

## THE MOLLUSCAN ASSEMBLAGES IN THE FLUVIO-LACUSTRINE SUCCESSION OF THE PLIO-PLEISTOCENE MUGELLO BASIN (TUSCANY, ITALY)

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**Riassunto.** Una revisione stratigrafico-sedimentologica della successione del bacino plio-pleistocenico del Mugello (Firenze) ha stimolato nuove raccolte di molluschi continentali conosciuti dalla fine del secolo scorso. La successione viene suddivisa in quattro sistemi caratterizzati da depositi fluvio-lacustri (sintema del Torrente Ensa, STE) ed alluvionali (sintemi di Scarperia, Luco di Mugello e Sagginale). Nel STE due discordanze angolari individuano tre sequenze deposizionali (S1, S2, S3) costituite da ciottolami e sabbie di delta conoide, silt argillosi lacustri (S1 e S2) e ciottolami e sabbie di conoide alluvionale (S3). Le associazioni a molluschi derivano dalle litofacies pelitico-sabbiose nelle sequenze S1 e S2 depostesi nella piana subaerea dei delta conoidi e nelle zone lacustri marginali. L'analisi paleoecologica individua habitats umidi (specchi d'acqua effimeri, paludi, zone umide limitrofe a canali ecc.) e habitats vegetati (boschi aperti) altrimenti non identificabili dalla sola analisi di facies. La presenza di taxa estinti riferibili al Villafranchiano (*Prososthenia oblonga*, *Emmericia cf. umbra* e *Tourmouerina belnensis*) è in accordo con il quadro biochronologico indicato dai vertebrati delle unità faunistiche Tasso e Farneta (Villafranchiano superiore) raccolti nel bacino fin dal secolo scorso. Una più dettagliata analisi di facies e delle associazioni a molluschi è stata condotta sui depositi conglomeratico-pelitici costituenti tipiche sequenze di facies *fining-upward* nella sequenza S2. I molluschi provengono dalle porzioni pelitiche depostesi durante innalzamenti relativi del livello di base locale e disattivazione dei canali di piena che trasportavano i ciottolami. L'ambiente di deposizione delle peliti era quindi un'area emersa, poco drenata assimilabile ad una piana di esondazione con associazioni di molluschi di habitats umidi. Le zone circostanti erano popolate da molluschi terrestri di bosco aperto trasportati durante episodi di piena moderata nella piana di esondazione. I cicli di sollevamento ed erosione registrati da queste sequenze di facies attivavano alternativamente habitats favorevoli a diverse specie di molluschi continentali.

**Abstract.** New geologic studies on the fluvio-lacustrine Mugello Basin (Florence, Italy) stimulated a revision of the continental molluscan assemblages known since the last century. The fluvio-lacustrine succession has been subdivided in four synthems composed of fluvio-lacustrine (Torrente Ensa synthem, STE) and alluvial deposits (Scarperia, Luco di Mugello and Sagginale synthems). Two progressive angular unconformities in the STE allowed to distinguish three depositional sequences (S1, S2 and S3) composed of fan-delta gravels and sands, lacustrine silty clays (S1 and S2) and alluvial-fan gravels and sands (S3). Molluscs have been collected in various localities where S1 and S2 fan-delta and lacustrine deposits are exposed. The pa-

leoecologic analysis of the molluscan assemblages is in accordance with the fluvio-lacustrine environment inferred from facies analysis. Different types of humid habitats, ranging from swamps, ponds, to channel-related environments (banks, levees etc.), and open woody habitats have been recognized. The presence of Villafranchian extinct taxa such as *Prososthenia oblonga*, *Emmericia cf. umbra* and *Tourmouerina belnensis* is in general agreement with the vertebrate fauna collected in the fluvio-lacustrine deposits since the last century and referred to the Tasso and Farneta faunal units (Late Villafranchian). A detailed integrated analysis of a 15 m thick gravelly-silty facies section of the S2 sequence reveals alternating depositional conditions in the subaerial portion of the fan deltas. Following a relative rise of base-level (i.e. the lake level) flood-channels were disactivated with the formation of a floodplain-like environment dominated by fine-grained deposition, where localized poorly-drained areas created favourable habitats for molluscan taxa loving humid conditions. The surrounding zones were characterized by open forests inhabited by terrestrial taxa. Low-magnitude, overland flows mixed the molluscan faunas of the different biotopes. The cyclic arrangement of gravels and silty clays reflects high-frequency uplift/denudational cycles during which biotopes for the molluscan fauna were alternatively activated.

### Introduction.

Recent lithostratigraphic and sedimentologic researches on the Plio-Pleistocene fluvio-lacustrine deposits of the Mugello Basin (Ghetti, 1993; Benvenuti, 1994) and new findings of continental molluscs stimulated a systematic revision of the molluscan fauna described in the basin since the last century and the reconstruction of the paleoenvironmental evolution of the basin based on the integrated sedimentary and molluscan facies analysis.

Rich continental molluscan assemblages are recorded by Ristori (1889) in the lignite-bearing clays and in the sandy deposits of various localities of the Mugello Basin. Freshwater and land molluscs are listed in his work under the following denominations: "*Hyalina* sp., *Helix* sp., *Planorbis* sp., *Nematurella oblonga* Bronn, *Bythinia tentaculata* Linneo, *Linnaeus ovatus* Draparnaud, *Valvata piscinalis* Müller, *Pisidium priscum* Eichwald, *Unio etruscus* D'Ancona, *Dreissena semen* De

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Stefani". The same species are also described by De Stefani (1891) from the same sites in which they were collected by Ristori (1889). All these taxa (now revised) and many others have been found by the authors of the present paper in several localities of the basin during new investigations.

Only one extinct species, *Nematurella oblonga*, was found by the older authors. This species, later on referred to the prosobranch genus *Prososthenia* (Schlickum, 1971; Esu & Girotti, 1975), and three other fossil prosobranch species, *Emmericia* cf. *umbra* De Stefani (fragmentary), *Tournouerina belnensis* (Délafond & Déperet) and a probably new species of the family Hydrobiidae, *Hydrobia* sp.n.?, have been recorded during the new field researches. *P. oblonga*, *E.* cf. *umbra* and *T. belnensis* characterize the Villafranchian deposits of Central Italy. The first one is spread in upper Pliocene (?) and lower Pleistocene deposits of Tuscany and Umbria (De Stefani, 1876-80; Esu & Girotti, 1991; Caredio et al., 1995), the other two are common in the upper Pliocene and lower Pleistocene deposits of Latium, Umbria, Tuscany (De Stefani, 1876-80; Esu & Girotti, 1991; Ambrosetti et al., 1995; Ciangherotti et al., in press). *T. belnensis* is also present in the Plio-Pleistocene basin of La Bresse in France (Esu et al., 1993) and in the Tiglian deposits of Holland (Meijer, 1996).

In this study the molluscan paleoecologic analysis has been carried out according to the method experienced by Lozek (1964) for the Quaternary non-marine molluscan faunas of eastern central Europe and later used by Puisségur (1976) for Quaternary malacofaunas of France. Afterwards this method was applied to some Pleistocene molluscan faunas of Italy by one of us (D.E.) (Esu, 1981; Crispino & Esu, 1996; Ciangherotti et al., 1996). The two Authors subdivide the living species of gastropods and bivalves in ecologic groups explicative of their habitat considering the present ecology of the taxa. The paleoecologic analysis of the Quaternary assemblages is so based on the ecological requirements of the living species.

The environmental preferences of extinct species are deduced in this study by the habitat of the living representatives or by the ecologic indications supplied by the fossil assemblages in which they have been recorded.

For each molluscan assemblage coming from the different levels the percentage of specimens belonging to species of the same group is calculated. These data are utilized to construct ecological spectra which give a good immediate information about the structure of the study assemblage from an ecological point of view. Paleo-environmental and climatic variations through time can be detected by variations of malacological record if the assemblages are in stratigraphic superposition. The ecologic codes used here for each species are listed in Tab. 1.

E C O L O G I C C L A S S E S	
(from Lozek, 1964)	
1W	strictly forestal species
2W	species living mainly in woods
2W(M)	species living mainly in woods, but also in mesophilous places and both damp and dry biotopes
3W(H)	forestal hygrophilous species
5O	species living in open places without arboreous vegetation
7M	mesophilous species which sometimes can live in damp or dry places
8H	hygrophilous species
9P	strongly hygrophilous species living in marshes or in similar very damp to wet places, generally very close to the water
10	aquatic species which can live in different biotopes or whose habitat can't be determined
10F	aquatic species living in moving waters
10FQ	aquatic species living in moving waters or springs
10F(S)	aquatic species living in moving waters or (less frequently) in still waters
10P	aquatic species living in marshes and in shallow waters rich in vegetation
10S	aquatic species living in still waters
10SF	aquatic species living in still or moving waters
10S(F)	aquatic species living in still waters or (less frequently) in moving waters
10SPpp	aquatic species living either in still waters or in marshes and periodic marshes
*	molluscs whose family has been identified, but whose genus and species can't be determined, so that there are not enough informations about their habitat

Tab. 1 - List of the ecologic classes mentioned in the text and explanation of symbols according to Lozek (1964).

### Geologic setting.

The Mugello basin located about 30 km North of Florence is a depression 25 km long and 15 km wide oriented in a WNW-ESE direction (Fig. 1). The basin was opened following a region-wide extensional episode which occurred between the latest Pliocene and the early Pleistocene (Gemina, 1962; Sanesi, 1965; Bartolini & Pranzini, 1979; Bernini et al., 1990). During the early stages of its tectono-sedimentary evolution (Benvenuti, 1994; in press), the basin was a half graben with its master fault system located along the SW shoulder and divided in two sub-basins, respectively Barberino (BSB) and Borgo S. Lorenzo (BSLSB) sub-basins, by the Campiano-Poggio Mausoni-Villa le Maschere threshold.

