



# The lacustrine deposits of Fornaci di Ranica (late Early Pleistocene, Italian Pre-Alps): stratigraphy, palaeoenvironment and geological evolution

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## Abstract

An interdisciplinary investigation of the Pleistocene clay succession of Fornaci di Ranica (Italian Pre-Alps) aimed to reconstruct the palaeoenvironmental history and its chronostratigraphic position and to consider the implications for the Quaternary evolution of the southern alpine borderland near the Early/Middle Pleistocene transition. A detailed survey of Quaternary deposits in boreholes and exposed sections provided a complete record of the basin. The most complete core was analyzed for palynology and magnetic properties. Plant macrofossils were obtained by flotation. Pollen and spectrometric analysis allowed a precise stratigraphic placement of a moose antler and braincase kept in museum collections.

The basin originated from fluvial obstruction of a tributary valley cut into bedrock. The basal deposits formed as a terrestrial hydromorphic soil under a dense *Tsuga*-forest (zone RNC 1). The overlying palustrine gyttja shows a marked forest withdrawal with a climatic signature (zone RNC 3), followed by a re-establishment of mixed conifer forests (zones RNC 4–6). The occurrences of pollen of cold-adapted taxa (*Saxifraga oppositifolia* type, *Saxifraga stellaris* type, *Larix*), are the oldest so far known south of the Alps and suggest that mean summer temperature was near or even below the thermic tree limit. High herb diversity, partially represented by tall forbs, characterizes this zone. A further increase of the water table can be assumed in zones RNC 4 and RNC 5, since pollen of aquatic plants increases. The find of *Larix decidua* L. cones demonstrates the existence of the European larch in the Early Pleistocene of the Alps, previously not identified at the species level. After the Serio river had reached the maximum Quaternary aggradation, the lake was rapidly filled up with turbiditic sediments.

The identification of *Cervalces latifrons* (Johnson, 1874) by Azzaroli (Palaeontogr. Italica 71(1979) 48) was confirmed. Pollen spectra obtained from clay fragments preserved in the braincase allowed us to constrain the stratigraphic position of these fossil remains in the lower palustrine portion of the sequence. Pollen and moose palaeoecology corroborate the reconstruction of a boreal landscape.

The succession of Fornaci di Ranica is attributed to the late Early Pleistocene on the basis of the following elements: (i) the occurrence of an acme pollen zone of *Tsuga*, with *Carya* and *Pterocarya*; (ii) the low representation of *Cedrus*; (iii) the biochronology of *Cervalces latifrons*; (iv) normal fossil magnetic polarity, interpreted as part of the Jaramillo subchron on the basis of correlations with other studied sections from the same region, and, finally, (v) indications from the regional geological evolution. The basin deposits spanned the final stage of a temperate period and the subsequent transition to a cold phase during the Jaramillo

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subchron or the Cobb cryptochron. The basin originated by fluvio-glacial aggradation, triggered by glaciation in the northern part of the Serio river catchment. The lake succession may represent an episode of marked increase of polar ice volume related to MIS (36) 30, or 28. The correlation with the Leffe sequence also suggests that cold climate conditions inferred for pollen zone RNC 3 did not occur earlier in the Early Pleistocene of this region.

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## 1. Introduction

The sediment stratigraphy and the palaeoenvironmental evolution of the late Early Pleistocene and near the Early/Middle Pleistocene boundary (e.g. 0.78 Myr, Brunhes/Matuyama transition, Richmond, 1986), in Northern Italy (Fig. 1a), are poorly known. Most of the alpine stratigraphic record was eroded and displaced by multiple glaciations (Billard and Orombelli, 1986), whereas Middle Pleistocene glacial deposits, commonly present at the southern alpine borderland (e.g. Bini, 1997b), are poorly dated. Unglaciated areas at the southern alpine borderland, however, are characterized by sedimentary basinal successions with potentially interesting biostratigraphic, biochronological and palaeoenvironmental information. Among these, the lacustrine succession of the ‘Fornaci di Ranica’ (Fig. 1b) was chosen for study in virtue of its continuity and geological significance. A multidisciplinary working group was therefore constituted in 1999 with the following objectives:

- to provide a palaeoenvironmental reconstruction and evolution of the ‘Fornaci di Ranica’ basin, of which little is known;
- to undertake the first multi-disciplinary investigation of the Early/Middle Pleistocene transition in the southern margin of the Alps;
- to improve the knowledge of the geologic evolution of the southern alpine borderland at the beginning of ‘glacial Pleistocene’, by comparing Pleistocene lacustrine basins under study in the same region (Fornaci di Ranica, Leffe and Pianico—Séllere, Fig. 1b). These sites should allow us to correlate the main steps in Early and Middle Pleistocene vegetation change, fluvial activity, and glacial advances, in the Southern Italian Alps.

## 2. Geological setting

### 2.1. The southern borderland of the Alps

The borderland of the Alps in Lombardy is formed by a Triassic to Palaeogene marine, mainly carbonatic succession belonging to the Southern Alps (Fig. 1b). These rocks were affected by the last pulses of the Alpine deformation during the Miocene, so they will be hereafter referred to as bedrock. At that time, most of

this area was emergent. Several valleys draining the external belt of the Pre-Alps had formed before the end of the Messinian (Bini et al., 1978) and were subsequently filled by Pliocene marine sediments, entrenched in bedrock (Martinis, 1948; Bini et al., 1978; Brambilla et al., 1983; Brambilla and Lualdi, 1987; Violanti, 1991). Marine Pliocene clay commonly crops out along the Lombardian Alpine borderland up to an altitude of 305 m a.s.l. (i.e. ‘Formazione del Tornago’, Corselli et al., 1985). This apparent sea-level rise is essentially due to the tectonic emergence of the upper Lombardian plain during the Plio–Pleistocene. Marine regression at the southern alpine borderland is not precisely dated. Marine deltaic deposits observed at the outlet of the Brembo valley (Fig. 1b) and connected to the terminal regressive phase have been assigned to the Middle–Late Pliocene (Corselli et al., 1985; updated according to the tripartite Pliocene series time scale: Cita, 1996). Pliocene regression is expected to have promoted fluvial erosion (Ravazzi, 1993), but direct observations of this are hampered by the thick fluvial cover deposited during the subsequent phase of Plio–Pleistocene aggradation. At maximum aggradation phases, tributary valleys were dammed and lacustrine basins were formed, examples of this are the Leffe basin, which is the largest in the region (Cremaschi and Ravazzi, 1995), and the Fornaci di Ranica basin. The Serio valley was only weakly glaciated on its northern sector (Fig. 1b), so unravelling the relationships between glacial, and Serio River fluvial deposits, is a risky task. The subsequent Middle and Late Pleistocene fluvial activity formed several terraced units which have been recently subdivided and mapped according to the allostratigraphic approach (Jadoul and Forcella, 2000).

### 2.2. The Fornaci di Ranica basin: previous geological and palaeontological investigations

The village of Ranica in the Bergamo foothills (coord. 45° 43′ 58″ N, 9° 42′ 35″ E; UTM 32 T NR 55456475, 290–310 m a.s.l.) is located at the outlet of the Serio valley towards the Po Plain (Figs. 1 and 2), where the Nesa creek merges into the larger Serio river (Fig. 1b). Several clay layers were exploited for brick production for about 200 years. A moose antler, discovered in the vicinity of a brick factory named Fornaci di Ranica, was stored at the Museum of Natural Sciences of Bergamo in 1929. In the 1970s, a braincase of a large mammal was collected at the same site. However, the precise

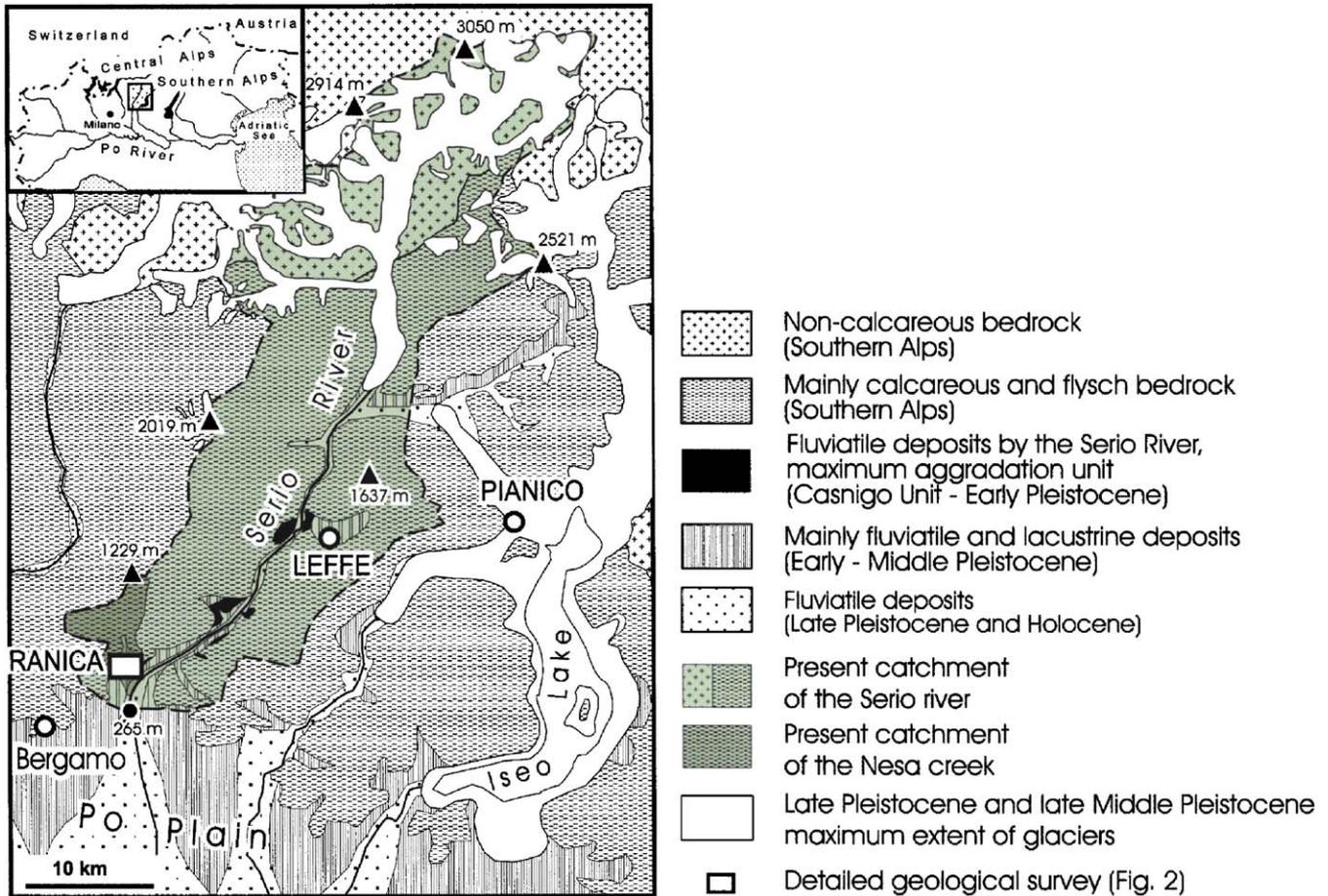


Fig. 1. Location of the studied area in Northern Italy and map of the Serio catchment area with maximum extent of Late Pleistocene glaciation (from Bini, 1993; Ravazzi, 2001, updated). The bedrock is defined by main lithological provinces. The lacustrine sites referred to in the text are also indicated. The Brembo River is on the left of the figure.

