

Bollettino della Società Paleontologica Italiana	36 (1-2), 1997	ISSN 0375-7633	5-22	1 pl.	Parma, Dicembre 1997
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Paleontological and sedimentological record in Pliocene distal alluvial fan deposits at Cava Toppetti (Todi, Central Italy)

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KEY WORDS - Sedimentology, Magnetostratigraphy, Palynology, Mammal fauna, Taphonomy, Late Pliocene, Tiberino Basin.

ABSTRACT - The Tiberino Basin is a Plio-Quaternary intermontane basin located in Central Italy (Umbria). This paper deals with the sedimentological, mammalofaunistic, and palynological aspects of the deposits of the Ponte Naja Formation (Late Pliocene), outcropping at Cava Toppetti and with the magnetostratigraphical data from the underlying Fosso Bianco Formation (Middle-Late Pliocene) outcropping at the same site.

In the Ponte Naja Formation, sheet flow deposits and paleosols constitute 98% of the sedimentological succession and they alternate with each other cyclically. The plausible short development time of the paleosols made it possible to identify each couplet as a high frequency cyclical depositional sequence.

From these sediments scattered, fragmented large and small mammal remains were found. Taking into consideration the inferred high sedimentation rate, the faunal assemblage may be considered as a local fauna which, owing to its taxonomic composition and in particular to the occurrence of the deer *Pseudodama* cf. *P. rhenana* can be attributed to the Middle Villafranchian. Paleomagnetic analysis of the underlying Fosso Bianco Formation, is in agreement with the mammal biochronology of the Ponte Naja Formation, restricting chronological attribution to the time interval of the Late Pliocene, more recent than the Reunion event, judging from the deposition of the alluvial fan deposits.

All the mammal bones occur in the paleosols, except for a scapula of a rhino which comes from sheet flow deposits.

The sheet-flow deposits have a rich and diversified pollen assemblage; paleosols are very poor in pollen grains, whereas Pteridophyta spores (mainly Pteridaceae) are abundant. The occurrence of selective degradation in some paleosols explains the strong difference between their palynomorph content and that of the sheet-flow deposits. Nevertheless, climatic influence cannot be ignored. Throughout the succession a complete climatic cycle and part of the following one can be established should further more detailed analyses support the climatic interpretation.

RIASSUNTO - [Documentazione paleontologica e sedimentologica in depositi pliocenici di conoide alluvionale a Cava Toppetti (Todi, Italia centrale)] - Il Bacino Tiberino è un bacino intermontano Plio-Quaternario localizzato in Italia centrale (Umbria). All'interno di questo bacino sono state identificate quattro unità litostratigrafiche: Formazione di Fosso Bianco (Pliocene medio-superiore), Formazione di Ponte Naja (Pliocene superiore), Formazione di S.Maria di Ciciliano (Pleistocene inferiore), Formazione di Acquasparta (Pleistocene inferiore).

In questo lavoro vengono presentati i risultati di analisi sedimentologiche, mammalofaunistiche e palinologiche condotte sui sedimenti della Formazione di Ponte Naja, affioranti nella località Cava Toppetti, integrati con i dati magnetostratigrafici provenienti dalla sottostante Formazione di Fosso Bianco che affiora nella medesima località.

Nella Formazione di Ponte Naja depositi di flussi non incanalati e paleosuoli rappresentano il 98% della successione sedimentaria, e per tutto il suo sviluppo si alternano ciclicamente. Il basso grado di maturità dei paleosuoli permette di identificare ogni coppia (deposito di flusso non incanalato-paleosuolo) come una sequenza deposizionale ciclica ad alta frequenza.

In alcuni livelli di questa successione sono stati rinvenuti resti frammentari di mammiferi che documentano la presenza di *Stephanorhinus* cf. *S. etruscus*, *Leptobos* sp., *Pseudodama* cf. *P. rhenana*, *Procapyrolus* sp., e *Apodemus* cf. *A. dominans*. Tenendo presente l'alto tasso di sedimentazione, i resti di mammiferi, seppure dispersi lungo una successione potente 150 m, possono essere considerati rappresentativi di un'unica fauna locale, che per l'associazione di taxa e soprattutto per la presenza del cervide *Pseudodama* cf. *P. rhenana* può essere riferita al Villafranchiano medio. L'analisi paleomagnetica dei depositi della Formazione Fosso Bianco, sottostanti a quelli della Formazione di Ponte Naja, sono in accordo con la posizione biocronologica desunta dai grandi mammiferi, e consentono l'attribuzione cronologica ad un intervallo temporale successivo all'evento paleomagnetico Reunion.

Tutti i resti fossili provengono dai paleosuoli, mentre la scapola di rinoceronte è stata rinvenuta nei depositi di flussi non incanalati. Alcuni reperti mostrano chiari segni di rosicchiature di roditori. Il confronto con altre associazioni fossili rinvenute nel Bacino Tiberino, permetterà il riconoscimento dei fattori tafonomici che influenzano le informazioni faunistiche, biocrono-

logiche e paleoecologiche.

I depositi di flussi non incanalati hanno restituito un'associazione palinologica ricca e diversificata; i paleosuoli sono spesso caratterizzati da scarsi contenuti pollinici, mentre sono abbondanti spore di Pteridophyta (principalmente Pteridaceae). Le differenze tra le due associazioni sono causate da processi di degradazione selettiva. L'influenza del segnale climatico è comunque presente. Le diverse fasi vegetazionali riconosciute possono essere considerate rappresentative della reale vegetazione; le variazioni di questa permettono di riconoscere nell'intera successione un ciclo climatico completo e parte del successivo.

INTRODUCTION

The Tiberino Basin is an intermontane basin with an Apenninic trend located in Central Italy (Umbria). It is made up of three main NNW directed branches (Text-fig. 1) with a total length of 110 km and a maximum width of 15 km. This paper deals with the south-western branch of the basin, where Basilici (1992) has recognized exposed continental deposits up to 600 m thick. This author has subdivided them into four lithostratigraphic formations: Fosso Bianco Formation (Middle-Late Pliocene), Ponte Naja Formation (Late Pliocene), S. Maria di Ciciliano Formation (Early Pleistocene), and Acquasparta Formation (Early Pleistocene).

The object of this work is the Ponte Naja Formation. The best outcrop of this formation is at the Cava Toppetti, a wide quarry located 1 km south of Todi (Text-fig. 1).

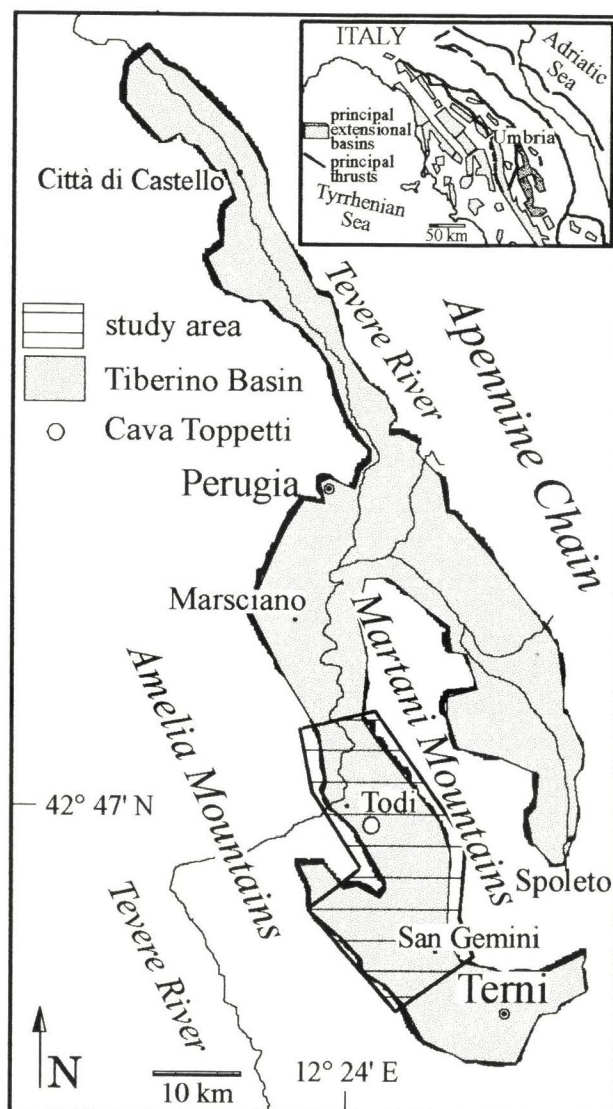
Late Pliocene mammal remains have been found within the alluvial fan deposits of the Ponte Naja Formation. A preliminary faunal list of the mammals has been reported in scientific literature (Basilici, 1992, 1995; Masini *et al.*, 1994; Sardella *et al.*, 1995) and attributed to the Early-Middle Villafranchian. Detailed studies of this fauna are presented in this paper and integrated with sedimentological and palynological data as well as with magnetostratigraphic data from the underlying Fosso Bianco Formation outcropping in the same locality.

