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FACIES ANALYSIS, STRATIGRAPHY AND PALAEONTOLOGY (MOLLUSCS AND VERTEBRATES) IN THE UPPER PLIOCENE SANDY FLOOD-BASIN DEPOSITS OF THE UPPER VALDARNO BASIN (NORTHERN APENNINES)

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Abstract. The Upper Valdarno Basin, one of the most investigated Neogene-Quaternary basins of the Northern Apennines, developed during three main phases, as testified by the occurrence of three unconformity-bounded stratigraphic units (UBSUs) in the basin infill. Despite numerous studies having been carried out, biochronological, paleoecological and stratigraphical issues in the lower portion of the Montevarchi Synthem (second phase) have yet to be understood. Sandy deposits (Montecarlo Sand and Silt Unit), stratigraphically located in this portion of the Montevarchi Synthem, are the focus of this multidisciplinary study. These deposits conformably overlie sandy fluvio-eolian sediments and are, in turn, capped by fluvio-palustrine deposits through a progressive unconformity. Facies analysis suggest a sandy flood-basin environment for these deposits, characterised by variations in water discharge and flood event energy. Mollusc and fish remains, pointing to quiet or slow-moving shallow waters, have been affected by transport processes before final burial in overbank areas. Fish remains of the primary marine family Mugilids highlight a connection between the basin and the sea that was previously only supposed. Small mammal remains, referred to the rodent *Mimomys polonicus*, are coherent with a water-rich environment. Cyclic variations in shell content and sedimentological characteristics testify to the occurrence of short-term climatic oscillations during this warming phase. This study fits with paleomagnetic and radiometric datings and mammal biochronology, in indicating that the Montecarlo Sand and Silt Unit belongs to a time interval preceding the Reunion paleomagnetic event. The depositional evolution of the Montecarlo Unit was driven by climatic change from arid to humid conditions, related to a global increase in temperature that occurred between 2.4 and 2.2 Ma.

Riassunto. Il Valdarno Superiore rappresenta uno dei bacini neogenico-quaternari più studiati dell'Appennino settentrionale soprattutto in relazione ai numerosi resti di mammiferi che hanno permesso la definizione e la caratterizzazione di molte unità faunistiche delle età a mammiferi plio-pleistoceniche Europee. Il bacino si sviluppa a partire dal Pliocene medio fino al Pleistocene superiore attraverso tre fasi tettono-sedimentarie, rappresentate nella successione di riempimento da tre principali UBSU (*unconformity bounded stratigraphic units*). Il presente lavoro è basato su un'analisi multidisciplinare di depositi sabbiosi collocati nella porzione inferiore del secondo sintema (Sintema di Montevarchi), la cui dinamica paleoambientale non risulta finora particolarmente chiara. Questi depositi (Sabbie e Limi di Montecarlo) poggiano in continuità stratigrafica su depositi fluvio-eolici (Sabbie della Rena Bianca) e localmente passano verso l'alto a sedimenti fluvio-palustri (Limi di Terranuova). Le Sabbie e Limi di Montecarlo sono state interpretate in termini di ambiente di floodbasin, caratterizzato da variazioni di contenuto d'acqua e dell'energia degli eventi di piena. Le associazioni faunistiche a pesci e molluschi indicano la presenza di acque basse e poco mosse, mentre l'assenza di ossa articolate e di bivalvi in posizione di vita, suggerisce l'azione di processi di trasporto prima del definitivo seppellimento. La presenza di resti di pesci appartenenti alla famiglia dei Mugilidi, testimonia l'esistenza di una connessione tra il bacino ed il mare all'inizio del Pliocene superiore, finora soltanto ipotizzata.

La presenza di ambienti acquatici, fluviali e/o lacustro/palustri, è inoltre suggerita dal rinvenimento di resti attribuiti alla specie *Mimomys polonicus*, appartenente al gruppo delle cosiddette "arvicole d'acqua". *M. polonicus* è diffuso in molte località europee durante il Pliocene medio p.p. e il Pliocene superiore p.p. Nel complesso le Sabbie e Limi di Montecarlo rappresentano un termine di passaggio dai sottostanti depositi di clima arido ai sovrastanti di ambiente umido, evidenziando la risposta dei processi sedimentari ad una variazione climatica avvenuta a scala globale tra 2.4 e 2.2 Ma. Nei depositi studiati tale transizione è caratterizzata da due brevi oscillazioni arido-umido evidenziate da incrementi ciclici di mortalità dei molluschi e di decrementi

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del contenuto di acqua nel sistema. Il quadro derivante dal presente studio è coerente con precedenti analisi paleomagnetiche e biocronologiche nel collocare temporalmente le Sabbie e Limi di Montecarlo poco al di sotto dell'evento paleomagnetico normale Reunion.

Introduction

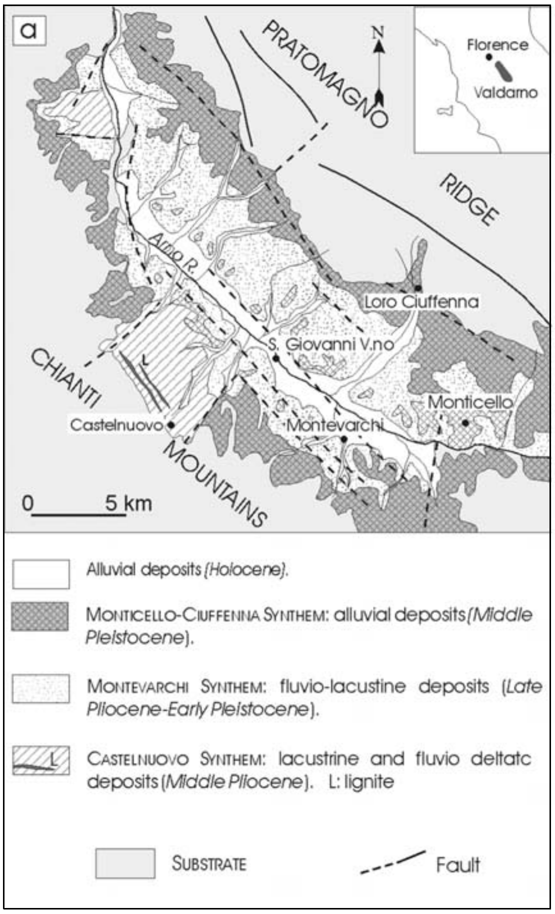
The Upper Valdarno Basin (Central Italy, Tuscany) has for a long time been the subject of numerous geological and palaeontological studies, because of the abundant and well-preserved mammal fossils which have allowed the characterization of some faunal units of the Villafranchian Mammal Age (Azzaroli 1977; Gliozzi et al. 1997). Formerly in 1936, Sestini recognised that the basin evolution occurred in three main depositional phases. Between 1989 and 2001, a general review of the geological setting of the basin took place (Magi 1989; Sagri 1991; Benvenuti 1992; Sagri & Magi 1992; Magi & Sagri 1994; Ghinassi 2000) and our knowledge of the chronostratigraphical evolution of the Upper Valdarno Basin was greatly improved (Torre et al. 1993; Albianelli et al. 1995, 1997, 2001). Multidisciplinary studies of the deposits of the first and second phases of the basin infill, were carried out in order to define a detailed paleomagnetic calibration of the Villafranchian mammalian faunas (Torre et al. 1993, 1996; Napoleone et al. 2001).

However, the stratigraphical framework at the transition between the first and second depositional phases had not been clarified. More recently, the deposits stratigraphically located at the transition between the first and second phase have been the target of detailed studies focused on UBSU stratigraphy (Ghinassi & Magi 2002, 2004; Ghinassi et al. 2004) and paleoclimatic changes (Bertini 1994; Albianelli et al. 1995; Bertini & Roiron 1997; Ghinassi et al. 2004). The present paper adds to these recent studies and summarises the results of a multidisciplinary investigation focused on the alluvial deposits (Montecarlo Sand and Silt Unit) stratigraphically located in the lower portion of the second depositional phase (Figs 1 and 2).

Geological setting of the upper Valdarno Basin

The Valdarno Basin is a 15-km wide half-graben located about 40 km SE of Florence between the Chianti Mountains and the Pratomagno Ridge (Fig. 1a). Based on the presence of unconformity-bounded stratigraphic units, Benvenuti (1992) subdivided the basin fill (550 m thick) into three synthems (sensu Salvador 1987, 1994): the Castelnuovo Synthem, the Montevarchi Synthem and the Monticello-Ciuffenna Synthem (Fig. 1b).

During deposition of the first synthem the basin evolved as an asymmetric depression with its depocen-



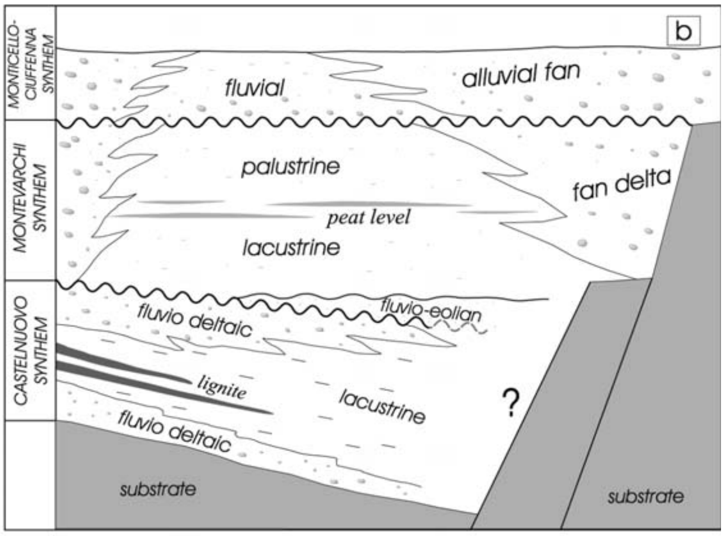


Fig. 1 - The Plio-Pleistocene Upper Valdarno Basin: (a) Geological map (from Sagri 1991); (b) stratigraphic framework (after Ghinassi et al. 2004).

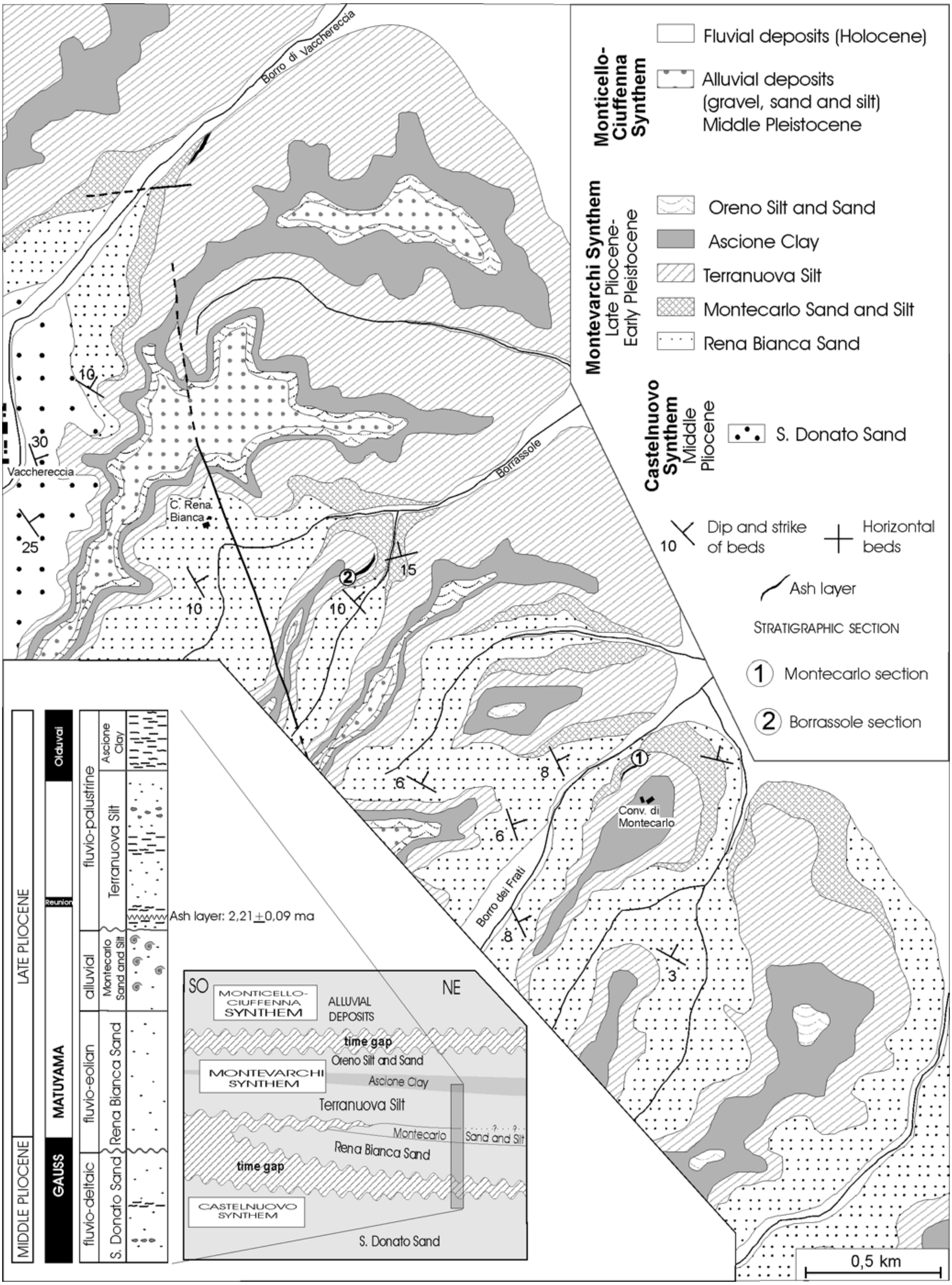


Fig. 2 - The Montecarlo Sand and Silt Unit: (a) Geological map; (b) stratigraphic framework showing the temporal distribution of main time gaps in the study area (magnetostratigraphy is from Ghinassi et al. 2004).

tre to the northeast. Fluvio-deltaic gravels and sands representing the base of Castelnuovo Synthem (Middle Pliocene), grade upwards into lignitiferous lacustrine clay, in turn overlain by fluvio-deltaic sands (Sagri 1991; Albianelli et al. 1995).

