ANNALI DI GEOFISICA, VOL. XXXVIII, N. 3-4, September-October 1995

Paleomagnetism of the Plio-Pleistocene continental sediments from the north-eastern edge of the Fucino basin (Central Italy)

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Abstract

The paleomagnetism of the Plio-Pleistocene continental sediments cropping out at the north-eastern edge of the Fucino extensional basin (Italy, Central Apennines) was investigated. The area is characterized by strong neo-tectonic activity and the original purpose was to investigate possible vertical axis rotations in Plio-Pleistocene sediments, in order to improve the understanding of the recent geodynamic processes. Scarcity of suitable outcrops limited sampling at 8 sites (83 specimens) from the north-eastern edge of the basin, in clay-rich intervals belonging to two different sedimentary cycles. The paleomagnetic results pointed out a peculiar magnetic behaviour common to the whole set of studied samples. The Natural Remanent Magnetization (NRM) is dominated by a viscous normal component acquired under the influence of the present geomagnetic field, stable only below 200°C. Another (reverse) very weak component, stable at higher temperatures (up to 400°C), is present in most of the samples. This component can be precisely isolated for only 7 specimens from 3 different sites and therefore the information gained is not statistically sufficient for any tectonic reconstruction. Rock magnetism analyses showed a variable magnetic mineralogy, but the NRM carriers are not well represented in the artificial remanences produced in the laboratory. Results suggest that the natural viscous remanence is most likely carried by coarse multi-domain magnetite.

Key words *paleomagnetism – Central Apennines – magnetic mineralogy*

1. Introduction

The paleomagnetic investigation of Plio-Pleistocene sequences within the Apennine chain, constitutes an important tool to recognize possible differences in the amount and sense of vertical axis rotations (if any), which in turn are crucial for the reconstruction of the recent geodynamic evolution of the Tyrrhenian Sea – Apennine system. Differences in timing, amount and style of Neogene deformations within the Apennine chain have been suggested by several investigations, based on geological and geophysical data (see synthesis in CNR, 1989). As a matter of fact, recent paleomagnetic analyses indicate that the Italian peninsula has not undergone homogeneous rotations during Plio-Pleistocene time. In fact, while paleomagnetic data from Southern Italy show differentiated amount and sense of rotations during Plio-Pleistocene (Sagnotti, 1992; Scheepers and Langereis, 1993; Scheepers *et al.*, 1993; Scheepers, 1994), in the Tyrrhenian Latium-Tuscany extensional margin there is no evidence for tectonic rotation during the same time interval (Sagnotti *et al.*, 1994; Mattei *et al.*, 1995). In this frame paleomagnetic data from the Central Apennines intermontane Plio-Pleistocene basins, still lacking, are important to reconstruct the tectonic puzzle of the area. The available paleomagnetic data in this area have been collected in the past few years and indicate a complex, structure-dependent, pattern of vertical-axis rotations. These data refer to:

– 7 localities in Cretaceous limestones from the Eastern Abruzzi range (Monte Greco-Monte Genzana and Monte Maiella structures). The results were interpreted as representative of about 40° of clockwise rotation relative to the Apulia foreland (Jackson, 1990; Marton and D'Andrea, 1992);

– 12 localities (sites) in the Cretaceous-Paleogene Scaglia formation and the Messinian Laga formation in the Gran Sasso range. The data were interpreted as indicative of a differentiated counter-clockwise rotation (up to 90°) of the Gran Sasso thrust belt with respect to the underlying Marche domain (De La Pierre *et al.*, 1992);

– 54 localities (sites) drilled through the Central Apennines, in formations of Cretaceous to Upper Miocene age, from different tectonic structures. From these data it was deduced that the area underwent at least two successive phases of rotations (Mattei, 1992; Mattei *et al.*, 1993).

This work is part of a research project for the acquisition of paleomagnetic data from Plio-Pleistocene units within the Central Apennines. The present paper reports and discusses the paleomagnetic results from the Plio-Pleistocene continental sediments cropping out at the north-eastern edge of the Fucino basin. A closer inspection of the demagnetization data for these sediments, with particular attention to the stability range of the NRM components, produced a substantial revision and upgrade of the preliminary interpretations (Alfonsi and Sagnotti, 1993). It will be shown that the magnetic properties of these sediments are not straightforward to infer possible tectonic rotations. Moreover, some peculiar paleomagnetic features were found, that deserve specific comments.

2. Geological background

The Fucino basin (Abruzzi region) is one of the largest and more representative intermontane depressions in the Central Apennines (fig. 1). It was occupied by a lake that was drained in the 19th century. The area has been affected by significant Quaternary tectonics and seismicity. In January 13, 1915 the region was struck by a destructive earthquake that was responsible for more than 30000 casualties and the formation of many fault scarps in the Fucino.

After the 1915 seismic event some investigations were carried out in the region in order to describe the physical effects of the earthquake (*e.g.* Oddone, 1915). A renewed interest has begun in recent years, thus new geophysical and geological analyses were made to clarify the kinematics of the seismogenetic structure, sometimes with different conclusions (Serva *et al.*, 1986; Giraudi, 1989; Ward and Valensise, 1989; Galadini *et al.*, 1995a). According to recent studies (Galadini *et al.*, 1995b) four NW-SE faults in the basin represent the surface expression of the seismogenetic fault.