SEDIMENTOLOGY

(by Basilici G.)

LITHOFACIES

In the Cava Toppetti (Text-fig.1) two formations are divided by an extensional fault: the Fosso Bianco Formation and the Ponte Naja Formation. The Fosso Bianco Formation is about 250 m thick, is made up of laminated silty clay deposited in an offshore lake system and has been the object of detailed sedimentary (Basilici, 1997), palynological (Basilici *et al.*, 1995; Pontini *et al.*, 1996) and magnetostratigraphical studies (Albianelli *et al.*, in



Text-fig. 1 - Location of the Tiberino Basin and of the Cava Toppetti locality. The study area is outlined with horizontal lines. In the upper sketch the principal extensional basins and the principal thrust fronts in Central Italy are shown.

prep.). The Ponte Naja Formation exposure is 150 m thick and 300 m wide, and consists mainly of clayey, sandy silt and silty clay (98%) with minor sand or sandy gravel (2%). Four lithofacies are recognised in the Ponte Naja Formation: a) clayey

sandy silt; b) silty clay; c) sand or sandy gravel; and d) sandy gravel. This work addresses the principal sedimentological characteristics of these facies; for a more detailed description and interpretation the reader is referred to Basilici (1995).

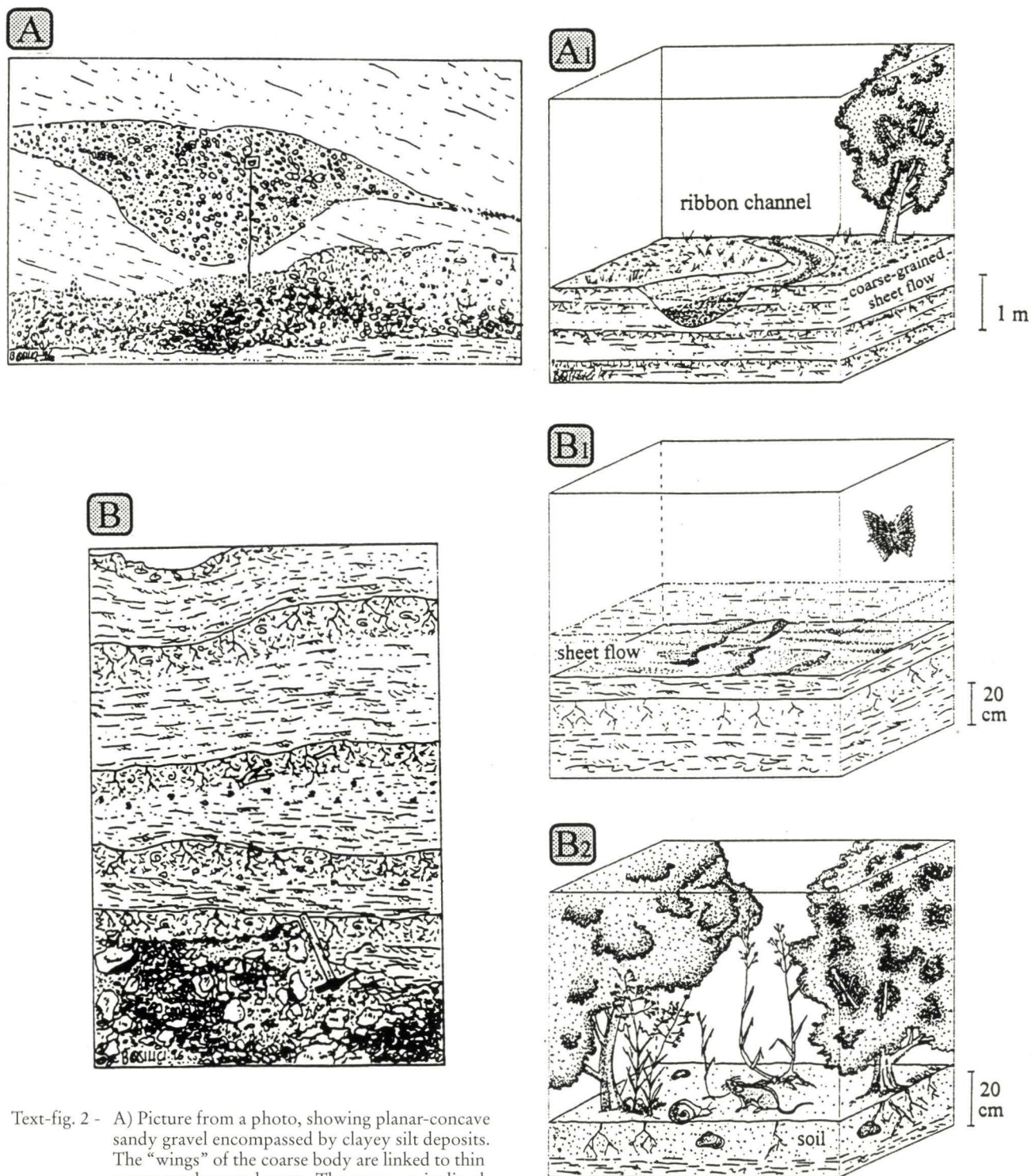
Clayey sandy silt (fine-grained sheet-flow deposit) - Bluish grey, clayey sandy silt forms rectangular-shaped strata (*sensu* Bridge, 1993) which range from 0.3 m to 3 m in thickness, with an average of 1 m (Text-fig.2B). These beds are laterally continuous for more than 100 m and, in a few cases, it is possible to observe triangular-shaped lateral ends (*sensu* Bridge, 1993) with a planar bottom and an inclined top (up to 1°). The bottom of each stratum is sharp but non-erosive, whereas the top grades into the overlying silty clay facies. The most frequent sedimentary structures are planar or undulated, discontinuous, parallel silt or very-fine-grained sand laminae which alternate with clayey silt laminae. Current ripple laminations, climbing ripples and trough cross-stratifications up to 10 cm high can also be observed, as well as local convolute laminations created by plastic deformation of partially liquefied sediment. The strata show normal grading from sandy silt to clayey silt. Neither erosion surfaces nor sharp grain-size variations are observed within the single grading bed, testifying that each bed was formed by a single depositional event. Paleocurrent data from current ripples and trough cross-stratifications indicate paleoflows towards the NE. In many cases the lower portion of the strata displays clayey-silt-filled vertical tubes which are 1-3 mm in diameter and up to 50 cm high. These structures, interpreted as bioturbation escape traces, arise out of the silty clay facies and cut the sedimentary structures of the clayey sandy silt facies. This is the most wide-spread Ponte Naja Formation facies (approximately 90%) and it alternates cyclically with the silty clay facies (Text-fig.2B).

Grain-size distribution suggests that the depositional flows were of low energy, while the sedimentary structures indicate depositional processes characterised by settling and, secondarily, by weak basal traction (Text-fig.2B1). Other sedimentological characteristics indicate a high sedimentation velocity from decelerating, highly-concentrated flows: i) silty clay laminae, which always alternate with planar or undulated, parallel, discontinuous laminae and sandy cross-laminations, are produced by normal inhomogeneities in the flow during a continuous supply of fine suspended sediment (Hubert & Hide, 1982); ii) the presence of clim-

bing ripples testifies to deposition from flows having an abundant suspended load (Jopling & Walker, 1978; Ashley *et al.*, 1988); iii) convolute laminations are typical syn-sedimentary deformations of water-saturated deposits formed in high-velocity sedimentary conditions (Ray, 1976); iv) bioturbation escape traces may be interpreted as animals escaping burial by rapid sedimentation. The flows were not channelled, as shown by sedimentary bodies which extended for more than 100 m with planar, non-erosive bottoms. In addition, the occurrence of a few triangular layer ends indicates that the depositional bodies had weak wedge or lobe ends, most likely forming flat, widespread lobes ($>10^4 \text{ m}^2$). Based on inferred depositional mechanisms and the geometry of the depositional bodies, this facies is interpreted as being sheet-flow deposits formed by decelerating, low-energy floods carrying a heavy, fine-grained suspended load.

Silty clay (paleosol) - Massive, dark-bluish-grey silty clay has a volumetric distribution of 8%, always alternates with the clayey sandy silt facies (Text-fig.2B), and forms rectangular strata (*sensu* Bridge, 1993) which can be traced over the entire width of the Cava Toppetti ($>100 \text{ m}$). The bottom boundary is always diffuse whereas the top boundary is sharp, a distinction accentuated by a grain-size increase and the appearance of sedimentary structures. The thickness varies from a few cm to 60 cm, with an average of 15 cm. Based on many characteristics, this facies is interpreted as being a paleosol (Text-fig.2B2).

