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FOSSIL VERTEBRATES IN THE LAMONE VALLEY ROMAGNA APENNINES

Field Trip Guidebook

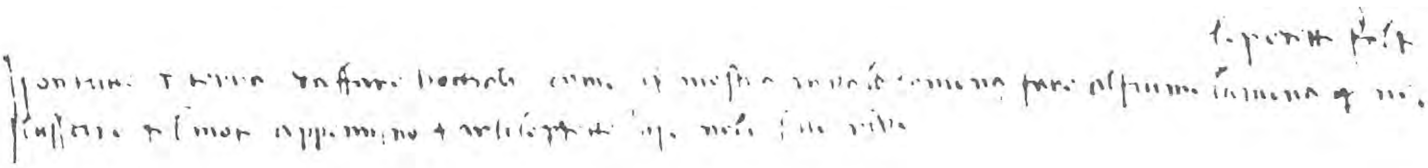
edited by Claudio De Giuli & Gian Battista Vai

Faenza

CONTINENTAL FAUNAS
AT THE MIOCENE/PLIOCENE BOUNDARY
International Workshop, Faenza, March 28-31, 1988

Secretary: Gian Paolo Costa

M·CM·LXXXVIII
Alma Mater Studiorum
Sæcularia Nona



le predette falde son tutte di terra da fare boccali, come si dimostrano, in Val di Lamona, fare al fiume Lamona nell'uscire del monte Appennino, far lì le predette cose nelle sue rive (Hammer 10A, 10r).

the mentioned beds are all made of earth used for pottery as it appears in Lamone Valley coming out of the Apennine mountain where the Lamone river is making the mentioned things on its banks (Hammer 10A, 10r).

Leonardo da Vinci (1506-1510)

Specular reproduction of Leonardo's notebook fragment with Italian translitteration and English translation.

Cover caption: *Plioviverrops faventinus* (1,3 x – ph. by F. Landucci, Dip. Scienze della Terra, Università di Firenze).

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This guidebook is dedicated to our colleague
Professor Antonietta Padovani

first excited from the Monticino fauna discovery
she was hampered to join this party
by her unexpected death

January 23, 1988

A nome dell'Amministrazione Comunale di Faenza desidero ringraziare i partecipanti al Workshop internazionale incentrato sulle «Faune continentali al limite Miocene-Pliocene» e gli estensori di questa guida, fondamentale contributo alla conoscenza del territorio Faentino.

La scoperta di una importantissima fauna fossile di età miocenica nella Valle del Lamone, l'impegno dei volontari che negli ultimi anni hanno speso gran parte del loro tempo libero per recuperare frammenti della nostra storia più remota ed il successivo lavoro degli studiosi sono alla base di questo momento d'incontro.

L'Amministrazione Comunale di Faenza, attraverso il Museo Civico di Scienze Naturali, non mancherà di porre in essere le iniziative di divulgazione necessarie affinché la mole di nuove conoscenze acquisita, destinata ad accrescersi con il procedere delle ricerche in corso, divenga realmente patrimonio comune.

L'ASSESSORE ALLA CULTURA
dott. Vittorio Ghinassi

A field trip guide to the Romagna Apennine geology
The Lamone valley

GIAN BATTISTA VAI

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The first quotation of the Lamone Valley as a site of major geological interest dates back to Leonardo da Vinci (approx. 1506-1510) as shown in the frontespiece of this guidebook.

The major contribution to the geology of the surrounding area (or, more generally, the Romagna Apennines) are due to Scarabelli (1851, 1854, 1880), Capellini (1876), Sacco (1899, 1937), Principi (1927), Signorini (1935, 1940), Merla (1952), Merla *et al.* (1964), Selli (1952, 1954, 1962, 1967, 1973), Ruggieri (1958, 1967, 1970), Lucchetti *et al.* (1963), Renzi (1964, 1967), Ten Haaf (1964, 1986), Rizzini & Passega (1964), Sestini (1970), Cremonini & Elmi (1971), Bruni (1973), Dallan Nardi & Nardi (1974), Giglia (1974), Elter (1975), Ricci Lucchi (1975, 1981, 1986), Vai & Ricci Lucchi (1977), Colalongo *et al.* (1978), Cremonini & Farabegoli (1979, 1982), De Jager (1979), Ten Haaf & Van Wamel (1979), Pieri & Groppi (1981), Cremonini & Ricci Lucchi (1982), Farabegoli (1983), Boccaletti *et al.* (1971, 1985), Marabini & Vai (1985), Castellarin & Vai (1986), Patacca & Scandone (1986, 1987), Castellarin *et al.* (1986a, 1986b), Gasperi *et al.* (1987).

Of great palaeontological interest are the papers by Scarabelli (1851), Scarabelli & Foresti (1897), Capellini (1879), Moroni (1955, 1957), Sangiorgi (1906), Ruggieri (1940), Cati *et al.* (1968), Cati & Borsetti (1970), Colalongo (1968), Colalongo *et al.* (1974, 1978a, 1978b), Colalongo & Sartoni (1979), D'Onofrio (1964), D'Onofrio *et al.* (1975), Gillet (1963), Cati *et al.* (1968), Padovani & Tampieri (1974), Marabini & Poluzzi (1977), Sorbini & Tirapelle (1980), Sorbini (1982).

Except for the famous work of Scarabelli (1846, 1848) about the «Villafranchian» fauna from the «Sabbie gialle» formation, near Imola, which was revised taxonomically by Azzaroli & Berzi (1970) and some papers by Capellini (e.g. 1888), discoveries of and studies on mammals from Romagna are lacking until the recent new findings (Vai, 1984: Costa *et al.*, 1986; Marabini *et al.*, 1988: Landuzzi & Castellari, this vol.).

New mammal remains have been found in a variety of formations, ranging in age from the late Messinian to the late Pleistocene. To give them their proper geologic meaning, an updated review of stratigraphy and structural evolution of the area is useful.

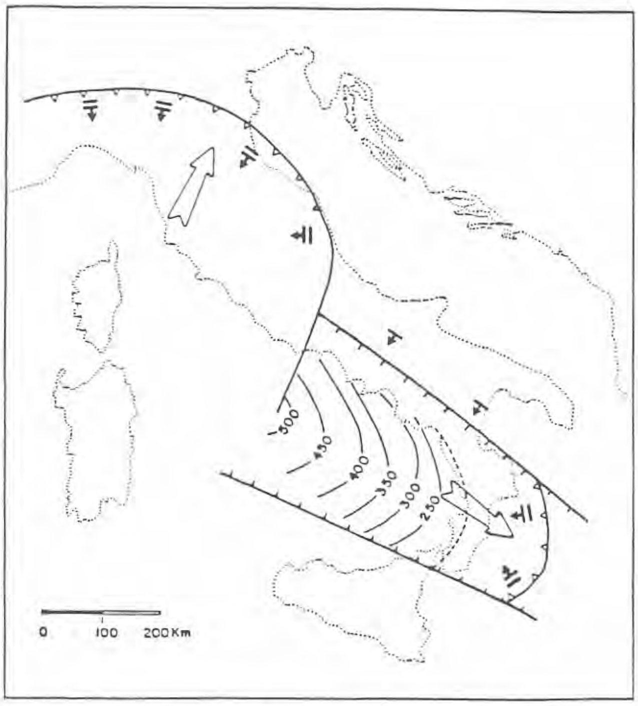


Fig. 1 – The two main Apenninic arcs. White arrows show direction of orogenic transport at shallow depths. Isobaths of the steep subducted Ionian lithospheric slab are drawn in the Tyrrhenian Sea (after Patacca & Scandone, 1987).

KINEMATIC AND STRUCTURAL OUTLINE OF THE NORTHERN APENNINE CHAIN

The Northern Apennines are a ~600-km-long, arcuated mountain chain produced by a NE-directed tectonic transport, as opposed to the Southern Apennine-Sicily arc characterized by a prominent tectonic transport towards the SE (Scandone & Patacca, 1987) (Fig. 1).

The overall arc shape of the Northern Apennine may be sub-divided into (at least) three minor, frontal, arc-shaped thrust belts, mostly buried beneath the Po Plain to Adriatic Sea Quaternary cover (Pieri & Groppi, 1981). From W to E the three arcs are (Fig. 2): 1) the *Monferrato Arc*, mostly deformed during Messinian to early Pliocene time; 2) the *Emilia Arc*, deformed during Messinian to late Pliocene time; 3) the *Ferrara-Romagna Arc*, and its continuation to the Adriatic-Marche Arc to the E, with the

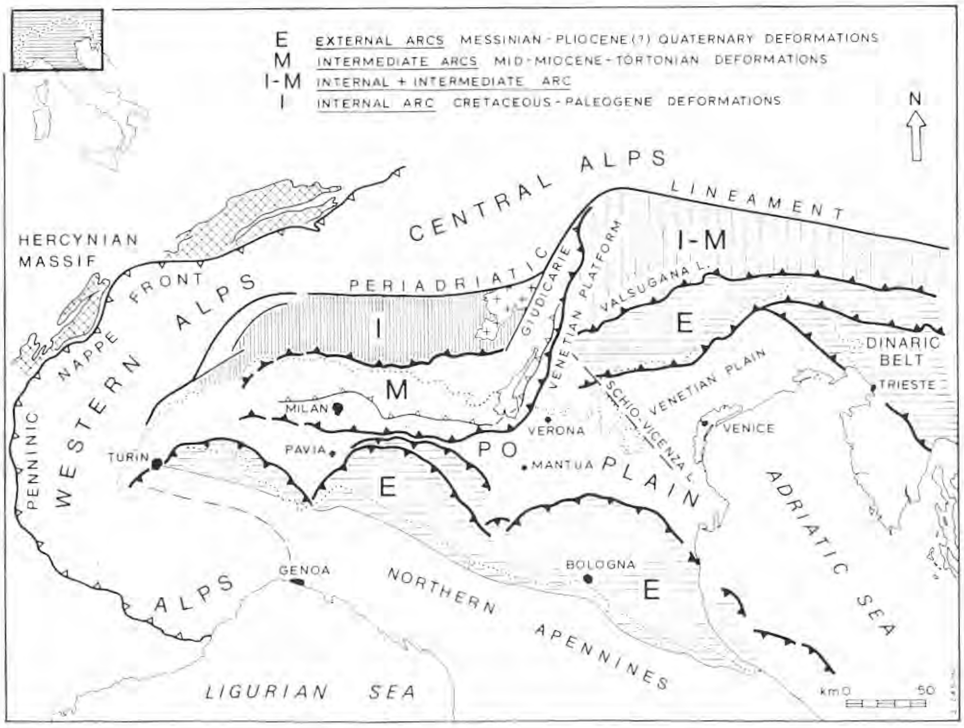


Fig. 2 – Simplified structural map of the Po Plain and adjoining Northapenninic and Southalpine arcs after removing the Quaternary undeformed cover (after Castellarin & Vai, 1986).

same age of main deformation. This last one is a composite system of little arcs representing the more complex, major structural feature of the outer part of the Northern Apennines. The Romagna folds and thrusts, the innermost structures of this arc, are characterized by structural disharmony of the clastic Tertiary formations with respect to the Mesozoic carbonates.

The buried arcs owe their origin, outline and location to the spike effect produced by the rigid Mantua and Pavia crustal blocks (high magnetic anomaly with repeated intrusions and volcanism), preventing lateral propagation of décollement surfaces (Castellarin & Vai, 1986).

This interpretation implies that at least the buried outer part of the Northern Apennines originated by active overthrusting of the Apennines onto the Po Plain foredeep and foreland, rather than by underthrusting of the Po Plain crust (Castellarin & Vai, 1986).

More internally, the three buried arcs are replaced by exposed, progressively older, still arcuate, roughly concentric thrust fronts strongly fragmented by transversal (trike-slip to transfer faults) (Fig. 3 and Castellarin *et al.* 1986a, Fig. 14).

According to Boccaletti *et al.* (1971), Dallan Nardi & Nardi (1974), Giglia (1974), Elter (1975), Iaccarino & Papani (1980), Pieri & Groppi (1981), Marabini & Vai (1985), Castellarin *et al.* (1986), Carmignani *et al.* (1978), Patacca & Scandone (1986, 1987), Sartori (1987), Gasperi *et al.* (1987), Boccaletti *et al.* (1987), Capozzi (1987), Conti (1987), Fesce (1987), Pini (1987), Vai (1988), the main *deformation* phases recognized in this exposed part of the Northern Apennine chain are (Fig. 4):

1) Ligurian phase (Late Eocene) sealed by latest Eocene-Oligocene Ranzano-Loiano sequence;

2) possible latest Oligocene phase, indirectly suggested by the oldest metamorphic dates of the Apuane (~26 Ma) and by the Late Oligocene-Early Miocene age of the Macigno del Chianti foredeep fill;

3) Burdigalian phase, poorly documented except for indirect evidences as the just accomplished Corsica rotation (18 Ma) and the Cervarola Sandstone foredeep fill (if the bulk of this lithosome will prove to be mainly of Middle Miocene age). It can also be supported by the first (pre-Tortonian) stage of the Marnoso-arenacea foredeep fill (Ricci-Lucchi, 1975);

4) Tortonian phase sealed by widespread late Tortonian deposits all over the internal area and mirrored by the second (post-Tortonian) stage of the Marnoso-arenacea foredeep fill;

5) intra-Messinian phase(s) clearly sealed by the Colombacci Formation (or equivalent deposits) and mirrored by the Laga Formation (SE) and the buried Po Plain turbidites (NE), both representing foredeep fills;

6) intra-early Pliocene phase, marked by a disconformity to angular unconformity at the base of the *puncticulata* Z., is mirrored by the lower-middle Pliocene foredeep deposits from Po Plain to Abruzzi;

7) middle Pliocene phase, known from the widespread transgression near the *aemiliana/crassaformis* Sbz. boundary. This is the last Apennine phase mirrored by the development of a consistent foredeep sedimentary wedge all along the front of the Apennine from the Po Plain to the Abruzzi. On land, this phase is often welded with or difficult to be distinguished from the next;

8) late Pliocene (to basal Pleistocene) phase within the *inflata* Z.; starting from this time, true foredeep Quaternary wedges are hardly recognized, whereas the front show a first clear retreat (Castellarin & Vai, 1986) which might imply a notable change in the stress pattern (Patacca & Scandone, 1987; Sartori, 1987);

9) the last remarkable tectonic peak is the middle-upper Pleistocene phase marked by the marine «Sabbie gialle» and continental equivalents uncon-

formity. At places, these deposits show further compressional activation (upthrust) (Vai, 1988; Sabadini *et al.*, 1987).

The intra-Messinian and the intra-early Pliocene phases are responsible for the two major outward front propagations (altogether exceeding 100 km) in both the exposed (Romagna) and buried Apennines.

The first deformation phases (from the Ligurian to the Burdigalian and possibly also the Tortonian) developed by means of shear zones cutting across the oceanic lithosphere (Ligurian), and then across the continental lithosphere (later phases) with involvement of Hercynian basement sheets or wedges (Elba, Punta Bianca, M. Pisano, Apuane-Risanguigno-Farma and P. Cerreto-Perugia subsurface (Vai & Cocozza, 1986: Lavecchia *et al.*, 1987) tectonic subunits) (Pl. 1). The post-Tortonian phases developed through suprabasement ramps with décollement surfaces located at different stratigraphic incompetent layers (Upper Triassic evaporites, Mesozoic to Tertiary pelagic muds, Messinian evaporites).

This articulated ramp-flat system merges internally with previous intracrustal shear and subduction zones (Pl. 1b).

Such main deformation phases can be visualized as relevant peaks in a continuous process of tectogenic and orogenic deformation (Marabini & Vai, 1985; Vai, 1988).

The assumed regular time-space polarity in the NE-ward migration of both deformation fronts and foredeep clastic wedges and peripheral bulge facies, though possible up to the Tortonian, is not supported

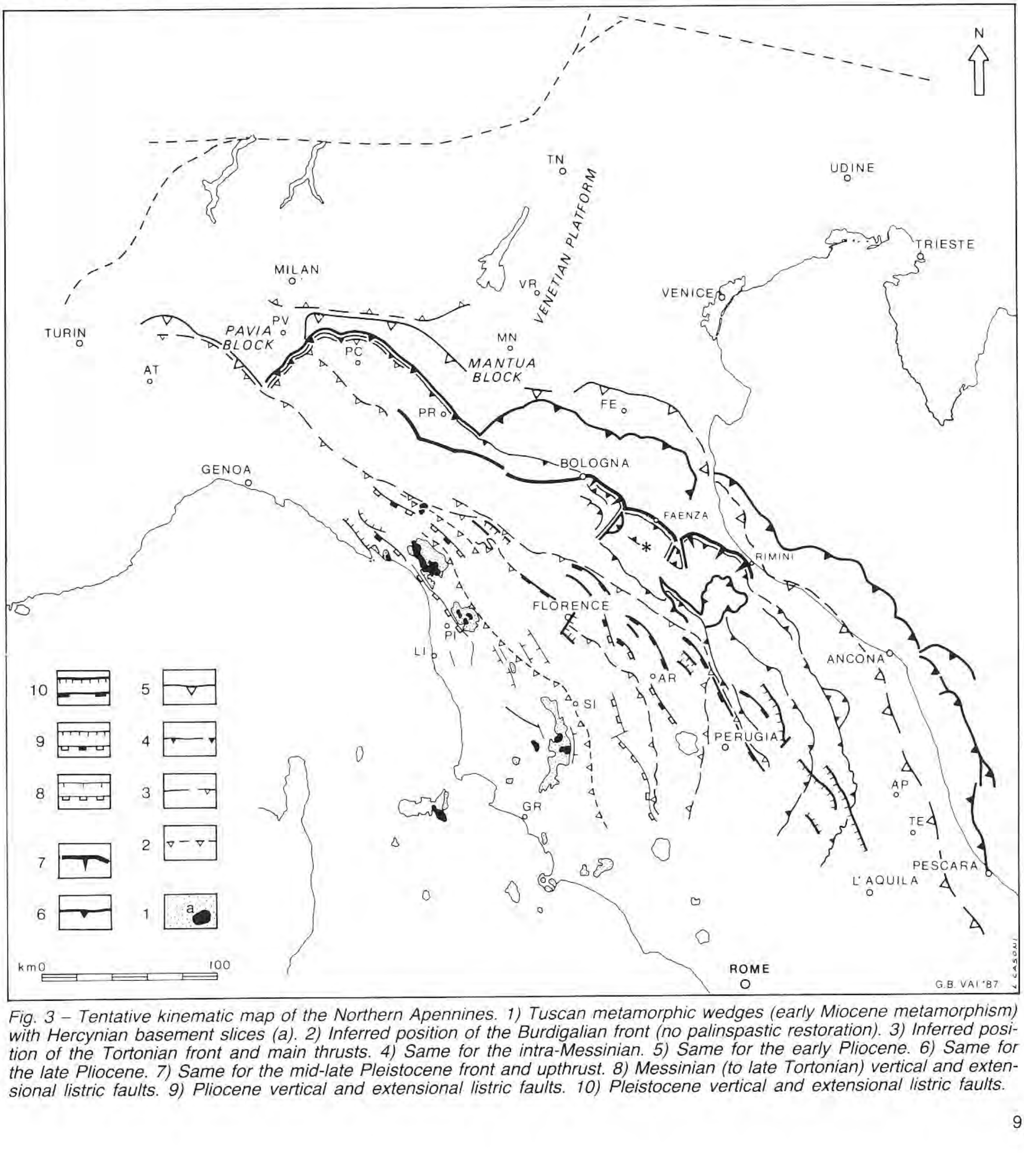


Fig. 3 – Tentative kinematic map of the Northern Apennines. 1) Tuscan metamorphic wedges (early Miocene metamorphism) with Hercynian basement slices (a). 2) Inferred position of the Burdigalian front (no palinspastic restoration). 3) Inferred position of the Tortonian front and main thrusts. 4) Same for the intra-Messinian. 5) Same for the early Pliocene. 6) Same for the late Pliocene. 7) Same for the mid-late Pleistocene front and upthrust. 8) Messinian (to late Tortonian) vertical and extensional listric faults. 9) Pliocene vertical and extensional listric faults. 10) Pleistocene vertical and extensional listric faults.

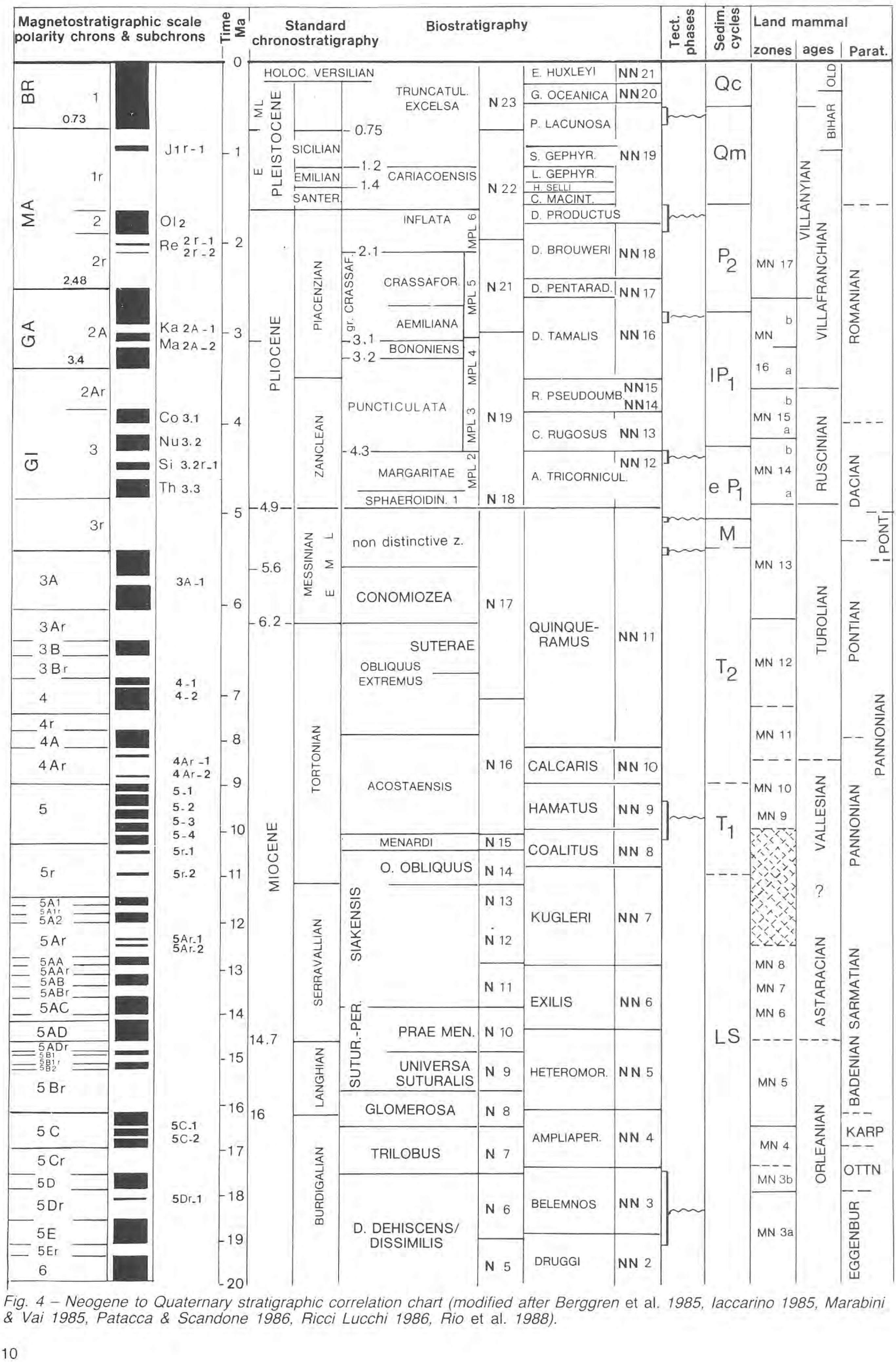


Fig. 4 – Neogene to Quaternary stratigraphic correlation chart (modified after Berggren et al. *1985, Iaccarino 1985, Marabini & Vai 1985, Patacca & Scandone 1986, Ricci Lucchi 1986, Rio* et al. *1988).*

by detailed kinematic analysis of post-Tortonian deformation (Castellarin *et al.*, 1986; Vai, 1988). In fact, the buried Po Plain front reached its maximum outward position during the Pliocene; during late Pliocene and Pleistocene, however, it was shifted for about 60 km back again in the same position reached during the intra-Messinian phase (Castellarin & Vai, 1986; Vai, 1988). Such irregular, unexpected pattern of front migration results in a complex tectonic setting.

This is even more relevant for the Southern Apenninic Arc (Patacca & Scandone, 1987, 1987).

The effects of each individual tectonic phase have been progressively obscured by the successive ones and, therefore, it is difficult to reconstruct a kinematic map without making large simplifications as was done for Fig. 3.

Looking at the *present structure* the *internal part* of the Northern Apennines consists of a complex tectonic superposition of three main (distinct) units (Pl. 1) in descending structural order:

1) the *Ligurian Nappes* (Argille Scagliose), the highest unit, composed of ophiolites and oceanic to suboceanic deposits of Jurassic to Eocene age, first obducted and thrust over both the African (Insubric) and the European (Corsica) continental margins during the Ligurian phase and still carrying evidences of this alpine deformation (westward transport, mainly mild greenschist-facies metamorphism).

After this alpine event the Ligurian Nappes underwent severe compressional reactivation (Castellarin *et al.*, 1986a, 1986b; Castellarin & Pini, 1988) and transport during each apennine phase (namely Burdigalian, Tortonian, intra-Messinian, early and late Pliocene and Pleistocene); gravitational spreading of the nappe after each diastrophic pulse was less important than always claimed until recently and limited to some epidermal (ultrathin-skinned) frontal and lateral tongues or olistostromes (Pini, 1987).

The post-Ligurian phase molasse-like Loiano-Ranzano-Bismantova cover deposits (*alias* «Tongriano» *Auct.*, *alias* episutural (Bally & Snelson, 1980) or satellite (Ricci Lucchi, 1986) basin fills) appear dismembered, tectonized and transported (therefore they are classified as semiallochthonous when compared with their teleallochthonous Ligurian basement).

