LATE MIDDLE PLEISTOCENE COOL NON-MARINE MOLLUSC AND SMALL MAMMAL FAUNAS FROM LIVORNO (ITALY)

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Abstract. New stratigraphic data (exposed sections and boreholes) allowed a detailed reconstruction of the northern sector of the "Terrazzo di Livorno" (Central Italy). A new unit, called "Corea formation" was discovered and correlated to marine isotope stage (MIS) 6 and to its transition to MIS 5. This formation comprises, at its base, fluvial gravels and sands followed by fine-grained alluvial plain deposits. Non-marine molluscs, small mammals and pollen allow a reconstruction of the environment present during the deposition of the alluvial plain deposits. The environment was mainly an open space, though sparse woodlands should have been present. The non-marine fauna shows features intermediate between typical interglacial and glacial assemblages described so far in Italy. Worth of note is the presence of *Orcula dolium* and *Vallonia enniensis*, which now inhabit northern Italy. These findings improve our knowledge on the biogeography of Quaternary non-marine faunas of Central Italy. Stable isotopes data on land snail shells, freshwater shells and pedogenic carbonates showed that climate conditions were cooler than today (possibly 1-2°C less) with a significant amount of C4 vegetation, in an environment with moderately dry conditions.

Riassunto. Nuovi dati stratigrafici, ottenuti dall'esame di sondaggi e sezioni esposte, hanno permesso una ricostruzione dettagliata della successione sedimentaria presente nel sottosuolo del settore settentrionale del "Terrazzo di Livorno" (Italia centrale). Di particolare interesse è stata la definizione di una nuova unità stratigrafica continentale. Sulla base dei dati stratigrafici e paleontologici, questa unità, definita come "formazione di Corea", è stata correlata con lo stadio isotopico marino 6 (MIS 6) e alla transizione con il successivo MIS 5. La "formazione di Corea" comprende, alla base, un deposito fluviale prevalente-

mente ghiaioso, seguito, in continuità, da sedimenti limoso-sabbiosi di piana alluvionale. I depositi di piana alluvionale hanno restituito numerosi fossili di molluschi continentali e micromammiferi. Lo studio di queste associazioni, accompagnato dallo studio del contenuto pollinico e delle ostracofaune, ha permesso una dettagliata ricostruzione paleoambientale. Durante la deposizione dei livelli di piana alluvionale, l'ambiente doveva essere caratterizzato da spazi aperti con rada copertura arborea. L'associazione dei molluschi continentali mostra caratteristiche intermedie rispetto a quelle tipicamente "glaciali" o "interglaciali", descritte finora in Italia. Di particolare interesse biogegrafico è la presenza, nell'associazione malacologica, di *Orcula dolium* e di *Vallonia enniensis*, specie oggi ristrette all'Italia settentrionale. L'analisi del contenuto isotopico (carbonio e ossigeno) dei molluschi continentali e dei carbonati pedogenici suggerisce che il clima locale doveva essere leggermente più fresco dell'attuale (1-2°C).

Introduction

Fossil non-marine molluscs are a valuable tool to investigate climate conditions that alternated during Quaternary (Ložek 1964; Puisségur 1976; Rousseau et al. 1992), to reconstruct biogeographic variations during time and the processes of re-colonisation after glacial periods (Rousseau et al. 1992; Meyrick 2001; Limondin-Lozouet & Preece 2004). In Central and North-Western Europe glacial and interglacial faunas have well defined characteristics and the transition between glacial and interglacial faunas are characterised by a complex succession of non-marine molluscs assemblages (Kerney

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1977; Rousseau et al. 1990; Green et al. 1996 Limondin-Lozouet & Antoine 2001). These snail assemblages were the result of the time-lag in the expansion of different snail species owing to their requirement in terms of humidity, temperature, and edaphic conditions that succeeded during glacial to interglacial climatic transitions. In this frame, during the phases of climatic deterioration, Southern Europe, the Mediterranean region and Anatolia may have represented the refuge areas of many land snails species (Taberlet et al. 1998; Hewitt 1999, 2004; Pinceel et al. 2005). However, detailed data on Quaternary land snail successions are still relatively scarce in these regions. An increasing number of studies performed in the last two decades in Central Italy (Esu 1980, 1981; Esu & Girotti 1990; Zanchetta et al. 1998, 2004; Ricci Lucchi et al. 2000; Marcolini et al. 2003) have shown that during cold periods (i.e. glacial) oligotypical assemblages, characterised by species preferring open spaces, dominated, while during mild conditions (i.e. interglacial) assemblages had a higher species diversity and were dominated by snails loving wooded environment. However, non-marine assemblages characterising glacial-interglacial transitions, or stadials, are not well defined (Zanchetta et al. 2004).

This paper illustrates a non-marine fauna found in the area of Livorno (Central Italy, Fig. 1), which partially fills this gap of knowledge. Such a finding is made precious by the collection in the same deposit of several small mammal remains. In order to complete the paleoenvironmental reconstruction, pollen, ostracods, and stable isotope measurements (carbon and oxygen) on land snail shells, freshwater shells and pedogenic carbonate were performed.

Geological setting

The studied area is the northern part of Livorno town which has developed on the deposits of the "Terrazzo di Livorno". In this area middle to late Pleistocene successions lay on a substrate which comprises Pliocene to lower Pleistocene (Santernian-Emilian and Sicilian) marine deposits and Mesozoic rocks (Barsotti et al. 1974; Lazzarotto et al. 1990; Dall'Antonia et al. 2004; Fig. 2). The older deposits of these successions, known as Conglomerati di Villa Umberto I formation, of coastal marine origin (Lazzarotto et al. 1990), forms the "Terrazzo della Fattoria Pianacce" (Barsotti et al. 1974). In its northern part this terrace is dissected by the continental deposits of the Casa Poggio ai Lecci formation (Lazzarotto et al. 1990). The Casa Poggio ai Lecci formation is actually a complex unit, because after its institution (Barsotti et al. 1974) it was extended toward east to include deposits of different ages (Mazzanti 1983; Marroni et al. 1990; Zanchetta et al. 1998). Mazzanti (2002) has recently correlated the Casa Poggio ai Lecci formation, as defined by Barsotti et al. (1974) in the Livorno area, with the San Romano unit defined by Zanchetta et al. (1998) and developed during the MIS 11-12 (Marcolini et al. 2003). Thus, the morphostratigraphic unit of "Terrazzo della Fattoria Pianacce" and the Conglomerati di Villa Umberto I formation, are older than MIS 12 but younger than Sicilian (Fig. 2).
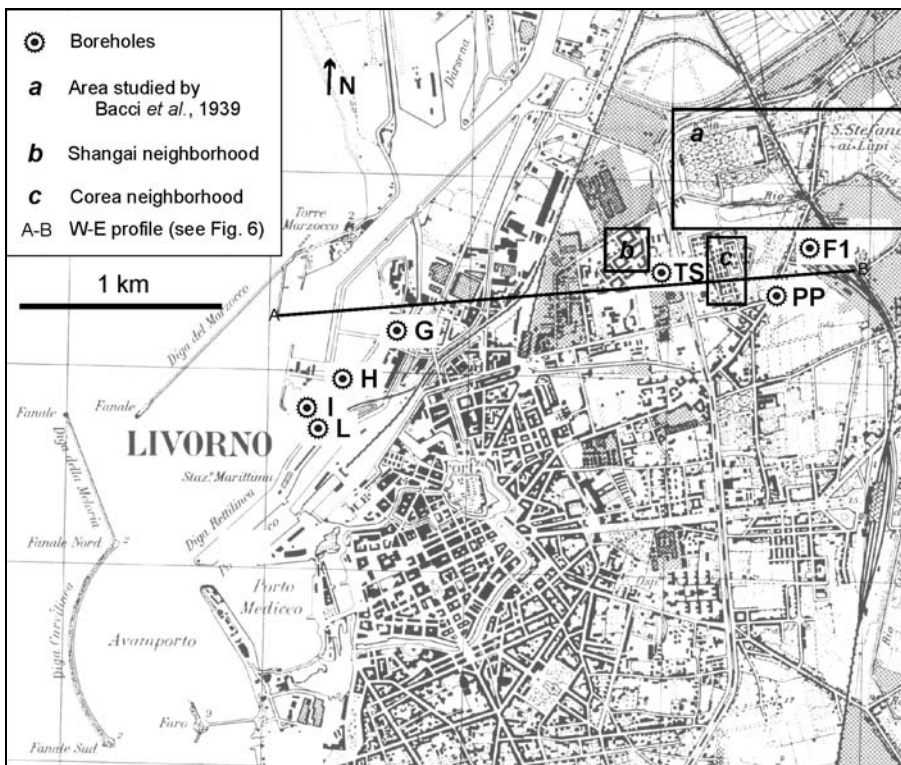

Fig. 1 - Location map of the investigated boreholes and outcrops. For the location of the boreholes in the areas **b** and **c** see Fig. 4. Boreholes G, H, I and L from Dall'Antonia et al. (2004).
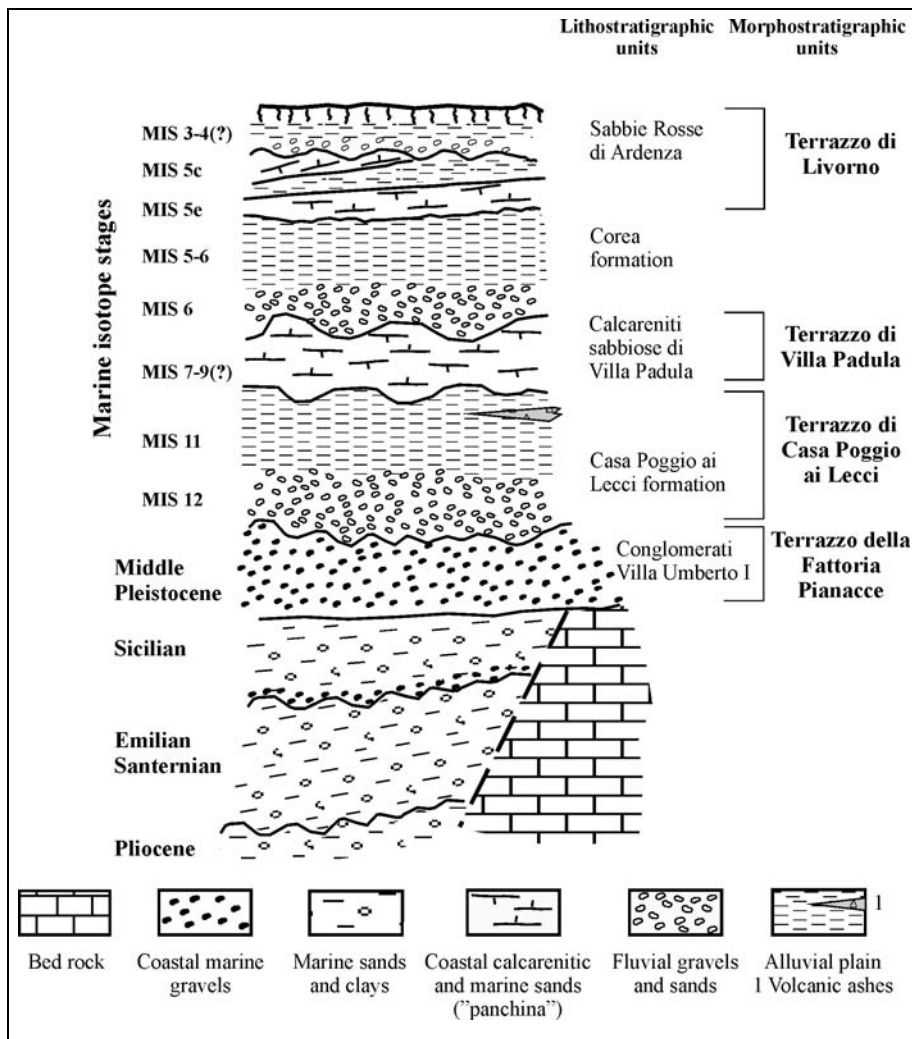
Fig. 2 - Composite stratigraphy of the Livorno area. Correlation with the marine isotope stages and the main morphostratigraphic unit are also shown. Note that Casa Poggio ai Lecci formation is equivalent, inland, to San Romano unit of Zanchetta et al. (1998).