According to Retallack (1988, 1990) the main aspects which make it possible to recognise paleosols in sedimentary successions are: root traces, soil structures, soil horizons, animal remains, bioturbation and massive beds. Within the silty clay facies root traces are abundant, consisting of 1-3 mm diameter carbonaceous cylinders which taper and branch downward. Locally large carbonaceous root traces, up to 5 mm in diameter, are found with a characteristic concertina-like outline due to the compaction of surrounding sediments. Calcareous glaebules (Birkeland, 1984), that is, irregular-shaped calcareous nodules, from 1 to 20 mm in size can be recognised as soil structures within the silty clay facies. The calcareous glaebules are distributed in the lower portion of the facies with a distribution of $<10\%$, indicating periodic drainage of the soil. Although real soil horizons do not exist in this facies, there is a weak colour differentiation between a darker-upper and a lighter-lower portion. With regard to this,



Text-fig. 2 - A) Picture from a photo, showing planar-concave sandy gravel encompassed by clayey silt deposits. The “wings” of the coarse body are linked to thin coarse sandy gravel strata. The strata are inclined towards the right, the Jacob’s stick is 1.5 m high.

A1) The planar-concave sandy gravel is interpreted as ribbon stream channels, flowing on the distal part of an alluvial fan. The stream channel did not have lateral migration. The laterally thin sandy gravel strata are coarse sheet flow deposits.

B) Silty clays (darker) alternated with clayey sandy silts (lighter). They form rectangular strata up to 100 m long. The hammer is 35 cm high. Picture from a photo.

B1) The clayey sandy silts are produced by fine grained sheet flows during cyclic floods.

B2) Silty clays represent paleosols developed on the upper part of clayey sandy silts. The pedogenesis developed between one sheet flow and another and it allows for the recognition of the recurrence time of the sheet flows on the distal alluvial fan.

Basilici (1995) observed that the darker colour is linked to organic matter content, which is normal considering that organic activity is concentrated in the upper part of the soil. As well as organic matter, animal remains and trace fossils are also conserved in the upper portion of this facies, including terrestrial snails and clay-filled tubes which are 2-3 mm in diameter and up to 5 cm long; occasionally disarticulated mammal bones (primarily teeth and antlers) have also been found, similar to those reported for Eocene paleosols by Bown and Kraus (1981). Apparent massive beds, that is, beds lacking any sedimentary structures, is a consequence of initial pedogenetic processes which destroy the genetic characteristics of the parent material (Wright, 1989). Analogous textural aspects and diffuse lower contacts with the clayey sandy silt facies indicate that pedogenesis developed on the latter facies, between two sheet flow events. The presence of carbonaceous roots and the relatively high organic-matter content (Basilici, 1995) indicate that the soil was dominantly hydromorphic; however, calcareous nodules testify to occasional drainage conditions. It is likely, therefore, that the water table was near the ground surface and that it oscillated seasonally. Lack of well-developed soil features (such as clearly-defined horizons, peds and cutans) and the reduced thickness of the paleosols, means that pedogenesis developed over a very short time, probably less than 10^3 y, as described by Wright (1989). About 95 cycles of alternating clayey sandy silt facies (sheet flow deposits) and silty clay facies (paleosols) can be observed in the 130 m-thick stratigraphic section.

Planar-concave sandy gravel (stream ribbon channel) - Sandy gravel makes up 1-5 m thick and 1.5-38 m wide, planar-concave bodies with a width : thickness ratio (perpendicular to paleo-flow direction) of $< 8:1$ (Text-fig.2A). In outcrop they have a distribution of 1.5% and are completely encompassed by fine-grained sediments. The concave bottom is erosive, the planar or weakly convex top is sharp and in a few cases sandy gravel "wings" may be observed laterally at the top (Text-fig.2A). The sandy gravel has a clast-supported framework, is polymodal (up to boulder sized) and the sandy matrix is abundant (up to 30% of the volume). Subrounded or subangular gravel originate from Cenozoic limestone units which outcrop a few kilometres towards the west. Normally the sandy gravel facies is disorganised, although in a few cases it is possible to observe a(t) b(i) imbrication (*sensu* Harms *et al.*, 1975) and

the accumulation of gravel around an exceptionally large clast, similar to that documented by Brayshaw (1984). Where the sandy component is higher, several trough cross-stratifications, up to 20 cm high, have been observed. Normally each planar-concave body seems to be filled by a single depositional event; however, occasionally, thin strata of sandy silt divide sandy gravel strata, indicating different depositional events in a single body. Imbrications and trough cross-stratifications indicate that paleoflows were from the west.

This facies is interpreted as being stream channels based on overall geometry, erosive bottoms and textural characteristics (Text-fig.2A1). The channels had a ribbon shape (*sensu* Friend *et al.*, 1979; Friend, 1983), which indicates that lateral migration was impossible and that natural channel shifting occurred via avulsion after the channel was completely filled. The common massive beds and the rare, traction-produced structures suggest that the depositional flows were normally unable to organise the clasts because of high flow density and/or rapid accumulation rates. Moreover, the grain size distribution suggests a high flow competence. Morison and Hein (1987) described similarly disorganised, gravelly facies and interpreted them as being deposited by channelled, sediment-laden gravelly flows having a consistently large amount of suspended sediment. Analogous facies could be produced by hyperconcentrated flows, as described by Smith (1986) and Costa (1988). The cluster bedforms, as interpreted by Brayshaw (1984), are the result of major floods. During waning or more-diluted flows, sediment traction could rework and organise the gravel and sand, yielding imbrication and trough cross-stratification. Gravel composition, poor clast rounding and paleocurrent data all indicate the clast source area to be restricted to an area located 2-15 km away from the Toppetti quarry towards the WSW.

Rectangular sandy gravel (coarse-grained sheet-flow deposit) - Polymodal, clast-supported, unsorted, sandy gravel makes up this facies. The strata have a rectangular-shape (*sensu* Bridge, 1993), are 20-30 cm thick on average and extend laterally (with minor local breaks) for up to 80 m. This facies is contained within the clayey sandy silt facies and has sharp upper and lower contacts. In general no particular fabric is observed in the sandy gravel except rare clast imbrications, which indicate paleoflow from the SW. Clast rounding and composition are similar to the planar-concave sandy gravel facies, although the grain-size is lower. In several cases this facies joins laterally

with the “wings” of the planar-concave sandy gravel facies, indicating a close genetic relationship (Text-fig.2A).

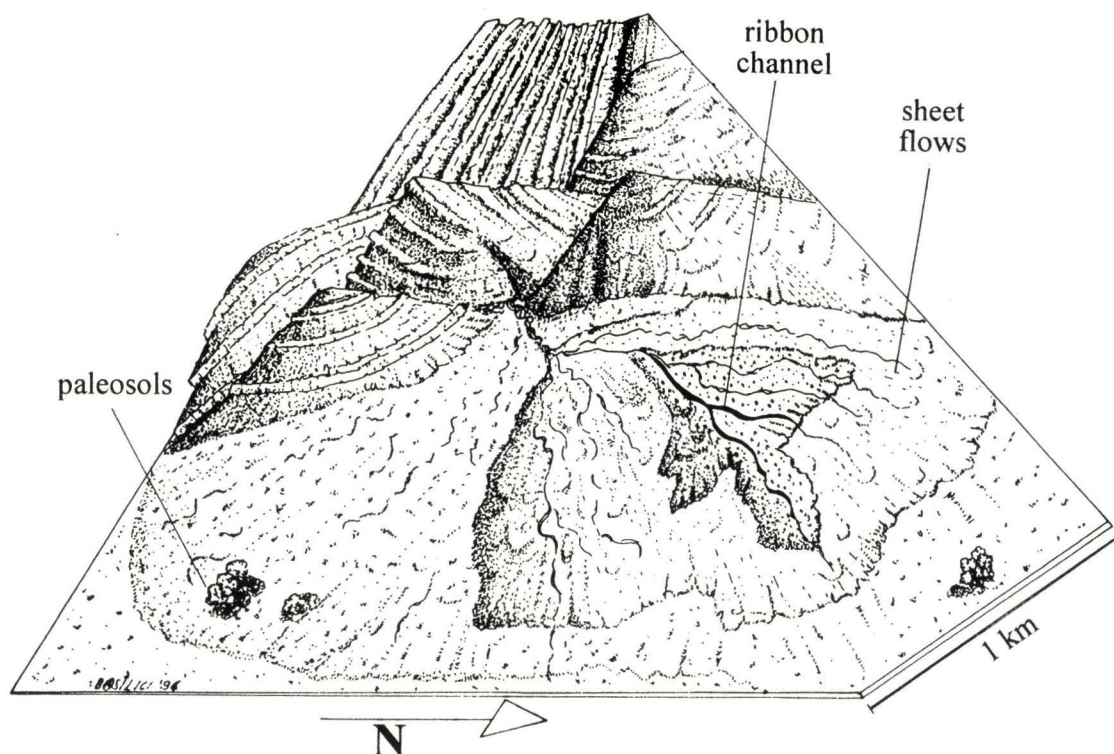
Strata geometry, massive beds and textural characteristics suggest that widespread, high-concentrated sediment-laden flows yielded these deposits. Moreover, as rectangular sandy gravel facies and planar-concave sandy gravel facies have clasts with the same characteristics and pass laterally from one to the other, it may be concluded that the rectangular sandy gravel deposits were produced by sheet flows emanating from the ribbon channel (Text-fig.2A1) when they were completely filled (Stear, 1983).