Seismic activity during historical time is also claimed for the Ovindoli-Piani di Pezza fault, few kilometres to the north of the Fucino basin, on the basis of paleoseismological analysis and critical review of the available historical data (D'Addezio *et al.*, 1995).

Plio-Pleistocene continental sedimentary sequences crop out in facies suitable to paleomagnetic analyses only at the north-eastern margin of the basin (fig. 1). Plio-Pleistocene sediments were differentiated by Bosi *et al.* (1993) into five main cycles, the oldest being Pliocene and the youngest being Middle Pleistocene-Upper Pleistocene in age. Only the first two are characterized by extensive outcrops of fine-grained (clayey) sediments. Therefore, only these two cycles have been sampled for paleomagnetic analysis. The first sedimentary cycle, the Aielli complex, consists of clay layers in the lower part and alternating sand and gravel layers or slope derived breccia horizons in the upper part. Bosi *et al.* (1993) dated this sequence as undifferentiated Pliocene.

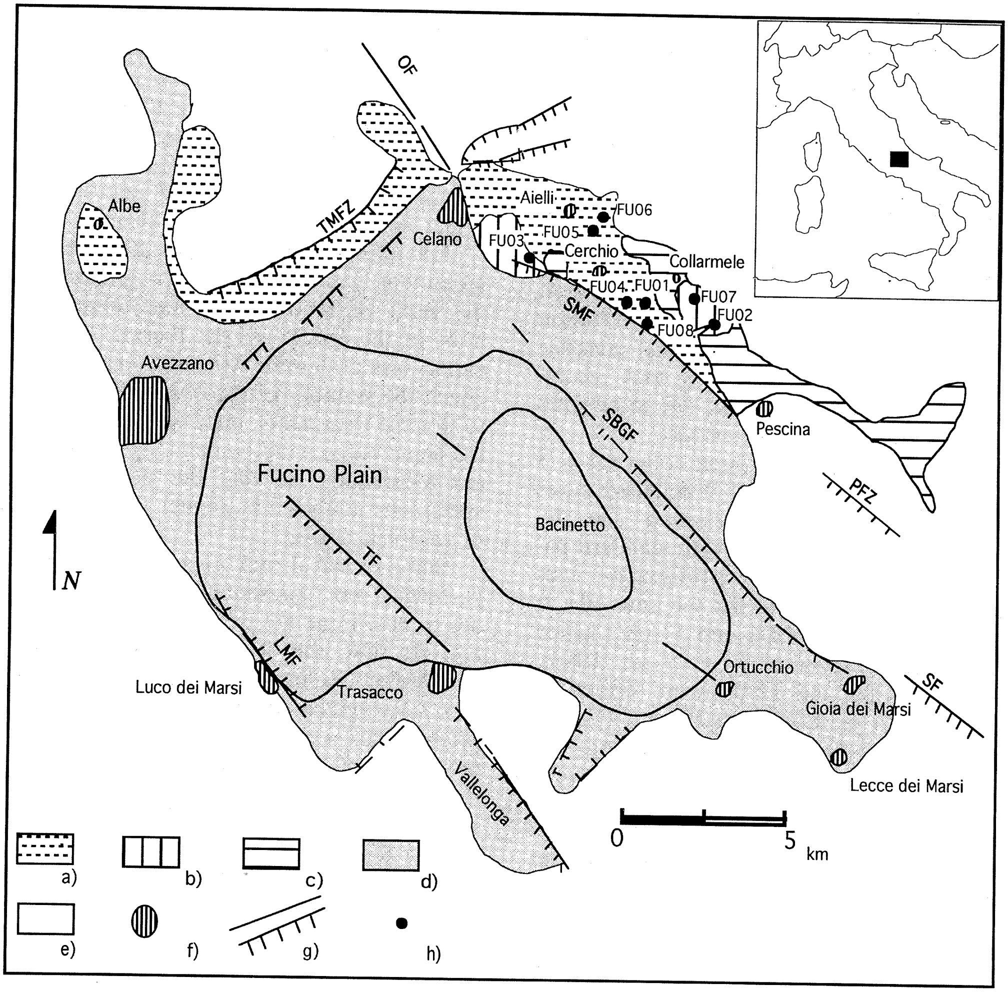

Fig. 1. Simplified structural and geological sketch of the Fucino basin (redrawn after Bosi *et al.*, 1993). a) Aielli complex (Pliocene); b) Cupoli complex (Lower Pleistocene); c) Pescina, Pervole and Boscito formations, undifferentiated (Middle Pleistocene); d) Upper Pleistocene-Holocene sequences; e) Meso-Cenozoic limestones or Pleistocene breccias and Holocene cover; f) villages; g) fractures and faults; h) location of the sampling sites. LMF = Luco de Marsi fault; TF = Trasacco fault; SBGF = S. Benedetto dei Marsi - Gioia dei Marsi fault; SF = Serrone fault; PFZ = Mt. Parasano Fault zone; SMF = Strada Statale Marsicana fault; TMFZ = Tre Monti fault; OF = Ovindoli fault.

