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Geology of the Monticino Quarry, Brisighella, Italy. Stratigraphic implications of its late Messinian mammal fauna

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ABSTRACT — The rich, diverse and good preserved, though fragmentary continental vertebrate fauna (including micro-and mega-forms) found recently in the Monticino Quarry near Faenza (Vena del Gesso Basin, Northern Apennines) was correlated with the late MN13 mammal zone.

This finding is of primary stratigraphic importance, enabling independent age calibrations. The fauna was always found inside the late Messinian Colombacci Fm. The fauna is predated by the evaporitic (early to middle Messinian) and is confined within the 3r reversed chron; it is particularly well postdated by the basal early Pliocene Sphaeroidinellopsis *(MPL1) Zone, by the lower* Amaurolithus tricorniculatus *Zone and by the Thvera (3.3) subchron.*

Three main biostratonomic and taphonomic settings of the bones were recognized: 1) partly karstified sedimentary dike fills and mechanical concentrations (bones, originally preserved within alluvial plain muds, were first disarticulated, transported and redeposited in a brackish environment and finally injected along with pebbly mudstone within partly karstified, late Messinian neptunian dykes); 2) biological concentrations in karst holes (symmetric collections of left and right micromammal teeth have been interpreted as karst hole concentrations where predator birds lived; in this case the micromammal fauna would predate slightly the Colombacci Fm and correspond to the early late Messinian emersion interval; the bone nests have been later incorporated as a whole within the Colombacci matrix during the late Messinian tectonic reactivation, injecting and infilling of karstified sedimentary dyke system); 3) pocket-like concentrations inside the in situ *Colombacci Fm (they occur close to the top fill of neptunian dykes and their fauna is coeval with the supporting Colombacci clay, i.e. latest Messinian).*

This contribution improves the correlations between the continental (and Paratethys), the standard stratigraphic marine (Mediterranean) and the biostratigraphic oceanic scales.

The eastern affinity of the Adriatic Monticino mammal fauna and its difference from the coeval Baccinello V3 Tyrrhenian one suggest connection of the emergent Adriatic Apennine with the eastern land masses and separation from the Tyrrhenian islands during the Messinian.

Once more, the question arises of the physical connections between Paratethys and eastern-central Mediterranean through a Iulian-Istrian and a Ionian corridor during the late Messinian.

RIASSUNTO — [Geologia della Cava Monticino, Brisighella, Italia. Implicazioni della sua fauna a mammiferi tardo messiniana]. *— La fauna a vertebrati continentali (macro e micro), ricca, varia e ben conservata, trovata da poco nella Cava Monticino (Vena del Gesso faentina, Appennino Settentrionale) è stata correlata con la zona a mammiferi MN 13 superiore.*

La straordinaria importanza stratigrafica della fauna sta nel fatto che essa permette una calibratura cronologica indipendente. La fauna infatti è sempre contenuta nella F. a Colombacci del Messiniano superiore, è preceduta dal Messiniano inferiore-medio evaporitico, è confinata nel crono rovescio 3r ed è suturata dal Pliocene inferiore basale con la Zona a Sphaeroidinellopsis*, la Zona inferiore ad* A. tricorniculatus *e il subcrono Thvera (3.3).*

Le ossa si trovano in tre disposizioni biostratinomiche e tafonomiche principali: 1) riempimenti e concentrazioni meccaniche in filoni sedimentari in parte carsificati (gli scheletri, originariamente sepolti in peliti di piana alluvionale, sono stati prima disarticolati, poi trasportati e ridepositati in ambiente salmastro lagunare e infine iniettati insieme con fanghi ciottolosi dentro filoni sedimentari del Messiniano superiore in parte carsificati); 2) concentrazioni biologiche in cavità carsiche (collezioni simmetriche di denti destri e sinistri di micromammiferi interpretate come boli di uccelli predatori; in questo caso la fauna a micromammiferi dovrebbe precedere di poco la F. a Colombacci e essersi accumulata nelle cavità gessose durante l'emersione all'inizio del tardo Messiniano; i resti di ossa sarebbero poi stati incorporati in massa nella matrice della F. a Colombacci durante la riattivazione tettonica tardo messiniana che ha provocato iniezione e riempimento dei filoni sedimentari originati lungo le fessure carsiche precedenti); 3) concentrazioni in tasche all'interno della F. a Colombacci in situ *(si trovano per lo più sulla verticale di filoni sedimentari e la loro fauna è coeva con le peliti incassanti della F. a Colombacci).*

La nuova fauna migliora le correlazioni fra la scala stratigrafica continentale e paratetidea, la scala stratigrafica standard marina e mediterranea e le scale biostratigrafiche oceaniche in un momento chiave come il limite Messiniano/Pliocene.

L'affinità orientale della fauna a mammiferi adriatica del Monticino e la sua differenza rispetto alla coeva fauna tirrenica di Baccinello V3 indicano una connessione dell'Appennino adriatico emerso con le terre orientali e una sua separazione rispetto alle isole tirreniche durante il Messinano.

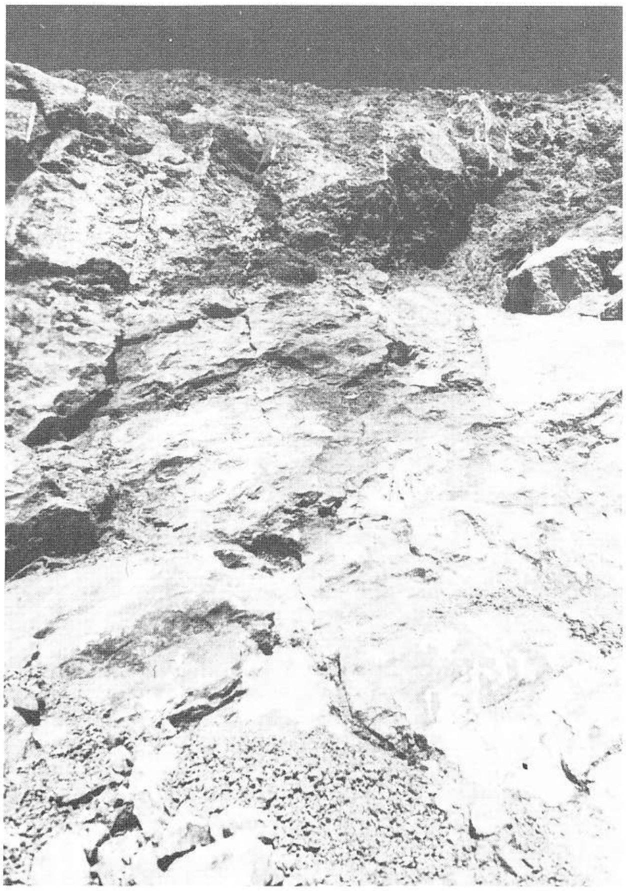
Si fa così ancora più pressante il problema della connessione fisica fra Paratetide e Mediterraneo centro-orientale mediante vie d'acqua giulio-istriana e ionica durante il Messiniano superiore.

Text-fig. 1 - Western part of Monticino gypsum quarry in 1987. Old and new quarry floor are shown. Notice a steep dipping gypsum bedding plane in the upper half. Notice, by contrast, the chaotic setting of the lower quarry wall.