DEPOSITIONAL ENVIRONMENT INTERPRETATION

The depositional system was dominated by the clayey sandy silt facies, therefore low-energy fine-grained sheet-flows were the main sedimentary mechanism. They formed tabular- or lobe-shaped fine-grained bodies that underwent pedogenesis on their upper surfaces (silty clay facies) until the next sheet flow sealed the soil. Planar-concave sandy gravel facies define channelled flow in small ribbon channels. It is likely that highly-concentra-

ted, suspended-sediment floods originated from these channels, spreading out on the interchannel areas and producing low-energy fine-grained sheet floods (clayey sandy silt facies). The ribbon channels were filled by high energy flows (similar to hyperconcentrated flows) that deposited disorganised sandy gravel facies. When the channels were completely filled, gravelly flows left the bed-channel and produced coarse-grained sheet flows (rectangular sandy gravel facies).

Other important observations include the following: i) paleocurrent data, gravel composition and clast rounding indicate that paleoflow was from the WSW, that is from a bedrock area just a few kilometres away from the outcrop zone; ii) ribbon stream-channel paleocurrents are perpendicular to the bedrock boundary of the Pliocene Tiberino Basin; iii) the sedimentary succession is dominated by non-channelled deposits; iv) the few ribbon stream channels are characterised by high-sediment-load gravelly flows, similar to hyperconcentrated flows (Smith, 1986; Costa, 1988); v) the Ponte Naja Formation is restricted to 5 km² around the town of Todi; vi) the neighbouring areas to the east of the Ponte Naja Formation depositional system were dominated by a deep



Text-fig. 3 - Paleodepositional reconstruction of the Ponte Naja Formation, at the Cava Toppetti, near Todi. The facies described correspond to the distal part of an alluvial fan formed on the eastern margin of the south-eastern branch of the Tiberino Basin. The complete alluvial fan was 5-10 km² wide.

lacustrine environment (Basilici, 1997).

Taking all of these points into consideration, as well as the depositional picture outlined above, it is possible to interpret the Ponte Naja Formation as having been formed in the distal part of a lacustrine-margin alluvial fan (Text-fig.3). This zone was dominated by fine sediments, most flows were non-channelled and the few occurring channels had a ribbon shape and a short life (Nilsen, 1982). Biostratigraphic data indicate a correlation between the Ponte Naja Formation and the Fosso Bianco Formation (the silty clay unit formed in a deep lake) and allow the author to interpret the alluvial fan (Ponte Naja Formation) as the coastal depositional area of a 60 km-long Pliocene lake.

Sedimentological analyses can give important insights into the rate of sedimentation. Wright (1989) determined that pedogenetic horizons and structures appear in paleosols after at least 10^3 y of pedogenesis; as the Ponte Naja Formation paleosols do not have these characteristics they probably evolved for a period of less than 10^3 y. In 130 m of stratigraphic succession, the occurrence of 95 paleosols indicates a sedimentation rate of >1.3 mm/y. This information would be of great use for biostratigraphic or biochronologic studies.

MAGNETOSTRATIGRAPHY

(by Albanielli A. & Napoleone G.)

Paleomagnetic investigations were carried out in the Fosso Bianco Formation outcropping in Cava Toppetti stratigraphically below the PNF. The study involved 107 m of the succession. As regards sampling, a constant spacing of 1 m was considered to be sufficient for detailed checking of the continuous evolution of the paleomagnetic vector during the deposition, and each rapid transition of polarity.

The magnetic properties of the rock were measured on a cubic sample of 12 cm^3 at the Magnetic Laboratory of EHT in Zurich. Natural remanent magnetisation (NRM) proved to be rather high, oscillating between 0.1 and 170 mA/m (average 19 mA/m), while susceptibility was maintained between 1 and $26 \cdot 10^{-4}$ Unit SI (average 5.5). Thermal demagnetisation of NRM proceeded up to the complete removal of remanent magnetisation, usually between 350°C and 500°C ; at the same time, monitoring of variations in magnetic susceptibility allowed us to verify that during this phase substantial changes in the magnetic mineralogy did not occur. Samples with both normal and reversed magnetic polarity were identified; in both cases, remanent magnetisation remained constant

at 100°C until the end of thermal treatment. By means of the characteristic directions obtained in this way, the latitude of the virtual geomagnetic pole for each sample was calculated, defining a magnetostratigraphic scale consisting of two normal and two reversed magnetozones. The first normal magnetozone extends from the base of the sampling up to 44 m, followed by the reversed one at 101 m. The second normal magnetozone extends between 102 m and 105 m. The succession stops with a reverse polarity (Text-fig. 4).

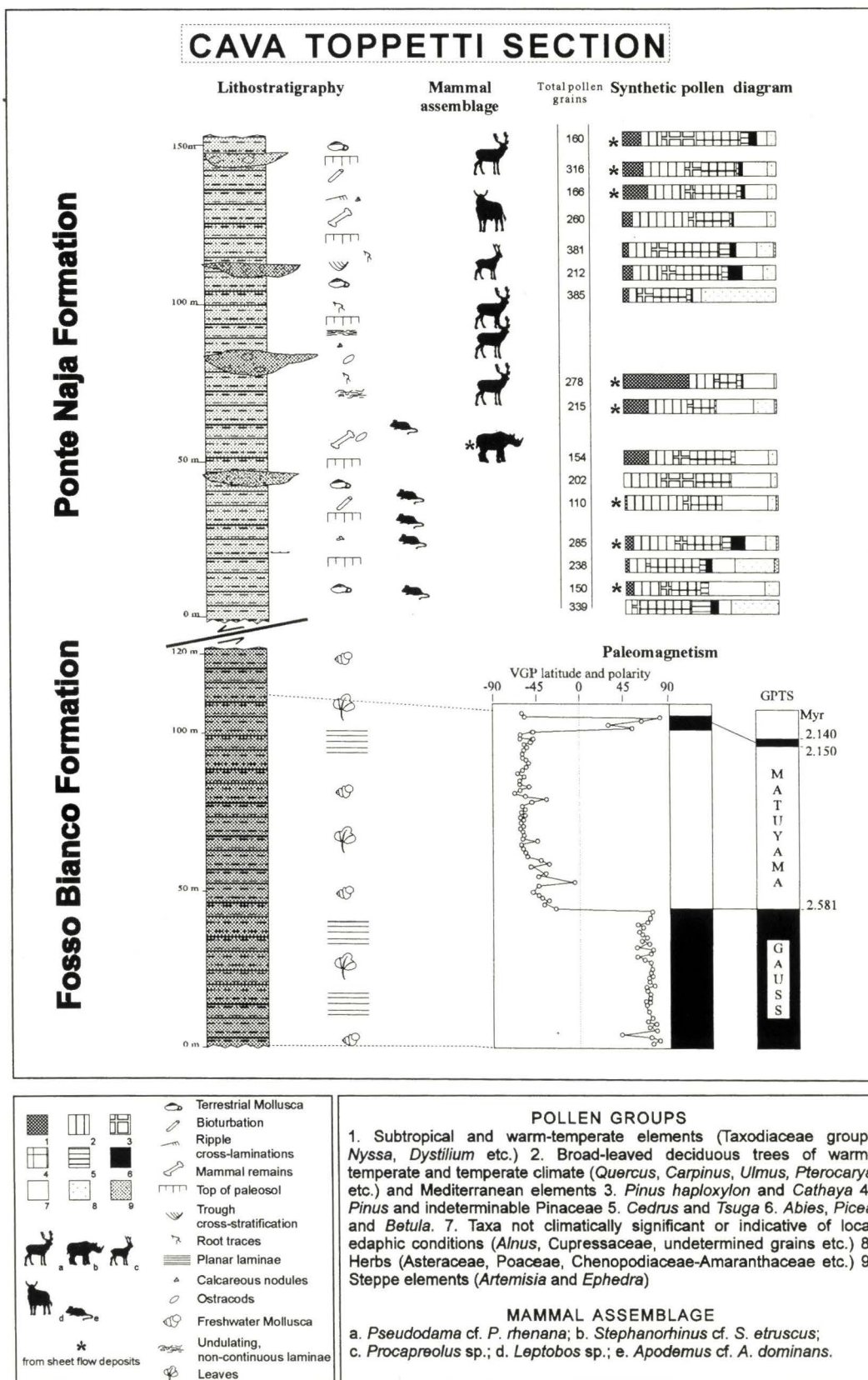
The paleomagnetic scale was correlated to the Geomagnetic Polarity Time Scale (GPTS) of Berggren *et al.* (1995); taking into account the paleontological data from the Ponte Naja Formation, the transition occurring at 44 m corresponds to the top of the normal Chron Gauss, and the normal magnetozone between 102-105 m to the Reunion event. The succession of Fosso Bianco in Cava Toppetti therefore refers to the Middle-Late Pliocene, and its mean apparent rate of sedimentation can be estimated at about 150 mm/ky. Consequently the PNF is more recent than the top of the Reunion event (2.14 My; Berggren *et al.*, 1995).