Between the deposits of the "Terrazzo di Livorno" and those of the Casa Poggio ai Lecci formation, Giannelli et al. (1982) have recognised a further sedimentary unit: the Sabbie rosse, calcareniti sabbiose di Villa Padula, which forms the homonymous "Terrazzo di Villa Padula" (Fig. 2). The Sabbie rosse, calcareniti sabbiose di Villa Padula, mainly aeolian, may indicate a phase of sea transgression developed during MIS 7 or MIS 9.

As shown in Fig. 2, the "Terrazzo di Livorno", the focus of our study, is the younger morphological unit preserved in the area. This morphological element is the remain of a policyclic marine terrace (Federici & Mazzanti 1995) developed during the marine isotope stage 5 (MIS 5). The "Terrazzo di Livorno" comprises four different layers (Fig. 2), from the base to the top:

1) Shallow marine calcarenitic deposit (locally known as panchina), which yielded warm marine mollusc faunas (Barsotti et al. 1974). This level has been correlated with MIS 5e, on the basis of faunal content, aminoacid racemization (Hearty et al. 1986) of fossil shells and thermoluminescence dating of sands (Mauz 1999).

2) A thin succession of continental sands and muddy-sands, that, westward, are transitional to brackish deposits (Barsotti et al. 1974). They preserve a rich non-marine mollusc fauna, whose snail species indicate a phase of climatic deterioration (Malatesta 1942; Zanchetta et al. 2004). According to Zanchetta et al. (2004) these deposits should correspond to MIS 5d.

3) A new calcarenitic layer, mainly aeolian, that has been correlated to MIS 5c according to its stratigraphic position (Federici & Mazzanti 1995) and thermoluminescence dating of sands (Mauz 1999).

4) A continental deposit, with a basal erosional surface, often deeply weathered and reddened (Sabbie di Ardenza formation; Lazzarotto et al. 1990). This deposit may be correlated with MIS 4 or the beginning of MIS 3 for the presence of middle Palaeolithic remains.

About the stratigraphy of the "Terrazzo di Livorno" there is a sort of historical misunderstanding recently re-raised by Zanchetta et al. (2004). In the first half of the last century, Bacci et al. (1939) described a non-marine fauna characteristic of cool climatic conditions and correlated this finding to the "Rissian", since the fauna was found below a level of panchina. Similar
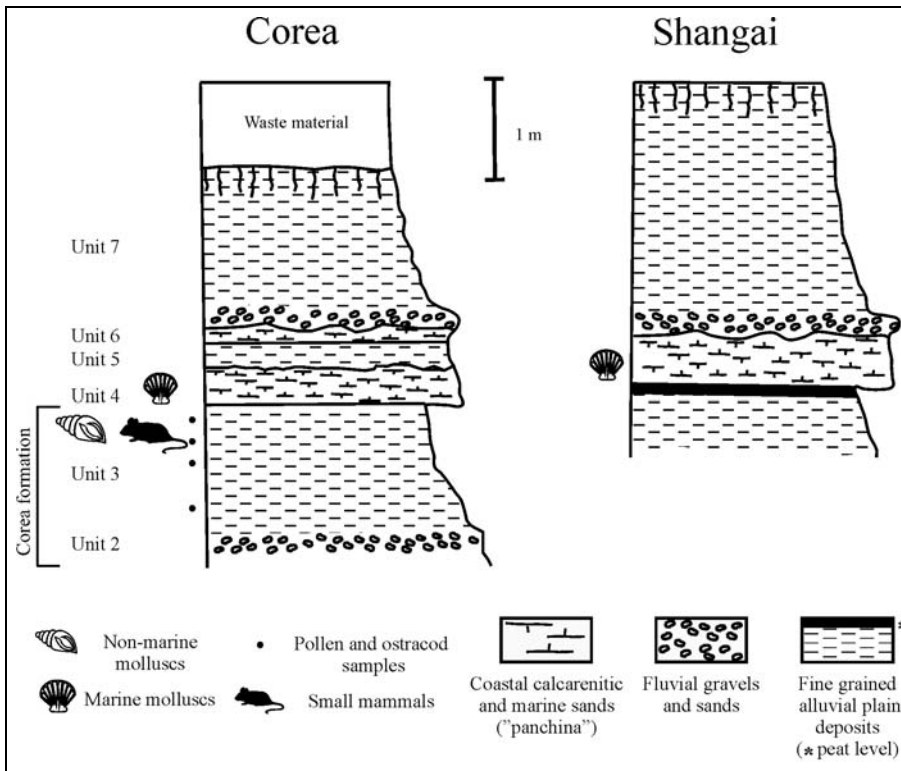
Fig. 3   - Schematic stratigraphy of the outcrops at Corea and Shangai neighbourhoods. Samples position is shown.

faunas were later on found between the two panchina layers. Therefore, Malatesta (1942) stated that both non-marine assemblages were sandwiched by the calcarenitic layers. This view has never changed in the following works because stratigraphic evidences substantially supported the opinion of Malatesta (Barsotti et al. 1974). Recently, Zanchetta et al. (2004) quantitatively studied the non-marine faunas embedded between the two panchina layers arguing that the fauna of Bacci et al. (1939) was older and possibly cooler than the faunas they studied.

Material and methods

The ongoing revision of the subsurface stratigraphy of Livorno (Dall'Antonia et al. 2004) has provided a detailed stratigraphic reconstruction for a restricted area close to the past finding of Bacci et al. (1939) (Fig. 1). Here, two sections were exposed for the construction of new buildings (Corea and Shangai neighbourhood, northern part of Livorno town, Fig. 1, 3) and seven boreholes were available for detailed stratigraphic studies (K1-K6 and G5, Fig. 4). In addition, sixteen older borehole stratigraphies were collected and re-interpreted (TS, F1 and PP, Fig. 1; S1-S10 and G1-G4; Fig. 4). Four additional borehole stratigraphies (G, H, I and L, Fig. 1) come from the work of Dall'Antonia et al. (2004).

The cores were carefully cleaned and sectioned longitudinally in the field, described and sampled. Samples for quantitative analyses of non-marine molluscs and small mammals were collected mainly in the Corea section (Fig. 3). Fossil extraction was performed according to standardised procedures described in detail by Zanchetta et al. (2004) and Marcolini et al. (2003). Non-marine molluscs were gathered in ecological groups (Ložek 1964; 1986; 1990 Puisségur 1976), as standardised for the study of other Italian non-marine molluscs assemblages (Esu 1978; 1981). Small mammals were measured following van der Meulen (1973) and gathered in ecological groups (Chaline 1977; Marquet 1989). Palynological analyses were performed on 4 samples collected from the Corea outcrop within clayey or silty-clayey layers (Fig. 3). Three additional samples were collected from the core K3 (Fig. 5). Each sample was treated according to standard procedures. Pollen concentration (Absolute Pollen Frequency, APF) was calculated according to Accorsi & Rodolfi (1975) method. Percentages in the spectra are calculated on the total of pollen grains and spores.

Well preserved non-marine shells (the land snail *Cepaea nemoralis* and the freshwater mollusc *Galba truncatula*) were carefully cleaned in an ultrasonic bath and some random samples of *Cepaea nemoralis* were powdered and analysed by X-ray diffraction (XRD) in order to check their preservation. Some carbonate glaebules and rhizoconcretions were also analysed to control the potential presence of clastic carbonate (Leone et al. 2000). Carbon dioxide for isotope analysis was produced by reacting the powder with 100% phosphoric acid at 90°C using a VG Isocarbon automated carbonate device attached to a VG PRISM2 mass spectrometer. Oxygen and carbon isotopic ratios are expressed in the well known δ‰ notation relative to V-PDB standard. Reproducibility based on replicate analyses was of 0.1‰ or better. When quoted, the isotopic composition of water is expressed relatively to V-SMOW.

Results and discussion

Stratigraphy

The stratigraphy and the palaeontological content allow to separate the investigated succession in 7 different informal lithostratigraphic units (Fig. 5). From the bottom to the top they are:

Unit 1: lower Pleistocene marine sands and silty-sands. It comprises an alternation of grey sands and silty-sands rich in shallow marine benthonic foraminifers (*Ammonia, Cibicides*, Miliolidae, *Valvulineria, Florilus* and Textularidae), and extremely rare planktonic forms (Globigerinida). Ostracods are locally well
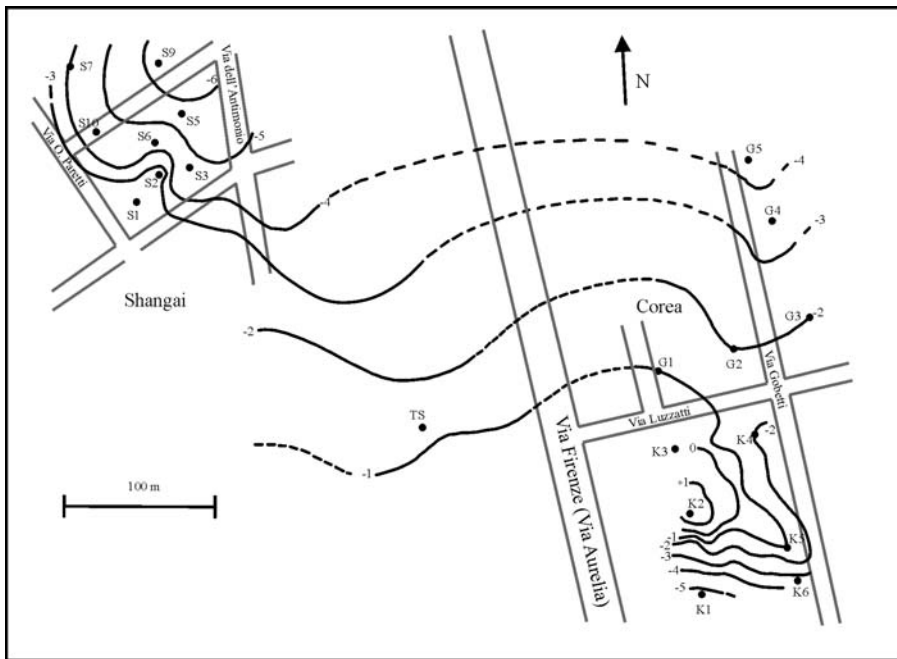
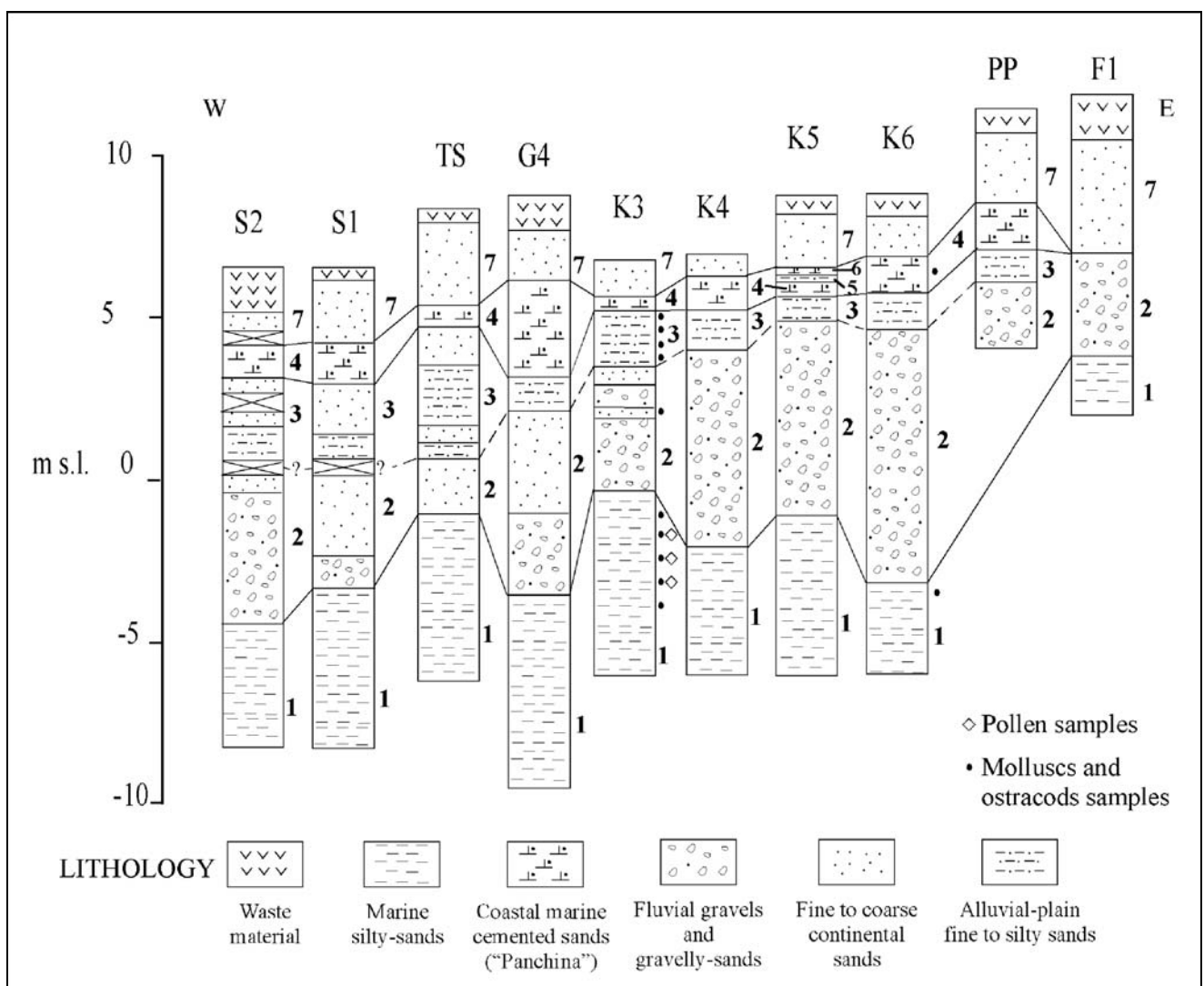Fig. 4 - Isobaths representing the base of Corea formation and location of the boreholes discussed in the text.

Fig. 5 - Schematic stratigraphy of the studied boreholes from Corea and Shangai neighbourhoods. Numbers refer to the lithostratigraphic units described in the text.

represented, although mainly represented by juveniles. The major components of the fauna are taxa typical of shallow marine environment with euhaline conditions, belonging to the Aurilinae (e.g. *Aurila convexa* (Baird), *A. cymbaeformis* (Seguenza), *A. pigadiana* Sissingh), Loxoconchinae (*Loxoconcha bairdi* Müller, *L. mutabilis* Ciampo, *L. ovulata* (Costa), *Palmoconcha turbida* (Müller)), Xestoleberidae (chiefly *Xestoleberis communis* Müller). Locally also Trachileberididae (*Costa edwardsii* (Roemer), *Carinocythereis whitei* (Baird)) and Semicytherurinae (e.g. *Semicytherura acuticostata* (Sars)) are relatively well represented. From the stratigraphical point of view, the occurrence of *Palmoconcha turbida* with *Aurila cymbaeformis* and *A. pigadiana* is of particular interest. To date *P. turbida* is not known to occur prior to the Pleistocene (Ruggieri 1980; Ciampo 1998), while *A. cymbaeformis* and *A. pigadiana*, are restrained to the Pliocene-Sicilian (sensu Ruggieri & Sprovieri 1977) interval (Ruggieri 1980 cum bib.). The ostracod species appear to be indicative of a generic Early Pleistocene age.

Unit 2: polygenic fluvial gravels and sands. So far, this unit (along with unit 3) has never been identified. The base of this unit is deeply carved in the marine unit 1. Fig. 4 shows the isobaths of the base of the sandy-gravel body reconstructed from borehole data. Upward this unit is in continuity with unit 3. In the outcrop the gravels show clast-supported fabric, often with clear imbrications and through stratification.

Unit 3: alluvial plain silty-sands and silty-clays. This unit is characterised at its base by an alternation of silty clays and sands, with rare levels of coarse sands and fine gravels. Upward, a massive greenish gray (5/GY/1, Munsell soil chart 1992) silty-sand deposit prevails, rich of calcareous glaebules, roots tracks and rhizoconcretions. Locally the top appear darker for the accumulation of finely dispersed organic matter. At Shangai section the top is represented by a peat deposit (Fig. 3). Lower levels of this unit yielded an extremely poor microfauna characterized by a mixing of usually strongly abraded benthonic foraminifers (e.g. Elphididae (*Elphidium*), Nonionidae (*Florilus*)) and very rare marine ostracod taxa (*Aurila* and Cytheridea), which are accompanied by rare well-preserved specimens of the fresh-oligohaline water genera *Candona* (juveniles) and *Iliocypris*. On the whole, the good state of preservation of the delicate fresh-oligohaline ostracod specimens attests for their authoctonous character, whereas the mainly abraded marine forms are clearly reworked. This unit sampled at Corea yielded a very rich non-marine fauna and small mammal remains (Fig. 3). No ostracods have been recovered in these upper samples. Overall, these features are indicative of poorly drained alluvial plain where pedogenic modifications occur with a slightly developed alteration profile (immature paleo-sols or Entisols/Inceptisols; Soil Survey Staff 1975). The upper, darker portion may represent the superficial pedogenic horizon (epipedon) richer in organic matter. The units 2 and 3 will be informally called hereafter as Corea formation.

Unit 4: lower calcarenitic layer. This unit is made of cemented calcareous sands with very fragmented marine shells remains. The deposit is often partially weathered. The base of this unit is sharp and faintly undulated. This corresponds to the lowermost panchina layer of the "Terrazzo di Livorno".

Unit 5: continental greenish clays and sands with mottles. This deposit contains fragmentary and partially decalcified remains of land snail shells. It corresponds to the continental layer between the two "panchina" in the "Terrazzo di Livorno" succession.

Unit 6: upper calcarenitic layer. This layer is very thin (10-20 cm) and often deeply weathered and corresponds to the uppermost panchina of the "Terrazzo di Livorno". However, in many boreholes its recognition is often problematic. Indeed, in many cores, units 5 and 6 have not been recognised as distinct layers, due to weathering processes that have interested the top of the succession. In such cases units 5 and 6 were grouped with unit 4 (Fig. 5).

Unit 7: reddened sands and clay-sands. This unit starts with a thin basal layer of gravels, that marks an erosive (although partially amalgamated by pedogenic processes) surface. The strong red colour and the presence of Mn-Fe concretions indicate that the deposit of this unit experienced a deep weathering with a formation of a well developed soil. This unit can be easily related to the Sabbie Rosse di Ardenza formation (Lazzarotto et al. 1990). Fig. 6 shows a W-E stratigraphic section obtained integrating outcrop and borehole data.

Units 2 and 3 (Corea formation) were never described before, with the exception of the controversial description of Bacci et al. (1939). Corea formation is stratigraphically older than the lowermost level of panchina (MIS 5e) and younger than early Pleistocene, as indicated by the basal discordance and erosive surface (Fig. 6). Simple geometrical considerations indicate that Corea formation is younger than Casa Poggio ai Lecci and Villa Padula formations, the way its age should be comprised within middle Pleistocene, if we accept the boundary between middle and late Pleistocene informally located at the transition with MIS 5e (Richmond 1997).