During deposition of the overlying Montevarchi Synthem, major reactivation and enlargement of the basin occurred, with the formation of back-stepping normal faults along the eastern margin (Sagri 1991; Sagri & Magi 1992). Recently, the Montevarchi Synthem (Middle Pliocene-Lower Pleistocene) was divided into two distinct portions, because of the occurrence of a progressive unconformity (Fig. 2), exposed along the western margin of the basin (Ghinassi & Magi 2002, 2004; Ghinassi et al. 2004). The lower portion (Fig. 2) consists of fluvio-eolian sand (Rena Bianca Sand Unit) grading upwards into alluvial sand (Montecarlo Sand and Silt Unit). The upper portion is represented by fan-delta gravelly deposits along the margins, and silty-sand fluvio-palustrine deposits in the central portions of the basin (Fig. 2; Sagri & Magi 1992). At the base of such fluvio-palustrine deposits (base of Terranuova Silt Unit), a thin ash layer (2.21+0.09 Ma with ^{40}Ar/^{39}Ar dating; Ghinassi et al. 2004) occurs (Fig. 2b).

A final tectonic phase affected the basin, just before the deposition of the third synthem (Monticello-Ciuffenna Synthem), which gave rise to the complete filling of the basin (Sagri 1991; Albianelli et al. 1995). The Monticello-Ciuffenna Synthem (Middle Pleistocene) consists of fluvial gravel and sand in the central portion of the basin, and poorly stratified massive gravel and coarse sand of alluvial fans developed at the margins (Fig. 1b).

Sedimentological and stratigraphical framework of the Montecarlo sand and silt unit

The Montecarlo Sand and Silt Unit, 13 m in thickness, crops out along the eastern margin of the basin in a narrow belt (7 km long and 0.3 km wide) oriented NW-SE (Fig. 2a). Paleomagnetic analyses and numerical dating (Fig. 2b) constrain the Montecarlo Sand and Silt Unit to the lower-middle portion of the Late Pliocene. Two well-exposed sections have been measured and sampled (Montecarlo and Borrassole sections) within the Montecarlo Unit (Fig. 3). Seven different lithofacies have been recognised (Tab. 1) and grouped into three main lithofacies associations (SB, SL and B).

Lithofacies association SB

Description. Lithofacies association SB (Figs 4 and 5) consists of prevailing yellowish mottled, medium to fine sand (lithofacies s1, s2, s3 and s4), locally interbedded with thin greyish silty layers (lithofacies sl).

Sandy tabular beds forming lithofacies s1 and s2 are massive, whereas beds of lithofacies s3 show horizontal planar lamination (locally deformed by flame structures). Lithofacies s4 (Fig. 4) is characterised by the presence of abundant symmetrical ripple forms (showing RI = 4.8 and RSI = 1.2, following Collins & Tompson 1982). Beds forming sandy lithofacies s1, s2 and s3 (Fig. 5) are generally ungraded (lithofacies s2), although normal grading occurs, frequently marked by the concentration of shells at the base of beds (lithofacies s1; Fig. 5b). The basal surfaces of lithofacies s1, s3 and s4 are not erosive, whereas at the base of lithofacies s2, small scours bearing abundant mollusc shells are present. Clasts 1-2 cm in size formed by shell agglomerates are locally present in the basal portion of beds forming lithofacies s2. Bivalves are generally articulated, but never in life position (Fig. 5c) both in silty and sandy lithofacies. Root remains are present at the top of some sandy beds, associated with thin reddish sandy crusts. Thin silty and sandy-silt irregular levels forming lithofacies sl are frequently interbedded with sandy lithofacies (Fig. 3).

Code	Lithofacies	Fossils	Interpretation
s1	Medium to fine massive mottled sand. Ungraded or normally graded tabular beds (5-35 cm), locally with shells at the base.	Common plant and rare fish remains. Locally small roots and molluscs.	Flash floods covering the flood basin. Turbulence can concentrate shells at the base of beds. Plant growth has probably masked sedimentary structures.
s2	Medium to fine-grained massive mottled sand. Ungraded or normally graded, erosively based tabular beds (10-15 cm). Scours (2–4 cm deep) at the base are filled by shells.	Very abundant molluscs. Common plant remains.	Flash floods covering the flood basin. Turbulence can erode small scours at the base.
s3	Horizontally laminated, medium-grained mottled sand in tabular beds (5-10 cm). Laminae are frequently deformed.	Common plant, fish and molluscs remains.	Super-critical planar lamination due to laminar flow formed during major continuance floods. Deformation could be due to fluid escape.
s4	Medium to fine massive mottled sandy beds (3-20 cm), showing faint symmetric ripple forms.	Rare plant remains	Wave ripples due to sand winnowing in shallow pools.
s5	Medium massive shell-rich sand, slightly erosive base, showing thin basal reverse grading overlain by a normally graded portion. Reverse to normal grading is marked by shell distribution. Bed tickness range from 10 to 30 cm.	Very abundant molluscs.	Hyperconcentrated flood flows, dumping sediment at very high rates.
bc	Multistorey erosively based bioclastic (shell) beds (10-30 cm), containing rare sandy matrix. Beds are massive, ungraded. Scours at the base are filled by shells.	Very abundant molluscs. Common plant and fish remains.	Turbulent flash floods spreading over the flood basin.
sl	Massive silty beds (20-25 cm) locally showing faint horizontal lamination. Rare level enriched in organic matter.	Common plant, fish and mollusc remains.	Fines settling in isolated pools.

Tab. 1 - Table of lithofacies.

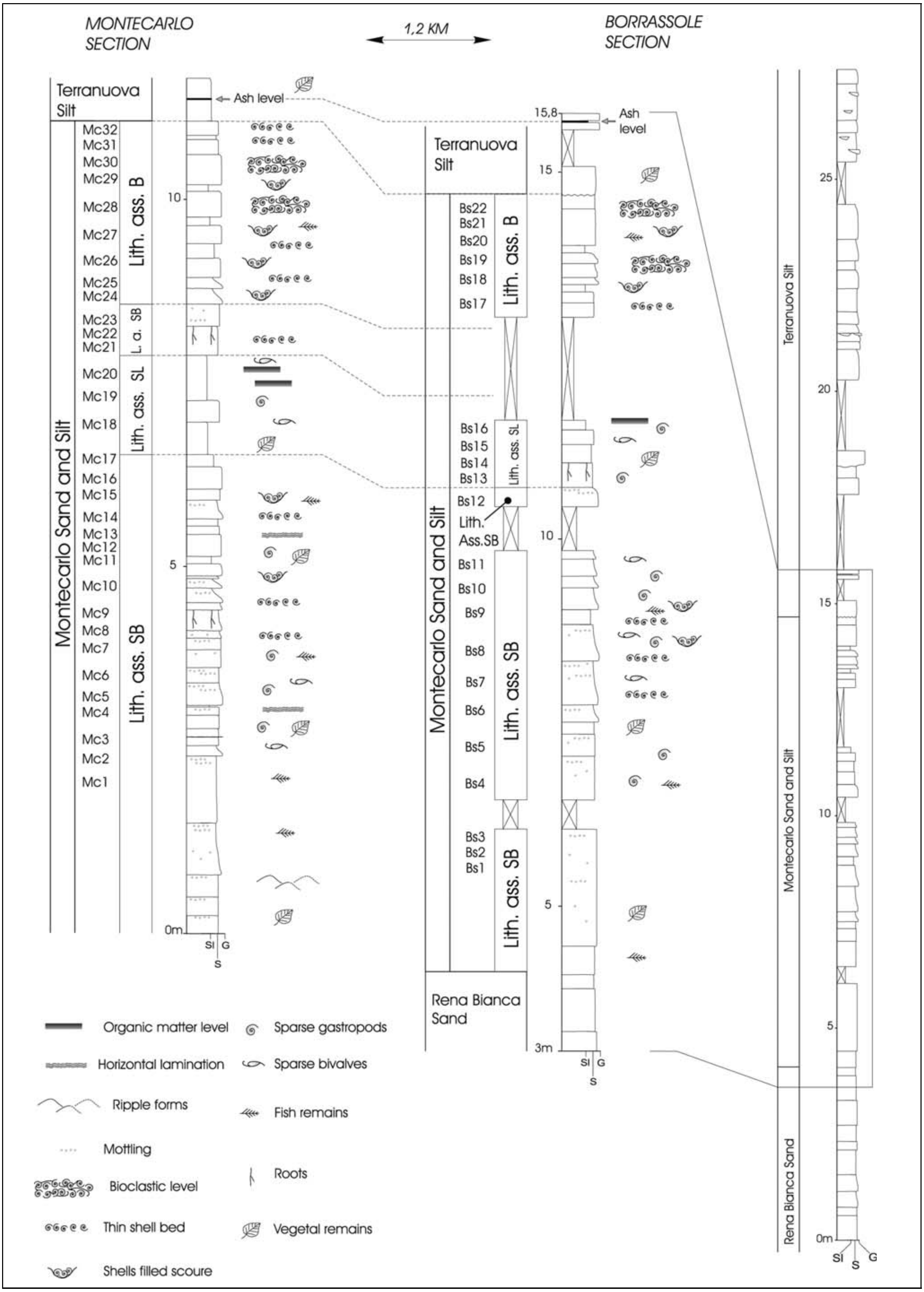


Fig. 3 - Sedimentological logs and lithofacial correlation between the studied sections.

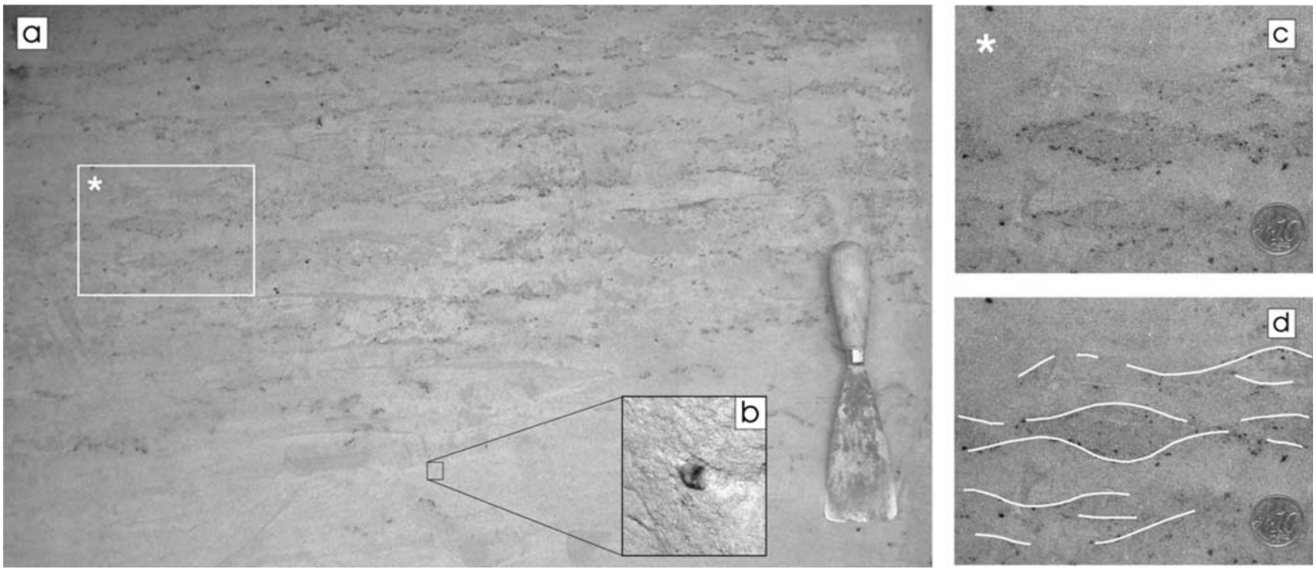


Fig. 4 - Rippled sands of lithofacies s4: (a) open view at the base of Montecarlo section; (b) pharyngeal teeth belonging to *Tinca* sp.; (c) detail from "a" showing morphology (symmetry) of ripples; (d) drawn version of "c".