PALYNOLOGICAL ANALYSIS

(by Pontini M. R. & Bertini A.)

Palynological analyses were carried out on the paleosols as well as on the sheet flow deposits (clayey sandy silt) of the Ponte Naja Formation. In some cases, the paleosol top and the subsequent sheet flow deposit bottom were sampled. The main aim was to analyse the different palynological assemblages and to separate the climatic signals from the taphonomic ones. Only 16 of the 32 treated samples allowed for a sufficient count of pollen grains and spores. In any case, the large stratigraphic distance between the samples (about 9 m on average up to 25 m) does not influence the results of these preliminary analyses (Pontini, in progress). In fact, on the basis of both the soil maturity and the development times of the entire alluvial fan (about 100,000 years, Basilici, 1995) we can assume mean time intervals between the samples of about 6,000 years and always less than 20,000 years. Pollen spectra from the 8 paleosols and 7 sheet flow deposits are shown in Text-fig. 4.

From the bottom, paleosol spectra are characterized by very high values of herbs (Asteraceae Cichorioideae mainly) whereas Taxodiaceae and the broad-deciduous elements (*Quercus*, *Carpinus* and *Pterocarya*) are very scant. Pinaceae (*Pinus diploxylon* type and indeterminate Pinaceae) are



Text-fig. 4 - Cava Toppetti section.

on the whole well represented. In contrast, the intercalated spectra from sheet flow deposits do not show significant values of herbs whereas broad-leaved deciduous elements (*Quercus*, *Pterocarya*, and *Ulmus* mainly, the latter with percentages of about 8,5 %) are better represented. Among Pinaceae, altitudinal elements (*Cedrus*, *Picea* and *Abies*) reach relatively high values (over 15%). Among steppe elements, *Ephedra* reaches its maximum (2.1%) here. *Artemisia* is also present as well as in the underlying paleosols. In the middle part of the succession the main features are the decrease in herbs to values of about 5% in the paleosols and a great increase in Taxodiaceae (*Taxodium* type) in the sheet flow deposits. A maximum increase in herbs (Asteraceae Cichorioideae mainly, and A. Asteroideae and Poaceae) and a new decrease in Taxodiaceae are recorded in the paleosol at altitudes of 110.6 m. The upper part of the succession is characterized by a good representation both of Taxodiaceae and broad-leaved deciduous elements (*Pterocarya* reaches percentages of over 20%), in paleosols as well as in sheet flow deposits. Repeated fluctuations in these elements were recorded. At the top of the sequence, among the Pinaceae a significant increase in *Cathaya* occurred.

As a whole, pollen spectra show very diversified pollen assemblages; the main question is to evaluate whether these variations can be linked to climatic changes (i.e. glacial/interglacial cycles) or rather to the different mechanisms of dispersion, deposition and preservation affecting the paleosols and sheet flow pollen assemblages. An interaction of all these factors is also very likely.

Taphonomic factors - Palynological assemblage from paleosols is known to derive from pollen rain besides the parent material. Moreover, the former can be affected by a selective destruction as a consequence of degradation processes, developed during pedogenesis (Cushing, 1967; Havinga, 1984; Accorsi, 1986; Bryant *et al.*, 1994). The results of a prolonged and selective degradation can be observed in the sporomorphs from the paleosols of the middle part of the succession, represented exclusively by Pteridophyta spores, more resistant to degradation than are other pollen grains. Palynological assemblages from the upper part are characterized by richer and better preserved palynological assemblages than the former, suggesting shorter pedogenesis times. This observation agrees with the sedimentological results (Basilici, 1995) which indicate an increase in the frequency of the sedimentary processes and

a diminution of paleosol maturity between the lower and the upper part of the succession. In the latter, more frequent episodes of sedimentation prevent protracted pedogenetic processes.

Usually, the instantaneous formation of the sheet flow deposits assures a palynological assemblage consisting predominantly of water-transported pollen. Our palynological spectra do not seem to indicate an anomalous presence of pollen grains concentrated by sorting during deposition, such as bigger or saccate grains (Holmes, 1994; Brush & Brush, 1994). This fact is not surprising: the spreading of the flux in the interchannel plain causes a loss of energy and a non-selective deposition of the whole pollen load.

Numerous sedimentological indications suggest a catchment basin less than 100km² in extension (Basilici, 1995); consequently the vegetation close to the sedimentation point yielded palynological assemblage from the sheet-flow deposits. The high percentages recorded in these layers of *Picea*, *Abies* and *Cedrus* compared with the rest of the succession can be related to the presence of a mountain forest not too distant and to low altitudes.

The strong occurrence in some paleosols of Asteraceae Cichorioideae and their absence or paucity in the sheet flow deposits suggest their dominance is not linked to water transport. At the same time, selective degradation processes are ruled out by the very high pollen concentration as well as by a high species richness (Delcourt & Delcourt, 1980; Hall, 1990). An *in situ* presence of these entomophilous plants is therefore the most likely hypothesis and it allows us to verify a climatic explanation.

Climatic inferences - Bearing in mind all the above-mentioned bias factors, climate changes can be evoked to explain the differences between paleosol and sheet flow pollen assemblage from the bottom and the upper part of the succession. Two forest phases (i.e. interglacial) seem to be present in correspondence both to sheet flow deposits and to paleosols, whereas the development of open vegetation (i.e. glacial) seems to have been recorded only in the paleosols (two main phases).

MAMMAL ASSEMBLAGE

(by Abbazzi L., Masini F., Gentili S., Ambrosetti P., Argenti P.)

SYSTEMATICS

Although represented by very few remains dispersed in several beds within the succession,

the mammal assemblage is fairly diversified. The following taxa have been identified: *Stephanorhinus* cf. *S. etruscus*, *Leptobos* sp., *Pseudodama* cf. *P. rhenana*, *Procapreolus* sp., and *Apodemus* cf. *A. dominans* among the micromammals.

Stephanorhinus cf. *S. etruscus* (Falconer, 1868)

Material: articular end of a left scapula broken at about half length, collected from sheet flow deposits at 55 m. Pl.1, fig. 1.

This single specimen indicates a small-sized rhino in the Cava Toppetti. The size (length of distal end=54.6 mm) and the morphology of the specimen agree with those of *Stephanorhinus etruscus* from the Upper Valdarno (data according to Fortelius et al., 1993). In particular the slender aspect, the morphology of the glenoid cavity and the supraglenoidal tubercle which is stretched cranially, confirm this attribution. However, since we deal with a single poorly diagnostic element systematic reference is made with reserve.

Leptobos sp.

Material: an atlas from sediments of paleosol at about 121 m. Pl. 1, fig. 2.

This single specimen (maximum height about 80 mm; width of the medullar cavity at distal end: 52 mm) indicates a bovid, possibly a very large *Leptobos*. This element does not allow a specific determination.

Pseudodama cf. *P. rhenana* (Dubois, 1905)

Material: a proximal fragment of a left shed antler at 93.4 m, a tine at 128 m, a distal antler fragment at 75.4 m, a left D\3 at 34 m, a labial fragment of right P/4 and a third phalanx at 90-95 m, are from paleosols. Pl. 1, fig. 3 - 8.

This deer is the best represented taxon among the macromammals. The basal antler found at 93.4 m is the most significant specimen for systematic purposes. This specimen is characterised by a first tine which is slightly curved, inserted quite high with respect to the burr, and which forms a narrow angle with the beam (Tab. 1; Pl. 1, fig. 3). The first tine and the beam lie approximately on the same plane in the proximal part of the antler, then the beam gently bends outwards, while the first tine bends inwards. The position and orientation of the first tine, the almost straight course of the beam, the angle between the first tine and the beam, and the markedly concave area at the insertion of the first tine, are characteristic of the less

derived species of the clade *Pseudodama*. Although the proximal parts of the antler provide scant diagnostic elements for distinction among plesiomorphic species of this genus, we can rule out our specimen as belonging to *P. pardinensis*, which is characterised by a more massive aspect of the first tine and of the beam, by a narrower insertion angle of this tine and by a straighter proximal part of the beam. The features of the specimen of Cava Toppetti agree with those of *P. lyra* and *P. rhenana* (= *philisi*).