The second sedimentary cycle (the Cupoli complex), markedly entrenched in the first, is represented by alternating fluviatile clayey-silt and gravel layers near Celano and by clayey silts in the area around Collarmele. The age of the Cupoli complex is Lower Pleistocene (Bosi *et al.*, 1993). In the two stratigraphic sequences the deformation is usually represented by tilting and broad folds. A significant uplift of the NE sector of the Fucino basin (a sector that constitutes the footwall of one of the 1915 co-seismic faults) can be determined by the presence of Pliocene lacustrine sediments (Aielli complex) at an elevation fairly above (about 350 m) the present plain level (Galadini and Messina, 1995).

3. Sampling and measurements

Exposed sections suitable for paleomagnetic sampling were found only at the north-eastern edge of the basin. Indeed, the site distribution was strongly influenced by the limited presence of fine-grained deposits. Sampling took advantage of some artificial exposures, due to trenches open for the laying of a gas-conduct.

A total of 83 cores has been collected at 8 sites (fig. 1), a minimum of 9 oriented cores has been taken at each sampling site, by drilling and orienting *in situ*, with standard paleomagnetic techniques. The stratigraphic ages are a generalized Pliocene for the sites FU01, FU02, FU04, FU05, FU06 and FU08 (drilled in the Aielli complex of Bosi *et al.*, 1993), while sites FU03 and FU07 were drilled in units referred to the Lower Pleistocene (Cupoli complex of Bosi *et al.*, 1993). Sampling was preferably performed on fine-grained (clayey) units; only at two sites an appreciable coarse clastic component was found (FU03, FU04). Calcareous silts have been drilled only at one locality (FU07). Bedding is variably oriented at the different sites. Only at site FU03 it is (sub) horizontal.

The paleomagnetic study followed the Anisotropy of Magnetic Susceptibility (AMS) analysis of the same samples; the details of the AMS study are discussed elsewhere (Alfonsi and Sagnotti, 1995). We only recall here that the magnetic fabric of these sites is typical of undeformed sediments or at the earliest stages of deformation.

All the paleomagnetic measurements were performed in the magnetic shielded room of the paleomagnetic laboratory of the Istituto Nazionale di Geofisica, using a JR-4 spinner magnetometer. Stepwise thermal and Alternating Field (AF) demagnetizations were carried out using a shielded electrical oven and a Molspin demagnetizer, respectively.

The overall stepwise cleaning treatment, thermal or AF, was designed on information coming from preliminary analyses carried out on two pilot specimens from each site: one specimen underwent AF treatment, while the other was thermally demagnetized. During thermal demagnetization the bulk susceptibility was monitored at each heating step, in order to detect possible mineralogical changes.

According to these results, all the remaining specimens were stepwise demagnetized up to the limit of reproducible measurements. For most of the specimens the thermal demagnetization was preferred. At some sites, in order to check the stability of the observed components to diverse treatments, different specimens from the same cores were demagnetized with different techniques, so that the number of total specimens analyzed is greater than the number of sampled cores.

Some classical rock magnetic analyses were performed on representative specimens, in order to determine the principal remanence carriers. At first, the stepwise acquisition of the Isothermal Remanent Magnetization (IRM) was investigated. Isothermal remanences were produced on a pulse magnetizer, up to a maximum field of 1.6 T. Then, the coercivity of remanence (B_{cr}) was estimated by application of a progressively increasing back-field to the saturation IRM. Furthermore, a thermal demagnetization of three orthogonal IRMs was performed, according to the method described by Lowrie (1990), in order to define the unblocking temperature of the magnetic fractions present, distinguished on the basis of their coercivity spectra.

4. Results

4.1 *Paleomagnetism*

The Natural Remanent Magnetization (NRM) values range from 85 μA/m to 24000 μA/m. Apart from very weak specimens, the data gave, in general, well defined demagnetization paths, represented either by linear paths toward the origin (fig. 2a) or by remagnetization circles toward the reverse hemisphere, that in most cases did not reach a stable end-point