The area of the "Terrazzo di Livorno" has been considered relatively stable during the last 120 ka (Nisi et al. 2003) or subject to slow progressive uplift (as suggested by the quotes of Villa Padula formation and that of "Terrazzo della Fattoria Pianacce"; Lazzarotto et al. 1990). In the context of a slow uplift, the accretion of different sedimentary units should be dominated by
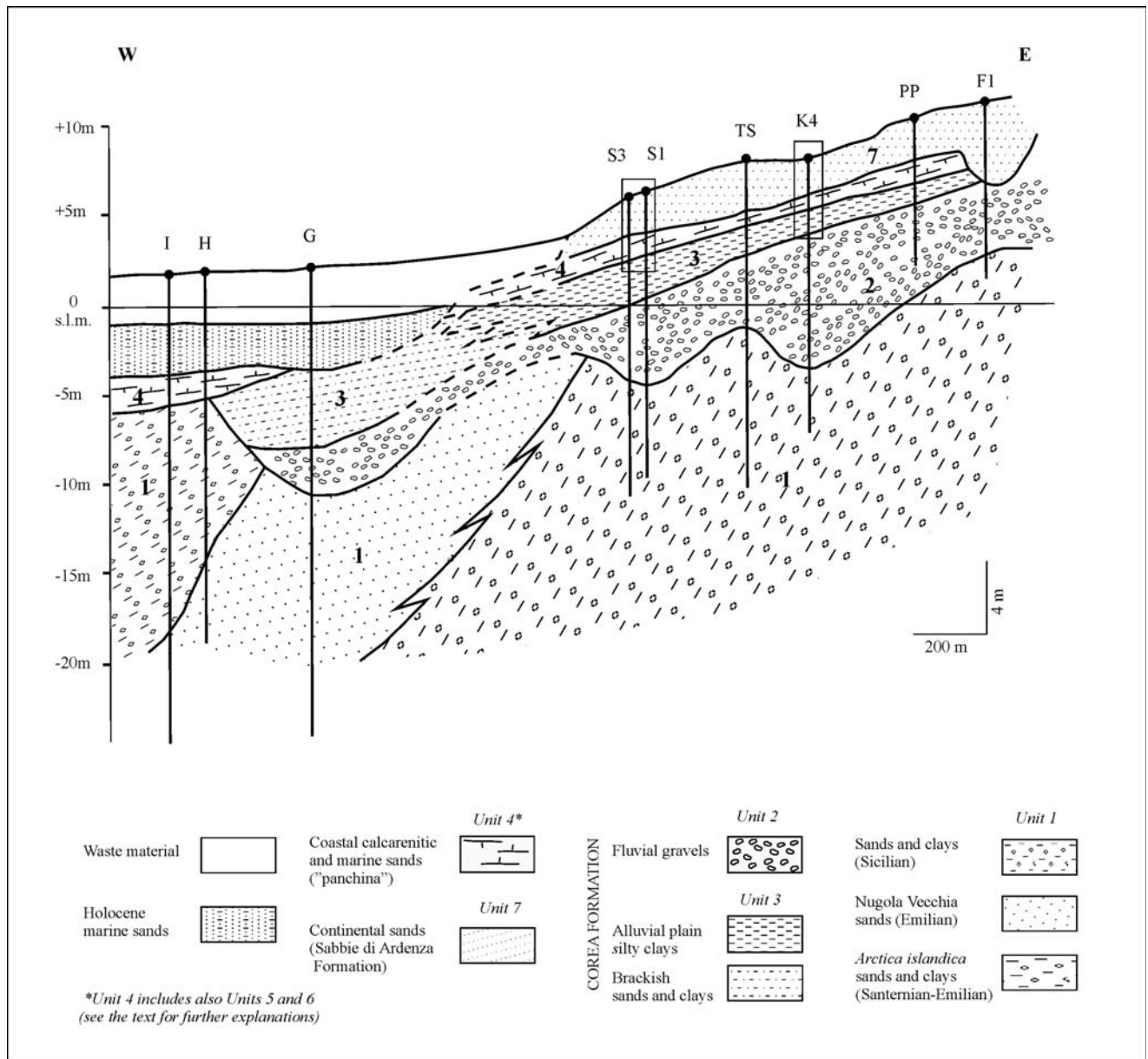
Fig. 6 - W-E geological profile of the studied area inferred from outcrops and borehole data. The position of the outcrops is indicated by squared areas. Stratigraphy of cores G, H, and I from Dall'Antonia et al. (2004).

high frequency sea level oscillations, controlled by the expansion and withdrawal of continental ice caps (Shackleton 1987), where the sea level controlled the accommodation space. We speculate that the erosive surface bounding the base of the Corea formation corresponds to a phase of valley incision during a sea level fall. This probably occurred in a morphological condition, where the slope of the shelf was steeper than the slope of the exposed coastal plain (Leckie 1994). The base of Corea formation (unit 2), which corresponds to coarse-grained bedload rivers (Collinson 1996), probably formed during a phase of low stand or during the first phase of a sea level rise (Shanley & McCabe 1993; 1994). Therefore, the erosive surface may have

formed during a maximum of decrease in the sea level, that can correspond to MIS 8 or MIS 6.

Unit 3, which corresponds to fine-grained deposition in an alluvial plain setting, can represent a first phase of the rise of sea level with diminishing sedimentary supply. If this reconstruction is correct, the phase of the definitive marine transgression and high stand is represented by the overlying first panchina (unit 4). So that, the succession has developed during MIS 6, MIS 5/6 (units 2-3), and MIS 5 (units 4, 5 and 6).

Non-marine mollusc fauna

Non-marine molluscs were collected in unit 3 (Fig. 3). The Gastropoda, which are represented only

Ecological group	Species	Number of specimens	Percentages
1	*Clausilia cruciata*	2	0.2
	Orcula dolium	277	24.1
2	*Cepaea nemoralis*	16	1.4
4	*Cernuella* cfr. *C. cisalpina*	23	2
	Monacha cantiana	20	1.7
5	*Vallonia pulchella*	95	8.3
	Pupilla muscorum	61	5.3
	Vertigo pygmaea	7	0.6
7	*Cochlicopa* cfr. *C. lubrica*	26	2.3
	Vitrinobrachium sp.	5	0.4
	Punctum pygmaeum	6	0.5
7'	Limacidae	3	0.3
8	*Carychium tridentatum*	4	0.3
	Succinea oblonga	330	28.7
	Vertigo angustior	36	3.1
9	*Succinea* cfr. *S. putris*	32	2.8
	Vertigo antivertigo	76	6.6
	Vertigo moulinsiana	2	0.2
	Zonitoides nitidus	19	1.7
	Vallonia enniensis	62	5.4
10	*Galba truncatula*	27	2.4
	Anisus spirorbis	15	1.3
	Lymnaea (*Stagnicola*) sp.	3	0.3
	Planorbis planorbis	2	0.2
	Pisidium cfr. *P. casertanum*	1	0.1
Total		**1150**	**100.2**

Tab. 1 - List of species and specimen percentages of the non-marine molluscs grouped according to their ecological requirements. 1, forest species; 2, semi-forest species; 4, steppe species; 5, open land species; 7, and 7', mesophilous species; 8, hygrophilous species; 9, marshy environment species; 10, freshwater species.

by Pulmonata, include 23 species, 2 identified at the genus level and 1 taxon identified at the family level; Bivalvia are represented only by one species (Tab. 1). All the species are extant in Italy (Bodon et al. 1995).

Tab. 1 and Fig. 7 show the distribution of the mollusc assemblage according to their ecological groups.
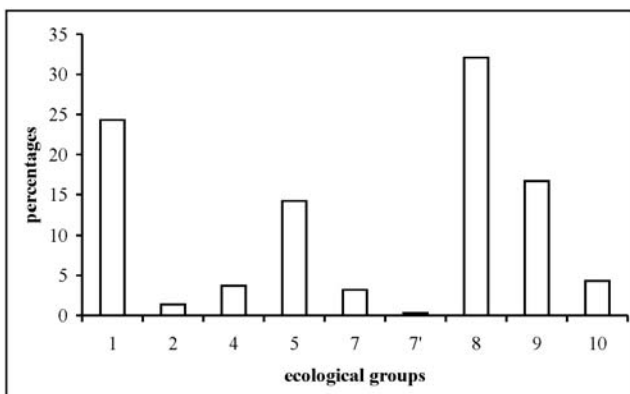

Fig. 7 - Histogram of the non-marine molluscs ecological groups. 1: forest; 2: open forest; 4: steppe; 5: open land; 7: mesophilous; 7': slug; 8: hygrophilous; 9: marshes; 10: freshwater.

Ecological group 1 (forest). The forest species are dominated by *Orcula dolium* (Pl. 1a). *O. dolium* is a mountain species, that now inhabits Northern Italy. This species is present in the Bellunese Alps, Venetia and Lombardy (Settepassi & Verdel 1965), southeastern Alps, Carniche Alps, Giulie Alps, Veneto, Southern Carinzia, and Istria (Boato et al. 1987). It is considered very rare along plains (Settepassi & Verdel 1965) and reaches up to 2000 m in Switzerland (Kerney & Cameron 1987). It prefers ground litter and mossy rocks in woods and sheltered slopes (Kerney & Cameron 1987). Ložek (1964) included this species in the ecological group 7 (mesophilous) but, according to more modern views on the ecological requirements of *Orcula dolium* (Kerney & Cameron 1987), it seems to be more correct to attribute this species to the forest group. Ecological group 1 is completed by two specimens of *Clau-*

PLATE 1

a: *Orcula dolium*; b: *Punctum pygmaeum*; c: *Pupilla muscorum*; d: *Succinea oblonga*; e: *Vallonia enniensis*; f: *Vallonia pulchella*.
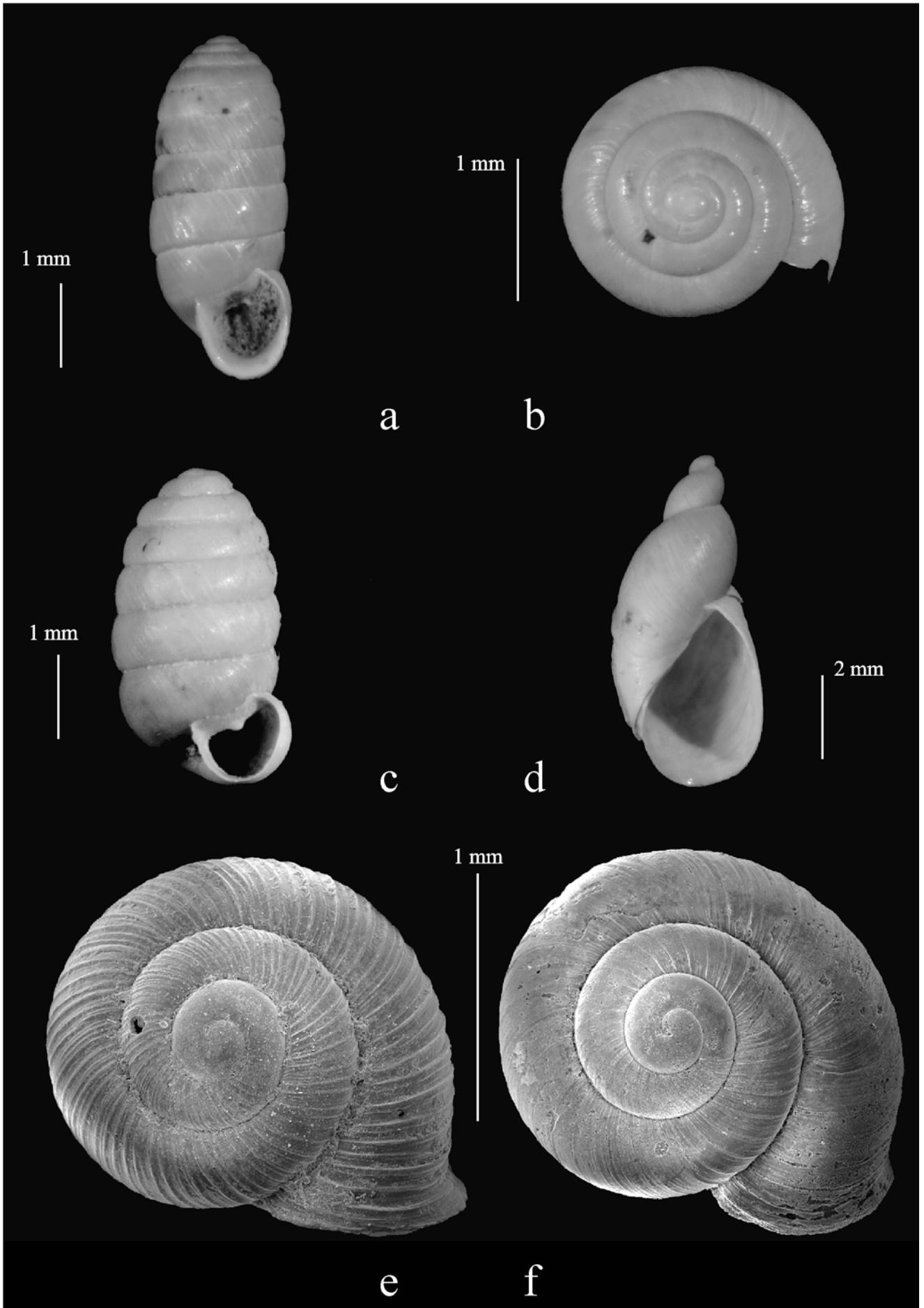
silia cruciata, that inhabits moist woodlands, but also lives on trees in open areas (Giusti et al. 1985).