These areas were filled with continental deposits during two main depositional phases: fluvio-lacustrine the first and alluvial the second. A biochronologic revision of the Mugello vertebrate fauna (Abbazzi et al., 1995) together with a preliminary magnetostratigraphic calibration of the fluvio-lacustrine deposits (Albianelli, unpublished) provided new data for the chronostratigraphy of this succession (Fig. 2). The most part of the fluvio-lacustrine phase is referred to the lower Pleistocene.

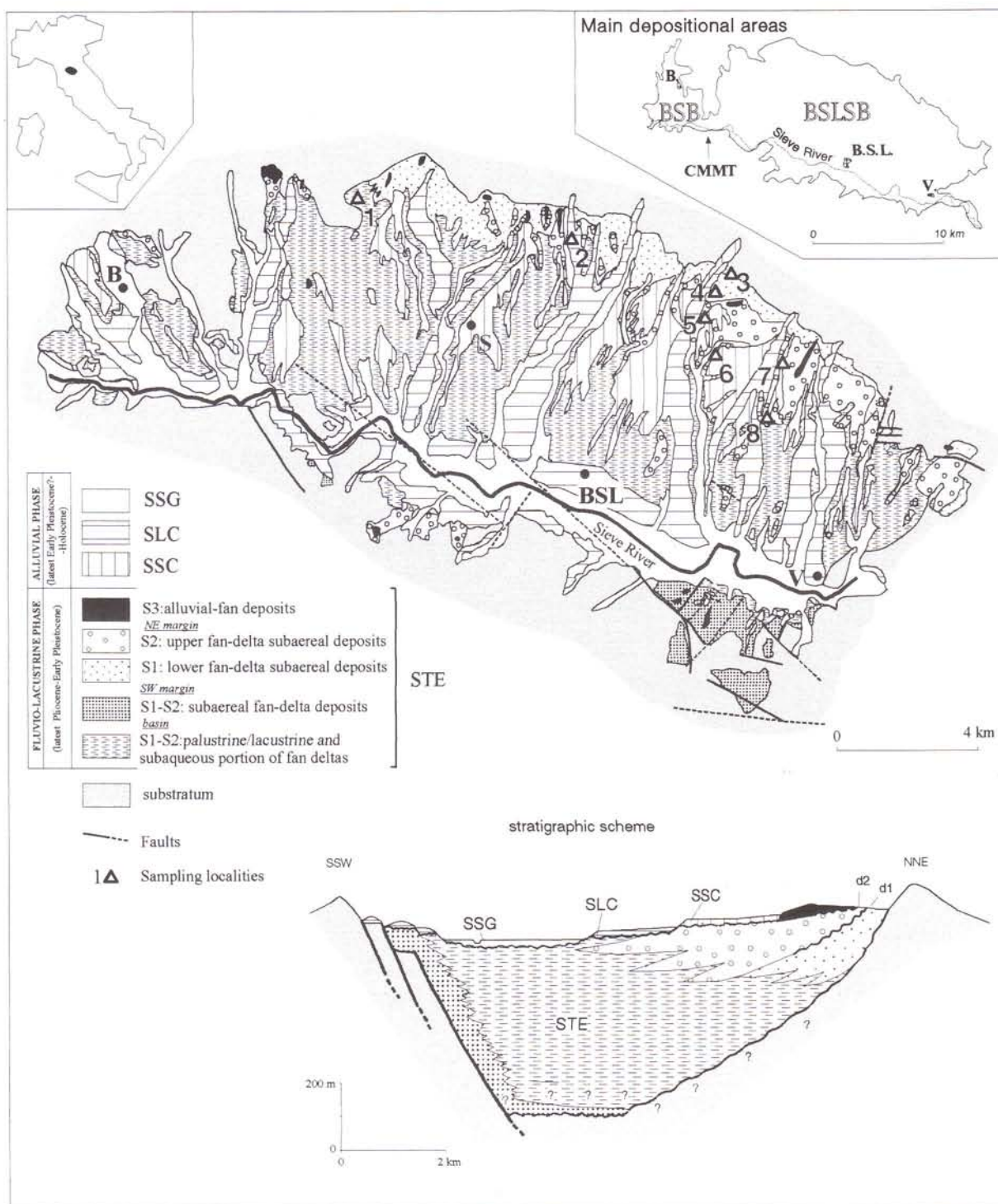


Fig. 1 - Schematic geological map, stratigraphic section and main depositional areas of the fluvio-lacustrine Mugello Basin. Abbreviations: B= Barberino di Mugello; S= Scarperia; BSL= Borgo S. Lorenzo; V= Vicchio; BSB= Barberino sub-basin; BSLSB= Borgo S. Lorenzo sub-basin; CMMT: Campiano-Poggio Mausoni-Villa Le Maschere threshold; STE: Torrente Ensa synthem; SSC: Scarperia synthem; SLC: Luco di Mugello synthem; SSG: Sagginale synthem.

ne. Several samples of silty clays collected along a more than 250 m thick section in the fluvio-lacustrine deposits resulted magnetized under a reverse polarity. Only one sample at the top of the succession showed normal magnetization although doubts exist on its significance. Basing on the mammal fauna coming from different stratigraphic levels (see Abbazzi et al., 1995 for detail)

prevalently indicating the Farneta Unit and, possibly only in the lower stratigraphic level (lignites) the Tasso Unit, the reverse interval is tentatively referred to the Matuyama, post-Olduvai, chron. On the base of the biochronologic data alternative hypotheses can be made for its early beginning (latest Pliocene or earliest Pleistocene, A1 or A2 in Fig. 2) and its end (latest early Plei-

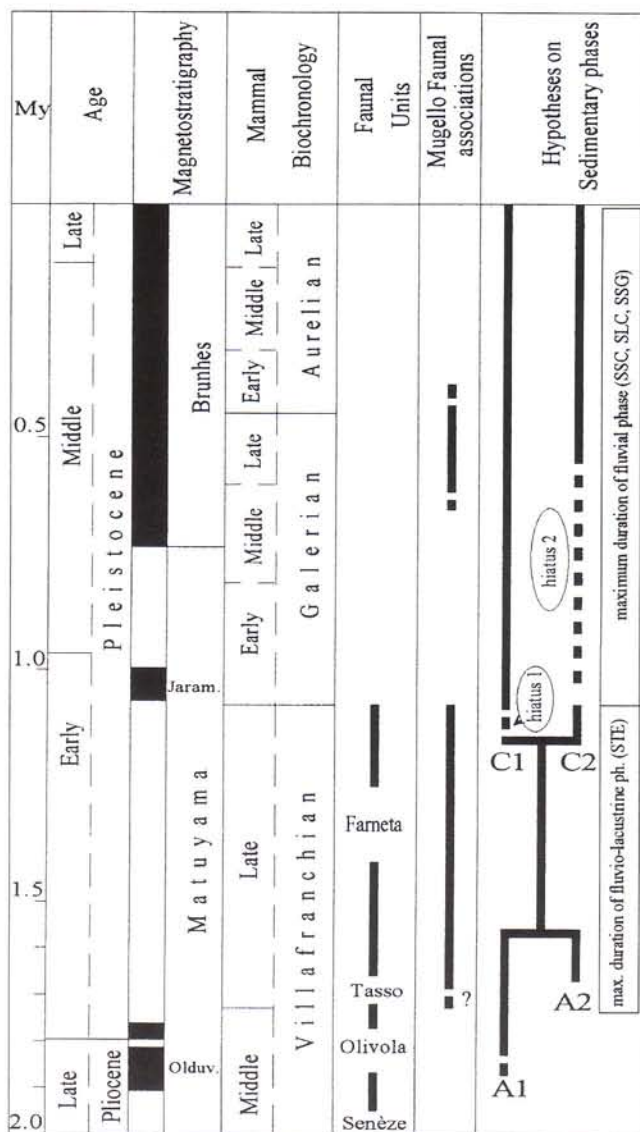


Fig. 2 - Chronostratigraphic scheme of the Mugello fluviolacustrine succession (from Abbazzi et al., 1995, the mammal biochronology column modified after Gliozzi et al., 1995 and A. Azzaroli, pers. com.).

stocene or middle Pleistocene, C1 or C2 in Fig. 2) (see Abbazzi et al., 1995 for further details).

During the fluviolacustrine phase (late Pliocene?-early Pleistocene) the Mugello Basin had an internal drainage and different depositional settings developed in the two sub-basins. In the BSB peaty silty clays up to 100 m thick were accumulated. In the larger BSLSB a stronger subsidence allowed the accumulation of more than 600 m thick deposits composed of a relatively thin level (20 m thick) of basal alluvial gravels (Gemina, 1962), which are overlain by lacustrine silty clays interfingered at the margins with fan delta gravels and sands. Fan deltas prograded mainly from the NE margin of the basin (hanging-wall), which experienced episodic uplift pulses recorded by angular unconformities and syndepositional deformation of the fan delta succession.

The alluvial phase (middle Pleistocene-Holocene) began as the consequence of the downcutting of a southeastern threshold creating an outlet through which the lake was emptied. The removal of successive thresholds downstream the Mugello Basin and pulses in tectonic subsidence along the southwestern master fault system led to three main local base-level lowerings. These are recorded in the typical alluvial terraced succession composed of pedogenized gravelly deposits (Sanesi, 1965).

#### The molluscan assemblages in the fluviolacustrine deposits.

The lithostratigraphic framework of the Mugello Basin fill has been recently revised through application of synthems (International Subcommittee on Stratigraphic Classification, 1987), sequence stratigraphy and detailed facies analysis (Benvenuti, 1994; 1996; in press). The fluviolacustrine deposits are separated from the fluvial ones by unconformable surfaces which allow to distinguish four main synthems. The fluviolacustrine succession constitutes the Torrente Ensa synthem (STE) and the terraced fluvial deposits are grouped respectively in the Scarperia, Luco di Mugello and Sagginale synthems (SSC, SLC, SSG).