stratigraphic position of these specimens, attributed to *Cervalces latifrons* (Johnson, 1874) by Azzaroli (1979), remained unknown. On the basis of the biochronology of this species, Azzaroli (1979) assigned the clay deposits either to the ‘Galerian warm period’ or to the ‘Mindel cold period’. Venzo (1950) recognized a terraced gravelly deposit (Borgosale terrace, Fig. 2) which obstructed a small valley and allowed the accumulation of the lacustrine succession at Fornaci di Ranica. He attributed the marked weathering of the terraced surface to the ‘Mindel–Riss interglacial’, and the river damming to the ‘Mindel period’, following Penck and Brückner’s (1909) nomenclature. Subsequently (Brambilla et al., 1983), the Ranica continental deposits were attributed to the ‘Villafranchian age’ because they were believed to continuously overlie the marine Pliocene sediments. Because of this assumption, Brambilla and Lualdi (1987) subdivided the clay sequence at Fornaci di Ranica into a lower marine part, containing a foraminiferal assemblage of Middle–Late Pliocene age, and an upper part containing freshwater mollusks (*Valvata*, *Corbicula*, *Unio*). Siddi et al. (1988) provided the first

stratigraphic description of the ‘Fornaci di Ranica’ sediments and examined several samples for marine microfauna, but instead found only freshwater mollusks, ostracods and plant remains.

### 3. Material and methods

The re-investigation of the stratigraphy of the Fornaci di Ranica deposits includes a review of Museum collections, a new geological survey (the geological map by Jadoul and Forcella, 2000, is not reliable for this area), large trenches and several corings in the brick factory. The most complete sequence is evident in a core (acronym RNC) that was obtained by rotation drilling (location: no. 1 in Fig. 2b, log given in Fig. 3) which reached the Cretaceous flysch bedrock at 12.20 m depth. The complete 13 m-long core was investigated for its magnetic properties, palynological content and lithological characteristics. A complete stratigraphic column (Fig. 3) was constructed by correlating the RNC core data with data from field sections excavated on the

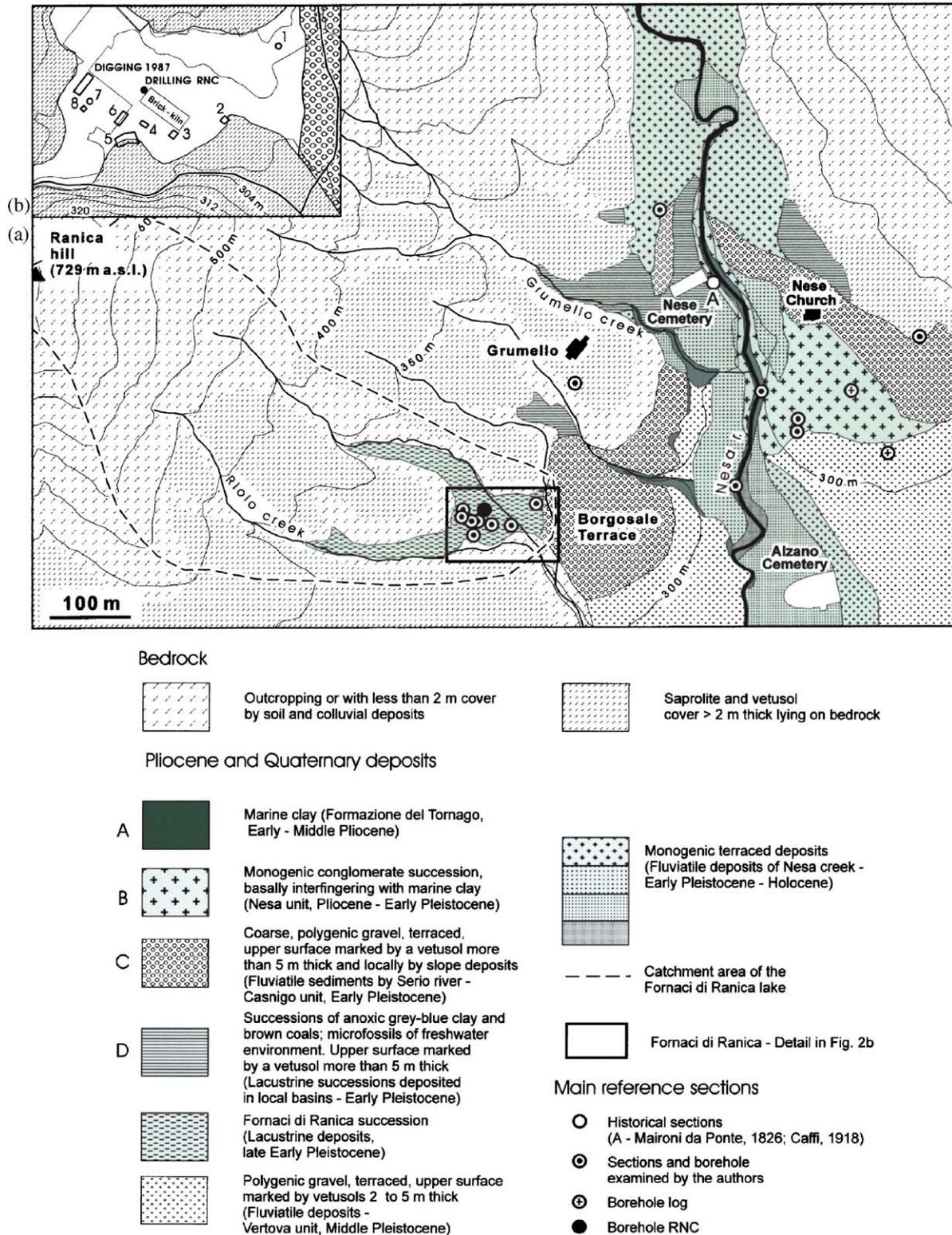


Fig. 2. Geological map of the studied area. (b) Detail of the Fornaci di Ranica site with location of excavations and drillings. The RNC drilling was carried out at the northern side of the ancient brick-kiln. The vetusol concept is from Cremaschi (1987). The Vertova unit is described in Jadoul and Forcella (2000). For historical sections see Maironi da Ponte, 1826.

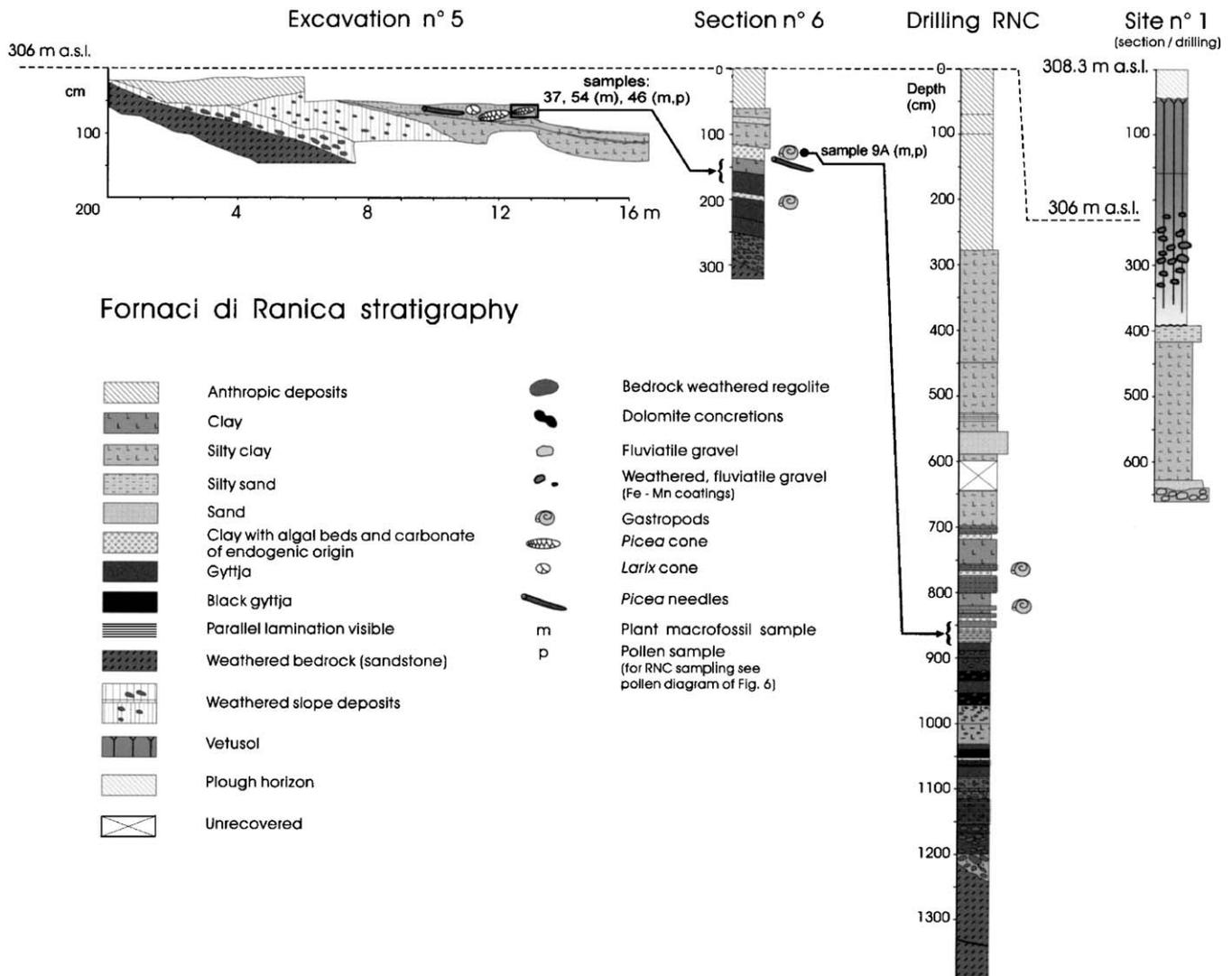


Fig. 3. Stratigraphy of the Fornaci di Ranica basin.

western side of the Fornaci di Ranica site (nos. 5 and 6 in Figs. 2b and 3) and additional short cores obtained by manual drilling at the site (nos. 1 and 7 in Fig. 2b); these analyses were conducted by the Ranica working group.