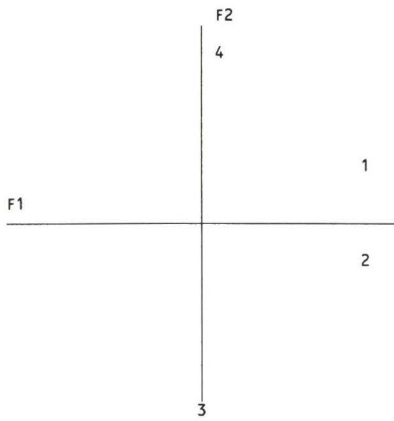
In order to achieve a better characterisation of this specimen, the antler from Cava Toppetti was quantitatively compared with antlers of *Pseudodama* recovered in several Plio-Pleistocene Italian sites which refer to the Late Villafranchian (*P. nestii nestii* from Olivola and Upper Valdarno; *P. nestii eurygonos* from Upper Valdarno; *P. nestii farnetensis* from Val di Chiana; *P. nestii* ssp. from Cava Pirro-Dell'Erba), to the Early Galerian mammal ages (*P. nestii* ssp. from Colle Curti). *P. ischnoceros* from the French locality of Blassac which refers to the Late Pliocene-Early Pleistocene (Boeuf et al., 1992), was also considered. The morphology of the basal part of the antlers was analysed by a factor analysis performed on the four measurements which best describe the differences among the populations, namely the antero-posterior and transversal diameters of the burr (APD-burr and TD-burr), the distance between the insertion of the first tine and the burr (1st branch), and the angle between the first tine

APD- burr	51	TD-1 ^o tine	21
TD- burr	50	1 ^o branch	72
APD- beam1	41.5	tine length1	185
TD- beam1	30	tine length2	190
APD- beam2	30	angle1	55°
TD- beam2	27	angle2	124°
APD-1 ^o tine	24	angle3	111°

Tab. 1 - Measurements (in mm) of proximal left antler of *Pseudodama* cf. *P. rhenana*.

Key: APD-burr= antero-posterior diameter of the burr, TD-burr= transversal diameter of the burr, APD-beam1= antero-posterior diameter of the beam above the burr, TD-beam1= transversal diameter of the beam above the burr, APD-beam2= antero-posterior diameter of the beam above the 1st tine, TD-beam2= transversal diameter of the beam above the 1st tine, APD-1st tine= antero-posterior diameter of the 1st tine, TD-1st tine= transversal diameter of the 1st tine, 1st branch= distance between the 1st tine and the burr, tine length1= length of the 1st tine, tine length2= curve length of the 1st tine, angle1= angle between first tine and beam, angle2= angle between beam and burr, angle3= angle between the 1st tine and the burr.

Symbols	Variable	Communality	Factor1	Factor2	Cum
1	APD-burr	.91971	.92568	.25068	
2	TD-burr	.93491	.96071	-.10936	
3	1°branch	.82764	.06774	-.90722	
4	4°angle	.79520	.18580	.87217	
Eigenvalue			1.98004	1.49744	3.47748
Pct of variance			45.47	41.46	86.93

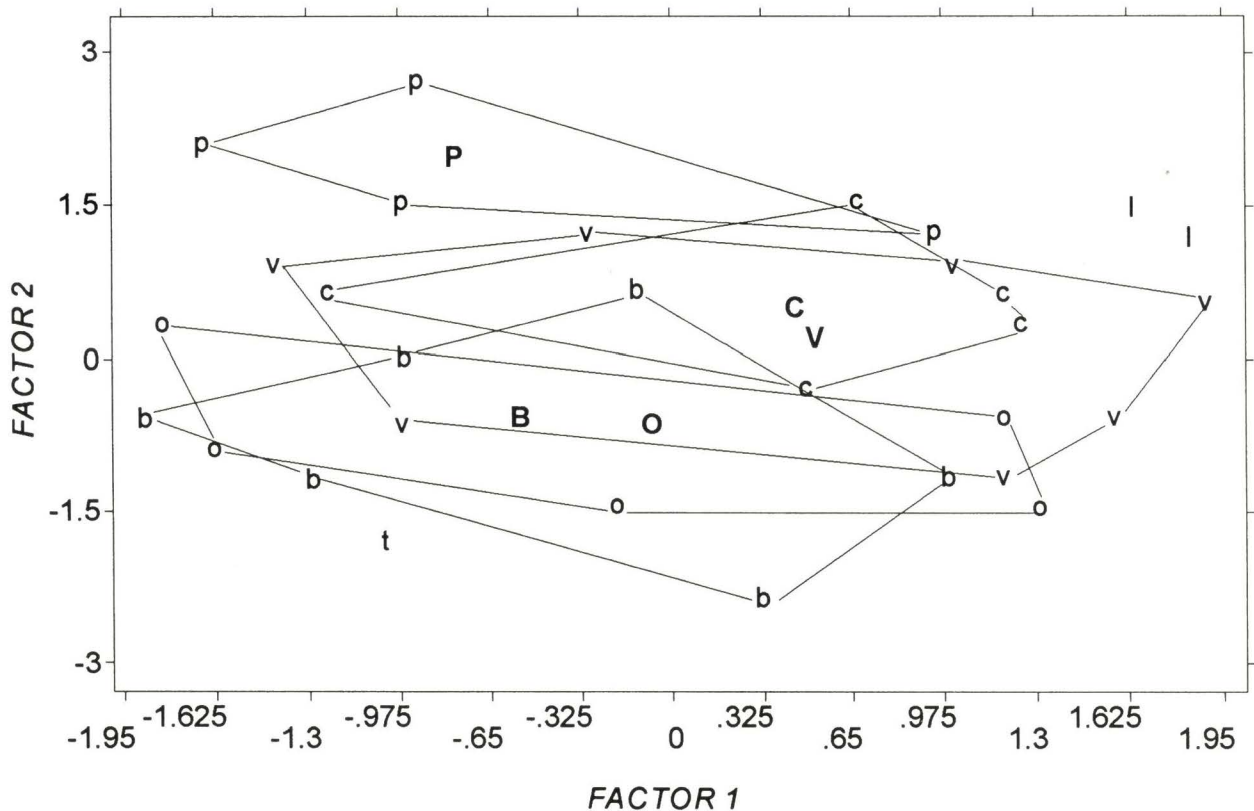


Text-fig. 5 - Statistics of Varimax factor analysis for *Pseudodama* data.

and the beam (angle 1).

Two factors with eigenvalues >1, which account for 86.93% of the total variance, were extracted from the correlation matrix. Varimax rotation was then used to facilitate the interpretation of the morphological significance of the axes (Text-fig. 5). The first factor, which explains 45.47% of the variance, expresses the size of the base of the antler (diameters of the burr). The second factor, which explains 41.46% of the variance, expresses the morphological variations relative to the angle of the first tine with respect to the beam, and to the distance between the first bifurcation and the beam. Morphotypes whose basal tine is inserted close to the burr, and whose angles are broad, have higher scores of this factor.

In Text-fig. 6 one can note an increase in factor 2 from the older to the younger populations of *Pseudodama*. The position of the specimen from Cava Toppetti (symbol t), is characterised by a low value of factor 2, which confirms its primitive morphology in comparison with the other samples.



Text-fig. 6 - Factor scores scatter diagram. Legend: o= *Pseudodama nestii nestii* from Olivola, v= *P. nestii nestii* and *P. nestii eurygonos* from Upper Valdarno, c= *P. nestii farnetensis* from Val di Chiana, p= *P. nestii* n. ssp. from Cava Pirro-Dell'Erba, l= *P. nestii* n. ssp. from Colle Curti; data from Colucci *et al.*, in progress; b= *P. ischnoceros* from Blassac (data from Boef *et al.*, 1992); t= *P. cf. P. rhenana* from Cava Toppetti (Ponte Naja Formation). The bold symbols correspond to the centroids of the samples; lines indicate the area of dispersion of the sample.

Taking into account the occurrence of *Stephanorhinus* cf. *S. etruscus*, the stratigraphic position of the succession and the paleomagnetic data of the underlying Fosso Bianco Formation, we are inclined to attribute the deer from Cava Toppetti to *P.* cf. *P. rhenana*. This species, well documented in the French localities of the Middle Villafranchian (e.g. Sénèze, Saint Vallier, Heintz, 1970, cfr. Boeuf *et al.*, 1992), also occurs in Italy at Costa S. Giacomo (Azzaroli, pers. comm.), a locality considered equivalent in age to Sénèze by Torre *et al.* (1992).

Procapreolus sp.

Material: a basal fragment of a shed antler broken off a few centimetres from the burr (110.5 m, paleosol). Pl. 1, fig. 9.