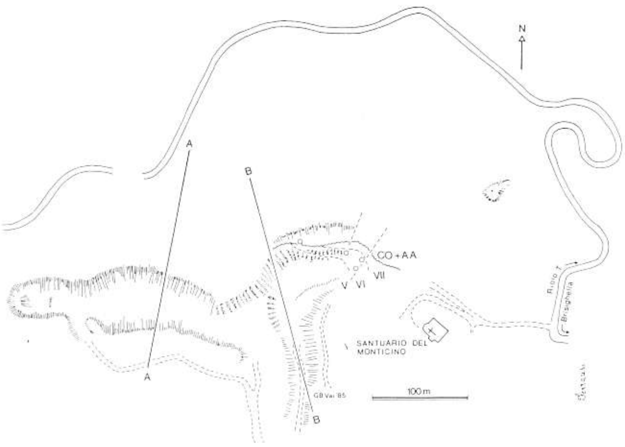
The Monticino gypsum quarry is located inside the thrust belt of the Romagna Apennines at the crossing with the Lamone river valley. This thrust belt is part of the outer Northern Apennines (see Vai, 1989). The quarry is known to the geological community as one of the type localities for Messinian evaporite stratigraphy and sedimentology (Borsetti, 1956; Vai & Ricci Lucchi, 1977) and for the intra-Messinian tectonic phase (Marabini & Vai, 1985; Castellarin *et al.* 1986; Patacca & Scandone, 1987).

Within and around the quarry, the four main formations building the Romagna Apennines are exposed: namely the upper part of the Marnoso-arenacea, the Gessoso-solfifera, the Colombacci and the lower part of the Argille Azzurre Fms (Vai, 1989, Text-figs. 5, 10). The quarry stratigraphy and sedimentology has been investigated for a long time in this crucial site at the eastern end of the Messinian Vena del Gesso Basin (Vai & Ricci Lucchi, 1977) that represents an important stage within the Apennine Foredeep development (Ricci Lucchi, 1975, 1986). A recent account on the Vena del Gesso regional mapping, facies analysis and structural geology was done by Marabini & Vai (1985). Update reviews of regional Tertiary to Quaternary stratigraphy and synsedimentary tectonics (Ricci Lucchi *et al.*, 1982; Ricci Lucchi, 1986) and of regional structural setting (Castellarin *et al.*, 1986a, 1986b; Castellarin & Vai, 1986) can act as useful introduction to the geology of the Northern Apennine - Padan margin. For a general overview on the Northern Apennine kinematic history and structural zonation, on Romagna Apennine stratigraphy and on northern Italian palaeographic evolution since the Burdigalian the reader can refer to Vai, (1989).

Thanks to the quarrying operations and to the enthusiastic survey of an amateur geologist (Tonino Benericetti from Zattaglia) a rich late Messinian continental vertebrate fauna, associated with many Paratethys faunal elements and capped by marine earliest Pliocene Mediterranean fauna, was found and syste-



Text-fig. 2 - About 20 m high eastern wall of the Monticino Quarry cut by karstified neptunian dykes yielding large amount of bones (about 20 m high).



Text-fig. 3 - Cross topography of the Monticino Quarry, with position of the cross sections (Text-fig. 15).

matically collected since 1985 (Costa *et al.*, 1986; De Giuli *et al.*, 1986).

Quarrying will be stopped within a couple of years at Monticino for reasons of environmental impact and best use of land resources. Regional and local Authorities have agreed to build up an open air natural science museum (wich will be part of Brisighella city park) starting from the former quarry site, to allow preservation of geological exposures for scientific, educational and cultural purposes.

Aim of this contribution is to provide the basic stratigraphic and structural frame of the Monticino quarry area, to describe the stratigraphic sections measured and sampled for specialist investigations, to discuss taphononomy and biostratinomy of the vertebrate fauna and to summarize its stratigraphic, geologic and environmental implications.

STRATIGRAPHY AND AGE

The new Monticino vertebrate fauna was first found in 1985 (Costa *et al.*, 1986) and is still being collected following the exploiting operations mainly in the eastern part of the quarry where a thin blanket of Colombacci Fm (0,5 to 2,5 m) underlies continuously and conformably the Argille Azzurre Fm. Both units rest with spectacular angular unconformity (Text-figs. 4, 6, 15, 18) on a strongly deformed, backtrusted middle Messinian evaporite unit (Marabini & Vai, 1985) (Text-figs. 15b and Text-fig. 23).

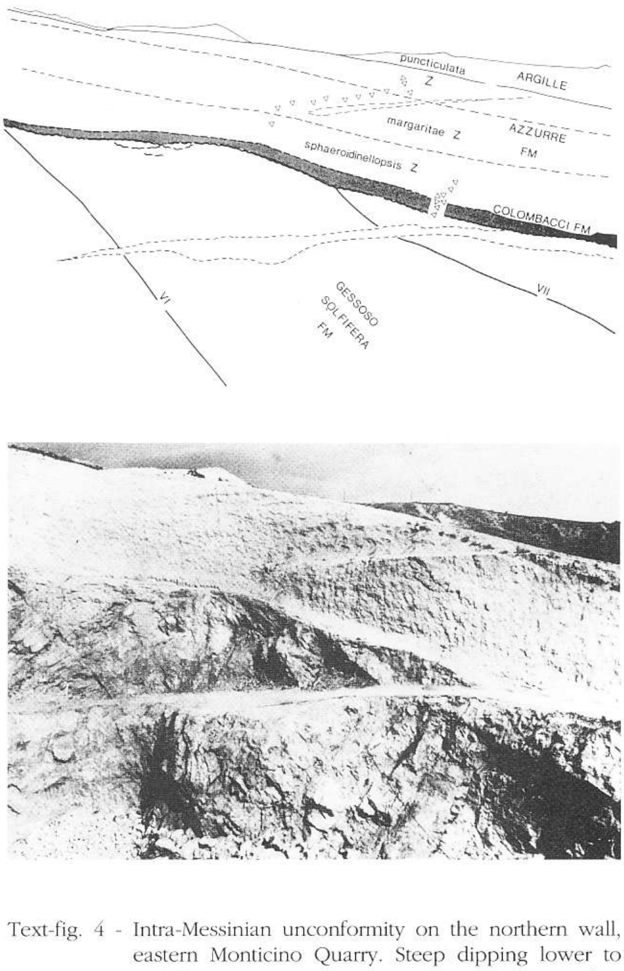
The thrust plane is developed inside the lower Messinian euxinic shales at the top of the Marnoso-arenacea Fm. A detailed stratigraphy of the pre-evaporitic and evaporitic Messinian of this area has been provided by Vai & Ricci Lucchi (1977) and Marabini & Vai (1985) (see also Vai, 1989, Text-fig. 10).

As for the Colombacci Fm., the Monticino Quarry area is included within the W Romagna thin intrafacies (Cremonini & Marabini, 1982; Vai, 1989). Inside the quarry, the Colombacci Fm never exceeds 2,5 m of thickness with a gradual southwestward pinch-out. The following informal units and lithotypes have been ricognized in the quarry from the bottom (Text-fig. 5).

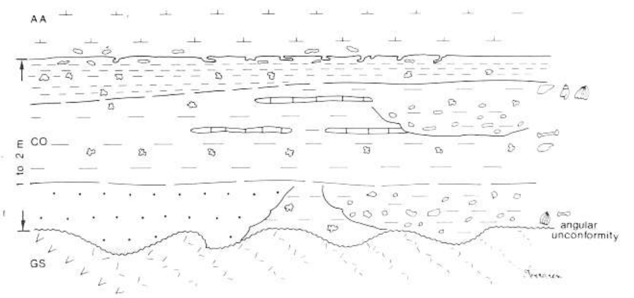
1) discontinuous pedogenic pocket-like *terra rossa* horizon.