The fluviolacustrine deposits of STE have been previously subdivided in gravels, sands and clays (see Sanesi, 1965; Canuti et al., 1989) and new detailed surveys allowed to distinguish gravelly and sandy lithofacies produced by different depositional processes in lacustrine fan-delta and alluvial-fan environments.

In the BSLSB two main progressive angular unconformities (d1 and d2, Fig. 1) (*sensu* Riba, 1976; Anadon et al., 1986), allowed to divide the STE in three depositional sequences (S1, S2, S3). These sequences developed during the syndepositional uplift and tilting of the NE shoulder of the BSLSB probably forced by compressive pulses (Benvenuti, 1994; in press; Boccaletti et al., 1995). The sequences record the stages of progradation of fan deltas (S1 and S2) and alluvial fans (S3) in the basin. The fan-delta deposits are characterized by different gravelly and sandy facies; in the S1 sequence, gravels and sands deposited by high-density sheetfloods in the subaerial portion of fan deltas. The subaqueous portion was characterized by sediment gravity flow deposits. In the S2 sequence, channelized highly-concentrated streamflood deposits accumulated in the subaerial portion of the fan deltas and macroforms ranging from small size lobes to Gilbert-type fan delta front (Benvenuti & Ghetti, 1996) developed in the subaqueous portion of the fan deltas. The coarse-grained fan-delta deposits of both S1 and S2 sequences are basinward interbedded with lacustrine silty clays.

Both S1 and S2 sequences can be internally subdivided in several gravelly-pelitic units produced by high-

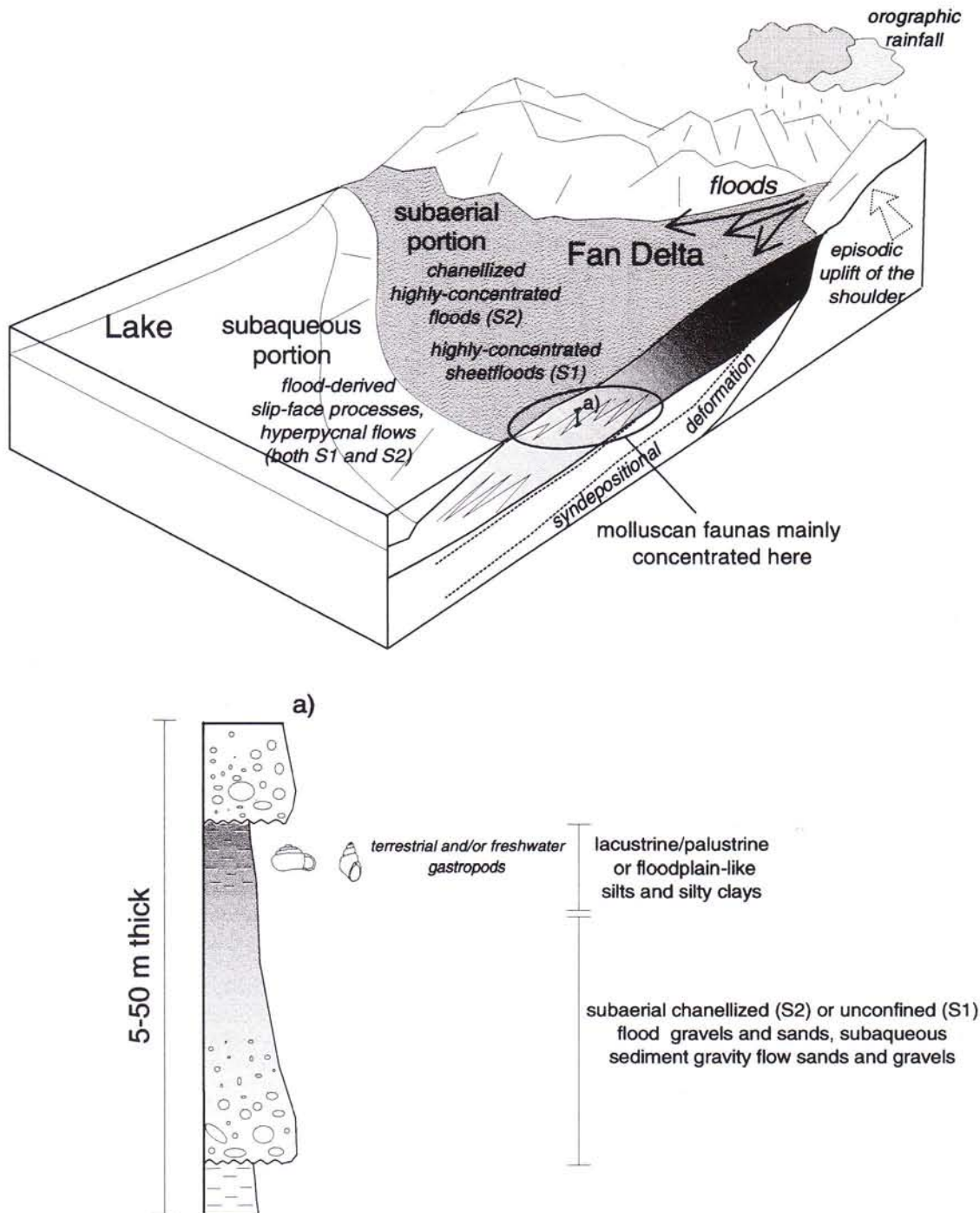


Fig. 3 - Conceptual model for the development of the lacustrine fan deltas in the Mugello Basin. a) generalized stratigraphic log of fining-up cycles punctuating the overall progradation of the S1 and S2 fan deltas.

frequency backstepping and disactivation of the flood-dominated fan deltas (see later). Molluscan faunas, typically concentrated in the pelitic portions of such fining-up cycles (Fig. 3), have been sampled in different parts of the basin and have become object of a first study (Geraci, 1994).

Molluscan assemblages in the S1 sequence.

Localities with deposits of S1 sequence are respectively Lumena village, Bagnone and Ensa creeks.

The molluscan assemblage found in the lignite-bearing silty clays around Lumena (site 1, Fig. 1) is composed of few species of freshwater prosobranchs and bivalves among which *Valvata piscinalis* (45.10%; Plate 1, Fig. 2) and *Dreissena polymorpha* (29.41%; Plate 1, Fig. 14) are prevailing reaching the 74.51% of the association. The former is characteristic of clear stagnant (swamps, marsh drains) or slowly moving water (10SF), the latter prefers weakly current water (10F(S)) characterizing slow rivers and canals but does not dislike lakes (Ellis, 1978; Castagnolo et al., 1980; Glöer et al., 1985).

## Bagnone

Species	Specim.	Ecol. classes	%	% Ecol. classes
<i>Valvata piscinalis</i>	124	10SF	16,43	10F 1,32
<i>Tourmouerina belnensis</i>	420	10SF	55,63	10FQ 0,13
<i>Bithynia sp. (opercula)</i>	2	10SF	0,26	10F(S) 26,23
<i>Emmericia cf. umbra</i>	1	10FQ	0,13	10SF 72,32
<i>Pisidium sp.</i>	10	10F	1,32	
<i>Dreissena polymorpha</i>	198	10F(S)	26,23	
	755			

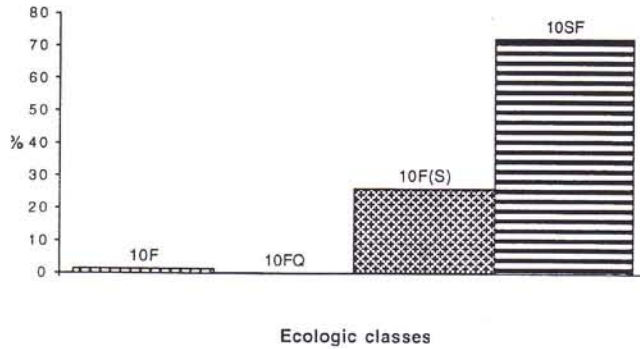


Fig. 4 - Paleoecologic feature of a molluscan aquatic assemblage from S1 sequence in the Bagnone Creek valley.

A species of more stagnant water, *Bithynia leachi* (10P) in low percentage (5.8%), and some fragmentary land gastropods of the family Helicidae also occur. The ecological character of the assemblage points to a palustrine-lacustrine environment with slowly moving water as requested mainly by the presence of *D. polymorpha*. The sampled sediments yielded also some remains of fishes and gyrogonites of Characeae which are proper to the inferred environment.