The very small size of this single sample (APD-burr=25.7 mm; TD-burr= 24.2 mm; APD-beam=17.1 mm; TD-beam= 15.1 mm), and its morphology testify to a Capreoline in the Cava Toppetti fauna. The evident pearl of the burr and the section of the beam confirm to the genus *Procapreolus*. This sample is too fragmentary for specific determination.

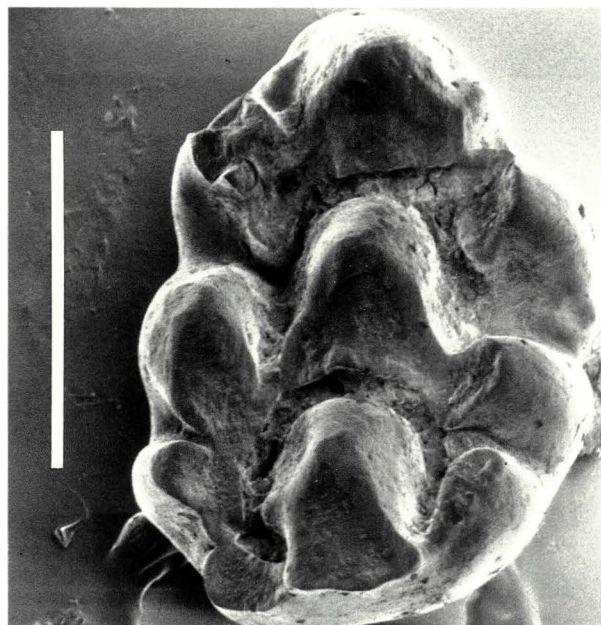
The genus *Procapreolus* is characteristic of the Ruscinian Mammal age and it occurs in the Early Villafranchian with the species *P. cusanus*. It is documented in Italy by scant finds in the localities of the Triversa and Montopoli units (Abbazzi *et al.*, 1995). Its occurrence at Cava Toppetti indicates the survival of this genus in the assemblages of the Middle Villafranchian.

Apodemus cf. *A. dominans* Kretzoi, 1959

Material: at least five incisors and five molars (right M1/, at 50 m; a fragment of M1/, at 9 m; left M/1, at 30 m; right M/3, at 9 m; a fragment of M2, at 27 m) were recovered in different paleosols. Text-fig. 7.

The most interesting remains are a first upper left molar and a first lower right molar. The teeth are without traces of digestion. These molars, having a morphology and size the same as the ancient forms, refer to *Apodemus* cf. *A. dominans* (Pasquier, 1974).

In the right M1/ (length = 1.87 mm, width = 1.08 mm) the anterior tubercles are joined, the medians are more hardy, and four supplementary tubercles occur. The tooth is well preserved and slightly worn. In the left M/1 (length = 1.58, width = 1 mm) the two anterior tubercles are par-



Text-fig. 7 - SEM micrographs of right M1/ of *Apodemus* cf. *A. dominans* from the paleosols of the Cava Toppetti (Ponte Naja Formation). Scale bar=1 mm.

tially blended with the anterior supplementary tubercle. The tooth has five external supplementary tubercles, the first and the second are blended. The tooth is not worn.

The genus is not very significant for biochronology.

BIOCHRONOLOGY

Even though fossil remains are distributed along a stratigraphic section about 150 m thick, the inferred high rate of sedimentation allows us to consider it as a local fauna for biochronological purposes. Moreover, in spite of the scarcity and the fragmentary nature of the mammal remains, which do not allow a very precise systematic identification of the species, the occurrence of *Stephanorhinus* cf. *S. etruscus* and *Pseudodama* cf. *P. rhenana*, suggests that the fauna is older than the Olivola unit and younger than the Montopoli unit, and therefore confines the attribution to the Middle Villafranchian (Text-fig. 8). The paleomagnetic data concerning the underlying Fosso Bianco Formation indicate that the assemblage post-dates the Reunion paleomagnetic event. Taking these results into account, the fauna should be attributed to the Sénèze faunal unit of the French biochronology. This unit roughly corresponds to the poorly documented Costa S.

Giacomo f.u. of the Italian mammal biochronological scale.

TAPHONOMIC REMARKS

Occurrence and abundance - Macromammal remains from the Ponte Naja Formation were found and collected at random during field sedimentological investigations. Micromammal teeth result only from screen-washing of about 800/1000 kg of matrix. It is difficult to estimate the abundance of fossils in the sediments: prospecting, quarrying and screen-washing of the Ponte Naja Formation should enrich the specimen collection.

Collecting of mammal remains in strata allow us to observe: (i) bony remains are distributed along the entire succession; (ii) these remains are related almost only to the finest deposits (silty clay). In fact, only one specimen was retrieved

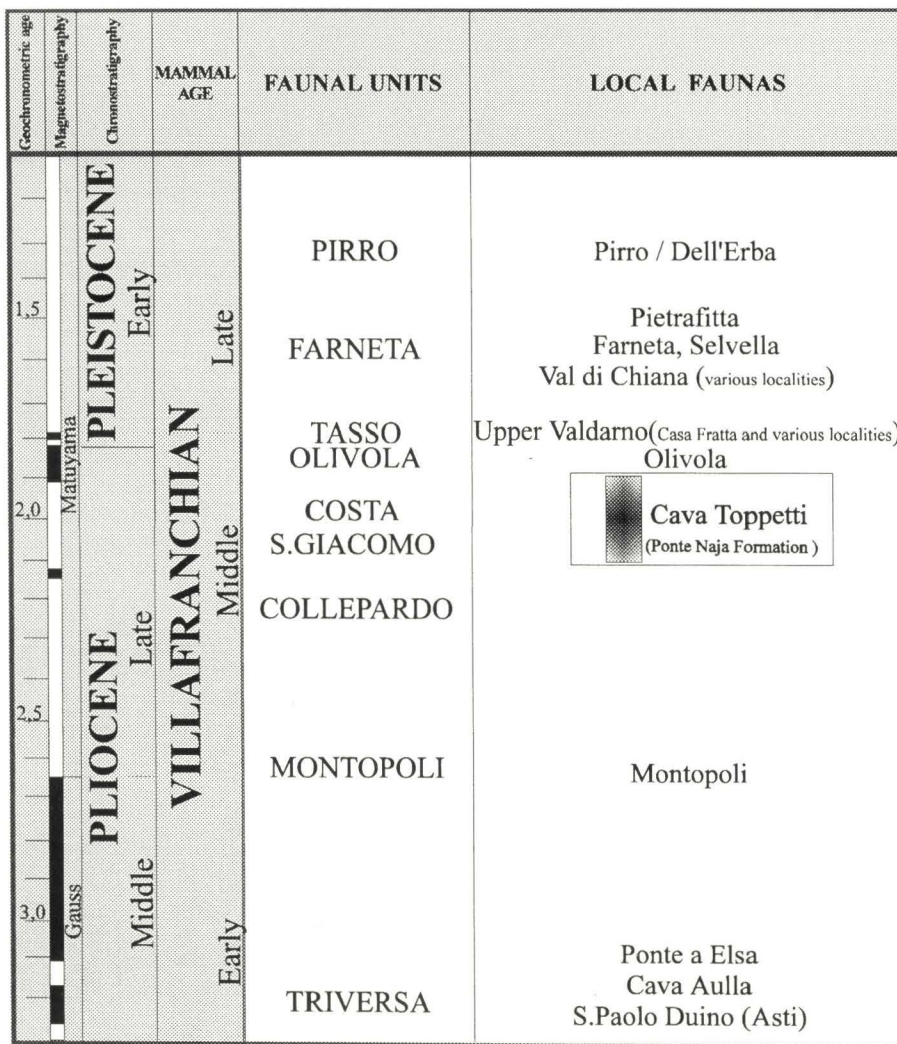
from the coarsest deposits (sandy gravel), while all the other remains were collected in paleosols.

Although the findings are too scarce to allow any statistically supported considerations, nevertheless some significant taphonomic observations can be made on the basis of the faunal assemblage.

Type of remains - The only bony remains from Ponte Naja Formation deposits (see Tab. 2) are of different sized herbivore mammals, perissodactyls (small sized rhinoceros), artiodactyls (small-medium sized deer, a very large bovid) and rodents (Muridae).

The coarse-grained sheet flow deposits contain a fragmental articular end of a left scapula of *Stephanorhinus* with weak traces of abrasion. The surface of the bone is altered in several areas by loss of bone tissue.

In the paleosols, scattered fragmental remains



Text-fig. 8 - Mammal Units of the Middle and Late Pliocene and the Early Pleistocene Italian local fauna. Cava Toppetti (Ponte Naja Formation) local fauna refers to middle Villafranchian.

Taxa	Antler fragment	Isolated teeth	Vertebra	Scapula	Phalanges
<i>Stephanorhinus</i> cf. <i>S. etruscus</i>				1	
<i>Pseudodama</i> cf. <i>P. rhenana</i>	3	2			1
<i>Procapreolus</i> sp.	1				
<i>Leptobos</i> sp.			1		
<i>Apodemus</i> cf. <i>A. dominans</i>		10			
Total	4	12	1	1*	1

Tab. 2 - Skeletal elements of mammals from Cava Toppetti (Ponte Naja Formation).