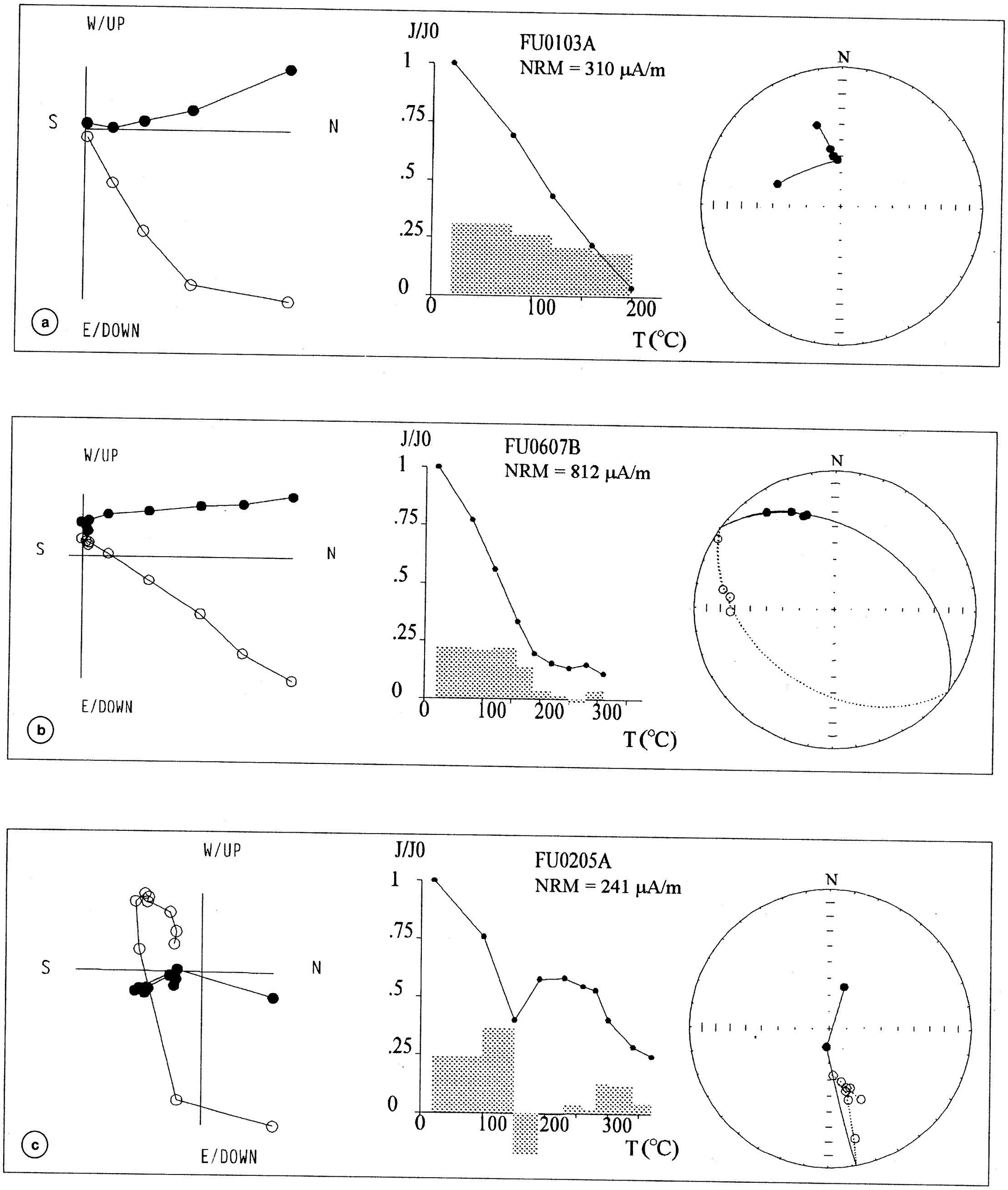

Fig. 2a-c. Thermal demagnetization diagrams for three representative specimens. From left to right: vector diagram (full circles: horizontal projection – open circles: vertical projection), normalized intensity variation and equal-area projection (closed circles and solid line: lower hemisphere – open circles and dashed line: upper hemisphere). Tilt corrected. a), b) and c): see text for explanation.

(fig. 2b) and only in few cases, less than 10%, allowed the identification of a stable reverse component (fig. 2c). Best-fit lines and planes were evaluated by principal component analyses, according to Kirschvinck (1980).

At all eight sites the NRM is dominated by a normal component, evidenced for all specimens by linear fits to the first demagnetization steps (fig. 2a,b). This component vanishes at temperatures ≤ 200°C during thermal demagnetization, while is stable up to 30-40 mT during the AF treatment (fig. 3). This low-temperature (LT) normal component is almost well defined at all sites and is oriented in the direction of the present geomagnetic field in geographic coordinates (table I).

In our preliminary analysis (Alfonsi and Sagnotti, 1993) the statistics for each site included both AF and thermally demagnetized specimens and was carried out combining linear paths and remagnetization circles (McFadden and McElhinny, 1988). In this paper the analysis was performed only on the thermally demagnetized specimens, separating the data for the LT component from the information left above 200°C. This has produced a substantial improvement of the early interpretation.

The LT normal component does not pass the fold test for paleomagnetic stability (performed according to McFadden, 1990). Better grouping of the site mean data (maximum $k = 155.9$) is obtained at 21% of complete unfolding. Moreover it is oriented, in geographic coordinates, near the expected direction for the geocentric axial dipole field at the locality (see table I). Consequently, this component is interpreted as a viscous remanence magnetization (VRM) acquired in the present geomagnetic field.