The deposits cropping out in the Bagnone Creek (site 2, Fig. 1) contain molluscan assemblages important for both paleoecologic and chronostratigraphic implications. Many species of freshwater prosobranchs and bivalves were found in the silty clays interbedded with gravels and sands on the whole referred to a distal subaerial-subaqueous fan-delta system. In some levels the molluscan assemblage is composed exclusively of aquatic ele-

## Ponte alle Docce

Species	Specim.	Ecol. classes	%	% Ecol. classes
<i>Valvata piscinalis</i>	264	10SF	13,41	10F 0,91
<i>Hydrobia sp.n.?</i>	4	10F(S)	0,20	10F(S) 6,04
<i>Prososthenia oblonga</i>	1493	10SF	75,83	10S 1,17
<i>Bithynia sp. (opercula)</i>	45	10SF	2,29	10SF 91,53
<i>Lymnaea peregra</i>	7	10S(F)	0,35	10S(F) 0,35
<i>Gyraulus albus</i>	23	10S	1,17	
<i>Unio sp.</i>	3	10F	0,15	
<i>Pisidium amnicum</i>	15	10F	0,76	
<i>Pisidium tenuilineatum</i>	115	10F(S)	5,84	
	1969			

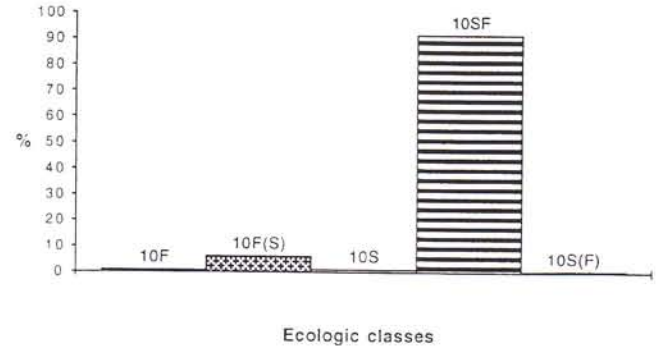
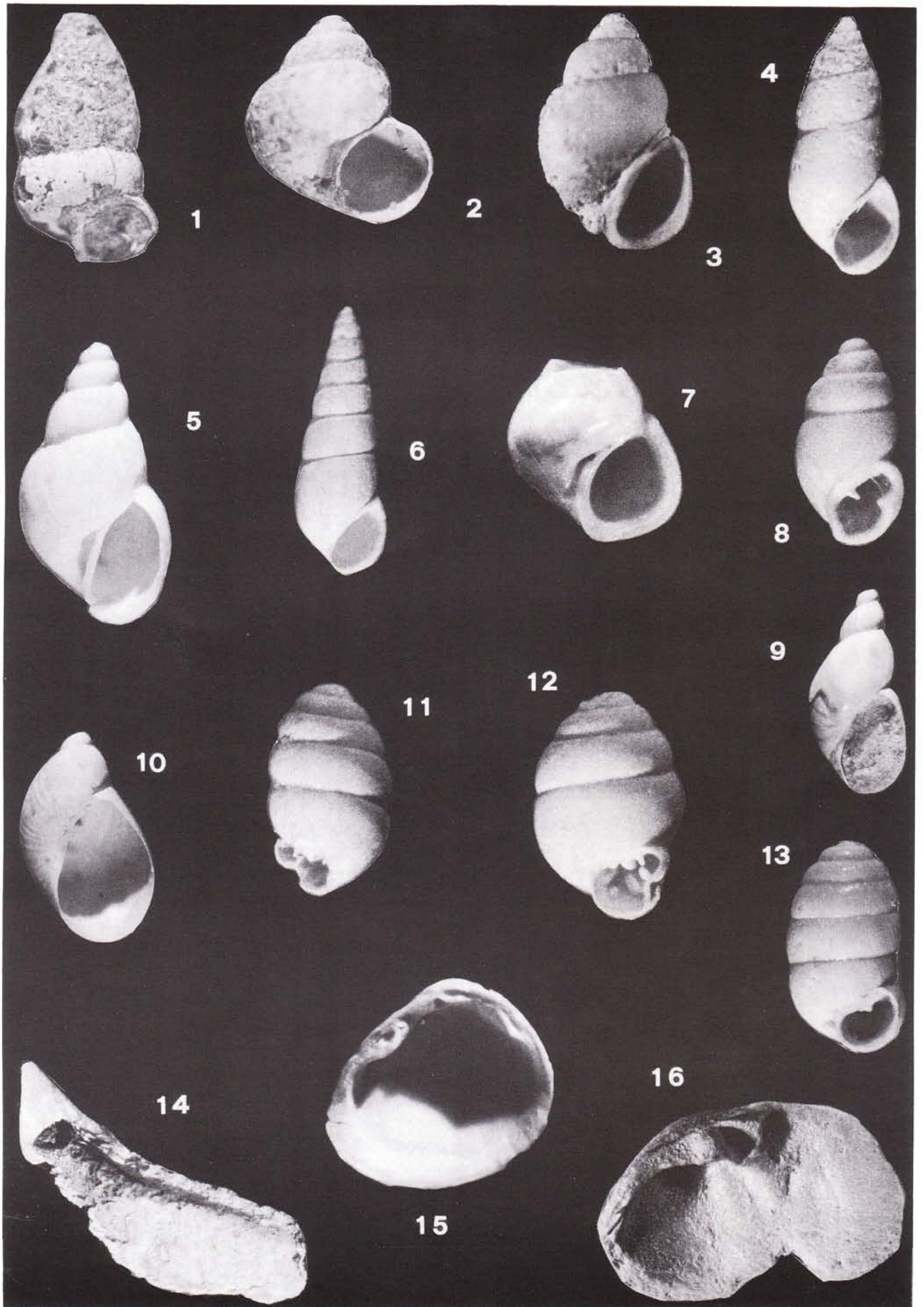


Fig. 5 - Paleoecologic feature of a molluscan assemblage from the upper portion of S1 sequence in the Ensa Creek valley (Ponte alle Docce samples).

ments living mostly in moving waters (Fig. 4); not strictly stagnant species are present and the ecological mark of each species is characterized by the acronym F (fluvial). The ecological meaning assigned to the extinct species *T. belnensis* (Plate 1, Fig. 3) is inferred by its presence in the upper Pliocene continental deposits of Duna-robbia (Tiber basin, Central Italy) assigned to the "lithofacies a" and "b" by Basilici in Ambrosetti et al. (1995). The facies "a" is characteristic of small ponds with low water energy and autochthonous fauna on a wetland lacustrine coastline. In these weak-energy environmental conditions *T. belnensis* is accompanied by almost stagnant water species like *Gyraulus albus* and *Acroloxus lacustris* (Ciangherotti et al. in Ambrosetti et al., 1995); the whole fauna indicates shallow water depth of about 1 meter. The "lithofacies b", proper to a lacustrine wetland margin, is yielded by weak wave mo-

## PLATE 1

- Fig. 1 - *Cochlostoma cf. patulum* (Draparnaud). Pesciola C8. M.P.U.R. - 7 - 1356; coll. Esu-Girotti; 10,6x.  
 Fig. 2 - *Valvata piscinalis* (Müller). Ponte alle Docce. M.P.U.R. - 7 - 1357; 7,4x.  
 Fig. 3 - *Tourmouerina belnensis* (Délafond & Dépéret). Bagnone. M.P.U.R. - 7 - 1358; 15x.  
 Fig. 4 - *Prososthenia oblonga* (Bronn). Ponte alle Docce. M.P.U.R. - 7 - 1359; 10x.  
 Fig. 5 - *Lymnaea truncatula* (Müller). Pesciola C7. M.P.U.R. - 7 - 1360; 11x.  
 Fig. 6 - *Hydrobia sp. n.?* Mucciano. M.P.U.R. - 7 - 1361; 9x.  
 Fig. 7 - *Emmericia cf. umbra* De Stefani. Bagnone. M.P.U.R. - 7 - 1362; 18,8x.  
 Fig. 8 - *Carychium minimum* Müller. Pesciola C7. M.P.U.R. - 7 - 1363; 23,4x.  
 Fig. 9 - *Succinea oblonga* Draparnaud. Pesciola C7. M.P.U.R. - 7 - 1364; 5,7x.  
 Fig. 10 - *Oxyloma elegans* (Risso). Pesciola, Gerbi il Mulino. M.P.U.R. - 7 - 1365; 5,4x.  
 Fig. 11 - *Vertigo angustior* Jeffreys. Pesciola C7. M.P.U.R. - 7 - 1366; 22,7x.  
 Fig. 12 - *Vertigo antivertigo* (Draparnaud). Pesciola C7. M.P.U.R. - 7 - 1367; 19,5x.  
 Fig. 13 - *Pupilla muscorum* (Linné). Pesciola, Gerbi il Mulino. M.P.U.R. - 7 - 1368; 13,2x.  
 Fig. 14 - *Dreissena polymorpha* (Pallas). Lumena. M.P.U.R. - 7 - 1369; 4,7x.  
 Fig. 15 - *Pisidium tenuilineatum* Stelfox. Ponte alle Docce. M.P.U.R. - 7 - 1370; 22,5x.  
 Fig. 16 - *Unio sp.* Ponte alle Docce. M.P.U.R. - 7 - 1371; 1,6x.



## Mucciano

Species	Specim.	Ecolog. classes	%	% Ecolog. classes
<i>Valvata piscinalis</i>	5	10SF	0,57	1W 0,11
<i>Pomatias elegans</i>	15	2W(M)	1,71	2W(M) 1,71
<i>Hydrobia</i> sp.n.?	733	10F(S)	83,49	9P 0,57
<i>Bithynia</i> sp. (opercula)	31	10SF	3,53	10F 8,31
<i>Lymnaea peregra</i>	4	10S(F)	0,46	10F(S) 83,60
<i>Gyraulus</i> sp.	4	10S	0,46	10S 0,46
<i>Azeca</i> cf. <i>goodalli</i>	1	1W	0,11	10SF 4,10
<i>Vertigo</i> sp.	1	9P	0,11	10S(F) 0,46
<i>Oryzoma</i> cf. <i>elegans</i>	4	9P	0,46	*
Clausiliidae undet.	1	*	0,11	
Helicidae undet.	5	*	0,57	
<i>Unio</i> sp.	1	10F	0,11	
<i>Pisidium amnicum</i>	57	10F	6,49	
<i>Pisidium tenuilineatum</i>	1	10F(S)	0,11	
<i>Pisidium</i> sp.	15	10F	1,71	
	878			

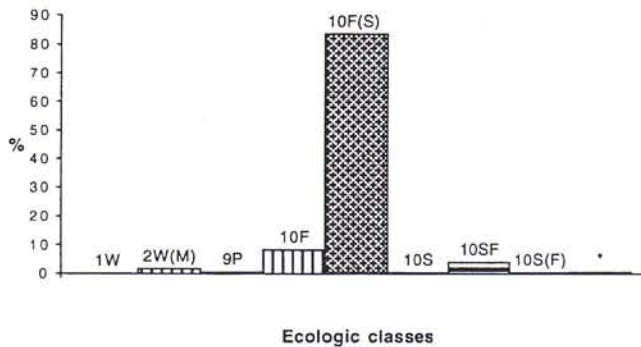


Fig. 6 - Paleoecologic feature of a molluscan assemblage from S2 sequence at Mucciano.