Ecological Group 2 (Open Forest). The species living both in woods and scrubs are represented only by *Cepaea nemoralis. C. nemoralis* is found in various habitats, usually woodland environments, though it can live sometimes in open areas (often in hedges and garden). It is a relatively common species in Italian Quaternary deposits (Settepassi & Verdel 1965 and references therein).

Ecological Group 4 (Steppe). The species living in dry and sunny places without arboreal vegetation have low incidence. They are represented by *Cernuella* cfr. *C. cisalpina* and *Monacha cantiana. M. cantiana* is a typical dweller of hedges and scrubs and is mainly a Mediterranean and North-western Europe species (Kerney & Cameron 1987). *Cernuella* cfr. *C. cisalpina* has an holomediterranean distribution (Giusti et al. 1985).

Ecological Group 5 (Open Land). This group includes the species living in open land but with different requirements in terms of humidity. They are represented by: *Vallonia pulchella, Pupilla muscorum* and *Vertigo pygmaea. V. pulchella* (Pl. 1f) is common in open calcareous habitats, moist meadows, marshes, sand dunes and, occasionally, dry grasslands and screes. It can reach, although rarely, Scandinavia (to 71°N in Norway) and North Britain (Kerney & Cameron 1987). *Vertigo pygmaea* is characteristic of dry calcareous grassy areas, but lives also in sand-dunes. It occasionally lives in marshes. The most common species of lowland *Vertigo* in Europe can reach 64°N latitude in Norway (Kerney & Cameron 1987). *Pupilla muscorum* (Pl. 1c) prefers open spaces, like dry exposed areas (screes, short-turfed grasslands). It is characteristic of coastal dunes. It attains 1500 m in the Alps (Kerney & Cameron 1987) and reaches 68°N in Europe.

Ecological Group 7 (Mesophilous). This group is characterised by species which sometimes live in damp or dry places as *Cochlicopa* cfr. *C. lubrica, Vitrinobrachium* sp., *Punctum pygmaeum. Cochlicopa* cfr. *C. lubrica* lives in moderately damp places of all kinds: marshes, grasslands, woods. Common throughout Europe reaches 70°N in Scandinavia (Kerney & Cameron 1987). *Punctum pygmaeum* (Pl. 1b) lives in a wide variety of moderately moist and well vegetated places, especially in leaf litter of deciduous woods and also in marshes. *P. pygmaeum* is common in the beech woods of the Apennines (Giusti et al. 1985). This species is known to live from low altitudes up to 2000-2200 m on the Alps.

Ecological Group 7' (Slug). The slugs of the Family Milacidae and Limacidae belong to this group. They have an internal shell (*limacella* or "slug plate"), which is often difficult to use for a specific attribution, the way that slugs are usually grouped altogether (Puis-

ségur 1976). Their interest in palaeoenvironmental reconstruction is rather limited and this group will not be discussed further.

Ecological group 8 (Hygrophilous species). The hygrophilous species belong to this group. However, they cannot be indicated as marsh inhabitants or related strictly to water bodies. This is the most represented group and comprises: *Carychium tridentatum, Succinea oblonga* and *Vertigo angustior. V. angustior* can live in very wet, permanently marshy grasslands (Manganelli et al. 2000) and among mosses in wet hollow of sand-dunes. It is a widespread but very local species, reaching southernmost Norway, Sweden and Finland (Kerney & Cameron 1987). *Carychium tridentatum* lives in shaded areas in woods and damp grasslands. *Succinea oblonga* (Pl. 1d) lives in sparsely-vegetated places, floodplains of rivers and is characteristic of dried-out bare muddy surface (Kerney & Cameron 1987).

Ecological Group 9 (Marshes). The group of marsh species is well represented and consists of *Succinea* cfr. *S. putris, Vertigo antivertigo, Vertigo moulinsiana, Zonitoides nitidus,* and *Vallonia enniensis.* They live in marshes or in very damp to wet places, generally very close to the water body. The presence of *Vallonia enniensis* (Pl. 1e) is worth of note. *V. enniensis* is considered a thermophilous species in northeastern Europe (Sümegi & Krolopp 2002) and indicative of moist conditions (Rousseau & Puisségur 1999). It has a central and southeastern European distribution (Gerber 1996; Sümegi & Krolopp 2002). In Italy *V. enniensis* is currently documented with certainty only in the Ligurian Alps (Boato et al. 1987), Trentino Alto Adige and Veneto (Bodon et al. 1995). The modern populations of *V. enniensis* are currently distributed in Egypt, Turkey and almost all continental Europe (Gerber 1996; Kerney & Cameron 1987). During the Pleistocene it is present only in interstadial and interglacial deposits of north and southern Europe with a diffusion greater than today (Gerber 1996), where it is documented in Germany, Hungary (Gerber 1996; Sümegi & Krolopp 2002), France (Gerber 1996; Rousseau & Puisségur 1999), and Czech Republic (Ložek 2001). During the Holocene the species shows up again with a wide presence in Germany, Greece, Austria, Switzerland, and Hungary (Gerber 1996). At present *Vallonia enniensis* appears in decrease, living in large but very isolated populations (Gerber 1996).

Vertigo antivertigo is characteristically found in fens and marshes and at lake margins. It reaches about 63°N in Scandinavia (Kerney & Cameron 1987). *Vertigo moulinsiana* is common on calcareous fens and marshes, at the edges of lowland lakes or rivers. It is considered to be a declining species (Kerney & Cameron 1987). *Succinea* cfr. *S. putris* lives on fen, marshes, water-meadows and at the margins of lakes and rivers (Kerney &

Cameron 1987). *Zonitoides nitidus* lives in very moist places like fen and marshes, especially at the lake margins and rivers in places liable to flooding (Kerney & Cameron 1987).

Ecological Group 10 (Freshwater). Freshwater species are less represented in terms of species and individuals (Tab. 1). The group living both in still water or in marshes consists of *Galba truncatula* and *Anisus spirorbis*. The freshwater species living in still water are less represented (Tab. 1) with *Lymnaea* (*Stagnicola*) sp. and *Planorbis planorbis*. *Pisidium* cfr. *P. casertanum* is the only species living in still or moving water.

Anisus spirorbis lives in shallow water of lakes, still water of ponds, marshes and mosses. During drought periods it sinks to the bottom within the decaying organic matter. It can tolerate salinity up to 2‰ (Girod et al. 1980). *Galba truncatula* lives in shallow water rich in organic matter. During dry periods it refuges into the mud. It can tolerate salinity up to 0.5‰ (Girod et al. 1980). *Planorbis planorbis* lives in still water or water with weak currents, in muddy bottoms within aquatic vegetation (Girod et al. 1980).

The non-marine molluscs are indicative of an environment rather articulated, characterised by the passage between a wet or medium-wet wood to an open environment characterised by local bodies of still water and rich vegetation. The presence of a wood is indicated by the abundance of *Orcula dolium*, and, to less extent, by the very low percentage of *Cepaea nemoralis* and *Clausilia cruciata*. *Succinea oblonga*, *Carychium tridentatum* and *Vertigo angustior* indicate the presence of damp sparsely vegetated places. This environment was suitable for species like *Cochlicopa* cfr. *C. lubrica*, *Vitrinobrachium* sp., *Punctum pygmaeum* and Limacidae. The presence of *Vallonia pulchella*, *Pupilla muscorum*, and *Vertigo pygmaea* (Ecological group 5) along with *Cernuella* cfr. *C. cisalpina* (Chalioconchae mesoxerofila) and *Monacha cantiana* (Keratoconchae) (Giusti & Castagnolo 1982) indicates well developed dry and open areas. The presence of species with more hygrophilous features, such as *Succinea* cfr. *S. putris*, *Vertigo antivertigo*, *Vertigo moulinsiana*, *Zonitoides nitudus*, and *Vallonia enniensis*, indicate the transition between wet-grassland and areas subject to partial inundation, with rich hygrophilous vegetation. This area was also populated by *Galba truncatula* e *Anisus spirorbis*. This ecosystem can be related to an environment characterised by shallow bodies of water, with low energy, a suitable environment for *Lymnaea* (*Stagnicola*) sp., *Planorbis planorbis* and to less extent to *Pisidium* cfr. *P. casertanum*.

The abundance of species and their ecological requirement is consistent with a temperate environment (Zanchetta et al. 1998; Marcolini et al. 2003; Zanchetta et al. 2004). This because almost all the species are now distributed in the Italian peninsula and because of the presence of termophilous elements as *Cernuella* cfr. *C. cisalpina*. However, the presence of *Orcula dolium*, and, in this context, of *Vallonia enniensis* which indicates a southward shift in the biogeographic distribution of these species, suggest climatic conditions cooler than today. This assemblage cannot be related, therefore, to a climatic optimum during an interglacial phase (Zanchetta et al. 2004). Indeed, if our stratigraphic reconstruction is correct, the climatic optimum in this areas is represented by the coastal marine deposits on top, which are related to MIS 5e and containing the classical warm "senegalese" marine faunas (Barsotti et al. 1974).