### 3.1. Pollen and plant macrofossil analysis

A total of 68 samples for analysis, 1 cm<sup>3</sup> in volume, were taken with a piston sampler at a resolution of 5–10 cm between 7 and 12.15 m, and 15–50 cm between 3.15 and 7 m depth. Preparation followed standard methods including HF and acetolysis and was performed at the Pollen Laboratory of the Institute of Plant Sciences (IPS) of the University of Bern, Switzerland. Pollen identification was carried out by comparing the fossil pollen with either reference pollen collections stored at the IPS, or published pollen floras and atlases (Punt and Blackmore, 1976–1995; Reille,

1992–1998). Nomenclature follows the ALPADABA (Alpine Palynological Database) list of pollen types (version 2000, housed at the Institute of Plant Sciences, University of Bern), which is based on the Northwest European Pollen Flora (Punt and Blackmore, 1976–1995), and then integrated with pollen types derived from Moore et al. (1991) and from the Alpine pollen flora. The ALPADABA also includes exotic types which appear in the Fornaci di Ranica sediments (e.g. *Tsuga*, *Carya*, *Pterocarya*, and *Cedrus*). The *Pinus Haploxylon* type does not include *Cathaya*, and *Cathaya* was not found. Pollen concentration was estimated by adding *Lycopodium* tablets (Stockmarr, 1971). Pollen percentages are calculated from a pollen sum that includes trees, shrubs, upland herbs, and excludes Cyperaceae, aquatics, and spores. The percentages are plotted on a simplified pollen diagram (Fig. 6a and 6b). Local pollen zones, defined by subjective zonation and prefixed by site designation, are numbered from the base upwards.

Table 1  
List of significant plant macrofossils found in the samples from Ranica

Volume analyzed (dm <sup>3</sup> ) sediment type	Type of remain	Sample number			
		26bis 34.7 Grey clay imbedding chaotic pebbles	37 1 Grey clay with sparse fine plant debris	46 2 Grey clay with sparse fine plant debris	54 15 Laminated clayay marl
Carex fusca All.	Fruits	—	1	1	1
Carex gr. flava L.	Fruits	1	—	—	1
Carex rostrata Stokes	Fruits	F	FF	FF	F
Carex sp. 1 (2-sided)	Fruits	—	3	2	9
Carex spp. (3-sided)	Fruits	2	1	3	1
Characeae	Oogonia	—	FF	F	F
Dianthus cf. barbatus L.	Seeds	—	—	—	1
Labiatae indet.	Fruits	2	—	—	—
Larix cf. decidua	Cones	—	—	1	—
Phragmites-type	Stems	F	F	F	5
Picea cf. abies (L.) Karst.	Cones	—	2	1	—
Picea cf. abies (L.) Karst.	Needles	F	FF	FF	F
Picea cf. abies (L.) Karst.	Seeds	F	5	8	2
Potamogeton natans L.	Fruits	FF	FF	FF	FF
Potamogeton sp. 1	Fruits	—	—	8	1
Ranunculus subg.	Fruits	2	—	—	2
Batrachium sp.					
Silene cf. dioica (L.) Clairv.	Seeds	—	3	5	—
Typha cf. latifolia L.	Seeds	1	—	—	1
Viola sp.	Seeds	1	1	2	—

The number of specimens which have been isolated from each sample are indicated in each column. FF, very frequent; F, frequent.

Large amounts of clay and clay marl (sample 26b in Table 1, 31.7 dm<sup>3</sup> sediment in total), collected from specific levels (Fig. 3) in trenches nos. 5 and 6 (Fig. 2b and 3), and also small samples (37, 46, 54, 9A in Table 1) from different stratigraphic levels (Fig. 3), were separately disaggregated in distilled water or in 3% H<sub>2</sub>O<sub>2</sub>, and sieved through 125 and 250 µm screens for fruits, seeds, charophytes, and other plant macroremains. The carpological material has been qualitatively and quantitatively analyzed; the most abundant species were not counted, but were tallied as frequent or very frequent (Table 1). Additional pollen spectra were created from samples analyzed for their macroremains. Finally, because the moose fossil's stratigraphic position could not be ascertained from the literature, two pollen samples were analyzed. The samples are from the coherent clay matrix preserved at the bottom of the *foramen magnum* of the moose braincase. The exposed sediment surfaces were carefully removed using glass-paper, and compared with the RNC pollen diagram in order to reconstruct the fossil's stratigraphic position.

### 3.2. Magnetic properties

Palaeomagnetic samples from the RNC core were taken from 1300 to 270 cm depth (above 270 cm depth, the RNC core is very weathered) with a piston sampler at an average sampling interval of 5 cm, producing a

total of 168 samples for analysis. The initial susceptibility, and the natural remanent magnetization (NRM) intensities, were measured with a Kappabridge KLY-2 susceptibility bridge (Geofysika Brno) and a DC SQUID three-axis cryogenic magnetometer (2G-Enterprises), respectively, at the palaeomagnetic laboratories of ETH Zürich, Switzerland. Alternating field demagnetization from 2 mT up to maximum values of 80–150 mT (mean of 50 mT) was applied in 5 mT steps to the majority (104) of the samples to retrieve the magnetization components of the NRM. Least-square analysis (Kirschvink, 1980) was used to determine the component directions of the NRM, chosen by inspection of vector end-point demagnetograms (Zijderveld, 1967).

Infrared spectra were obtained from 10 samples at 0.5 m interval from a RNC core for a semiquantitative estimation of carbonates (calcite, aragonite, dolomite, siderite) and quartz following Chester and Elderfield (1967).

### 4. Survey of the Neogene–Pleistocene deposits and landforms

The top part of the fine-grained, littoral succession of Pliocene age, filling the lower Seriana valley, includes monogenic large-scale, cross-stratificated conglomerates, forming a fan-delta built up by the Nesa creek

(Nesa unit, B in Fig. 2a; catchment 14 km<sup>2</sup>, Fig. 1b). Conglomerates from the Serio River, instead, are petrographically distinct for they contain Palaeozoic rock fragments, which indicate a catchment area extending far to the north (presently ca. 700 km<sup>2</sup>, Fig. 1b). These polygenic, coarse deposits overlie the Nesa unit conglomerates or lie directly on top of marine clays. The Serio and Nesa Rivers deposits dammed the bedrock-entrenched valleys, thereby triggering the formation of closed basins characterized by palustrine (gyttja and brown coals) and lacustrine (laminated clay and clay marls) sedimentation (D in Fig. 2a). Damming occurred especially during the maximum aggradation of the Serio River, which is represented by part of the Borgosale terraced surface (belonging to the Casnigo unit) located at the top of heavily weathered gravel bodies, and locally covered by slope deposits (C in Fig. 2a). Borehole no. 1, drilled on the border of the Fornaci di Ranica basin (Fig. 2b), contains stratigraphic evidence for this fluvial dam (Fig. 3). Moreover, the uppermost lacustrine succession of Fornaci di Ranica onlaps the fluvial body up to the altitude of the terraced Borgosale surface. This indicates that lacustrine deposition continued well after river aggradation ceased, and confirms that the lake level threshold was indeed represented by the terraced Borgosale surface. The post-erosional morphology, shaped after the lake was completely filled with sediments, was controlled by the southward diversion of the Riolo creek (Fig. 2a). However, most of the area has remained stable since emplacement of the fluvial dam, as indicated by the overlying and continuous vetusol layer (Cremaschi, 1987), which is 3–7 m thick (site no. 1 in Fig. 3). Thus, the taphonomical processes and the palaeoenvironment of the catchment area, and the morphology of the Ranica site (Fig. 2a), did not change significantly after deposition of the lake sediments.

## 5. Lithostratigraphy of the basin sediment fill

At the depocentre of the Fornaci di Ranica basin (RNC drilling site in Figs. 2b and 3), sediments lie on deeply weathered slope deposits, which cover the saprolitic bedrock (sites 5, 6 and RNC). The RNC core reached bedrock at 12.20 m depth. In this core, a basal coarse regolithic layer (from 12.20 to 12 m) is covered by a fine, matrix-supported, clinostratified diamicton (12–11.6 m RNC) which contains plant remains interpreted as slope deposits. It passes upward into organic clay embedded with Cretaceous flysch bedrock fragments, the clay is carbonate-free according to its infrared spectra (clay gyttja, 11.6–8.8 m), and was likely deposited in a mire supplied by a creek. Organic sediments are thin or even missing in the marginal part of the basin (sites 5 and 6). The gyttja is overlain by

laminated grey clay and marl (8.8–6.8 m in RNC and 1.8–1.2 m in Section 6). Graded, centimetric-thick clay layers are interpreted as microturbidites. Surfaces between single clay beds are marked by light laminations of partially biogenic marls, composed of Charophytes talli, calcified *Potamogeton* leaves, gastropods, and fine calcareous detritus (calcite by IR spectra). This clay/marl alternation may therefore be evidence of a lacustrine environment. The upper part of the succession (6.8–2.8 m in RNC, 1.2–0.6 m in Section 6) is composed of microturbidites, locally rich in dolomite concretions, but lacking any distinct calcareous layers of biogenic origin. It is truncated upward by anthropic deposits related to the brick-kiln activity. The top vetusol is preserved only at site no. 1.

## 6. Magnetic properties

The initial susceptibility variations allow us to subdivide the Ranica core lithology (Fig. 4a) into three portions. The lower portion, up to 9.75 m depth, is characterized by scattered but generally low-intensity values, whereas a marked peak in susceptibility is observed up to a depth of 9.08 m (Fig. 4b). From this depth upwards, the susceptibility generally shows constant low values. The NRM intensity curve substantially conforms to the initial susceptibility trend. These variations clearly reflect the lithostratigraphic evolution of the Ranica basin. The lower part of the core with higher susceptibility and NRM intensities includes basal slope deposits characterized by darker (i.e. poorly oxidized) clays (gyttja), whereas the upper part from 8.75 m upwards is characterized by relatively lighter-colored sandy-clayey lacustrine and turbiditic sediments (Fig. 4a). Alternating field demagnetization up to 50–80 mT was usually sufficient to demagnetize samples (e.g. Figs. 5a and b). This suggests the occurrence of a magnetic mineral with relatively soft coercivity, possibly magnetite. The presence also of a harder magnetic mineral, probably a sulfide phase, cannot however be excluded in those samples where fields up to 150 mT were not effective in resolving the component structure of the magnetization (e.g. Fig. 5c). Interpretable palaeomagnetic directions were obtained in only 54 out of a total of 104 samples analyzed. The generally poor response to demagnetization discouraged us from undertaking further analysis. The magnetization components retrieved from the lower part of the core, up to a depth of 11.87 m, revealed however, the occurrence of predominantly negative palaeomagnetic inclinations (e.g. Fig. 5a). The interval between 10.90 and 9.07 m is instead characterized by positive palaeomagnetic inclinations (e.g. Fig. 5b) acquired during a normal polarity interval. In between these two clearly magnetized intervals, the magnetization components are either

