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PALEOMAGNETIC AND PALYNOLOGIC INVESTIGATIONS IN THE UPPER VALDARNO BASIN (CENTRAL ITALY): CALIBRATION OF AN EARLY VILLAFRANCHIAN FAUNA

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Key-words: Magnetic stratigraphy, Palynology, Middle Pliocene, Early Villafranchian, Upper Valdarno, Central Italy.

Riassunto. La fauna a vertebrati rinvenuta nella parte inferiore dei depositi del 1° ciclo fluvio-lacustre del Bacino del Valdarno Superiore (successione di Castelnuovo dei Sabbioni) è stata attribuita all'unità faunistica Triversa del Villafranchiano inferiore. I più antichi giacimenti dell'Europa occidentale, come Layna (Spagna), suggeriscono un'età della base del Villafranchiano non più antica di 3.6 Ma. In Italia l'u.f. Triversa è stata datata tra 3.0 e 3.3 Ma.

Le indagini paleomagnetiche hanno permesso il riconoscimento della porzione superiore dell'intervallo a polarità normale Gauss e della prima breve inversione sottostante (Kaena); in quest'ultima è contenuto il tetto delle ligniti basali e dei primi livelli argillosi sovrastanti dove furono raccolti i resti di mammiferi attribuiti all'u.f. Triversa. L'associazione a mammiferi è quindi databile tra 3.10 e 3.17 Ma. La base della successione conserva la testimonianza palinologica di una vegetazione indicativa di un clima caldo-umido a carattere subtropicale, che evolve verso condizioni più fresche con progressiva riduzione degli elementi tropicali-subtropicali. Nel loro insieme le associazioni vegetazionali ricostruite possono essere correlate con quelle del Reuveriano dell'Europa centrale. In prossimità del tetto del corpo sabbioso che chiude il ciclo di Castelnuovo, in località "Rena Bianca", si hanno evidenze di una fase marcatamente arida seguita da condizioni più calde ed umide. Quest'ultimo cambiamento potrebbe corrispondere al passaggio Pretigliano-Tigliano oppure a una fluttuazione stadiale-interstadiale del Pretigliano. Sulla base dei dati raccolti, quindi, si può indicare per l'inizio del Villafranchiano un'età più antica di 3.1 Ma.

Abstract. The silty clays embedding an early Villafranchian mammal fauna of the Triversa faunal unit (f.u.) have been paleomagnetically and palynologically studied in a continuous sequence exposed in the Santa Barbara quarry. The study has allowed to date the earliest occurrence in Italy of a faunal assemblage of this unit and to define the corresponding climatic conditions. The sampled section has provided a magnetic polarity sequence of the late Gauss, where the fossiliferous layer fits the Kaena reversed interval. Its age of ca. 3.1 Ma, during subtropical climate conditions correlatable to the Reuverian of Netherlands, suggests an older age for the beginning of the Villafranchian, possibly associated to a more dramatic scenario able to trigger the faunal turnover.

Introduction.

The beginning of the Villafranchian was dated between 3.0 and 3.6 Ma on the basis of radiometric and paleomagnetic analyses carried out in sites with most significant local faunas.

In Spain the Layna local fauna (Province of Soria) is characterized by a well differentiated association in which the occurrence of *Leptobos* sp. and *Mimomys cappettai*, alongside Ruscinian species, lends the fauna a character transitional towards the Villafranchian (Perez and Soria, 1992). The sediments in which the fauna was collected show normal polarity magnetization most plausibly assigned to the Gauss chron and therefore the deposit cannot be older than 3.6 Ma, according to the magnetic time scale of Baksi (1993). In the Gaudix-Baza basin, where a complete continental sequence from latest Pliocene to Middle Pleistocene is present, the paleomagnetic survey has also placed the beginning of Villafranchian in the Gauss chron, after the 2An.2r Chron (Agusti et al., 1995).