The presence of *Orcula dolium* is of particular interest. This species is completely absent in the list of species found in the Villafranchian continental successions of Central Italy (Crispino & Esu 1995; Gliozzi et al. 1997) and has been reported only for middle Pleistocene sites and for the first part of the late Pleistocene. In particular all the middle Pleistocene findings can be related to the late middle Pleistocene: Fiano Romano and Malagrotta, near Rome (Clerici 1887), Lower Liri Valley (southern Latium) (Settepassi & Verdel 1965), Livorno area (Bacci et al. 1939; Malatesta 1942 and the present paper), Aurelia Formation (Latium, Conato et al. 1980; Esu & Girotti 1991), Via Flaminia (Latium, Esu 1980; Esu & Girotti 1991). Therefore the habitat of *Orcula dolium* extended toward south during these periods, possibly during phases of cool conditions. This may imply that *Orcula dolium* is a good stratigraphic indicator for the middle Pleistocene of Central Italy and, probably, for the first part of the late Pleistocene.

Orcula dolium is not characteristic of the oligo-typical assemblages of open habitats usually related to cold and arid conditions developed during pleniglacial phases in Central Italy (Esu 1981; Conato et al. 1980; Esu et al. 1989; Di Vito et al. 1998; Zanchetta et al. 1998; Marcolini et al. 2003). This presence can, therefore, be related to the particular requirements in terms of temperature and humidity (and possibly vegetation) that can have been present during some phases of the middle Pleistocene and the first part of the late Pleistocene. The data from Corea formation probably indicate that these conditions occurred after glacial phases but prior to an interglacial climatic optimum. The remains of Corea formation are the best documented occurrence in middle Pleistocene assemblages of the Central Italy. The presence of *Vallonia enniensis* is also quite significant. So far, its presence in Central Italy is documented only at Valle di Castiglione after ca. 5000 yr BP (Esu, in Alessio et al. 1988). Therefore, its presence in the Corea formation is the oldest occurrence documented in Central Italy.

Ecological group	Species	Number of specimens	Percentages
G	*Microtus arvalis*	7	29,2
H	*Microtus agrestis*	12	50,0
I	*Arvicola cantianus*	2	8,3
K	*Apodemus* gr. *sylvaticus - flavicollis*	3	12,5
Total		24	100

Tab. 2   - Percentages of ecological groups of small mammals from Unit 3. G, open not dry spaces; H, prairies and wet spaces; I, water proximity; K, temperate forests.

Small mammals

Small mammals were collected only from Unit 3 (Fig. 3). Remains belong mainly to arvicolids, while only three murid and two crocidurine molars were recovered. Murid teeth, one M_1, one M_2 and one M^1, belong to *Apodemus* gr. *sylvaticus-flavicollis*. The scarcity of remains does not allow a more specific attribution. The field mouse is widespread in Europe since Miocene (Pasquier 1974). It is very adaptable and has a large ecological range but it prefers to live in forest borders, in temperate wooded environments (ecological group K, Tab. 2).

Insectivores are represented by two crocidurine molars, one M_2 (length 1.5 mm) and one fragment of M^{1-2}. Pigmentation is absent and the triangular shape with a W profile of M_2 allow a tentative attribution to *Crocidura* cf. *C. leucodon*.

More than 20 whole and fragmentary arvicolid first lower molars were found in the assemblage (Fig. 8). The two large sized first lower molars (total length is 3.8 mm in both cases; Tab. 3) have been attributed to

Arvicola cantianus (Fig. 8a-b) on the basis of the enamel differentiation index SDQ (Schmelband-Differenzierungs-Quozient; Heinrich 1978). The obtained values for the two specimens, 101.7 and 106.8, correspond to the range measured for *A. cantianus* from Taubach by Maul et al. (1998). In Italy, the oldest finding of *Arvicola cantianus* is at Isernia La Pineta, while the last occurrence is at Spessa II, correlated with a late phase of Early Toringian (Kotsakis et al. 2003). *Arvicola cantianus* is the ancestor of present day *A. terrestris* a species living along bank of lakes and rivers, in meadows, bogs and marshland forests preferring cool and humid soils (ecological group I, Tab. 2). It is pretty common in the middle to late Pleistocene sediments (Gliozzi et al. 1997; Kotsakis et al. 2003 and references therein), unless the assemblages represent cold environments. Being *A. terrestris* quoted from level A of Scario (Ronchitelli et al. 1998), it suggests that *Arvicola* from Unit 3 might be slightly older than that of Scario/A. Scario/A (slightly younger than Scario SG) has been correlated with one of the temperate-cold oscillation of MIS 5 (Maul et al. 1998). Nevertheless SDQ from Scario/A are higher than those of Unit 3 and, above all, definitely higher than 100 (108.84 - 131.90; Maul et al. 1998). Overall, arvicolids from Unit 3 appear slightly older than those of Taubach and Scario/A and could be tentatively correlated with MIS 5/6.

According to the size of the smaller first lower molars two different microtines were identified and attributed to *Microtus arvalis* and *M. agrestis* (Fig. 8). Both *M. arvalis* and *M. agrestis* are widespread in Italy since the middle Pleistocene (Fontana Ranuccio Faunal Unit, early phases of early Toringian; Kotsakis et al. 2003) and are quite common in Italy during stadial

species	n	min	med	max	St. Dev.	Ci (95%)
M. arvalis						
L	4	2,66	2,81	2,94	0,1379	0,3426
W	7	0,95	1,06	1,09	0,084138	0,077814
A/L	4	51,50	53,06	53,90	1,350036	3,353678
M. agrestis						
L	6	2,88	2,97	3,19	0,240803	0,222706
W	10	1,02	1,08	1,17	0,079523	0,056888
A/L	6	50,00	51,33	55,31	1,998512	2,097307
A. cantianus						
L	2	3,80		3,84		
W	2	1,47		1,44		
A/L	2	37,06		37,42		

Tab. 3   - Main measurements of the occlusal surface of Unit 3 arvicolids, according to van der Meulen (1973).
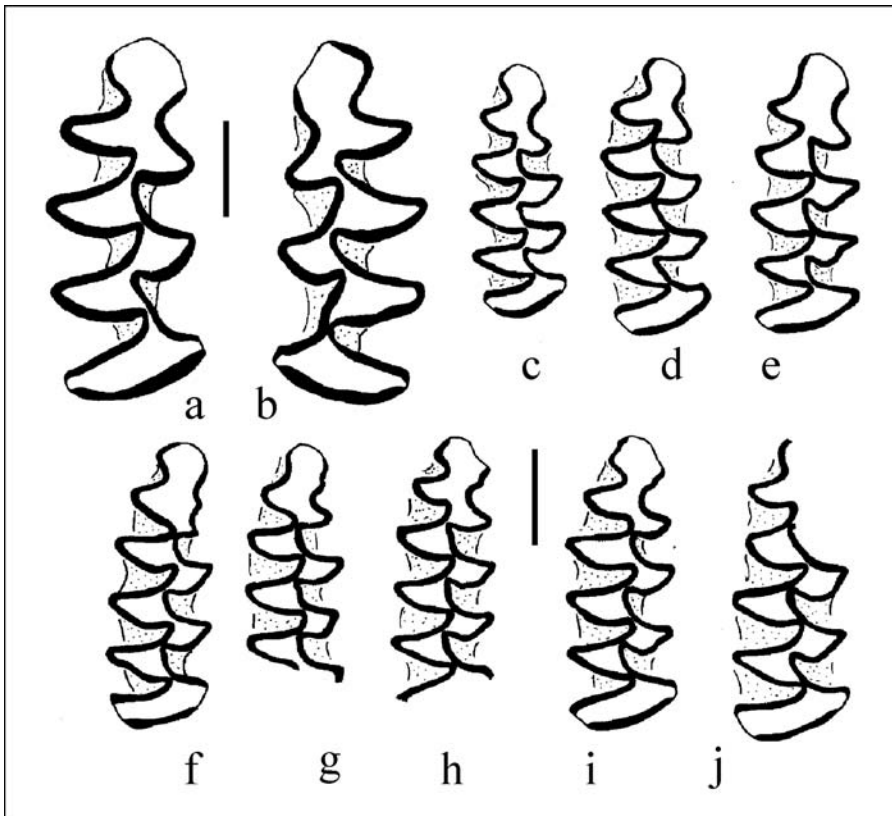
Fig. 8 - Arvicolids first lower molars from unit 3. a-b: *Arvicola cantianus*; c- e: *M. agrestis*; f-k: *Microtus arvalis*. Scale bar represents 1mm.

phases of middle to late Pleistocene assemblages (Gliozzi et al. 1997; Kotsakis et al. 2003 and references therein).

The common vole, *M. arvalis*, lives in scarcely wooded environments, where grass is present all-year long, reaching up to 2000 m. It does not like humid prairies, though survives there, still prefers mesophilous environments (ecological group G, Tab. 2). The field vole, *M. agrestis* prefers cool wet and marshy environments in middle to high altitude prairies, living also in wooded environments (ecological group H, Tab. 2). If does not have to compete with *M. arvalis* it might also live in drier environments.

A quantitative analysis of the evolutionary degree of the two species from Unit 3 has been attempted using the A/L ratio (Meulen 1973; Tab. 3), which expresses the relative elongation of the anteroconid of first lower molars. A comparison of the A/L ratios of our specimens with the curve obtained by Maul et al. (1998) shows that are comparable with those of same species coming from Taubach or Burgtonna 2 in Germany or Scario/SG in Italy. After the calibration of Maul et al. (1998), the inferred ages for these sites are 0.11 ± 0.01 Ma (U/Th dating on travertines; Brunnaker et al. 1983), 0.10 - 0.06 Ma (indirect correlation) and 0.20 - 0.14 Ma (correlation with MIS 6) respectively.

The evolutionary degree of the small mammals is in perfect agreement with the stratigraphic inferences.

From a paleoenvironment point of view (Tab. 2, Fig. 9) almost 80% of remains belong to species preferring an open environment (*M. arvalis* and *M. agrestis*) and almost 60% indicate humid conditions (*A. cantianus* and *M. agrestis*), suggesting an open and quite humid environment.

Pollen analyses

The two groups of samples, collected within unit 3 (Corea formation; samples k4, k5, k6, k7; Fig. 3) and unit 1 (samples k1, k2, k3, core K3, Fig. 5), show a very different pollen content.