2) The *Tuscan Nappes*, the intermediate unit, con-

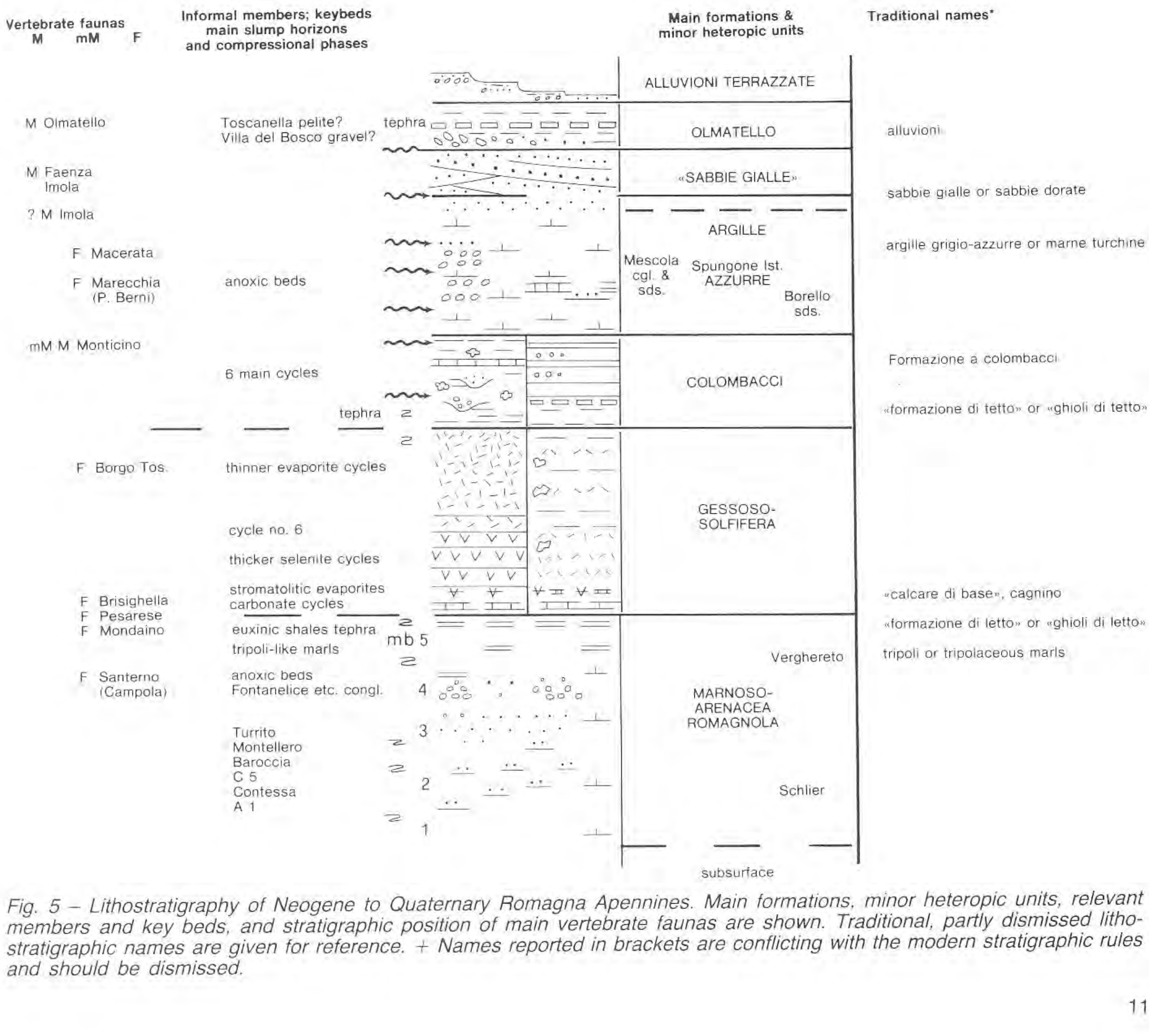


Fig. 5 – Lithostratigraphy of Neogene to Quaternary Romagna Apennines. Main formations, minor heteropic units, relevant members and key beds, and stratigraphic position of main vertebrate faunas are shown. Traditional, partly dismissed lithostratigraphic names are given for reference. + Names reported in brackets are conflicting with the modern stratigraphic rules and should be dismissed.

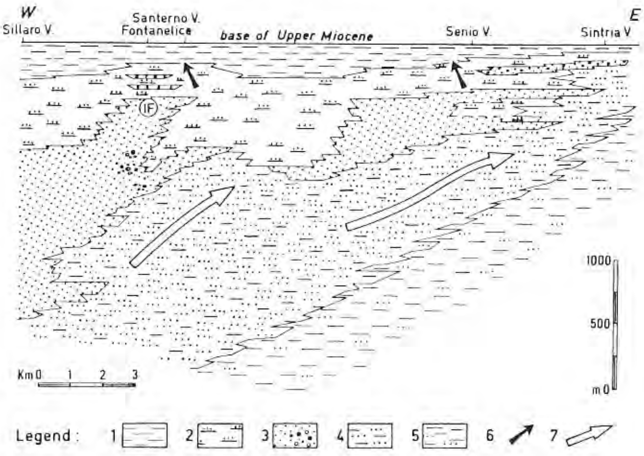


Fig. 6 – Lithosome geometry of the upper Marnoso-arenacea Fm in western Romagna. Section parallel to basin axis and oblique to axes of fan valleys. 1, slope and ‹clay plug›. 2, interchannel to fan fringe. 3, mid to inner fan (IF). 4, outer fan. 5, outer fan to basin plain. 6, recessional phase. 7, progradational phase (after Ricci Lucchi, 1975).

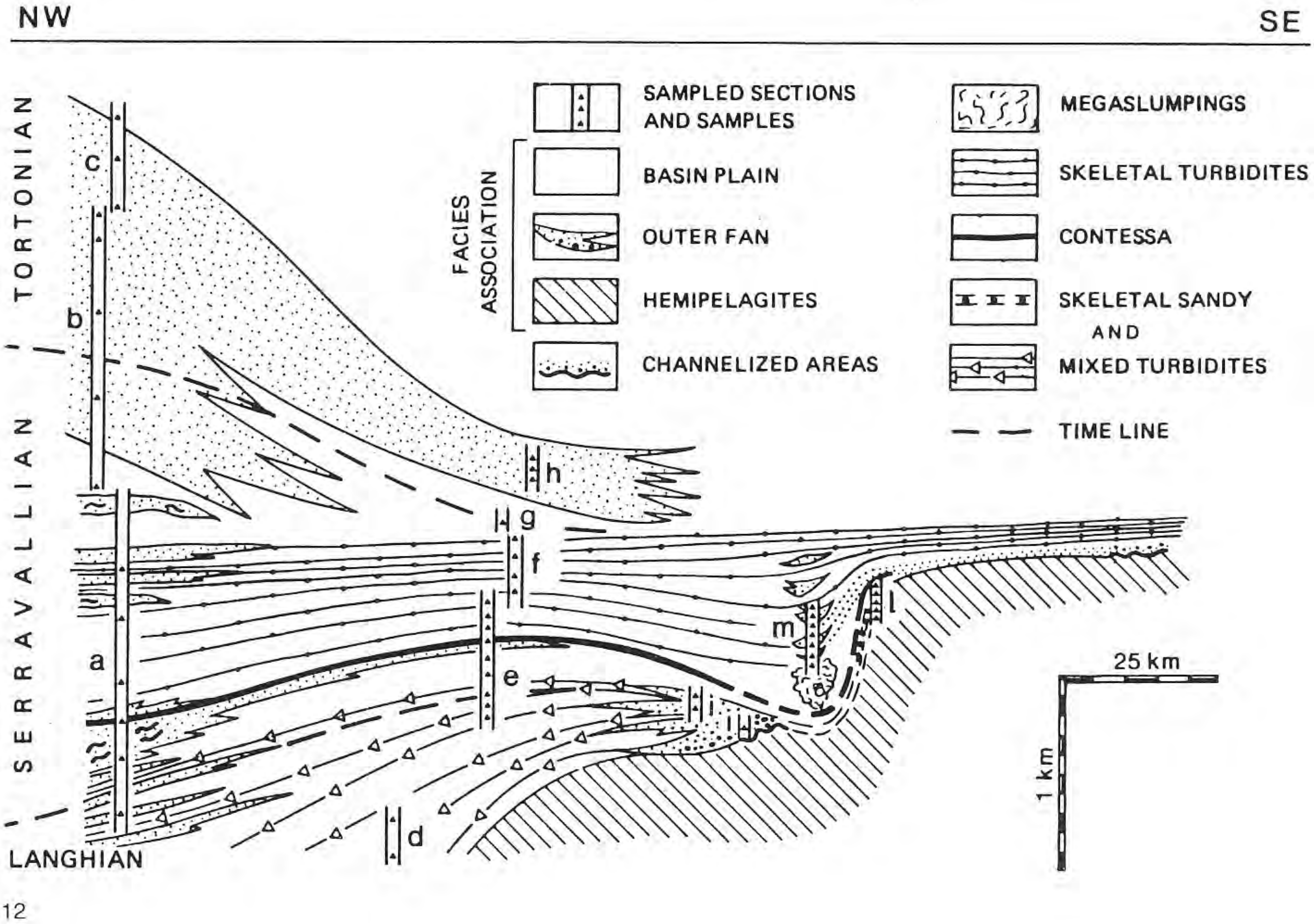
Fig. 7 – Schematic longitudinal section across the outcropping Marnoso-arenacea Fm a: Sambuca, b: Castel del Rio, c: Fontanelice, d: Campigna, e: Bagno di Romagna, f: Quarto, g: Turrito, h: Sarsina, i: Città di Castello, l: Gubbio, m: Val Fabbrica sections (after Gandolfi et al., *1983).*

sisting of different, less diversified elements characterized by essentially unmetamorphosed Upper Triassic (Norian evaporites acting as décollement horizon) to Oligocene (Macigno) sequence. The Jurassic to Eocene part of this sequence represents continental margin deposits.

During latest Oligocene time, this unit overrode (along with the Ligurides) the metamorphic nappes and was eventually emplaced in the Tortonian.

3) The *Metamorphic Nappes*, the lowest unit, characterized by greenschist facies metamorphism and involving late- to post- Hercynian, pre-Verrucano s.s. deposits (Cocozza *et al.*, 1974; Vai, 1978). They crop out only in tectonic windows. Some of them (e.g. Apuane, Elba, M. Pisano, P. Cerreto, Farma and Risanguigno outcrops) show a Lower-Middle Palaeozoic basement with Hercynian deformation and metamorphism (Vai, 1972; Bagnoli & Tongiorgi, 1980) followed by a late Palaeozoic to Oligocene cover (its Mesozoic to Tertiary sequence exibit close affinity with the isochronous sequence of the Tuscan Nappes). Other windows (e.g. Massa, Iano, Argentario, M. Romani outcrops) present only Upper Palaeozoic to Verrucano deposits. In addition to the known Massa and Apuane Units (Baldacci *et al.*, 1967), at least an inner Elba Unit and an outer Passo del Cerreto Unit (Vai & Cocozza, 1986) can be distinguished. The old misleading term «Autochton» (here Apuane Unit) should be definitely abandoned and exclusively used for strictly historical purposes (Fig. 3, Pl. 1).

The *outer part* of the exposed Northern Apennines (roughly NE of the present divide) still shows a complex tectonic superposition of two main distinct facies



domain (at least as far E as the Marecchia fault bundle).

1) The *Ligurian Nappe*, almost reaching the Po Plain and locally entering it for many km. The Romagna Apennines only, from the Sillaro to the Marecchia Lines, seems to be devoided of Ligurides. However, this area may be considered as a large, late Pleistocene, incomplete tectonic window corresponding to a gentle axial culmination (Pl. 1c) of possible intra-Messinian age, as shown by the Plio-Quaternary neoautochthonous sealing the structure (evidences for the above interpretation are found in Vai, 1984 and Ten Haaf, 1986).

2) The tightly imbricate *thrust system of the Romagna-Umbria-Padan-Marche Domain* is the external equivalent of both the Tuscan and Metamorphic Nappes.

In terms of Mediterranean palaeogeography and plate tectonics the sedimentation in the Ligurian Domain reflects deposition during the opening of a narrow Mesozoic ocean basin driven by the Atlantic ocean evolution. Sedimentation in the Tuscan to Marche Domain reflects deposition during the initial rifting, subsidence, and development of the Insubric-Adriatic continental margin (Carmignani *et al.*, 1978). The deformation in the Northern Apennines throughout both domains, closely associated with deformation of the Insubric-Adriatic continental margin is commonly attributed to continent-continent collision after suture of the oceanic seaway between the Adria plate and the Corsica-Sardinia microplate (Boccaletti *et al.*, 1971; Dewey *et al.*, 1973). The apenninic development of the Northern Apennines is therefore entirely post-collisional at expenses of the Adria attenuated continental lithosphere through a series of discrete shear zones (Carmignani *et al.*, 1978).

In terms of original domains we can distinguish 1) an internal zone (the Ligurian Domain to the farther W) from a composite external one (including the Tuscan, Massa, Apuane, Cervarola, Cerreto and Romagna-Umbria-Padan-Marche Domains).

In chrono-structural terms, the Ligurid Nappes together with the Metamorphic Nappes show internides characters, whereas the remaining units can be classified as externides.

STRATIGRAPHY OF THE ROMAGNA APENNINES

The basic units in the lithostratigraphic classification of this area have been introduced by Leonardo da Vinci (1506-1510) (cfr. Vai, 1988b), Brocchi (1814) (cfr. Lyell, 1830), Scarabelli (1851, 1854, 1880), Capellini (1879) and Selli (1954).

Refinements, precisions, integrations and amendments in lithostratigraphy, lithosome geometry, facies analysis and environmental interpretation have been worked out for the Marnoso-arenacea Formation (Renzi, 1964; Ricci Lucchi, 1969, 1975, 1987; Ricci Lucchi & Valmori, 1980), the Gessoso-solfifera Formation (Vai & Ricci Lucchi, 1977; Rabbi

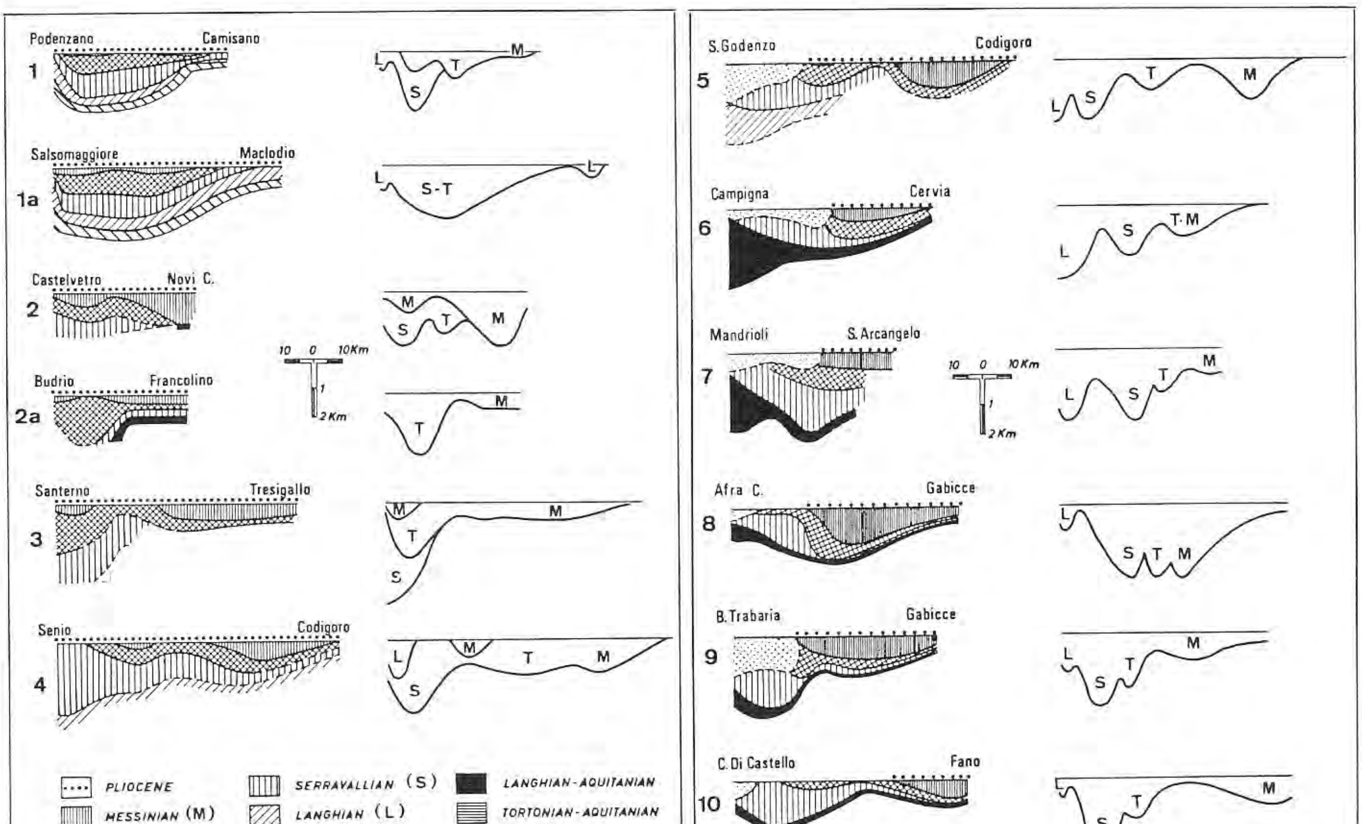


Fig. 8 – Simplified transversal sections across the outcropping and buried Marnoso-arenacea and Gessoso-solfifera Fms showing complex migration of individual stage depocenters toward the foreland (right). Composite thicknesses to the left, subsidence peaks to the right. Datum is the base of Pliocene (after Ricci Lucchi, 1975).

& Ricci Lucchi, 1968; Marabini & Vai, 1985), the Colombacci Formation (Casati *et al*, 1978; Colalongo *et al.*, 1978; Cremonini & Farabegoli, 1982; Cremonini & Marabini, 1982; Farabegoli, 1983), the Argille Azzurre Formation (Lucchetti, 1963; Cremonini & Ricci Lucchi, 1982; Cremonini & Farabegoli, 1982) the «Sabbie gialle» and equivalent units (Cremonini & Ricci Lucchi, 1982; Cremaschi, 1982; Vai, 1984; Marabini *et al.*, 1987a, 1987b) and the Po Plain subsurface units (Dondi *et al.*, 1982; Dondi & D'Andrea, 1987).

Most of the present day chronologic and standard stratigraphic definition and correlation frame was already cleared starting from Ruggieri & Selli (1949).

I should recall here that the Romagna Apennines is part of the type area for standard chronostratigraphic classification of Neogene to Quaternary rocks and contain many type localities and stratotypes for the biostratigraphic subdivision of the same time interval (see f. i. Selli (1962), Cati *et. al.* (1968), Selli *et al.* (1971), Colalongo (1968), D'Onofrio *et. al.* (1975), Selli (1977), Colalongo & Sartoni (1979), etc.).

More recently, the Romagna Neogene-to-Quaternary rock suite has been successfully classified in terms of sedimentary cycles (Ricci Lucchi *et al.*, 1982; Ricci Lucchi, 1986), and the first attempts at implementing concepts and methods of physical stratigraphy (including stratimetry) have been made (Ricci Lucchi, 1975; Ricci Lucchi & Valmori, 1980; Marabini & Vai, 1985).

The main recognized *lithostratigraphic units* in ascending order are the following (Fig. 5).

Marnoso-arenacea Formation

Its base in the Romagna Apennines is not exposed, being the place of a wide, major décollement surface probably originated within the Scaglia cinerea Formation (and implying tectonic squeezing back of the Bisciaro Formation) or at the top of Bisciaro Formation.

The Marnoso-arenacea Fm. is a composite turbidite, wedge-shaped body deposited in a migrating foredeep basin from Langhian to late Tortonian time and locally exceeding the thickness of 3 to 4 km (Ricci Lucchi, 1975; 1986). It crops out extensively and spectacularly over an area about 180 km long and 40 km wide (Figs. 7 & 9).

The Marnoso-arenacea Fm. has been originally subdivided into five informal members (fig. 5) (Ricci Lucchi, 1969) characterized later also in terms of lithosome geometry (Fig. 6) (Ricci Lucchi, 1975). This turbidite succession of members shows an overall coarsening upward trend with a sudden inversion at the top, made of discrete, diachronous, muddy hemipelagic bodies: Verghereto, Tossignano (Lucchetti *et al.*, 1963), Diaterna (Bruni, 1973), Castelvecchio (De Jager, 1979) and other unnamed.

Marker beds or set of beds have also been distinguished. Of major importance is the basin-wide Contessa Layer (Renzi, 1964, 1967; Ricci Lucchi & Pialli, 1973; Ricci Lucchi & Valmori, 1980). Great usefulness in stratigraphic and tectonic analysis may also derive from the pre-Contessa A1 layer (Ricci Lucchi & Valmori, 1980) and the post-Contessa Baroccia and Montellero layers (Benini, 1986), as well as other layers distinguished and characterized by Ricci Lucchi & Valmori (1980) and Zuffa *et al.* (1983) (e.g. Turrito layer) (Figs. 5 & 7).

Large, regionally extended slumps are concentrated shortly below and above the Contessa Layer E of the Sillaro Line for over 20 km. Upper Tortonian slump horizons are even wider, though less continuous. Great interest bears also a set of euxinic, fish rich, dark beds found for the first time in the early-middle Tortonian (upper marly member of the Marnoso-arenacea Fm.) of the Santerno Valley by the writer (cfr. Calderoni, 1979).

Three more relevant and persistent (though complexely migrating outward) depocentres have been recognized: Langhian, Serravallian and Tortonian (Fig. 8). However, two main time/space distinct stages and basins have also been separated (Ricci Lucchi, 1975; 1981; 1986): an inner basin (stage) with finer grained ($CaCO_3$ rich) deposits exibiting impressive lateral continuity and parallelism of bedding and corresponding to the maximum extension and subsidence of the Miocene foredeep; an outer basin (stage) with coarser grained ($CaCO_3$ poor) deposits, narrower trough and indirect evidences of the thrust front approaching the back of the inner basin (in disagreement with Ricci Lucchi, 1986) during the Tortonian, as suggested by Ligurid frontal olistostromes embedded in the topmost muddy member.

Palaeogeographic setting and dispersal patterns of the two stages are represented in Fig. 9.

Gessoso-solfifera Formation

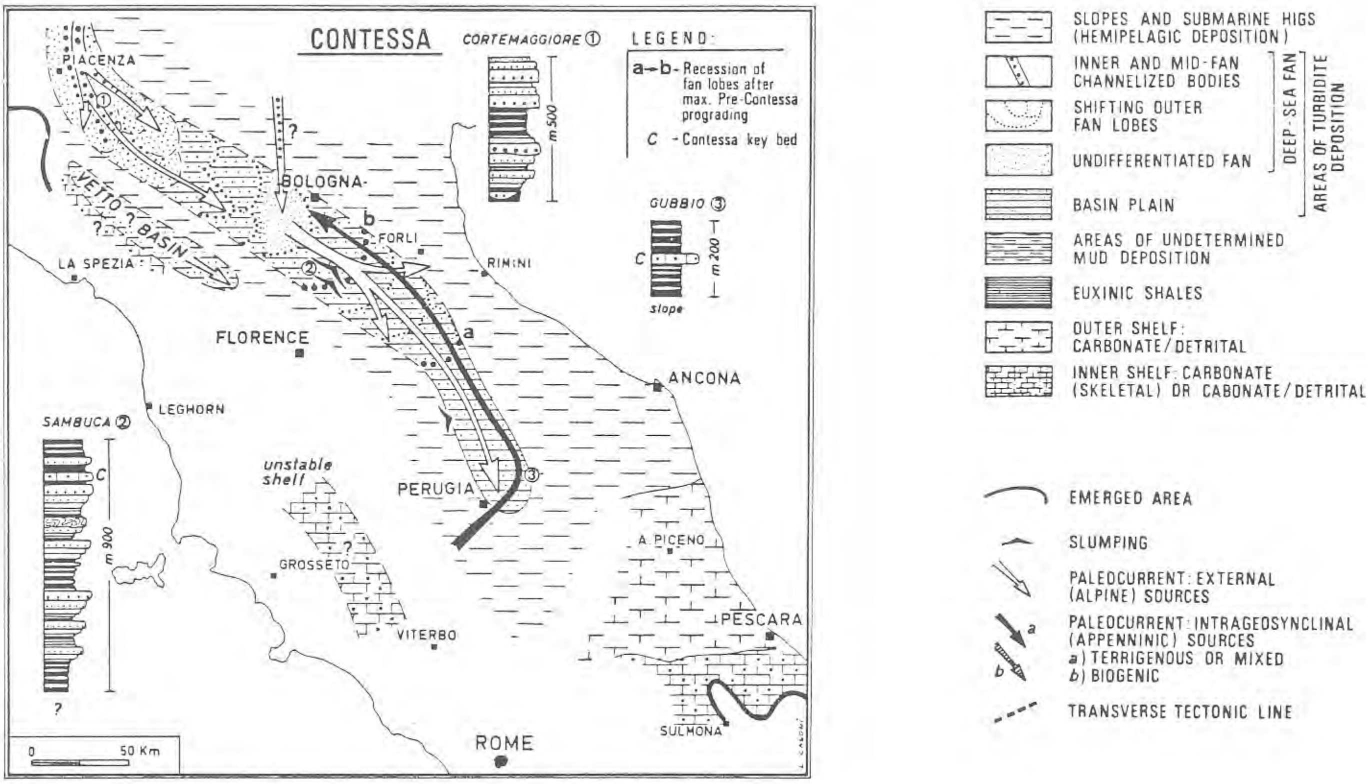
As usual, the term includes the *«Calcare di base»* and *Cagnino* units, and excludes the *«Formazione di letto»*, the equivalent *«Ghioli di letto»*, the *Tripoli* and *Marne tripolacee* units of older Authors; the latter units in fact correspond to part of member 4 and member 5 of the Marnoso-arenacea Fm. (Ricci-Lucchi, 1969), whereas the shaly, organic-matter-rich part of them was also given the name of *pre-evaporitic euxinic shales* (Vai & Ricci Lucchi, 1977; Marabini & Poluzzi, 1977) (Fig. *11)*. The names above reported in brackets disagree with modern stratigraphic rules (Hedberg, 1976) and should be dismissed.

The Gessoso-solfifera Fm. is the depositional response to the famous Messinian salinity crisis. Two main intrafacies can be separated in the Romagna Apennines across the Montone (Forlì) transversal Line: a W Romagna to Emilia selenitic facies (Vena del Gesso Basin) and a E Romagna to N Marche balatino-clayey-and-sulphur rich facies (Romagna-Marche Basin) containing reworked clasts of the former.

The *Vena del Gesso sequence* is the best known and can be subdivided, according to Vai & Ricci Lucchi (1977) and Marabini & Vai (1985), in the following suite of informal members in ascending order (Fig. 11).