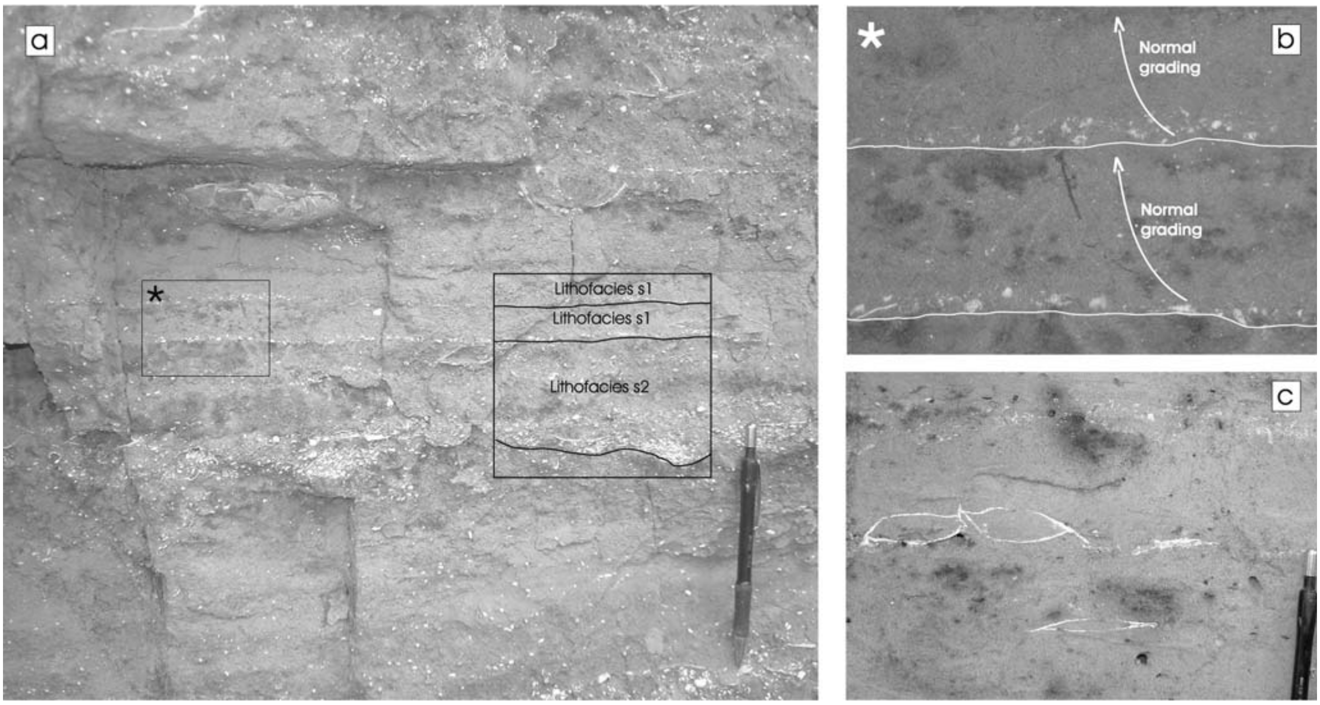


Fig. 5 - Lithofacies association SB: (a) stacking of non-erosively (lithofacies s1) and erosively (lithofacies s2) based tabular beds (see drawn portion); (b) detail from "a" showing normally graded sandy beds with shells at the base (lithofacies s1); (c) transported articulated bivalves at the base of beds forming lithofacies s1.

Interpretation. The occurrence of tabular sandy beds, forming lithofacies s1, s2 and s3, suggests spreading of unconfined flows.

The prevalence of ungraded and non-erosively based beds (lithofacies s1) suggests scarce turbulence for most of the flows, probably short-lived flows that dumped sediment at a rate too fast for hydraulic sorting processes to work effectively ("hyperconcentrated flood-flows" sensu Smith 1986; Hjellbakk 1997).

Normally graded and erosive-based beds, forming lithofacies s2, testify to turbulent flows (Tunbridge 1984; Lowe 1988), according with the occurrence of bioclastic agglomerates, probably eroded during the rising phase of the event and rapidly deposited after a short transport distance. The uncommon horizontal laminated beds (lithofacies s3) point to upper regime laminar flow (Allen 1984; Paola et al. 1989).

Symmetric ripple forms in lithofacies s4 could be related to the wave winnowing of sandy beds (Collins & Tompson 1982), firstly originated by the emplacement of flows in wide shallow-water bodies. On the other hand, these ripples could also be due to slight wave reworking of asymmetric traction ripples.

The presence of thin silty beds (lithofacies sl), from fines settling in a low-energy environment, confirms the presence of still-water bodies (Miall 1996). Small roots may be due to the growth of scarce vegetation, during phases of non deposition. Vegetation growth could be also responsible for the genesis of some massive beds from originally sedimentary-structured deposits (Miall 1996).

Sedimentological features of lithofacies association SB suggest a depositional environment similar to a wide flat area, mainly characterised by the expansion of high sediment laden flows, and locally by plant growth during low sedimentation rate stages. On the whole, such characters could suggest a depositional setting similar to an alluvial plain (Miall 1996), even if the absence of other distinctive characteristics (i.e. coarser-grained channelized deposits) prevents us from pinpointing these deposits as an alluvial plain. On the basis of previous considerations, we suggest classifying lithofacies association SB as indicative of a flood-basin environment (Pole 2001).

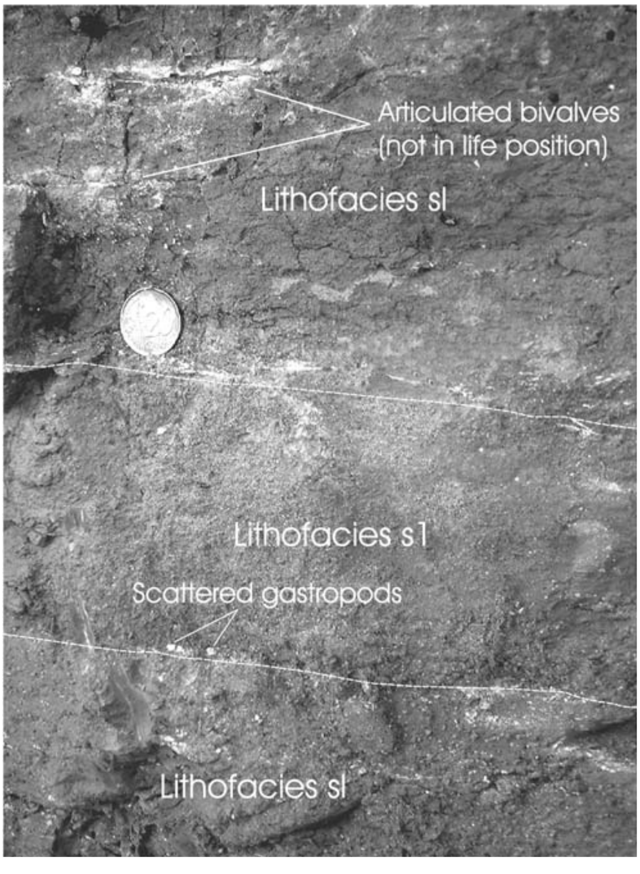


Fig. 6 - Stacked silty and sandy beds (lithofacies sl and s1) forming lithofacies association SL.

Lithofacies association SL

Description. Lithofacies association SL consists of prevailing greyish silty beds (lithofacies sl) interbedded with sandy beds of lithofacies s1, and generally occurs in the middle portion of the unit (Fig. 3). Silty beds, tabular at the outcrop scale, are massive or show faint horizontal lamination. These deposits (Fig. 6), locally poorly enriched in organic matter, contain sparse molluscs and abundant vegetal remains. Sandy beds (1-3 cm thick) representing lithofacies s1 are generally discontinuous and show concentrations of shells at the base. Bivalves occurring in lithofacies association sl and s1 are generally articulated, but never in life position.

Interpretation. The fine settling (lithofacies sl) represents the main depositional mechanism acting in shallow ponds (according with lithofacies association SB), where occasionally emplacement of sandy flows (lithofacies s1) occurs. Massive silt beds are probably due to bioturbation, whereas locally faint planar laminations testify to the gradual settling of fines. Despite water permanence in some pools, according to the lack of root remains, the lack of bivalves in life position confirms that mollusc shells were transported into the ponds.

This lithofacies association is interpreted to represent the development of extended and standing ponds in the flood-basin environment.

Lithofacies association B

Description. This lithofacies association (Fig. 7) includes prevailing lithofacies bc, s2 and sl, and subordinate lithofacies s5 and s1.

Tabular massive beds of lithofacies bc are entirely formed by shells and shell fragments, with scanty sandy matrix. Bivalves in these deposits are frequently broken or inarticulated. The beds are generally ungraded and the basal surface is erosive, with shell-filled scours (2-4 cm deep). Silty irregular beds of lithofacies sl and sandy erosively-based beds (lithofacies s2; Fig. 7d) are frequently interbedded with lithofacies bc. Lithofacies s5 consists of massive sandy beds containing abundant shells. Beds are slightly erosive based, and show a thin basal reverse-graded lamina-set overlain by a normally graded portion. Reverse to normal grading is generally evidenced by shell distribution (Fig. 7c).

Lithofacies s1 is rare and generally associated with lithofacies s5.

Interpretation. Normally graded, bioclastic, erosively-based beds (lithofacies bc) could be due to the expansion of turbulent flows (Tunbridge 1984; Lowe 1988) similar to lithofacies s2. The presence of silty beds of lithofacies sl, interbedded with bioclastic deposits, suggests an emplacement of bioclast-charged flows into small ponds, according to the lack of root remains. Lateral pinching of silty layers could be due to the emplacement of lithofacies bc beds, that locally erode the fine layers deposited during periods of low sediment supply. The absence of bivalves in life position, as for lithofacies associations SB and SL, implies post-mortem transport of molluscs. Reverse to normally graded beds of lithofacies s5 may be interpreted as high sediment charged flows, with dispersive pressure acting in the lower por-

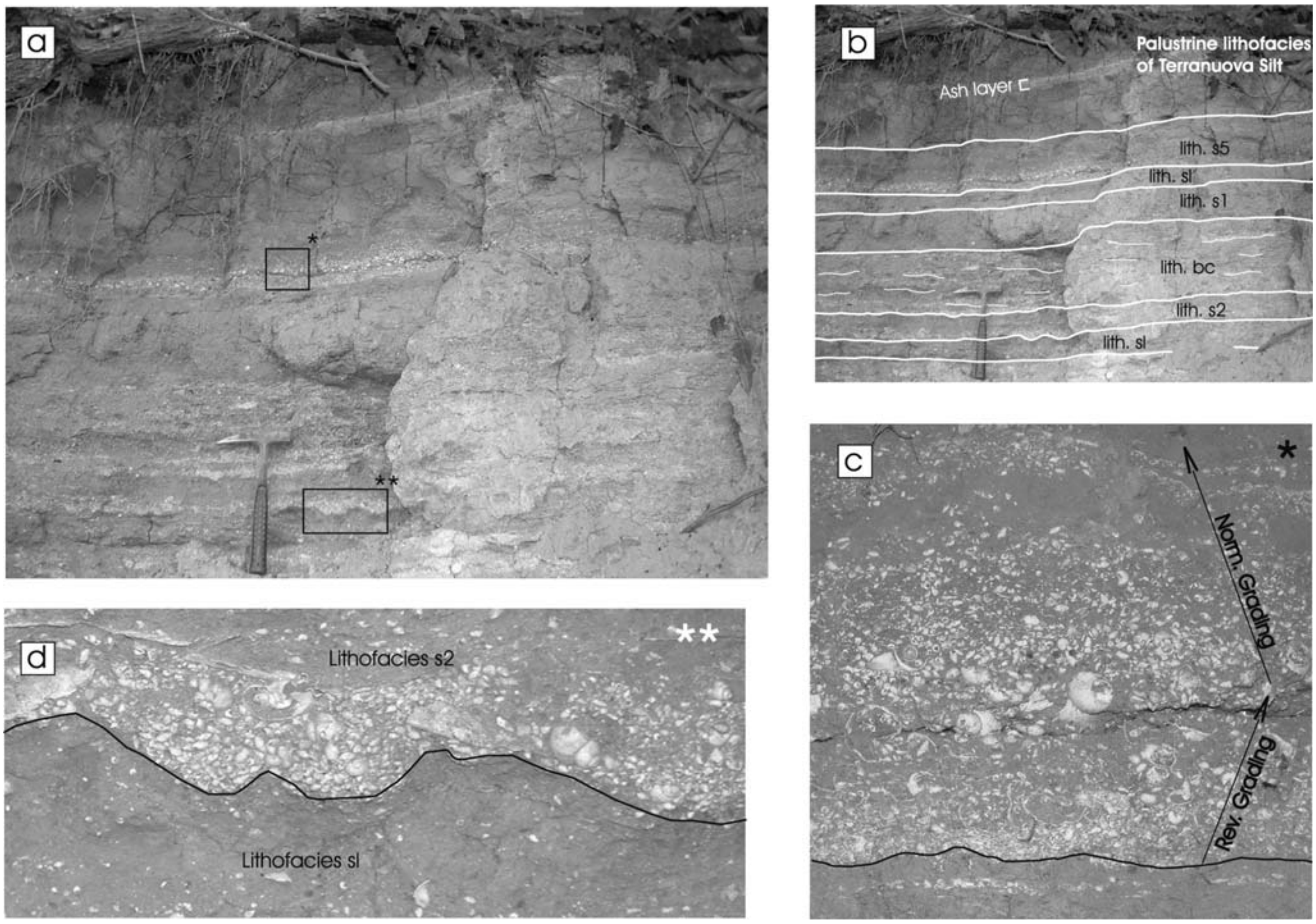


Fig. 7 - Upper portion of the Montecarlo section: (a) gradual transition from the Montecarlo Unit to palustrine facies of the Terranuova Silt; (b) drawn version of "a"; (c) reverse to normally graded bed forming lithofacies s5 (detail from "a"); (d) erosively based bed of lithofacies s2 cutting lithofacies sl (detail from "a")