2) 20 to 60 cm of grey to green silty clays with carbonate concretions and scattered *Dreissena-Melanopsis* fauna; they are laterally channelized and refilled with either yellowish *Limnocardium* sand or with mud-supported polygenic conglomerate and breccias containing few loose bone and fragments.

3) 60 to 100 cm of $CaCO_3$ concretion-rich grey-green-brown varicoloured silty clay up to light marly



Text-fig. 4 - Intra-Messinian unconformity on the northern wall, eastern Monticino Quarry. Steep dipping lower to middle Messinian gypsum evaporites are unconformably overlain by faintly bedded gentle dipping Colombacci and Argille Azzurre Fms. (upper Messinian and earliest Pliocene). Planktic foraminifera biozones are shown in the sketch above, where roman numbers refer to gypsum cycles and open triangles point to sampling sites.



Text-fig. 5 - Stratigraphic scheme of the upper Messinian Colombacci Fm in the eastern Monticino Quarry (legend to symbols see Text-fig. 7).

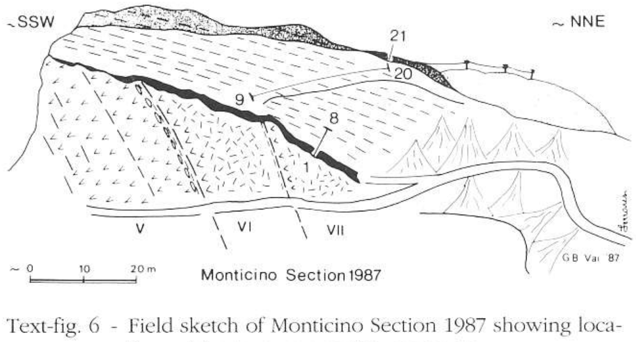
(Colombacci like) thin discontinuous layers (at least two); this unit too is laterally channelized by mud-supported polygenic conglomerates; mollusks are frequent. At a peculiar place (see below) a pocket-like filling of olive-green silty *Cyprideis* clay rich of micro-vertebrate bones was found.

4) 20 to 40 cm of bioturbated, concretion-bearing, mollusk-rich dark clay.

The mollusk fauna, the lithotypes and the sedimentary structures suggest a flat, brackish, shallow environment not far from a distributary channel system and from an alluvial fresh water plain. Periodical retreat of brackish water (at least two) made possible oscillation of water table and development of connected two main $CaCO_3$ concretion rich horizons. The basal *terra rossa* horizon support a major emersion interval with karst development at expenses of gypsum evaporites followed by the transgression of the Colombacci Fm

Two different stratigraphic sections have been measured some tens of metres apart each other across the Colombacci Fm and the overlying Argille Azzurre Fm at different stages of the quarrying activity: the Monticino 1985 (Costa *et al.*, 1986) and 1987 sections (Text-figs. 7, 8).

The second section was the object of coordinated specialist investigations (Bertolani-Marchetti & Marzi, Colalongo, De Giuli *et al.*, Rio & Negri, Taviani, Vigliotti, 1988) and will be descrived and commented with some details.



Text-fig. 6 - Field sketch of Monticino Section 1987 showing location of the two composing segments.

THE MONTICINO 1987 SECTION

DESCRIPTION

1) *Bottom* — Steep dipping *Gessoso-solfifera Fm* (Text-fig. 7) cross-cut by different magnitude fracture systems filled with lithotypes of the overlying Colombacci Fm.

The Gessoso-solfifera Fm is represented here by the seventh evaporitic cycle (Vai, 1989). A sharp, major *angular unconformity* truncates obliquely the evaporitic suite. It is taken as an example of intra-Messinian phase unconformity (Marabini & Vai, 1985).

The unconformity surface on the evaporites shows decametric to decimetric sized (m to cm deep) wavy karst morphology documented by thin residual pocket-like *terra rossa* deposits. Larger erosional features are usually connected with major fracture systems.

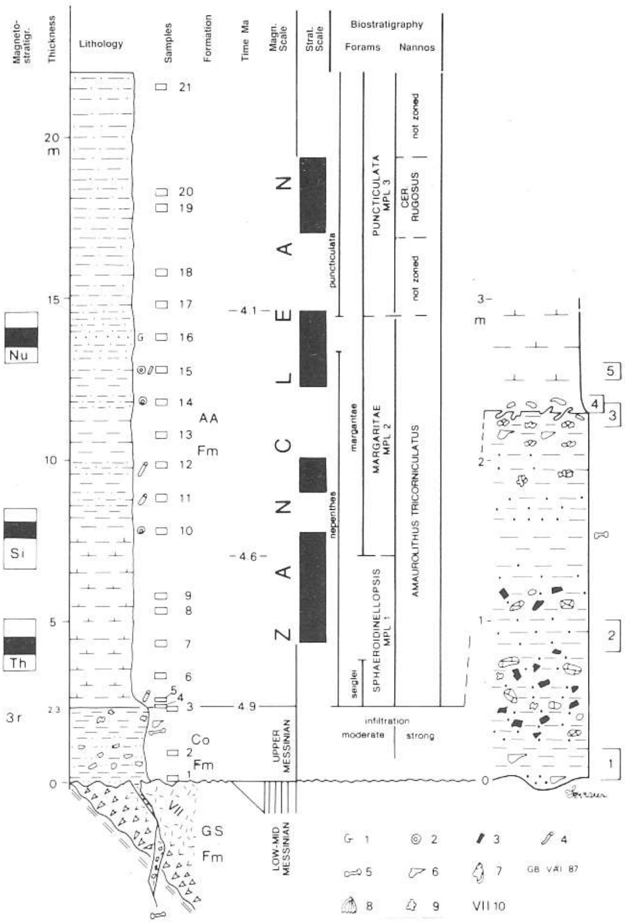
2) *Colombacci Fm* — It is represented by 2.3 metres of alternating dark-grey to green, brown and black brackish clays and fine grained, silt to fine sand-supported rudite, including green-gray to blackish ripped-up angular clasts, mollusc fragments, small possibly reworked concretions and well-rounded lithic pebbles (mainly carbonates up to 5-6 cm of size). A *caliche* horizon is almost developed in the uppermost blackish clay. *Limnocardium* sp. was found at the very silty-sandy base. Rich, small mollusc assemblages of brackish water *(Dreissena, Limnocardium, Melanopsis,* etc.) are common in the upper part, where a few loose bones occur.

The transition to the overlying Fm is sharp (particularly due to the color change).