1) *Carbonate cycles*

Two to six light grey, yellowish weathering carbo-



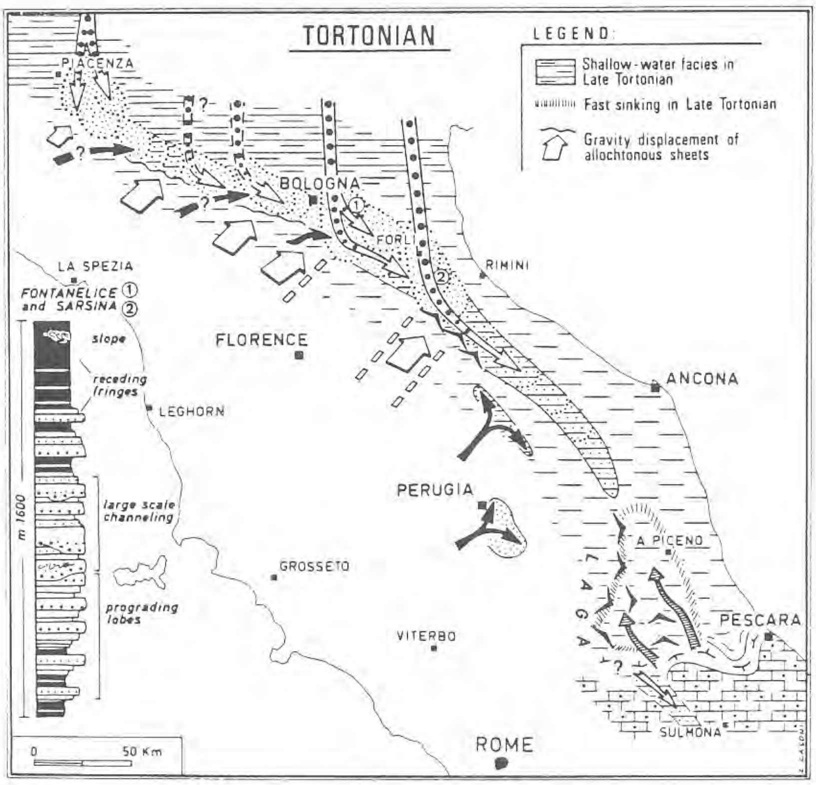


Fig. 9 – Dispersal pattern, palaeogeography and representing sections of Marnoso-arenacea Fm during Contessa (early Serravallian) and Tortonian stages of development (after Ricci Lucci, 1975).

nate beds cyclically alternating with grey to dark-grey, mainly euxinic shales and pelites. The main carbonate lithofacies range from circalittoral mass-extinction layers (mainly at expense of forams) to shallow normal water marly carbonates, subtidal-to-intertidal carbonate stromatolites and calcareous dolomitic breccias. The upper beds are commonly involved in medium-scale 1-3 m thick slumps. Total thickness is 1 to 6 metres. This member practically corresponds to the «Calcare di base» or Cagnino of eastern Romagna and Sicily (Ogniben, 1957; Vai & Ricci Lucchi, 1977) where sulphur mineralization are commonly associated. The first scanty evidences of syngenetic evaporite precipitation usually occur in the upper carbonate beds where the base of the Gessoso-solfifera Fm. is conventionally drawn (in spite in the fact that the bulk of the carbonate is biogenic or bioinduced instead of evaporitic as previously thought: see Vai & Ricci Lucchi, 1977).

2) *Early diagenetic gypsified stromatolites*

Usually represented by two cycles totalling a thickness of about 10 m. They consist mainly of subtidal-to-intertidal carbonate stromatolites replaced during early diagenesis by gypsum, as suggested by reworking of clasts which have been already gypsified before the onset of the next evaporitic cycle (Vai & Ricci Lucchi, 1977).

3) *Major (thicker) evaporitic cycles*

Regularly represented by three massive, selenitic gypsum beds alternating with thin, finely (mm) laminated euxinic shales. The bulk of the typical, swallow-tail selenite crystals is a ghost primary structure composed by concurrent, *in situ* growth of gypsum crystal and related filamentous algae drape. For this reason this type of gypsum is referred to as autochthonous. Late diagenetic syntaxial overgrowth took also place as shown by the clear growth stages of the crystals. Total thickness 60-80 m.

4) *VI evaporitic cycle*

Usually over 25 m thick gypsum bed characterized by the occurrence of the complete evaporitic lithofacies sequence (modal cycle of Vai & Ricci Lucchi, 1977). It starts with (1) transgressive euxinic shales and is followed by a regressive suite of (2) stromatolitic carbonates and/or gypsum plus clastic gypsum laminae, (3) autochthonous selenite with algal inclusions, (4) banded selenite rhythms, (5) clastic selenite, fine-grained acicular gypsum and reworked gypsum with flaser-like bedding, large diagenetic nodules and scanty evidences of subaerial exposure, and finally (6) chaotic, mass transported selenite.

5) *Minor (thinner) evaporitic cycles*

Represented by 9 to 10 gypsum beds, ranging in thickness from 5 to 18 meters, interbedded with euxi-

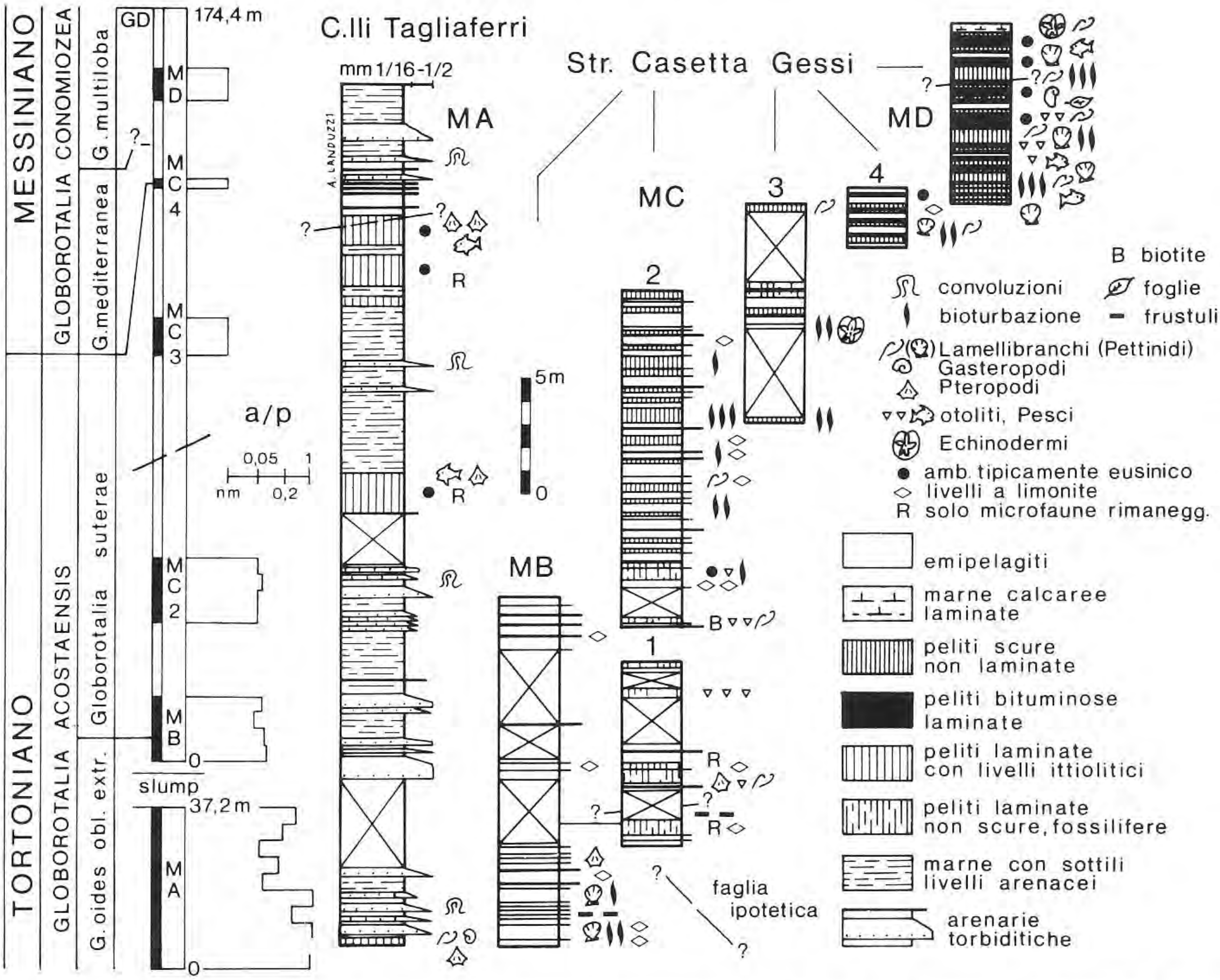


Fig. 10 – Middle Tortonian to early (pre-evaporitic) Messinian representative sections in the Santerno valley (western Romagna) (after Landuzzi, 1984).

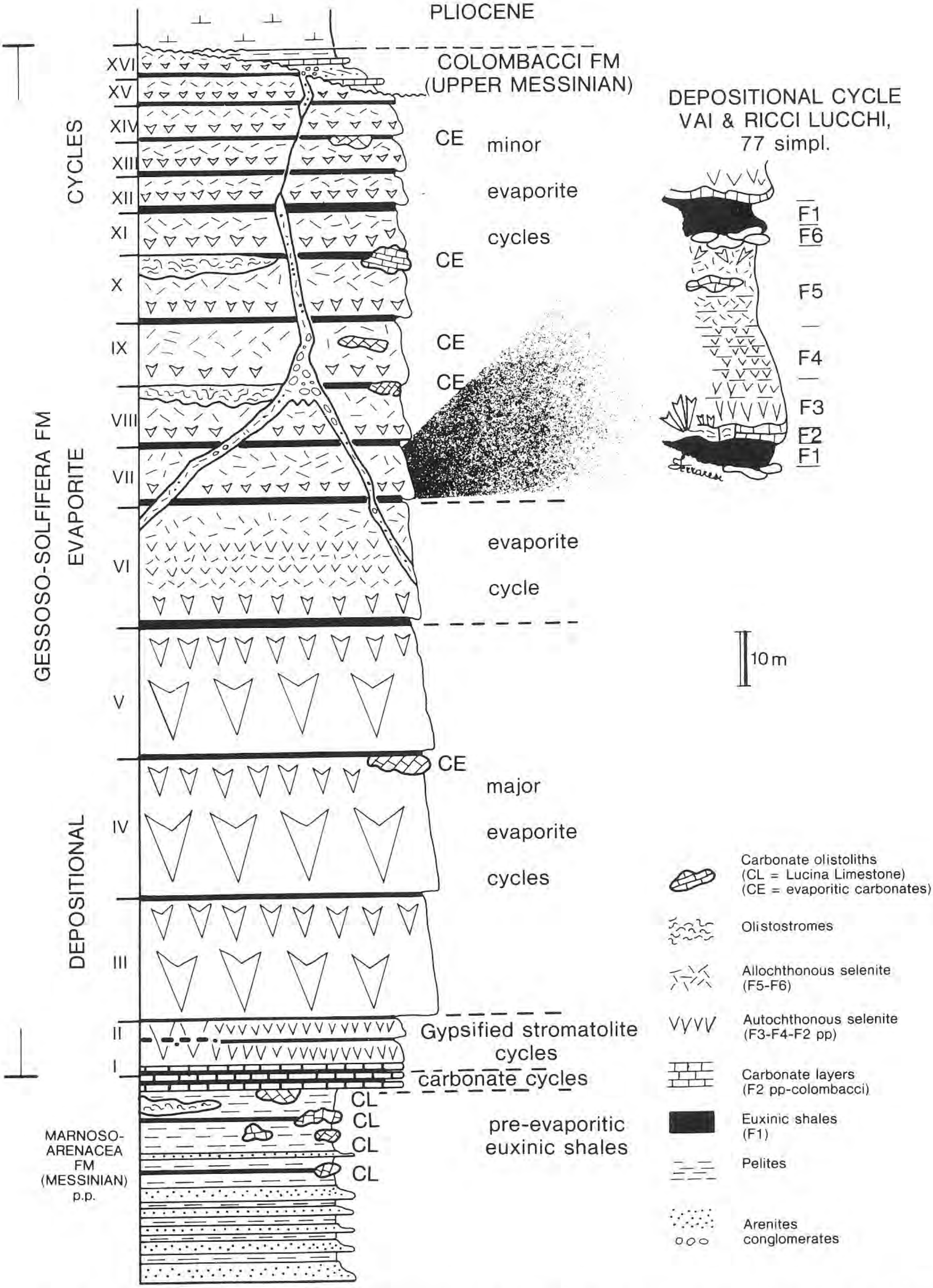


Fig. 11 – Schematic lithostratigraphic column of Messinian units in the Vena del Gesso basin, western Romagna (modified after Marabini & Vai, 1985).

nic fish-rich shales. These gypsum beds, whilst containing the complete sequence of evaporitic lithofacies (see above), are increasingly dominated by the fine grained, reworked lithofacies 5, suggesting a generalized regressive trend for the entire evaporite sequence.

The more complete section shows a transition to the overlying Colombacci Fm. characterized by cherty (chalcedony rich) fresh water to oligohaline *Paludina* horizon (schizohaline environment).

The *E Romagna-N Marche balatino clayey and sulphur rich facies* was described by Selli (1954), Rabbi & Ricci Lucchi (1968), Girotti & Parotto (1969), Carloni *et al.* (1974), Borsetti *et al.* (1975) Savelli & Wezel (1979), Cremonini & Farabegoli (1982), Farabegoli (1983). It consists of carbonate cycles similar to those found in the previous W Romagna facies, followed by 10 to 15 finely laminated, microcrystalline to fine grained, variegated *balatino* gypsum cycles alternating with thick shale and pelite interlayers. Maximum thickness is about 100 m.

A complete, synthetic review of the Italian Messinian on land is found in Selli (1973) (Fig. 14). Key contribution to the Po Plain subsurface Messinian and to the Messinian drowned under the Pliocene to Pleistocene Tyrrhenian Sea deposits are found in Rizzini & Dondi (1979), Dondi & D'Andrea (1978) and Fabbri & Curzi (1979). The largest collection of Messinian data from Italy was compiled by Camerlenghi *et al.* (1983).

Colombacci Formation

As used here, this term includes both the «*Formazione di tetto*» (or *Terreni di ‹tetto›*) and *Argille e marne a Colombacci* (or *Serie a ‹Colombacci›)* described by Selli (1954), as already done by Ruggieri (1970), Vai & Ricci Lucchi (1977) and Cremonini & Marabini (1982), for practical (see also Cremonini & Farabegoli, 1982) and procedural reasons (the first term is unsuitable according to the present stratigraphic rules).

The Colombacci Fm. is still a response to the Messinian salinity crisis, even more schizoid in the Periadriatic regions characterized by increasing freshwater influx.

As for the underlying Gessoso-solfifera Fm., the Colombacci Fm. shows two main intrafacies limited by the Montone (Forlì) transversal line: a W Romagna to Emilia thinner to discontinuous facies and the E Romagna to Marche thicker classical facies.

Referred to as «strati a Congerie» by older authors (Scarabelli, 1851), *the W Romagna facies* consists of

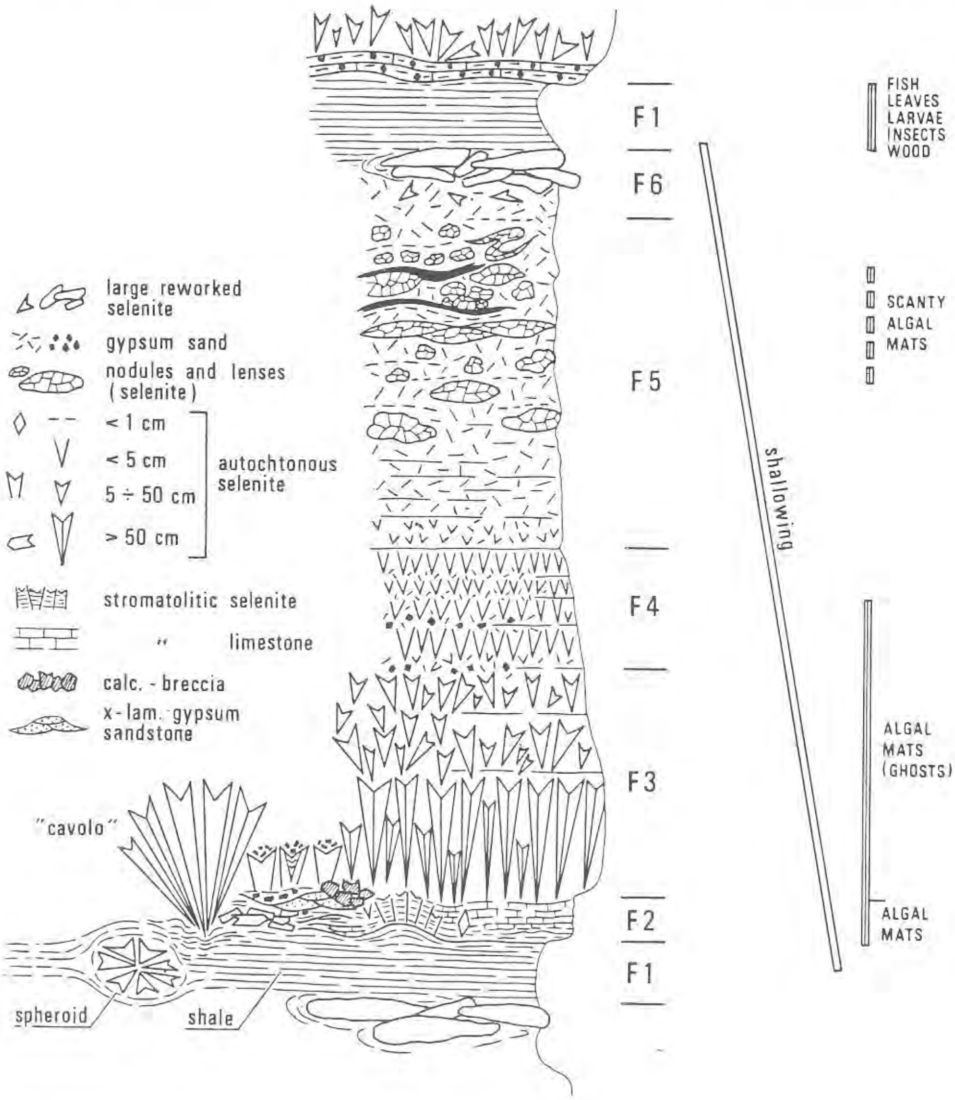


Fig. 12 – The modal evaporitic cycle in the Messinian Vena del Gesso Basin, western Romagna (after Vai & Ricci Lucchi, 1977).

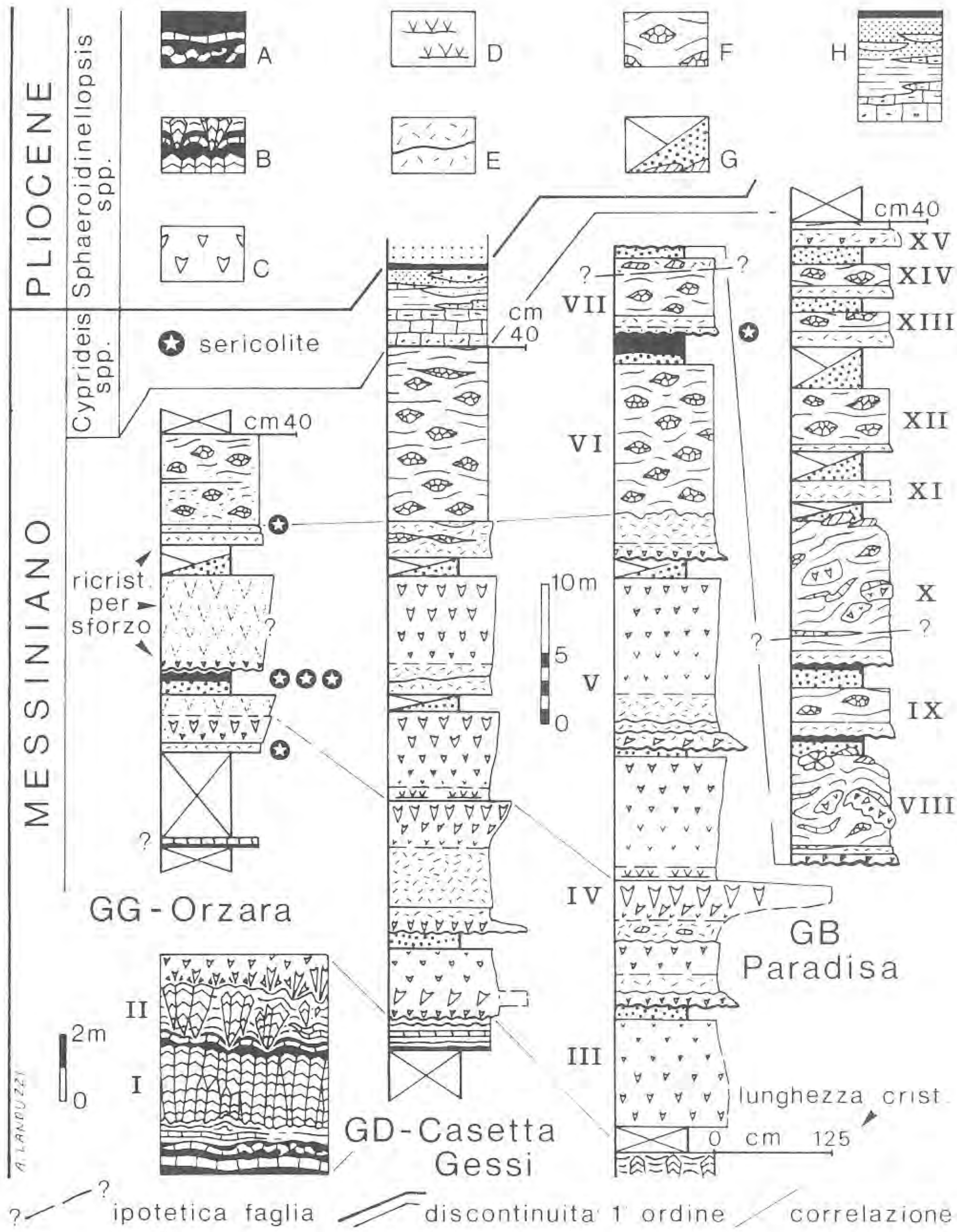


Fig. 13 – Lithostratigraphic correlation of representative middle (evaporitic) Messinian sections, Vena del Gesso Basin, western Santerno valley, western Romagna (after Landuzzi, 1984). Key to symbols in Fig. 10 and 15.

grey, acicular gypsum-rich pelites, variegated marly clays with abundant carbonate concretions and whitish to yellow, thin bedded, evaporitic marly limestone. Euryhaline to brackish molluscs and brackish to fresh water ostracods are common in the pelites and clays, whereas limestones are virtually azoic (very rare ostracod shells). The fine grained lithotypes are often crosscut by string-like sandy to conglomeratic channelized bodies. Their clasts show and Apenninic, Ligurid-rich provenance. The sequence, with a modal thickness of some meters to a few tens of meters, is capped by a 20-to-60 cm-thick black clayey, ostracods, rich, bioturbated horizon (Vai & Ricci Lucchi, 1976; Landuzzi, 1984; Landuzzi & Castellari, this vol.) (Fig. 15).

The lower contact, when deposited and preserved, is conformable and continuous. However, right a few dm to few cm above the base of the Formation a major angular unconformity (the main intra-Messinian compressional phase) is found almost all over this area (Iaccarino & Papani, 1980; Marabini & Vai, 1985; Castellarin *et al.*, 1986). A minor unconformity is also found locally at the very base of the terminal black clay horizon. This last horizon is usually conformable and continuous with the overlying basal strata of the Argille Azzurre Fm. (*Sphaeroidinellopsis* acme Z.). In this case the age of the Colombacci Fm. is late Messinian by definition.

Maximum thickness of the Colombacci Fm. in this area is reached in the Idice section, showing intermediate condition, as compared with the two main facies. It is remarkable that this section shows intermediate facies conditions also for the Gessoso-solfifera Fm. (Vai, 1982 internal report). This feature is tentatively related to the more relevant supply of clayey material from the Ligurid Sillaro thrust sheets.

The E Romagna-Marche facies is usually over 200-300 m thick, with a sequence of six main, composite cycles (Selli, 1954; 1973; Colalongo *et al.*, 1978; Cremonini & Farabegoli, 1982; Cremonini & Marabini, 1982) highlighted by the thin evaporitic limestone layers (Selli, 1952). Here, too, the dominant lithotype is marly clay with scattered fine-grained large channelized turbidite and sandy and/or

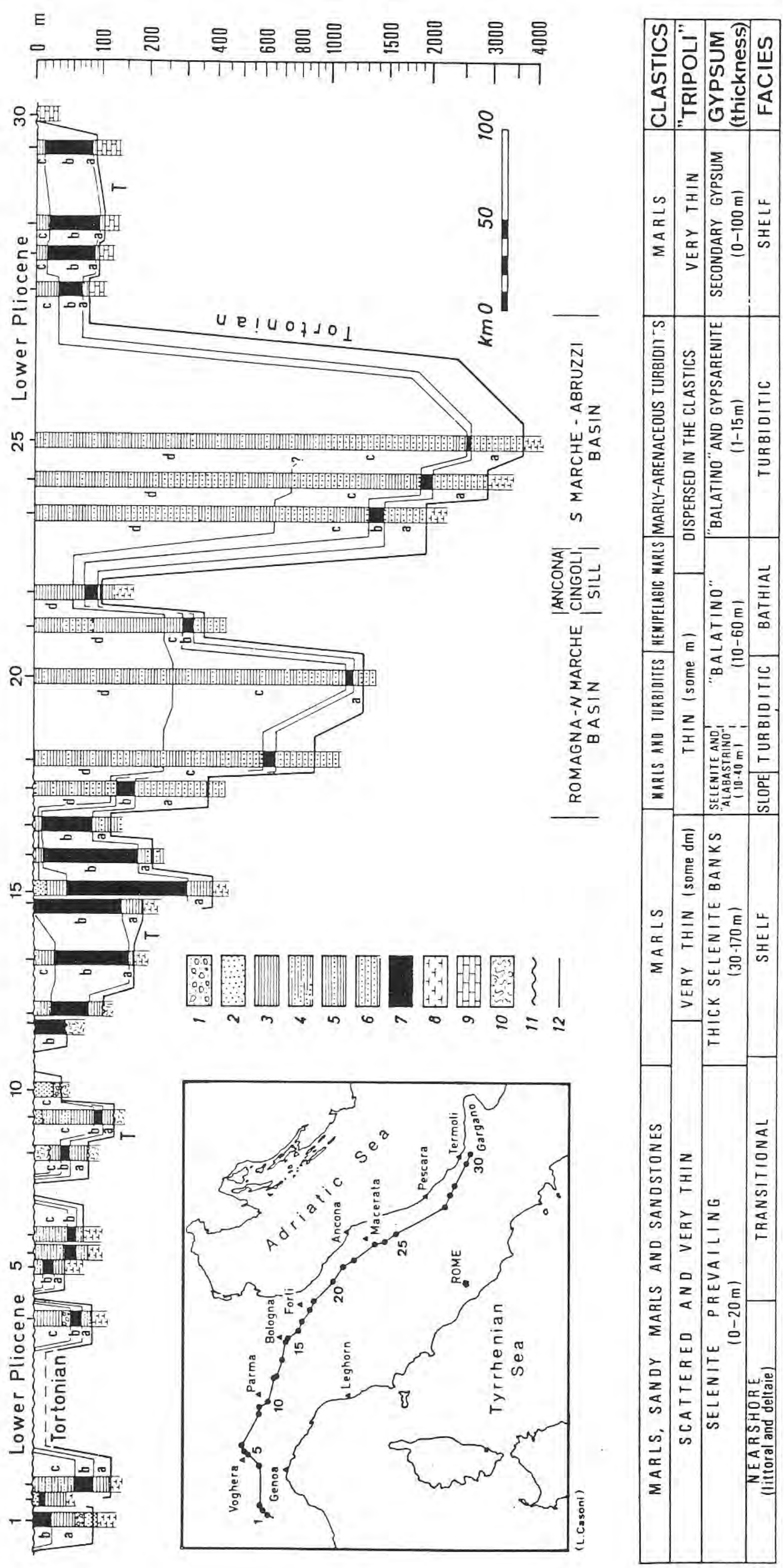


Fig. 14 – Main lithostratigraphic correlation of Messinian columnar sections from Piedmont to Gargano (Adriatic foretrough). a: basal formation, b: lower evaporites (or Gessoso-solfifera Fm), c: intermediate formation, d: Colombacci Fm (after Selli, 1973).