tion of the flow, generating the reverse graded basal layer (Lowe 1982, 1988; Smith 1986).

Palaeontology

Molluscs

Detailed quantitative malacological analyses have been carried on 53 samples (32 from the Montecarlo section and 21 from the Borrassole section). Each sample (1 dm^3 of sediment) was sieved (125 µm), shell remains were counted and the percentage of specimens for each species has been calculated (Figs 8 and 9).

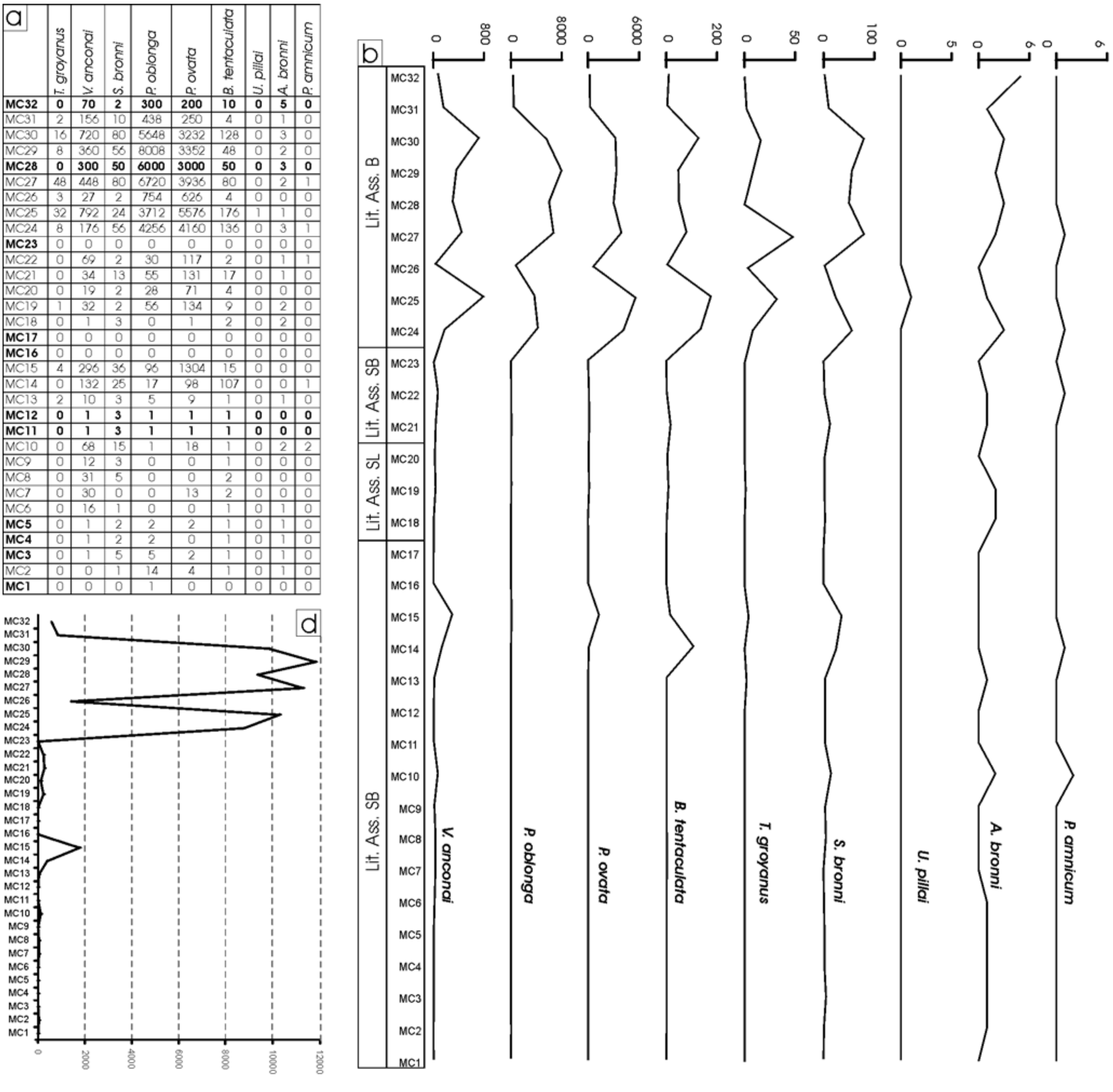
The two studied sections are characterised by similar oligotypical assemblages very rich in specimens of freshwater prosobranch gastropods and bivalves. Both sections show a low species diversity, from three to seven (rarely eight) species, in the analysed levels; some layers are barren.

Nine species of freshwater molluscs, six gastropods and three bivalves, have been recorded in total (Pl. 1; Figs 8 and 9). The gastropods which belong to the prosobranchs Neritidae, Viviparidae, Bithyniidae, Hydrobiidae and heterobranchs Valvatidae are represented by *Theodoxus groyanus* (Férussac), *Stephania bronni* (D'Ancona), *Bithynia tentaculata* (Linné), *Prososthenia oblonga* (Bronn), *Prososthenia ovata* (Bronn), *Valvata anconai* De Stefani. The bivalves, Unionidae and Sphaeriidae, are represented by *Unio pillai* De Stefani, *Anodonta bronni* D'Ancona and *Pisidium amnicum* (Müller). The gastropods are generally dominant in the assemblages, whilst the bivalves are scattered throughout the two sections. Most of the recorded species became extinct; only two, *B. tentaculata* and *P. amnicum*, are extant.

Both the stratigraphic sections are characterised by a cyclic deposition of mollusc-bearing layers interbedded with barren or nearly barren layers.

The Montecarlo section, the best exposed one, and Borrassole are here described in detail (Figs 8 and 9). They can be subdivided into some correlated intervals distinguished by the different composition of the molluscan assemblages.

Interval 1 (0-5.5m MC; 4-8m BS). From MC 1 to MC 5, basal part of the Montecarlo section (Figs 3 and 8), a sporadic presence of molluscs is shown. Few specimens of *V. anconai, S. bronni, P. oblonga, P. ovata* and



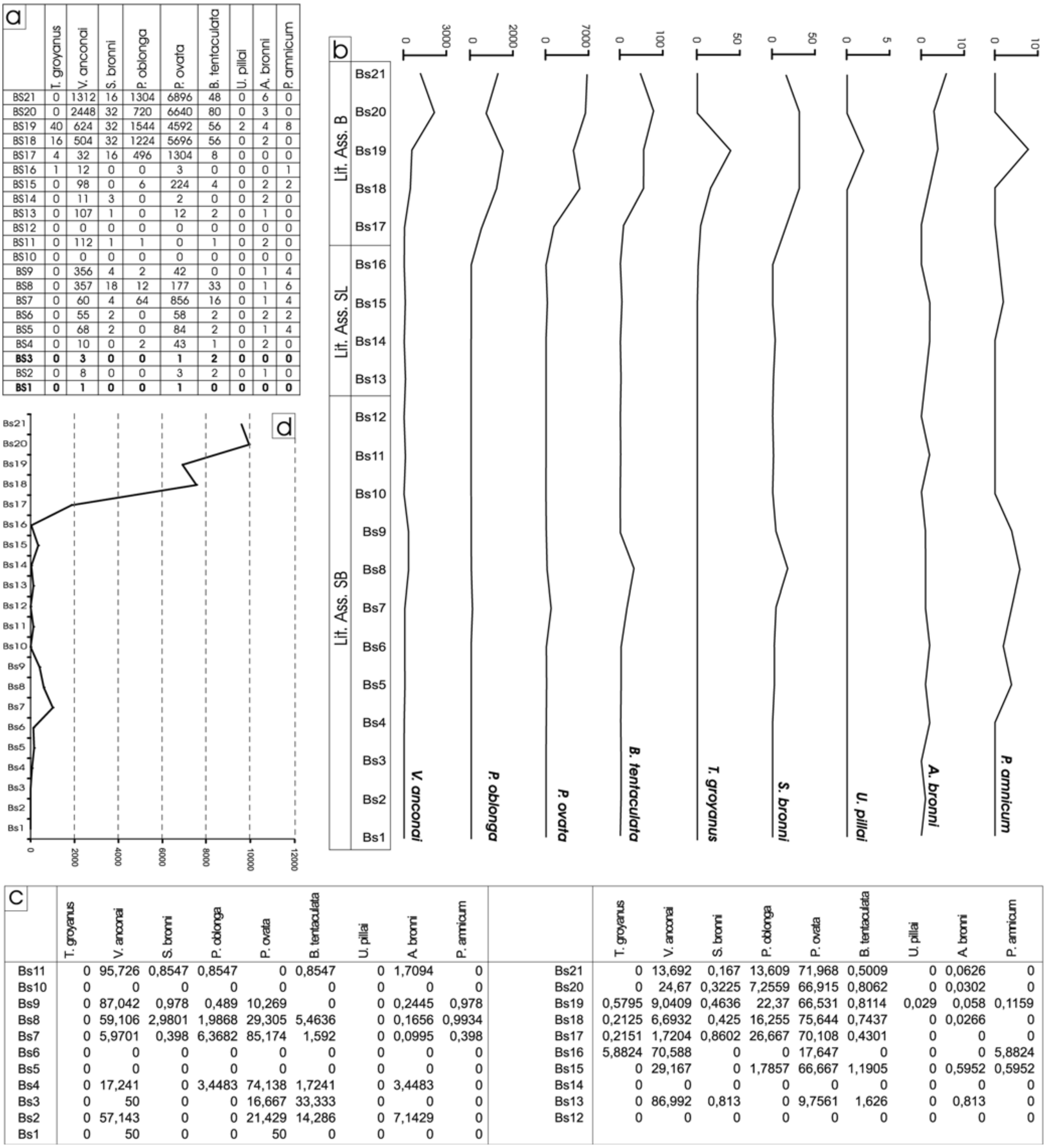
a

	T. groyanus	*V. anconai*	*S. bronni*	*P. oblonga*	*P. ovata*	*B. tentaculata*	*U. pillai*	*A. bronni*	*P. amnicum*
MC32	**0**	**70**	**2**	**300**	**200**	**10**	**0**	**5**	**0**
MC31	2	156	10	438	250	4	0	1	0
MC30	16	720	80	5648	3232	128	0	3	0
MC29	8	360	56	8008	3352	48	0	2	0
MC28	**0**	**300**	**50**	**6000**	**3000**	**50**	**0**	**3**	**0**
MC27	48	448	80	6720	3936	80	0	2	1
MC26	3	27	2	754	626	4	0	0	0
MC25	32	792	24	3712	5576	176	1	1	0
MC24	8	176	56	4256	4160	136	0	3	1
MC23	0	0	0	0	0	0	0	0	0
MC22	0	69	2	30	117	2	0	1	1
MC21	0	34	13	55	131	17	0	1	0
MC20	0	19	2	28	71	4	0	0	0
MC19	1	32	2	56	134	9	0	2	0
MC18	0	1	3	0	1	2	0	2	0
MC17	0	0	0	0	0	0	0	0	0
MC16	0	0	0	0	0	0	0	0	0
MC15	4	296	36	96	1304	15	0	0	0
MC14	0	132	25	17	98	107	0	0	1
MC13	2	10	3	5	9	1	0	1	0
MC12	**0**	**1**	**3**	**1**	**1**	**1**	**0**	**0**	**0**
MC11	**0**	**1**	**3**	**1**	**1**	**1**	**0**	**0**	**0**
MC10	0	68	15	1	18	1	0	2	2
MC9	0	12	3	0	0	1	0	0	0
MC8	0	31	5	0	0	2	0	0	0
MC7	0	30	0	0	13	2	0	0	0
MC6	0	16	1	0	0	1	0	1	0
MC5	0	1	2	2	2	1	0	1	0
MC4	0	1	2	2	0	1	0	1	0
MC3	0	1	5	5	2	1	0	1	0
MC2	0	0	1	14	4	1	0	1	0
MC1	0	0	0	1	0	0	0	0	0