At all sites but FU01 a second component of magnetization, left at T ≥ 200°C is also present. This latter component is enhanced by remagnetization circles with a general trend toward the reverse hemisphere (fig. 2b,c). A

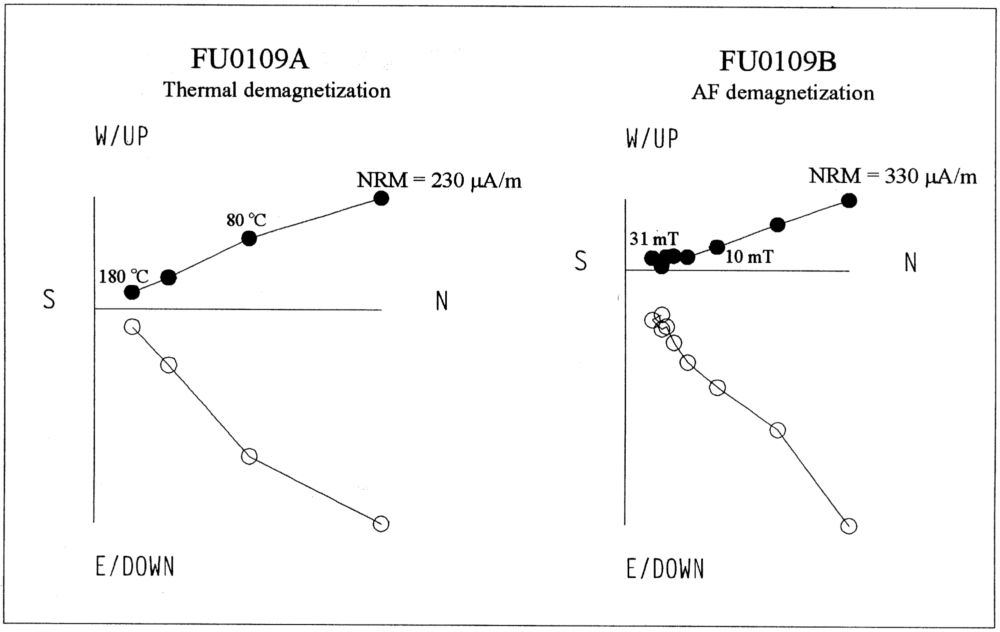

Fig. 3. Representative vector diagrams showing the demagnetization data during thermal and AF demagnetization of two pilot specimens from the same core (full circles = horizontal projection; open circles = vertical projection). Tilt corrected.

Table I. Paleomagnetic data for the LT component (T < 200°C).

Sites	*N*	*D*	*I*	*Az. Dip*	*Dip*	*D'*	*I'*	*k*	α_{95}
FU01	7	358.4	45.9	268	16	342.5	43.8	65.2	7.5
FU02	5	353.8	55.7	221	20	321.7	65.1	30.5	14.1
FU03	7	343.5	65.6	–	–	343.5	65.6	17.4	14.9
FU04	10	14.8	52.7	270	25	341.5	51.9	33.9	8.4
FU05	11	4.3	61.1	325	11	354.8	52.0	142.8	3.8
FU06	9	353.1	55.4	1	17	355.3	38.5	97.8	5.2
FU07	6	356.6	59.3	56	6	4.4	55.9	86.1	7.3
FU08	9	356.9	62.9	60	15	16.6	53.8	30.1	9.5
Total	(8 sites)								
b.t.c.		358.3	57.6					105.2	5.4
a.t.c.						351.2	54.2	38.6	7.8

N = number of samples; *D*, *I* = declination and inclination, before tectonic correction; *Az. Dip* = azimuth of dip; *D'*, *I'* = declination and inclination, after tectonic correction; *k* = precision parameter; α_{95} = half-angle of the 95% confidence cone about the mean direction; b.t.c. = before tectonic correction; a.t.c. = after tectonic correction.

Table II. Paleomagnetic data for the HT component (T > 200°C).

Specimens	*D*	*I*	*Az. Dip*	*Dip*	*D'*	*I'*	*k*	α_{95}
FU0202	179.8	−41.7	221	20	162.4	−54.8		
FU0205	180.2	−40.7	221	20	163.6	−54.0		
FU0206	175.2	−28.1	221	20	164.4	−40.8		
FU0505	165.2	−67.1	325	11	159.1	−56.6		
FU0507	154.7	−44.4	325	11	153.3	−33.5		
FU0509	174.8	−51.2	325	11	169.5	−41.4		
FU0801	123.4	−61.5	60	15	152.8	−64.7		
Total (7 specimens)								
b.t.c.	167.7	−49.1					20.4	13.7
a.t.c.					161.1	−49.5	48.1	8.8

D, *I* = declination and inclination, before tectonic correction; *Az. Dip* = azimuth of dip; *D'*, *I'* = declination and inclination, after tectonic correction; *k* = precision parameter; α_{95} = half-angle of the 95% confidence cone about the mean direction; b.t.c. = before tectonic correction; a.t.c. = after tectonic correction.

clear reverse component, coming from linear paths fitted to stable-end points reached during demagnetization (fig. 2c), has been observed only seven specimens (table II) from three different sites drilled in the Aielli unit Pliocene aged (out of 83 samples belonging to 8 sites). These seven specimens define a reverse polarity component measured up to 400°C. Eventhough this component has been detected only at seven specimens, it passes the fold test (maximum *k* = 48.2 is obtained at 97% of complete unfolding).

The remagnetization circles fitted to demagnetization paths not reaching a stable end-point in the reverse hemisphere, converge on the LT normal component (see example relative to site FU05 in fig. 4, data in geographic coordinates, and table III).