tion (or by distal deposits of a delta system); here *T. belnensis* is often accompanied by *E. umbra*, a species loving clear and slightly current water. Recently *T. belnensis* was found in Tiglian deposits of slowly moving fluvial and fluvio-lacustrine environments in The Netherlands (Meijer, 1996). This last datum and the character of the assemblage of the Bagnone Creek permit to give to *T. belnensis* a paleoecologic meaning more consistent with fluvial water, that is 10SF, than 10S(F) as given in Ambrosetti et al. (1995). In the Bagnone Creek the presence of *D. polymorpha* in a fair percentage (26.23%) and of species not disliking slowly moving water points to a riverine environment which was affected by temporary emersions as shown by the presence in some interbedded levels of scanty and fragmentary land and palustrine or hygrophilous elements, like *Limax* sp., fragments of Helicidae, *Lymnaea* sp. and *Carychium tridentatum*. The paleoecologic meaning of these assemblages is in a good accordance with the subaerial to subaqueous fan-delta environment interpreted from sedimentary facies analysis. Two Villafranchian species, *T. belnensis*, very well represented and *Emmericia* cf. *umbra* (Plate 1, Fig. 7), very scanty, are present in the deposits of S1 sequence of Bagnone Creek.

The molluscan assemblage coming from the lower silty-clayey laminated portion of S1 sequence exposed in the Ensa Creek valley (site 3 and 4, Fig. 1), is composed prevalently of the slowly moving water *D. polymorpha* and by a very high number (500 specimens) of opercula of *Bithynia*. Transported fragments of shells of Helicidae

are also present. A so high number of opercula and shell fragments suggests that this quiet, probably lacustrine environment was periodically affected by running water related to floods. The upper gravelly and sandy portion of S1 yielded a rich assemblage (Fig. 5) composed only of aquatic molluscs in which the species *Prosostrhenia oblonga* (Plate 1, Fig. 4) and *V. piscinalis*, characteristic of a fluvio-lacustrine environment, are dominant (10SF, 75.83% and 13.41% respectively). *V. piscinalis*, as said above, inhabits ponds or marsh drains as well as slow flowing water. The extinct species *P. oblonga* is recorded in lower Pleistocene continental deposits of Tuscany (Lucca-Montecarlo-Vinci basin) referred to lacustrine environment or channel with slow-flowing water (Caredio et al., 1995). In these last deposits *P. oblonga* is present in low percentage in assemblage with species loving moving water as *Ancylus fluviatilis*, *Corbicula fluminalis* and *Anodonta* sp. In lower Pleistocene continental deposits of Tiber basin (Umbria) this species is recorded in assemblage with species loving still or slowly moving water (10 SF) (Esu & Girotti, 1975). These informations suggest for *P. oblonga* the ecological conditions of a species adapted to still as well as slowly current water (10SF).

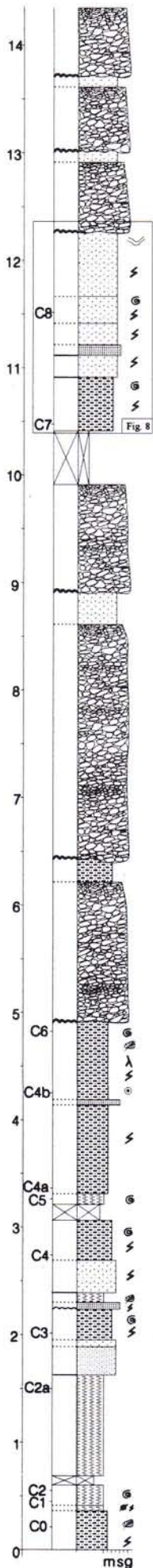
In the Mugello basin, at Ponte alle Docce, *P. oblonga* and *V. piscinalis* are associated to some elements preferring current water, like *Pisidium amnicum* (10F), *P. tenuilineatum* (10F(S)) (Plate 1, Fig. 15), *Unio* sp. (10F) (Plate 1, Fig. 16), which as a whole reach a percentage of 6.95% and to transported opercula of *Bithynia*. Other species of mostly stagnant water as *Lymnaea peregra* (10S(F)) and *Gyraulus albus* (10S) are present in lower percentage (1.52%). The fluvio-lacustrine environment suggested by this assemblage is in accordance with the subaerial to subaqueous fan-delta environment interpreted from facies analysis. The presence of the prosobranch *P. oblonga* points to a Villafranchian age for this assemblage.

#### Molluscan assemblages in the S2 sequence.

Deposits belonging to the S2 sequence have been sampled in three areas, respectively Mucciano, Ensa and Pesciola creeks.

The silty clayey sediments interbedded with gravels sampled at Mucciano (site 6, Fig. 1) yielded a rich assemblage of land and freshwater molluscs in which the aquatic component is prevailing (Fig. 6). A probably new species of prosobranchs (in study by D. Esu and V. Geraci) belonging to the family Hydrobiidae (*Hydrobia* sp.n.?; Plate 1, Fig. 6) is dominant, reaching the 83.49% with a high number of specimens (733 specimens). Its ecology is referred to slowly moving water, 10F(S), as it also occurs in other assemblages sampled in the S1 deposits of the Ensa Creek pointing to a fluvio-lacustrine





environment. Other riverine elements, as *Unio* sp., *P. amnicum*, *P. tenuilineatum*, *Pisidium* sp. and opercula of *Bithynia* are present in the assemblage with a percentage of 11.95%. Some palustrine taxa, as *Oxyloma* cf. *elegans* (9P), *Vertigo* sp. (sinistral) (9P) and *Gyraulus* sp. (10S), are scanty and fragmentary (1.03%). A few fragmentary land gastropods, clearly transported, pointing to a bushy land around, as *Pomatias elegans*, *Azeca* cf. *goodalli*, fragments of Helicidae and Clausiliidae, are present in a very low percentage (2.50%).

The composition of the assemblage is indicative of a fluvio-lacustrine environment with an open woodland or bushy land in the surroundings.

A poor assemblage represented by both terrestrial and freshwater molluscs was found in the silty clays interbedded with sands and gravels cropping out in the Ensa Creek valley (site 5, Fig. 1). Land species of open environment without arboreal vegetation like *Pupilla muscorum* (Plate 1, Fig. 13) and *Candidula unifasciata* (Lozek, 1964; Kerney & Cameron, 1979) are prevailing. Fragmentary specimens of species inhabiting mesophilous woody environment, as *Limax* sp., *Vitrinobranchium* sp. and *Azeca* sp., are present in lower percentage. Aquatic species of flu-

vio-lacustrine environment are represented by fragments of *Valvata* sp., *Lymnaea* sp., *Gyraulus* sp., *P. amnicum* and opercula of *Bithynia* sp. Scattered remains of Characeae are also present. The fragmentary conditions of the land and freshwater molluscs point to a transport of the fossil material. On the whole this assemblage is paleoecologically coherent with the subaerial to subaqueous fan-delta environment interpreted from facies analysis.

In the S2 deposits cropping out in the Pesciola Creek (site 7 and 8, Fig. 1) a mixed molluscan fauna comprising species of different habitat was recorded. The assemblage is dominated by species loving fens, marshes or damp sparsely-vegetated places as floodplains such as *Carychium minimum* (9P) (Plate 1, fig. 8), *Succinea oblonga* (8H) (Plate 1, fig. 9), *Oxyloma elegans* (9P) (Plate 1, fig. 10), *Lymnaea truncatula* (10SPPp) (Plate 1, fig. 5) and *Vertigo antivertigo* (9P) (Plate 1, fig. 12) (Lozek, 1964; Kerney & Cameron, 1979; Killeen, 1992). The presence in lower percentage of mesophilous land molluscs loving medium humidity conditions belonging to the ecological group 7M, as *Cochlicopa lubrica*, *Lauria* cf. *cylindracea* and *Limax* sp., and species of open land also belonging to the group 50, as *P. muscorum* and *Valtonia pulchella*, support the type of habitat inferred by the dominant species with open land around.

The study of the molluscan assemblages in the fluvio-lacustrine deposits (sequence S1 and S2) of the STE confirms and details the paleoenvironmental picture of the basin derived from facies analysis. Furthermore the chronostratigraphic meaning of these assemblages fits well the conclusion of a biochronologic revision of the vertebrate fauna of the Mugello Basin (Abbazzi et al., 1995). Villafranchian species of molluscs such as *T. belnensis*, *E. cf. umbra* and *P. oblonga* thrived in a fluvio-lacustrine environment populated also by mammals belonging to the Tasso and Farneta faunal units (late Villafranchian). The presence of the Villafranchian molluscs exclusively in the deposits of sequence S1 can be explai-

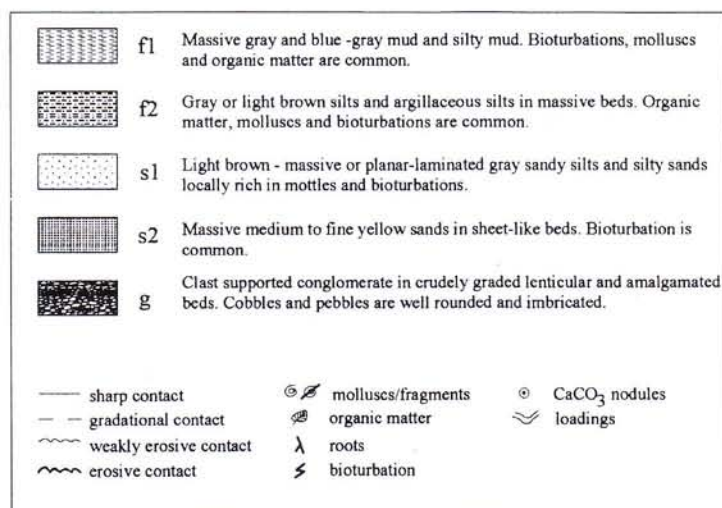


Fig. 7 - Stratigraphic and sedimentologic log of S2 sequence measured in the Pesciola Creek.

ned with two interpretations. In the first the fluvio-lacustrine sequence S2 is post-Villafranchian. This interpretation fits the second hypothesis (C2) for the end of the fluvio-lacustrine phase in Fig. 2. In the second interpretation the missing of Villafranchian species in the sequence S2 can reflect an environmental change due to the progressive advance of subaerial, coarse-grained portions of the fan deltas and the relative reduction of flooded habitats dominated by fine-grained deposition. This interpretation could be supported by the consideration that in the sequence S2 land species and hence a subaerial environment, more or less humid, are much better represented than in sequence S1 deposits.