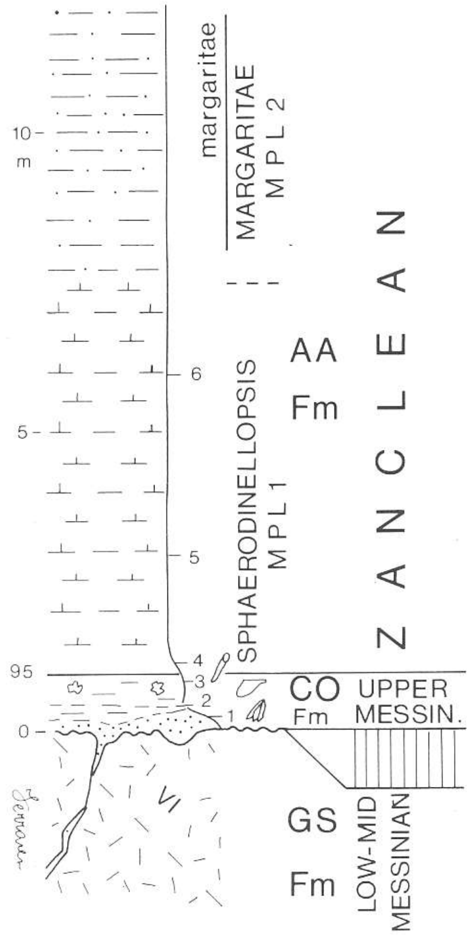
3) *Argille Azzurre Fm* — It follows conformably and continuosly the Colombacci Fm. The basal unit is caracteristically a bioturbation horizon (Vai, 1981) produced by the feeding processes of larger (molluscs, echinids, etc.) Trubi-linked scavangers (drilled holes up to 5-6 cm in diameter).

A massive, light-grey, Trubi-like, 5 to 6 m thick clayey interval can be distinguished, after which silty intercalations with pirite-marcasite nodules are getting frequent within the blue-grey clays. Shortly before 14 m from the base of the section (i.e. 11,5 m above the base of AA Fm) a bioturbated silty-sandy bed (5-7 cm) rich of coarse sandy sized glauconite particles occurs.

No futher variation was noticed up to the top of measured section encompassing 18 m of AA Fm. Further analytical data on this same section concerning foraminifera and nannofossils biostratigraphy and magne-



Text-fig. 7 - Stratigraphic column of Monticino Section 1987. 1) glauconite; 2) marcasite nodules; 3) wood fragments; 4) bioturbation; 5) bones; 6) molluscs *(Dreissena)*; 7) *Melanopsis*; 8) *Limnocardium*; 9) Ca concretions; VII, evaporite cycle.



Text-fig. 8 - Stratigraphic column of Monticino Section 1985 (legend to symbols as in Text-fig. 7).

tostratigraphy are found in Colalongo, Rio & Negri, and Vigliotti (1988). Data on mollusks and palynomorphs (Taviani and Bertolani-Marchetti & Marzi, 1988) come from other sections of the same quarry (mainly the Monticino section 1985).

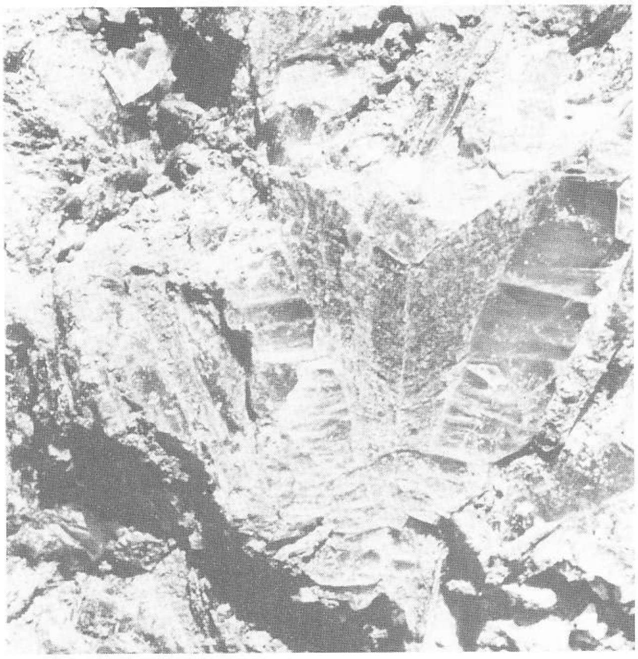
DISCUSSION

The first point concernes the nature of the boundary between Colombacci and Argille Azzurre Fms. It represents an environmental jump from brackish (and possibly short sub-aerial exposure) to bathial marine water, but it is continuous in term of geologic time resolution.

Evidence of continuity are independently provided by foraminifera (Colalongo 1988), nannofossils (Rio & Negri, 1988), biostratigraphy and by magnetostratigraphy (Vigliotti, 1988) (see Text-fig. 7).

Both biostratigraphic scales show an upper Messinian interval (the Colombacci Fm) characterized by poor fossiliferous evidences except reworking of older Miocene and prominent infiltration of younger Pliocene forms. Pattern of infiltration are worth mentioning. Infiltration occurs in all three Colombacci Fm samples. However, it is moderate for foraminifera and strong for nannofossils (one order of magnitude less in size).

Infiltration is self explanatory for sample 3, where large diameter bioturbation occur and can esily be assumed at a narrower scale for the entire very thin Colombacci interval. Moreover, the early compaction and lithification which can be expected for this Colombacci environment may suggest easy development of a micro-net of tectonically linked fractures and fissures (neptunian dykes), which in turn would have allowed infiltration of early Pliocene mud and fossils. At any



Text-fig. 9 - Swallow-tail primary twin gypsum crystal with seasonal, algae-draped growth facies and clear diagenetic syntaxial overgrowth on sides. Basal part of cycle VII massive selenite. The bifurcate tail is a good tool for stratigraphic polarity. Crystal size about 5 cm.

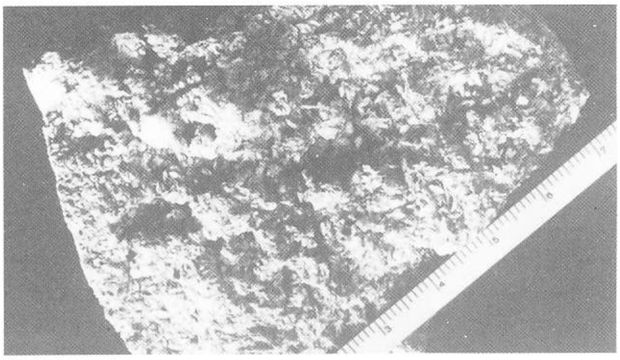
rate, the best typical earliest Pliocene assemblage seems to be preserved within the scavanger tunnels or the microneptunian dykes.

Foram- and nannos-biostratigraphy also provide a good documentation of the earliest Pliocene MPl1 (*Sphaeroidinellopsis*) Zone. The base of Pliocene is calibrated to 4.87 Ma according to the new ODP results (see below).

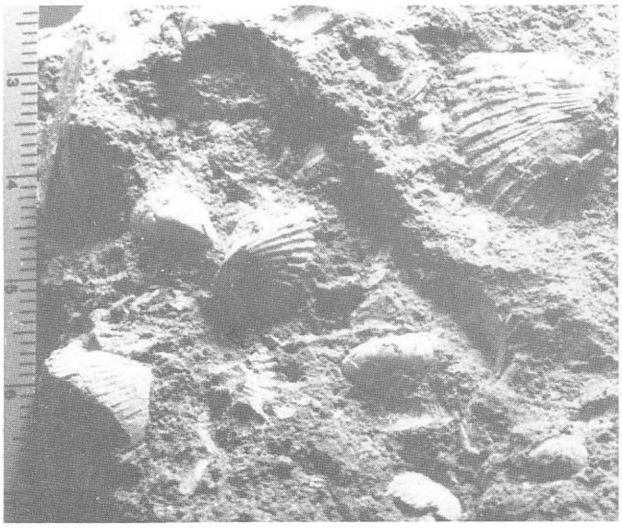
In the same way, both the lowermost Pliocene Thvera (3.3) normal magnetostratigraphic subchron and the 3r reversed chron bridging the Messinian/ Pliocene boundary have been recognized in the section (Text-fig. 7) (Vigliotti, 1988, fig. 2) (Vai, 1989, Text-fig. 4).