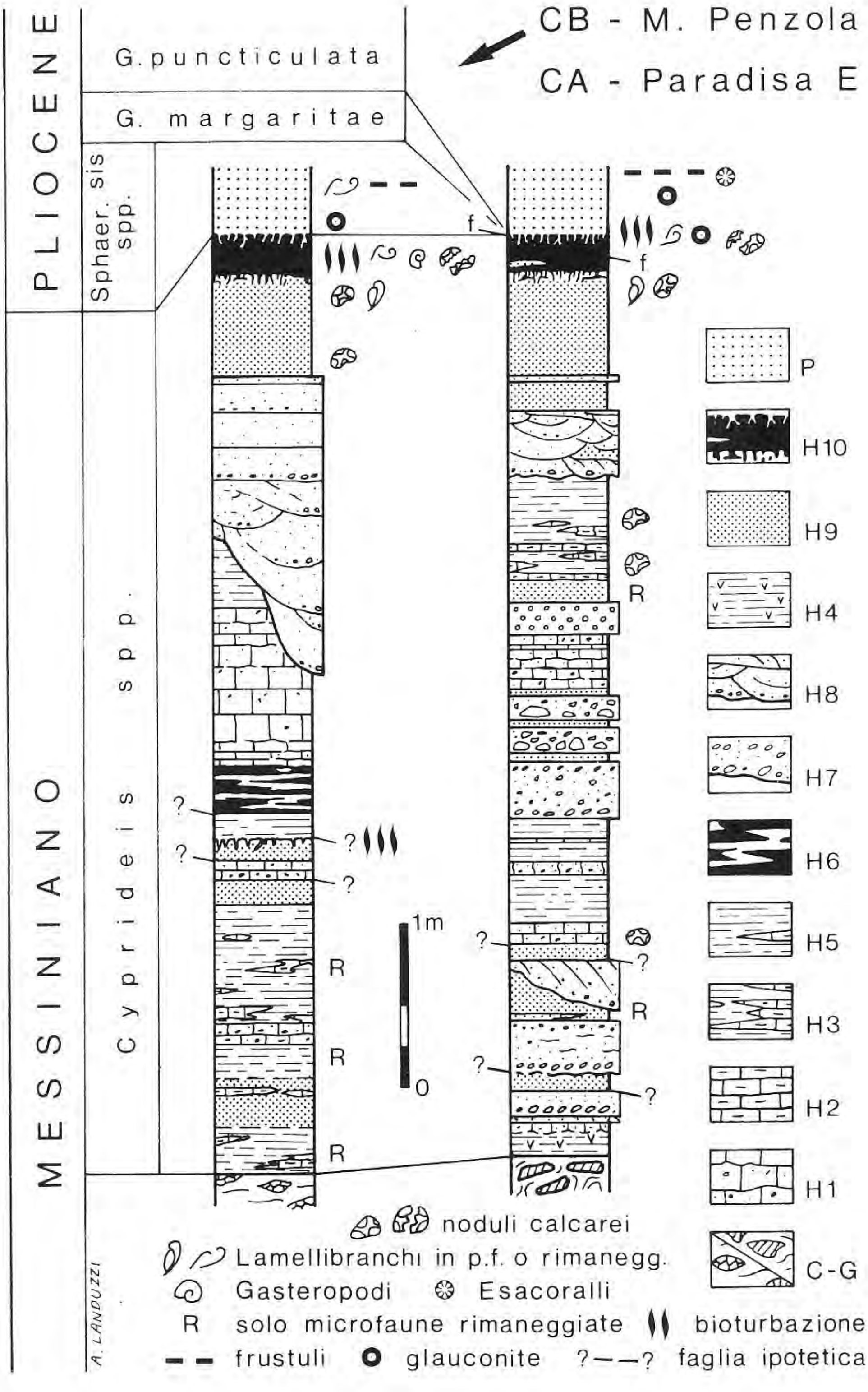


Fig. 15 – Representative columnar sections of the Colombacci Fm (western Romagna thin intrafacies) in the western Santerno valley. Transition to the early Pliocene Argille Azzurre Fm is also shown. C-G: Gessoso-solfifera Fm: clastic-nodular gypsum and gypsiferous debris-flow deposits (facies 5 and 6). H: Colombacci Fm: 1) detrital, vuggy (once gypsum-bearing) limestone, grading into fine marly limestone (2) or «varved» limy mudstone (3); 5) light green mudstone, partly gypsiferous (4) or limy; 6) vari-coloured, laminated mudstones; 7) channelized conglomeratic or sandy (8) bodies; 9) olive-green, fossiliferous and nodule-bearing mudstone; 10) blackish, disturbed pebbly mudstone. P: Argille Azzurre Fm: blue-gray glauconitic, fossiliferous clays.

conglomerate bodies clustered mainly between the ‹Colombacci› nos. 2-3 but also between nos. 4-5.

A tephra horizon found by Selli (1954) in the S Marche area under the first ‹Colombaccio› (see also Girotti & Parotto, 1969; Carloni *et al.*, 1974) has been traced as far as E Romagna (Cremonini & Farabegoli, 1982).

Lithofacies interpretation, ^{18}O and ^{13}C isotope analysis, clay mineralogy and faunal evaluation support full pertinence of the Periadriatic Colombacci Fm. to the Paratethys realm.

The lower limit of this facies is less exposed or preserved. A major intra-Colombacci tectonic angular unconformity has been recently found W of Cusercoli below the ‹Colombaccio› no. 3.

Generally, however, the major amount of the Colombacci Fm. show a remarkable cartographic angular unconformity above the more severely folded and thrusted Gessoso-solfifera and Marnoso-arenacea Fms. in E Romagna and N Marche.

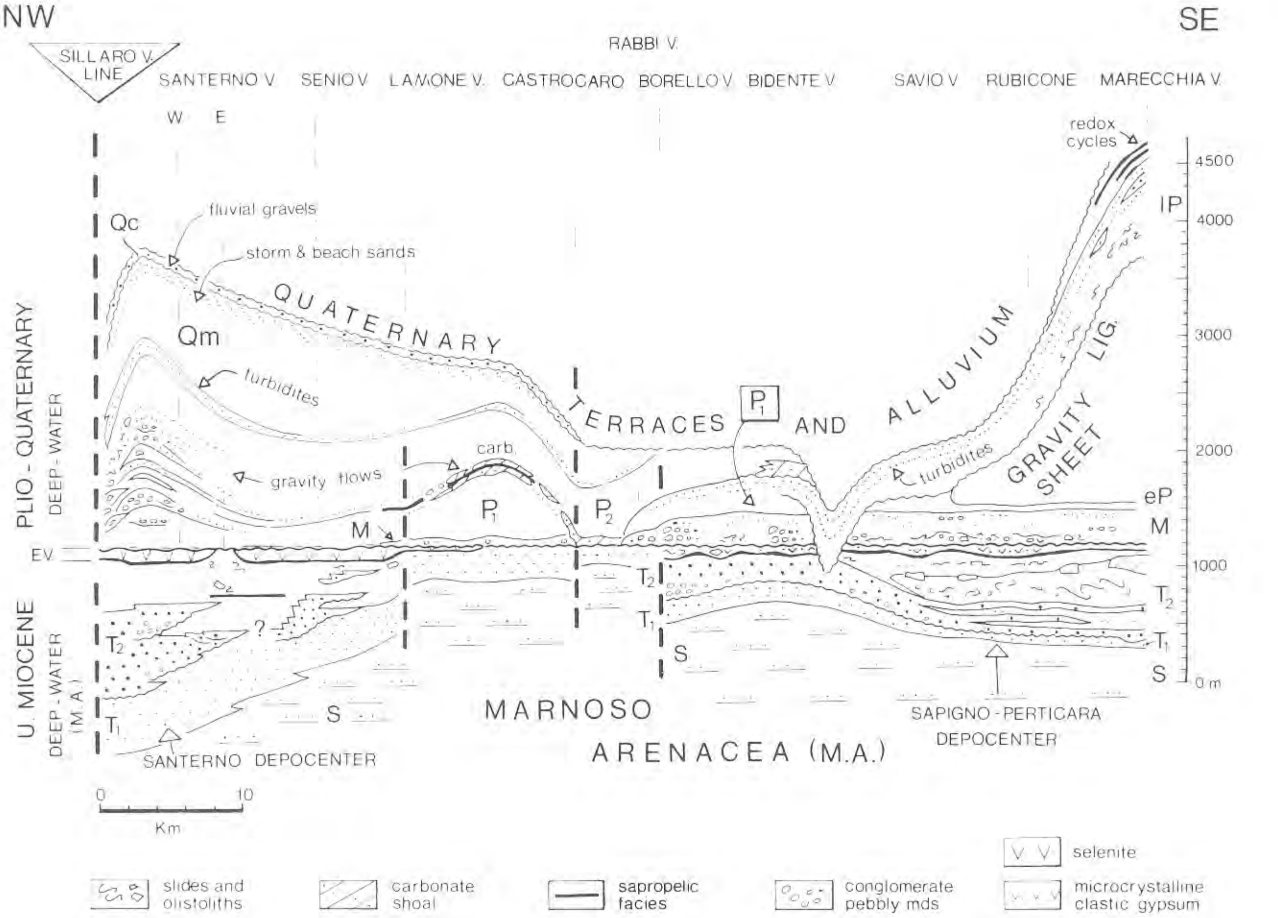


Fig. 16 – Schematic longitudinal cross section of upper Miocene to Pleistocene deposits of the Romagna foredeep. Datum is represented by the Messinian evaporites (after Ricci Lucchi, 1986, with IAS permission).

Argille Azzurre Formation

The original (Leonardo, 1506-1510) and traditional name (Cuvier, 1812; Brocchi, 1814; Lyell, 1830; etc.), formally recognized (Vai, 1986; 1988) is used here for the largely uniform, clayey unit characterizing the neoautochthonous, fully marine, Plio-Pleistocene, sub-Apennine deposits.

Argille Azzurre appears to be the most suitable term, almost perfectly matching the requirements of the International Stratigraphic Guide (Hedberg, 1976). The term ‹Gruppo del Santerno› which was recently introduced as a lump-name for the same unit in regional cartography (Farabegoli, 1983) is a junior synonimy of Argille Azzurre; it is unsuitable as a lithostratigraphic name, being already pre-occupied by *Santernian* (Ruggieri & Sprovieri, 1977), a chronostratographic/chronologic term of the Standard Stratigraphic Scale (Harland, *et al.*, 1982) (Fig. 19). Furthermore, the use of the Santerno section and name for chronostratigraphic (and related biostratigraphic purposes) dates back to the '50 at least. The term «Argille del Santerno» used by AGIP in the subsurface (e.g. AGIP, 1982) is informal and justified for the internal, purely utilitarian use of the companies. If not used as a such, the stratigraphic subsurface taxonomy too must conform to the rules and practice of the ISSC surface taxonomy, the latter having priority.

Inside the Argille Azzurre Fm. proper (characterized by grey-blue, basinal marly clay, with thin silt to fine sand intercalations, with a total thickness exceeding 3000 m), some informal members have been distinguished (Fig. 5): the *Mescola conglomerates and sandstone* (mainly channelized gravity flows and turbidites) developed close parallel to the Sillaro Line from the late Lower Pliocene to Plio-Pleistocene boundary interval (Lucchetti *et al.*, 1963; Colalongo *et al.*, 1982); the *‹Spungone› limestones* (carbonate shoals and grain flow deposits, up to few hundreds of m thick) developed in central Romagna between the Lamone-Marzeno and the Bevano-Savio Valley at the early-middle Pliocene boundary interval (Cremonini *et al.*, 1982); the *Borello sandstones* (Cremonini & Farabegoli, 1982) (turbidites) of late Lower Pliocene age developed in E Romagna (with thickness up to few hundreds of m). A 500 m thick redox cyclic sequence, with remarkable fish and pteropods mass-extinction layers, marks an euxinic interval at the lower-middle Pliocene boundary beautifully exposed in the Marecchia river banks (Colalongo *et al.*, 1982; Sorbini, 1982) (Figs. 5 & 16).

«Sabbie gialle» formation

With this name is traditionally known the stratigraphic unit immediately overlying the Argille Azzurre Fm. at the Apennine foothill (Figs. 17-20), at least starting from Brocchi (1814). The poorly exposed lower contact, however, and the marked cyclicity of the factors controlling the middle-late Pleistocene sedimentation on a basin margin belt make it difficult to recognize precisely age, sequence trend and internal stratigraphic subdivision of the unit, which is used here informally.

At the Northern Apennine scale, the basal age of the unit is strongly diachronous from late Pliocene to Pleistocene (roughly from W to E) (Castellarin *et al.*, 1986). In the Romagna area (between the Sillaro and the Montone Lines), however, all Authors agree upon a post-Calabrian s.s. (or post-Santernian, or post 1.4-1.3 Ma) age for the unit. Discussion arises whether this unit preceedes or follows the glacial Pleistocene (about 0.75 Ma): the first solution is shared by Azzaroli & Berzi (1970), whereas the second one represents the classic «Milazzian» dating of Ruggieri & Selli (1949) and Selli (1962; 1973a) (the unsuitable term «Milazzian» simply recalling the time interval between Sicilian and Tyrrhenian) (Fig. 19).

Furthermore, later Authors suggest two main sedimentary settings for the ‹Sabbie gialle›, 1) continuous, gradual, regressive sequence at the top of the Argille Azzurre Fm. still inside the Qm cycle (Ricci Lucchi *et al.*, 1982), or 2) sharp, unconformable, initially transgressive sequence (Vai, 1984; Farabegoli, 1985; Marabini *et al.*, 1987) in agreement with the old Ruggieri & Selli (1949) view.

At a more general level, the Pleistocene deposits of the Northern Apennine foothills were divided into two main sedimentary cycles: Qm and Qc (Ricci Lucchi *et al.*, 1982). The boundary between the two is an irregular, subaerial (emerged) erosional surface, followed by fluvio-lacustrine deposits with paleosol horizons (Cremaschi, 1982, fig. 6.1; Cremonini & Ricci Lucchi, 1982, fig. II, 18; Colalongo *et al.*, 1982, fig. 10.1). The recognition of this boundary may be difficult because a) gravels reworked in shore environment are found also below the limit and b) yellow sands occur also above it. At any rate, these problems affect the upper limit of the ‹Sabbie gialle›, the lower one being still even more open to question. Marabini *et al.* (1987a, b) suggested that the ‹Sabbie gialle› of Romagna can be subdivided into two distinct sedimentary cycles (see also Colalongo *et al.*, 1982 and Vai, 1984). In fact, a first, thin (possibly Sicilian) yellow sand interval might represent the

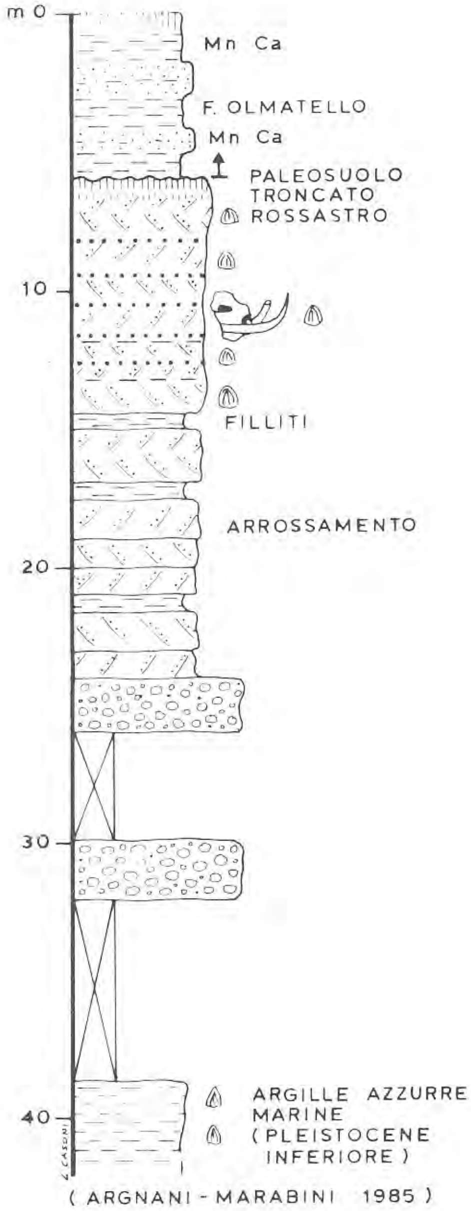


Fig. 17 – Columnar section of ‹Sabbie gialle› fm at Salita Quarry, near Fenza, where Elephas *and* Bison *skulls have been found recently (after Marabini* et al., *1987b).*

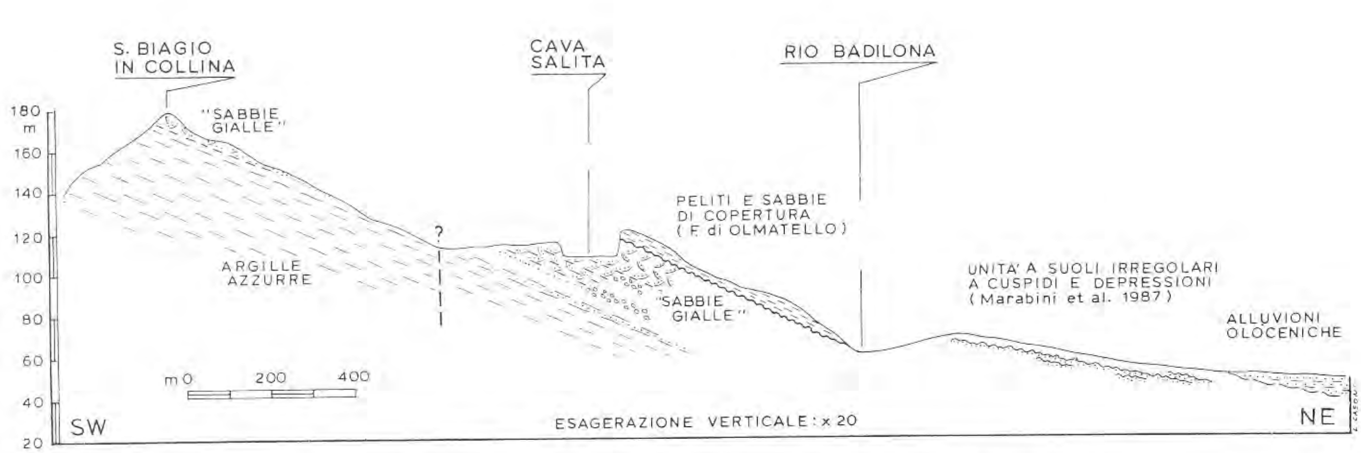


Fig. 18 – Geological section across the Salita Quarry, near Faenza (after Marabini et al., *1987b).*

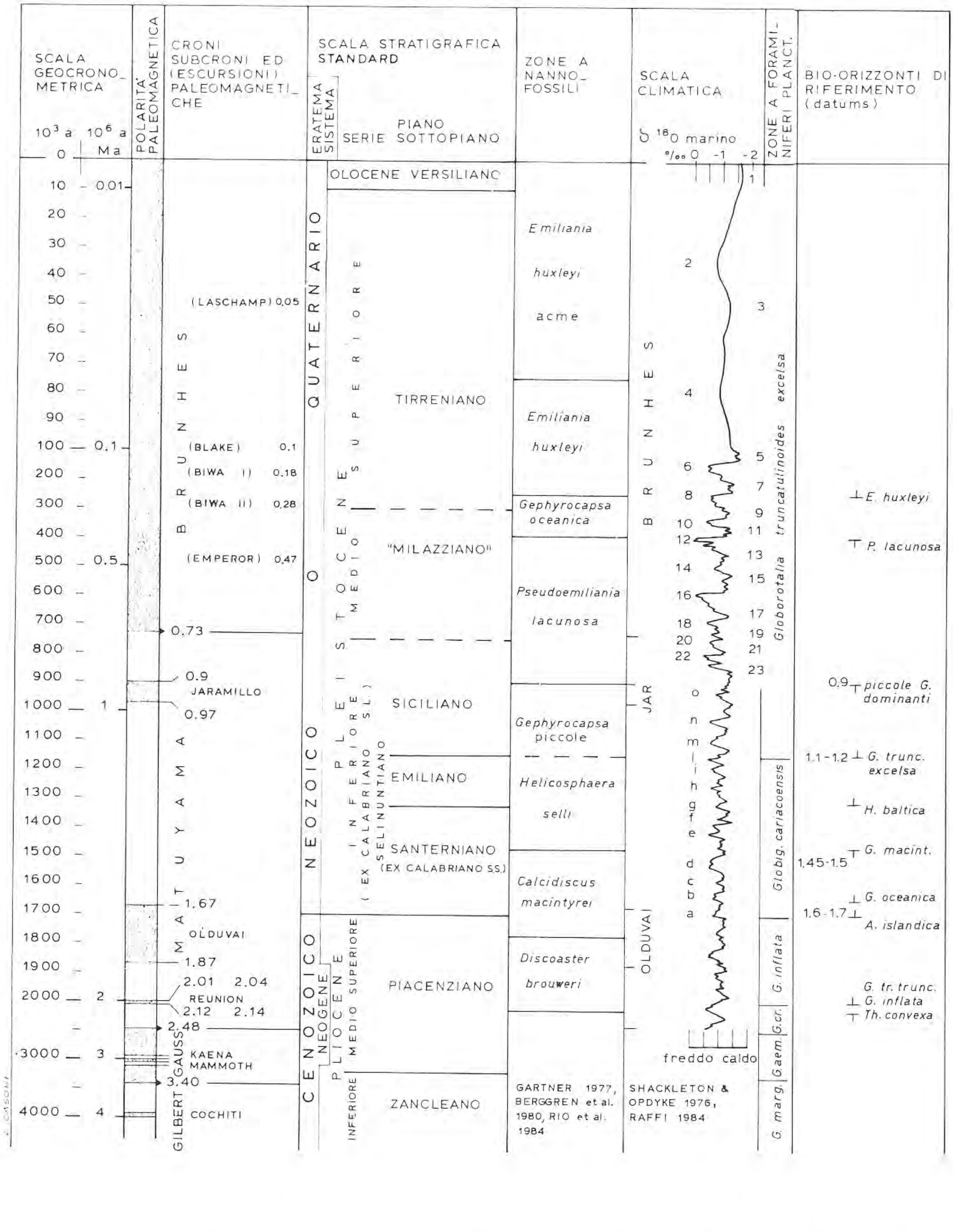
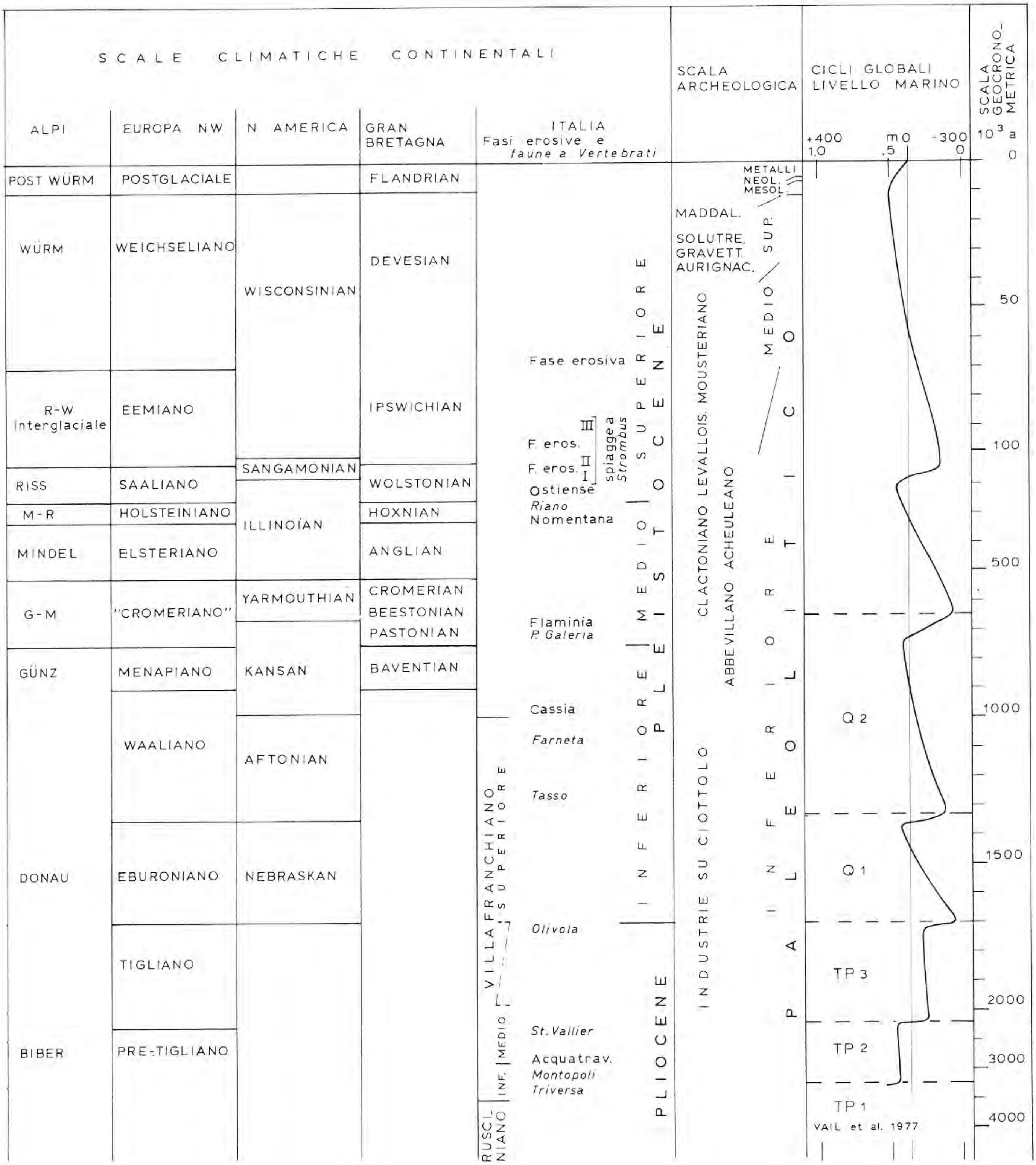