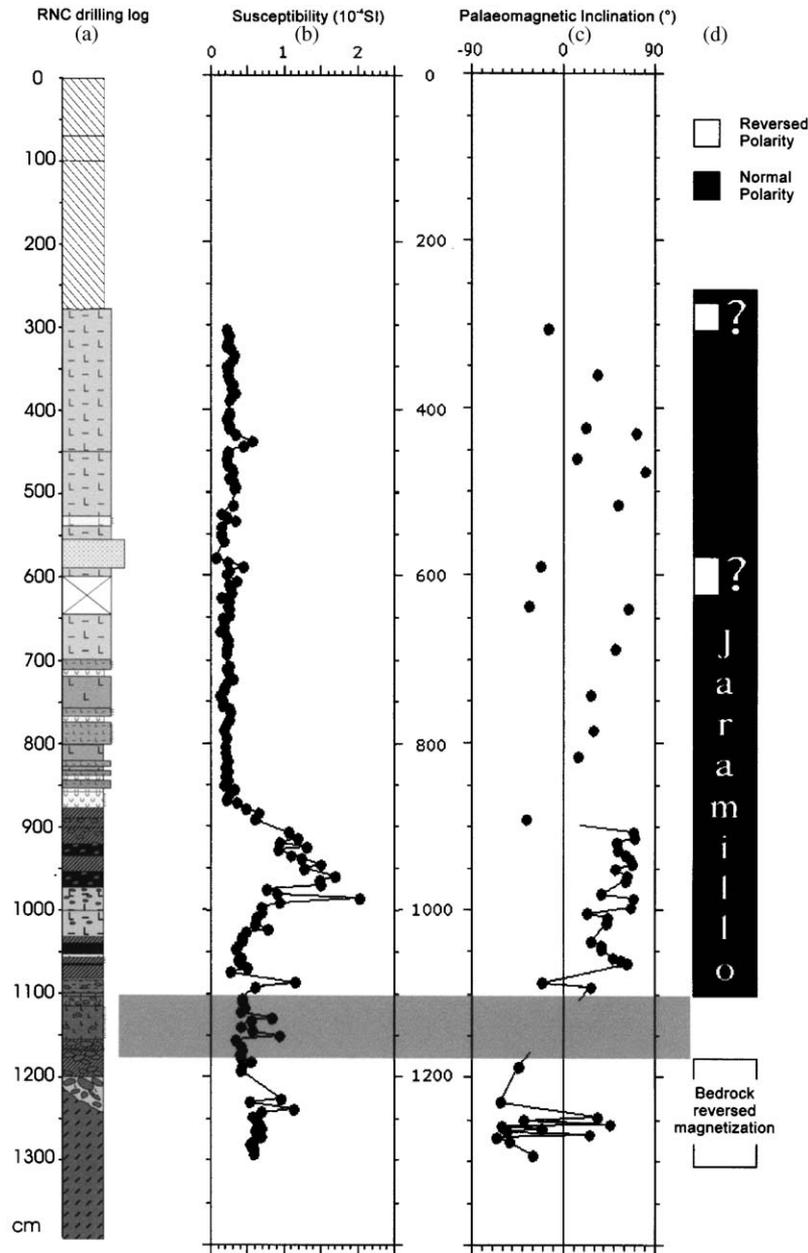


Fig. 4. The 'Fornaci di Ranica' core. In panel (a) is the lithological column, in panel (b) the variations of the initial magnetic susceptibility, in (c) the characteristic palaeomagnetic component of inclination, with the polarity interpretation and in (d) Magnetic polarity zones are shown by filled (of open) bars for normal (of reversed) polarity. Note that palaeomagnetic samples are unoriented, therefore the inclination is used to derive a stratigraphy of the changing polarity. The box at 11–11.7 m depth indicates chaotic slope deposits overlying the bedrock.

hardly interpretable or scattered (e.g. Fig. 5d). Above level 9.07 m, usable magnetization components are few but they are characterized by generally consistent positive inclinations. An inspection of Fig. 4 suggests that the stratigraphic distribution of negative (reversed) and positive (normal) palaeomagnetic directions is apparently correlative with the boundary between bedrock and basin sediments (12.20 m depth). On the other hand, across this critical interval susceptibility shows no particular variations. Nevertheless, we propose that the

basal reversed magnetization at Ranica may represent the Cretaceous bedrock magnetization, whereas the normal magnetization, from 10.90 m and upwards, may represent the original magnetization of the palustrine/lacustrine deposits at Ranica. There is an overall lithologic control on sediment magnetization because interpretable palaeomagnetic directions have been obtained mostly in the lower portion of the core where the sediments are darker, rich in organic material and texturally less homogeneous, than the upper portion

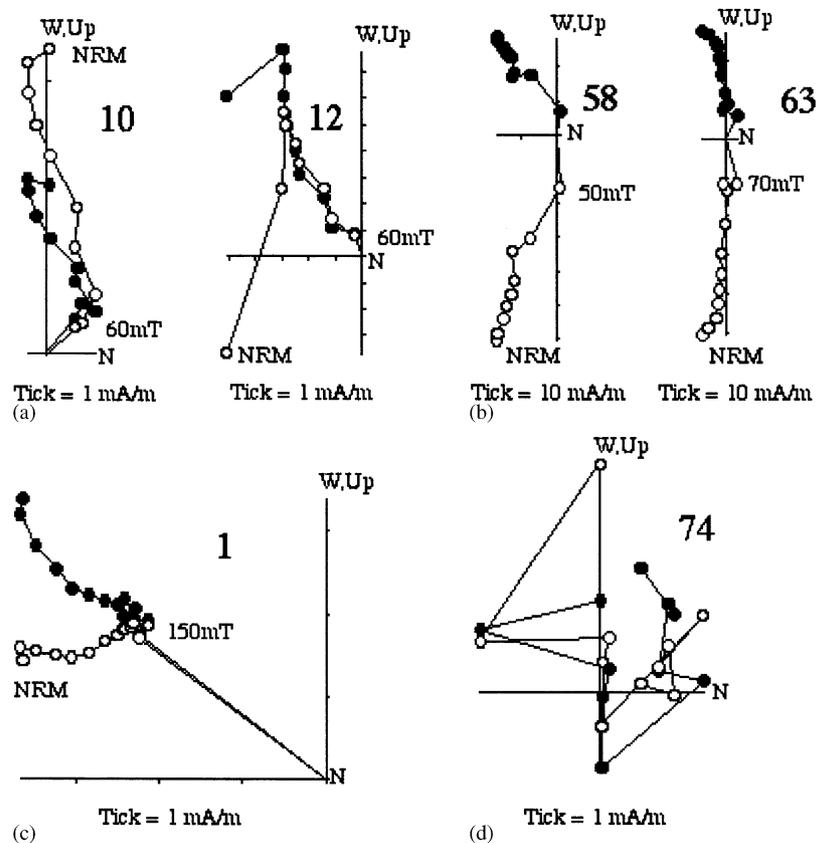


Fig. 5. Zijderveld demagnetization diagrams of the NRM of representative samples from the 'Fornaci di Ranica' core. Closed symbols are projections onto the horizontal plane and open symbols are projections onto the vertical plane in in situ (equal to tilt-corrected) coordinates. Demagnetization steps in mT.

which is lighter in color and composed of fine detrital sediments (lacustrine turbidites).

## 7. The palynological results

Fig. 6a and 6b presents the simplified pollen percentage diagram, the total pollen concentrations, and charcoal particle concentrations from the RNC core. The pollen record shows an overall dominance of conifer tree pollen (*Pinus sylvestris/mugo*, *Picea*, and *Tsuga*). Non Arboreal Pollen (NAP) includes both marsh plants (Cyperaceae), tall herbs (many Umbelliferae), cold spring and cold/wet meadow-plants (*Utricularia*, *Saxifraga stellaris*) and also grasses, chamaephytes, and shrubs of drier environments (*Helianthemum*, *Artemisia*, Chenopodiaceae). Reworked pollen grains have not been found.

### 7.1. RNC 1 (12.15–11.65 m)—*Tsuga* (dominance)

The basal zone shows high arboreal pollen (AP) percentages (85–92%), comprised mainly by *Tsuga* (30–65%). *Pinus*, *Picea* are also present in the stomata record. Small stomata belonging to cf. *Tsuga* were

observed in only one sample. Broad-leaved tree pollen is represented by the continuous curves of *Alnus glutinosa* type, *Carya*, *Corylus*, *Ulmus*, *Tilia*, *Quercus*, *Pterocarya* and *Castanea*, which total from 8% to 10%. Considering the under-representation of *Tsuga* pollen (Janssen, 1984), this conifer likely dominated a dense in situ conifer forest. *Pinus* and *Picea* were also present in the small catchment area of the Fornaci di Ranica basin (Fig. 2a). Thermophilous, broad-leaved trees (*Carya*, *Corylus*) may have been sporadic components of the extralocal forest. Large peaks in the fluctuating distribution of charcoal particles are also evident. This zone lacks any evidence of limnic or telmatic plants.

### 7.2. RNC 2 (11.65–11.3 m)—*Pinus*–*Picea*–*Tsuga* (dominance), *Abies* (continuous occurrence)

This zone registers increasing *P. sylvestris/mugo* and *Picea* pollen, and stomata, and declining *Tsuga* (10–12%) and broad-leaved pollen taxa. This indicates that the site was surrounded by conifer forests. Given the under-representation of *Abies* and especially of *Tsuga* in pollen records, we suggest that the latter was still abundant and co-occurring with *Picea*, *Pinus*, and





the zone contains 45–55% of *Pinus* pollen and a total of 60–75% AP. Above 4.9 m, *Pinus* and *Picea* values increase and AP reaches 85–90%. *Larix* is sporadically represented, whereas *Tsuga* is absent above 6.47 m depth. Sporadic *Pinus* stomata occur. Because of the low pollen sum, the diversity among herbs is also lower relative to zones RNC 1–5 and detailed percentage changes are not apparent. However, pollen of the *Saxifraga oppositifolia* type, and *Gentiana pneumonanthe* type are evidence of cold wetlands and meadows-steppes. The complete assemblage indicates an extensive boreal conifer forests (taiga), with wetlands in the lower depressions. The uppermost part of this zone (3.7–3.2 m) shows an increase of pollen concentration and of *Picea* percentage values, which apparently depresses the values of *Pinus* and the xerophytes. Unfortunately, the uppermost 3 m of the lacustrine succession were reworked at the time of the brick-kiln activity.

## 8. Plant macroremains

The residue of all examined samples was composed primarily of freshwater and terrestrial plants remains (woody fragments and a few fruits and seeds in the coarse fraction; and in the fine fraction, the same remains along with cuticles and small roots). Fruit and seed assemblages are species-poor in all samples, owing to the taphonomy (see further). It follows that the presently available plant macrofossil data can just provide only a partial contribution to the reconstruction of ancient plant communities.

Despite the differences of sediment type, the flora (represented by the fruits and seeds) within all the samples are very similar (Table 1 and Fig. 7): fruits of *Potamogeton natans* and *Carex rostrata* seeds are invariably dominant, together with Characeae oogonia. The next most abundant carpological macrofossils are *Picea* seeds. The macrofossils that occur infrequently and yet are present in more than two samples are: *Carex* gr. *flava*, *Carex fusca* All., *Ranunculus* subgen. *Batrachium*, *Silene* cf. *dioica*, and *Viola* sp. Three other species are present and represented by single or a few specimens: *Cirsium?* sp., *Dianthus* cf. *barbatus* L., and *Typha* cf. *latifolia* L. In addition, all the samples contain varying quantities of needles and leafless shoots of *Picea*, and fragments of *Phragmites*-like stems.