#### Detailed sedimentary facies and molluscan assemblage analysis in the S2 sequence deposits.

The gravels and sands of sequence S2 are arranged in facies sequences 5-15 m thick internally characterized by a fining-upward trend and vertically stacked to outline a progradational wedge of fan-delta deposits. In the Pesciola Creek valley good exposures and locally abundant molluscan fauna allowed to integrate sedimentologic and paleoecologic observations at the scale of these facies sequences. A composite section has been sampled for the molluscs and studied in detail for the facies analysis (Fig. 7).

Five muddy, sandy and gravelly lithofacies have been defined. Fine-grained lithofacies are represented by f1 and f2. Lithofacies f1 is made of massive, bioturbated grey and blue-grey silty clays in levels from 5 to 100 cm thick with organic matter and molluscs; lithofacies f2 is composed of light brown greyish massive, bioturbated clayey silts with molluscs, vegetal remains, calcareous nodules and locally root traces. Sandy lithofacies are represented by s1 and s2. Lithofacies s1 is made of light brown yellowish, bioturbated silty sands massive or with parallel lamination; scattered molluscs may be present. Lithofacies s2 is constituted of yellowish massive medium-fine sands in beds up to 10 cm thick. The gravelly lithofacies g is made of well-rounded pebbly-cobbly, ungraded gravels arranged in lenticular bodies composed by one or more sometimes amalgamated beds with erosive bases. Clasts are self-supported, imbricated and with a sandy-silty matrix increasing towards the top. A typical facies sequence is made of beds of lithofacies g which erosively overlie lithofacies f1-f2 with minor interbedding of lithofacies s1-s2 (Fig. 8).

Molluscs are concentrated in the lithofacies f1 and f2 and some levels yielded quite a rich fauna (Fig. 9). At the base of the section the sample C0 yielded poor remains of land snails clearly transported: only one specimen of *Vitrinobrachium breve*, a true woodland species (1W), and some fragments of *P. elegans* (2W(M)) and He-

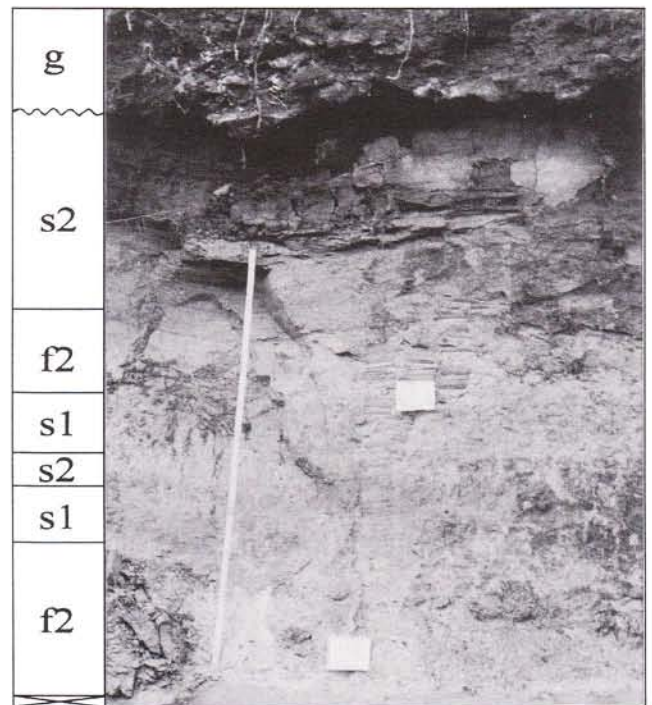


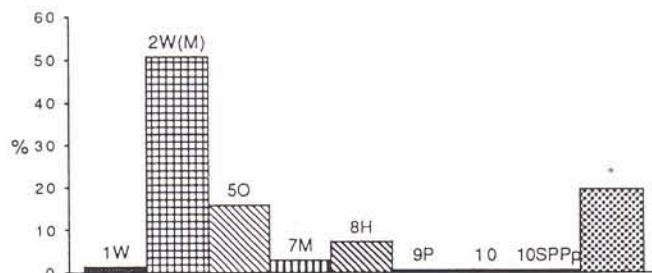
Fig. 8 - Detailed view of the upper part of the Pesciola Creek log.

licidae were found. They point to the presence of an adjacent open woody environment. In the overlying samples (C1 and C2) fairly rich molluscan assemblages are present: forestal species of open woody environment with a medium degree of humidity (2W(M), 3W(H)) are dominant (73,08% in C1 and 52,63% in C2); in particular *P. elegans* is prevailing in both the samples. In sample C1 only terrestrial species are present. In sample C2 sporadic elements of palustrine environment (*Succinea oblonga*, *Lymnaea* sp., *Bithynia* sp.) occur in very low percentage besides the woodland mesophilous species which present a little transport. The assemblages of C1 and C2 point to a temperate climate for the presence of two elements, *Discus rotundatus* and *Pomatias elegans*, particularly linked to the warm Quaternary climatic phases of Europe (Lozek, 1964; Crispino & Esu, 1996).

Scanty transported fragments of land species (*P. elegans*, Clausiliidae, Helicidae) are found in the sample C2a. Above, sample C3 yielded a poor molluscan assemblage composed of few land gastropods characterizing on the whole an open woody environment *P. elegans* is the dominant species (84%). The bad preservation of the shells indicates that the fossil material has suffered little transport. The overlying sample C4 contains a fragmentary assemblage composed of few aquatic species of palustrine environment (*Lymnaea* sp., *Pisidium* sp.) and land hygrophilous species (*Carychium* sp., *Vertigo* cf. *angustior*, Plate 1, fig. 11) of very wet habitat (fen, pond or river bank) (Kerney & Cameron, 1979). No woody elements are present. The assemblage points to a temporary palustrine environment which is also te-

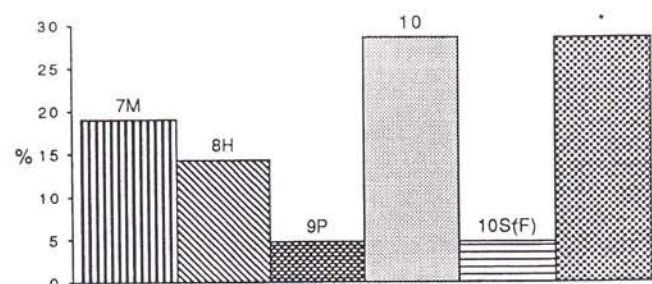
Pesciola - C5

Species	Specim.	Ecol. classes	%	% Ecol. classes
<i>Cochlostoma cf. patulum</i>	22	5O	15,94	1W 1,44
<i>Pomatias elegans</i>	64	2W(M)	46,38	2W(M) 50,72
<i>Acicula</i> sp.	1	1W	0,72	5O 15,94
<i>Carychium tridentatum</i>	5	8H	3,62	7M 2,90
<i>Carychium</i> sp.	3	8H	2,17	8H 7,24
<i>Lymnaea truncatula</i>	1	10SPPp	0,72	9P 0,72
<i>Vertigo angustior</i>	1	9P	0,72	10 0,72
<i>Succinea oblonga</i>	2	8H	1,45	10SPPp 0,72
<i>Discus rotundatus</i>	1	2W(M)	0,72	* 19,60
<i>Limax</i> sp.	4	7M	2,90	
Clausiliidae undet.	4	*	2,90	
<i>Testacella halionidacea</i>	4	2W(M)	2,90	
Helicidae undet.	23	*	16,70	
<i>Helicodonta obvolva</i>	1	1W	0,72	
<i>Cepaea</i> sp.	1	2W(M)	0,72	
<i>Pisidium</i> sp.	1	10	0,72	
	138			



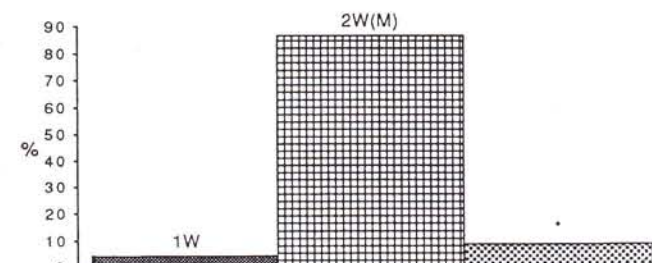
Pesciola - C4

Species	Specim.	Ecol. classes	%	% Ecol. classes
<i>Carychium</i> sp.	3	8H	14,29	7M 19,05
<i>Lymnaea</i> sp.	1	10S(F)	4,76	8H 14,29
<i>Vertigo cf. angustior</i>	1	9P	4,76	9P 4,76
<i>Limax</i> sp.	4	7M	19,05	10 28,58
Clausiliidae undet.	1	*	4,76	10S(F) 4,76
Helicidae undet.	5	*	23,80	* 28,56
<i>Pisidium</i> sp.	6	10	28,58	
	21			