Fig. 19 – Stratigraphic correlation chart of Pliocene to Quaternary marine and continental deposits (after Vai, 1984).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FLANDRIAN
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DEVESIAN
R-W Interglaciale
EEMIANO
IPSWICHIAN
RISS
SAALIANO
SANGAMONIAN
WOLSTONIAN
M-R
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ILLINOIAN
HOXNIAN
MINDEL
ELSTERIANO
ANGLIAN
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YARMOUTHIAN
CROMERIAN
BEESTONIAN
PASTONIAN
GÜNZ
MENAPIANO
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AFTONIAN
DONAU
EBURONIANO
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TIGLIANO
BIBER
PRE-TIGLIANO
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P. Galeria
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Farneta
Tasso
Olivola
St. Vallier
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Montopoli
Triversa
VILLAFRANCHIANO
SUPERIORE
MEDIO
INF.
RUSCINIANO
PLEISTOCENE SUPERIORE
PLEISTOCENE MEDIO
PLEISTOCENE INFERIORE
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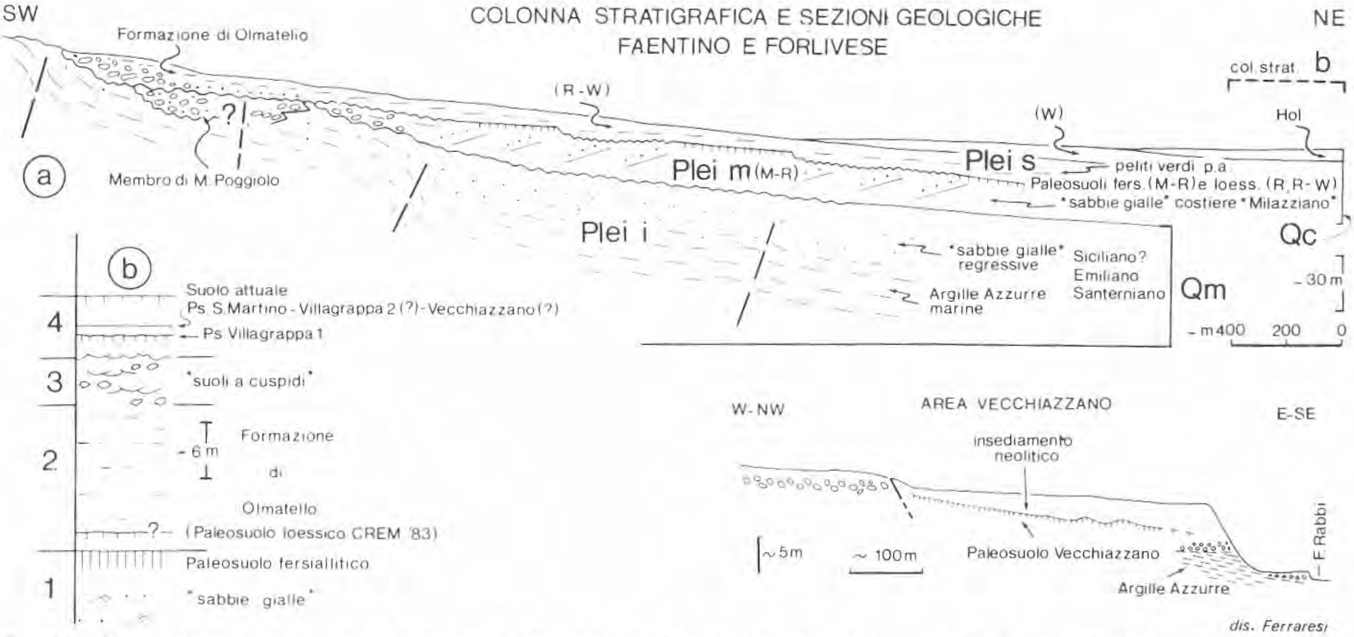

Fig. 20 – Transversal cross section and stratigraphic column of the foothill belt between Faenza and Forlì (Romagna) showing inferred mutual relationships of Argille Azzurre, ‹Sabbie gialle› and Olmatello Fms with the uppermost Pleistocene and Holocene paleosol-rich deposits.

regressive closure of the Qm cycle and is characterized by gradual transition to the underlying Argille Azzurre Fm., restricted to brackish faunal condition and common deformation evidences including folding. A second, thicker and younger (possibly ‹Milazzian›) yellow sand and gravel interval represents the unconformable transgressive beginning of the Qc cycle in the foothill belt, and is characterized by shoreface to foreshore sedimentary structures and is almost devoid of deformation.

The thickness of the unit seems not to exceed 30-40 m. Well preserved *Elephas* and *Bison* skulls have been found recently in the Salita Quarry, near Faenza (Marabini *et al.*, 1987b).

Olmatello Formation

This unit was introduced and preliminarly described by Vai (1984) and Marabini *et al.* (1987a). It consists of a thin lower member of gravel and grey sand followed upwards and distally by a greenish pelite member (Figs. 20 & 22). Both members represent continental environment, as shown by frequent carbonate concretions, scattered vertebrate remains (including an *Elephas* thusk) and common freshwater molluscs, such as *Pomatias elegans, Helicodonta obvoluta*, etc. (Vai, 1984). This fining upward sequence points out to a transition from braided stream to floodplain deposits. The unit is only some meters to about twenty meters thick, but remarkably uniform from Montone to Santerno Valleys. The units ‹Ghiaie di Villa del Bosco› and ‹Peliti di Toscanella› described by Farabegoli (1985) near Bologna could be lithostratigraphic equivalent of this unit having a similar lithology and the same relative position in the stratigraphic sequence (Marabini *et al.*, 1987a).

The lower limit of the unit is sharp, discontinuous (locally a weathered pedogenic horizon directly underlies the limit), disconformable to slightly unconformable at places (Figs. 20 & 22).

The upper limit, though less exposed, is usually erosional (early-to-middle alluvial terraces). The unit itself seems to correlate with the highest strongly tilted (up to 6 degrees towards the NNE) erosional surface (pediment).

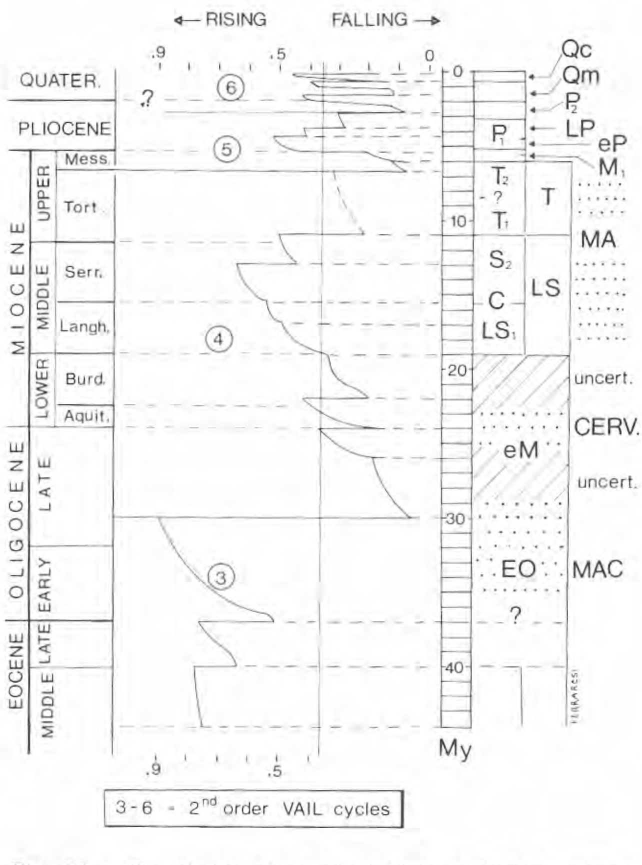

Fig. 21 – Correlation chart of Northern Apennine cycles and Vail curve (after Ricci Lucchi, 1986, with IAS permission).

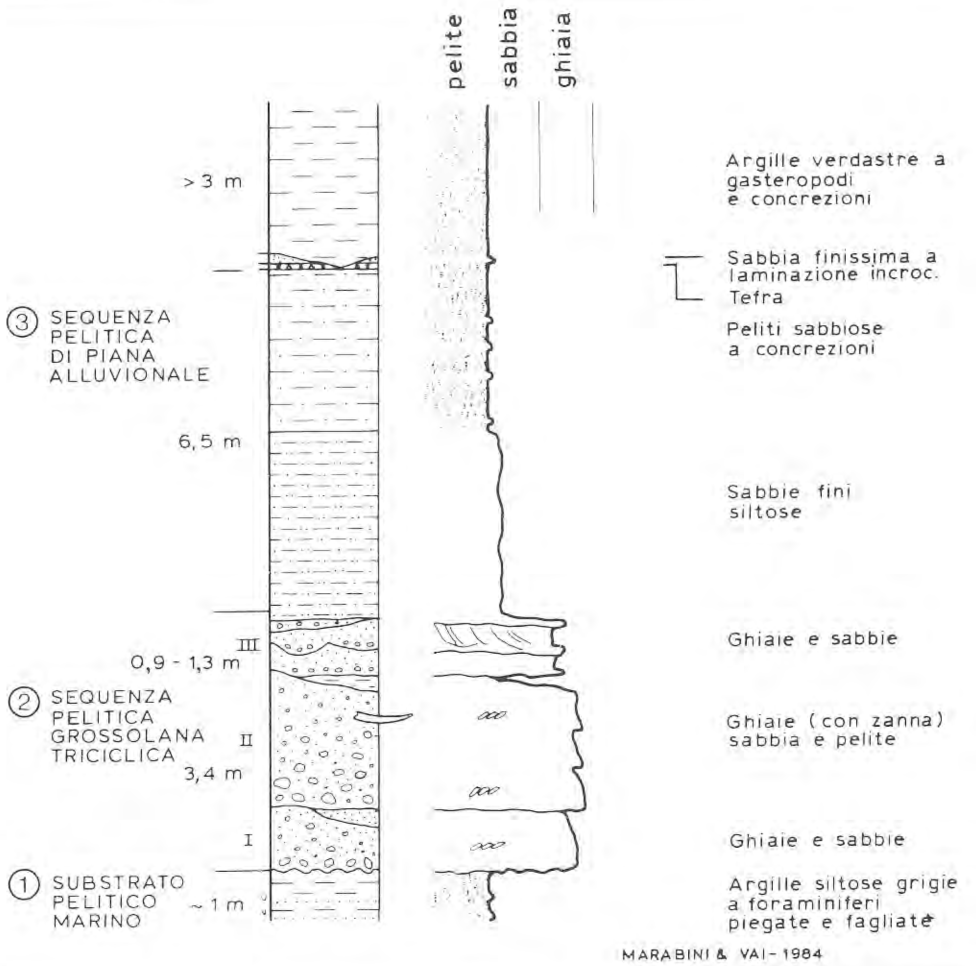

Fig. 22 – Columnar section of the Olmatello Fm at the type locality near Faenza where an Elephas *tusk has been found recently (after Vai, 1984).*

In the morphologic culminations between the terraced valleys this unit is distally overlain by a loamy unit with few peculiar deformed (cuspate to depressed) Mn pisolite rich paleosol horizons (possibly of glacial age) with upper Palaeolithic cherty tools. This is in turn onlapped by Holocene fine grained alluvial deposits with intercalated some paleosol horizons, one of which yields Neolithic pottery (4,000-3,000 BC) (Marabini *et al.*, 1987a).

In terms of classic *sedimentary cycles* or seismostratigraphic depositional sequences (Mitchum *et al.*, 1977), the succession of lithostratigraphic units just summarized has been subdivided by Ricci Lucchi (1982) as follows (Fig. 16 & 21).

LS (Langhian-Serravallian) cycle, possibly subdivided into two subcycles (LS1 and S2).

T (Tortonian) cycle (including also large part of the Messinian) more easily separated from the LS cycle, is in turn possibly devided into two subcycles (T1 and T2) by an erosional surface.

No internal angular unconformity is found in the field separating cycles each other inside the Marnoso-arenacea and Gessoso-solfifera Fms.

M (Messinian) cycle (corresponding to the Colombacci Fm). A major unconformity (Marabini & Vai, 1985; Landuzzi, 1984; Nait, 1987) followed by emersion and denudation (Cremonini & Farabegoli, 1978; Costa *et al.*, 1986) marks the passage (once believed continuous) between evaporitic and subsequent fine clastic freshwater-to-brackish deposition.

P1 (lower Pliocene) cycle. Best defined in subsurface, it can be split in a lower (eP1) clayey ‹trubi›-like subcycle and an upper (lP1) sandy turbiditic subcycle especially in E Romagna basin margins; the eP1/lP1 boundary is an unconformity (Farabegoli, 1983). P1 thickness does not exceeds 500 m in outcrop, but reaches 3,500-4,500 m in subsurface.

P2 (mid-upper Pliocene) cycle. Marginal unconformities and transition from clay in the highs to sandy turbidites in the depocenters characterize also this cycle. Maximum thickness: 4,000 m.

Qm (marine Pleistocene) cycle. Its basal limit is unconformable only in marginal areas but conformable in depocenters, including the Santerno area with a thickness of about 1000 m. The top shows gradual transition from sandy muds to regressive ‹yellow sands›.

Qc (mainly continental Pleistocene) cycle, reflecting the last Pleistocene sea level high stand. it is marked by a marginal unconformity and consists of stranded ‹yellow sands› (a possible second cycle) and different subcycles of continental deposits. It corresponds to part of the ‹Sabbie gialle› fm. plus the Olmatello Fm.

This synthetic review of sedimentary cycles in the Romagna Apennines follows Ricci Lucchi (1986) (where details can be found) except for minor disagreement in interpretation (Miocene cycles) and clas-

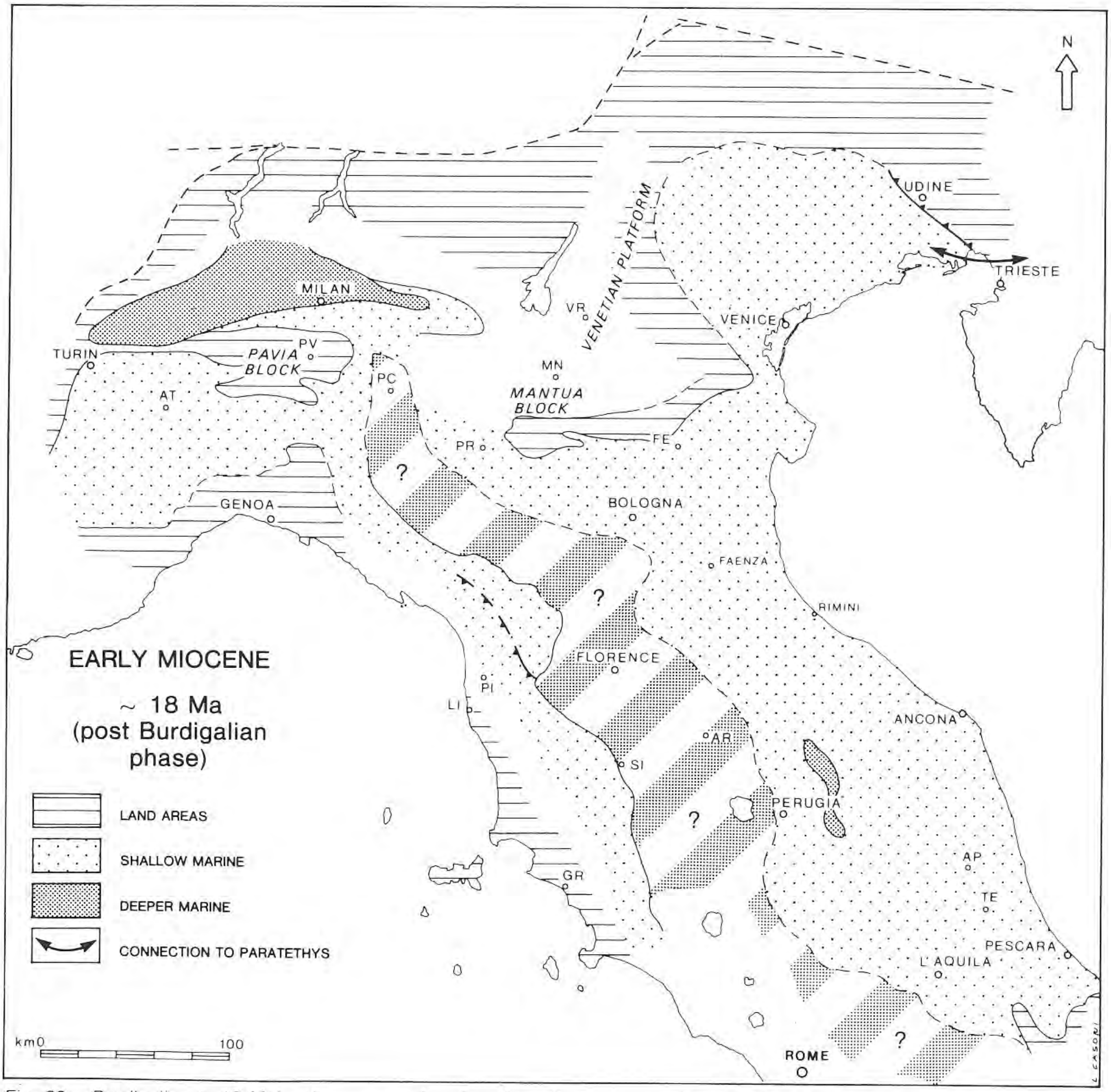

Fig. 23 – Burdigalian (~18 Ma) palaeogeography of northern Italy (sources: Boccaletti et al., *1987; Castellarin* et al., *1986a; Dallan Nardi & Nardi, 1974; Dondi & D'Andrea, 1987; Giglia, 1974; Massari* et al., *1987; Ricci Lucchi, 1975; Geologic Map of Italy, 1:100.000; Carta Tettonica d'Italia, 1:1.500.000 (1981); Neotectonic Model of Italy, 1:1.500.000 (1985) and writer's unpublished data). Only selected faults, mainly in the Romagna Apennines, have been reported. No palinspastic restoration was attempted. Magnitude of front displacements at different times is found in Vai, 1988.*

sification (Qm-Qc boundary) of the cycles.

PALAEOTECTONIC AND PALAEOGEOGRAPHIC EVOLUTION OF THE ROMAGNA APENNINES

A very schematic, simplified, tentative reconstruction of this kind may be attempted at selected time steps taking into critical account all data summarized above and some unpublished writer informations. Five main stages and/or events can be highlighted (see also Vai, 1988).

1) Langhian to lower Messinian thalassocratic extensional stage

2) Messinian salinity crisis

3) Intra-Messinian tectonic revolution

4) Plio-Pleistocene thalassocratic compressional stage

5) Middle Pleistocene to Holocene uprise stage.

These stages are schematically described and commented by means of six sequential palaeogeographic maps extended to most of the north-central Italian area to provide a larger scale integrated picture of the Romagna Apennines which can help in visualizing migration routes of vertebrate faunas (Figs. 23 to 28) (for the SE Italian area see De Giuli *et al.*, 1987).

1) Deep sea foredeep turbidites characterize this interval. The uneven outward migration of the Marnoso-arenacea depocenter (Ricci Lucchi, 1975) might be explained in terms of thrust front advancement in the back of the foredeep (e.g. the Burdiga-

lian-Tortonian Tuscan/Cervarola nappe system). The coeval and connected outward migration of the peripheral bulge, confining the foredeep externally, resulted in a complex extensional setting marked by large scale, though spatially limited slumps and by still preserved discontinuous block-faulting patterns (Vai, 1988). Neither angular unconformity nor clear disconformity was found to support the assumption of Tortonian or even earlier folding in this area, at least roughly north of the present-day divide. The Tortonian folding phase in the back was noticed in this area only in the form of increased sediment instability at any sloping surface.

A major sedimentation change was recognized by Ricci Lucchi (1975, 1986) inside the Marnoso-arenacea Fm. near the base of Tortonian. It correlates chronologically with a major sea-level fall (Vail *et al.*, 1977) (on one side) and a major tectonic phase (on the other side) in the internal Northern Apennines and in the Southalpine area (Castellarin & Vai, 1986). Change in drainage patterns following the Tortonian tectonic phase might account for the sedimentation change in the Marnoso-arenacea basin, mainly supplied from Southalpine sources (Fig. 23). With the early-middle Tortonian *acostaensis* Z. (Fig. 24) the first anoxic event occurs in the foredeep. It is followed by the upper Tortonian-lower Messinian «Tripoli» like events and finally by the repeated euxinic shale cycles announcing the Messinian salinity crisis.

2) The Messinian salinity crisis (Selli, 1973; Hsü *et al.*, 1973; Cita, 1982) is an anomalous event, occuring at the scale of the entire Mediterranean, triggered by a peculiar tectonic setting through all this area

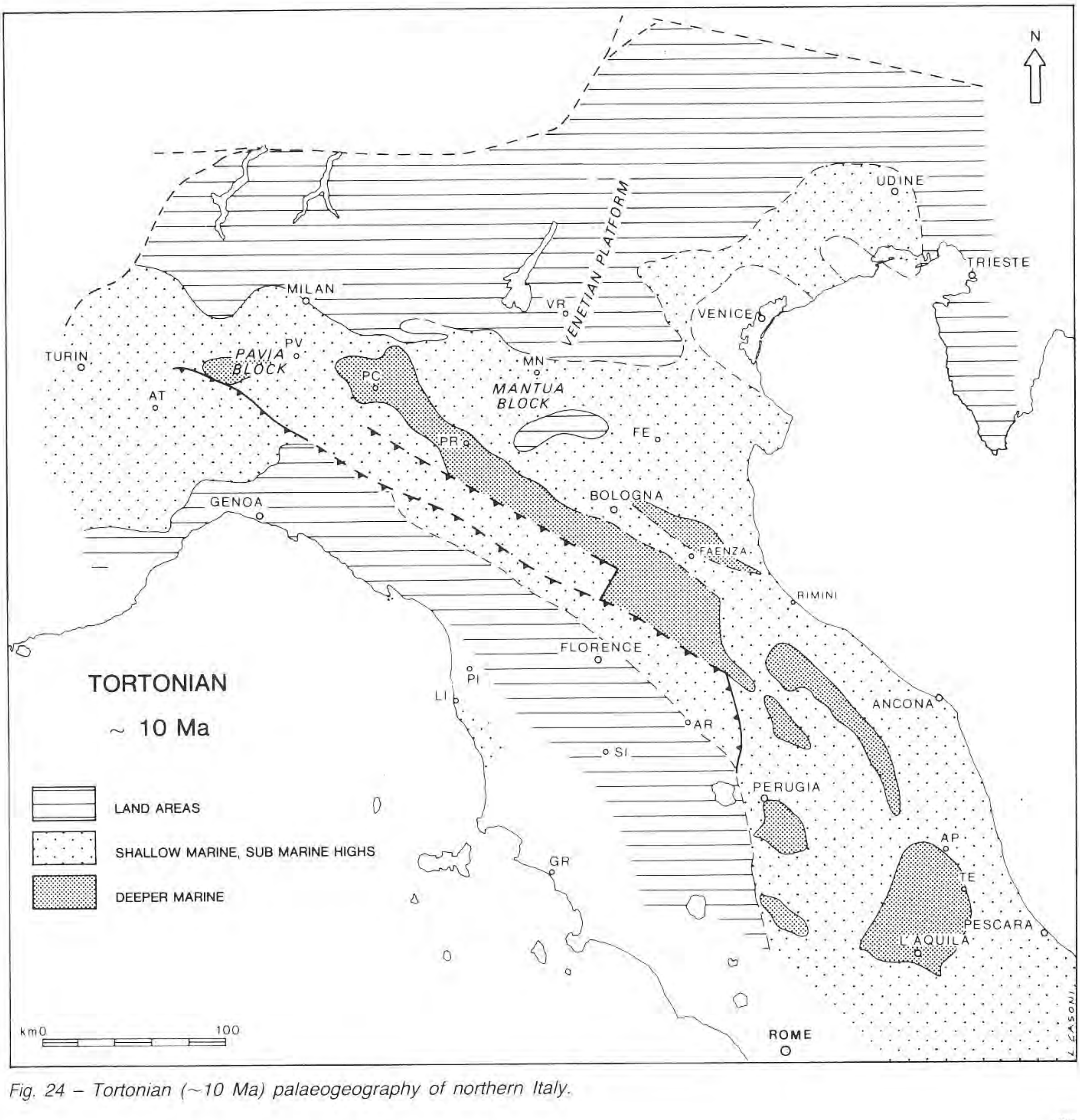

Fig. 24 – Tortonian (~10 Ma) palaeogeography of northern Italy.