Furthermore, the Sidufjall (3.2r-1) subchron and the Nunivak (3.2) chron have also been recognized within the MPl2 biostratigraphic interval, whereas the following Cochiti (3.1) chron has been either bypassed by the sampling (less likely) or not reached with the section (Text-fig. 7) (Vigliotti, 1988, fig. 2).

The second point refers to age and time span of the Colombacci Fm in this section. A main line of evidence can be followed based on pollen biostratigraphy (Bertolani-Marchetti & Marzi, 1988). Their detailed pollen-curve through the Colombacci section shows clear cyclic climatic variations (at least two and half cycles). Assuming an overall cyclicity of about 10^5a for each of the six major Colombacci cycles and further



Text-fig. 10 - Partly silicified (chalcedony) *Paludina coquina*. Basal Colombacci Fm, M. Mauro area.



Text-fig. 11 - Disarticulated valves of Limnocardids (three different species) and *Dreissena* within a gray-green silty clay, from the *in situ* Colombacci Fm, Monticino Quarry.

Text-fig. 12 - Westward thinning out of the dark Colombacci Fm at the base of the light, Trubi-like marls of the *Sphaeroidinellopsis* Zone (MPl1, earliest Pliocene). The floor of the trench is the top of the gypsum evaporites.

Text-fig. 13 - Hammer points to the sharp contact between dark Colombacci Fm (with a discontinuous calcareous Colombaccio layer) and light earliest Pliocene marls of Argille Azzurre Fm.

correlating the Colombacci cycle with the pollen-climatic cycle shown in this section, the time span represented here would be about 2 to $3 \cdot 10^5$a.

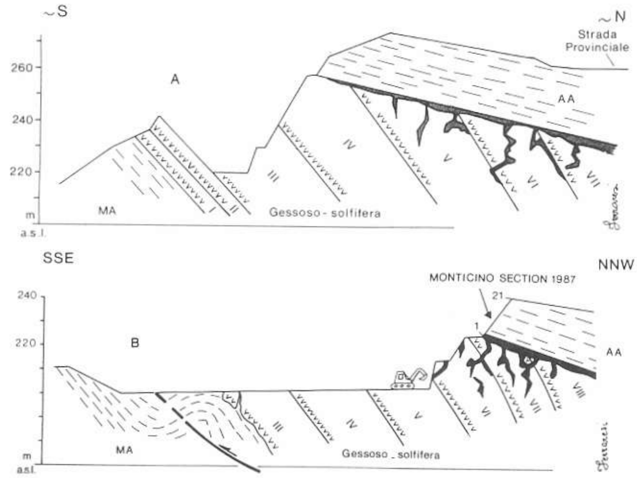
The third point is related to the mainly carbonate, rounded pebbles contained in the mud-supported conglomerates and eroded almost exclusively from the underlying Gessoso-solfifera Fm and from the same Colombacci Fm. They suggest 1) a short transport distance linked by a step-like topography and 2) a local, still active, emergent thrust culmination of the Gessoso-solfifera Fm (and of part of the Colombacci Fm) separated from a main, SW-located chain by means of an intervening, lacustrine to brackish depression able to stop supply of exotic material.

The fourth point relates to the lower Pliocene sequence recorded in the measured section. The sequence of the first three normal intra-Gilbert chrons and subchron have been recognized in the section (Vigliotti, 1988). However, the thickness of the MPl2 *(margaritae)* Zone is considerably thin and the nannos zonation, after a fully developed A. *tricorniculatus* Zone, presents some difficulties in recognizing the *C. rugosus* Zone, just close to the major occurrence of glauconite in this section

This event is most likely related to the new, late early Pliocene trasgression after the *puncticulata* tectonic phase (Vai, 1989) responsible for major disconformity to unconformity in many places of the Adriatic Foredeep (Ricci Lucchi *et al.*, 1982; Patacca & Scandone 1986, 1987). At any rate the occurrence of *H. selli* (devoid of *P. lacunosa* concurrence) in samples 19 and 20 is fully consistent with the MPl3 *(puncticulata)* Zone. As for the underlying Colombacci Fm, here too we have evidence of increasing and persisting very low sedimentation rate (about 10 m/Ma as compared with frequent 200 to 500 m/Ma).

The Monticino area, therefore, show almost con-

Text-fig. 14 - Fossiliferous (brackish molluscs) bioturbated Colombacci Fm (with marked 20 cm thick apical black clay horizon) conformably overlain by whitish, benthos and plankton-rich Trubi-like marls. Notice large, 2 cm thick, dark burrow infiled with the underlying black clay material. Hammer point for scale.



Text-fig. 15 - Cross sections of the Monticino Quarry.

tinuous sedimentation from the late Messinian Colombacci Fm to the Zanclean *puncticulata* Zone. However, structural high condition especially developed during the Colombacci and *margaritae* intervals, resulted in a strongly condensed sedimentation where omission and elision surfaces are too short and weak to be detected and are statistically dispersed across the sequence. This allows preservation of regular and complete superposition of units in both magnetostratigraphic and biostratigraphic scales.

Finally, the Monticino Quarry magnetostratigraphy (Vigliotti, 1988) fully supports the new ODP calibration of the Miocene/Pliocene boundary at 4.87 Ma [less than 2 m below the Thvera chron (sample 7, Text-fig. 7) whose duration is calibrated from 4.57 to 4.77 Ma (Vigliotti, 1988)]. The new age of the boundary was, therefore, adopted in this paper.

DEFORMATION PHASES

Deformation phases detected in the field by correlative angular unconformities as shown in Text-fig. 23 , are as follows.

a) Intra-Messinian phase, characterized by strong developed thrust sheets verging toward the Po Plain with back-thrust commonly associated with the «frontal anticline» (pop-up). Back-thrust are more frequent and prominent close to transversal and tear faults (transpressive conditions); they are best exposed in brittle lithotypes like the Gessoso-solfifera Fm. This is the most severe phase affecting the area, especially the Monticino surrounding where it forms a spectacular angular unconformity (Text-figs. 4, 6, 15, 18).

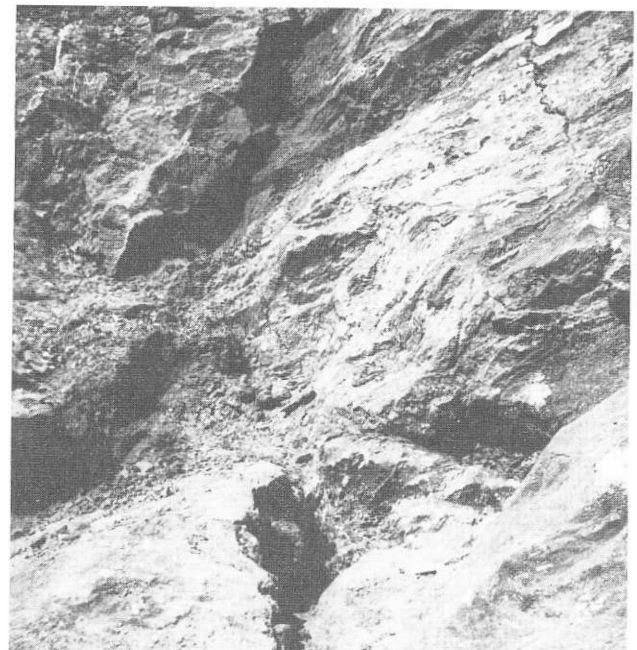
b) Late Messinian and intra-Pliocene phases are only suggested here by the two strongly condensed intervals during the Colombacci and the *margaritae* deposition. A further possible disconformity to unconformity of middle to upper Pliocene age reported on the Faenza sheet (1:100.000 Geological Map of Italy) was not checked in detail.

