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Sedimentological and palaeontological features of an ancient alluvial plain in the Lucca Basin (Central Italy)

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Key words: Alluvial plain, backswamp, mammals, pollen, Tuscany, Italy

ABSTRACT

The multidisciplinary analysis of the deposits outcropping in the Nuova Lam Quarry (Lucca, Central Italy) permitted a palaeoenvironmental reconstruction which differs considerably from those traditionally proposed for the continental deposits present in this area and hitherto interpreted as lacustrine. The sequence described here is interpreted as an alluvial plain deposit. Five main associations of lithofacies have been recognised and referred to different subenvironments. Backswamp deposits crop out in the basal part. They indicate the presence of ponds periodically affected by crevasse splay processes and phases of subaerial exposure, which caused the formation of immature soils. An avulsion process, which gave rise to two main fluvial channels can be detected in the uppermost part of the sequence. A new avulsion caused a return to a backswamp zone. The investigated sequence is an example of aggradation of an ancient alluvial plain under humid climatic conditions as suggested by pollen analysis. The sequence studied makes part of continental deposits whose age has long been a matter of debate. The finding of astragali of very rare *Pliotragus ardeus* in the first channel deposits, along with some freshwater molluscs, allows to assign the sequence studied to the Villafranchian (Middle Pliocene-Lower Pleistocene).

RIASSUNTO

In questo lavoro vengono descritti i deposti affioranti nella cava Nuova Lam (Lucca, Italia centrale) attraverso l'analisi sedimentologica e paleontologica (pollini e molluschi continentali). Sulla base dei dati acquisiti, la sequenza viene interpretata come deposta in una piana alluvionale durante condizioni di clima umido. Fasi di prevalente esposizione subaerea con formazione di suoli vengono interrotte periodicamente dalla deposizione di sedimenti di rotta fluviale e dalla formazione di paludi e laghi poco profondi. Nella sezione studiata vengono, inoltre, registrati due eventi di avulsione fluviale con la formazione di due canali principali. Il ritrovamento di un astragalo di *Pliotragus ardesus*, insieme con alcuni molluschi dulcicoli permette l'attribuzione di questa successione al Villafranchiano (Pliocene medio-Pleistocene inferiore).

Introduction

Floodplain fine-grained facies have hitherto undergone little intensive study relative to trunk channel deposits, although in the last years an increasing literature is focusing on this topic (e.g. Bridge 1984; Smith & Pèrez-Arlucea 1994; Jorgensen & Fielding 1996; Amorosi et al. 1999; McCarthy et al. 1999). These studies have shown that floodplains commonly contain distinct depositional subenvironments characterised by different facies and architectural organisation. Moreover, soil-forming processes have been recognised to represent an important feature of alluvial settings (e.g. Bowen & Kraus 1987; Kraus 1987, 1999; Aslan & Autin 1998). This scenario contrasts with the traditional schemes in which alluvial plain fine-grained deposits were normally included in the overbank-fines (e.g. Miall 1985). However, in the absence of extensive modern data sets on subenvironment of alluvial plains the relative deposits in ancient depositional settings are still often poorly understood (Smith & Pèrez-Arlucea 1994; Jorgensen & Fielding 1996). As an example no comprehensive depositional model was produced despite the great care spend in endeavour to interpret several coal-bearing deposits (e.g. Ethridge et al. 1981; Flores 1981; Gersib & McCabe 1981) and the role of backswamp area.

The present study proposes to contribute to the knowledge of floodplains by describing an interesting example of fine-grained "Villafranchian" (middle Pliocene to lower Pleistocene) continental deposits outcropping in the Lucca basin (Tuscany, central Italy), for long interpreted as sediments of lacustrine environment (e.g. Trevisan et al. 1971; Federici &

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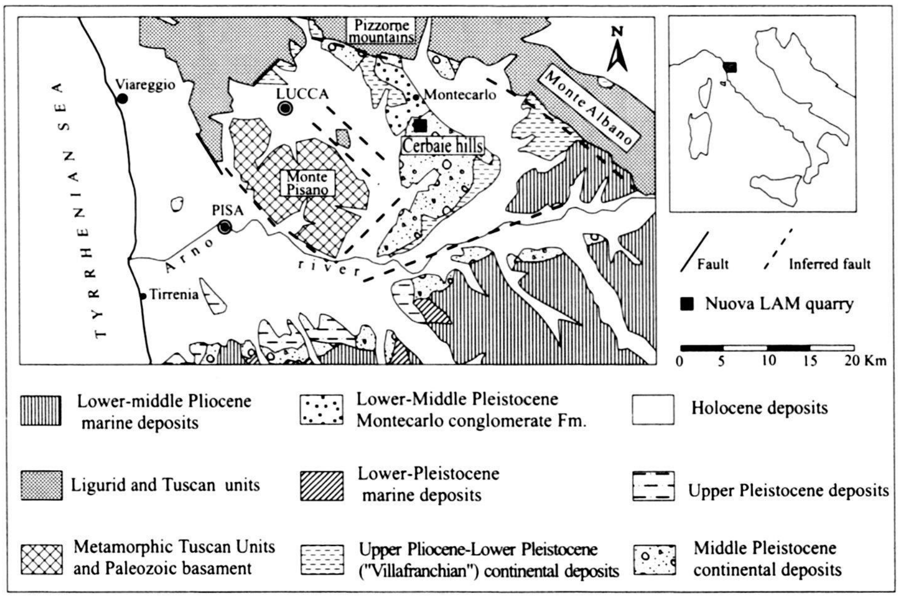

Fig. 1. Schematic geological map of Lucca basin and the surrounding area.