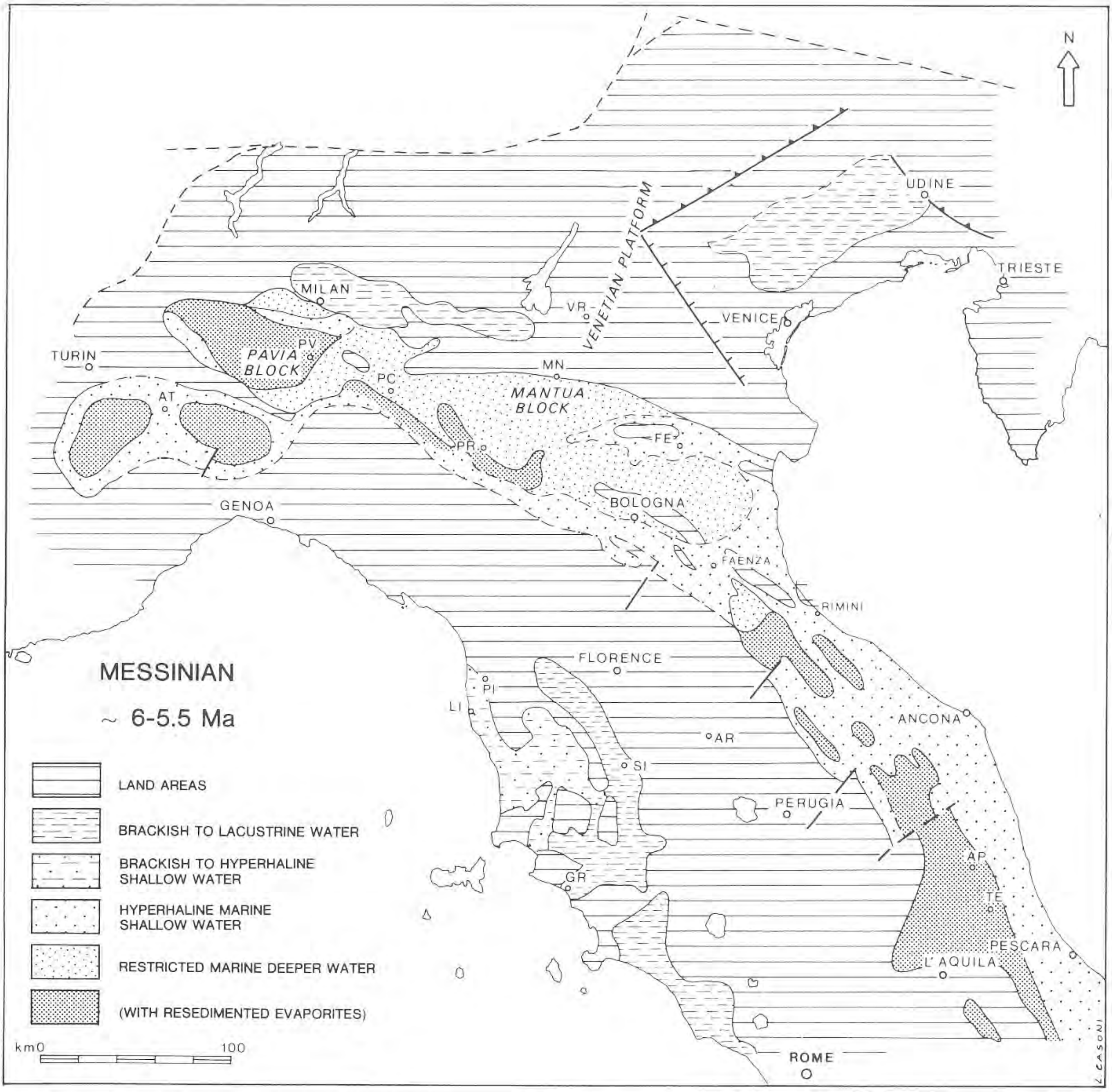

Fig. 25 – Messinian (~5.5 Ma) palaeogeography of northern Italy.

(resulting in a centrifugal drainage pattern) and by a world wide sea level fall (the lowest after the late Oligocene one). It is characterized by a huge amount of evaporites deposited atop of a variety of different tectofacies from hinterland to foreland. It appears, therefore, somewhat alien inside very different sedimentary units (Fig. 25).

Repeated evaporative drawdown (desiccations) in the order of few hundreds of meters, followed by refluxes, account for most of the facts observed (as f.i. the relationship to the Paratethys area or the Plio-Pleistocene oceanic development of the central-eastern Tyrrhenian Sea).

Messinian evaporites accumulated mainly at the margin of the Northern Apennines and in the southern part of the Po Plain. They lack completely north of a line connecting Milan with the Po delta.

In the Romagna Apennine a preferred site for evaporite basin development was the former peripheral bulge belt, whose inherited block-faulting system controlled evaporite deposition block by block (Vai, 1988).

3) The intra-Messinian tectonic revolution is produced by a very short (0.1-0.2 Ma), almost synchronous, tectonic phase recorded through the entire Mediterranean, having compressional effects in the external parts and extensional effects in the internal parts of the Mediterranea chains, expecially the Apennine-Maghrebian system. The present-day configuration of most of these mountain belts dates back to this phase (and to the following early Pliocene phase or phases) (Fig. 26).

The Northern Apennines, especially the E Emilia and Romagna sectors, are characterized by relevant (outward) advancement of the thrust front, up to 50 km (Vai, 1988). Front migration and evaporative drawdown imply first emersion of large Apennine areas most of them draped by the Ligurid thrust sheets. For the first time the Apennine replaced the Southalpine chain as main supply area for the coarse-grained clastic deposits (Fig. 26).

The main intra-Messinian tectonic event, often marked by spectacular angular unconformities, occurs within the Colombacci Fm. (before the third Colombaccio layer and very close to the ash layer) (Fig. 5). It is followed by a second minor event shortly before the end of the Formation.

As a whole, the Colombacci Fm. characterizes the upper Messinian of the entire peri-Adriatic area and represents the maximum westward expansion of the Paratethys Realm (Rögl & Steininger, 1983; Massari *et al.*, 1987) devoid of upper Messinian sulphates. Only Sicily (‹Gessi superiori›) and possibly Tuscany (Patacca & Scandone, pers. comm.), i.e. the peri-Tyrrhenian areas, still show sulphates accumulation during the late Messinian. This difference is explained mainly by direct connection of the peri-Adriatic regions with the Paratethys Lagomare (through both the Ionian and possibly the Julian-Istrian straits), but also in terms of fairly well developed bilateral drainage system preventing critical concentration of sulphates in the peri-Adriatic basins.

Grain-size distribution of clasts suggests only one major widespread high relief area at the Southalpine front (Sergnano, Montello, Ragogna or Pontian conglomerates). Minor conglomerate bodies (e.g.

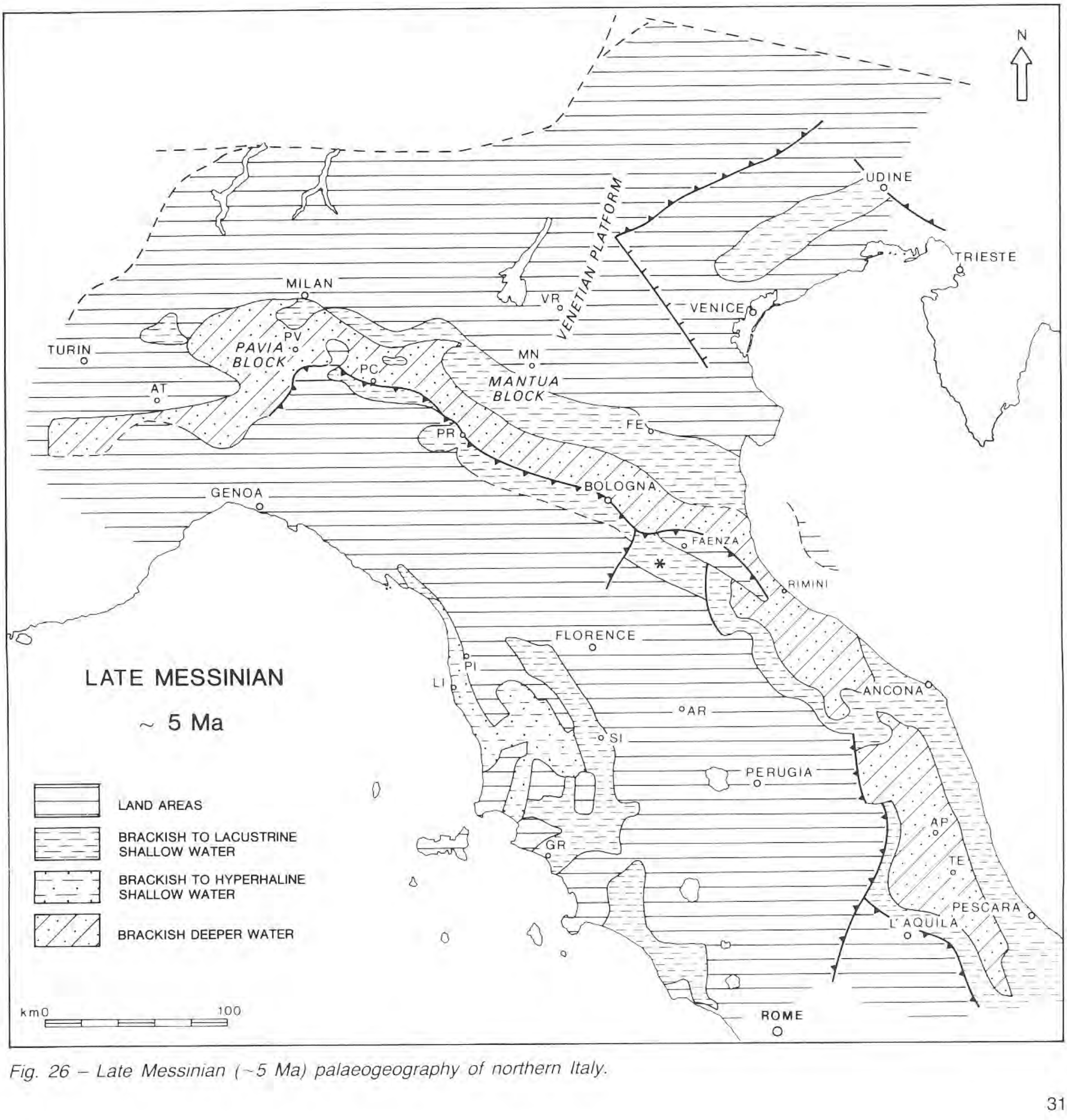

Fig. 26 – Late Messinian (~5 Ma) palaeogeography of northern Italy.

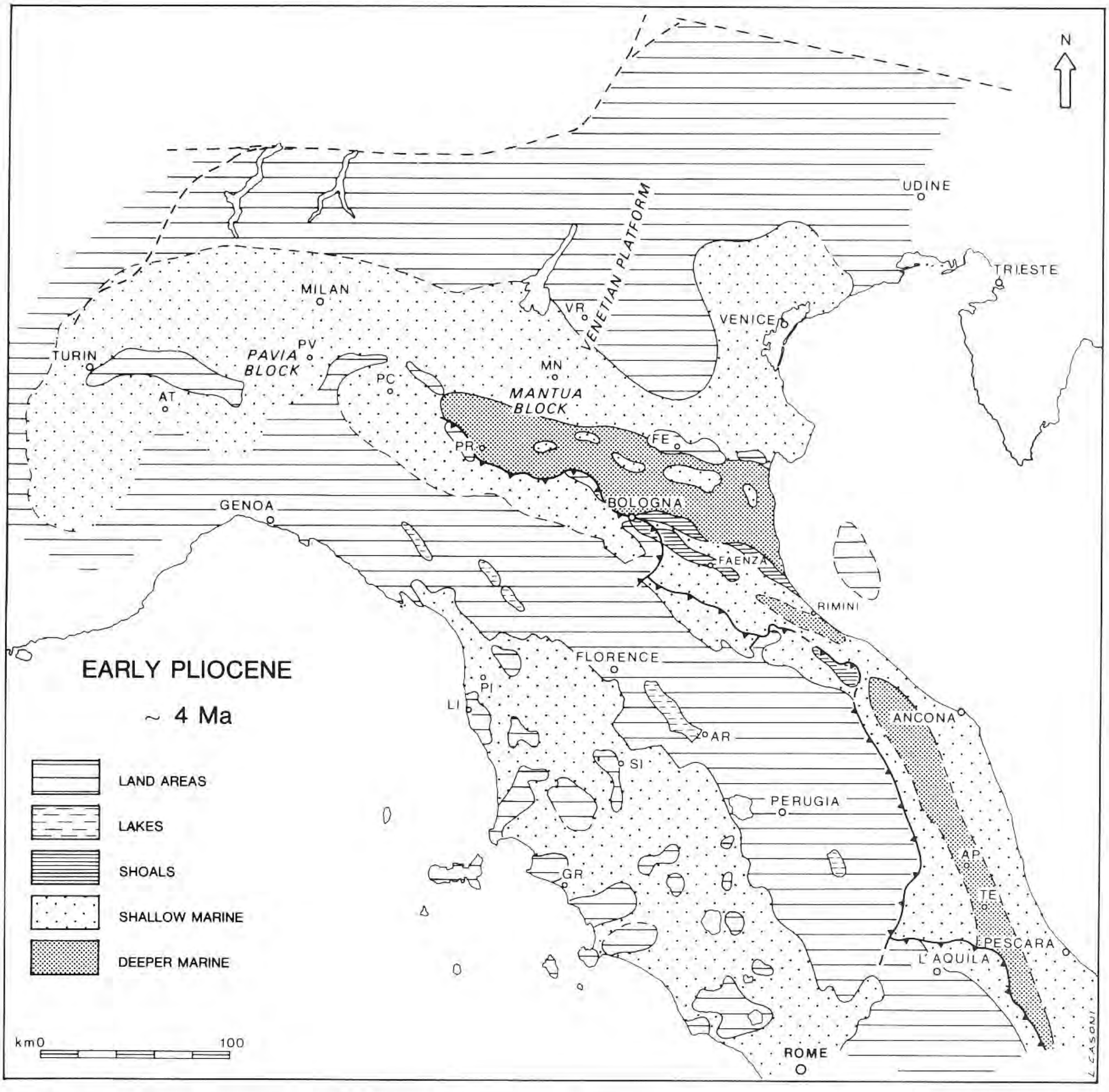

Fig. 27 – Early Pliocene (~4 Ma) palaeogeography of northern Italy.

Boreca and Cusercoli conglomerates), punctuating an overhelming mass of pelites usually at the crossing of the thrust front with transfer faults, characterize the Po Plain at the Northern Apennine margin. Such features witness steep, discrete and localized slopes in a landscape dominated by large alluvial plains on both adjoining, flat depressions and plateaus limited by a narrow mountain ridge SW of the present divide. This type of physiography is consistent with both prevailing tangential tectonics (in the Apennine side) and high rate of supply linked to evaporative drawdown (in the Alpine side of the Po Plain).

4) The Miocene thalassocratic regime is reproduced with the sudden, geologically instantaneous, earliest Pliocene transgression (Fig. 27) terminating the Messinian salinity crisis. This Plio-Pleistocene thalassocratic stage differs from the Miocene one for its main compressional tectonics as compared with the previous extensional one, as far as the Romagna Apennines are concerned. Extensional tectonics, however, is strongly developing from Tuscany to Umbria (extension tectonic is not shown on Figs. 24 to 28) as response to the Plio-Pleistocene opening of the Tyrrhenian Sea (Sartori, 1987; Sartori *et al.*, 1987). Authors have stressed enough two main features of this abrupt transgression (e.g. Hsü *et al.*, 1973; Cita, 1982): a) the lack of transitional coarse-grained facies and b) the immediate onset of bathypelagic fauna, both implying a sort of Walther's law jump. This appears particularly true at the broad scale for the peri-Adriatic lowermost Pliocene. At a

smaller scale, however, the basal centimeters of the *Sphaeroidinellopsis* Zone contain large amount of benthos and, more important, some representatives of intermediate depth even at the megafaunal level. This fact still implies a sudden, but not anomalous deepening, provided an adequately low sedimentation rate is taken into account (10^2 less than the mean Pliocene figure). Furthermore, a step-like physiography, with steps coincident or parallelling thrust fronts along the peri-Adriatic margins (Fig. 27), favoured development of inter-front (piggy-back) and (partly) intermontane basins (e.g. the Bologna and Marecchia Intrapennine Basins and the assumed basin of Alta Romagna). Such basin fills contain shallow water fauna and coarser grained clastics (mainly supplied by the blocks floating in the Argille Scagliose) but have been easily removed by erosion, except for some tectonically favoured positions (Fig. 28). This same step-like physiography is recognized also for the Upper Messinian (Fig. 26) and accounts for a) distinction between shallow-thin (easily eroded) and deeper-thick (preserved) Pliocene basins and b) large clayey content of the lowermost Pliocene deposits mainly supplied by the widespread clayey alluvial plains of the Colombacci Formation.

All previous remarks contradict the hypothesis of a ‹marine Deluge› over the Apennines and are consistent with the assumption of Messinian desiccations not exceeding a few hundreds of meters. The subsequent Pliocene ‹flood› was of the same order of magnitude in the (ever) shallow Adriatic Sea and in the still shallow, major part of the Tyrrhenian Sea, where deepening occured in later Pliocene and Pleistocene times only (a still shallow, archipelago-like

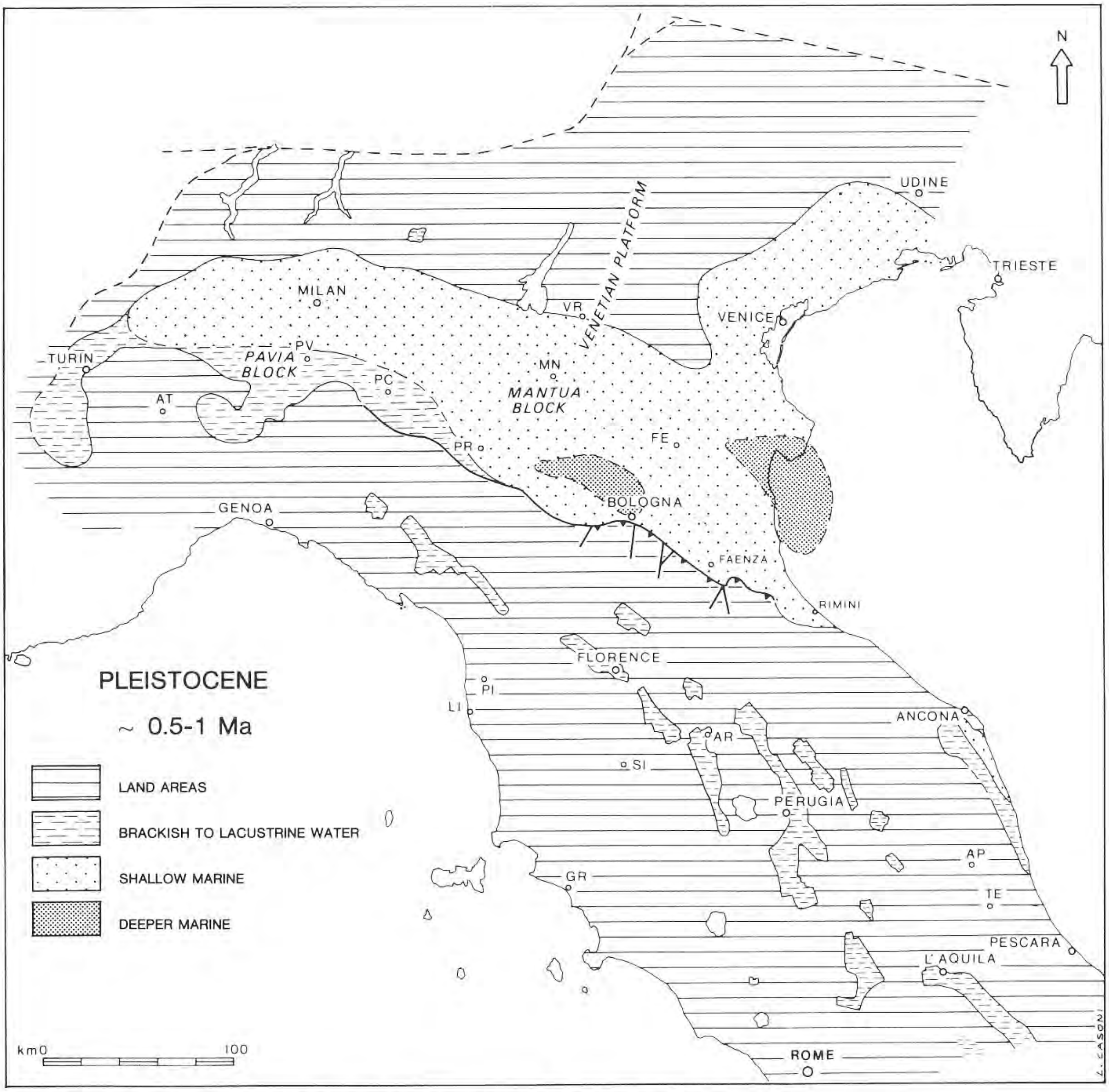

Fig. 28 – Middle Pleistocene (~1-0.5 Ma) palaeogeography of northern Italy.

Messinian Tyrrhenian Sea [Selli 1954, 1973] represents an additional migration route for African mammals toward Italy [Azzaroli & Guazzone, 1980; Kotsakis, 1987]). Theoretical possibilities of deep desiccations (Hsü, 1986) still survive for the (already) deep Provencal Basin (this would imply considerably less problems than for the entire Mediterranean). A fairly large amount of the Apennines was left emergent, though not elevated, as suggested by the combined distribution of lakes (Fig. 27) and old pediment surfaces, except for a narrow mountain ridge SW of the present divide. This is also consistent with prevailing tangential or extensional (NE and SE of the present divide respectively) versus uplift movements.

This stage is still characterized by relevant tangential stress in the Emilia-Romagna Apennines including the maximum outward advancement of the thrust front up to 60 km (early Pliocene) followed by repeated tangential recessions of the same front (Castellarin & Vai, 1986; Vai, 1988).

5) Starting from mid-upper Pleistocene a major change in the stress field is reflected in both a) lithosome geometry (from thick syntectonic wedges to prevailing flat, wide and thin blankets) (Castellarin *et al.*, 1986; Castellarin & Vai, 1986) and b) physiographic outline (relevant increase of land areas in the Apennines and linear reactivation of the Pedeapennine Lineament) (Castellarin & Vai, 1986). This palaeogeographic change is shown in Fig. 28 representing an interglacial high stand of sea level.

These data support the assumption of a drastic decrease of tangential movements in the external belt, replaced here, as well as in the internal belt, by increasing vertical movements (Castellarin & Vai, 1986; Sabadini *et al.*, 1987; Vai, 1988).

Outward migration of lakes related to extensional tectonics and their increase in number and size account for a vigorous development of the Tyrrhenian opening during Pleistocene, at least partly independent from coeval tangential movements in the outer Apennine belt. The northward displacement of the Italian peninsula, driven by the African Plate motion, appears to be accomodated only by the eastern Southalpine subduction in Friuli at this time (Castellarin & Vai, 1986).

In conclusion, this schematic evolutionary sequence explains why the two climaxes in radiation of continental faunas over the Apennines occured in Messinian and Pleistocene times, just as the faunas which will be dealt with in the next section of this guidebook and shown during the Congress.

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

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The Monticino gypsum quarry is located inside the thrust belt of the Romagna Appennines at the crossing with the Lamone river valley. This thrust belt is part of the outer Northern Appennines (see Vai, this vol., with references). 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 Appennines 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, this vol., Figs. 5,11). 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 Appennine Foredeep developement (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 Appennine – Padan margin. For a general overview on the Northern Apennine kinematic history and structural zonation, on Romagna Appennine stratigraphy and on northern Italian palaeographic evolution since the Burdigalian the reader can refer to Vai (this vol.).

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 systematically collected since 1985 (Costa *et al.*, 1986; De Giuli *et al.*, this vol.).

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 (all next contributions in this vol.), to discuss taphononomy and biostratinomy of the vertebrate fauna and to summarise its stratigraphic, geologic and environmental implications.

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.

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 (Figs. 4,7,16,19) on a strongly deformed, backtrusted middle Messinian evaporite unit (Marabini e Vai, 1985) (Pl. 1 and Fig. 16B).

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, this vol., Fig. 11).

As for the Colombacci Fm., the Monticino quarry area is included within the W Romagna thin intrafacies (Cremonini & Marabini, 1982; Vai, this vol.). 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 (Fig. 6):

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 (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 overying Argille Azzurre Fm. at different stages of the quarrying activity: the Monticino 1985 (Costa *et al.* 1986) and 1987 sections (Figs. 8,9).

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

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).

THE MONTICINO 1987 SECTION

Description

1) *Bottom* – Steep dipping *Gessoso-solfifera Fm.* (Fig. 8) 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, this guide). 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 clayey clasts, mollusc

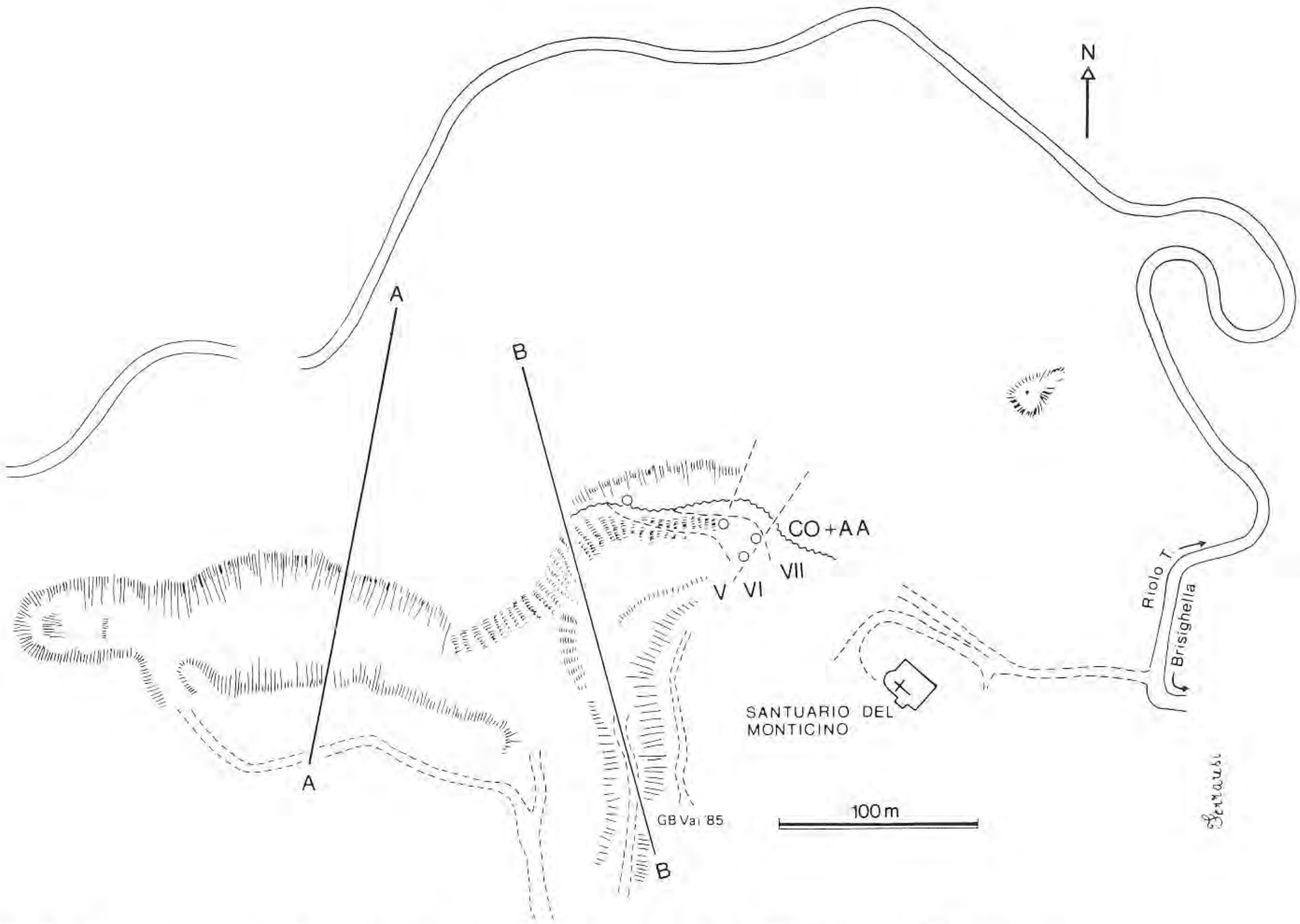

Fig. 3 – Cross topography of the Monticino Quarry, with position of the cross sections (Fig. 16).