### 8.1. Taxonomical notes on ecologically important species

#### 8.1.1. Pinaceae

Only the two almost complete and well-preserved cone specimens and six poorly-preserved or fragmentary cones were available for the present study. The best preserved cones have a combination of size, shape, scale

number, and margin type that are diagnostic of the genera *Picea* and *Larix*. By comparing different fossilized parts from a single species, it appears that each genera is represented by only one species. Both species are represented either by cones, seeds (Fig. 7 c,c'), or needles, in the same assemblage. The systematic relationships of the fossil pinaceous species and the recent European counterparts are discussed below.

#### 8.1.2. *Larix decidua* Mill

The narrowly ovate fossil cone that is 3-cm long with a coarse, short, and curved stalk appears identical to the cones of the living alpine populations of *L. decidua*. Even the cone-scale margins are well preserved, while the bract scales are poorly visible. Farjon (1990) highlighted the species' diagnostic characteristics of recent cones, and the historical biogeography of *Larix* is dealt with by LePage and Basinger (1991). In central Europe, the occurrence of this genus in the Pliocene is doubtful (Szafer, 1947), while it is rather frequent in several Pleistocene intervals and found as far away as southwestern England (Field et al., 1997). *Larix* pollen has been identified in the lower-Pleistocene conifer-*Artemisia* assemblages in the Alps (Ravazzi and Rossignol Strick, 1995). In the Quaternary of Europe, no extinct *Larix* fossil species have been identified, only the extant *L. decidua* is identified. The distribution and ecology of this species are summarized by Field et al. (1997) and Hoffmann et al. (1998).

#### 8.1.3. *Picea abies* (L.) karst. subsp. *obovata?* Ledeb

Cones are the most diagnostic fossils for a species identification of *Picea*. The best cone specimen from Ranica is 7.5 cm long and 2 cm wide (due to fossilization these dimensions are likely to be 80% of the original ones). The obtuse upper margin on the fossil cone scales and the near absence of striation distinguishes it from the comparably sized cones of the modern *P. omorika* (Pancic) Purkyne and *P. orientalis* (L.) Link. In addition the needles of *P. orientalis* (L.) Link are shorter and narrower than the fossil needles, while *P. omorika* (Pancic) Purkyne needles are relatively flatter in shape and exhibit wider stomatal bands. The Fornaci di Ranica spruce are not identified as the well-known fossil species *P. omoricoides* Weber (= *P. heissiana* Ludwig) because of the marked differences in cone and needle structure (Buzek et al., 1985; Mai and Palamarev 1997). Sordelli (1896) reports two other extinct (but doubtfully valid) species for the Pleistocene in Lombardy. Although the type material of these other extinct species is not available, the original descriptions and drawings exclude any similarity to the Fornaci di Ranica specimens. Therefore the only remaining possibilities are *Picea abies* (L.) Karst., or, perhaps more likely, the Siberian *P. obovata* Ledeb., which is a close relative (Farjon, 1990) that is often regarded as a subspecies

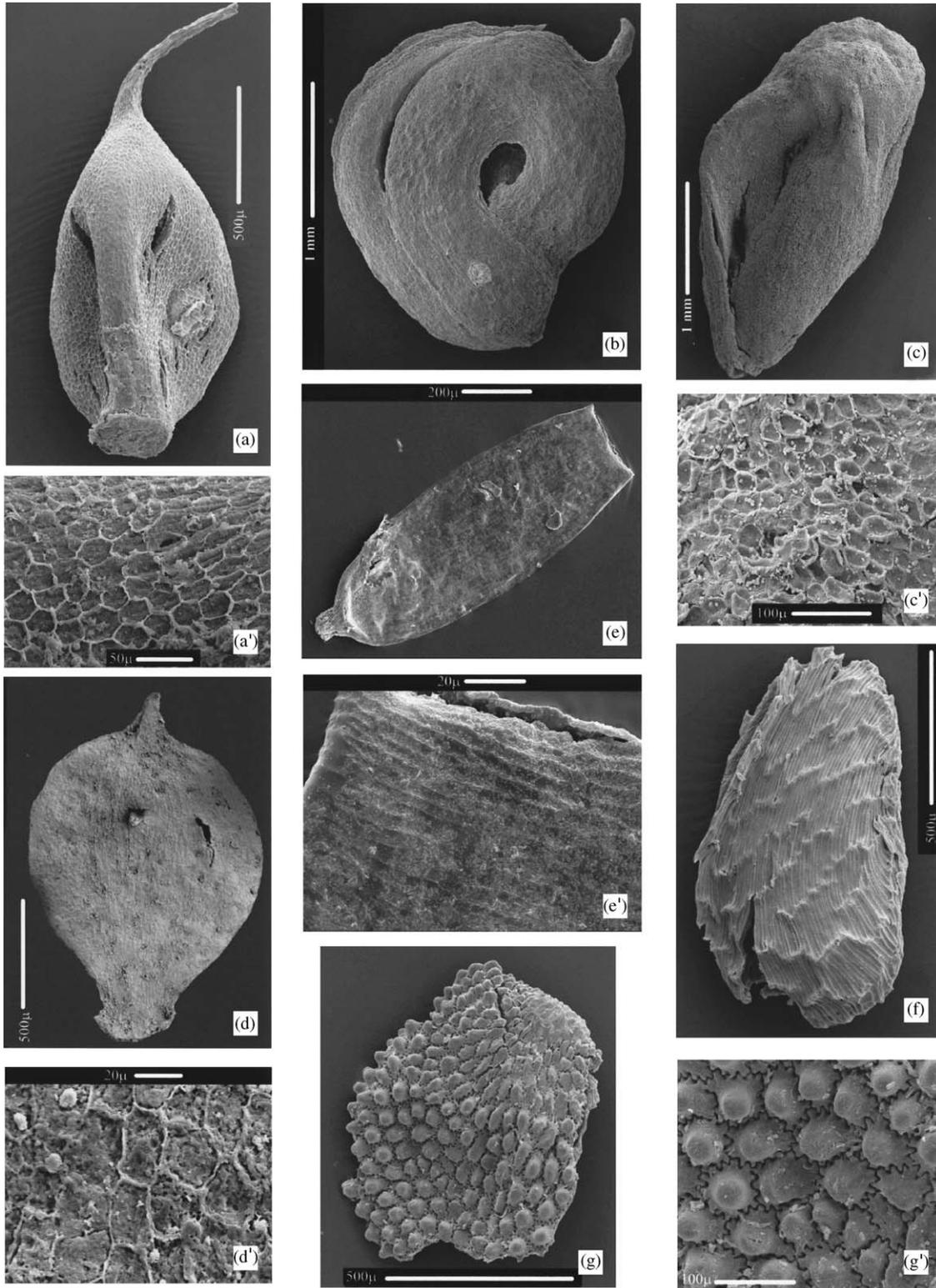


Fig. 7. Scanning electron micrographs of fruits and seeds from the early Middle Pleistocene of Ranica: (a, a') nutlet of *Carex rostrata* Stokes with detail of external surface; (b) endocarp of *Potamogeton natans* L.; (c, c') wingless seed of *Picea abies?* (L.) Karst. with detail of external surface; (d, d') nutlet of *Carex fusca* All. with detail of external surface; (e, e') seed of *Typha* cf. *latifolia* L. and detail of external surface; (f) fruit of *Ranunculus* subg. *Batrachium* sp.; (g, g') seed of *Silene* cf. *dioca* (L.) Clairv. and detail of external surface.

(= *P. abies* ssp. *obovata* (Ledeb) Hultén). The Ranica fossil cone specimens are shorter, in the mean, than cones from *P. abies* populations presently growing in the Alps, and the Ranica cone scales are invariably obtuse-pointed, instead of apiculate to retuse as in the *subsp. europaea* (Schmidt-Vogt, 1977). *P. abies* macroremains have been found during temperate/cold temperate stages since the (Middle) Pliocene in Western Europe (Mai and Walther, 1988; Zagwijn, 1989; Ravazzi, 2002). Cones and needles described from the Middle Pleistocene in southern France were also identified as *P. abies* ssp. *obovata* (Bazile et al., 1977).

#### 8.1.4. Other taxa

*Silene* cf. *dioca* (L.) Clairv. (Fig. 7 g, g'). Based upon Berggren (1981) and upon the examination of seed samples of 10 modern species, the one dozen Caryophyllaceae seeds are identified as *S. dioca* (L.) Clairv., a hemicyptophyte growing in nitrogen-rich meadows and clearings in the Alps, mostly at altitudes from 500 to 1800 m a.s.l.

*Carex fusca* All. (Fig. 7 d, d') was identified by comparing nutlets of fossil and living species. This sedge forms extensive fens in oligotrophic basins (Pignatti, 1982; Oberdorfer, 1990) and today is widespread in the mountain and subalpine zones of the Alps (700–2200 m a.s.l.) with rare occurrences at lower-altitude bogs.

*Carex rostrata* Stokes (Fig. 7a, a') can be identified based upon the characteristics of Pliocene and Quaternary fruits examined by Mai and Walther (1988) in Western Europe. The modern ecological preferences of this species are very broad. It grows in mires in the Alps, and from the plains to 2000 m a.s.l.

*P. natans* L. (Fig. 7b) is a hydrophyte, but it survives droughts as a hemicyptophyte. It tolerates large water-level oscillations in shallow and calm freshwater basins (Hartog den and van der Velde, 1988; Venanzoni and Gigante, 2000) and becomes a dominant species in some mesotrophic communities of aquatic plants in Italy up to 1500 (rarely up to 1900) m a.s.l. (Pignatti, 1982).

*Typha* cf. *latifolia* L. (Fig. 7e, e') Two seeds can be assigned to this species based upon a characteristic combination of shape and seed coat ornamentation. The small number of propagules does not allow us to infer its local occurrence, since the seeds have cotton-like fibers that facilitate long-distance wind dispersal. *T. latifolia* is a typical freshwater helophyte (Best, 1988). Presently in Italy it is rare above 1000 m a.s.l., though its maximum altitude is up to 2000 m a.s.l. (Pignatti, 1982).

#### 8.2. Taphonomy

The incorporation of plant parts in the sediment of the lake bottom was limited to the following components: (1) propagules of water plants growing in place,

such as Characeae, *Potamogeton*, and *Ranunculus* subgen. *Batrachium*; (2) stem fragments of *Phragmites*-like Gramineae, possibly forming a reed-belt around the lake, where also *Typha* cf. *latifolia* could grow; (3) fruits of *Carex* species, a marsh sedge that grew possibly near an inlet or behind the reed-belt on the lake shore (in fact *Carex* fruits are rather tiny and float for long time, so they can easily penetrate the reed-belt barrier); and (4) cones, shoots, needles, and seeds of *Picea* and cones of *Larix*, coming from a terrestrial environment. Some of these objects could be transported into the lake by wind, but the cones need to be transported by a stream, possibly an inlet (unless the conifer branches hung over the lake). Additionally, *Silene* cf. *dioca* and *Dianthus* cf. *barbatus* seeds may indicate clearings in the vegetation, based upon the species' preferred habitat ecology and the association of these fossil seeds with the conifer cones.