Mazzanti 1988; Dallan 1988). Particularly, the case history presented here describes the alluvial plain subenvironments with significant development of backswamp deposits. Sedimentological and paleontological evidence of backswamp deposits portrays a complex depositional architecture formed by ponds, small lake and crevasse splay deposits alternating both in space and time. These kinds of deposits are poorly studied in modern alluvial plain setting (e.g. Tye & Colemann 1989) and even fewer ancient examples are so far available (e.g. Ethridge et al. 1981; Flores 1981; Jorgensen & Fielding 1996). The study addresses modern and ancient deposits, and can therefore contribute considerable knowledge to this field of research.

Geological setting

The Lucca basin (Fig. 1) is one of the many tectonic depressions which formed along the Tyrrhenian margin of the Apennine chain since the Late Tortonian as a consequence of extensional tectonics still active today (e.g. Elter et al. 1975).

These processes are connected with the Tyrrhenian sea rifting. The most recent modelling associates them with the counter-clockwise temporal and spatial migration of the chain-foredeep-foreland system (Malinverno & Ryan 1986; Sartori 1989a; Scandone & Patacca 1989; Patacca et al. 1990) with the migration of the extensional and compressive processes in the same direction.

The Lucca basin is bounded by the Monte Albano, Pizzorne and Monte Pisano mountain systems (Fig. 1). The first two systems are mainly formed by Oligocene quartz-feldspathic sandstones, whereas the Monti Pisano are mainly composed of Carboniferous-Triassic metamorphic material, such as quarzites and phyllites (Rau & Tongiorgi 1974). The infilling of the basin started in the Late Miocene, as attested by the continental deposits of this age encountered by boreholes in the southern part of the basin (Ghelardoni et al. 1968). During the early and middle Pliocene, the basin experienced a marine transgression that led to deposition of siliciclastic sediments of coastal marine environment (Ghelardoni et al. 1968; Trevisan et al. 1971; Caredio et al. 1995). The extension of the Pliocene marine ingression within the basin is matter of debate (Dallan 1988; Federici & Mazzanti 1988; Puccinelli 1992; Zanchetta 1995; Cantini et al. 2000). During the middle Pliocene, a regional uplift (Sartori 1989b; Bossio et al. 1993) marks the end of the coastal marine sedimentation. The marine Middle Pliocene deposits are disconformably overlain by a continental unit (Caredio et al. 1995; Zanchetta et al. 1995). Dallan (1988) concluded that this continental unit started to accumulate during the early Pliocene (Ruscinian). In contrast to Dallan's opinion newly discovered paleontologic evidence tells us that the basal portion of the continental unit accumulated in part during the late Pliocene (middle Villafranchian, Caredio et al. 1995; Zanchetta 1995; Marcolini et al. 2000), while the upper part is thought to pass laterally to Lower Pleistocene marine deposits outcropping on the "Colline Pisane" (Zanchetta 1995). The find of a mammal bone within the studied deposits, adds further constraints to the chronological problem. During the Middle-Late Pleistocene several units of coarse gravelly fluvial deposits were formed.

The present study, supported by basin scale survey, is mainly aimed at the analysis of the "Villafranchian" continental succession. The best outcrop is at Cava Nuova Lam (Altopascio, Lucca) where a detailed survey was performed. The stratigraphic relationships between the different units are schematically shown in Fig. 2.

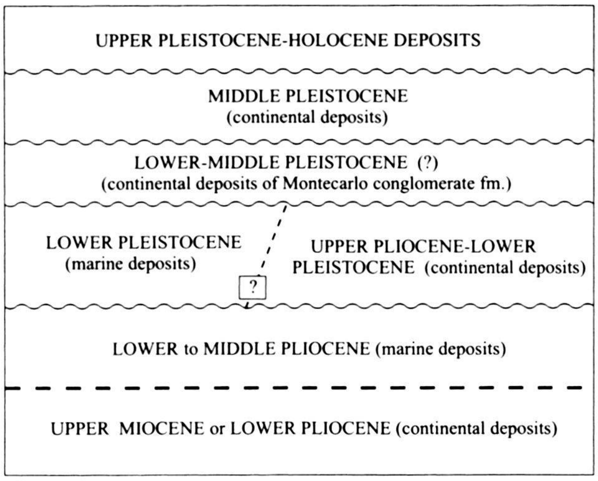

Fig. 2. Schematic stratigraphic relationship between marine and continental deposits illustrated in figure 1.

Facies analysis

A detailed facies analysis was performed on the upper Pliocene-lower Pleistocene (Villafranchian) deposits, exploited by the Nuova LAM society. Macropalaeontologic and palynologic investigations were also carried out on these sediments. Five different lithofacies and their mutual geometric relationships were identified. The investigated sequence, which is structurally arranged as a monocline trending N140° and dipping 25°NE, reaches a total thickness of about 50 m. At its top the sequence is separated from the overlying gravel deposits (middle Pleistocene age), by a marked angular unconformity (Fig. 2). A summary stratigraphic column is shown in Fig. 3.

Palaeosols (Lithofacies a)

Description:

this lithofacies is formed by muddy-sands some 0.60 to 2 m thick, and is devoid of sedimentary structures (Fig. 4a). Its lower limit fades into the underlying facies, while the upper boundary is well marked. In a typical exposure the upper part is 0.10 to 0.30 m thick and is slightly darker because of the presence of organic matter, its colours ranging from N4 to 5Y4/1 (Munsell Soil Color Charts 1975). Tree remains with the roots still in their original life position, are locally found at the top of this facies. The lower part (from 0,50 m to 2 m thick), on the other hand, has colours ranging from 5GY 4/1 to 5G 4/1 and is characterised by the occurrence of calcareous glaebulae. The lithofacies bears calcareous rhizoconcretions, millimetric lignified roots and rare slickensides (Fig. 4a). Small, well rounded siliceous or carbonate clasts (3-5 mm) are dispersed in the sediment. The fossils are mainly concentrated in the upper portion and are represented only by badly preserved land molluscs, among which *Helix* sp., Clausilidea, *Limax* sp., *Pomatias* sp., *Carychium* sp. have been recognised.