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 continuously 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 cm 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 bioturbed silty-sandy bed (5-7 cm) rich of coarse sandy sized glauconite particles occurs.
No further 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 magnetostratigraphy are found in Colalongo, Rio & Negri, and Vigliotti (this vol.). Data on molluscs and palynomorphs (Taviani and Bertolani-Marchetti & Marzi, this vol.) 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, this vol.), nannofossils (Rio & Negri, this vol.), biostratigraphy and by magnetotratigraphy (Vigliotti, this vol.) (see Fig. 8).

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 easily be assumed at a narrower scale for the entire very thin

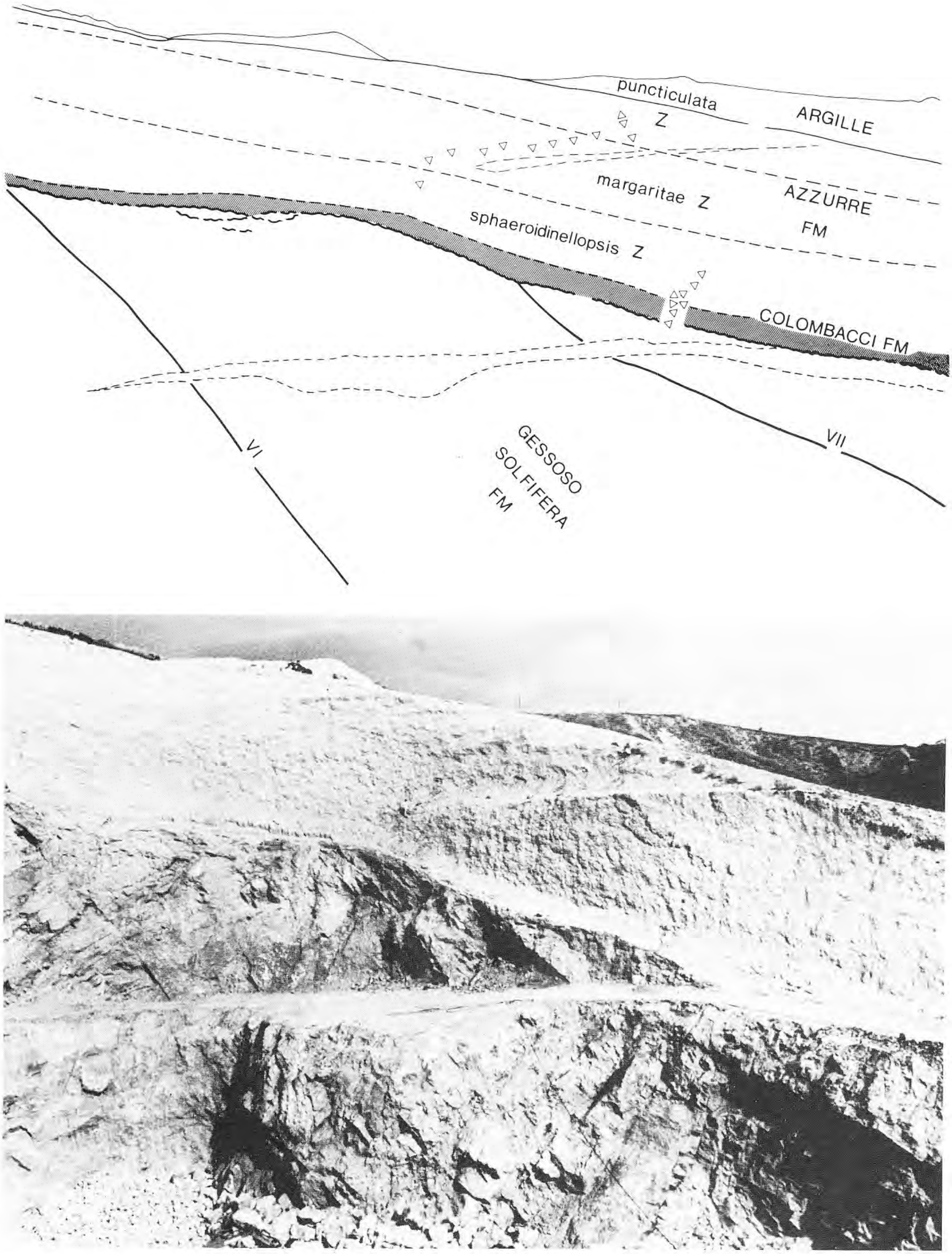

Fig. 4 – Intra-Messinian unconformity on the northern wall, eastern Monticino Quarry. Steep dipping lower to middle Messinian gypsum evaporites are unconformably overlain by faintly bedded gentle dipping Colombacci and Argille Azzurre Fms. (upper Messinian and earliest Pliocene). Upper segment of Monticino section 1987 is limited by two geologists (Fig. 5). Planktic foraminifera biozones are shown in the sketch above, where roman numbers refer to gypsum cycles and open triangles point to sampling sites.

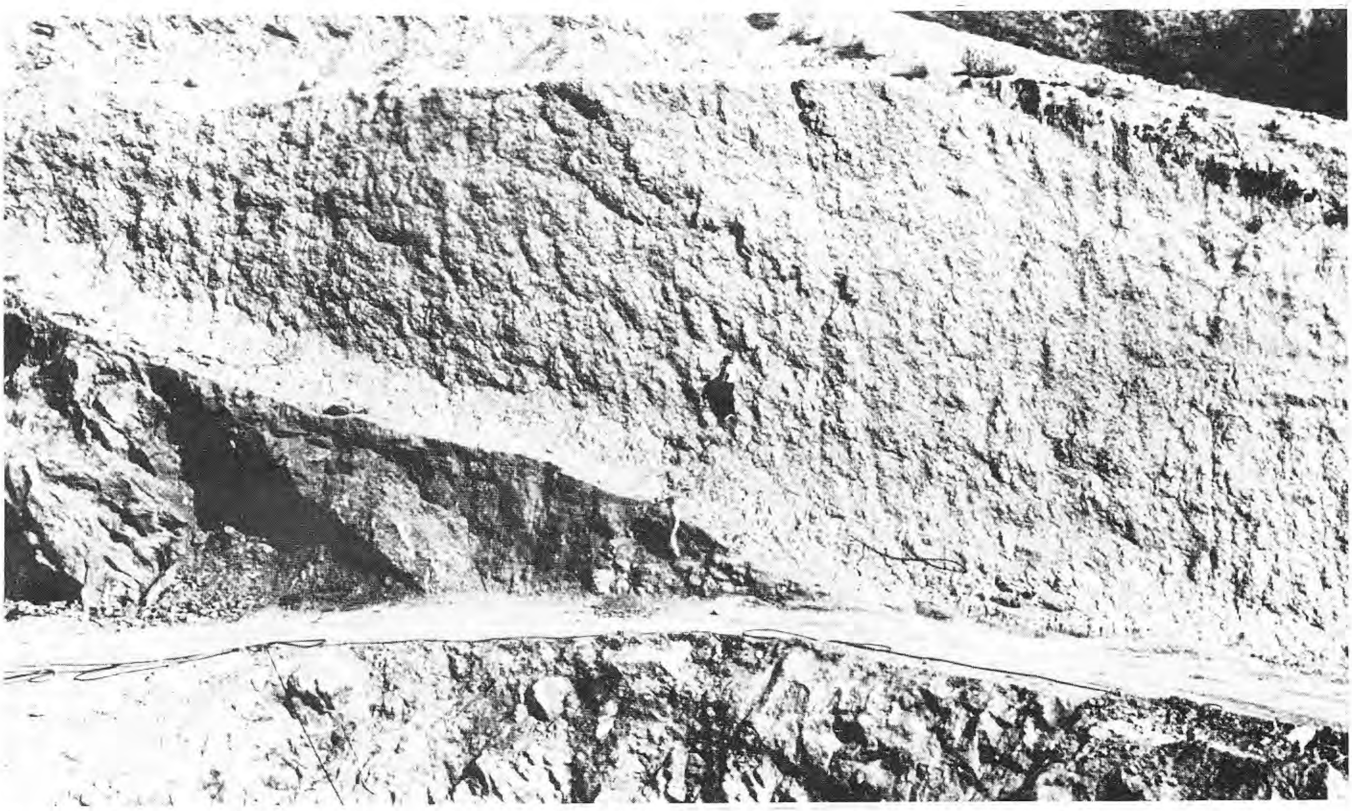

Fig. 5 – Detail of Fig. 4 showing position of lower segment of Monticino Section 1987 (between the two geologists).

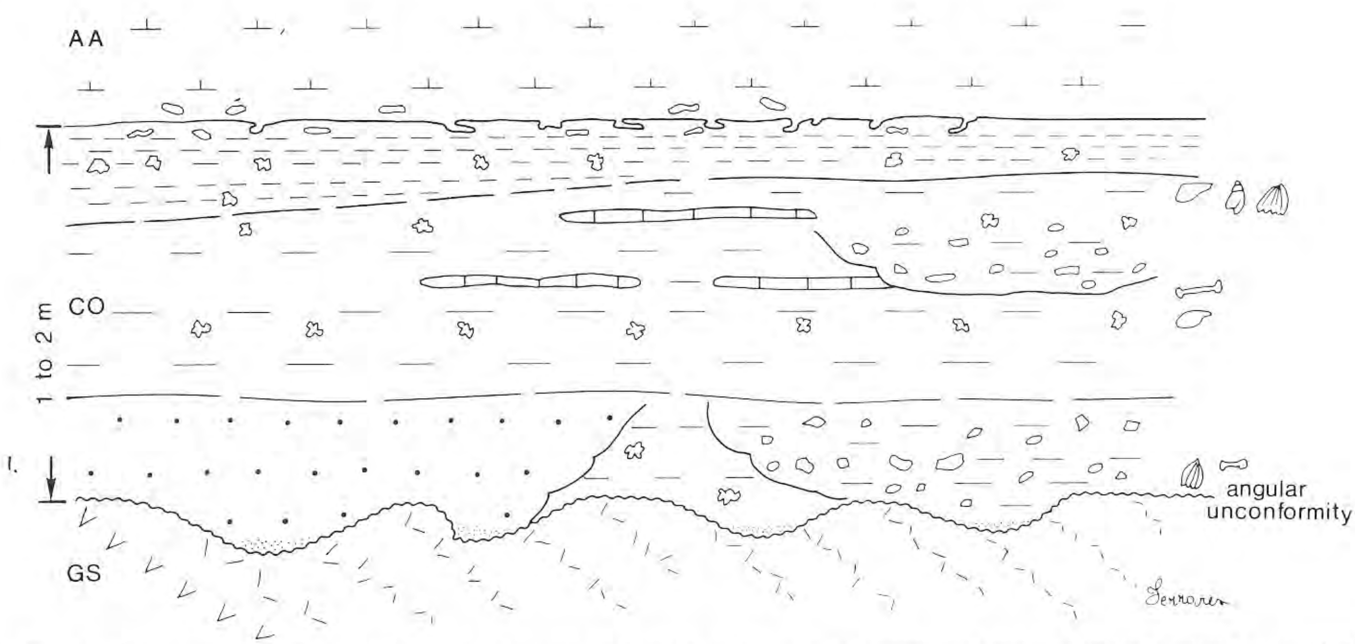

Fig. 6 – Stratigraphic scheme of the upper Messinian Colombacci Fm. in the eastern Monticino Quarry (legend to symbols see Fig. 8).

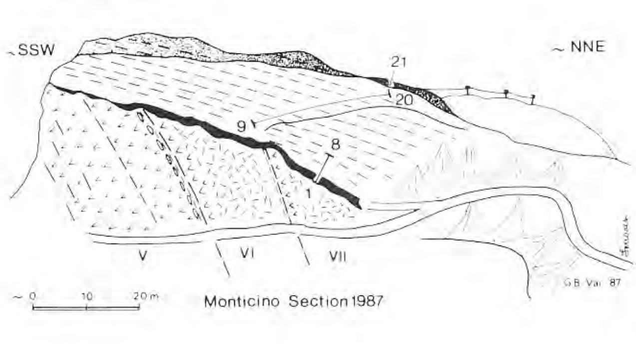

Fig. 7 – Field sketch of Monticino Section 1987 showing location of the two composing segments.

Colombacci interval. Moreover, the early compaction and lithification which can be expected for this Colombacci environment may suggest easy develo-pement 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 rate, the best typical earliest Pliocene assemblage seems to be preserved within the sca-vanger 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 (Fig. 8) (Vigliotti, this vol. Fig. 2) (Vai, this vol., 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 by-passed by the sampling (less likely) or not reached with the section (Fig. 8) (Vigliotti, this vol., 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, this vol.). Their

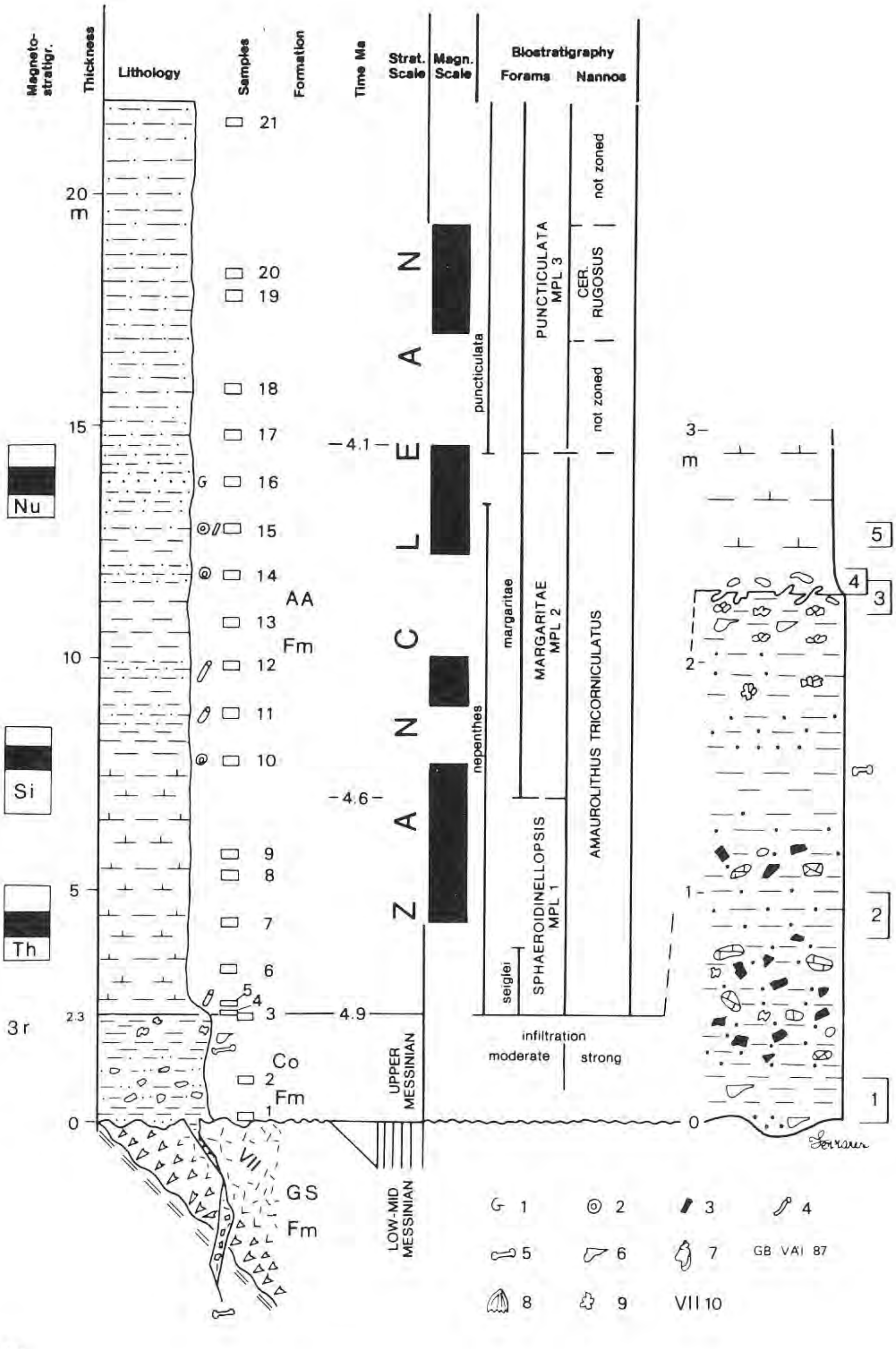

*Fig. 8 – Stratigraphic column of Monticino Section 1987. 1, glauconite; 2, marcasite nodules; 3, wood fragments; 4, bioturbation; 5, bones; 6, molluscs (*Dreissena*); 7,* Melanopsis*; 8,* Limnocardium*; 9, Ca concretions; VII, evaporite cycle.*

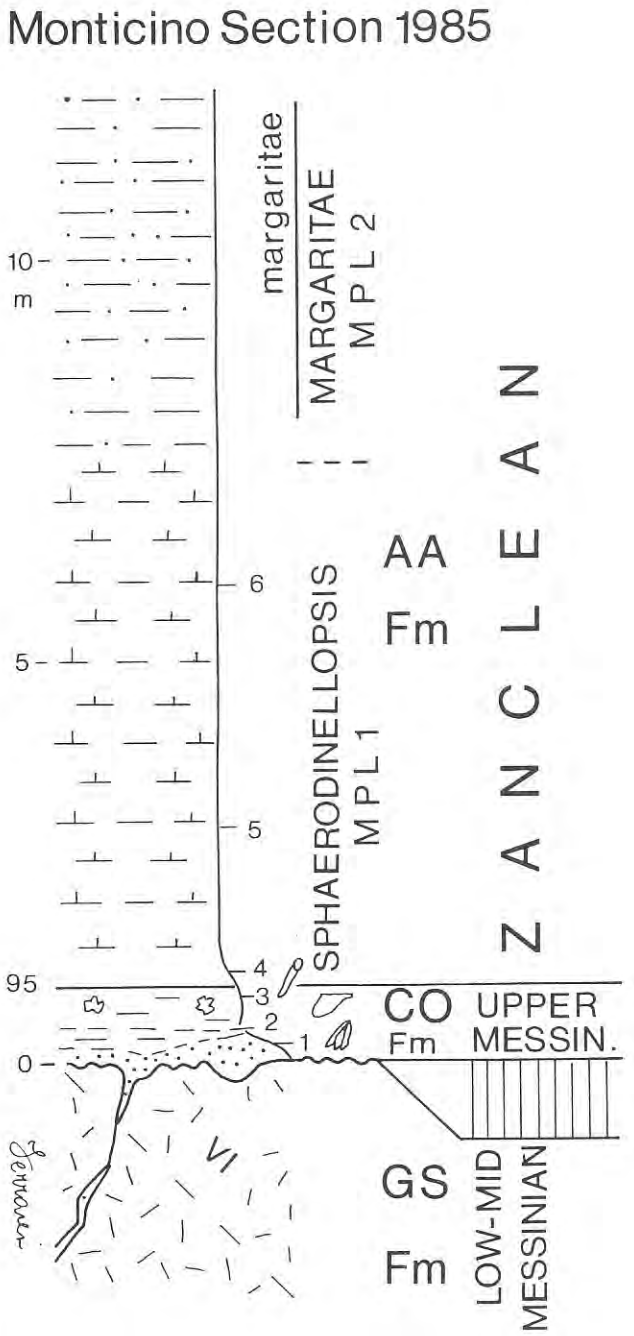

Fig. 9 – Stratigraphic column of Monticino Section 1985 (legend to symbols as in Fig. 8).

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 correlating the Colombacci cycle with the pollen-climatic cycle shown in this section, the time span represented here would be about 2 to 3.10^5a.

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 interventing, 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, this vol.). 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, this vol.) 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 continuous sedimentation from the late Messinian Colombacci Fm. to the late 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.

Fig. 10 – 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.

Fig. 11 – Partly silicified (chalcedony) Paludina *coquina. Basal Colombacci Fm., M. Mauro area.*

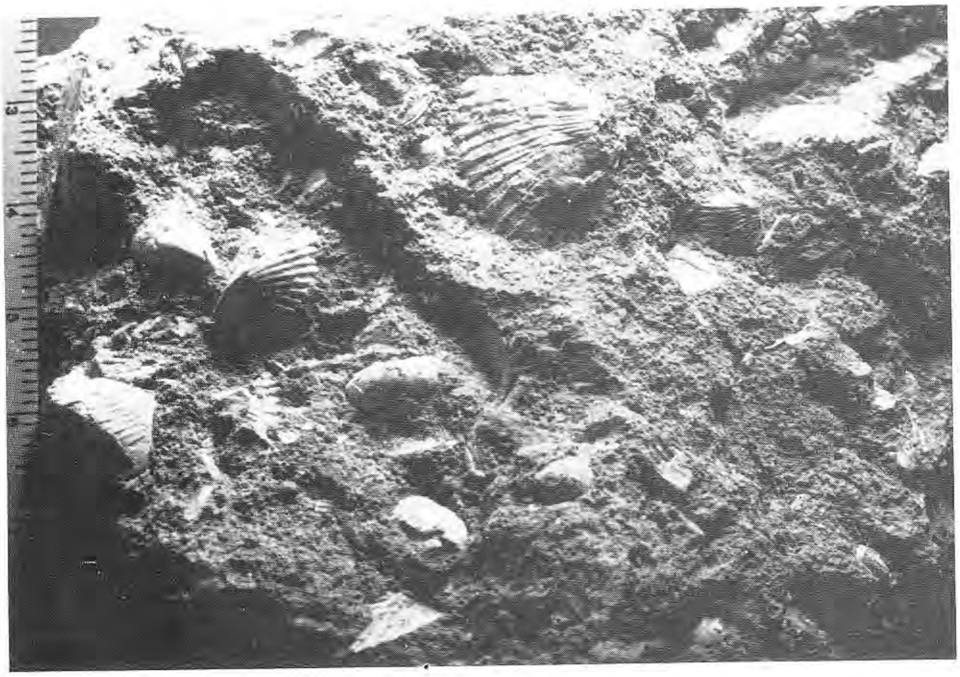

Fig. 12 – Disarticulated valves of Limnocardids (three different species) and Dreissena *within a gray-green silty clay, from the* in situ *Colombacci Fm., Monticino Quarry.*

Fig. 13 – 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.*

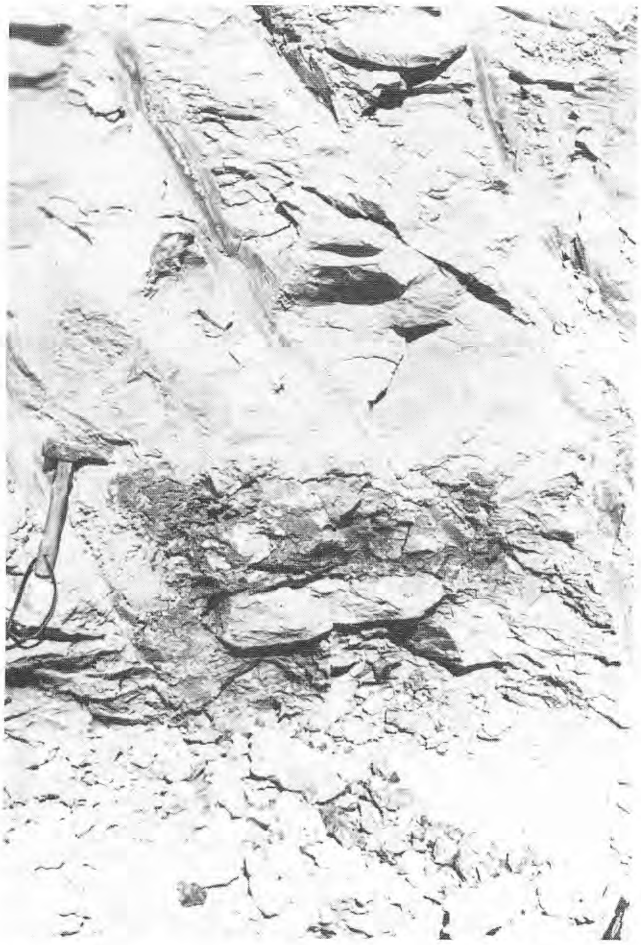

Fig. 14 – Hammer points to the sharp contact between dark Colombacci Fm. (with a discontinuous calcareous Colombaccio layer) and light earliest Pliocene marls of Argille Azzurre Fm.

Finally, the Monticino quarry magnetostratigraphy (Vigliotti, this vol.) 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, Fig. 8] whose duration is calibrated from 4.57 to 4.77 Ma [Vigliotti, this vol.]). The new age of the boundary was, therefore, adopted in this paper and volume.

DEFORMATION PHASES

Deformation phases detected in the field by correlative angular unconformities as shown in the cross section (Pl.1) 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 of Pl.1, especially the Monticino surrounding where it forms a spectacular angular unconformity (Figs. 4,7,16,19).

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 (PL.1).

c) Two relative 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, this vol.).

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 (Fig. 16) 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

Fig. 15 – 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 infilled with the underlying black clay material (arrow). Hammer point for scale.