In France, the Vialette fossil bearing level, characterized by a typical early Villafranchian association (Triversa f.u. = MN16a), overlies a volcanic bed and is probably older than the Azanieras lava flow. According to the K/Ar dates of the volcanic rocks (Bandet et al., 1978) the fauna is no older than 3.3 Ma, but older than 2.6 Ma. Still in France, the well known Les Etouaires fossil site of early Villafranchian age, was dated between 3.3 and 2.6 Ma by Couthure & Pastre (1983), on minerals collected from the fossil bearing deposit. Ly et al. (1983) proposed an age of 2.6-2.5 Ma, on extrapolation from the Grande Nappe volcanic event, in the frame of a general geological reconstruction of the history of the area. Savage and Curtis (1970) reported an age of 3.4-3.5 Ma from a sediment rich in volcanic elements under-

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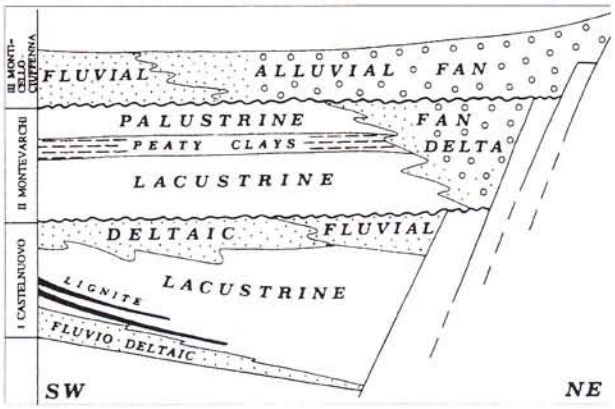


Fig. 1 - Schematic stratigraphy and environment interpretation of the Valdarno Basin fill. Modified after Sagri et al. (1994).

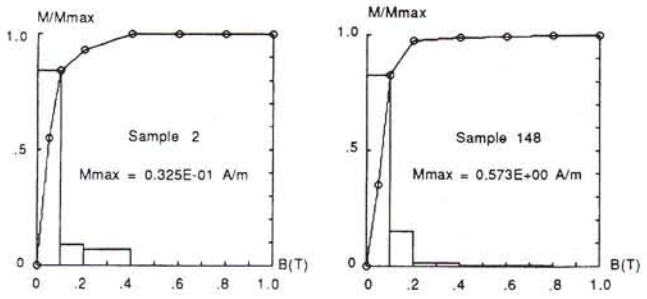


Fig. 2 - IRM acquisition curves from two extreme samples, labeled in meters, starting from the base of the 13 m thick lignite seam. Sample n. 2 is from the core, sample 148 from the upper outcrop: in the most anoxic deposits the low magnetic coercivity behavior does not differ from that fixed in less reducing environment.

lying the fossil bearing level. The age proposed by Ly et al. (1983) appears anomalous in comparison with other datings and deserves deeper inquiry.

In Italy, the Poggio Mirteto lignite-bearing clays (near Rome), with scanty fossils referred to the Triversa f.u., are heteropic of marine sediments of the *Globorotalia crassaformis* zone, in which a volcanic ash level gave a reversed polarity magnetization, in all likelihood corresponding to the Mammoth subchron. In the type locality of the Triversa f.u. (Boano & Forno, 1994), Lindsay et al. (1980) made a palaeomagnetic survey in the section of RDB brick factory (San Martino Formation). They found two reversed intervals separated by a normal polarity zone, and interpreted the reversed intervals as Kaena and Mammoth subchron, respectively. The short vertical extent of the section and the low quality of magnetic response left their interpretation uncertain.

The majority of datings reported above indicates a most probable age for the oldest Villafranchian faunal unit (Triversa f.u. = MN16a) of 3.0-3.3 Ma.

In order to improve our understanding of the chronology and climatic evolution, a paleomagnetic and palynologic study was carried out in the sediments of the oldest fluvio-lacustrine cycle of the Upper Valdarno (Castelnuovo dei Sabbioni sequence). The sequence is well exposed in the Castelnuovo dei Sabbioni area, on the left bank of the Arno river (SE of Florence).

