}. 95% confidence ellipses around mean principal axes are also shown.

mens in orthogonal fields of decreasing intensities (Lowrie, 1990).

In this study, these field intensities were 1.6 T (hard component), followed by 0.6 T (medium component) and finally 0.125 T (soft component). As for the NRM stepwise thermal treatment, susceptibility in low field was also measured at each thermal step, to detect any possible mineralogical change. The IRM acquisition curves show, in the upper interval, between 21.1 and 25.0 m, that 96% (1.34×10^{-1} A/m) of the SIRM was reached at a field (H) of 0.3 T. For $0.3\ T < H < 1.6\ T$ the curves increase slowly, within the experimental error (fig. 10a). The remanence coercive force value is about 55.5 mT (fig. 10b). The thermal demagnetisation of three orthogonal IRMs confirms that most of the remanence is held by the soft coercive fraction. The intensity decays in a quasi-linear fashion from room temperature to 580 °C, with a weak change in the slope of the curve at 250 °C (fig. 10c). During the thermal

Table I. Listing of anisotropy factors.

Specimens number	k_m (10^{-6} SI)	L	F	P	P'	T
RO0101	171.7	1.008	1.020	1.029	1.029	0.431
RO0103B	164.1	1.005	1.039	1.044	1.049	0.782
RO0105	167.6	1.003	1.028	1.031	1.034	0.799
RO0109	152.7	1.003	1.029	1.031	1.035	0.836
RO0110B	153.8	1.004	1.033	1.037	1.040	0.765
RO0111B	157.4	1.005	1.027	1.032	1.034	0.710
RO0113	167.6	1.007	1.028	1.035	1.037	0.599
RO0116	199.6	1.007	1.037	1.044	1.047	0.663
RO0117	185.3	1.002	1.043	1.045	1.051	0.910

	k_m (10^{-6} SI)	L	F	P	P'	T
Average	168.9	1.005	1.031	1.036	1.040	0.722
St. dev.	15.3	0.002	0.007	0.006	0.008	0.143

$k_m = k_1 + k_2 + k_3$; $L = k_1/k_2$; $F = k_2/k_3$; $P = k_1/k_3$; $P' = \exp\{2[(\eta_1 - \eta)^2 + (\eta_2 - \eta)^2 + (\eta_3 - \eta)^2]\}^{0.5}$;
$T = 2(\eta_2 - \eta_3)/(\eta_1 - \eta_3)^2 \cdot \eta_1 = \ln k_1$, $\eta_2 = \ln k_2$, $\eta_3 = \ln k_3$.

treatment the bulk susceptibility k increases at 350-400 °C probably due either to the thermal alteration of clay minerals or sulphides. Therefore, there is an apparent absence of high-coercivity minerals. Magnetite or moderate Ti titanomagnetite seems to be the main magnetic carrier. The IRM acquisition curves indicate, in the lower interval between 25.0 and 26.5 m, that 96% (1.663 A/m and 0.708 A/m for specimens Ro0116 and Ro0117 respectively) of the SIRM was reached at a field (H) of 0.3 T. Also in this interval, for 0.3 T < H < 1.6 T the curves increase slowly within the experimental error (fig. 10d). The remanence coercive force value is about 82.5 mT (fig. 10e). The thermal demagnetisation of three orthogonal IRMs confirms that most of the IRM resides in the 0.125-0.6 T coercivity fractions and their contribution is removed at 250-300 °C with a weak residual remanence completely removed at 580 °C (fig. 10f). As for the upper interval, the increase in susceptibility above 400 °C, suggests growth of new mineralogical phases. For two samples from this interval (Ro0116 and Ro0117), the ratio of saturation IRM to susceptibility (SIRM/k) and the ratio (s-ratio) of a backfield IRM measurement at 100 mT to the saturation IRM (SIRM) in a forward field of 1 T (Stober and Thompson, 1979), were also investigated. We obtained 4.0 and 8.7 kA/m respectively for the SIRM/k ratio and −0.37 and −0.43 for the s-ratio. The magnetic parameters obtained for this narrow interval (25.0-26.5 m) indicate the prevalence of Fe-sulphides as the main magnetic carriers, together with minor traces of magnetite or moderate Ti titano-magnetite.

The macroscopic evidence of pervasive alteration observed in the lower part of the core is probably related to the hydrothermal acid gas emissions originating from the volcanic activity of the Colli Albani and could be responsible for the Fe-sulphides late origin. Evidence of this hydrothermal activity has previously been observed in the Colosseum area, where several secondary calcite rich fractures and travertine deposits affect the oldest volcanics (first Pyroclastic Flow Unit from the Colli Albani).