The low species diversity of components (1)–(3) may be linked to low-diversity of the water and wetland plant communities. However, the range of *Picea* remains, combined with the almost complete absence of other non-limnic plant remains, indicates that the surroundings were forested with a species-poor understory. A similar assemblage from Middle Pleistocene lake deposits in France has been interpreted as resulting from the shade cast by a coniferous woods (Field et al., 2000, p. 67). The local catchment of the Fornaci di Ranica basin (Fig. 2a) was so small that the plant material brought into the lake could not have come from an altitudinal range of more than about 200 m above the lake. In this context, the absence of woody angiosperm macroremains can be interpreted as evidence of the scarcity of these plants in the catchment basin.

#### 9. The remains of *Cervalces latifrons*

The two remains of *C. latifrons* (Johnson, 1874) (Fig. 8), extracted from the clay succession of Fornaci di Ranica, consist of a braincase (listed in the catalogue of the Museum of Natural Sciences of Bergamo as MCSNBG 2609) and the basal portion of an antler (MCSNBG 1421). The antler preserves the shedding surface (with elliptical section), the burr, and the beam. The beam begins to flatten in a surface perpendicular to the major diameter of the burr and stops at the beginning of the palmation. This specimen is readily attributed to the tribe Alcinae, as it lacks any spike between the burr and the beginning of palmation. The long beam indicates the genus *Cervalces*, although the large variation in shape and size of antlers, due to both ontogenetical growth and annual regeneration, makes the species identification difficult (for measurements see Azzaroli, 1979, p. 53). The braincase's neurocranial

***Cervalces latifrons* (Johnson, 1874)  
from Fornaci di Ranica lacustrine succession**

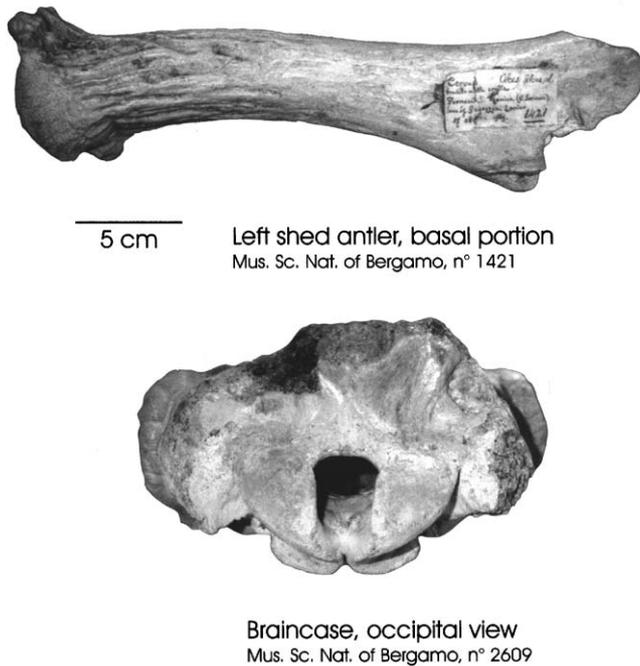


Fig. 8. Basal portion of the antler (a) and the braincase, occipital view (b) of *C. latifrons* from Fornaci di Ranica.

portion indicates a strong adult male. The parietal, occipital, temporal, and frontal bones with pedicles are all preserved. The wide frontals, where the antlers would be inserted laterally on either side of the head, are a typical characteristic of the tribe Alcinae. In the sample from Ranica, the facial portion, which is useful in distinguishing between *Cervalces* and the extant genus *Alces*, is not preserved. However, the occipital region, which in the fossil is broad and relatively shallow, whereas that of *Alces* is narrow and deep, identifies the fossils as *Cervalces* (Azzaroli, 1979, 1982, 1985). The braincase's morphology could illustrate the higher mass of the *Cervalces* head, caused by longer antlers, and thus the need for a wider insertion for the neck muscles (Breda, 2001a).

For the determination of the species, we examined the *Cervalces gallicus* holotype (kept in the Palaeontological Museum of the University Claude Bernard—Lyon 1), the neotype of *C. latifrons*, and other specimens of both species from the Norfolk Coast (kept in the Natural History Museum of London), which have preserved the same neurocranial portion. In addition to the large size of the Ranica specimen, as already stated by Azzaroli (1979), the morphology of the occipital condilus and foramen magnum confirms Azzaroli's initial species determination as *C. latifrons* (for detailed descriptions see Breda, 2001a).

**9.1. Palynostratigraphic position of the *Cervalces* braincase**

Two pollen spectra were obtained from the center of clay fragments extracted from different parts of the braincase. Recent contamination is unlikely based upon: the absence of pollen types which might derive from Holocene, similarity of the two spectra, and the high pollen concentrations.

The spectra are indeed very similar: both are dominated by herbs (76.2% and 72.4%—Gramineae, Cyperaceae, *Artemisia*, and Apiaceae, the last comprises 11 pollen types). Other Compositae (7 pollen types), *Filipendula*, *Galium*, and *Thalictrum* are of minor importance. Numerous taxa sporadically occur: *Helleborus viridis*, *Plantago lanceolata* type, *Campanula*, *Scrophularia* type, *Urtica*, *S. stellaris* type, *Epilobium*, *Echinops*, *V. officinalis* type, and *Pulmonaria obscura* type, etc. Among the woody taxa, *P. sylvestris/mugo* is the most common (20.9% and 24%); all other woody plants show pollen percentages below 1%. The pollen spectra from the moose skull are similar to pollen zone RNC 3 (Fig. 6a and b). In zone RNC 3, the lowest percentage values of *Picea* apparent within the whole pollen record are combined with high herb diversity, especially among the Umbelliferae. Other facts corroborate this correlation: both sample sets have high percentages of organic matter, similar pollen concentration values; and the same rare pollen types and spores (e.g. *Veratrum*, *Vicia* type, *Astrantia major* type, *Sparanium erectum* type, and *Polypodium vulgare*). This indicates that the *C. latifrons* lived in the surroundings of the Fornaci di Ranica basin, during a time when the lower palustrine facies was deposited, and represented by pollen zone RNC 3.

**10. Environmental synthesis and evolution**

A multi-disciplinary reconstruction of the changing palaeoenvironment can be based upon the stratigraphic framing of the geological setting, the lithology, the plant macrofossils, the location of the *Cervalces*, and the pollen record.

The basal slope deposits overlie the bedrock, that was reached by RNC drilling, and pre-date sedimentation in the basin. The palaeomorphology of the site (Section 4) and the hydromorphic features indicate the slope deposits accumulated in a terrestrial environment, at the bottom of a small channel which drained a foothill slope. According to the pollen analysis, the channel (or valley) bottom was covered by a *Tsuga*-dominated forest (zone RNC 1)—perhaps the pollen reflects only the local vegetation since *Tsuga* species are shade-tolerant and some species are adapted to wet soils (Franklin, 1988). The pollen of broad-leaved trees might represent the

influx from adjacent well-drained areas that may have supported a more diversified forest cover. The large peaks of charcoal particles are characteristic of *Tsuga*-dominated vegetation, which is particularly susceptible to fire stress (Foster and Zebryk, 1993). In the Early Pleistocene pollen record of Leffe, *Tsuga* peaks are often coincident with charcoal maxima, or precede them (Pini, 1997). An example of a fossil *Tsuga*-forest, which burned and then slumped into lake sediments, has been described in the Leffe basin (Pini et al., 1998). The *Tsuga* pollen curve, and especially the percentage drop at the beginning of zone RNC 2 (11.65 m depth), parallels, with a time lag, the trend of the charcoal particles (which decrease at 11.50 m depth). We therefore argue that this hemlock decline was related to catastrophic fires. This decline may be compared to the Holocene hemlock decline in Eastern North America, which has been linked to a marked decrease in mean annual precipitation, especially caused by summer drought, which triggered fires and severe insect outbreaks (Foster and Zebryk, 1993; Haas and McAndrews, 1999).

The subsequent development of a mire which accumulated organic clay sediments has been related to the valley's damming by fluvial aggradation. The water-table may have risen and caused the retreat of the forest and expansion of the herbaceous vegetation, evident in pollen zone RNC 3. However, the concurrent decline of broad-leaved trees characteristic of a warm-temperate climate (*Carya* and *Pterocarya*), indicates that climate changes may have accompanied the local environmental changes. The increase of steppic plant pollen indicates that the forest withdrawal and broad-leaved tree pollen decline occurred at a regional scale. The landscape was partially tree-covered, with cold or cold-temperate adapted vegetation, and a variety of herbaceous phytocoenoses, although no specific tundra indicator species have been found. Therefore, we argue that the environmental changes from RNC 1 to RNC 3 were triggered by climatic changes. Zones from RNC 1 to RNC 3 probably represent the final part of a temperate period and the subsequent transition into a cold phase. The lithostratigraphical evidence indicates that this climate change also triggered river aggradation, and enhanced river discharge and sediment supply into the main valley, as commonly occurs in fluvio-glacial environments. Therefore, we deduce the existence of alpine glaciation in the northern part of the Serio River catchment, during the phase of fluvial aggradation that lead to the basin's formation.

Correlating the pollen and geochemical evidence shows that the *C. latifrons* skull was originally deposited in the interval represented by pollen zone RNC 3. Pollen from the braincase and moose palaeoecology corroborate the reconstruction of a boreal landscape, with parkland and/or open vegetation. Modern moose (*Alces alces*) habitat is a coniferous forest at high

latitudes, with many moist meadows and water bodies (river systems and lakes). Moose will move across open spaces, although they usually require some minimum woody cover. They browse on twigs of willows, aspen, conifers and many shrubs, but aquatic plants also constitute a large forage source. Probably the *Cervalces* occupied a more open habitat than modern *Alces*, because its big antler span (2 m or more) may have prevented it from moving in dense forests. Comparative studies of vegetation and mammal changes in the Canadian forest-tundra ecotone also show that moose occurrence is related to an open woodland habitat (Ritchie, 1983). However, the flora and fauna associated with fossils of *Cervalces* indicate that it lived in a relatively open, steppe-like habitat (Sher, 1974).

Another water table rise can be inferred from zones RNC 4 and RNC 5, since pollen from limnic aquatic plants increases. The plant macrofossil assemblages presented in Table 1 (see Figs. 3 and 6 for the correlation) were taken from these two zones. The main features apparent in Table 1 (low species diversity, absence of woody angiosperms, *L. decidua* fossils, and abundant *Picea abies*) are consistent with the pollen record: together they are evidence of a landscape dominated by extensive mixed coniferous forest. The continuous *Larix* pollen curve is accompanied by *L. decidua* cones. These macrofossils demonstrate that the European larch existed during the Early Pleistocene in the Alps, it has not been previously identified at the species level. The occurrence of pollen of arctic-alpine and other cold-adapted plants (*Utricularia*, *S. oppositifolia* type) is also noteworthy, these plants are low pollen producers and probably indicative of cold meadows and springs around the basin's margin. These are the oldest macrofossils of these taxa identified in the Alps, up to now.