The deposits consist (Sagri et al., 1994) of basal alluvial and fluvio-deltaic sands and gravels (Spedalino Sands and Gravels), grading upwards into well-bedded lacustrine silty clays and sands (Meleto Clays). Lignite seams occur in the lower part of the lacustrine deposits and have been exploited industrially in the Santa Barbara mine. The lacustrine deposits are conformably overlain by more coarse-grained deltaic sands and well sorted, light coloured fluvial sands (San Donato Sands) (Fig. 1). The main lignite seam, and the silt beds overlying it, yielded a scanty mammalian fauna represented by *Ursus minimus, Tapirus arvernensis, Dicerorhinus* sp., *Leptobos* sp. and *Anancus arvernensis*. From the same deposits, but from an unknown locality, came a molar tooth of *Zygolophodon borsoni*. This association is typical of the Triversa f.u. (Torre et al., 1996).

Magnetic investigations

Sampling site.

A section of the Meleto Clays, in the open Santa Barbara pit, has been chosen for the paleomagnetic analyses. Along an outcrop of gently dipping layers, the silty clays, including the lignite, were sampled up to the base of San Donato Sands for 150 meters. A reference level was fixed at a sandy layer 0.6 m thick, 17 m above the lignite seam. The sampling extended downwards for more than 14 m, as close as possible to the lignite bed, since the mine was being filled and the section is now covered almost completely. During the filling a borehole 62 meters long was drilled alongside the sampled outcrop; it passed the lignite and penetrated the underlying sandstones; another 18 m long core penetrated the sandy level and reached the top of lignite. From the outcrop and the two cores, cubes of about 10 cc were prepared for the magnetic measurements. These were carried out at the ETH magnetic laboratory in Zürich.

Magnetic properties.

The quality of the magnetic character of the rock type has been enhanced by measuring the isothermal remanent magnetization (IRM), for several samples taken at different stratigraphic levels, and the susceptibility of all samples at each step during the natural remanent magnetization (NRM) thermal treatment.

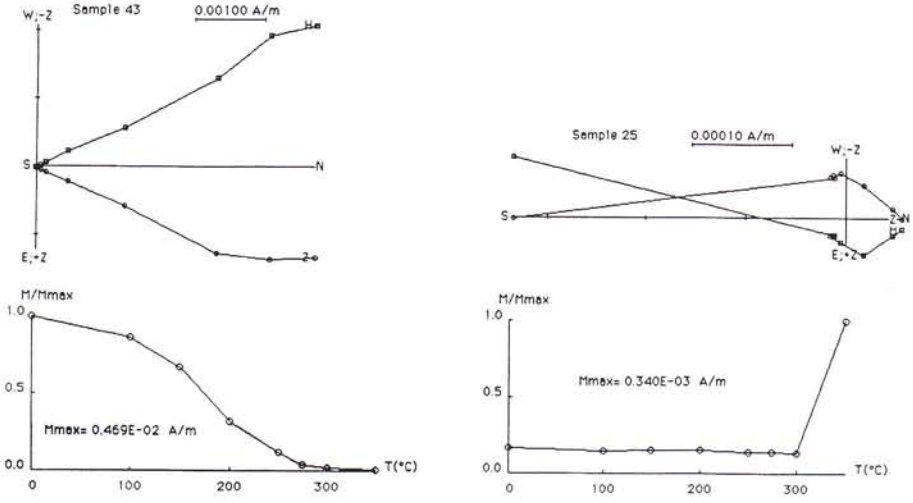


Fig. 3 - Two typical demagnetization curves (geographic coordinates) of opposite patterns. In sample 43 (30 m above the lignite) the intensity of normal polarity is progressively decaying and after 300°C it vanishes, while in sample 25, from layers still in proximity of the lignite and reversely magnetized, it undergoes a sudden jump after 300°C as occurring in the anoxic lignite samples.