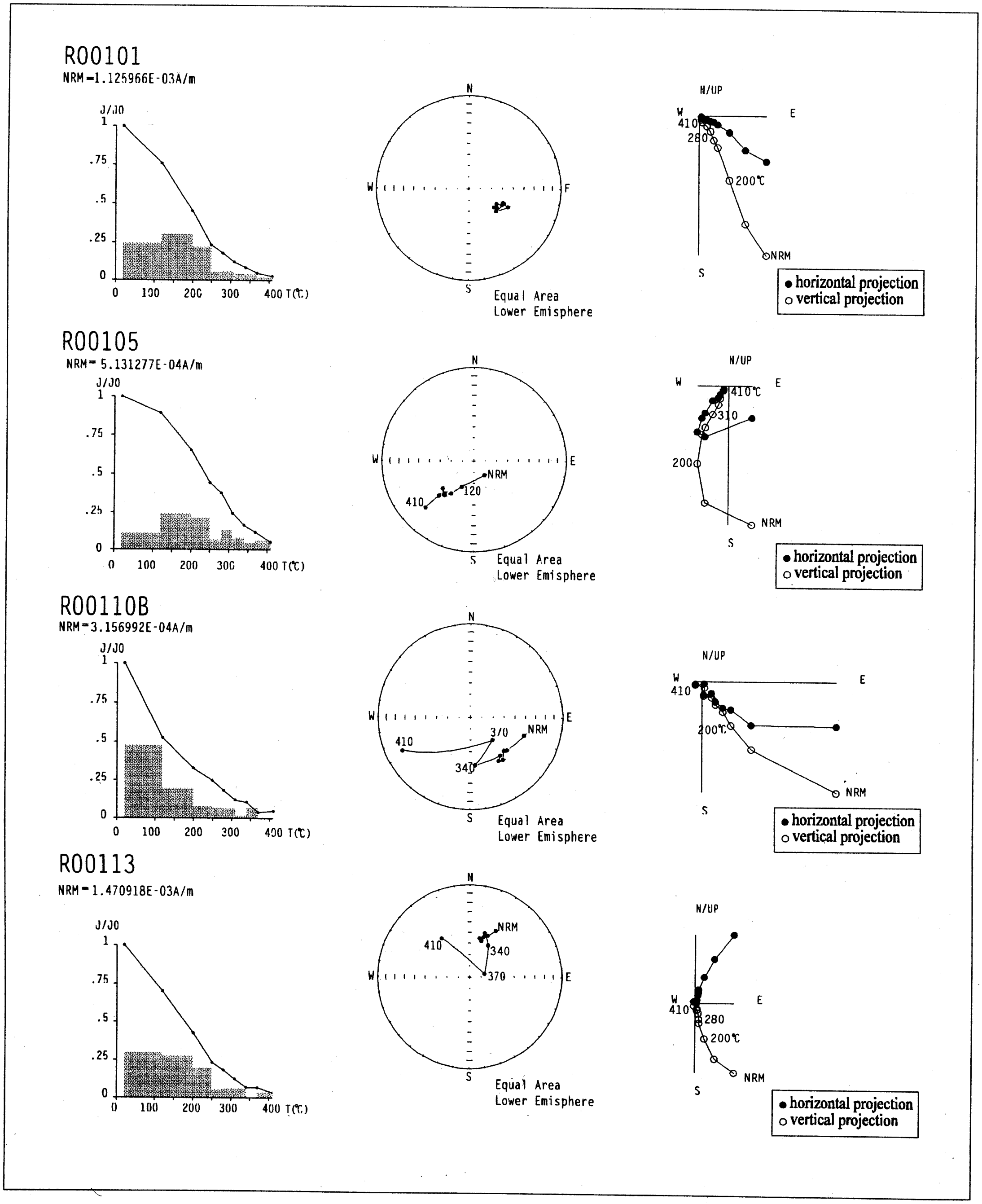

Fig. 9. Demagnetisation data for four representative specimens. Normalized intensity-demagnetisation field plot, vector component diagram and equal area projection.