c

	T. groyanus	V. anconai	S. bronni	P. oblonga	P. ovata	B. tentaculata	U. pillai	A. bronni	P. amnicum		T. groyanus	V. anconai	S. bronni	P. oblonga	P. ovata	B. tentaculata	U. pillai	A. bronni	P. amnicum
MC16	0	0	0	0	0	0	0	0	0	MC32	0	0	0	0	0	0	0	0	0
MC15	0,2284	16,905	2,056	5,4826	74,472	0,8567	0	0	0	MC31	0,2323	18,118	1,1614	50,871	29,036	0,4646	0	0,1161	0
MC14	0	34,737	6,5789	4,4737	25,789	28,158	0	0	0,2632	MC30	0,1628	7,3268	0,8141	57,474	32,889	1,3025	0	0,0305	0
MC13	6,4516	32,258	9,6774	16,129	29,032	3,2258	0	3,2258	0	MC29	0,0676	3,0421	0,4732	67,669	28,325	0,4056	0	0,0169	0
MC12	0	14,286	42,857	14,286	14,286	14,286	0	0	0	MC28	0	3,1905	0,5317	63,809	31,905	0,5317	0	0,0319	0
MC11	0	14,286	42,857	14,286	14,286	14,286	0	0	0	MC27	0,4242	3,9593	0,707	59,39	34,786	0,707	0	0,0177	0,0088
MC10	0	63,551	14,019	0,9346	16,822	0,9346	0	1,8692	1,8692	MC26	0,2119	1,9068	0,1412	53,249	44,209	0,2825	0	0	0
MC9	0	75	18,75	0	0	6,25	0	0	0	MC25	0,3103	7,6789	0,2327	35,99	54,062	1,7064	0,0097	0,0097	0
MC8	0	81,579	13,158	0	0	5,2632	0	0	0	MC24	0,091	2,0009	0,6367	48,386	47,294	1,5462	0	0,0341	0,0114
MC7	0	66,667	0	0	28,889	4,4444	0	0	0	MC23	0	0	0	0	0	0	0	0	0
MC6	0	84,211	5,2632	0	0	5,2632	0	5,2632	0	MC22	0	31,081	0,9009	13,514	52,703	0,9009	0	0,4505	0,4505
MC5	0	11,111	22,222	22,222	22,222	11,111	0	11,111	0	MC21	0	13,546	5,1793	21,912	52,191	6,7729	0	0,3984	0
MC4	0	14,286	28,571	28,571	0	14,286	0	14,286	0	MC20	0	15,323	1,6129	22,581	57,258	3,2258	0	0	0
MC3	0	6,6667	33,333	33,333	13,333	6,6667	0	6,6667	0	MC19	0,4237	13,559	0,8475	23,729	56,78	3,8136	0	0,8475	0
MC2	0	0	4,7619	66,667	19,048	4,7619	0	4,7619	0	MC18	0	11,111	33,333	0	11,111	22,222	0	22,222	0
MC1	0	0	0	100	0	0	0	0	0	MC17	0	0	0	0	0	0	0	0	0

Fig. 8 - Mollusc distribution along the Montecarlo section. The number of specimens of each species (a and b) and their percentage (c) is shown for each level, with the total amount of mollusc specimens along the entire section (d).



a	T. groyanus	V. anconai	S. bronni	P. oblonga	P. ovata	B. tentaculata	U. pillai	A. bronni	P. amnicum
BS21	0	1312	16	1304	6896	48	0	6	0
BS20	0	2448	32	720	6640	80	0	3	0
BS19	40	624	32	1544	4592	56	2	4	8
BS18	16	504	32	1224	5696	56	0	2	0
BS17	4	32	16	496	1304	8	0	0	0
BS16	1	12	0	0	3	0	0	0	1
BS15	0	98	0	6	224	4	0	2	2
BS14	0	11	3	0	2	0	0	2	0
BS13	0	107	1	0	12	2	0	1	0
BS12	0	0	0	0	0	0	0	0	0
BS11	0	112	1	1	0	1	0	2	0
BS10	0	0	0	0	0	0	0	0	0
BS9	0	356	4	2	42	0	0	1	4
BS8	0	357	18	12	177	33	0	1	6
BS7	0	60	4	64	856	16	0	1	4
BS6	0	55	2	0	58	2	0	2	2
BS5	0	68	2	0	84	2	0	1	4
BS4	0	10	0	2	43	1	0	2	0
BS3	**0**	**3**	**0**	**0**	**1**	**2**	**0**	**0**	**0**
BS2	0	8	0	0	3	2	0	1	0
BS1	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**

c	T. groyanus	V. anconai	S. bronni	P. oblonga	P. ovata	B. tentaculata	U. pillai	A. bronni	P. amnicum
Bs11	0	95,726	0,8547	0,8547	0	0,8547	0	1,7094	0
Bs10	0	0	0	0	0	0	0	0	0
Bs9	0	87,042	0,978	0,489	10,269	0	0	0,2445	0,978
Bs8	0	59,106	2,9801	1,9868	29,305	5,4636	0	0,1656	0,9934
Bs7	0	5,9701	0,398	6,3682	85,174	1,592	0	0,0995	0,398
Bs6	0	0	0	0	0	0	0	0	0
Bs5	0	0	0	0	0	0	0	0	0
Bs4	0	17,241	0	3,4483	74,138	1,7241	0	3,4483	0
Bs3	0	50	0	0	16,667	33,333	0	0	0
Bs2	0	57,143	0	0	21,429	14,286	0	7,1429	0
Bs1	0	50	0	0	50	0	0	0	0
Bs21	0	13,692	0,167	13,609	71,968	0,5009	0	0,0626	0
Bs20	0	24,67	0,3225	7,2559	66,915	0,8062	0	0,0302	0
Bs19	0,5795	9,0409	0,4636	22,37	66,531	0,8114	0,029	0,058	0,1159
Bs18	0,2125	6,6932	0,425	16,255	75,644	0,7437	0	0,0266	0
Bs17	0,2151	1,7204	0,8602	26,667	70,108	0,4301	0	0	0
Bs16	5,8824	70,588	0	0	17,647	0	0	0	5,8824
Bs15	0	29,167	0	1,7857	66,667	1,1905	0	0,5952	0,5952
Bs14	0	0	0	0	0	0	0	0	0
Bs13	0	86,992	0,813	0	9,7561	1,626	0	0,813	0
Bs12	0	0	0	0	0	0	0	0	0

Fig. 9 - Mollusc distribution along the Borrassole section. The number of specimens of each species (a and b) and their percentage (c) is shown for each level, with the total amount of mollusc specimens along the entire section (d).

B. tentaculata, along with the bivalve *A. bronni*, occur in this portion. From MC 6 to MC 10 a slight increase in the number of specimens of the same species is registered among which *V. anconai* is dominant. From MC 11 to MC 12 the total number of specimens drops sharply. A similar distribution of molluscs is registered in the lower part of the Borrassole section (up to BS6) (Figs 3 and 9); poor remains of shells, followed by a slight enrichment in specimens and by the dominance of *V. anconai*, occur.

This first portion, showing a low mollusc content in both sections, is entirely represented by lithofacies association SB, characterised by a dominance of lithofacies s4 with respect to s1 and s2 lithofacies.

Interval 2 (5.5 – 6.5m MC; 8 – 10.5m BS). From MC 13 to MC 15, middle part of the Montecarlo section, a considerable rise in the number of specimens occurs like in the Borrassole section from BS7 to BS9. Two species, *V. anconai* and *P. ovata*, prevail, the latter reaching more than 850 specimens per dm^3 in both sections with a percentage of 74.4% and 85.1% respectively. *P. oblonga* and *B. tentaculata* also increase. The occurrence of *T. groyanus*, even if at a very low percentage, is recorded in this interval only in the Montecarlo section. Barren sediments occur from MC 16 to MC 17 and at BS10 and BS12.

This second portion, as with the previous one, is represented by lithofacies association SB (Fig. 3), even if lithofacies s1 and s2 prevail over lithofacies sl and s4.

Interval 3 (6.5 – 8.5m MC; 10.5 – 12m BS). From MC 18 to MC 22 and from BS13 to BS16, middle-upper part of the two sections, the total number of specimens increases again, but with lower value than in the previous interval reaching only 261 specimens at Montecarlo and 336 at Borrassole. The prevalence of *P. ovata* (up to 57%) and a good percentage of *P. oblonga* (23.7%) and *V. anconai* (15.3 up to 31%) at Montecarlo and the prevalence of *V. anconai* (up to 86%) along with a low percentage of *P. oblonga* at Borrassole, suggest local environmental variation. At MC 23 a barren layer occur.

This portion corresponds to lithofacies association SL and SB, whereas the last one is dominated by lithofacies sl.

Interval 4 (8.5 – 11m MC; 13 – 14.5m BS). From MC 24 to MC 32 and from BS17 to BS21, upper part of the two sections, a very high number of specimens (more than 9.900 per dm^3 in some levels) occurs. Alternatively *P. oblonga* and *P. ovata* are dominant. *T. groyanus,* occurring for the first time in both sections, displays a continuous presence, even if with a low percentage (maximum 0.5%). Among the bivalves, *A. bronni* shows a constant scarce presence, while *U. pillai* and *P. amnicum* are scattered in the two sections.

This portion very rich in molluscs corresponds to lithofacies associations B and SB, where SB is dominated by lithofacies s2.

A slight decrease in the total number of specimens is seen in the last two levels at the top of the Montecarlo section, where lithofacies sl is more common.

Species autoecology

The ecological requirements of the recorded molluscs can be deduced from the present-day habitat of still-living close relatives, or from the palaeoenvironmental context of similar fossil assemblages.

Theodoxus groyanus. The extant representatives of this genus live in running waters in rivers or streams on hard surfaces (Killeen 1992); fossil remains of *T. groyanus* generally characterise Late Pliocene or Early Pleistocene low-energy fluvial deposits from Italy (Ponte Naja Unit at Toppetti quarry, Todi, Ciangherotti 1997, Gliozzi et al. 1997; Santa Maria di Ciciliano Fm., Umbria, Ambrosetti et al. 1995; Girotti et al. 2003).

Stephania bronni. The ecology of *S. bronni* is not well known, being an endemic species confined in the sedimentary successions under investigation to the Valdarno basin.

Bithynia tentaculata. It inhabits lakes, ponds, marshes, meanders and ditches, preferring stagnant water up to 25-30 m deep (Girod et al. 1980).

Prososthenia oblonga and *Prososthenia ovata.* Both became extinct in the Early Pleistocene; they are frequently recorded in Plio-Pleistocene fluvio-lacustrine deposits of central Italy (Umbria and Tuscany), often in oligotypical assemblages with species preferring slow current water, such as *T. groyanus* or the genus *Anodonta* (Esu & Girotti 1991; Caredio et al. 1995; Benvenuti et al. 1998).

Valvata anconai. The species of the genus *Valvata* are found in a variety of aquatic habitats, preferring flowing oxygenated waters or occasionally ponds or lakes with slow currents (Girod et al. 1980; Killeen 1992); the ecology of *V. anconai* is not well-defined, this species being very scattered in fossil assemblages of central Italy (Esu & Girotti 1974; Ciangherotti et al. 1998).

Anodonta bronni. The living species of *Anodonta* are inhabitants of rivers with slow-flowing waters, canals, lakes and large ponds, with sandy or muddy bottom, up to 20 m deep (Killeen 1992).

Unio pillai. The ecology of this species is deduced from the living congeners which inhabit fluvial and channel environments.

Pisidium amnicum. It is widely distributed in rivers and channels and in nearly all freshwater bodies (Killeen 1992).

Palaeoenvironmental interpretation

The irregular distribution of molluscs detected in the two sections seems to be regulated by a cyclic depositional pattern which points to a high degree of instability of the depositional environment. The alternating concentrations of molluscs through the sedimentary succession are probably due to recurrent floods. Indeed, the molluscs were not recorded in life position, and towards the top broken shells occur. Moreover, the oligotypical character of the recorded assemblages characterises restricted or unstable environments subjected to sharp changes in ecological or physical parameters, such as climatic variations or oscillations in water level.