Examples of IRM patterns are shown in Fig. 2. Sample 148 comes from the cliff and sample 2 from the core, in a layer near the bottom of the lignite. In both cases the acquisition of IRM is detected in fields up to 1 T (Tesla) and more than 90% of it steeply grows within 0.2 T; the saturation is practically attained at 0.4 T.

The NRM thermal demagnetization curves show how a relatively strong remanence decays slightly up to 100°C, and more severely beyond this: at 250°C almost 90% of it is lost, and at 300°C actually nothing is left (Fig. 3). The lower diagram of sample 43 is the common curve for samples magnetized with a normal polarity; all samples collected from 25 m above the top of lignite going upward are normally magnetized. The vector directions belong to a single magnetic phase and point straightforward to the origin already at 150°C along the characteristic direction of the primary magnetization.

Samples in and close to the lignite (e.g., sample 25) show a sudden increase between 300 and 350°C, with a higher intensity ascribed to a new mineralogical phase implying that magnetite is produced. A possible alteration of clay minerals with temperature could produce moderate increases while the abruptly strong contribution to susceptibility can be ascribed to alteration of sulfides, as these features are more pronounced in the levels closer to the lignite (Albianelli, 1994; Albianelli et al., 1995).

In the present materials sulfides are not macroscopically evident and only diffraction analysis, made on separates above 63 microns in diameter, has shown traces of pyrrhotite and pyrite. Low coercivity and rapid decay of magnetization, at increasing temperatures, are characteristic of such minerals. This is supported by the behavior in Fig. 4, that shows the demagnetization path for a sample taken in the clay levels still close to the lignite and associated to the changes in susceptibility occurring at around 300-350°C. Thereafter a strong increase in susceptibility occurs and the directions become unstable. The low temperature trends are interpreted as representative of the primary magnetization, according to the results discussed by Albianelli (1994) and Albianelli et al. (1993; 1995), carried by magnetite and authigenic sulfides produced during and/or immediately after deposition. The magnetic polarity stratigraphy has been interpreted accordingly (Fig. 5).

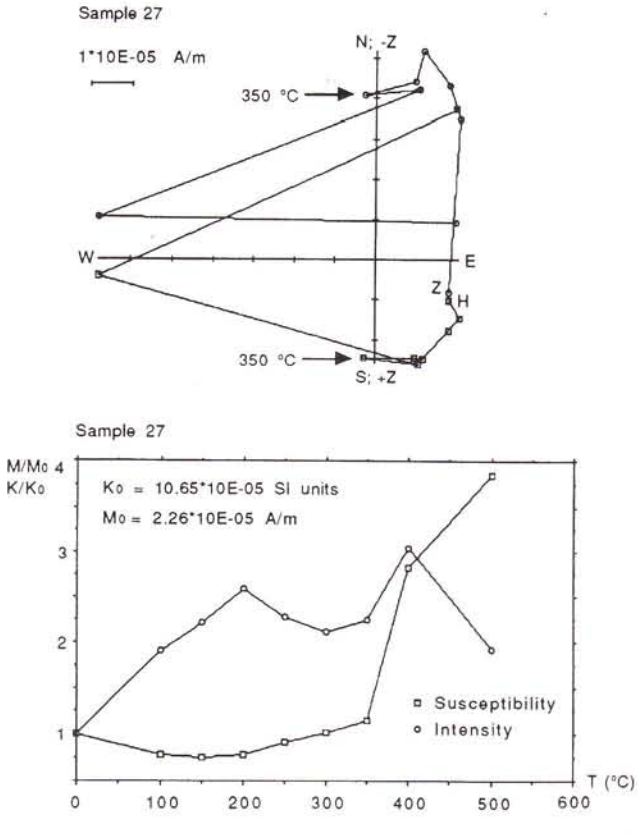
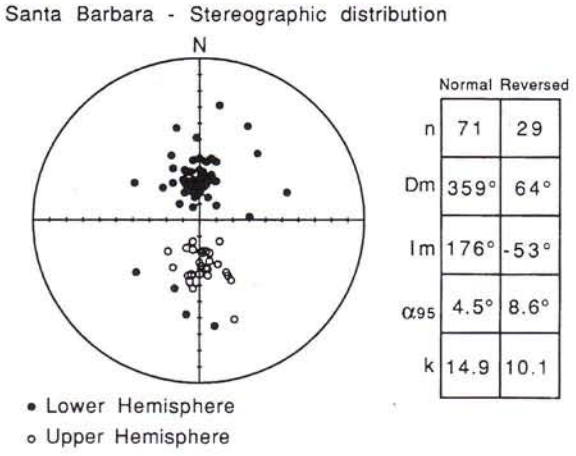