Interpretation:

lithofacies A can be interpreted as paleosols with slightly developed alteration profiles (immature paleosols or Entisols/Inceptisols, Soil Survey Staff 1975). The upper, darker portion is the superficial pedogenic horizon (epipedon) rich in organic matter. The vertical development of the paleosols is often interrupted by sandy deposits of lithofacies B. This succession is fairly similar to the bipartite cycles described by Kraus (1987) in the Bighorn Basin, which are formed by slightly pedogenically modified sands at their base covered by one or two paleosols profiles (simple pedofacies sequences). Paleosols similar to the latter occur, for example, in the Ponte Naja Unit, at Toppetti Quarry, in Umbria (Basilici 1995). Lithofacies A matches Miall's (1978) lithofacies P.

Pond deposits (lithofacies b)

Description:

this lithofacies is about 1,50 m to 5 m thick and is formed by alternating horizontally laminated clays and silts with rare sharply based centimetric intercalations of fine-grained sands (Fig. 4b). Three possible inner patterns have been observed:

i) the horizontal lamination is marked by granulometric variations ranging from clay to silt; in this case the clay is light grey in colour and bears isolated coarse organic matter. On the contrary, the silt is dark grey due to the occurrence of dispersed fragmented organic matter normally comparable in grain size to the silt itself.

ii) millimetric to centimetric horizontal lamination formed by the concentration of organic matter of silt or clay size, in small, irregular levels.

iii) centimetric horizontal lamination formed by small fining-upwards (FU) sequences consisting of a coarse silt at the base abruptly passing to a clay upwards. The deposition of the clay is either preceded or interrupted by amounts of small, millimetric, irregularly arranged horizons of lignified organic matter associated with pyrite. These levels are overlain by a clay level containing dispersed organic matter. The top of each of these small sequences is interrupted by a sharp surface marking a new deposition of silts, which inaugurates a new sequence. The base is at places marked by small-scale soft deformation structures.

A marked convolute lamination is also occasionally present (Fig. 4c). Rare vertical escape traces have also been observed (Fig. 4b). The plane parallel lamination is repeatedly interrupted by decimetric accumulations of lignite, wherein leaves, lying parallel to the stratification, wood splinters, seeds and freshwater molluscs occur. In these layers the siliciclastic content is still considerably high. The fossil assemblage from this lithofacies is only represented by fresh-water molluscs, such as *Planorbarius* sp., *Prososthenia oblonga, Emmericia umbra, Valvata piscinalis, Theodoxus groyanus.*

A tree trunk rooted in facies A, preserved in life position and completely drowned in sediments belonging to lithofacies

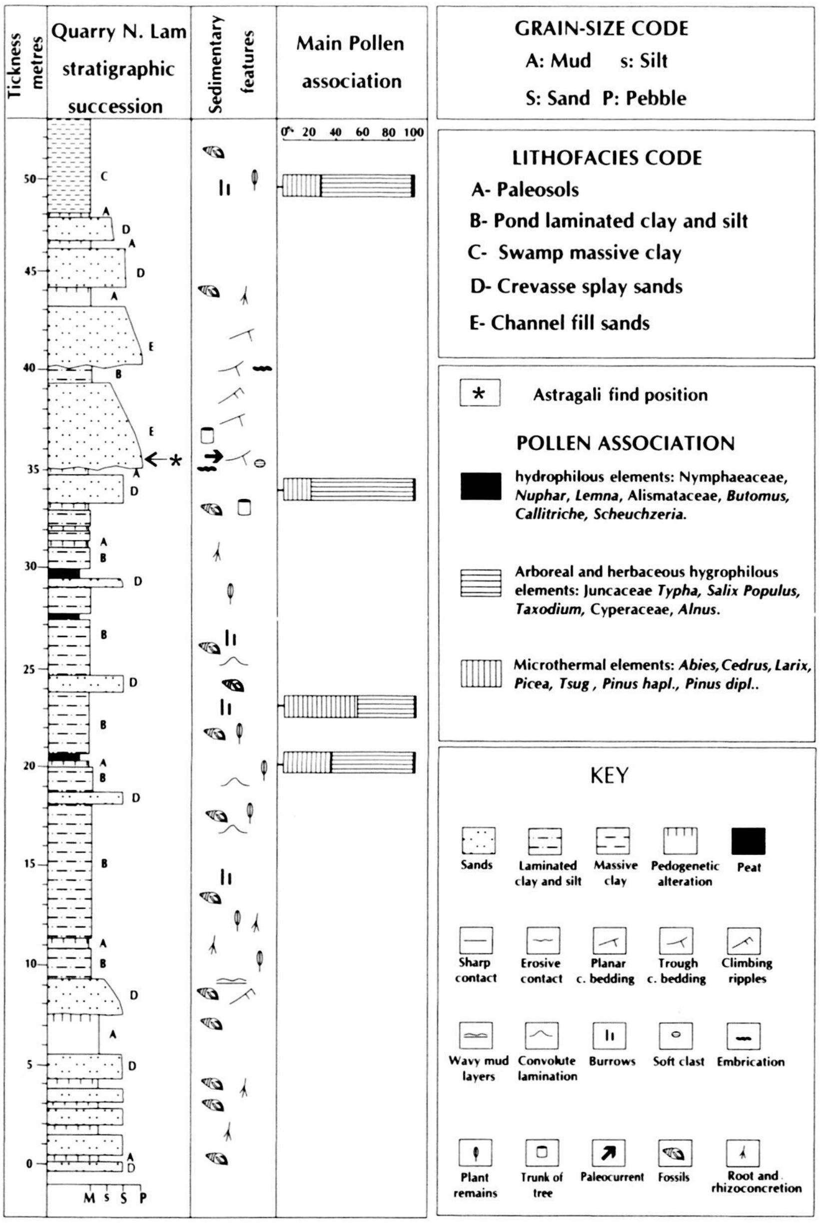

Fig. 3. Representative stratigraphic section of the succession studied. Note the synthetic bar diagrams of the pollen associations selected for each lithofacies. Percentages were estimated on the total amount of the three ecological groups considered, indicating edaphic local conditions; only the average value for each sample is shown, while no reference is given on the stratigraphic trend.