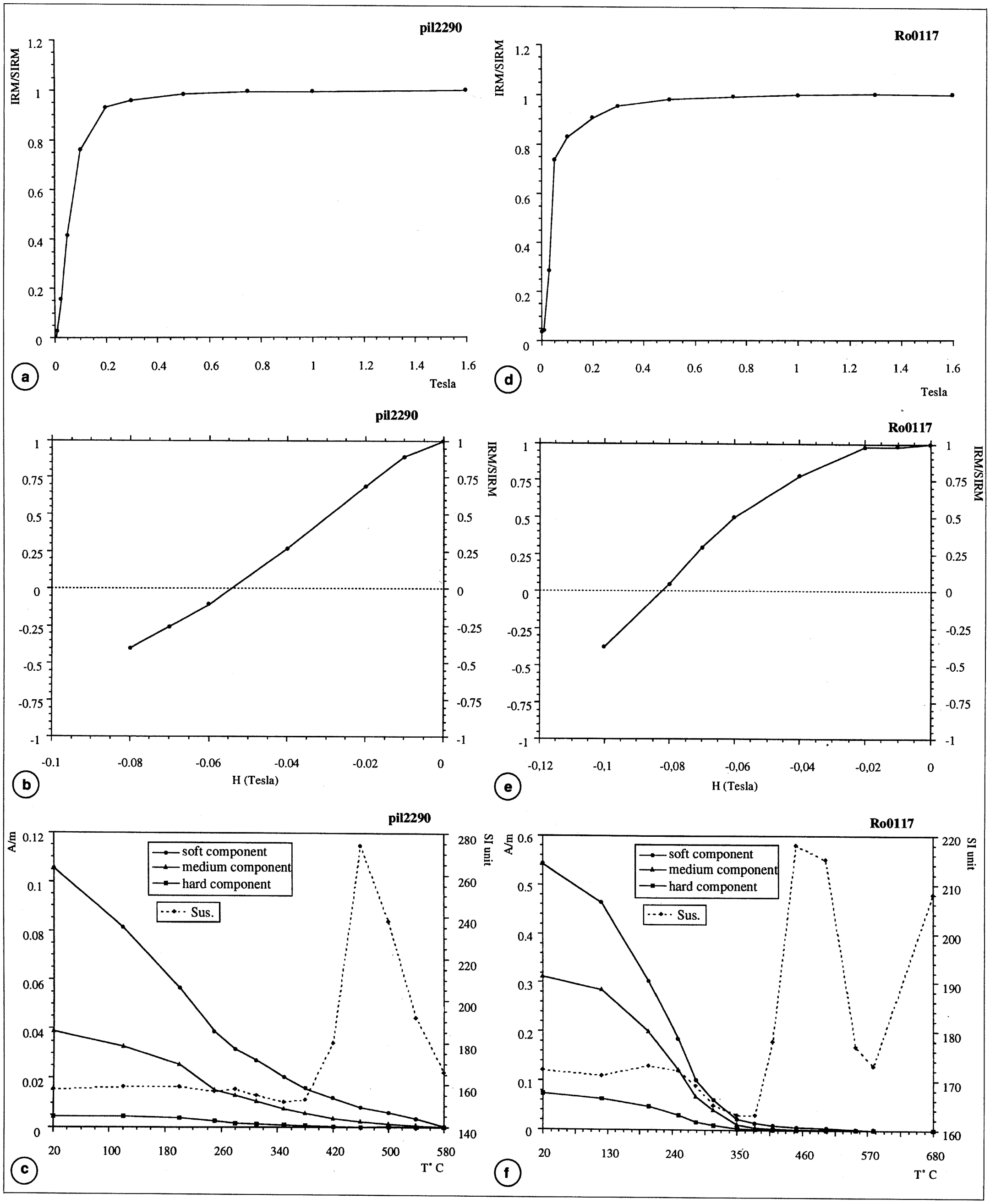

Fig. 10a-f. Acquisition of Isothermal Remanent Magnetization (IRM), back-field curves and stepwise thermal demagnetisation of IRMs artificially imparted along the three sample axes (in field of 1.6, 0.4 and 0.125 T respectively) for two representative specimens for the upper and the lower interval.

4. Conclusions

Palaeomagnetic investigations have been performed on the fluvial-lacustrine layer of the first Middle Pleistocene depositional sequence in the urban area of Rome, proving that it was deposited after the Matuyama-Brunhes Reversal. Its age is therefore younger than the *Helicella clays*, which belong to the Matuyama chron.

The portions of the core from 21.1 m to 25.3 m below the ground surface, clearly belong to a normal polarity interval, attributed to the Brunhes chron (1n). These results demonstrate that the fluvial-lacustrine clays of the urban area of Rome (Palaeotiber 2 units) cannot be correlated with the basal members of the Ponte Galeria Formation (including the *Helicella clays*), confirming previous suggestions based on morphostratigraphic considerations (Marra *et al.*, 1995), that these deposits are diachronous and related to two distinct sedimentary cycles associated to the Middle Pleistocene tectonic diversion of the Palaeotiber course. This conclusion also gives a better constraint to the Middle Pleistocene tectonic activity in the Roman area.

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