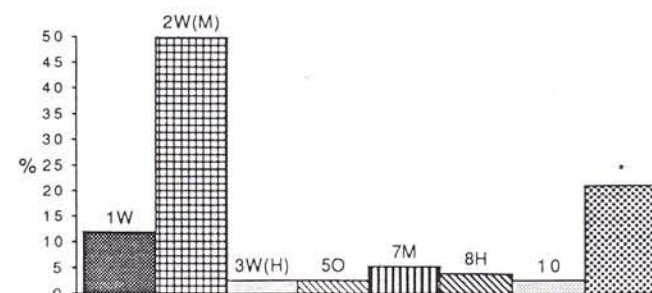
Pesciola - C3

Species	Specim.	Ecol. classes	%	% Ecol. classes
<i>Pomatias elegans</i>	38	2W(M)	84,45	1W 4,44
<i>Acicula</i> sp.	1	1W	2,22	2W(M) 86,67
<i>Discus</i> sp.	1	2W(M)	2,22	* 8,89
Clausiliidae undet.	1	*	2,22	
Helicidae undet.	3	*	6,67	
<i>Helicodonta obvolva</i>	1	1W	2,22	
	45			



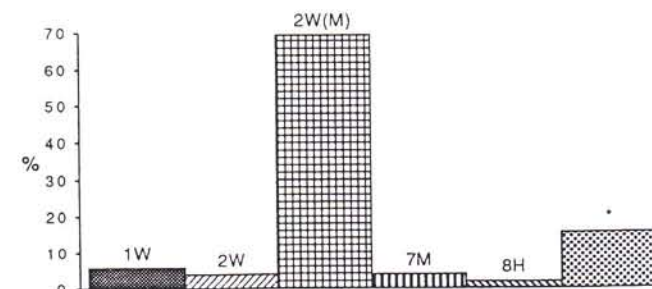
Pesciola - C2

Species	Specim.	Ecol. classes	%	% Ecol. classes
<i>Pomatias elegans</i>	37	2W(M)	48,68	1W 11,84
<i>Bithynia</i> sp.	1	10	1,32	2W(M) 50
<i>Lymnaea</i> sp.	1	10	1,32	3W(H) 2,63
<i>Truncatellina cf. cylindrica</i>	2	5O	2,63	5O 2,63
<i>Succinea oblonga</i>	3	8H	3,94	7M 5,26
<i>Punctum pygmaeum</i>	3	7M	3,94	8H 3,94
<i>Discus</i> sp.	1	2W(M)	1,32	10 2,64
<i>Vitrinobrachium breve</i>	9	1W	11,84	* 21,06
<i>Limax</i> sp.	1	7M	1,32	
Clausiliidae undet.	5	*	6,58	
<i>Poiretia</i> sp.	1	*	1,32	
Helicidae undet.	10	*	13,16	
<i>Hygromia</i> sp.	2	3W(H)	2,63	
	76			



Pesciola - C1

Species	Specim.	Ecol. classes	%	% Ecol. classes
<i>Pomatias elegans</i>	32	2W(M)	61,54	1W 5,77
<i>Carychium</i> sp.	1	8H	1,92	2W 3,85
<i>Argna biplicata</i>	1	2W(M)	1,92	2W(M) 69,23
<i>Punctum pygmaeum</i>	1	7M	1,92	7M 3,84
<i>Discus rotundatus</i>	3	2W(M)	5,77	8H 1,92
<i>Vitrinobrachium cf. breve</i>	3	1W	5,77	* 15,39
<i>Limax</i> sp.	1	7M	1,92	
Clausiliidae undet.	1	*	1,92	
<i>Clausilia rugosa pinii</i>	2	2W	3,85	
Helicidae undet.	7	*	13,47	
	52			



Ecologic classes

Fig. 9 - Paleocologic features of molluscan assemblages recorded in S2 sequence (from C1 to C5) in the Pesciola Creek log.

## Pesciola - C8

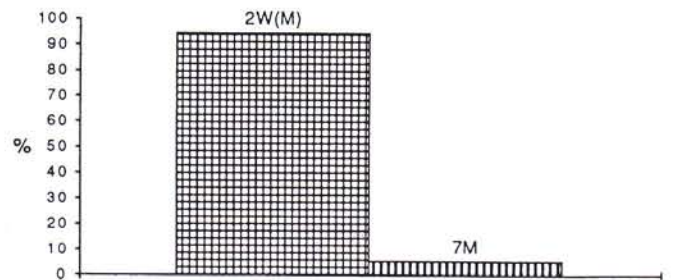
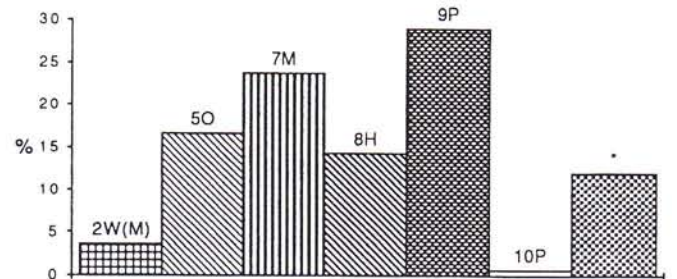
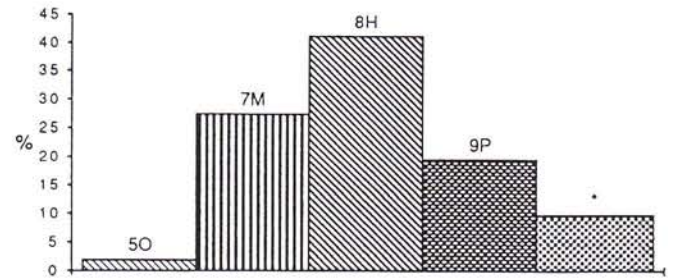
Species	Specim.	Ecol. classes	%	% Ecol. classes	
<i>Carychium</i> sp.	2	8H	3,92	5O	1,96
<i>Vertigo antivertigo</i>	10	9P	19,61	7M	27,45
<i>Vertigo angustior</i>	12	8H	23,53	8H	41,18
<i>Vallonia pulchella</i>	1	5O	1,96	9P	19,61
<i>Succinea oblonga</i>	7	8H	13,73	*	9,80
<i>Punctum pygmaeum</i>	2	7M	3,92		
<i>Milax</i> sp.	3	7M	5,88		
<i>Limax</i> sp.	9	7M	17,65		
Helicidae undet.	5	*	9,80		
	51				

## Pesciola - C7

Species	Specim.	Ecol. classes	%	% Ecol. classes	
<i>Carychium minimum</i>	3	9P	0,98	2W(M)	3,58
<i>Cochlicopa lubrica</i>	18	7M	5,86	5O	16,61
<i>Vertigo antivertigo</i>	47	9P	15,31	7M	23,77
<i>Vertigo angustior</i>	38	9P	12,38	8H	14,33
Pupillidae undet.	17	*	5,54	9P	29,00
<i>Pupilla</i> cf. <i>muscorum</i>	5	5O	1,63	10P	0,66
<i>Pupilla</i> sp.	27	5O	8,79	*	12,05
<i>Vallonia pulchella</i>	19	5O	6,19		
<i>Succinea oblonga</i>	44	8H	14,33		
<i>Oxyloma</i> cf. <i>elegans</i>	1	9P	0,33		
<i>Punctum pygmaeum</i>	8	7M	2,60		
<i>Limax</i> sp.	47	7M	15,31		
Helicidae undet.	20	*	6,51		
<i>Cepaea</i> cf. <i>hortensis</i>	11	2W(M)	3,58		
<i>Pisidium pseudosphaerium</i>	2	10P	0,66		
	307				

## Pesciola - C6

Species	Specim.	Ecol. classes	%	% Ecol. classes	
<i>Pomatias elegans</i> (apex)	35	2W(M)	94,59	2W(M)	94,59
<i>Limax</i> sp.	2	7M	5,41	7M	5,41
	37				



## Ecologic classes

Fig. 10 - Paleocologic features of molluscan assemblages recorded in S2 sequence (from C6 to C8) in the Pesciola Creek log.

stified by the presence of a monospecific assemblage of the ostracod *Candona neglecta* (det. E. Gliozzi) which point to temporary water body subject to drying up.

In the middle part of the section (sample C5) a rich molluscan assemblage with many species and a large number of specimens was found. It is characterized by the dominance of land species. A high percentage (50,72%) of open woodland mesophilous elements (2W(M)) and a fairly good percentage of *Cochlostoma* cf. *patulum* (Plate 1, Fig. 1), a species of open grassland habitat (5O; 15,94%) (Kerney & Cameron, 1979), is detected. Palustral species (8H, 9P, 10SPp) are present in low percentage pointing to temporary small water bodies (marsh, water-course) near a woody area with wide open spaces. At this level the occurrence of the representatives of many genera inhabiting woody area (*Pomatias*, *Acicula*, *Discus*, *Testacella*, *Helicodonta*, *Cepaea*) is indicative of an expansion of the woodland as is clear shown by the paleoecologic spectrum (Fig. 9). The overlaying samples C4a, C4b and C6 yielded only scanty fragments of land snails and apex and opercula of *Poma-*

*tias* indicating a transport of the material. In C6 some micromammal remains represented by fragments of teeth and a molar of rodent of woody environment (*Apodemus* sp.) were also found.