Samples k1, k2, k3 (unit 1) - In these samples the APF (Arboreal Pollen Frequency) decreases upwards (Fig. 10), while the AP (arboreal, shrubby and climbing
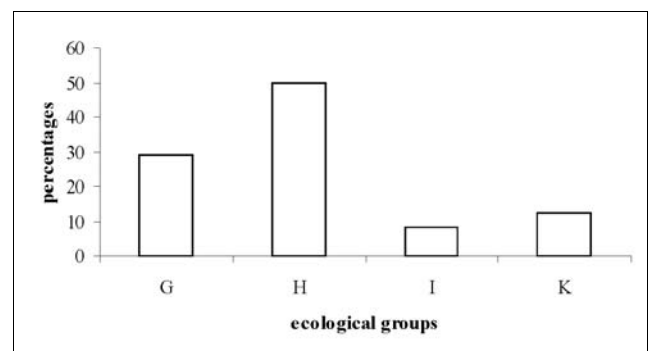

Fig. 9 - Histogram of the small mammals ecological groups. G: open not too dry spaces; H: prairies and wet spaces; I: water proximity; K: species of temperate forest.
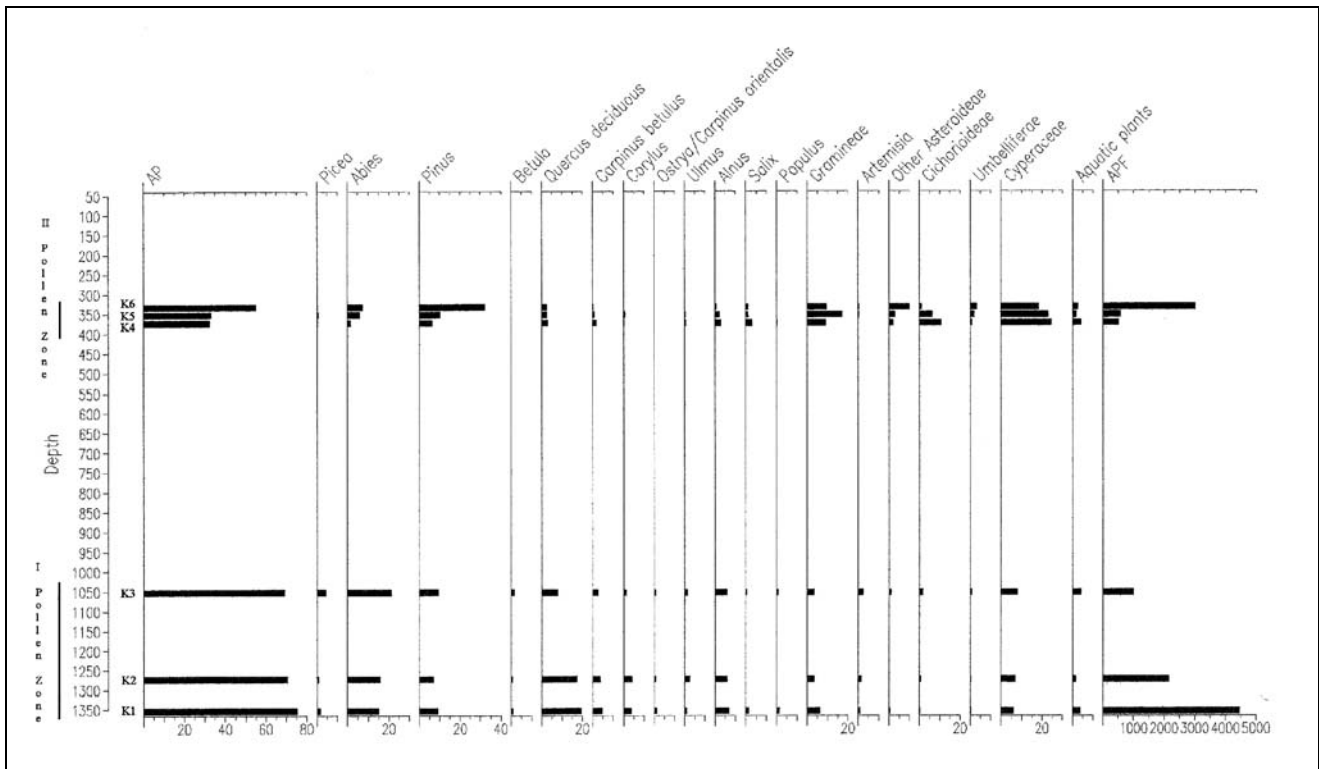
Fig. 10   - Pollen spectrum of Corea boreholes.

plant pollen) percentages does not show significant var-
iations (Fig. 10). In the oldest sample, *Quercus deci-
duous* group is the best represented tree (Fig. 10), and
is accompanied by *Carpinus, Corylus, Ulmus, Tilia,* etc.
However, the percentages of *Quercus* decrease upwards,
whereas *Abies, Picea* and *Betula* show an opposite
trend, with the maximum expansion in sample k3. *Pinus
sylvestris/mugo* group pollen grains are also present.
The hygrophilous trees *Alnus, Salix,* and *Populus* always
show low percentages (Fig. 10). Sporadic pollen grains
belonging to elements of the Tertiary flora (*Carya, Pter-
ocarya, Tsuga*) were recorded in all these samples.

Among the NAP (herbaceous plant pollen), the
best represented taxa are Cyperaceae, Gramineae, and
Compositae (Fig. 10). In particular *Artemisia* progres-
sively increase, with a peak in the sample k3, together
with those of *Abies, Picea,* and *Betula.* The aquatic
plants are represented by Juncaceae, Alismataceae,
Nymphaeaceae, *Typha, Potamogeton,* etc. Their values
suggest the occurrence of wetlands, but their extension
should not have been very wide.

Samples k7-k4 (unit 3) - In these samples the pol-
len grains are badly preserved and samples k7 is almost
sterile. The spectra are dominated by herbaceous plants.
AP percentage increases upwards (Fig. 10), and in par-
ticular *Abies* and *Pinus* show a peak in the sample k6.
The occurrence of some deteriorated saccate grains sug-
gests that they may have been transported from the
surroundings. In all of the samples, *Quercus* and the
other elements of the mixed oak forest have low per-

centages (Fig. 10), slowly decreasing upwards. The same
trend is exhibited by the hygrophilous *Alnus, Salix,* and
Populus. Elements of the Mediterranean evergreen for-
est are sporadically found.

Among NAP, Cyperaceae are the best represented
taxon followed by other herbaceous taxa like Grami-
neae, Compositae and Umbelliferae. However, Cyper-
aceae decrease upwards along with aquatic plant percen-
tages.

The two groups of samples indicate a very differ-
ent environment. The three most ancient samples (k1-
k3) show the presence of a well-developed mixed oak
forest that, most probably, covered the plain and the hill
slopes. The presence of scarce elements of the Tertiary
flora is worth of note and in agreement with the persis-
tence of these plants during lower Pleistocene in the
Lower Valdarno (Grassi 1999). Wetlands are indicated
by the occurrence of hygrophilous and aquatic plants,
but their extension should not have been very wide. The
increasing pollen percentages of *Abies* and *Betula* and
the peak of *Picea* in sample k3, where also *Artemisia*
reaches its maximum value, suggest a trend towards a
climatic deterioration. At the same time, a general im-
poverishment of the mixed oak forest seems to occur.

The pollen spectra of the Corea formation are
dominated by herbaceous plants, with numerous genera
typical of swampy and freshwater environment. Among
the AP, *Pinus* is the best represented tree and its curve
remarkably rises upwards. Deciduous *Quercus, Carpi-
nus, Corylus, Ulmus* are always scanty represented, and

	δ^{13}C PDB ‰	δ^{18}O PDB ‰
Corea formation		
Pedogenic carbonate	-8.86	-2.23
" "	-8.90	-3.13
" "	-8.85	-3.27
" "	-8.84	-2.95
Mean (± 1σ)	*-8.86±0.03*	*-2.90±0.46*
Cepaea nemoralis	-7.89	-0.96
" "	-7.50	-1.75
" "	-7.15	-0.29
Mean (± 1σ)	*-7.51±0.37*	*-1.00±0.73*
Galba truncatula	-12.07	-1.86
" "	-12.74	-0.73
" "	-10.86	-1.05
" "	-12.05	-2.36
Mean (± 1σ)	*-11.93±0.78*	*-1.50±0.75*
Living land snails		
Pomatias elegans (Livorno)	-9.05	-0.62
" "	-9.30	-0.41
Mean (± 1σ)	*-9.17±0.13*	*-0.52±0.11*
Cepaea nemoralis (Pisa)	-10.61	-0.44
" "	-10.90	-0.40
" "	-12.62	-0.31
Mean (± 1σ)	*-11.38±1.09*	*-0.38±0.07*
Helix pomatias (Pisa)	-12.35	-0.36
" "	-12.18	-0.52
Mean (± 1σ)	*-12.27±0.08*	*-0.44±0.08*

Tab. 4 - δ^{13}C and δ^{18}O of selected living and fossil non-marine molluscs.

their percentages decrease upwards, reaching their minimum values in sample k6. The same trend is exhibited by the hygrophilous *Alnus, Salix,* and *Populus.* Other elements of the plain forest are only sporadically recorded. Among NAP, the highest percentages are showed by Cyperaceae, which have a decrease upwards, as is also shown by the aquatic plants. This suggests a progressive reduction of wetlands, which may have favoured the widespread of *Pinus* in drained areas of the plain.

Stable isotope data

XRD analyses showed that land snail shells preserved their original aragonitic crystallography, while the pedogenic carbonate concretions were almost formed by calcite and minor amount of quartz and feldspar. Table 4 and Fig. 11 show the isotopic results of analyses on unit 3, along with the isotopic data obtained on living snails collected in the area.

The oxygen isotopic composition of the freshwater shells is controlled by the temperature of shell growth, by the presence of kinetic or near equilibrium isotopic reactions and by the isotopic composition of the environmental water (White et al. 1999), where the change in the isotopic composition of water is the most important parameter (Eicher & Siegenthaler 1976; von Grafenstein et al. 1996).

The mean δ^{18}O values measured in *Galba truncatula* are typical, at this latitude, of shells that precipitates from water bodies ^{18}O-enriched through evaporation, being mean δ^{18}O of local rainfall ca. -5.5‰ (Mussi et al. 1998). Since during colder phases it should be expected that δ^{18}O of local rainfall decreases, owing to the decrease in the mean surface temperature (Rozanski et al. 1993), we infer that the relatively high δ^{18}O values of freshwater shells are the evidence of evaporated water. This is in agreement with paleontological data, which suggest the presence of open spaces, and the presence of freshwater molluscs that can tolerate periods of drying up of the water body.

The Holocene pedogenic carbonates from different sites in Italy have δ^{18}O values of ca. -5‰ (Solomon et al. 1978; Zanchetta et al. 2000), which are consistent with past pedogenic carbonates from Central Italy that

precipitated in soils subject to mild climatic conditions (Zanchetta et al. 1998; 2000; Leone et al. 2000). These $\delta^{18}O$ values are lower than those measured in Corea formation. Therefore, in agreement with faunal assemblage and $\delta^{18}O$ values of freshwater shells, the $\delta^{18}O$ values of pedogenic carbonates are the expression of significant soil water evaporation in agreement with an environment characterised by scarce vegetation cover (Zanchetta et al. 2000).