Fig. 4 - The demagnetization curves for a sample still in the reverse interval shows the removal of a secondary component with normal polarity, in the graph on the left, up to 200°C treatment. The primary magnetization, with stable direction, slightly decays up to 300°C. The successive increase depicts the growth of a new magnetic phase, as furtherly remarked by the susceptibility jump after 350°C.

Magnetic stratigraphy.

The whole set of samples shows directions of the paleomagnetic vectors trending consistently from the initial steps of demagnetization. As discussed above, the measured polarities throughout the section yield a reliable reversal sequence. Even near the bottom, where the lignite seam has evidence for more reducing conditions, directions remain consistent (Albianelli et al., 1993).



	Normal	Reversed
n	71	29
Dm	359°	64°
Im	176°	-53°
α95	4.5°	8.6°
k	14.9	10.1

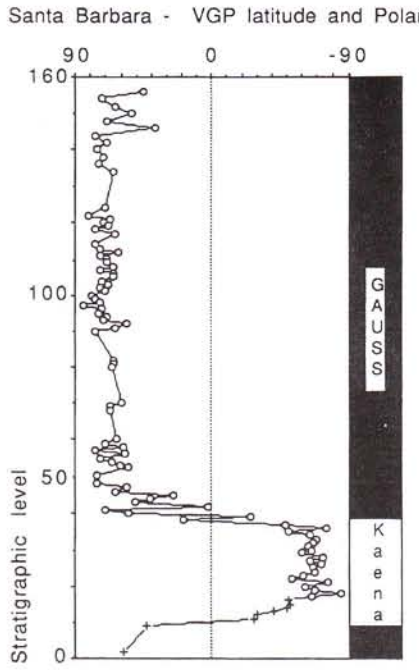


Fig. 5 - Stereographic distribution (bedding corrected) of all selected samples used for build up the Virtual Geomagnetic Pole path in the Meleto Clays. The list on the right summarizes the number of samples (n) defining the normal and reversed magnetozone, the mean declination (Dm) and inclination (Im), the confidence cone (α95), and the precision parameter (k). The polarity sequence is interpreted on the base of mammal remains located in the lignite seam and just above it, corresponding to the transition from the short reverse interval to the next normal (See also Fig. 6). Circles denote samples from the outcrop, crosses from the core.

Normal magnetic polarity occurs for more than 100 meters in the higher portion of the outcropping beds. In the lower section a reversed polarity takes place near the lignite, followed downwards by a normal one. The composite of Fig. 6 contains all the data produced by the overlapping sequences from the two boreholes and the surface section; in its lower portion the composite section extends down to the sandstone basement and the reversed interval is located to cover the upper half of the lignite seam and several meters above it. In the layers close to the top of lignite and just above it, fossils of the mid-Pliocene Triversa faunal unit were recovered during 1957-1958 quarrying.