A direct response to the intra-Pliocene phases is the onset of the carbonate shoal deposition («spungone», Cremonini *et al.*, 1982) outcropping a few km to the NE.

c) Two relatively important Pleistocene phases have been recognized in the intra-Sabbie gialle (middle Pleistocene) unconformity and the unconformity at the base of the (late Pleistocene) Olmatello Fm (Vai, 1989).

STRUCTURAL SETTING

The Monticino Quarry is just located upon a «frontal anticline» of a thrust sheet verging toward the Po Plain severely affecting the pre-Colombacci terrains



Text-fig. 16 - Detail of Text-fig. 2 showing prominent, karstified neptunian dyke filled with mud-supported conglomerate yielding large amount of bones.

(Text-fig. 15) and mainly buried beneath the sealing Colombacci to Argille Azzurre Fms.

The intra-Messinian building is tightly associated with some neptunian dyke systems filled by the Colombacci Fm lithotypes and rejuvenated in middle to late Pleistocene time.

Within the quarry, the gypsum setting is usually represented by a steep dipping monocline (Text-fig. 15A) passing westward to an asymmetrical fold (SW limb dipping up to 45° and NE limb up to 60). The cover sequence (Colombacci and Argille Azzurre Fms) forms a monocline gentle dipping toward NE (30°-20°).

The SE part of the quarry still shows a complex pseudodiapiric folded to chaotic structure of the preavaporitic euxinic marly clay with tectonic elision of the lower gypsum cycles (Text-fig. 15B). The fault surface of Text-fig. 15B is assumed to be part of a transpressive back-thrust system.

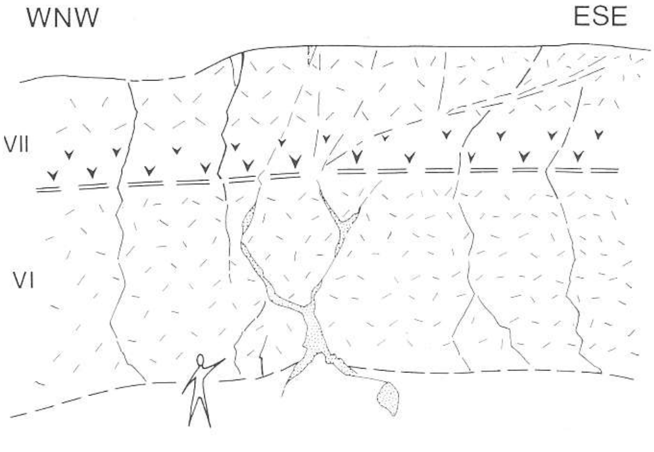
BIOSTRATINOMY AND TAPHONOMY

The major amount of concentrated land vertebrate bones have been found inside or at the top of holes connected by a complex network of karstified clefts and neptunian dykes cutting across the whole gypsum evaporite sequence and filled with lithotypes of the overlying Colombacci Fm. Loose bones or fragments, however, are scattered also within the Colombacci Fm. in its proper stratigraphic *(in situ)* position.

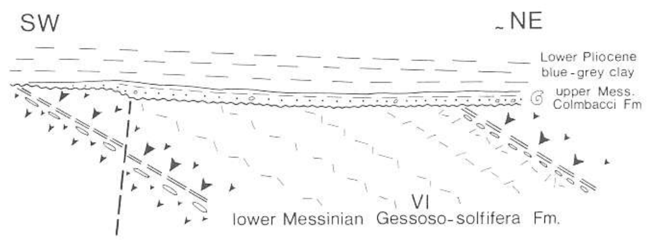
SEDIMENTARY DYKE FILLS AND MECHANICAL CONCENTRATION (Text-fig. 16-21).

They were already know in the quarry and were described from many parts of the Vena del Gesso Basin (Marabini & Vai, 1985). They form a dense, irregular net of medium (meter-size) to fine (cm-size) sedimentary dykes, statistically trending as the main strike-slip fault systems, which intersects the thick-bedded evaporites of the Gessoso-solfifera Fm from the erosional top to its bottom. The infilling occured in two phases (Text-fig. 19).

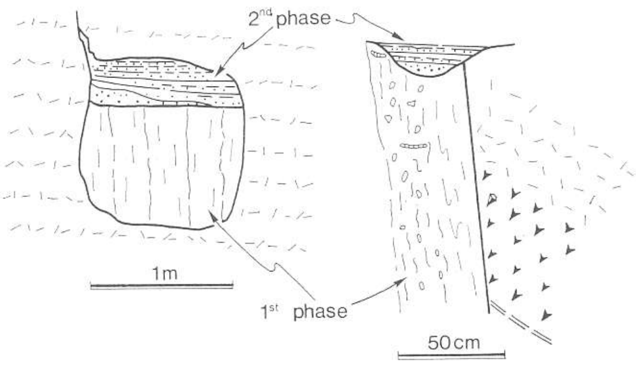
The first phase was characterized by the isoclinally folded to chaotic structure of the infilled material, with banding markedly parallel to the dyke walls. This setting, emphasized by the different lithotypes swallowed in the dykes, suggest an emplacement by injection (underpressure in the opening dyke holes plus hydrostatic and lithostatic load) (Castellarin, 1982). The infilling material of this phase, besides a few gypsum fragments scraped off the walls, consists exclusively of all different lithotypes of the Colombacci Fm which unconformably overlies the evaporites in the same Monticino Quarry (Text-fig. 15). The main local lithotypes are: olive-green silty clay, calcrete-rich light-



Text-fig. 17 - North-eastern front of Monticino Quarry. Irregular, anastomosed net of sedimentary dykes cutting across the Lower Messinian evaporites (numbered according to the major evaporitic cycles). Dotted areas represent major, bone-rich Colombacci Fm bodies filling the sedimentary dykes (after Costa *et al*, 1986).



Text-fig. 18 - North-western front of Monticino Quarry, showing angular unconformity between gypsum evaporites and the Colombacci Fm housing pocket-like concentration of small vertebrate bones (after Costa *et al.*, 1986).



Text-fig. 19 - Two-phase infilling of sedimentary dykes cutting across the gypsum evaporites (Lower Messinian). Infilled material consists of Upper Messinian Colombacci Fm (1 st phase) and Pleistocene sandy clay (2nd phase) (after Costa *et al.*, 1986).

Text-fig. 20 - Thick sedimentary dyke cutting across the gypsum layers (light grey) and filled with bone-bearing mud-supported conglomerates.

green clay, limestone paraconglomerate, brown *Melanopsis* and *Dreissena* clay, bluegreen clay, dark *Cyprideis* clay. Paraconglomerates are more abundant in the infilled material than in the *in situ* preserved Colombacci Fm. This can be explained by both the original setting of the conglomerates and their subsequent mechanical sorting and concentration; it can have occurred during the injectional filling process and by a filtering effect linked to the variable mesh of the irregular dyke net. The location of primary shoe-string-like paraconglomerate bodies, commonly recognized in the Colombacci Fm, seems to have been directly controlled by the major transversal strike-slip faults, which are also responsible for development of sedimentary dykes, at least in the Vena del Gesso area (Marabini & Vai, 1985).