The decrease of pollen concentration at the beginning of zone RNC 6 is accompanied by a sudden change in sedimentary conditions from a mixture of both endogenic (organic and bioprecipitated calcite in the interval RNC 5) and fine detritus, to only detrital layers that were deposited by microturbiditic processes. This is evident from the increase of carbonates, especially dolomite, which is of detrital and/or partially diagenetic origin, and by the disappearance of Charophyte beds, which are the organisms responsible for endogenic sedimentation. The AP/xerophytes ratio, used as an improved tree biomass index similar to the AP/NAP ratio (Magri, 1994; Ravazzi and Moscariello, 1998) is roughly stable in zones RNC 4–6 (Fig. 6a and b). We therefore conclude that tree biomass variations are not responsible for the AP concentration decrease at the boundary between zones RNC 5 and RNC 6. The declining pollen concentration is accompanied by a marked increase in sedimentation rate, that is related to recurrent turbiditic events that caused rapid infilling of the basin.

## 11. The stratigraphic position of the Fornaci di Ranica succession

The stratigraphic position of the Fornaci di Ranica succession can be assessed on the basis of four types of evidence: (i) the palynoflora's composition and the occurrences of a few *taxa* that exhibit unique distributions during the Early–Middle Pleistocene in Europe (*Tsuga*, *Carya*, *Pterocarya*, and *Cedrus*); (ii) the biochronology of *C. latifrons*; (iii) the polarity of the fossil magnetization; and (iv) the geological and palaeoenvironmental evolution of the southern alpine borderland with changes evident at key-site lacustrine successions provided with bio- and geochronological constraints (Leffe, Piànico-Sèllere).

### 11.1. Palynostratigraphy

The abundance of *Tsuga* and continuous pollen percentage curves of *Carya* and *Pterocarya* in zone RNC 1 are characteristic features of the Early Pleistocene interglacial assemblages in Central and Southern Europe (van der Hammen et al., 1971; Zagwijn, 1975; Gibbard et al., 1991). *Tsuga* and *Carya* are absent in the Central-European Cromerian assemblages dated to the early Middle Pleistocene from East England (West, 1980, 1996), from the Netherlands (Zagwijn and Zonneveld, 1956; Zagwijn, 1996), and from Germany (Grüger, 1968, 1996; Hahne, 1996). The last occurrence of *Tsuga* pollen grains in Central Europe is during the Leerdam interglacial, which is one of the post-Jaramillo late Early Pleistocene warm stages (Zagwijn and De Jong, 1984). Interestingly, the Bavel interglacial, preceding the Leerdam interglacial, contains the highest percentages of *Tsuga* (10–30%, Zagwijn and De Jong (1984)) recorded for the entire Neogene and Quaternary in the Netherlands. A *Tsuga* pollen percentage peak occurs in other temperate intervals, during the Jaramillo subchron, in southern Europe. The Colle Curti sequence (Central Italy) includes a *Tsuga*–*Cedrus* dominated pollen assemblage (Coltorti et al., 1998; Bertini, 2000). The flora of Colle Curti is chronologically constrained by the Jaramillo subchron and by an extensive mammal fauna, the earliest of Galerian character (Ficcarelli and Mazza, 1990). The nearby site of Cesi (Ficcarelli et al., 1997; Bertini, 2000) shows *Tsuga* and *Cedrus* declining to only a few sporadic grains, at the beginning of the Brunhes chron, while *Carya* is absent. The 900 kyr-long Tenaghi Philippon pollen record (Greece; Van der Wiel and Wilmstra, 1987; Mommersteeg et al., 1995) displays a *Tsuga* peak (8–10%) in zone 47, occurring at the top of the Jaramillo subchron (Van der Wiel and Wilmstra, 1987). Sporadic grains of *Carya* and *Tsuga* occur upwards to zone 39, and then both taxa disappear before the Brunhes/Matuyama boundary. The lacustrine succession of Pianico-Sèllere, which is very close to the

Fornaci di Ranica site (Moscariello et al., 2000), provides a key site for calibrating the pollen stratigraphy of the Early/Middle Pleistocene boundary: chronologically consistent K/Ar dates on tephra occur in an interval with palaeomagnetic evidence for the Brunhes/Matuyama reversal (Pinti et al., 2001) are coupled with only sporadic grains of *Tsuga* and *Carya* (Moscariello et al., 2000; Rossi et al., 2000 and pers. com.). Although long pollen records from southern Italy show a persistence of *Carya* until MIS stages 17 and 15 during the early Middle Pleistocene (Russo Ermolli, 1994; Russo Ermolli and Cheddadi, 1997; Karner et al., 1999), *Tsuga* is absent. In the only Early–Middle Pleistocene pollen record available from the Po plain (Müllenders et al., 1996), *Carya* disappears before *Tsuga*. All this evidence suggests that the RNC 1 pollen zone is older than the base of Middle Pleistocene. Additional palynostratigraphic data can be used to constrain zone RNC 1 to the uppermost part of Early Pleistocene. The long pollen record from the biogenic unit of the Leffe Formation (Ravazzi, 1995; Ravazzi and Moscariello, 1998), shows a continuous curve of *Tsuga* and *Cedrus* with low to moderate percentages (0.5–10%), as well as large peaks of *Carya* (10–50%) during the warm temperate phases. This record, only 10 km from Ranica (Fig. 1b), is assigned to the Early Pleistocene, between the top of the Olduvai and the base of the Jaramillo subchron, based upon the magnetostratigraphy and mammal faunas (Ravazzi, 1993; Cremaschi and Ravazzi, 1995; Muttoni et al., submitted). In the topmost part of the Leffe Formation, also within the Matuyama chron (Billard et al., 1983), temperate pollen phases are characterized by *Tsuga*–*Carya* codominance, or even *Tsuga* dominance (up to 50%) (Pini and Ravazzi, in progress). The preceding evidence supports a late Early Pleistocene age for the *Tsuga* maxima in the Italian Alps.

The Early/Middle Pleistocene range of *Cedrus* aff. *atlantica* (Ravazzi, 1993), in the Italian Pre-Alps, is also of palynostratigraphic interest. This tree is a relatively abundant pollen producer (Salamani, 1993); identification of its pollen is easy and thus it is a valuable tool for regional biostratigraphic reconstructions. The present-day ecology of *Cedrus atlantica* (Emberger, 1938; Farjon, 1990) and the taphonomy of *Cedrus* in the Leffe record (Lona, 1950; Ravazzi, 1995) indicates that it preferentially colonized calcareous bedrock slopes during the Early Pleistocene. The Leffe, Ranica, and Pianico-Sèllere sites are very near to each other and all belong to the same southern Calcareous Pre-Alps biogeographic province (Fig. 1b). Therefore, the occurrence of *Cedrus* pollen at all sites cannot be dependent on only local edaphic factors. *Cedrus* pollen is continuously present (2–10%) within the investigated part of the biogenic section of the Leffe Formation (Ravazzi and Moscariello, 1998) and also in the higher levels

(Pini and Ravazzi, in progress), but it is absent at Piànico-Sèllere (Moscarello et al., 2000). Its sporadic occurrence in zone RNC 1 and its absence in the overlying and younger pollen zones is evidence that the Fornaci di Ranica record occupies an intermediate position, between the biogenic unit of the Leffe Formation and the base of Piànico-Sèllere Formation, in the floristic evolution of the southern alpine borderland (Fig. 9). This is consistent with the chronology inferred from the occurrence of *Tsuga*.

Based upon the palynostratigraphic data, the Fornaci di Ranica record should be placed in the latest part of the Matuyama epoch. Zone RNC 1, with the *Tsuga* maximum, and lesser amounts of *Carya* and *Pterocarya*, represents an environment which is consistent with the temperate episodes interpreted for Central and Southern Europe during the Jaramillo subchron.

11.2. Biochronology of *Cervalces latifrons*

We focus on the Pleistocene taxonomy of Alcini at the species level, and the ensuing stratigraphic implications (taxonomy for the genus has been discussed in Azzaroli (1979, 1982, 1985, 1994), Heintz and Poplin (1981), Kahlke (1990), Lister (1993, 1996), Pfeiffer (1999), and Breda (2001b)). There is consensus for the existence of

two Pleistocene moose species in Europe: *C. gallicus* (Azzaroli, 1952) and *C. latifrons* (Johnson, 1874): *C. latifrons* evolved from *C. gallicus*. Heintz and Poplin (1981) proposed a new species, *Alces carnutorum* (Laugel, 1862), which was intermediate in size and age between the two *Cervalces* species. Kahlke (1990, 1995, 1997, 2001) accepted the definition of this species, while Geraads (1983), Vislobokova (1986), Sher (1987), and Lister (1996) did not. The remains of *Alces recte Cervalces carnutorum* are very scanty and the few dental characteristics described by Heintz and Poplin as unique to the species, were in fact found in some exemplars of both *C. gallicus* and *C. latifrons*. Breda (2001b) suggested that while waiting for the discovery of *C. carnutorum* fossils that might resolve the controversy, the species could be conditionally accepted in order to prevent a further increase of taxonomical confusion in the literature.

Table 2 shows that the biochronological range of *C. latifrons* (including the *C. carnutorum* forms) extends from the late Upper Villafranchian (Pirro Faunal Unit, *sensu* Gliozzi et al., 1997) to the Upper Galerian (Fontana Ranuccio Faunal Unit, *sensu* Gliozzi et al., 1997) Faunal Ages (Table 2 and Fig. 9). In terms of chronostratigraphy, its range extends from the late Early Pleistocene, shortly prior to the Jaramillo onset,