The succeeding long normal polarity, persisting through several hundred ka of sedimentation, can be interpreted as belonging to the upper Gauss, subchron C2An.1n; this, in addition, can be supported by the fact that it follows a short reversal (Fig. 5-6). The latter, therefore, well defined within the two normals, is interpreted as C2An.1r. The presence of the fossil level assigned to the Triversa f.u. in a well defined position, within the Kaena subchron (C2An.1r), offers firm biostratigraphic constraint and yields an age between 3.10-3.17 Ma, according to Baksi's scale (1993).

Palynology

Sampling and Methods.

The Castelnuovo succession was investigated for palynological analyses since 1990, in a section 2 km distant from that for paleomagnetics. The Meleto Clays were sampled along a well exposed and continous section in the Allori pit of Santa Barbara mine. In the overlying San Donato Sands the few silty-clay levels intercalated within sands were sampled in the Rena Bianca quarry. On the whole, 380 samples were collected (Bertini, 1994).

Laboratory techniques involve both physical and chemical procedures (hydrochloric acid, hydrofluoric acid, Luber method, Sodium esametaphosphate, Zinc chloride of density 2, potassium hydroxide plus sieving, ultrasound sieving) in order to isolate palynomorphs from other organic components and minerals.

A minimum of 400 identified pollen grains were counted for each sample. Taxa were organized in 11 groups on the basis of ecologic and climatic requirements of their modern equivalents and represented in a synthetic palynologic diagram (Fig. 6). A list of groups is here reported as a caption to the figure:

1. Tropical-subtropical elements (Sapotaceae, Clethraceae-Cyrillaceae, etc.) and subtropical/warm-temperate elements (*Taxodium, Nyssa, Myrica,* etc.) deman-

ding year-round humidity and warm conditions which may also be related to local edaphic or/and microclimatic conditions.

2. Deciduous elements of warm-temperate and temperate climate: *Carya, Quercus, Pterocarya, Juglans, Engelhardtia, Liquidambar,* Ulmaceae, etc.

3. *Cathaya* and *Pinus haploxylon* type.

4. *Pinus* and other Pinaceae represented by poorly preserved grains.