B, has also been observed. This lithofacies (Fcs of Miall 1978; 1985) passes laterally to lithofacies D and vertically to lithofacies C.

Interpretation:

the sedimentological and paleontological characters of this lithofacies point to a low-energy depositional environment dominated by fall-out or weak traction. The mollusc assemblage is suggestive of standing or slightly moving clear and fairly shallow water. The vertical escape traces attest to high rate of sedimentation which prevented the disruption of lamination by bioturbation. The convolute lamination is also consistent with high rates of sedimentation, since it represents soft deformation almost contemporaneous to the deposition of sediment still strongly imbued with water. A further possibility is the liquefaction of the deposit due to earthquake shock (Alfaro et al. 1997; Ringrose 1989; Hempton & Dewey 1983; Sims 1975). A direct cause-effect relationship is nevertheless hard to establish. This lithofacies is suggestive of deposition in ponds or small shallow lake environments characterised by high sedimentary supply. Examples of this facies are described from both modern alluvial plain settings (Aslan & Autin 1999; Tye & Coleman 1989) and ancient deposits (e.g. Ambrosetti et al. 1995).

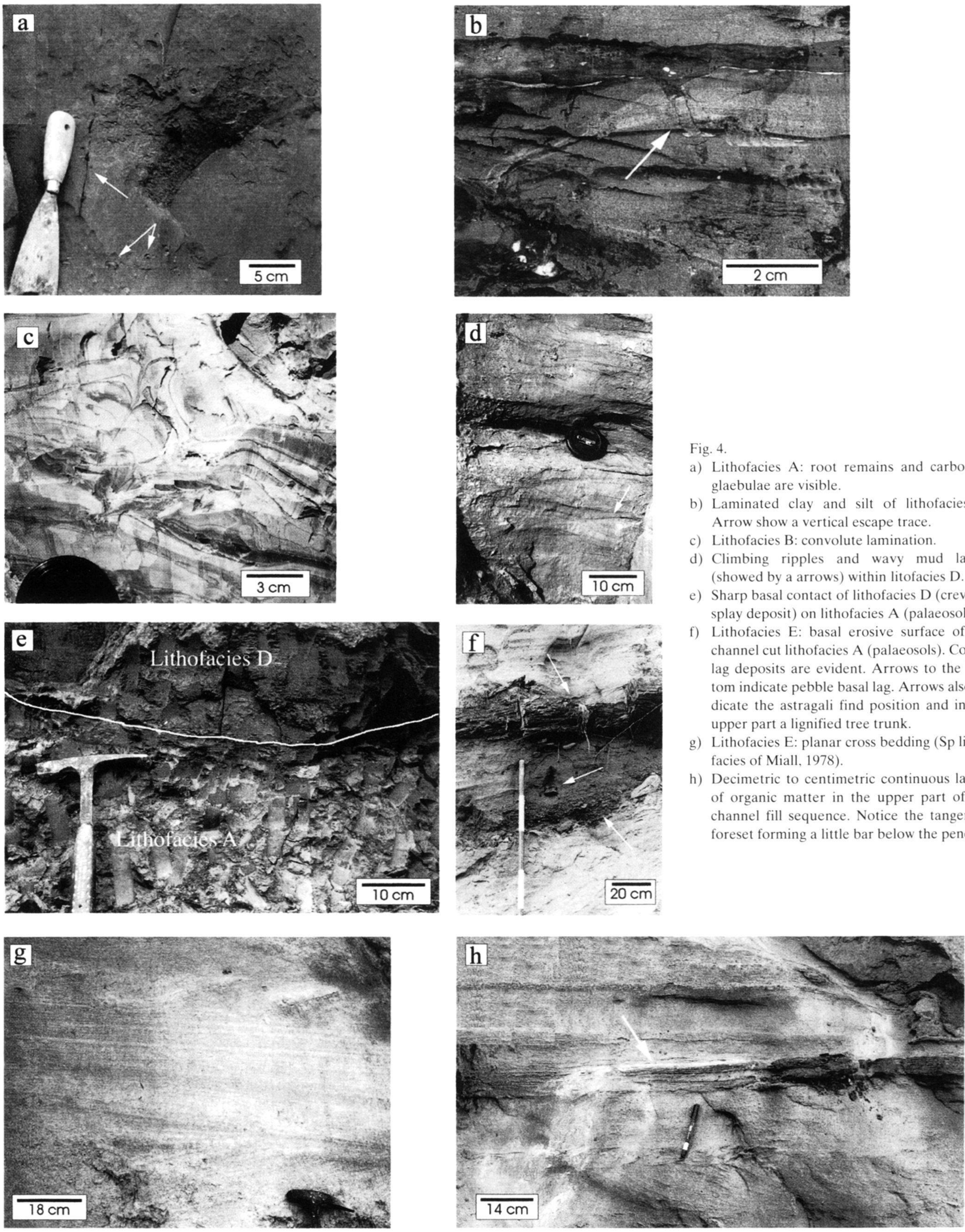

Fig. 4.
a) Lithofacies A: root remains and carbonate glaebulae are visible.
b) Laminated clay and silt of lithofacies B. Arrow show a vertical escape trace.
c) Lithofacies B: convolute lamination.
d) Climbing ripples and wavy mud layers (showed by a arrows) within litofacies D.
e) Sharp basal contact of lithofacies D (crevasse splay deposit) on lithofacies A (palaeosols).
f) Lithofacies E: basal erosive surface of the channel cut lithofacies A (palaeosols). Coarse lag deposits are evident. Arrows to the bottom indicate pebble basal lag. Arrows also indicate the astragali find position and in the upper part a lignified tree trunk.
g) Lithofacies E: planar cross bedding (Sp lithofacies of Miall, 1978).
h) Decimetric to centimetric continuous layers of organic matter in the upper part of the channel fill sequence. Notice the tangential foreset forming a little bar below the pencil.