The ecology of the recorded aquatic molluscs points to shallow-water systems, such as canals, streams or large ponds, dominated by slow-flowing oxygenated water, sometimes subjected to higher hydrological regime.

In the Montecarlo section a trend toward a major expansion of the water bodies and higher water energy can be registered from base to top on the basis of the ecological meaning of the assemblages. A similar trend can be recognised in the Borrassole section (Figs 8 and 9).

In the basal part of the two sections the poor recorded malacological assemblages are representative of a very shallow-water body with slow-flowing water. The dominance of a representative of the genus *Valvata* in the overlying layers at Montecarlo, and *P. ovata* at Borrassole, both requiring more oxygenated water, point to a greater influx of flowing waters. The middle part of the two sections (MC13-MC15, BS7-BS9) characterised by the dominance of flowing-water species, such as *P. ovata* and *V. anconai*, points to an oxygenated aquatic environment. In particular the occurrence of *Theodoxus* and *Pisidium*, loving current water, and the low percentage of *B. tentaculata*, which prefers more stagnant water bodies, confirms such environmental conditions. In the middle-upper part (MC18-MC22 and BS13-BS15) a moderate rise in specimens, and the prevalence at Montecarlo of *P. ovata* and *P. oblonga* along with a high percentage of *V. anconai,* point to a slight increase of the water body. At Borrassole, a more unstable aquatic environment is registered by a discontinuous increase in the molluscs. Since the composition of the assemblages in the two sections is very similar, local variations in the water energy can be deduced. In the uppermost part of the two sections (MC24-MC30; BS17-BS20), characterised by a very high number of specimens, the dominance of *Prososthenia*, along with the occurrence of the reophilous *T. groyanus*, which was very scarce or absent in the middle and lower part of the two successions, points to more oxygenated and free-flowing waters. An increase in the amount of water can be deduced from the very rich recorded assemblages and from the constant presence of the bivalve *Anodonta*, preferring major water bodies, in both the successions. The topmost of the two section is characterised by a decrease in the number of specimens.

In conclusion, taking into account the dominance of species characterising slow-flowing waters throughout both sections, the life environment of the molluscs would have been a channel or a stream-water system with prevailing slow-flowing shallow water in the lower part, and more oxygenated and persistent water bodies in the upper part, probably due to a more humid climate. The molluscs from such an environment were accumulated by recurrent floods in an alluvial plain.

Biochronological remarks. Freshwater mollusc species from Montecarlo Valdarno are mentioned by Bronn (1831), D'Ancona in Cocchi (1867), D'Ancona (1869) and De Stefani (1876-80) as coming from "lacustrine sediments at Montecarlo and at Figline, near S. Giovanni, Upper Valdarno" and ascribed to the Pliocene. The historical authors gave the following list of molluscs: "*Neritina bronni (= T. groyanus), Viviparus ampullaceus, Valvata anconae, Valvata bronni (= S. bronni), Bithynia bronni (= B. tentaculata), Melania (= Prososthenia) oblonga, Melania (= Prososthenia) ovata, Anodonta bronni*, *Unio pillae*, *Pisidium priscum (= P. amnicum)*". In the 1970s Esu & Girotti (1974) collected and described new mollusc samples from the non-marine sandy and silty deposits cropping out at Borro ai Frati, at the foot of the Montecarlo monastery, which yielded the same species as listed by the ancient authors, with the exception of *V. ampullaceus* and *P. amnicum*, probably due to local variations since in the Geological Museum "G. Capellini" of Bologna some specimens of *V. ampullaceus* from Poggio ai Frati (Montecarlo) are stored (ancient collection).

The recorded extinct species were endemic to the continental Plio-Pleistocene basins of central Italy (Upper Valdarno, Val di Chiana, Tiberino basin and Sabina valleys), ranging from Late Pliocene to Early Pleistocene in age; only *P. ovata* is known since the Late Miocene of Tuscany (Esu & Girotti 1974; Petronio et al. 2003). In particular, *S. bronni* seems localised in Upper Valdarno and *A. bronni* in Upper Valdarno and Val di Chiana (De Stefani 1876-80, Esu & Girotti 1991). Ciangherotti et al. (1998), reviewing the Italian Plio-Pleistocene non-marine mollusc fauna, gave a biochronological scheme of the most significant assemblages of non-marine molluscs from Italy, calibrated using data from vertebrate faunas, palaeomagnetic stratigraphy, and correlation with marine stratigraphy of selected fossiliferous stratigraphical sections. In this scheme the freshwater malacological assemblages recorded from the Montecarlo Sand and Silt Unit are proposed to be Late Pliocene in age, on the basis of their comparison with other aquatic assemblages from upper Pliocene deposits of Umbria, such as the Fosso Bianco section (Montecastrilli), the Ponte Naja Unit (Todi) and Dunarobba (Avigliano Umbro). The temperate climatic indications yielded by the mollusc assemblages from Montecarlo suggest they pertain to the more humid and temperate phase following the cold phase of about 2.6-2.4 Ma (Rio et al. 1994), indicated also by pollen analyses carried out on the San Donato Sands Unit (uppermost part of the Castelnuovo Synthem) by Albianelli et al. (1995) which are referred to the top of Gauss (about 2.6 Ma). The radiometric date of 2.25 Ma obtained recently from the ash layer occurring at the base of the Terranuova Silt Unit overlying the Montecarlo Sand and Silt Unit (Ghinassi et al. 2004) confirms such a hypothesis.

Fishes

In the Montecarlo hill area, several fish remains were collected from the Montecarlo Unit, and four different taxa and three different families of Teleosts were recognised.

The most abundant remains – mainly pharyngeal teeth and pharyngeal bones (Pl. 2, Fig. 1) – indicate the occurrence of the tench, *Tinca* sp. (Family Cyprinidae). Additionally, less abundant isolated pharyngeal teeth and some pharyngeal bones demonstrate the occurrence of a second Cyprinid genus: *Scardinius* Bonaparte, apparently represented by its recent species *Scardinius erythrophthalmus* (L.) (Pl. 2, Fig. 2).

Cephalic bones belonging to a salmonid have also been collected. Among them, a vomer (Pl. 2, Fig. 3), a maxillary, an incomplete dentary and an angular belong to the recent genus *Salmo* L. and, more precisely, to the species *Salmo trutta* L., as shown by the characteristic triangular outline of the anterior part of the vomer and by the occurrence of two irregular longitudinal rows of conical teeth on the ventral surface of this bone.

Finally, several vertebrae – among them some abdominal ones bearing very characteristic parapophyses (Pl. 2, Figs 4-5) – bear witness to a Mugilid.

Palaeoecological remarks and palaeoenvironmental interpretation. The first impression provided by the fish remains found in the Late Pliocene of Montecarlo is related to their taxonomic heterogeneity, which seems to be indicative of transportation, sorting and mixing of bones from fishes with different palaeoecological requirements.

According to the biology of the only living species of tench, *Tinca tinca* (L.), which is mainly distributed in Europe and Western Siberia, the occurrence of the genus *Tinca* Cuvier at Montecarlo is indicative of quiet, muddy fresh waters with rather rich subaquatic vegetation (Tortonese 1970). However, it was more widely distributed than *Tinca tinca* (L.), as it lived not only in lakes, ponds and swampy areas, but also in slow-moving rivers; *Scardinius erythrophthalmus* (L.) also prefers muddy bottoms and waters invaded by a submerged vegetation.

The third component of the fish fauna found at Montecarlo is a trout, *Salmo trutta* L. Trouts are fishes that are able to live mainly in the upper reaches of rivers, in streams, and also lakes having waters with high contents of dissolved oxygen. At present in Southern Europe, the trouts are only exceptionally migrating to the sea, although some specimens are occasionally found in the Ligurian, Tyrrhenian and Adriatic seas. Although the lake trouts are mainly present in Alpine lakes, it should be noted that they are also present in some plain lakes such as Lake Bracciano, near Rome (Tortonese 1970). The occurrence at Montecarlo of isolated cephalic bones of trouts can be interpreted, in relation to information provided by molluscs, as indicating the presence in the Valdarno area of small rivers flowing down from the Apennines, the waters of which were comparatively rich in oxygen.

The last identified taxon belongs to the primary marine family Mugilids. However, its occurrence at Montecarlo can be understand if we consider that several of the species that presently live in the Mediterranean - *Mugil cephalus* L. and *Liza ramada* (Risso) – can easily adapt to fresh waters, entering the lower reaches of rivers and even durably living in land-locked continental waters, like Trasimeno lake (Tortonese 1975).

To conclude, the fish remains collected at Montecarlo should clearly be considered as components of a thanatocoenosis, because *Salmo trutta* L. has ecological requirements that strongly differ from those of the three other identified genera of fishes. Additionally, it should be emphasized that the occurrence of a taxon belonging to a primary marine family (Mugilids) throws little doubt over the continental origin of this material, although it may suggest the occurrence of a river connection between the Valdarno area and the sea.

Biochronological remarks. The very low evolutionary rate of Teleosts does not allow any chronostratigraphical deductions from the composition of the Montecarlo fish fauna. Additionally, it should be noted that information concerning the Villafranchian fish fauna of Europe is rather scarce, as is related mainly to the Early Villafranchian of Hajnacka, (Slovakia – Obrhelovà 1970) and the late Middle Villafranchian of Tegelen (the Netherlands) (Gaudant 1979). In both localities the genera *Tinca* and *Scardinius* had already been identified.

Mammals

Two incomplete right mandibles (n. 1 and 2; Fig. 10), belonging to a representative of the rodent family Arvicolidae, have been found within the Montecarlo Sand and Silt Unit in a horizon correlatable to the lower part of the Montecarlo section. These remains testify to the occurrence of a large sized and fairly hypsodont *Mimomys* (see Tab. 2); they are here ascribed to the species *Mimomys polonicus* Kowalski.

M. polonicus belongs to the evolutionary lineage of the large sized water-voles common during the Middle Pliocene-Early Pleistocene p.p: *M. hassiacus (= hajnackensis*, after Fejfar et al. 1998)-*M. polonicus-M. pliocaenicus-M. ostramosensis-M. savini* (Fejfar & Heinrich 1982; Chaline and Laurin 1984; Chaline & Sevilla 1990; Viriot et al. 1990; Koenigswald 1993; Fejfar 2001). The occurrence of these species characterises the Villanyian and Biharian units, according to the Plio-Pleistocene small mammal ages (Fejfar & Heinrich 1990).

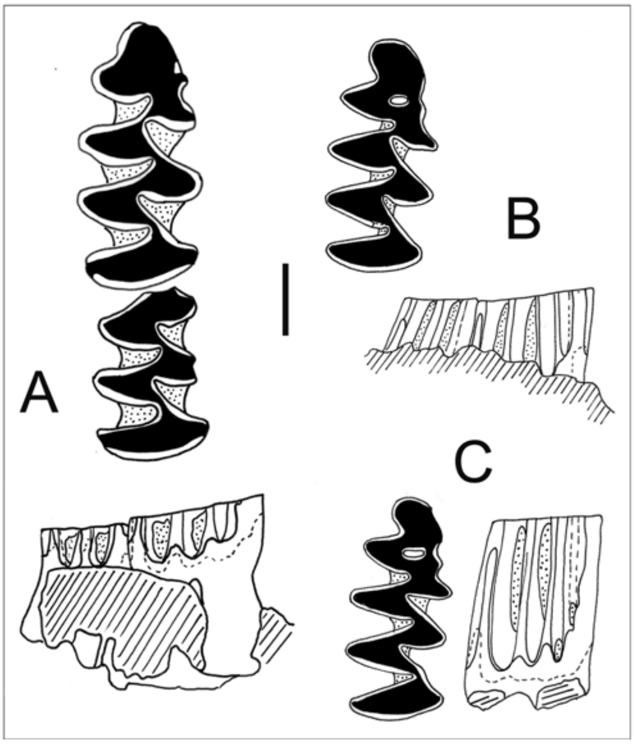


Fig. 10 - *Mimomys polonicus* Kowalski, 1960 from Montecarlo: (A) specimen 2, occlusal and labial views; (B) specimen 1, occlusal and labial views and (C) occlusal and labial views of *M. polonicus* from the type locality Rebielice Krolewskie 1. Scale is 1 mm.

Taxa	L	ACC	W	A/L
M. polonicus n. 1	3,24	1,35	1,41	41,67
" n. 2	3,73	1,32	1,41	35,39

Tab. 2 - Measurements of lower first molars (M_{1s}) of specimens 1 and 2 of *Mimomys polonicus* from Montecarlo. L=occlusal length; ACC=length of anteroconid; W= occlusal width.