The stratigraphic position of the Ranica succession

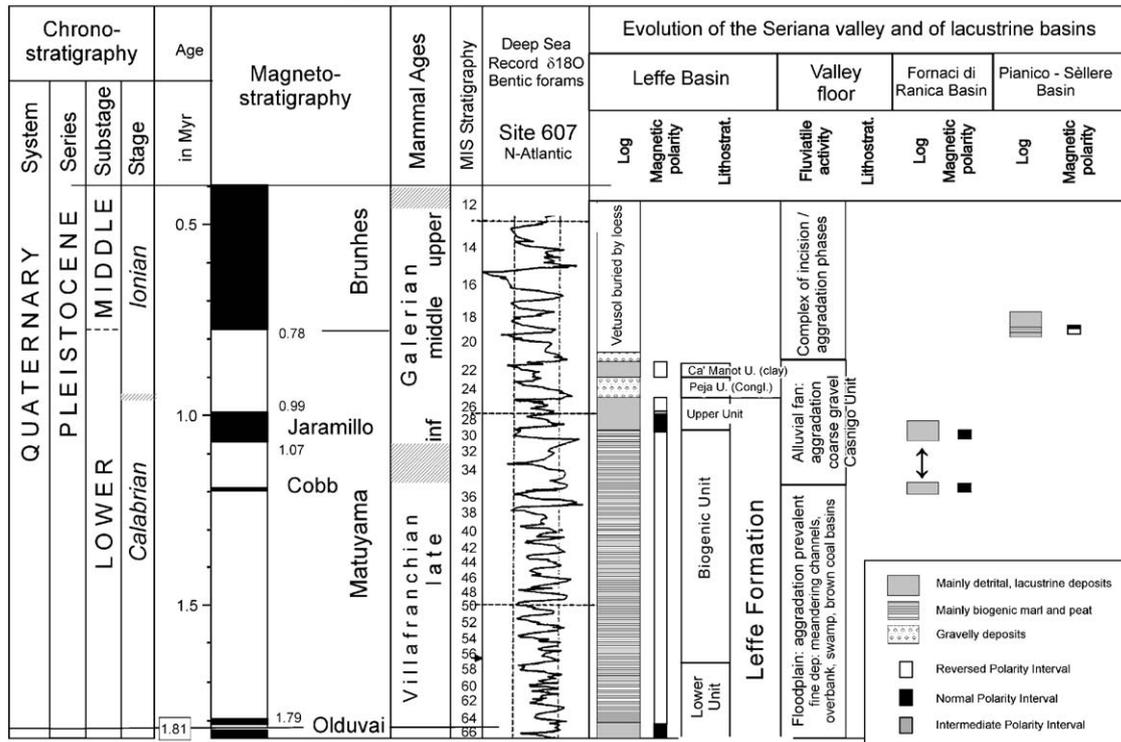


Fig. 9. Chronostratigraphic framework of the Fornaci di Ranica lacustrine succession and comparison with the Leffe and Pianico-Sèllere lacustrine successions. Pleistocene chronostratigraphy according to Cita and Castradori (1994). Magnetostratigraphy from Cande and Kent (1992); reversal ages according to Hilgen et al. (1993); Cobb age according to Lovlie and Leroy (1995). The site 607 data are from Tiedemann et al. (1994) and the Leffe Basin data from Ravazzi (1993) and Ravazzi and Moscarello (1998).

to the late Middle Pleistocene. Since we include *C. carnutorum* within *C. latifrons*, then the appearance of *C. latifrons* s.l. may have occurred as early as 1.2 Myr ago, which is within the Cobb cryptochron (Lovlie and Leroy, 1995), or perhaps even earlier.

### 11.3. Regional correlation between Leffe and Ranica successions

The Fornaci di Ranica site is located only a few km from Leffe (Fig. 1b), a reference site for Early Pleistocene continental stratigraphy in northern Italy. Here we focus on the correlation between these two lacustrine successions.

As mentioned in section 2.1, the present-day terraced morphology at the Alpine borderland in Lombardy resulted from alternating phases of fluvial downcutting and alluvial deposition, which followed a phase of maximum river aggradation (Gabert, 1962; Chardon, 1974, 1975, p. 397; Ferliga and Corbari, 2000). According to Venzo (1952), the maximum height reached by the alluvial deposits was attained during a glacial advance, which was the ‘Mindel’ phase according to Penck and Brückner’s nomenclature. Venzo (1950) recognized that the gravel forming the ‘Borgosale Terrace’ at Ranica was part of the Serio river maximum aggradation unit, and therefore of ‘Mindel age’. Once Penck and Brückner’s scheme was no longer used (Sibrava, 1986), the correlation of the maximum aggradation level in different fluvial systems was called into question (e.g. Richmond & Fullerton, 1986; Bini, 1997a). Within the Serio River valley, Billard et al. (1983), Azzaroli et al. (1986), Ravazzi (1993) and Muttoni et al. (submitted) presented palaeomagnetic and biostratigraphic evidence that the maximum aggradation phase (the uppermost Casnigo depositional unit, Figs. 1b and 2b) dates to magnetic polarity subchron C1r.1r (late Matuyama Reversed Polarity Chron) when a sudden increase of coarse-grained detritus supplied by the Serio river was coeval to turbiditic deposition in the Leffe basin (Ca’ Manot unit in Fig. 9).

The topmost part of the Biogenic Unit of the Leffe Formation records the base of the Jaramillo Normal Polarity Subchron at 1.07 Myr ago, in agreement with palynological and mammal palaeontological evidence (Ravazzi, 2003; Muttoni et al., submitted). These layers yielded the only postcranial remains of *Cervalces* so far known from the Leffe succession. The bone surface shows evidence of burning before deposition (Ravazzi, 2003). Pollen zones Ob1–Ob2 from these layers (Pini, 1997) showed a marked peak of charcoal microparticles accompanied by an evident hemlock pollen decline (see also Ravazzi & Moscariello, 1998, Fig. 5, *Tsuga-Cedrus* decline at 27.2 m). This is the only charcoal peak registered in the Jaramillo Normal Polarity Subchron of the Leffe lacustrine succession. A similar sequence of

Table 2  
Stratigraphic positions of *Libralces carnutorum* (Laugel, 1862) and *Limralces latifrons* (Johnson, 1874) Western Europe

Determination	Locality	Country	References	Mammal age	Faunal unit
<i>L. latifrons</i>	Mosbach 2	Germany	Kahlke (1961)	Late Galerian	Fontana Ranuccio
<i>L. latifrons</i>	Happisburg, Overstrand u.l.	England	Azzaroli (1953, 1994)	Late Galerian	Fontana Ranuccio
<i>L. latifrons</i>	Mundesley u.l.	England	Azzaroli (1953, 1994)	Middle or Late Galerian	Isernia or Fontana Ranuccio
<i>L. latifrons</i> or <i>L. carnutorum</i>	Vergranne	France	Geraads (1983); Kahlke (1990)	Late Galerian	Isernia
<i>L. latifrons</i>	Wurzberg-Schalksberg	Germany	Mausler (1990)	Middle Galerian	Isernia
<i>L. latifrons</i>	Sussenborn m.l.	Germany	Kahlke (1956–1959, 1960, 1961, 1969)	Middle Galerian	Isernia
<i>L. latifrons</i>	West Runton	England	Azzaroli (1953, 1994)	Middle Galerian	Isernia
<i>L. latifrons</i>	Bilshausen (Lower Saxony)	Germany	Schmidt (1930)	Middle or Late Galerian	Slivia or Fontana Ranuccio
<i>L. latifrons</i>	Goldshofe (NE Aalen)	Germany	Pfeiffer (1999)	Middle Galerian	Slivia
<i>L. latifrons</i> : <i>L. sp.</i>	Voigtstedt m.l.	Germany	Kahlke (1965, 1958)	Middle Galerian	Slivia
<i>L. latifrons</i>	Dorn-Durkheim 3	Germany	Franzen et al. (2000)	Middle Galerian	Slivia
<i>L. carnutorum</i>	Mosbach 1	Germany	Kahlke (1961)	Early–Middle Galerian	Colle Curti and/or Slivia
<i>L. carnutorum</i>	Untermassfeld	Germany	Kahlke (1990, 1997)	Early Galerian	Colle Curti and/or Slivia
<i>L. latifrons</i>	Maasvlakte 1	The Netherlands	Vervoort-Kerkhoff and Kolschoten (1988)	Early Galerian	Colle Curti
<i>L. carnutorum</i>	Saint-Prest (Chartres)	France	Heintz and Poplin (1981)	Late Villafranchian	Pirro

events is recorded in pollen zones RNC 1-3 at Fornaci di Ranica, also belonging to the Jaramillo Normal Polarity Subchron. We therefore propose here that the charcoal peak before hemlock decline in Leffe pollen zones Ob1-Ob2 should correspond to Ranica pollen zones RNC 2-3. This correlation implies that: (i) The Ranica cold event does correlate with the end of the Leffe Formation Biogenic Unit, thus representing one of the cold stages within the Jaramillo Subchron (MIS 30 or 28). In the earlier part of the Leffe Formation, spanning the interval between top Olduvai and base Jaramillo, there is no further palynological evidence of cold events of similar intensity. In view of the preliminary of this correlation, we maintained in Fig. 9 and in the conclusions of the present paper the less favourable alternative possibility that Fornaci di Ranica would correlate to the Cobb event (MIS 36).

(ii) The fluvial damming and deposition of the Fornaci di Ranica succession pre-dates the maximum aggradation phase recorded by the Ca' Manot Unit in the Leffe basin, which was deposited after the Jaramillo Normal Polarity Subchron and during polarity subchron C1r.1r. (Fig. 9).

We therefore conclude that the maximum height reached by the alluvial deposits within the Serio valley system is related to several different episodes during the late Early Pleistocene (late Matuyama Chron).

## 12. Conclusions

The lacustrine succession preserved at Fornaci di Ranica allows a reconstruction of the evolving palaeoenvironment, during the oldest episode of Quaternary cold climate so far described south of the Alps. Palynostratigraphy, fossil magnetization of lake deposits, and the geological correlations indicate that sedimentation occurred during the late Early Pleistocene, probably in the Jaramillo interval. The palaeobotanical record and the moose remains indicate first a phase with dense conifer forest indicative of a cool-temperate climate, and then a subsequent phase of palustrine and lake sedimentation within an environment characterized by an open boreal forest, meadows, and steppes, with cold-adapted species (*S. stellaris* type, *S. oppositifolia* type, *L. decidua*). The Ranica plant fossil record provides the first evidence, south of the Alps, of mean summer temperatures that were near or below the thermal tree limit. A marked phase of forest withdrawal, forced by climate, is recorded by the pollen record (the transition from pollen zone RNC 1 to RNC 3). Pollen from the fossil moose's braincase (*C. latifrons*), separated from the clay, places the moose in pollen zone RNC 3. Moose palaeoecology corroborates the reconstruction of a boreal landscape, with parkland and/or open vegetation.

The climate change responsible for the transition evident from zones RNC 1 to RNC 3, was contemporaneous with enhanced river discharge and sediment supply in the main valley. We hypothesize that the dam of the Fornaci di Ranica lake was caused by fluvio-glacial aggradation triggered by glaciation in the northern part of the Serio river catchment. By correlating Fornaci di Ranica with the long lacustrine Leffe pollen record, located a few kilometres upstream in the same valley, it appears that no cold intervals of such magnitude occurred during the earliest and middle part of the Early Pleistocene within the southern alpine borderland. Fornaci di Ranica thus documents the earliest phase of cold climate and probable alpine glaciation so far evident in the Quaternary evolution of the Serio river catchment, this cold phase likely occurred during the Jaramillo Subchron, or in the Cobb cryptochron. The unit cannot yet be traced laterally due to incomplete geological knowledge of the southern alpine margin, therefore its larger regional importance, for Quaternary Alpine glaciations, remains unknown. According to Cremaschi (1987), the earliest Pleistocene glaciation during which glaciers reached their maximal position in the southern Italian Alps should be dated to the late Matuyama Chron, probably post-Jaramillo. It has been proposed that between 900 and 700 kyr, the strength of the obliquity period was being progressively superseded by the strength of the 100 kyr period of orbital eccentricity (Ruddiman and Raymo, 1988; Turner, 1996). Therefore, the Fornaci di Ranica succession may represent an episode of significant polar ice volume increase, and be related to Marine Isotope Stages (36) 30 or 28.

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