Furthermore, four specimens from site FU06 exhibit a high intensity component, that is stable only up to 330°C, but it is of reverse polarity (Decl. = 205.8°; Incl. =−57.4°). These specimens are those with the higher NRM intensities and can be distinguished on the basis on their magnetic mineralogy (see below).

4.2 *Rock magnetism*

One representative specimen per site was analyzed in order to detect the nature of the magnetic carriers. Only for site FU06 two specimens were analysed, representative of two clearly distinct groups with different basic magnetic properties (magnetic susceptibility and NRM intensities) and different behaviour during thermal demagnetization. A first group with NRM in the range of 10^{-4} A/m and a LT normal component removed below 200°C, a second group (four specimens) with NRM intensities if the range of 10^{-2} A/m and a single reverse component stable up to 330°C. The main rock magnetic parameters are synthetized in table IV.

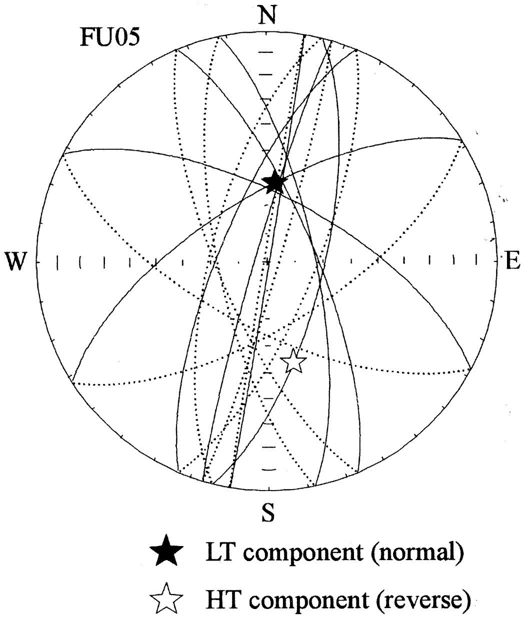

Fig. 4. Remagnetization circles fitted to demagnetization paths toward the upper hemisphere not reaching a stable-end point for site FU05. Equal-area projection (solid line = lower hemisphere; dashed line = upper hemisphere). Geographic coordinates. The full (open) star indicates the site mean direction of the normal LT (reverse HT) component.

IRM acquisition experiments showed that the predominant magnetic carriers are low-coercivity minerals for almost all the specimens, that reach saturation in fields of about 0.3 T. Only at the FU03 site (a thin and purple-reddish clayey level in a conglomerate sequence of the Cupoli complex) an additional high-coercivity magnetic fraction was detected and saturation was not achieved in the maximum field of 1.6 T.

The progressive thermal demagnetization of a composite IRM, produced according to Lowrie (1990), was used to distinguish the magnetic minerals on the basis of both coercivity and (un)blocking temperature spectra (fig. 5a-d'). Magnetic mineralogy is not homogeneous between the different specimens. The soft-coercivity phases show two distinct maximum unblocking temperature ranges; the higher around 580°C (magnetite; fig. 5a,b), the lower around 300°C-330°C (fig. 5b intermediate-coercivity curve, 5c). The high value of the interparametric ratio SIRM/*k* for the specimens where the latter unblocking temperature range prevails (see table IV) suggests that ferrimagnetic iron-sulphides (most likely greigite) could be the main magnetic carriers in such specimens (see *e.g.* Snowball, 1991; Reynolds *et al.*, 1994). This is also confirmed by a significant decrease of the low-field magnetic susceptibility between 200°C and 300°C, during thermal demagnetization, that is typical for iron-sulphides (*e.g.* Roberts and Pillans, 1993). The high-coercivity fraction at site FU03 (fig. 5d) has a maximum unblocking temperature > 650°C and is therefore identified as hematite.

Table III. Convergence points (normal hemisphere) for the remagnetization circles.

Sites	*N*	*D*	*I*	*Az. Dip*	*Dip*	*D'*	*I'*	*k*	α_{95}
FU02	3	359.9	61.4	221	20	318.0	71.5	147.9	10.2
FU03	6	1.2	61.6	–	–	1.2	61.6	70.3	8.0
FU04	9	10.6	46.7	270	25	344.3	45.6	85.6	5.6
FU05	8	14.0	58.8	325	11	3.2	50.8	102.8	5.5
FU06	7	349.1	53.8	1	17	352.2	37.1	640.2	2.4
FU07	7	4.4	55.9	56	6	10.6	51.9	403.3	3.0
FU08	9	337.8	63.8	60	15	3.5	58.3	98.2	5.2

N = number of samples; *D, I* = declination and inclination, before tectonic correction; *Az. Dip* = azimuth of dip; *D', I'* = declination and inclination, after tectonic correction; *k* = precision parameter; α_{95} = half-angle of the 95% confidence cone about the mean direction.

Table IV. Rock magnetic parameters.