5. Mid-altitude conifers: *Cedrus* and *Tsuga*.

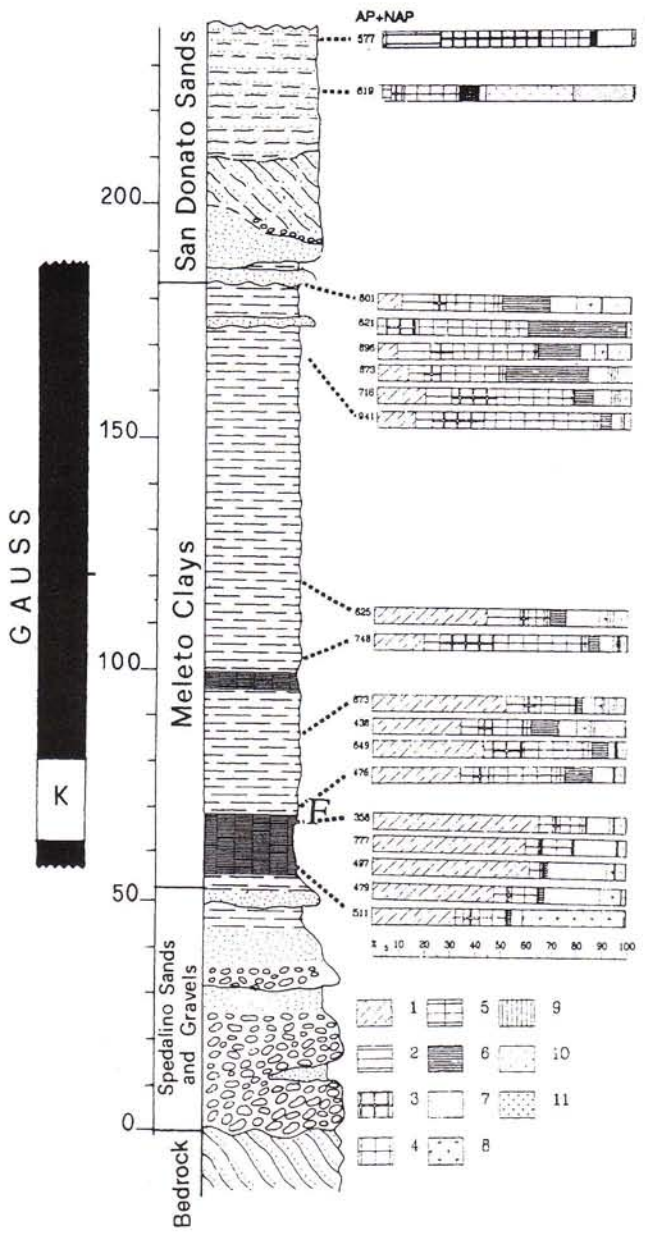


Fig. 6 - Composite stratigraphic section of the whole Castelnuovo dei Sabbioni sequence (tickness in meters). The sampled section starts from the base of lignite. "F" indicates the fossiliferous level. From left: magnetic polarity, lithostratigraphy and syntetic pollen diagram that displays the percentage of the pollen groups for which explanations are in the text.

6. High altitude elements: *Picea* and *Abies* plus *Betula* and *Fagus*.

7. and 8. Taxa lacking climatically significance plus indeterminate and/or indeterminable pollen grains; in group 8 *Alnus* and *Salix* are evident.

9. Mediterranean xerophytes: *Quercus ilex* type, *Olea, Phillyrea, Pistacia,* etc.

10. and 11.contain non-arboreal plants, prevalent herbs: Poaceae, Asteraceae, Ericaceae, etc., including such hydrophilous taxa as Nymphaeaceae, Potamogetonaceae, Sparganiaceae. Steppe elements (*Artemisia* and *Ephedra*) are represented in group 11.

Pollen flora.

A rich flora is recorded, composed of elements nowadays living in different regions in Europe, Asia and America.

The high concentration of well preserved palynomorphs confirms the occurrence of anoxic conditions on the lake bottom. This also favoured the preservation of leaves, fruits and seeds, which are consistently present all along the Santa Barbara section. In the sandy levels of the overlaying San Donato Sands, carpoflora is dominant whereas remains of leaves are sporadic and poorly preserved. Here pollen grains are recovered only in the rare silty-clayey beds.

In the overall pollen spectra of Fig.6 forest elements sharply dominate over the herbaceous ones, with exception of one spectrum corresponding to the first viable bed of the San Donato Sands.

The five spectra from the main lignite level show a very high percentage of arboreal pollen grains; pollen of Taxodiaceae is dominant (*Taxodium/Glyptostrobus*). *Alnus* pollen grains are occasionally highly abundant, possibly because of strong fluviatile influx. *Myrica*, *Nyssa*, Clethraceae-Cyrillaceae, *Quercus*, *Carya*, *Engelhardtia*, *Tilia*, Magnoliaceae, Rhamnaceae, *Rhoiptelea*, Sapotaceae, *Symplocos*, Araliaceae are also present.

The four spectra between the main lignite level and the minor one show an increase of the Pinaceae pollen grains percentage, especially of *Pinus*, probably recording a change in the depositional environment.

Spectra belonging to the levels shortly above the secondary lignite seam do not differ significantly from the underlying ones. The first of these samples brings a strong increase of *Cathaya* while *Pinus* pollen grains are noted; the second one shows a new increase of Taxodiaceae and of thermophilous broad-leaves pollen grains.

Spectra from the five uppermost levels of the Meleto clays show a decrease of subtropical and warm-temperate elements; the mesophylous element *Cathaya* increases, as well as the microthermal ones, particularly *Picea*. Macroflora studies reveal the prominent occurren-

ce of *Fagus* in the same levels (Roiron P., pers. comm. 1994).

The upper San Donato Sands is dominated by pollen grains of steppe elements, mainly *Artemisia* and a new increase of forest elements (particularly *Cathaya* and *Carya*) is recorded on its top.