Swamp deposits (Lithofacies c)

Description:

lithofacies C is composed of silty clay to sandy-silt without sedimentary structures. It is intensely bioturbated (thickness 0.20 to 7.50 m), with a high organic content; remains of leaves and wood locally occur. Residual evidence of plane parallel lamination is occasionally recognisable. The palaeontologic content is characterised by fresh-water molluscs, including gastropods *Planorbarius* sp., *Viviparus* sp. *Lymnaea* sp., *Bythinia* sp. and the bivalve *Pisidium* sp. The latter is often represented by individuals with closed valves. This lithofacies was observed only in the upper part of the stratigraphic succession. It passes vertically to lithofacies B and A. It can be referred to Miall's (1978; 1985) Fcf lithofacies.

Interpretation:

lithofacies C formed in a very-low energy aquatic environment. The lack of sedimentary structures is due to intense bioturbation. The fossil content is consistent with an environment characterised by still or slightly running shallow waters. The intense bioturbation and the high amount of organic remains is suggestive of a swamp depositional environment (*sensu* Reeves 1968; see also Martini & Glooshenko 1985). Lithofacies similar to these have been recently described by Aslan & Autin (1999) for the Holocene backswamp deposits of the Mississippi.

Crevasse splay deposit (Lithofacies d)

Description:

lithofacies D is represented by sands and silty sands with decametric lenticular geometry some 0.4 to 2 meters thick and by centimetric levels of mud arranged in FU sequences some tens of meters in extent. Extensive climbing-ripple stratification and wavy mud layers are met in this lithofacies (Fig. 4d). The mud layers occur in the upper part of the lithofacies. The climbing-ripple stratification is emphasised by concentrations of organic material along the stoss and lee sides. The climbing ripples observed are mainly referable to Jopling & Walker's (1968) type C (Type 1 ripple laminae in drift of Reineck & Singh 1975). Sedimentary bodies of lithofacies D, have a sharp or slightly erosive base overlying both facies A or facies B (Fig. 4e). The transition to the upper facies is sharp where the sediments are overlain by facies B beds, while it is more gradual where lithofacies D is overlain by facies A beds (palaeosols). In this case the sedimentary structures of lithofacies D may be lacking or just faintly preserved. At the bottom of one of these sedimentary bodies reworked remains of the fresh-water molluscs *Melanopsis affinis* and *Theodoxus groyanus* and of *Helix* sp., a terrestrial species, have been encountered. This facies partially corresponds to Miall's (1978; 1985) Fl lithofacies.

Interpretation:

facies characteristics and the latero-vertical relationships with lithofacies B and A indicate that these sediments were deposited in a low energy environment with a variable suspended load to bottom load ratio. The two possible extremes are the prevalence of traction (climbing ripple in drift) or the exclusive occurrence of settlement processes (wavy mud layers). These deposits were interpreted as crevasse splay. During the crevasse splay event the flow was able to load in the alluvial plain the remains of land molluscs such as *Helix* sp., whereas the fresh-water molluscs *Melanopsis* and *Theodoxus* lived in the fluvial channels in areas characterised by lower energy currents.

Channel fill deposits (Lithofacies E)

Description:

lithofacies E is represented by two lenticular (concave-plane) decametric sand bodies, respectively 4 and 3 m thick. Both are characterised by a marked erosional base, which cut lithofacies A and B. The two sandy bodies are separated by a 1 m thick body of lithofacies C sediments. The inner pattern shows a manifest FU tendency with coarse-grained sand and gravels at the base and silty sands and silt at the top.

The base is characterised by intraformational mudclasts (size 1 to 10 cm), iso-oriented and occasionally imbricated. The gravels occur almost exclusively at the base and mark the erosional surface in association with mudclasts (channel lag deposits, Fig. 4f). They may concentrate in lenses or be dispersed in the coarse-grained matrix. In the first case they display a clast-supported fabric, are fairly well sorted and show an abrupt FU tendency (grain size about 3–4 cm at the base) which passes rapidly to coarse-grained sands. The clasts are rounded to sub-rounded and are prevalently formed by quarzites supplied by the metamorphic succession of the Monte Pisano and by sandstones of the Macigno Formation. Within the sands, gravels are aligned along the base of the scours. This lithofacies is characterised by a trough cross-bedding (lithofacies St of Miall 1978) and, but less frequently, a planar cross-bedding (lithofacies Sp of Miall 1978). The latter prevails in the intermediate part of the deposit (Fig. 4g), while in the uppermost part silts or fine-grained sands are arranged in lower energy structures, such as ripples and climbing ripples (lithofacies Sr, Miall 1978). The organic matter content increases considerably in this portion, forming small uninterrupted layers up to 4–5 cm thick (Fig. 4h). Paleocurrent measurements point to a direction of flow trending about N90°, which is fairly consistent with the supposed supplying areas of the lithic clasts. In the lower sand body low angle lateral accretion structures have been observed. An interesting find from sandy gravels at the base of this deposit is a very well preserved fossil astragalus (Fig. 4f, Fig. 5) lacking any evidence of transportation. A fluvially transported lignified trunk of metric size (Fig. 4f) lies about a meter above the fossil astragalus. Other tree remains were observed in other parts of the same sand body.