Specimen	NRM (A/m)	*k* (10^{-6} SI)	SIRM (A/m)	B_{cr} (mT)	MDF$_{\text{NRM}}$ (mT)	*Tb* (°C)	SIRM/*k* (A/m)	*S*-ratio
FU0114A	5×10^{-4}	110	1.2×10^{-1}	−42	10	580	1091	−0.65
FU0203A	2.4×10^{-3}	213	4.9	−65	23	330(580)	22846	−0.56
FU0301A	2.7×10^{-4}	122	–	−73	10	580; >650	–	−0.18
FU0409A	3.8×10^{-4}	114	1.2×10^{-1}	−48	9	300; 580	1053	−0.57
FU0507A	3×10^{-4}	130	9.1×10^{-2}	−40	9.5	580	700	−0.64
FU0608A	7.7×10^{-4}	151	1.7×10^{-2}	−48	9	580	1113	−0.56
FU0610A	2.4×10^{-2}	315	11	−64	40	330; 400	34921	−0.63
FU0705B	1.1×10^{-4}	36	2.5×10^{-2}	−45	5	300; 580	694	−0.6
FU0809A	3.2×10^{-4}	101	1.4×10^{-1}	−40	8.5	580	1416	−0.79

NRM = Natural Remanent Magnetization; *k* = mean low-field magnetic susceptibility; SIRM = Saturation Isothermal Remanent Magnetization; B_{cr} = coercivity of remanence; MDF$_{\text{NRM}}$ = median destructive field of the NRM; *Tb* = maximum unblocking temperatures; *S*-ratio = IRM(−0.1 Tesla) / IRM(1 Tesla).

Magnetite has been identified in almost all specimens. Iron sulphides (possibly greigite) have been recognized only in some specimens. They could constitute the unique magnetic phase identified in the specimen representative of the «anomalous» four samples of site FU06 (see fig. 5c).

The strong decrease observed for the intensity of the LT normal component of the NRM below 180°C-200°C was not observed during the thermal demagnetization of the artificially produced IRM, so that the NRM carriers are not well represented by the IRM carriers. We have therefore to conclude that the two remanences (NRM and IRM) are carried by two distinct populations of magnetic grains.

The NRM Median Destructive Field (MDF$_{\text{NRM}}$) during AF demagnetization of the specimens with magnetite as the only identified magnetic carrier is ≤ 10 mT (see table IV). This suggests that the magnetite grains carrying the natural remanence have to be either larger than 5μm and therefore in a truly Multi-Domain (MD) magnetic state, or extremely fine, near the single domain – superparamagnetic threshold (Maher, 1988).