Paleoenvironmental evolution.

The preliminary palynological data evidence different vegetational phases which took place during the deposition of the Castelnuovo succession.

During the development of the peat bog, starting about 3.1 Ma, the vegetation is dominated by forest elements such as Taxodiaceae, *Nyssa*, *Myrica*, *Engelhardtia*, while Pinaceae probably had a restricted distribution. Climatic conditions seem characterized by low seasonality and by high humidity and temperature. A humid subtropical, warm-temperate climate may be suggested, similar to the climate now characterizing South-eastern Asia. These conditions are in agreement with what is known from literature about this period (Suc et al., 1995a, 1995b). Subsequently the basin underwent a rapid and strong subsidence, the water level rose and a deeper lacustrine environment developed. The pollen flora shows a progressive reduction of tropical-subtropical elements, particularly evident in pollen spectra from the uppermost Meleto Clays. Here a decrease in temperaure is marked by the increase of highland elements (mainly *Picea*), among Pinaceae, and by the decrease of subtropical/warm-temperate elements. A forest vegetation, though, seems to have been still dominant.

A significant environmental change is recorded during the deposition of the upper San Donato Sands, characterized by episodes of ephemeral stream and terminal fans.

The first spectrum, characterized by herbaceous vegetation of steppe type, seems to reflect highly arid conditions.

The pollen assemblages from the Meleto Clays, representative of a forest vegetation, can be correlated with the Reuverian (Zagwijn, 1974; Suc and Zagwijn, 1983) whereas those of steppe type from the San Donato Sands can be correlated with the Praetiglian (Zagwijn, 1960) and the first glacial cycles following the onset of the Arctic glaciation dated at 2.6 Ma. This event witnessed the development of tundra in northern Europe (Zagwijn, 1960) and of steppe in the north-western Mediterranean area (Suc et al., 1995a, 1995b). In northern Italy a strong increase of highland taxa, mainly *Picea*, is found in the sections of Stirone (Bertini & Vannucchi, 1993) and Castell'Arquato (Lona, 1990), of the external Apennines. In these sections the absence of a dominantly herbaceous pollen flora could be related to local environmental conditions, although it could have been also produced by unfavourable sedimentary features.

In the uppermost part of the San Donato sands a new climatic amelioration, reflecting conditions of higher humidity and temperature (increase of *Cathaya* and *Carya*), could be ascribed either to an interstadial of Praetiglian or to the Praetiglian-Tiglian transition.

Conclusions

The fossil mammals found in the Castelnuovo dei Sabbioni deposits identify the normal polarity of the paleomagnetic record from the Meleto Clays with the Gauss Chron C2An.1n. The continuity of the section, the high reliability of the magnetic signature and the sampling resolution place the local mammal assemblage within the Kaena subchron (C2An.1r) dated as 3.10-3.17 Ma.

Palynological analysis points to a warm-humid climate drifting progressively to cooler conditions that, near the top, produced a significant increase in *Picea*, *Abies* and *Fagus*. Further upwards, at the top of the San Donato Sands, two closely spaced layers show two contrasting features, of a strongly arid climate followed by a warmer and humid one.

Pollen records for the Meleto Clays appear to have correlatives to the Reuverian of the biochronologic scale of Zagwijn (1960); those for the upper S. Donato Sands could indicate either the Praetiglian and the transition from Praetiglian to Tiglian or a stadial-interstadial fluctuation within the Praetiglian.

New light is shed on the beginning of the Villafranchian mammal age. The mammal association of the first sedimentary cycle in the Upper Valdarno developed in a warm-humid, subtropical climate. Since it seems unlikely that the faunal turnover giving rise to the Villafranchian fauna could occur in such a climate, the lower boundary of Villafranchian preceded the Kaena paleomagnetic event. A possible trigger for the turnover could be better identified in the cooling event picked by $\delta^{18}O$ anomaly at ca. 3.3 Ma.

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