Interpretation:

the geometry and the mutual arrangement of the identified lithofacies associations suggest that the two sand bodies are channel fills stemming from a sandy bedload river (Orton & Reading 1993). A progressive decrease of the system's energy is usually detected by both the FU trend and the vertical succession of sedimentary structures (transition from trough cross-bedding to planar cross-bedding to ripple to climbing ripples). Large scour surfaces marked by a thin lag of grey mudclast and rare gravels subdivide the channels into several stories (multistorey channel of Friend et al. 1979; Miall 1985). This implies the existence of lower order pulses of increasing and decreasing energy within a general decrease of energy of the system. In this scenario the organic matter accumulations at the top of the two channels formed when the channels were almost completely abandoned, while the tree trunks in the middle part of the first channel fill accumulated during episodes of major flooding. The second channel is displaced several meters NW from the first one. The width-depth ratio (W/D) is > 20, a value consistent with slightly cut mobile channels subject to lateral migration (Miall 1985).

Pollen analysis

Further information can be obtained by analysis of the pollen content. Brief outlines of pollen content of each lithofacies identified are discussed in this context in order to improve the palaeonvironmental reconstruction. Detailed discussion of palynological data from the Nuova Lam Quarry presented is available in Grassi (1999). Synthetic pollen spectra selected for each lithofacies are reported in Fig. 3 according to their stratigraphic position, but the average values for each sample are merely provided with no reference to the stratigraphic trend. Pollen was found in all the lithofacies, with the only exception of the ones from lithofacies E (channel deposits) which had a trivial pollen content.

Lithofacies A (paleosols) usually contains badly preserved pollen; the grains are often broken, intensely abraded and show lower total concentration values compared to other lithofacies. The total concentration of pollen in the samples from the paleosoils ranges from about 80-100 grains/g in the lowest paleosoils of the sequence, to 280-300 grains/g in the uppermost paleosoils, which are better preserved. Grains are selectively attacked by pedogenesis: the pollen of some arboreal elements, for instance *Populus,* is more prone to destruction than that of herbaceous essences and therefore this may be responsible for the slight variations in the arboreal/herbaceous ratio. The morphological characters of the wall were found to be best preserved in the most resistent elements (Havinga 1984). Low total pollen concentration values of lithofacies A match high values in the sum of indeterminable grains. This denotes that selective processes connected with a prolonged weathering have caused the destruction of a part of the pollen matter.

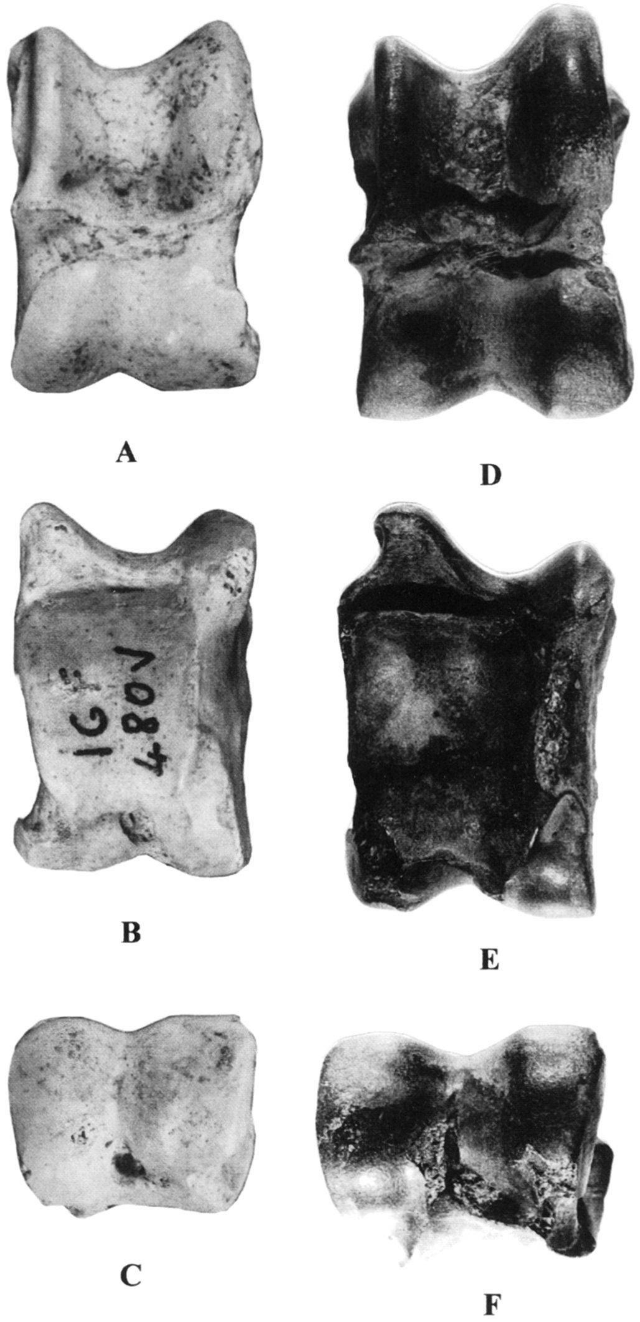

Fig. 5. *Rupicapra rupicapra* -Grotta di Equi- left astragalus A) dorsal view; B) plantar view C) distal view (x1,6)
Pliotragus ardeus; D) dorsal view; E) plantar view; F) distal view (x 0.8)

Lithofacies B, C and D, on the other hand, yielded richer and better preserved pollen assemblages, characterised by higher percentages of total concentration. The total concentration of the pollen in the samples of the other lithofacies ranges from 5000 to 6000 grains/g. The characteristics of the palynological association are similar in each lithofacies and do not show significant changes from bottom to top of the succession (Grassi 1999). The changes detected in the series, verified also within the same ecologic groups, seem to be more due to edaphic than to climatic causes: it was already mentioned that slight variations of this type are more likely to be due to pedogenic causes than to climatic events. The pollen association reported in Fig. 3 concerns groups of plants utilised to describe environmental conditions. In particular hydrophile elements, arboreal and herbaceous hygrophile elements and microthermal elements. The sum of hygrophile arboreal and herbaceous elements is usually greater than 40% suggesting vegetation close to water body. Furthermore, aquatic elements are normally under-represented in the pollen spectra (Faegri & Iversen 1989).