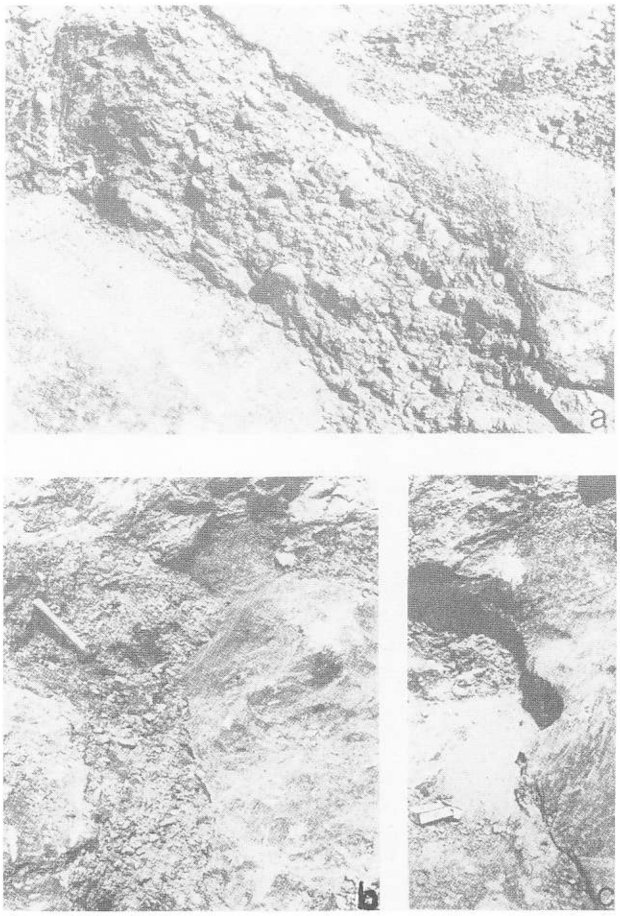
The second phase filling is characterized by a flat lying, gravitative, fine bedded, fining-upward sequence made up by alternating yellowish sand and gray silty clay of still undetermined (possibly Pleistocene) age.

The vertebrate fauna is limited to the first filling phase. It is exclusively associated with the Colombacci Fm lithotypes, mainly the paraconglomerates and the concretion-rich light-green clay. The state of preservation of disarticulated bones is usually excellent, due to their mud-supported setting.

The dyke walls are usually plane, almost parallel each other. However, dm-size (exceptionally m-size, see Text-fig. 19) hemispherical depressions can often be observed. They suggest a palaeokarst-modeling phase enlarging previous fracture systems, and predating the major sedimentary dyke development.

Biological concentration in karst holes

Some ot the richest collecting sites show almost the same number of right and left teeth and the same



Text-fig. 21 - a) Chaotic (injection) structure of the mud-supported conglomerate infilling a) sedimentary dyke; b) sphaerical hole connecting segments of sedimentary dykes. c) Small-scale (cm-size) palaeokarst depressions preserved in the straight wall of a sedimentary dyke.

transport for bones formed in these sites. Moreover, it implies that concentration occurred before deposition and/or emplacement of the matrix supporting the bones, i.e. the Colombacci Fm.

De Giuli *et al.*, (1988) suggest a biological concentration mechanism due to predator birds living in the former karst holes. Implications arising from this interpretation concern age and biostratinomy of the micromammal remains found in these sites. The age of these biologically concentrated micromammal nests would predate the Colombacci deposits of the quarry and correspond most likely to the early-late Messinian emersion interval. The present floating setting of the bones within the Colombacci matrix would have been accomplished during the subsequent phase of synsedimentary tectonic reactivation, injecting and infilling of the sedimentary dykes.

Two subsequent filtering effects (first a biologic and second a mechanical one linked to the hole and neptunian dyke mesh) may account for the common separation of large and small mammal remains and for the rare occurrence of very large sized mammal bones.

POCKET-LIKE CONCENTRATIONS INSIDE THE *in situ* COLOMBACCI FM (Text-fig. 22)

They are much less frequent than the previous concentration types and occur within olive-green silty clay of the Colombacci Fm, very close to the top fill of neptunian dykes. The process of filling itself was likely to produce at its top whirlpools able to concentrate small and very light vertebrate bones. This part of the Monticino fauna is more likely coeval with the supporting Colombacci clay, i.e. latest Messinian.

Text-fig. 22 - Pocket-like olive-green bone-rich Colombacci clay at the top of a medium sized neptunian-karstic fessure (Z-shaped dark band). Medium size sample bags for scale.

INTERPRETATION

Shortly after completion of the early-middle Messinian evaporitic cyclic sequence, the Monticino area was subjected to severe intra-Messinian deformation and backthrusting followed by a short emersion interval.

Karst weathering started along discontinuous evaporitic cliffs more prominently exposed on the sites of the present Santerno (Landuzzi & Castellari, 1988) and Sintria-Lamone valleys (structural highs).

The cliffs were facing northeastward a large, flat alluvial plain cyclically flooded by brackish Lagomare water; southwestward, they were bordered by a steplike low relief landscape, followed at far distance (SW of the present devide) by a prominent narrow mountain ridge separating climatically the relatively wet Po Plain Lagomare from the dryer Tuscan-Tyrrhenian-Sicilian area (Vai, 1989). A thorough critical, palaeobotanical analysis of Mediterranean climate during Messinian is still lacking. However, known pollen diagrams (Bertolani-Marchetti, 1985; Bertolani-Marchetti & Marzi, 1988) suggest:

1) cool to cold and wet spells punctuating the mainly warm and dry evaporitic early-middle Messinian and possibly corresponding to the cyclic normal marine water incomes (euxinic shale interbeds, Vai & Ricci Lucchi, 1977);

2) marked regional vegetation and climate changes moving from S to N in the Mediterranean basins;

3) increasing cooler and wet conditions in the upper Messinian Colombacci Fm (mediocratic index) still coupled, however, with marked climatic cyclicity.

Of major importance is the recurrence of *Sciadopitys*, which implies cyclic establishment of aseasonal, continuously wet climate in the late Messinian Northern Apennines.

STRATIGRAPHIC AND PALAEOGEOGRAPHIC IMPLICATIONS OF THE MAMMAL FAUNA

Two points need to be stressed. Though biologically incomplete and unbalanced as compared with the uppermost Miocene mammal communities (De Giuli *et al.*, 1988), the Monticino association is of primary biochronological importance for its diverse and rich rodent content. On the other hand, few other mammal fauna have a clear calibration by marine magneto- and biostratigraphic scales on the same section, as the Monticino fauna has.

The Monticino mammal assemblage is particularly well postdated by the basal early Pliocene *Sphaeroidinellopsis* (MPl1) Zone, by the lower *Amaurolithus tricorniculatus* Zone and by the Thvera (3.3) subchron.

The fauna is predated by the evaporitic (early-middle) Messinian, by the intra-Messinian phase and is coeval with part the 3r reversed chron. If the biological concentration process is correctly interpreted, part of the fauna should be of post evaporitic Messinian age, but slightly older than the remaining part of the fauna which is scattered within the *in situ* Colombacci Fm. The Monticino section strongly supports a late to latest Messinian age of the late MN13 mammal zone, provided the Monticino fauna is correctly related to the late MN13 zone (De Giuli *et al.*, 1988).