For land snails rainfalls, dew and water vapour represent different and complementary sources of metabolic water (Lécolle 1985; Goodfriend et al. 1989; Balakrishnan & Yapp 2004; Zanchetta et al. 2005). The different isotopic fractionation that occurs among these sources of environmental water and the metabolic water are responsible, along with the temperature of precipitation, of the oxygen isotopic composition of the shell (Balakrishnan & Yapp 2004).

Fossil shells from unit 3 have lower values than living shells collected in the nearby areas, suggesting low mean isotopic composition of the rainfall (Lécolle 1985; Zanchetta et al. 2005), which may imply a mean surface temperature lower than today (Rozanski et al. 1993), in agreement with the cool character of the faunal assemblages. Using the equation proposed by Zanchetta et al. (2005) for the Italian peninsula it is possible to calculate the past isotopic composition of rainfall:

$$\delta^{18}Or = 0.65 \ \delta^{18}Os - 5.44 \quad (1)$$

where $\delta^{18}Or$ is the mean annual isotopic composition of the local rainfall (expressed with respect to V-SMOW) and $\delta^{18}Os$ is the isotopic composition of the shells (expressed with respect to V-PDB). Calculations suggest that mean $\delta^{18}O$ of past rainfall could be ca. -6‰, which is about 0.5‰ ^{18}O-depleted than today. In the Mediterranean area the relation between mean surface temperature and rainfall is ca. 0.3 ‰/°C and, according to Bard et al. (2002) this value seems to be valid for the past 200 ka. From this coefficient it will be possible to calculate the changes in temperature compared to the present. The calculation suggests that the temperature was ca. 1.5°C lower than the present.

The carbon isotopic composition of continental carbonates is complicated by many interplaying factors and the isotopic fractionation that occurs among different phases of dissolved CO_2. For freshwater shells the $\delta^{13}C$ is mainly controlled by the isotopic composition of the dissolved inorganic carbon (DIC) (Fritz & Poplawsky 1974). Low values of $\delta^{13}C$ of shells are usually derived by DIC due to the oxidation of organic matter, which is usually ^{12}C-enriched (Deines 1980). The mean values of ca. -11‰ found in *Galba truncatula* is what can be expected from a carbonate precipitating from a

DIC originated by the leaching of soil CO_2 dominated by C_3 vegetation (Cerling & Quade 1993).

The mean values of pedogenic carbonate, ca. -9‰, is not as low as that of freshwater shells. If CO_2 supplied to DIC was originated from soils, we should expect a quite similar value, once taken into account the different isotopic fractionation between aragonite and calcite ($10^3\ln a = +1.8‰$; Rubinson & Clayton 1969). This because the carbon isotope composition of pedogenic carbonates ultimately derives from the isotopic composition of soil CO_2, which depends on soil respiration rate and the amount and typology of vegetation (i.e. C_4/C_3 ratio; Cerling & Quade 1993). Therefore, lower values of freshwater shells could be better explained by the recycling of organic matter into the water body. Mean $\delta^{13}C$ values of Holocene, middle Pleistocene, and upper Pliocene of pedogenic carbonates obtained from Italian sections (Solomon et al. 1978; Zanchetta et al. 1998, 2000; Leone et al. 2000) have usually lower values (from 1 to 2‰) than those measured in unit 3. This could imply a small component of C_4 in the vegetation (Deines 1980).

According to Wang & Zheng (1989) the proportion of C_4 plant (x) is given by:

$$x = (11.9 + \delta^{13}C)/14 \quad (2)$$

The calculation indicate an amount of C_4 vegetation of about 20%.

The $\delta^{13}C$ values of *Cepaea nemoralis* are also very intriguing. The mean $\delta^{13}C$ values of *Cepaea* collected in the Corea formation are ca. 4‰ higher than living *C. nemoralis* (Tab. 4; Fig. 11). The $\delta^{13}C$ of land snail shells is governed by several factors among which the diet seems to be the most important (Stott 2002; Metref et al. 2003; Balakrishnan & Yapp 2004). The isotopic composition of food ($\delta^{13}C_{food}$) can be calculated from the $\delta^{13}C$ of shell ($\delta^{13}C_s$) according to Stott's (2002) equation:

$$\delta^{13}C_{food} = 1.35 \ \delta^{13}C_s - 11.73 \quad (3)$$

Because the equation (3) has been obtained for *Helix pomatia* the generalization to all the snail species is rather questionable. Tab. 4 shows that living *Helix* has the lower $\delta^{13}C$, *Cepaea* $\delta^{13}C$ is close to *Helix* but slightly ^{13}C-enriched (ca 0.7‰), whereas *Pomatias* has the higher $\delta^{13}C$ values, in agreement with the Lécolle (1983; 1984) data. Applying to equation (3) a correction of about 0.7‰, we obtain a value for $\delta^{13}C_{food}$ of ca. -23‰. Mass isotopic balance allows to estimate the fraction of C_3 and C_4 plants, assuming a mean value of -13 and -27‰ for C_4 and C_3 respectively. This calculation implies an amount of C_4 plants in the snails diet of ca. 30%. The isotopic signal could also easily be produced by a C_3 vegetation with different proportion of differ-
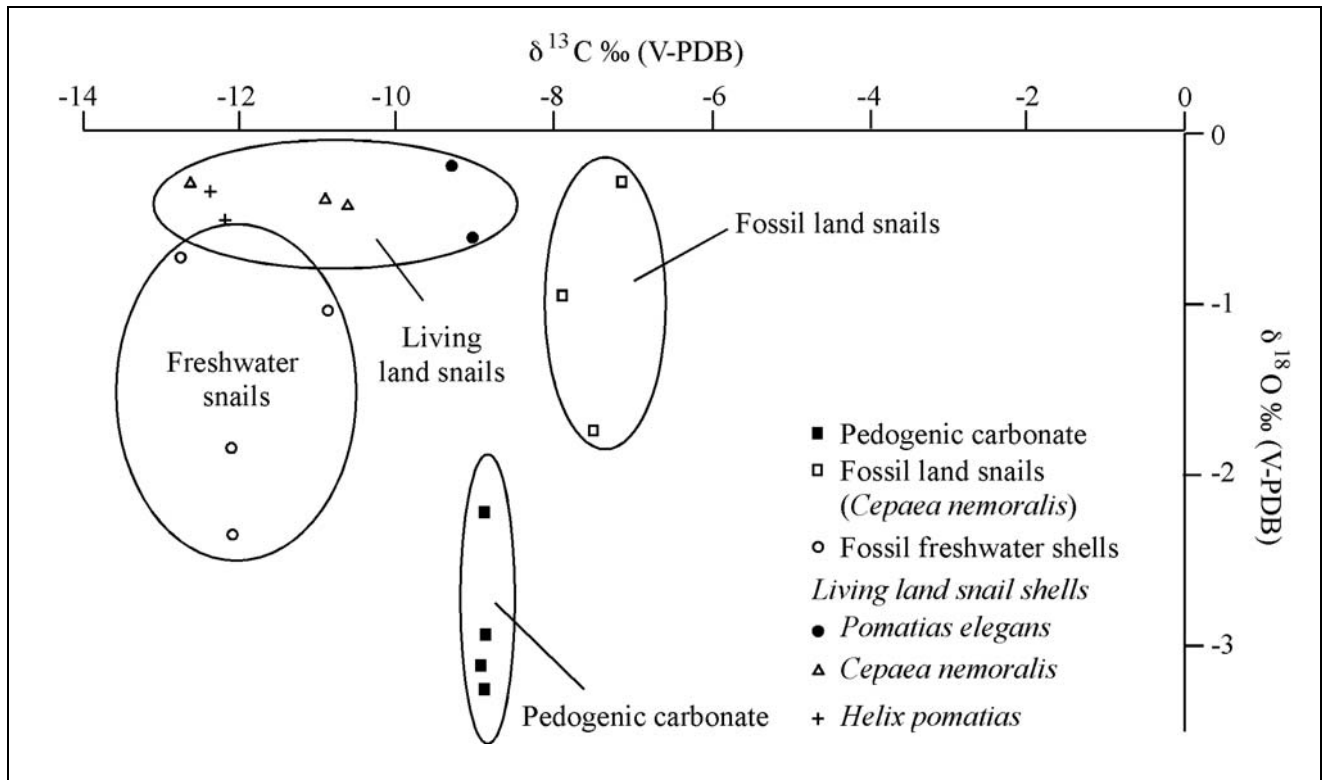
Fig. 11 - δ¹³C vs. δ¹⁸O of non-marine molluscs and pedogenic carbonate from the upper part (unit 3) of Corea formation. Isotopic data from living land snail shells are also shown.

ent plants (e.g. shrubs and trees ratio and/or evergreen and deciduous species) or by environmental stress. A fact that can be applied also to the δ¹³C values of pedogenic carbonates. The values found in the pedogenic carbonates can be also associated to soil with low vegetation and low respiration rate (Wang et al. 1996). However, the amount of the C_4 vegetation calculated from pedogenic carbonates and land snail shells suggest a genuine paleovegetational signal, in agreement with the presence of a significant amount of Gramineae and Cyperaceae in the pollen spectra.

Conclusions

Stratigraphic data and small mammals indicate that Corea formation developed during MIS 6 and the transition to MIS 5.

The non-marine mollusc and small mammal remains described in this paper represent an example of intermediate faunas developed during climate conditions at the transition between a glacial and an interglacial phase. Here an articulated, mostly open environment with cool and moderately dry climate conditions was present. The presence of an open environment is supported by pollen data, which also suggest a progressive reduction of wetlands. The non-marine mollusc assemblage shows the presence of immigrants that are now restricted to northern Italy.

Stable isotopes on pedogenic carbonates and non-marine shells further constrain the environment. Lower isotopic composition of rainfall was inferred possibly as the effect of a temperature 1-2°C lower than today. However, the effect of lower isotopic composition of rainfall on environmental water was partially skewed in pedogenic carbonates and freshwater environment by evaporative processes that operated in a moderately dry environment. Vegetation typology was probably dominated by C_3 plants even if the presence of a significant amount of C_4 vegetation could be supposed: indeed, Gramineae and Cyperaceae show significant pollen percentages.

The Corea formation is a new unit for the subsurface stratigraphy of the Livorno area. The original description of Bacci et al. (1939) of the section at Cimitero dei Lupi perfectly matches with the description of Corea formation. Indeed Bacci et al. (1939) described the presence of a basal gravel unit, followed by clay layers with a non-marine fauna and a final panchina at the top. The species recognised by Bacci et al. (1939), revised by Zanchetta et al. (2004) were: *Carychium mariae, Oxyloma elegans, Succinea oblonga, Cochlicopa lubrica, Pupilla muscorum, Vertigo antivertigo, V. angustior, Orcula dolium, Vallonia pulchella, Limax* sp., *Vitrina* sp., *Cepaea nemoralis,* and the freshwater species *Galba truncatula.* This association substantially matches that of Corea formation, whereas it is different from that embedded between the two

panchina layers, as extensively discussed by Zanchetta et al. (2004).

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