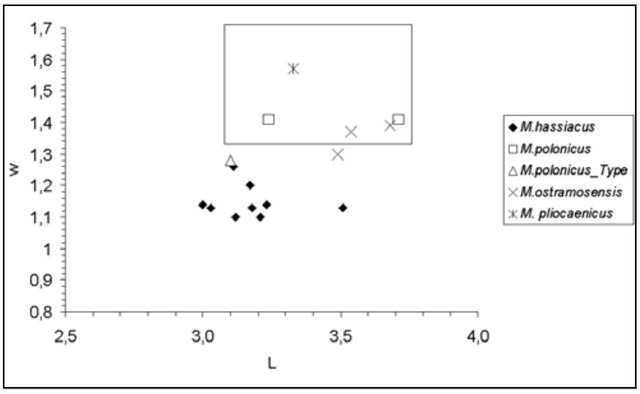


Fig. 11 - Scatter diagram of occlusal length *vs* width of M_{1s} of some large-sized *Mimomys.*
Data for *M. hassiacus* are from Arcille site (stored in the Department of Earth Sciences of Florence); data for *M. pliocaenicus* are the average values of the sample from Tegelen - for this sample the dispersal field of both measurements has been reported (rectangular area) (from Tesakov 1998); data for *M. polonicus* are from a specimen from the type locality Rebielice Krolewskie 1; data for *M. ostramosensis* are from samples from the Polish localities Kadzienlia and Kamyk.

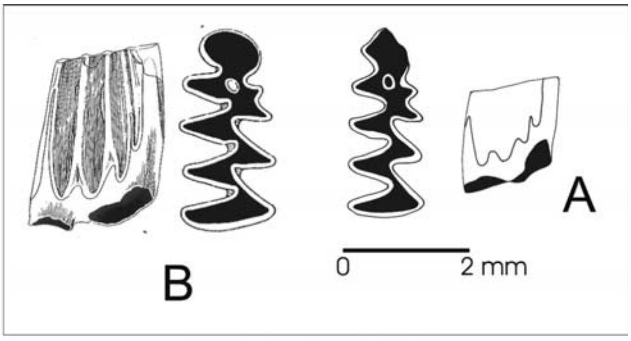


Fig. 12 - (A) *Mimomys hassiacus* from Arcille, redrawn from Masini & Torre (1987); (B) *Mimomys polonicus* from Les Etouaires, redrawn from Fejfar et al. (1998).

The evolution of these *Mimomys* involves the development of high-crowned teeth with increasing height of the sinuids of the linea sinuosa, the occurrence and increase of dental cement in the re-entrant angles, and the progressive disappearance of enamel islet and *Mimomys*-kante (the terminology follows the scheme of Van der Meulen 1973). The acquisition of the above features has been considered as induced by the climatic changes that modified the vegetation patterns during the Middle-Late Pliocene and that determined the adaptation of this rodent to feed more abrasive food.

The characteristics displayed by the *Mimomys* from Montecarlo indicate a grade of evolution that is comparable to that reached by the late Middle-Late Pliocene species *M. polonicus* (Kowalski 1960). As a matter of fact, our specimens are distinct from *M. hassiacus* from Arcille (Early Villanyian, Middle Pliocene; Masini & Torre 1987; Maul et al. 1998) in some aspects: the size, in particular the dental width, is fairly large (Fig. 11) and, although not directly measurable since the teeth are inserted in the mandible, the dentine tracts of the linea sinuosa are more elevated, suggesting higher hypsodonty (Fig. 12).

On the other hand, with respect to the late Villanyian species *M. pliocaenicus* (Late Pliocene; e.g. from Castelfranco di Sopra type locality, and from Tegelen, Tesakov 1998), the remains from Montecarlo denote a more primitive evolutionary degree, being less hypsodont and with less cement. Montecarlo specimens are also distinct, being more primitive, from *M. medasensis,* another Late Villanyian large-sized *Mimomys*, endemic to southern Mediterranean regions (Michaux 1971; Esteban Aenlle & Lopez Martinez 1987; cf. Kotsakis et al. 2003), considered as very close to *M. pliocaenicus* and *M. ostramosensis.*

Biochronological and palaeoecological remarks. The occurrence of *M. polonicus* in the deposits of Montecarlo is a novelty for the whole Italian peninsula, if we exclude the doubtful presence of this large vole from the locality Bocchignano (Latium, Central Italy, cf. Kotsakis et al. 2003). Moreover, no other small mammals characterising the *Mimomys polonicus* zone of the early Villanyian age have been found in Italy. The *Mimomys polonicus* zone has been correlated to the Montopoli faunal unit (late part of Early Villafranchian) and to the Middle Villafranchian (MN16b unit of Mein 1990) of the large mammal biochronological schema, and roughly corresponds to the time interval from 2.9 Ma to 2.3 Ma (Fejfar & Heinrich 1990).

M. polonicus from Montecarlo confirms the presence within the Upper Valdarno of mammals typical of the Early-Middle Villafranchian, as suggested by the occurrence of mastodont remains referred to *Anancus arvernensis* (stored in the Paleontological collection of the Natural History Museum of Florence). *A. arvernensis* vanished at the so-called "wolf-event" which defines the Olivola faunal unit of the beginning of the Late Villafranchian (latest Pliocene). Unfortunately, the exact provenance of these fossils is unknown however, they came from the vicinity of the Montecarlo convent, where deposits of the Rena Bianca and Montecarlo units crop out (Ghinassi et al. 2004; Ghinassi & Magi 2004).

The remains from Montecarlo increase, at least, the poorly documented record of arvicolids in this area. Indeed, notwistanding the rich large mammalian faunas from the Plio-Pleistocene deposits, which contributed to the definition of Italian biochronological units (e.g. Villafranchian Mammal age; Azzaroli 1977; Torre et al. 1993), the rodent findings in such sediments are extremely scarce, due to taphonomic bias. The type specimen of the Late Pliocene species *Mimomys pliocaenicus* is reported from Castelfranco di Sopra, *M. savini* occurs at Le Strette del Tasso (Early Biharian/Late Villafranchian, Early Pleistocene), and *Arvicola mosbachensis* (= *cantianus* according to Maul et al. 2000) is described from Middle Pleistocene deposits (Torre 1985; Masini & Torre 1987).

As regards the palaeoecological reconstruction, the occurrence of this large *Mimomys* is interpreted as suggestive of the presence of open waters; however, its remains are also found in limnic/paludal environments (cf. Fejfar 2001).

Discussion

The multidisciplinary approach shown in the previous sections allows the definition of a detailed paleoenvironmental setting for the Montecarlo Sand and Silt Unit.

The vertebrate and molluscan assemblages point to a persistent, shallow fresh-water system characterised by oxygenated waters, rich in subaquatic vegetation. The occurrence of specimens testifying to prevailing standing waters (such as *Tinca tinca* and *Scardinius erythrophthalmus* among fish, and *Bithynia tentaculata* among molluscs) with specimens related to flowing waters (*Salmo trutta* among fish and *Theodoxus groyanus*, *Unio pillai* and *Pisidium amnicum* among molluscs) suggest the coexistence of two main sub-environments, and a "post-mortem" mixture of different organism remains. The occurrence of highly sediment-charged flows, combined with the lack of life-position bivalves and the presence of numerous broken shells, strongly support the hypothesis of transport and reworking of organic remains before final deposition.

Despite sedimentological data fit with an alluvial plane depositional setting, the lacking of distinctive features (i.e. coarser-grained channelized deposits or crevasse deposits), prevent a totally reliable interpretation. In this framework, we suggest that the Montecarlo Unit was deposited in a flood-basin (Pole 2001) environment, characterised by a high sedimentation rate, according with the scarce vegetation growth. Shell and fish remains probably accumulated along the banks of slow-flowing channels (Farrell 2001), and were successively picked up during flood events, because of the erosion of banks, and deposited in the overbank areas (Hjellbakk 1997; Jones et al. 2001). The lacking of coarse-grained lithofacies feeding the Montecarlo Sand and Silt Unit could be due to the erosion of up-current lithofacies close to the SE margin, because of the development of a progressive unconformity at the top of the unit (Ghinassi & Magi 2002, 2004).

Facies architecture of the study sections (1.2 km far) show that the Montecarlo Unit is characterized by a recurrent stacking of lithofacies associations. The lower portion of the unit is mainly formed by lithofacies association SB, whereas the middle one consists of prevailing lithofacies association SL, with subordinate SB. The uppermost part is mainly formed by lithofacies association B. On the basis of these sedimentological features and mollusc assemblages, two main episodes, showing an upwards increase in erosive competence of flows and mollusc content, can be recognised. The first episode is from the base up to 6.6 m in the Montecarlo section, and from 4 m to 10.5 m in the Borrassole section, and is entirely represented by lithofacies association SB. This episode is characterised by an upwards decrease in the frequency of lithofacies s4 (pointing to sand winnowing in shallow ponds), with a parallel increase in occurrence of lithofacies s2 (indicating growing turbulence of flows) and shell content. The second episode is placed from 6.6 m up to 11 m in the Montecarlo section, and from 10.5 m to 14.7 m in the Borrassole section, and is represented by lithofacies associations SL and B. The second event shows an upwards decrease in pond-related deposits (lithofacies sl), linked to an increase in frequency of turbulent flood emplacement (lithofacies bc) and shell content.

Intermontane basins of the Northern Apennines (such as the Upper Valdarno Basin) were characterized by numerous different depositional settings, extremely variable in space and time (Martini & Sagri 1993). The occurrence in the Montecarlo unit of a recurrent stacking of the lithofacies association over extended areas suggests a depositional evolution mainly driven by basin-scale factors rather than local factors. Arid climatic conditions, developed by the interaction between a global climatic deterioration (Shackleton et al. 1995; Raymo et al. 1992; Thunell 1979; Zagwijn 1974; Martini et al. 2001) and local orographic factors (Ghinassi et al. 2004), drove the development of fluvio-aeolian depositional environments in the Upper Valdarno Basin at the Middle-Late Pliocene transition. The fluvio-aeolian unit (Rena Bianca Sand) grades upwards into the Montecarlo Sand and Silt Unit, and is characterized by the stacking of sandy deposits pertaining to short-lived climatic oscillations, from arid to less arid conditions ("wet-dry-wet" cycles in Ghinassi et al. 2004).

In the Montecarlo unit, the presence of episodes showing regular changes in moisture of the depositional setting (Fig. 13) could be explained as short-lived climatic oscillations similar to those of the underlying Rena Bianca Sand, but acting in more temperate climatic conditions. The lower portion of each cycle is characterised by the emplacement of flood flows (lithofacies s1, s2, s3) in shallow permanent ponds (lithofacies s4 and sl), whereas the upper portion indicates the spreading of high-energy flood flows (lithofacies s2 and bc) on subaerial surfaces or very shallow ponds. The lower portion could represent the "wet" stage of the cycle, with proliferation of molluscs in flowing waters, and pond development in shallow depressions. Mollusc remains were transported in ponds during flood events. The upper part could be related to the "dry" stage of the cycle, with decreasing moisture of the depositional setting, desiccation of ponds and channels, mortality of molluscs, and reworking of abundant shells during the occasional high-energy flash-floods. Following this hypothesis, the occurrence of silty lithofacies at the top of the Montecarlo section, just above the bioclastic deposits (lithofacies association B), could be interpreted as the re-establishment of "wet" conditions, heralding the beginning of fluvio-palustrine deposition of the Limi di Terranuova unit (Albianelli et al. 1995; Bertini & Roiron 1997). On the basis of previous considerations, the Montecarlo unit could testify to the shifting of flood-basin deposits, from ephemeral stream settings (Rena Bianca Sand) towards fluvio-palustrine environments