Sample C7, the first above lithofacies g, yielded a rich molluscan assemblage composed of numerous species of different habitat (Fig. 10). Species of marshy environment as *C. minimum*, *V. antivertigo*, *V. angustior* (Plate 1, Fig. 11), *S. oblonga*, *Oxyloma* cf. *elegans*, *Pisidium pseudosphaerium* are dominant (44%, 8H, 9P, 10P); the strictly woodland environment is very scantily represented (2W(M), 3.5%), whilst species of open land without arboreal vegetation, as *P. muscorum* and *V. pulchella* (5O), and mesophilous habitat, as *Cochlicopa lubrica* and *Limax* sp. (7M), are more frequent (40%). The environment was characterized by damp sparsely-vegetated places, as underlined also by the presence of a high number of specimens of *S. oblonga* typical inhabitant of floodplains and marshes (Kerney & Cameron, 1979). The overlaying sample C8 is characterized by a molluscan assemblage with prevailing land hygrophilous ele-

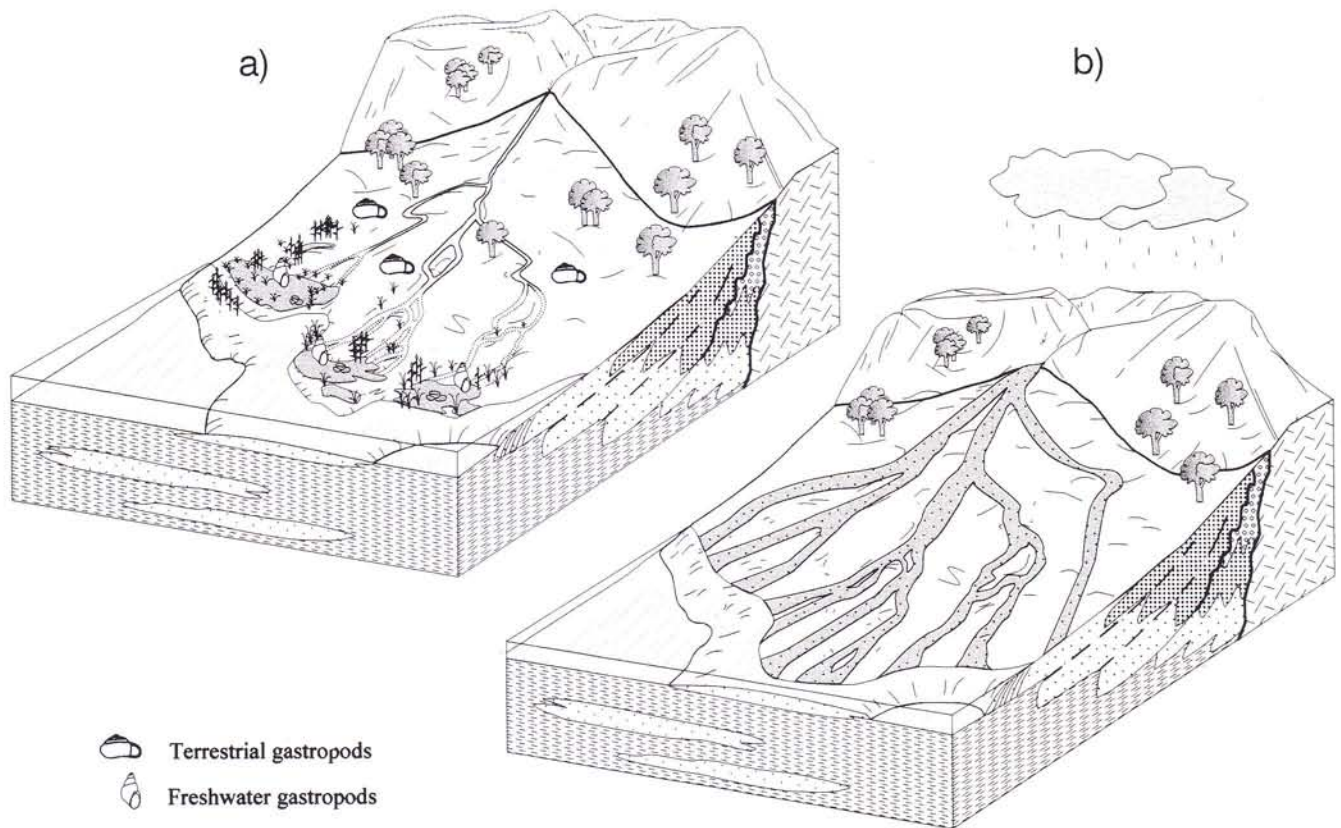


Fig. 11 - Paleoenvironmental reconstruction of the fan delta in the S2 sequence. a) stage of relative high base-level during a period of renewed uplift and tilting with development of ponds and almost complete disactivation of flood distributary channels, b) stage of floods and coarse deposition after a major uplift pulse of the NE shoulder.

ments of palustral environment (60.7%, 8H, 9P) accompanied in a lower percentage (29.4%) by mesophilous species (7M) which can live in more or less wet places.

The paleoecologic significance of the molluscan fauna adds important informations for the paleoenvironmental meaning of these facies sequences. From a sedimentologic point of view the muddy-sandy lithofacies point to a subaerial low-energy depositional environment with prevailing settlement of fine-grained material (lithofacies f1 and f2) occasionally interrupted by deposition from sandy suspensions (lithofacies s1 and s2) possibly related to overland flows. Strong biologic activity of both animal (molluscs) and vegetal (root traces) organisms, as well as pedogenic modification (calcareous nodules), characterized this environment. The dominant yellowish colour of these sediment stems from prevailing subaerial oxidizing conditions, and only the greyish colour of lithofacies f1 suggests reducing conditions probably in temporary poorly-drained environment. Textural features of the channelized gravel beds (lithofacies g) suggest deposition from highly-concentrated flows possibly associated with flood discharges (Benvenuti, 1994).

The malacological analysis of the Pesciola Creek section shows that not great environmental variations occurred during the deposition as pointed out by the presence, more or less constant, of the same genera and

species throughout the section. Moreover the molluscan faunas are generally characterized by mixed assemblages composed of palustrine and terrestrial species and frequently by transported elements.

Most of the molluscs lived in an open woody environment that surrounded the local depositional area recorded in the section. Limited flooded zones (pond, swamp etc.) are recorded in molluscan assemblages of samples C2, C4 and C5. Molluscs of samples C7 and C8 point to a more developed palustrine environment. On the whole the paleoecologic picture shows an environment with localized and temporary humid habitats where a local autochthonous molluscan fauna lived. Molluscs living in nearby open woody habitats (alloctonous molluscan fauna) were transported and deposited in these areas. Integration of sedimentologic and paleoecologic data indicates that the facies sequences in the S2 formed in the subaerial fan deltas by alternating deposition of gravels in shallow flood channels and the development of areas dominated by low-energy, fine-grained deposition. The cyclic stacking pattern of channel and floodplain-like facies could reflect lateral shifting of channels (autocyclic mechanism) or interplay of periodic flood discharges and change of accommodation space in the subaerial portion of the fan deltas (allocyclic mechanism). In this hypothesis channel erosion and

massive gravelly deposition occurred during flood discharges and the floodplain aggradation occurred during rising of the local base-level. The consequent elevation of the water-table enhanced poorly-drained condition in the floodplain giving rise to short-lived humid sub-environments. Variations of local base-level in the subaerial portion of the fan deltas could have been forced by climatic lake-level fluctuations or by deformative pulses associated with the syndepositional uplift of the NE margin of the Mugello Basin (Benvenuti, 1994; 1995). This latter hypothesis (Fig. 11) allows us to put in a unitarian scheme tectonic uplift, basin subsidence, variation of local base-level and changes of sediment supply. During the uplift pulse affecting the NE shoulder the basin underwent rapid subsidence causing a relative rising of the local base-level (i.e. the lake level) and a sudden break in the coarse grained sedimentation with dominant deposition of floodplain-like fine-grained sediments (Fig. 11a). After the tectonic pulse erosion in the catchment provided coarse-grained material which was redistributed in the fan deltas by flood discharges generated from intense rainfalls possibly amplified by orographic controls (Fig. 11b). A fining-upward facies sequence reflects therefore a high-frequency uplift/denudational cycle as recorded in flood-dominated fan deltas (see also Mutti et al., 1996).

### Conclusion.

The main results of the present study can be summarized in the following points:

1) the integration of stratigraphic and paleontological (molluscan faunas) revisions of the Plio-Pleistocene fluvio-lacustrine deposits of the Mugello Basin resulted in a better definition of the paleoenvironmental evolution of this basin. The gravelly, sandy and silty deposits of sequences S1 and S2 interpreted from facies analysis to be deposited in lacustrine, flood-dominated fan deltas contain different genera and species of molluscs which are paleoecologically in accordance with a fluvio-lacustrine settings. Moreover these molluscs provided detailed information on both local vegetational and edaphic conditions during the deposition which are not directly detectable from facies analysis;

2) from a biochronologic point of view the molluscan assemblages of sequence S1 are characterized by the presence of extinct Villafranchian taxa such as the aquatic species *T. belnensis*, *E. cf. umbra* and *P. oblonga* which are in accordance with the late Villafranchian (latest Pliocene-early Pleistocene) mammal assemblages collected in the fan-delta and lacustrine deposits of the STE;

3) the distribution of the molluscan assemblages appears to have been strongly controlled by facies and this dependence reflects at different scales the tectonically-influenced dynamic of the basin fill during the fluvio-lacustrine phase. At the scale of the whole fluvio-lacustrine basin-fill the lack of the aquatic Villafranchian species in the S2 and the prevalence of terrestrial taxa could be due to the progressive progradation of coarse-grained, subaerial facies forced by syndepositional uplift and tilting of the NE shoulder of the basin with gradual reduction of flooded habitats.

The molluscan assemblages in the fining-upward facies sequences forming the architecture of the sequence S2 (also common in S1), record the periodic development of a poorly-drained floodplain-like environment surrounded by open forests. The former habitat developed when cyclic abrupt base-level rise deactivated the fan delta. Variations in base-level and sediment supply are here considered the consequence of high-frequency uplift/denudational cycles.

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