The pollen spectra are characterised by a higher arboreous content with respect to the herbaceous one. The percentage of arboreal pollen exceeds 50%; in the richest and best preserved samples the percentage rises to about 70% of the total pollen content (Grassi 1999). The arboreous plants typical of moist environments are well represented in each lithofacies; *Taxodium* and *Alnus* show the highest percentages. The arboreous plants are represented by significant percentages of deciduous broad-leaf trees, Juglandaceae, *Quercus, Liquidambar.* The Pinaceae, particularly the *Pinus haploxylon-* type and indeterminable Pinaceae, are present in high percentages. The percentage of *Pinus hapl.-t.* ranges from 4% to 16%; the indeterminate Pinaceae do not reach percentages exceeding 20% the average value is about 10%; on the other hand, other microthermal elements, among which *Picea, Abies, Tsuga,* are usually present in low percentages: the sum of the percentages relative to each one of these microthermal elements does not exceed 15% over the whole succession (Grassi 1999). The herbaceous plants are mainly represented by Cyperaceae and Liliaceae; the latter are associated with Asteraceae Asteroideae, Cheno-Amaranthaceae and Lamiaceae, though in far lower percentages. The percentage of Cyperaceae is included between 0.5% and 12%; the Asteraceae Asteroideae and the Lamiaceae do not exceed 2% respectively; the highest values are reached by the Cheno-Amaranthaceae which reach a total of 7% in some samples. The xerophylous elements, *Artemisia* and *Ephedra,* are fitfully present, and show low percentage values: the percentage of pollen of *Artemisia* and *Ephedra* oscillates, respectively, between 0.5% and 2% of the total. Consistently with the environmental reconstruction outlined by the facies analysis, the hygrophilous and hydrophilous plants occur along the whole profile, although the pollen of the hydrophilous is constantly present in low amounts. To sum up, the flora observed is characterised by sub-tropical and warm-temperate forms, especially represented by Taxodiaceae and deciduous hardwood forest trees, such as the Juglandaceae, *Quercus, Tilia, Ulmus* etc (Grassi 1999). This type of association is suggestive of a humid and relatively warm climate.

The chronological problem

The sequence studied makes part of continental deposits whose age has long been matter of debate, especially since a fragmentary metacarpal bone, referred to *Alephis lyrix* by Dallan (1989), was found on the northern margin of the basin. *Alephis lyrix* is a typical Ruscinian (early Pliocene) (Gromolard 1981) faunal component. The stratigraphic information provided by this find contrasts with the consolidated opinion (Trevisan et al. 1971; Federici & Mazzanti 1988) that the continental deposits are altogether correlable with the "Upper Villafranchian". The fossil astragalus found in the lowermost deposits of the lower channel fill and some of the fresh-water molluscs contribute significantly to clear the stratigraphic position of the deposits studied.

The fossil astragalus belongs to a fairly large mammal, approximately the size of *Eucladoceros dicranios, Alephis lyrix* or *Leptobos etruscus.* In dorsal and proximal views (Fig. 5), the bone has a number of typical cervid-like characters. It is quite slender in its general proportions, the proximal-distal diameter exceeding the latero-medial one. Both lips of the proximal trochlea are well sculptured and have steep flanks, especially the medial one. This makes the trough of the proximal trochlea very wide and fairly symmetrical. The distal trochlea, again in dorsal view, is also well sculptured and the lateral lip has a very well marked medial border, another typical cervid trait. The trough of the distal trochlea is thus also symmetrical.

The picture changes when one examines the bone in plantar and distal views. The plantar articular surface for the calcaneum is markedly concave latero-medially, its medial portion being quite more prominent than its lateral one. Even more important, distally the two grooves housing the two proximal main protuberances of the naviculocuboid are very deep, a feature typical of large-sized bovid astragali which is never observed in cervid astragali of comparable size.

The specimen also differs from the known astragali of the Ruscinian and Villafranchian bovids of Europe of comparable size, while it grossly resembles to a caprine or rupicaprine astragalus. A logical conclusion therefore is that it might belong to a large-sized Villafranchian antelope, *Pliotragus ardeus.* Unfortunately, the astragali of this bovid are unkown, at the moment. But the conclusions drawn by Duvernois & Guérin (1989) on this peculiar artiodactyl are illuminating. Guérin (1965) had suggested a possible attribution of the Ardé bovid to the Rupicaprinae, but he had not the possibility to find the holotype of the species at that time. Gentry (1970, 1971) expressed a different opinion, placing the species in the synonymy of *Megalovis latifrons.* However, Duvernois & Guérin (1989) resumed Guérin's (1965) impression on the basis of a beautiful cast of the holotype preserved in the Museum of Basel, concluding that *Pliotragus ardeus* is "more or less intermediate between the Ovibovinae and the Rupicaprinae and closer to the latter". The possibility that the rupicaprinae-like astragalus from Lucca basin might belong to the very rare *Pliotragus ardeus* is therefore not so remote. From the stratigraphic point of view, Duvernois & Guérin (1989) stress that *Pliotragus ardeus* distributes from MNQ16a to MNQ 18, that is practically through the whole Villafranchian. Should the attribution of the astragalus from the Lucca basin to *Pliotragus ardeus* ever be confirmed, it would not only represent the first known occurrence of the species in Italy, but it would provide also substantial weight to a possible correlation of the beds in which it was found to the middle Pliocene-early Pleistocene time span. Moreover, the possibility that the fragmental metacarpal from Montecarlo, attributed to *Alephis lyrix* by Dallan (1988), might actually belong to *Pliotragus ardeus* and thus be misattributed, cannot be ruled out. This certainly calls for a careful revision of the Montecarlo specimen, because if further research should confirm our suspect, the deposits which contained that fossil should be correlated with the Villafranchian and therefore placed in a younger stratigraphical position.