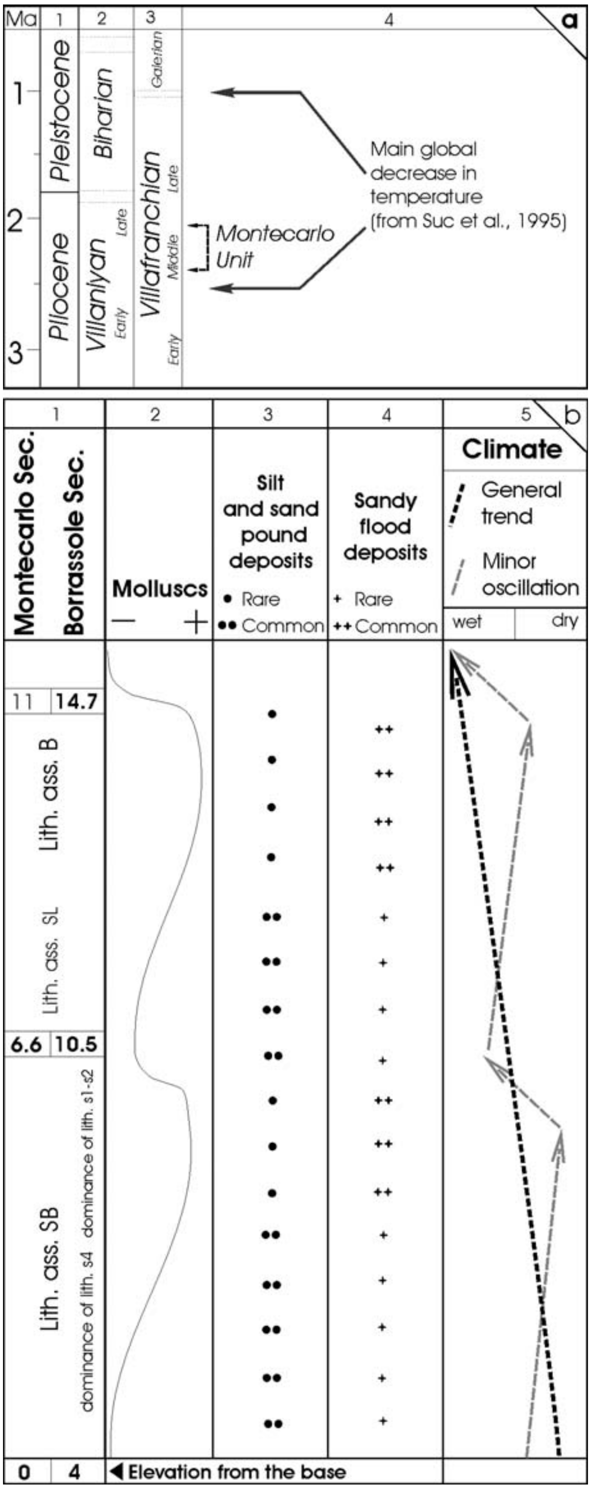


Fig. 13 - Middle Pliocene to Middle Pleistocene geochronology (a1), Mammal ages according to the small mammal biochronological scheme of Fejfar & Heinrich 1990 (a2), Mammal ages according to the large mammal biochronological scheme of Gliozzi et al. 1997 (a3), and Montecarlo Unit chronological position with respect to major global climatic changes (a4). Summarising sketch of the Montecarlo Unit framework: (b1) lithofacies association distribution; (b2) mollusc content changing; (b3) distribution of lithofacies testifying to deposition in lakes and ponds; (b4) distribution of lithofacies testifying to deposition by floods; (b5) simplified model explaining climatic changes driving the Montecarlo Unit depositional evolution.

(Terranuova Silt), driven by a global increase in temperature at around 2.4-2.2 Ma (Shackleton et al. 1995; Raymo et al. 1992).

Studies carried out on the vertebrate assemblage of the Montecarlo Unit allow us to report the occurrence an evolved form of *Mimomys polonicus* in the Italian peninsula, and to give, for the first time since Simonelli (1888), a detailed description of the fish fossil assemblages. The fish assemblage reveals itself to be a good palaeoenvironmental indicator in agreement with the molluscan assemblage. In particular, the occurrence of a taxon belonging to a primary marine family (Mugilids) is an important discovery for the palaeogeographical setting of the Upper Valdarno Basin. Bartolini & Pranzini (1981) only supposed the presence of a basin emissary during the Middle Pliocene on the basis of geological data, whereas the occurrence of Mugilids, even if easily adaptable to fresh water, implies the presence of a temporary connection between the basin and the sea at around 2.2 Ma (or before).

The most relevant result to emerge from the occurrence of vole *Mimomys polonicus* is biochronological. Indeed, this species characterised the mammal faunas of Middle-Late Pliocene age, and defines the homonymous unit of Early Villaniyan Mammal Age. The presence of this species is moreover in agreement with the mastodont remains (*A. arvernensis*) from an unknown site in the Montecarlo area, and allows confirmation of the occurrence of latest Early-Middle Villafranchian faunal assemblages in the Montevarchi synthem.

Conclusions

The main results of this study can be summarised as follows:

- In the Upper Valdarno Basin, sandy deposits occur, ranging in age between 2.4 and 2.2 Ma and containing abundant mollusc and fish remains. Molluscan and fish assemblages testify to quiet, shallow, oxygenated waters, locally rich in subaquatic vegetation, such as small alluvial channels. Sedimentological and palaeontological analyses allow us to relate these fossil-rich deposits to a flood-basin environment, characterised by the frequent deposition of flood events carrying abundant shells and fish remains from the nearby channels.
- Changes in sedimentological characteristics and mollusc abundance in the Montecarlo Sand and Silt Unit indicate a paleo-environmental evolution driven by an increase in water content of the system. Chronological and stratigraphic evidence helps to explain this change in terms of climatic transition from dry (underlying fluvio-eolian deposits) to wet conditions (overlying fluvio-palustrine sediments) which pertained to global climatic warming (Bertini 1994; Suc et al. 1995). Two minor climatic oscillations, from moderately dry to relatively wet conditions, drove this major change.
- The occurrence of *Mimomys polonicus* from a horizon correlatable to the lower part of the Montecarlo section is in agreement with the correlation of these deposits to a time interval preceding the Reunion paleomagnetic event.
- In the fish assemblage, the occurrence of a taxon belonging to a primary marine family (Mugilids) testifies to the presence of a basin emissary during the Middle Pliocene.

The picture derived from the present multidisciplinary study is coherent, with paleomagnetism, radiometric dates and mammal biochronology, all consistent with a referral of the fossiliferous horizon to a time interval preceding the Reunion paleomagnetic event.

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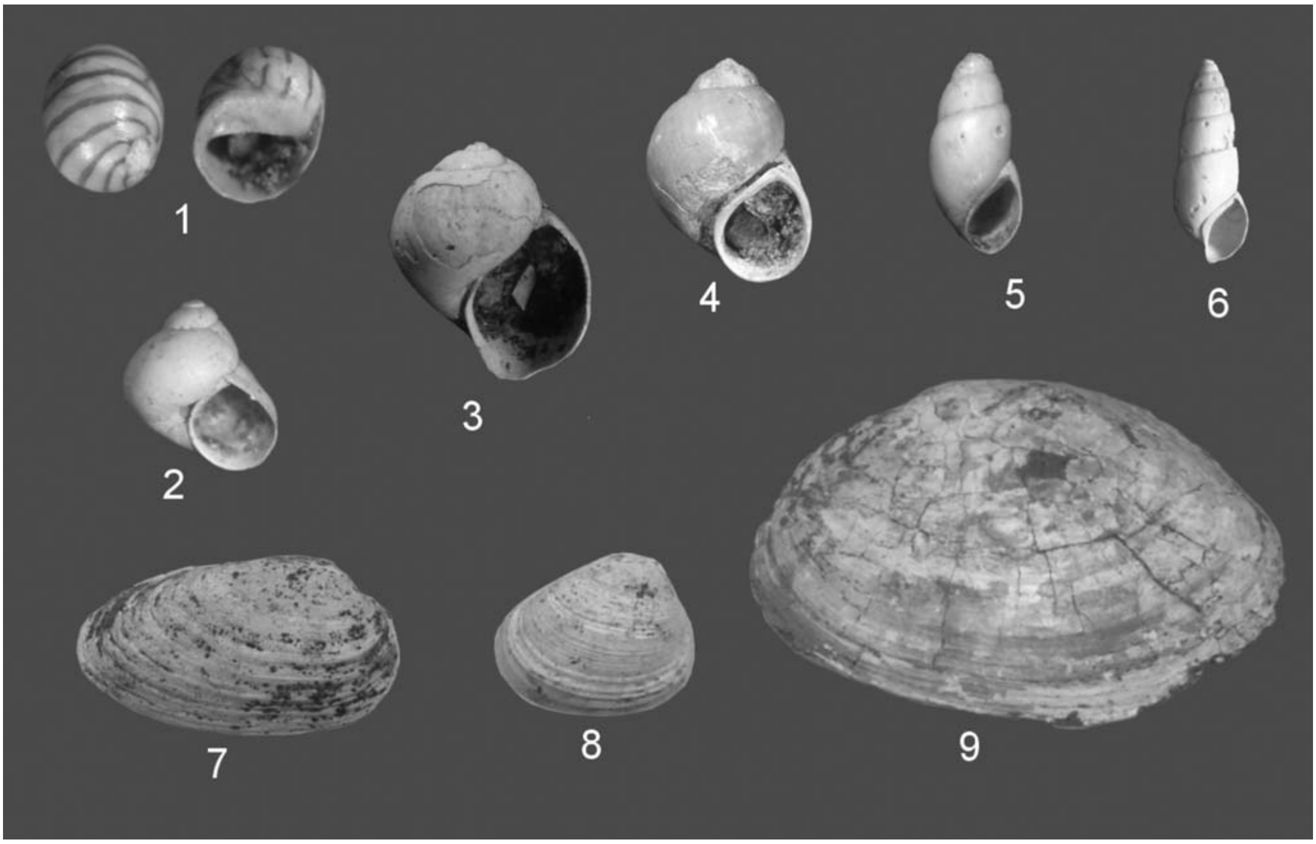

PLATE 1

Non-marine molluscs from the Montecarlo Sand and Silt Unit. Fig. 1 - *Theodoxus groyanus* (Férussac) 2x. Fig. 2 - *Valvata anconai* De Stefani 2x. Fig. 3 - *Stephania bronni* (D'Ancona) 1x. Fig. 4 - *Bithynia tentaculata* (Linné) 2x. Fig. 5 - *Prososthenia ovata* (Bronn) 3x. Fig. 6 - *Prososthenia oblonga* (Bronn) 2x. Fig. 7 - *Unio pillai* De Stefani 0.7x. Fig. 8 - *Pisidium amnicum* (Müller) 3.5x. Fig. 9 - *Anodonta bronni* D'Ancona 0.7x.

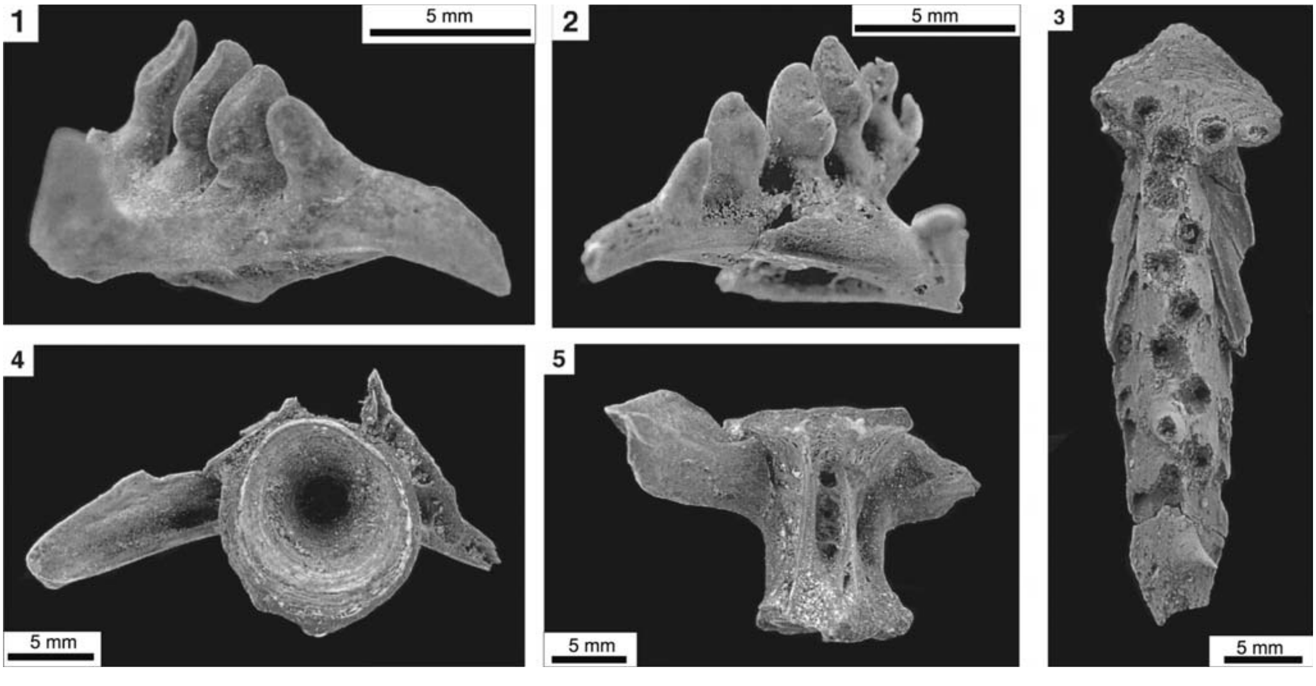

PLATE 2

Fig. 1 - Pharyngeal bone of *Tinca* sp.. Fig. 2 - Pharyngeal bone of *Scardinius erythrophthalmus*. Fig. 3 - Vomer of *Salmo trutta*. Fig. 4 - Caudal view of vertebra of Mugilid. Fig. 5 - Dorsal view of vertebra of Mugilid.

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