Recent growing progress made in biostratigraphy, event stratigraphy, physical stratigraphy and seismostratigraphy have enhanced the need to bridge the correlation gap between isochronous, different magnafacies. This need resulted in an increasing use of the ecostratigraphic approach, especially in the areas of potential interfingering of different magnafacies.

Classical examples of such problems are represented by the puzzling correlation between the Old Red and the Rhenish (or even Bohemian) Devonian stages (Martinsson, 1977, 1980), or between Mediterranean and Paratethys Neogene sequences (Rögl & Steininger, 1984). In both cases, the critical point is given by the apparent disconnection between vertebrate (mainly continental) and marine invertebrate zonations. This fact brings in turn difficulties in defining boundaries of standard chronostratigraphic units (at whatever hierarchical level) and in performing reliable chronologic correlations.

Our contribution is a further step towards the improvement of the correlation between the continental (and Paratethyan), the standard stratigraphic marine (Mediterranean) and the biostratigraphic oceanic scales. In fact the final goal of the ecostratigraphic framework is not to increase the number of independent regional stratigraphic scales (as one could infer from fig. 10.2 in Rögl & Steininger, 1984) but to extend the use of the standard chronostratigraphic units by means improved and refined correlations.

As for palaeogeography, the northern Slovenian or Julian seaway from central Paratethys to Mediterranean should have been closed with the middle Miocene (about 14 Ma) late Badenian (intra-Serravallian) time. Our data are partly conflicting with this assumption. There is a generalized late Messinian invasion of the Paratethys euryhaline biotas into the Adriatic and Ionian Sea and the Eastern Mediterranean, which can hardly been explained without physical connections (both N and S) with the Paratethyan water masses. On the other hand, the marked eastern affinity of the Adriatic Monticino mammal fauna (De Giuli *et al.*, 1988) and its difference from the Tyrrhenian Baccinello V3 coeval fauna suggest connection of the emergent Adriatic Apennine with the eastern land masses and separation from the Tyrrhenian islands. In this view, the terminal Messinian tectonics, with the associated strong shortening at the eastern Southalpine front (Castellarin & Vai, 1981), was probably responsible for the final closure of the northern Yugoslavian corridor, subsequently fully hidden beneath a pile of Pliocene emplaced thrust sheets.

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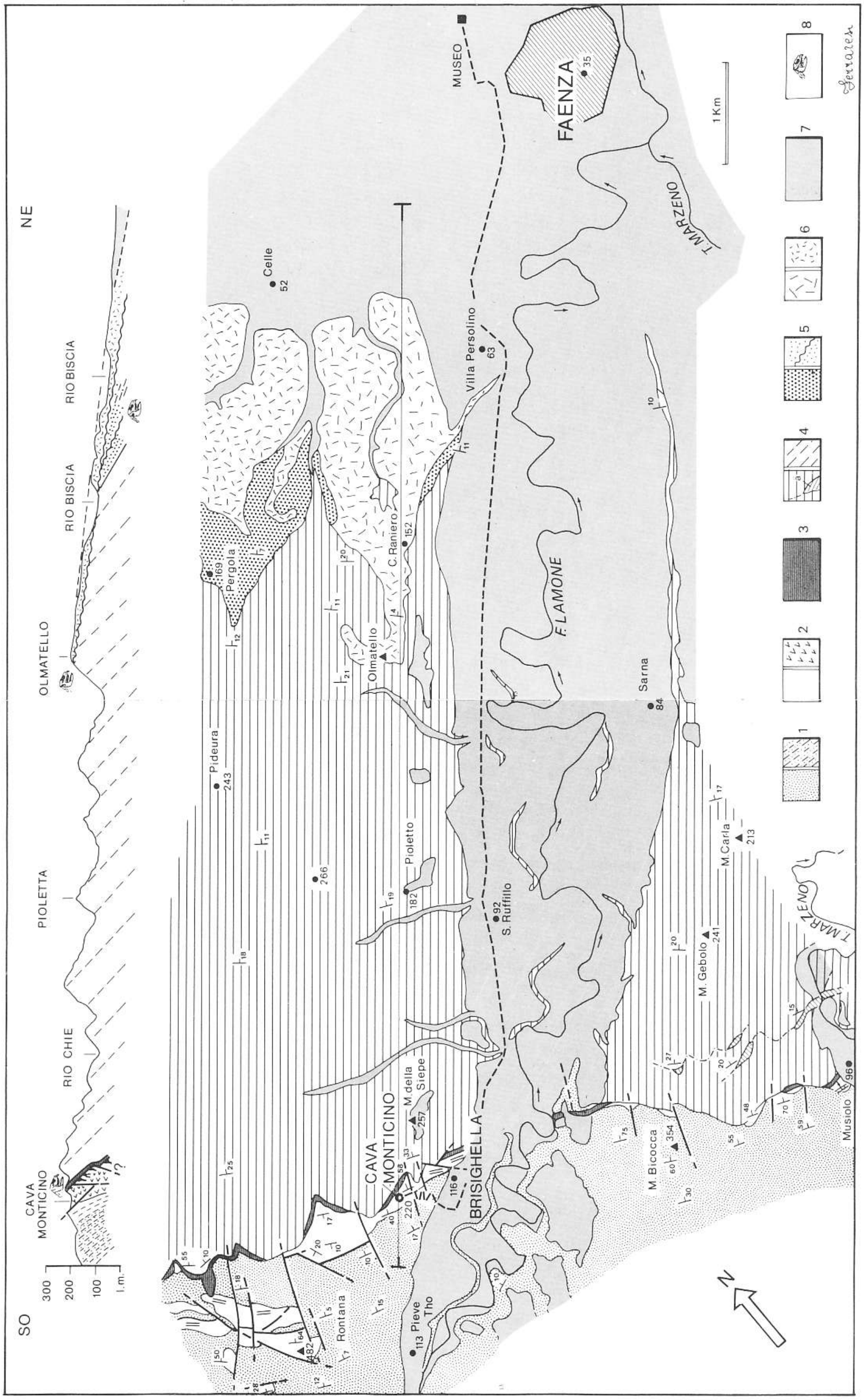
Text-fig. 23 - Geological map and cross section of the middle Lamone Valley showing location of the late Messinian Monticino fauna and of recent Pleistocene large mammal findings. 1) Marnoso-arenacea Fm ; 2) Gessoso-solfifera Fm; 3) Colombacci Fm; 4) Argille Azzurre Fm (a «Spungone» member); 5) «Sabbie gialle» fm; 6) Olmatello Fm; 7) Alluvial terraces; 8-faunal localities.


SO
NE
CAVA MONTICINO
RIO CHIE
PIOLETTA
OLMATELLO
RIO BISCIA
RIOBISCIA
300
200
100
l.m.
MUSEO
FAENZA
35
1 Km
T. MARZENO
Celle
52
Villa Persolino
63
F. LAMONE
Sarna
84
C. Raniero
152
Pergola
169
Olmatello
Pideura
243
266
Pioletto
182
S. Ruffillo
92
M. Carla
213
M. Gebolo
241
M. della Siepe
257
CAVA MONTICINO
220
BRISIGHELLA
116
M. Bicocca
354
Musiolo
96
Pieve Tho
113
Rontana
482
1
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3
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