The pollen content is consistent with the chronological indication based on palaeontologic evidence. Similar assemblages have been found in basins of central and northern Italy (Bertini 1994; Ravazzi & Rossignol Strick 1995; Abbazzi et al. 1997; Pontini 1997) during the same time span. The invertebrate species *Emmericia umbra, Prososthenia oblonga, Melanopsis affinis* and *Thedoxus groyanus* have some biochronologic importance. These species, endemic of Central Italy, during the Villafranchian (Esu & Girotti 1974,1991; Gliozzi et al. 1997), had been already reported from these outcrops by Zanchetta (1995). *Emmericia umbra, Melanopsis affinis* and *Theodoxus groyanus* are known to distribute since the Middle Villafranchian (middle Pliocene) and progressively become extinct in the course of the late Villafranchian (early Pleistocene). On the other hand, *Prososthenia oblonga* is reported from the Plio-Pleistocene transition (Middle-Upper Villafranchian transition) to the end of the Late Villafranchian.

Dicussion and Conclusion

The depositional sequence described so far can be grossly subdivided into 4 main intervals. A basal part (~ 0–10 m) dominated by palaeosols (lithofacies A) successions, whose development is frequently interrupted by the input of crevasse splay sandy-silty material (lithofacies D). The middle part (~ 10–31 m) is prevalently characterised by the facies deposited in ponds or shallow lake environments (lithofacies B) with intercalations of crevasse splay (lithofacies D) deposit and minor phases of subaerial exposure (lithofacies A). This middle part is followed by two multistoried channel events. The transition to the upper part of the sequence is characterised by alternating crevasse splays and paleosols. The sequence is topped by lithofacies C beds (~ 48–52 m) deposited in a swamp environment. The deposition occurred originally in a flood plain environment dominated by superficial alteration processes (paleosols). The deposition was due to intermittent crevasse processes and the sediment underwent rapid subaerial alteration. The development of immature soils is suggestive of a sedimentation rate exceeding the superficial alteration rate (e.g. Kraus 1999). The overlying deposits record the persistence of a morphologically depressed and prevalently submersed environment whose hydraulic supply was given by both precipitation, overbank, and crevasse splay flooding. It is interesting to note that overbank deposits are not recognised in the sequence. But we inferred that overbank processes supplied siliciclastic material to the submersed environment. When the sedimentary supply exceeded the accommodation space the fill was completed and the consequent subaerial emersion favoured the development of paleosols (lithofacies A). Successively, subsidence and compaction restored the topographic depression favouring a new drowning. This is evidenced by the tree trunk rooted in a paleosoil and then submersed and embedded in the lithofacies B deposits. The occurrence of soft deformation and convolute lamination, associated with biological escape traces, prompts to frequent flooding processes, rich in suspended material and characterised by high sedimentation rates. During the phases of reduced siliciclastic supply the deposition of organic matter prevailed either in the form of thin laminae or, in case of longer spans, with the formation of lignite layers. Lithofacies A, B, C and D formed therefore in an ancient backswamp area. Backswamp areas include swamp, pounds, small lakes and crevasse splay channels (e.g. Tye & Colemann 1989; Aslan & Autin 1998).

The fluvial channel deposits attest the avulsion of a fluvial channel in previous backswamp areas. The avulsion process (*sensu* Mack & Leeder 1998) is consistent with the observed W/D characters, typical of systems with rapid and intense lateral variation. The kind of multistorey fill of the channels (in a prevalently sandy bed-load transportation pattern) is consistent with a system characterised by energy variation. Flooding episodes, attested to by the occurrence of transported tree trunks of metric scale in the first channel, alternated to moments of weaker energy. The channel avulsion evolved, at first through the abandonment of the first channel and the channel migration towards NW (lateral erosion *sensu* Mack & Leeder 1998). A further avulsion marks the complete abandonment of the channelling processes in the area studied. In the last part of the sequence a restored swamp depositional environment is documented in an area which turns to a topographic low again by subsidence. The palaeoecologic indications deriving from the palynologic analysis are consistent with the conclusions based on sedimentologic observations: the co-occurrence of Juglandaceae, *Quercus, Tilia* with *Taxodium* and *Alnus* is suggestive of a discontinuous forest landscape interrupted by shallow-water bodies. The study of the palynofloras suggests warm-temperate and humid palaeoclimatic conditions. The co-occurrence of *Prosothenia oblonga* with *Emmericia umbra, Melanopsis affinis* and *Theodoxus groyanus* in the deposits studied here is suggestive of an age attribution between the late Pliocene and early Pleistocene, a stratigraphic datum which is in very good agreement with the possible presence of the Villafranchian bovid *Pliotragus ardeus.*

The lithofacies association described here finds analogies in the present-day Mississippi (Aslan & Autin 1999; Tye & Coleman 1989) and Saskatchewan (Smith & Pèrez-Arlucea 1994) plains as well as in some ancient alluvial deposits (references in Aslan & Autin 1999). The vertical lithofacies organisation indicates alternation between phases of slow floodplain aggradation with soil formation and phases of flooding during which crevassing and swamp sedimentation dominated floodplain construction. Recently, Aslan & Autin (1999) stressed that these processes together with channel avulsions contribute to the construction of fine grained floodplains at a greater extent than generally recognised. The case history studied here support these conclusion showing an ancient example of this kind of floodplain aggradation.

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