The normalized decay curves during AF demagnetization of the NRM, IRM and Anhys-

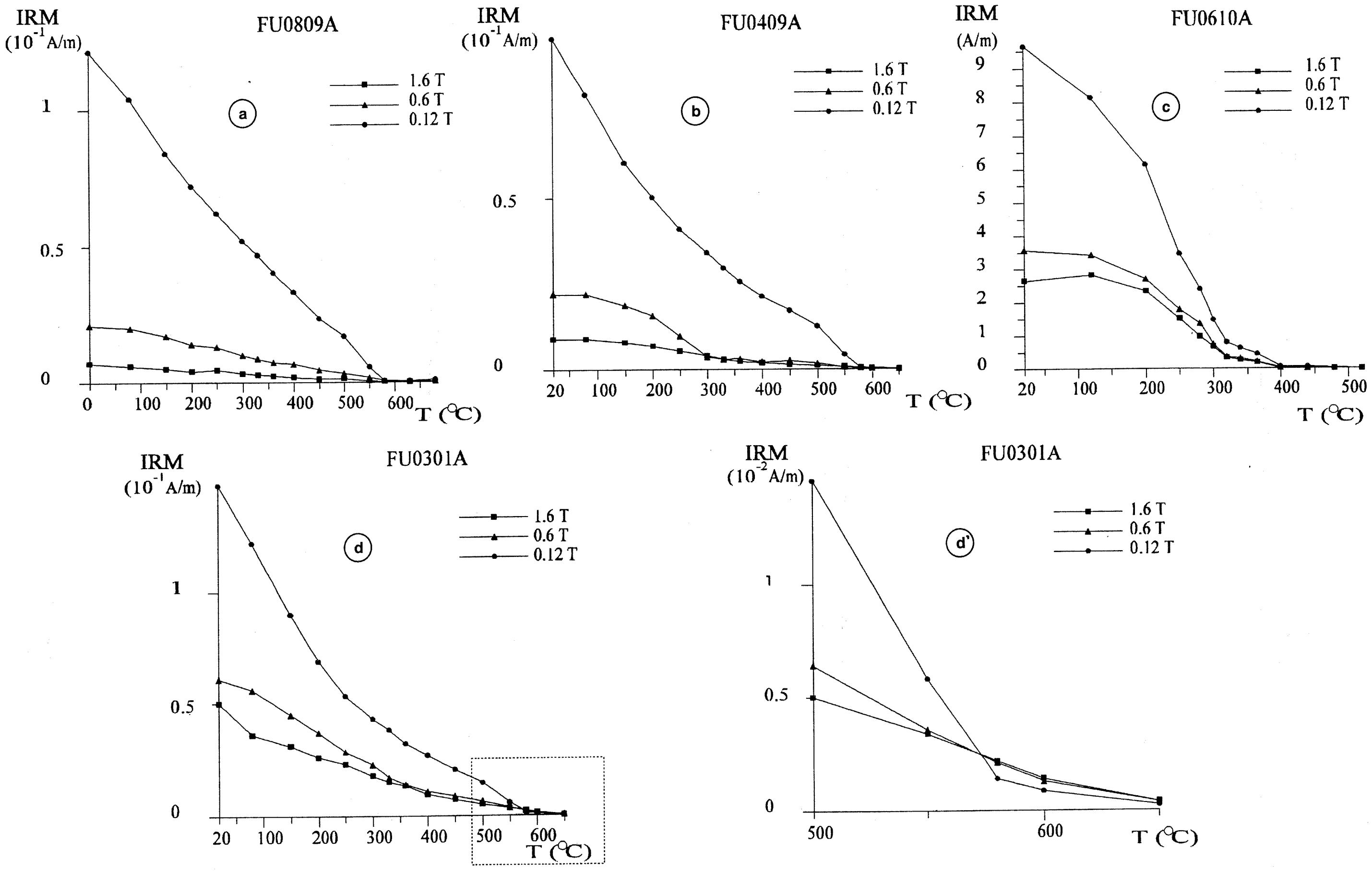

Fig. 5a-d′. Stepwise thermal demagnetization of a three component IRM produced by successively applying 1.6 T along the specimen *z*-axis, 0.6 T along the *y*-axis and 0.12 T along the *x*-axis, for four representative specimens. The area enclosed in the dashed rectangle in diagram (d) is enlarged in (d').

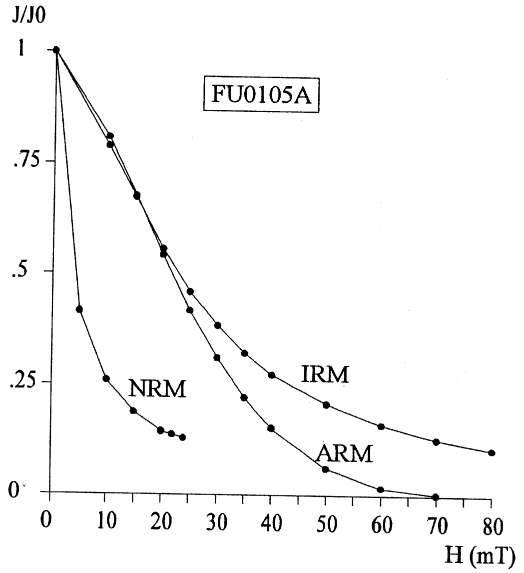

Fig. 6. Normalized AF demagnetization curves of NRM, IRM (at 1.6 T) and ARM (AF peak of 80 mT + 0.1 mT steady field), for specimen FU0105A.

teretic Remanent Magnetization (ARM, produced in AF peak of 80 mT + 0.1 mT steady field) of a representative specimen are compared in fig. 6. It is evident that natural remanence is much softer than both the laboratory-induced remanences. Furthermore, the IRM is harder than ARM. According to the Lowrie-Fuller test, this behaviour is typical for MD magnetite grains (see Lowrie and Fuller, 1971; Johnson *et al.*, 1975).

5. Conclusions

The paleomagnetic data obtained in this study are not suitable for any geodinamic reconstruction of the investigated area. In fact the analyzed continental Plio-Pleistocene units at the north-eastern edge of the Fucino basin show a natural remanent magnetization dominated by a strong viscous component. This component is parallel to the present geomagnetic field in geographic coordinates and it permeates almost all the analyzed samples.

Once the viscous component is removed (at temperatures ≥ 200°C) only very weak indications of the primary magnetization remain in a few specimens. Indeed, only in seven specimens, out of the 83 demagnetized, it was possible to isolate a characteristic remanence. This component is of reverse polarity and better defined after tectonic correction. It is slightly counterclockwise deviated from the north-south direction (Decl. = 161.1°; Incl. = −49.5°). Nevertheless, it has been determined in too few specimens for being statistically meaningful for tectonic reconstructions.

The observed paleomagnetic features are related to the magnetic mineralogy of the studied units. The widespread occurrence of a significant viscous remanent magnetization is probably due to the uniform presence of multidomain magnetite. In any case, the detrital input of magnetite in the size range favourable to VRM acquisition should have been nearly constant in the area, and through the different facies, during the deposition of the Aielli and Cupoli complexes (Pliocene to Lower Pleistocene).

Magnetic iron sulphides (greigite?) are present with magnetite in some specimens. In the specimens (four specimens from site FU06, grey-blue clays) where they represent the unique magnetic phase, a strong increase in the NRM intensity was observed and the remanence is dominated by a reverse component that disappears at 330°C.

Acknowledgements

Massimo Mattei, Paolo Messina, Aldo Winkler and Fabio Florindo helped during the field work. We are grateful to Fabio Speranza for constructive comments on the manuscript. Reviews by Don Tarling and Luigi Vigliotti helped in the improvement of the manuscript.

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(received May 8, 1995;
accepted August 24, 1995)