*specimen retrieved from sheet flow deposits.

of antlers and teeth occurred in greater numbers than postcranial bones, which are represented only by a fragmental atlas and a phalanx (Tab. 2). These remains do not show traces of being water-worn and are slightly weathered (Stage 1-2 of Berhensmeyer, 1978). Extensively elongated and parallel-sided double grooves shown by antlers and atlas are produced by rodent gnawing (Andrew, 1990; Lee Lyman, 1994). Micromammal teeth are not modified (Stage 0 of Andrew, 1990). Cancellous tissue of antlers and of bones is impregnated with mineral iron.

Taphonomic observations - Taphonomic analysis of the bone and teeth remains collected from paleosols led to the following considerations.

i) Fragmental, gnawed, broken and disarticulated remains were exposed subaerially for some time prior to burial. *Pseudodama* antlers and the *Leptobos* atlas were chewed by small rodents. The latter is extensively gnawed and the exposure of the cancellous tissue and the incisor grooves are evident (Text-fig. 9). Andrews (1990) suggests that small rodents do not collect bone, but chew it to keep their incisors in good condition and for its calcium and phosphate content. Small rodents mostly gnaw larger pieces of bone rather than small mammal bones.

ii) Antlers, teeth and bone do not present traces of being water-worn. Furthermore, the occurrence among the remains of the atlas, a skeletal element of the I Group of Voorhies (1969), suggests a non-fluvially winnowed assemblage (Berhensmeyer, 1975).

iii) Antler fragments are mostly shed antlers. As regards problems linked to conservation,

(Payne, 1972; Sturdy, 1975) antlers in velvet are very prone to decay and probably do not fossilise; moreover, Bown & Kraus (1981) did not find skulls in the very rich mammal fossil collection from paleosol deposits. Furthermore, since the production of shed antlers during the life of the males is greater than that of non-shed antlers, it could be that shed antlers are hypothetically rather common in soil deposits frequented by deer.

CONCLUSIONS

The Ponte Naja Formation is a 150 m thick unit which consists predominantly of fine-grained sediments (clayey sandy silt and silty clay) and minor sandy gravel. It is regionally restricted to a few km² around the town of Todi, located along the western bedrock margins of the Tiberino Basin.

The succession consists mainly of cyclic alternations of fine-grained sheet-flow deposits and paleosols, with minor sandy gravel-filled ribbon channels and coarse-grained sheet-flow deposits occurring locally. Sedimentological analyses indicate that the Ponte Naja Formation was deposited on the distal portion of an alluvial fan where fine sediments were deposited via sheet flows and where small ribbon channels controlled channelled flow.

The paleosols occurring between two sheet-flow deposits are very immature, permitting a semi-quantitative estimation of approximately >1.3 mm/y for the local sedimentation rate.

In the deposits of the Ponte Naja Formation, macro- and micromammal remains occur mainly

EXPLANATION OF PLATE 1

- Fig. 1 - *Stephanorhinus* cf. *S. etruscus* from Cava Toppetti (Ponte Naja Formation). Left scapula (x 0.5).
 Fig. 2 - *Leptobos* sp. from Cava Toppetti (Ponte Naja Formation). Atlas (x 0.7).
 Figs. 3-8 - *Pseudodama* cf. *P. rhenana* from Cava Toppetti (Ponte Naja Formation). 3) Left shed antler (x 0.5); 4) Tine (x 0.7); 5) Distal fragment of antler (x 0.9); 6) Fragment of right P/4 (x 2); 7) Left D\3 (x 2); 8) Third phalanx (x 1.5).
 Fig. 9 - *Procapreolus* sp. from Cava Toppetti (Ponte Naja Formation). Basal fragment of a shed antler (x 1.3).



in the finest facies deposits interpreted as paleosols. This taphonomic mode is analogous with that reported by Bown & Kraus (1981) concerning a rich vertebrate collection retrieved from tabular gray mudstones, interpreted as remnants of horizon A of paleosol deposits. According to these authors, vertebrate remains accumulated gradually as litter on the surface of the soils and subsequently became incorporated into the horizon A.

The faunal composition with the occurrence of *Pseudodama* cf. *P. rhenana* and *Stephanorhinus* cf. *S. etruscus* is indicative of the Middle Villafranchian. Magnetic stratigraphy was carried out in the Fosso Bianco Formation which extends through Late Gauss to Matuyama, just above the Reunion event. Therefore the Ponte Naja Formation is no older than about 2.1 Ma, while the faunas of Middle Villafranchian affinity imply an age no younger than the Olivola fauna which is calibrated close to the P/P boundary (Torre *et al.*, 1993). These data are very significant for the calibration of the Middle Villafranchian mammal assemblages (Costa S. Giacomo unit), which are still poorly known in Italy.

Palynological data revealed a rich and quite diversified floristic association characterized by subtropical and warm-temperate elements mainly represented by Taxodiaceae (*Taxodium* type), followed by *Nyssa* and *Distylium*, as well as broad-

leaved deciduous elements (*Quercus*, *Carpinus*, *Ulmus*, *Pterocarya*, Araliaceae *Panax* type, etc.) typical of a warm-temperate and temperate climate. This floristic composition is very similar to those known for the same time interval in North and Central Italy (Lona, 1962, 1971; Lona & Bertoldi, 1972; Bertini, 1985, 1994, Ravazzi & Rossignol-Strick, 1995). Similar assemblages are recorded in the section outcropping at the Fosso Bianco locality (Tiberino basin, Fosso Bianco Formation), attributable to the same chronological interval as the Ponte Naja Formation (Basilici *et al.*, 1995; Pontini, 1997).

Forest elements and herbs alternately show at least four main phases of increase. The forest phases are characterized principally by broad-leaved deciduous elements and Taxodiaceae (*Taxodium* type). The open vegetation phases are characterized mainly by the expansion of Asteraceae Cichorioideae, while steppic elements (*Ephedra* and *Artemisia*), although present, do not reach very significant values.

Similar open vegetation forest alternations, recorded in many Mediterranean deposits (Suc *et al.*, 1995), have been linked to glacial-interglacial cycles starting at 2.6 Ma.

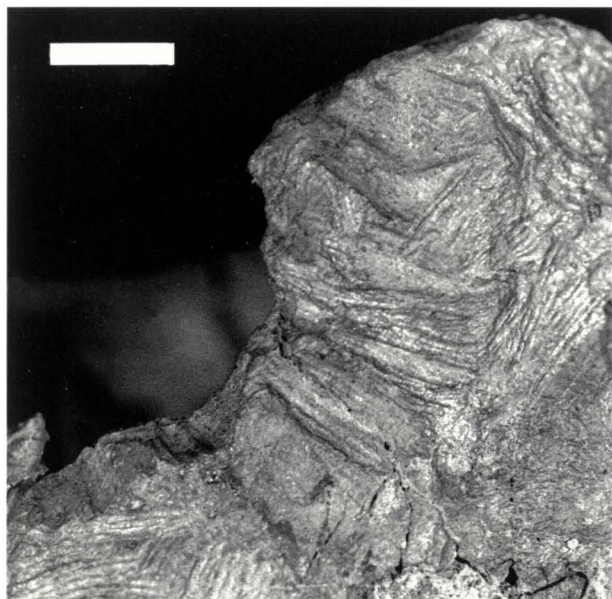
Taphonomic biases, related to the peculiarity of the deposits, were analysed and evaluated on the basis of the available data. In any case the influence of climate cannot be ignored. The vegetational phases above discussed could thus be considered quite representative of the real vegetation. Throughout the succession a complete climatic cycle and part of the following one will be established should further, more detailed analyses (Pontini, in progress) support the climatic interpretation.

The refinement of palynological analysis and the possibility of new finds of mammals coupled with a future paleomagnetic analysis of the deposit of the Ponte Naja Formation could supply well-calibrated paleoclimatic and biochronological data for a time interval of the Late Pliocene, detailed knowledge of which is still scarce in Italy.

ACKNOWLEDGMENT

Many thanks are due to Friedrich Heller who made available to us the Magnetic Laboratory of the EHT in Zurich. We are very grateful to Gianni Zanchetta and Daniela Esu for the sample of Muridae teeth and Giampiero Tosti for the photographs.

We would like to thank the management of the Cava Toppetti for giving us permission to enter Alfio Lucaroni in particular.



Text-fig. 9 - Atlas of *Leptobos* sp. from paleosols of the Cava Toppetti (Ponte Naja Formation) gnawed by small rodents; note the incisor grooves. Scale bar = 1 cm.

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(manuscript received November 30, 1996
accepted June 30, 1997)

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