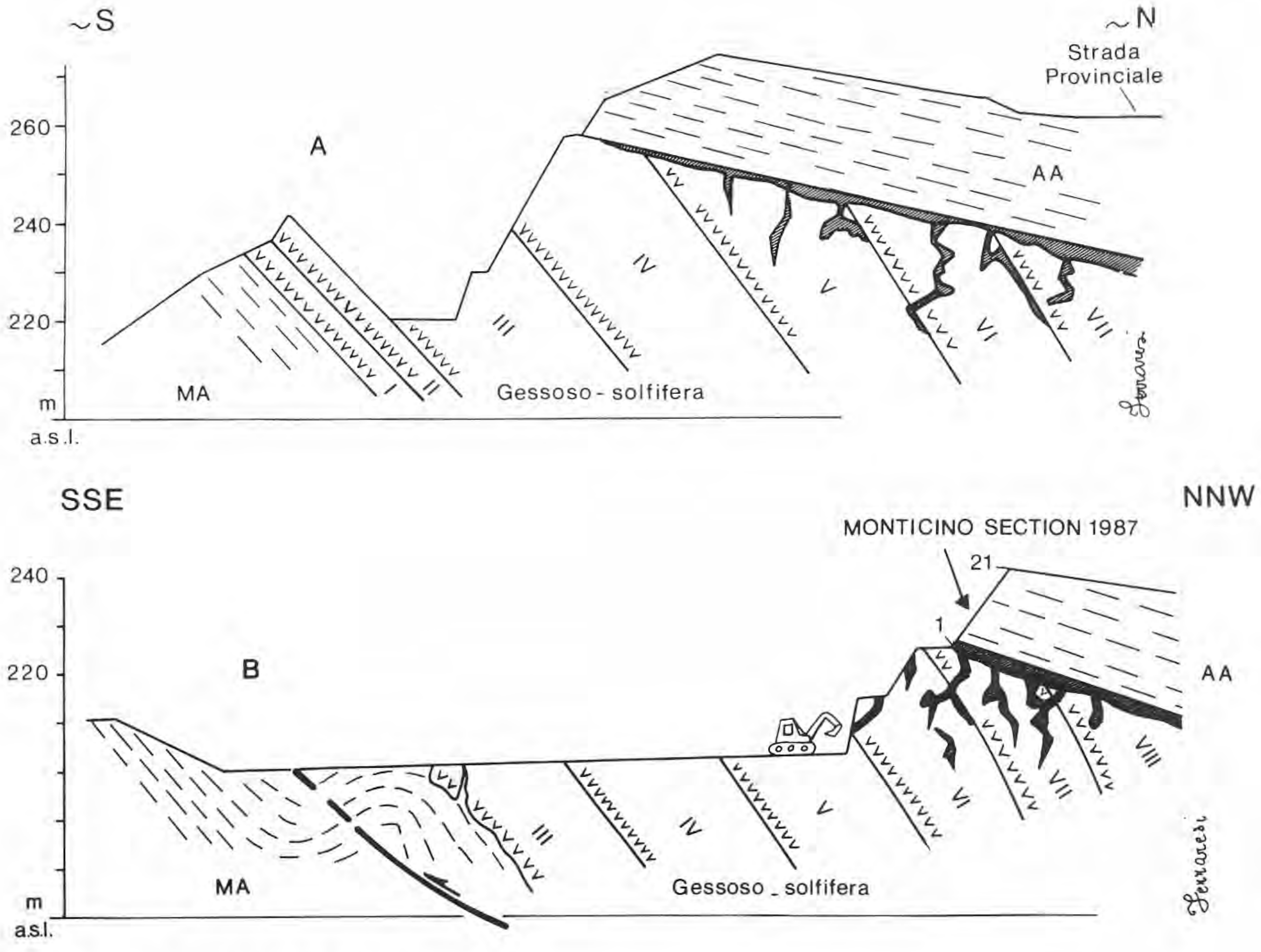

Fig. 16 – Cross sections of the Monticino Quarry.

Colombacci Fm. lithotypes and rejuvinated in middle to late Pleistocene time.

Within the quarry, the gypsum setting is usually represented by a steep dipping monocline (Fig. 16 A) 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 pre-evaporitic euxinic marly clay with tectonic elision of the lower gypsum cycles (Fig. 16 B). The fault surface of Fig. 16 B 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 (Fig. 17-22)

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 (Fig. 20).

The first phase was characterized by 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 (Fig. 16). The main local lithotypes are: olive-green silty clay, calcrete-rich light-green clay, limestone paraconglomerate, brown *Melanopsis* and *Dreissena* clay, blue-green clay, dark *Cyprideis* clay. Paraconglomerates

Fig. 17 – Detail of Fig. 2 showing prominent karstified neptunian dyke filled with mud-supported conglomerate yielding large amount of bones.

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 been 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 transerval 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 Fig. 20) hemispherical depressions can often be observed. They suggest a palaeokarst-modeling phase enlarging previous fracture systems, and predating the major sedimentary dyke development.

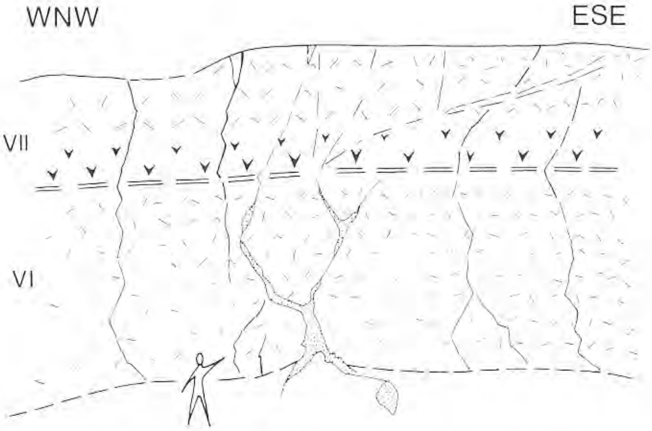

Fig. 18 – North-eastern front of Monticino Quarry. Irregular, anostomosed net of sedimentary dykes cutting across the Lower Messinian evaporites (numbered according to the major evaporitic cycles). Dotted areas represent major, bone-rich Colombacci Fm. bodies filling the sedimentary dykes (after Costa et al., *1986).*

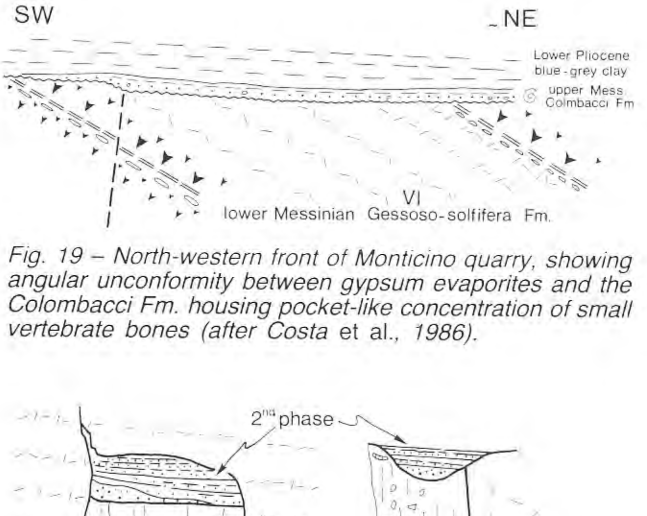

Fig. 19 – North-western front of Monticino quarry, showing angular unconformity between gypsum evaporites and the Colombacci Fm. housing pocket-like concentration of small vertebrate bones (after Costa et al., *1986).*

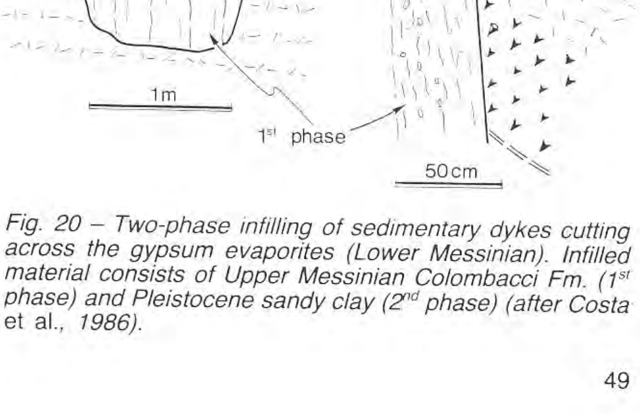

Fig. 20 – Two-phase infilling of sedimentary dykes cutting across the gypsum evaporites (Lower Messinian). Infilled material consists of Upper Messinian Colombacci Fm. (1st phase) and Pleistocene sandy clay (2nd phase) (after Costa et al., *1986).*

Fig. 21 – Thick sedimentary dyke cutting across the gypsum layers (light grey) and filled with bone-bearing mud-supported conglomerates.

Biological concentrations in karst holes

Some of the richest collecting sites show almost the same number of right and left teeth and the same distribution of tooth types. This fact suggest lack of 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.* (this vol.) suggest a biological concentration mechanism due to predator birds living in the former karst holes. Implications arising from this interpretation concern age and biotratinomy 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. (Fig. 23)*

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 Monticino fauna is more likely coeval with the supporting Colombacci clay, i.e. latest Messinian.

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, this vol.) 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 step-like 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-Tyrrenian-Sicilian area (Vai, this vol.). A thorough critical, palaeobotanical analysis of Mediterranean climate during Messinian is still lacking. However, known pollen diagrams (Bertolani-Marchetti, 1985; Bertolani-Marchetti & Marzi, this vol.) 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 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.*, this vol.), 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.

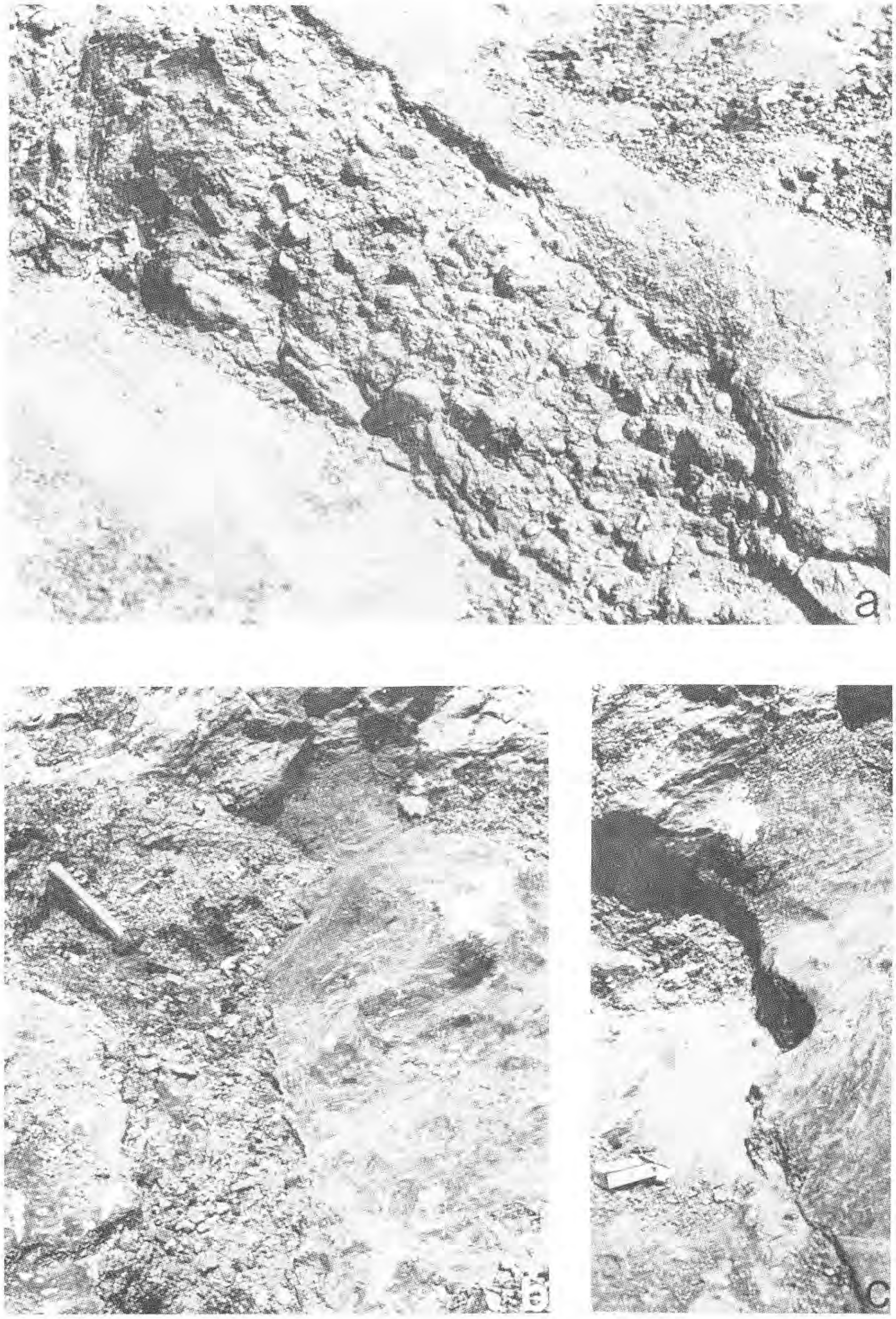

Fig. 22 – a: Chaotic (injection) structure of the mud-supported conglomerate infilling a sedimentary dyke.
b: Sphaerical hole connecting segments of sedimentary dykes.
c: Small-scale (dm-size) palaeokarst depressions preserved in the straight wall of a sedimentary dyke.

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 of 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 wich 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.*, this vol.).

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 and 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

Fig. 23 – 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.

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 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.*, this vol.) 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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Planktic foraminifer biostratigraphy, with remarks on benthic foraminifers and ostracodes (Monticino Quarry, Faenza)

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The micropaleontological examination of the Monticino 1987 Section permitted to recognize, within a thickness of only 21 meters (Fig. 8, Marabini & Vai, this vol.), the following biostratigraphic units (for the Pliocene interval the biostratigraphic scheme of Colalongo & Sartoni 1979, slightly emended by Colalongo *et al.*, 1984, was utilized).

a) From 0 to 2.3 m: upper part of the Colombacci Formation (post-evaporitic Messinian)

The faunistic assemblage is characterized by the presence of the brackish ostracode *Cyprideis* ex gr. *pannonica* and of small foraminifers, mainly planktic, reworked from the underlying miocenic sediments (as demonstrated by the presence of species of different stages).

All the sample of this interval, especially sample No. 3 (Fig. 8, Marabini & Vai, this vol.), show a moderate percentage of pliocenic species, coming from the overlying clays clearly as a result of burrowing for sample No. 3 and probably infiltrated through small-scale fractures of unit *a* for samples Nos. 2 and 1.

The *Cyprideis* ex gr. *pannonica* assemblage – typical of brackish lagoons – is well-known in literature. It was recognized in the upper part of the post-evaporitic Messinian of several Italian regions, as, e.g., in the Arenazzolo Formation of Sicily (Ruggieri & Sprovieri 1978), in the Colombacci Formation of the Marche-Romagna (Colalongo *et al.* 1978) and of the eastern Po plain (AGIP 1982), in the Fusignano Formation of the Po plain (AGIP, 1982).

In the Monticino 1987 section, although the lithologic equivalent of the «black clay» located at the top of the Colombacci Formation of eastern Romagna is recognizable, the fresh-water ostracodes normally present in these sediments were not found. This absence of fresh-water ostracofauna is common in the W Romagna thin intrafacies of the Colombacci Formation (Cremonini & Marabini, 1982; Vai, this vol.).

b) From 2.3 to 7 m ca.: Sphaeroidinellopsis spp. zone

The planktic foraminifers assemblage of this interval is typical of the above-mentioned biostratigraphic zone. The most significant species are: *Globigerina apertura, G. decoraperta, G. nepenthes, Globorotalia acostaensis, Globigerinoides obliquus obliquus, G. obliquus extremus, G. seiglei* (present only in samples No. 4, 5 and 6), *Globoquadrina altispira, Sphaeroidinellopsis* spp. (rare).

The benthic foraminifers are always less abundant than the planktic foraminifers, but they become rather frequent in the upper part of the unit, where a moderate increment of nodosarids is recorded. The most common species are: *Anomalinoides helicinus, Cibicidoides robertsonianus, Dentalina aciculata, D. filiformis, Eggerella bradyi, Martinottiella perparva, Melonis soldanii, Oridorsalis umbonatus, Pleurostomella alternans, P. brevis, Uvigerina rutila.*

The ostracofauna is rather poor: rare specimens of *Henryhowella asperrima* and instars of *Ktithe* spp. and *Cytherella* spp. were identified.

c) From 7 m ca. to 14.50 m: Globorotalia margaritae zone

The planktic foraminifers assemblage is characterized by the presence of *G. margaritae* and of *Globigerina apertura, G. decoraperta, G. nepenthes* (which disappears in sample No. 15), *Globorotalia acostaensis, G. planispira, Globigerinoides elongatus, G. obliquus obliquus, G. obliquus extremus, G. quadrilobatus, G. trilobus, G. sacculifer.*

The benthic foraminifers are much more frequent than in unit *b*; the increment of genus *Lenticulina* is remarkable. Among the several species are noteworthy: *Bulimina aculeata minima, Bolivina lucidopunctata, Cibicidoides italicus, Marginulina costata, M. hirsuta, Anomalinoides helicinus, Uvigerina rutila, Vulvulina pennatula.*

The ostracofauna, rather poor, is represented prevailingly by *Krithe aequabilis, K. sinuosa, K. ariminensis, Henrihowella asperrima* and by instars of *Cytherella* spp.

It is opportune to remark that the thickness of this biostratigraphic unit in the Monticino 1987 Section is particularly small in comparison with the normal thicknesses that the same unit has in the Romagna and the Marche regions.

d) From 14.50 to 21.50 m: Globorotalia puncticulata zone

The planktic foraminifers assemblage, characterized by the contemporaneous presence of *G. puncticulata* and *G. margaritae*, is almost identical to the one of unit *c*. Nevertheless are peculiar of unit *d* horizons rich in *Globoquadrina altispira globosa*. In fact high percentages of this fossil within the lower portion of the *G. puncticulata* zone are a characteristic feature of the lower Pliocene in the Romagna and the Marche regions.

Also as regards the benthic foraminifers, there are not remarkable differences with respect to unit *c*, except for a further increase in percentage of *Lagenidae*. Besides the numerous species of the genus *Lenticulina, Marginulina coarctata, M. costata, M. glabra,Mucronina gemina, Planularia auris, P. cymba, Vaginulina legumen* are frequent. Moreover is worth mentioning the presence of *Cylindroclavulina rudis, Vulvulina italica* and *Uvigerina rutila*.

The ostracofauna of unit *d* is very similar to the one of unit *c*.

All the samples of unit *d* contain high percentages of glauconite (Marabini & Vai, this vol.).

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Calcareous nannofossils (Monticino Quarry, Faenza)

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The calcareous nannofossil contents of 21 samples from the Monticino Section 1987 (Fig. 8, Marabini & Vai, this vol.) has been analyzed in a high magnification (800X to 1200X) polarizing microscope, following standard preparation techniques.

Biostratigraphic zonal assignments (Fig. 8, Marabini & Vai, this vol.) were made with reference to the scheme of Raffi and Rio (1979) as emended recently in Rio *et al.* (in press) (Fig. 1). This scheme can be easily compared with the so called Martini's «standard» zonation (1971), which, however, is not easily applied in the early Pliocene Mediterranean record and provides a low biostratigraphic resolution in the Pleistocene.

As reported in Fig. 1, the scheme of Raffi and Rio (1979) has been directly correlated to the planktic foraminifera Mediterranean zonations by studying the same set of samples from several Italian mainland and offshore sections (see, among others, Rio and Sprovieri, 1986; Glaucon *et al.*, in press). This allow an integrated approach to the biostratigraphic classification of the section, which should improve the reliability of our interpretation and allow a better biochronological resolution. Most calcareous plankton events, reported in Fig. 1, have been correlated in the last years to the Magnetic Reversal Time Scale, thus making the calcareous plankton biostratigraphy in the Mediterranean an accurate tool for biochronological chronometric age evaluation.

The calcareous plankton biochronology adopted in the present study is reported in Fig. 1. For a detailed review of the data on which the adopted biochronology is based, the reader is referred to Rio *et al.* (in press) and to Channel *et al.* (in preparation).

Colombacci Fm.

Three samples (Fig. 8, Marabini & Vai, this vol.) from the Colombacci Fm. were analyzed. The basalmost sample (Mont-1) yielded an impoverished nannofossil assemblage with small and medium sized reticulofenestrids, *Coccolithus pelagicus, Spenolithus* spp., *Pontosphaera* spp., small to medium sized *Dictyococcytes* spp. These forms are common in the Miocene series and can be considered as reworked. It should be noted that reworked Paleogene and older forms are rare or missing in these samples.

Mont-2 and Mont-3 samples yielded fairly rich similar nannofossil assemblages characterized by the dominance of small to medium sized reticulofenestrids, by common *Dictyococcytes* ssp. and rare *Sphenolithus abies, Scyphosphaera* spp. and *Amaurolithus delicatus. Helicosphaera sellii* and *Reticulofenestra pseudoumbilica* (large forms) were not detected. Obviously reworked forms are rare or missing. This assemblage can be considered indicative of the early Pliocene «*Amaurolithus tricorniculatus* zone» (Fig. 1). This zonal assignements is mainly based upon the presence in these two samples of *Amaurolithus delicatus* (only few specimens in sample Mont-2 and several specimens in sample Mont-3), which in the Mediterranean is distributed with fairly good continuity, albeit in low frequency, only in the early Early Pliocene (Raffi and Rio, 1979; Rio *et al.*, in press) and which has little chance of being reworked from older sediments, since it has been reported in the Mediterranean pre-Pleistocene record only in a short interval, with low frequency, close to the Tortonian-Messinian boundary (Rio *et al.*, 1978).

The finding of this apparently «normal» calcareous nannofossil assemblages (indicative of fully marine conditions) in the brackish Colombacci Fm. is easily explained in terms of infiltration. Two main processes may be responsible for the infiltration. The first one is bioturbation. Effects of this process are clearly exposed in the field close to sample Mont-3 (Marabini & Vai, this vol.) and mirrored by evidences of strong infiltration of Foraminifera in the same sample (Colalongo, this vol.).

The second process could be a microscopic system of sedimentary dykes cutting across the Colombacci Fm. and infilled with early Pliocene mud. Microfissures, common in the Colombacci Fm. clays, can be referred to the early Pliocene tectonic event (Vai, this guidebook). A such process at very fine scale would explain the stronger infiltration rate of nannofossils as compared with Foraminifera in sample Mont-2, just as a matter of size.

Argille Azzurre Fm.

All samples analyzed from the Argille Azzurre Fm. (from Mont-4 to Mont-21) contain common calcareous nannofossils in poor to moderate preservation state. Obviously reworked forms are generally common to abundant in this interval.

The lithostratigraphic interval between Mont-4 and Mont-16 (included) samples has to be assigned to

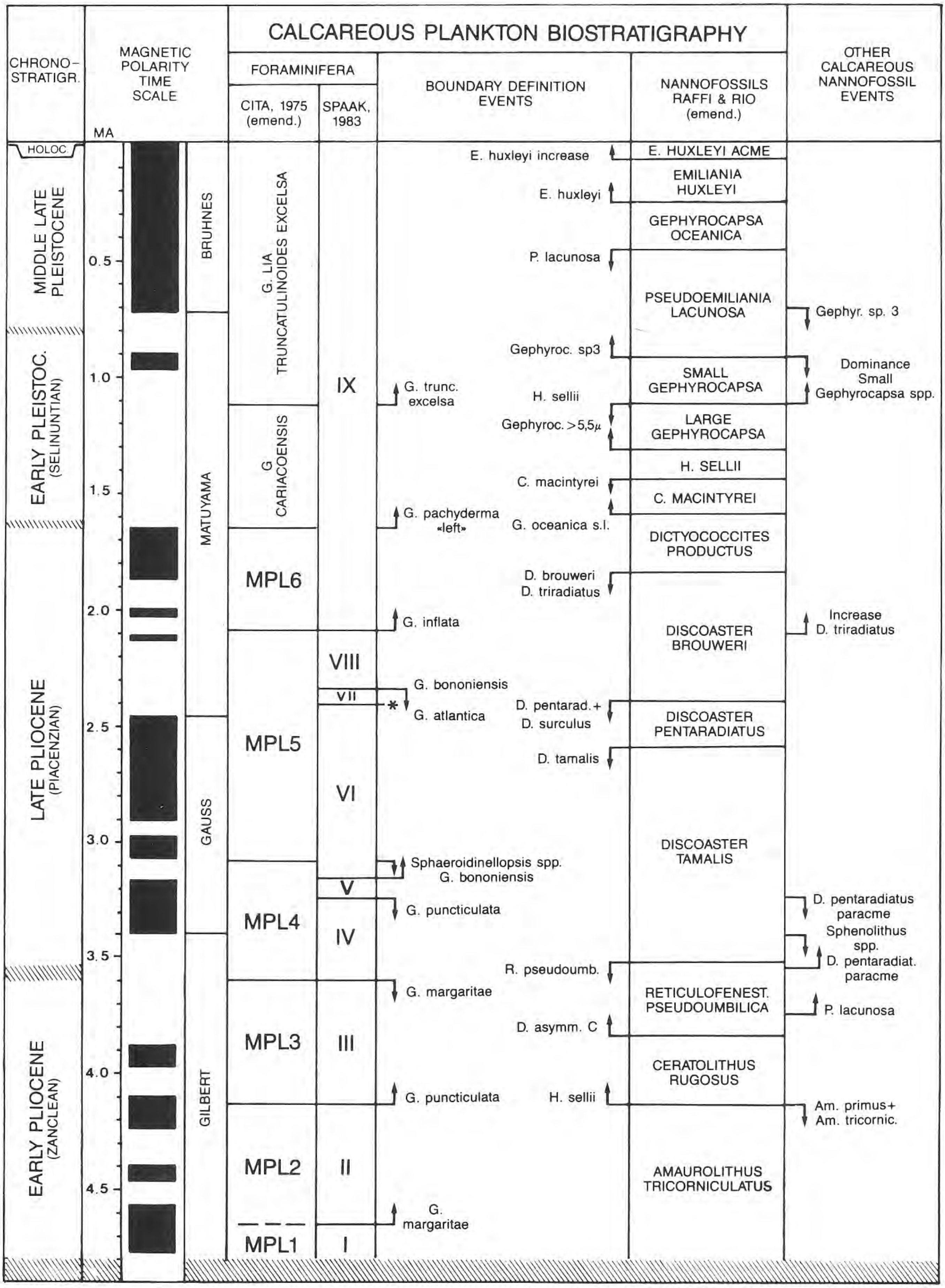

Fig. 1 – Plio-Quaternary correlation chart with magnetostratigraphic calibration of calcareous plankton biostratigraphy.

*Fig. 2 – Sharp contact between the topmost Colombacci Fm. (black clay horizon) and the light-grey MPL1 (*Amaurolithus tricorniculatus *zone) Argille Azzurre marl. Notice large black and grey burrows inside the light Argille Azzurre marl, as well as light burrows across the black to grey Colombacci clay (white triangles). The white arrows point to formation boundary.*

the «*Amaurolithus tricorniculatus* zone». In fact, in this interval *Helicosphaera sellii* is missing, while *Amaurolithus delicatus* is present, albeit in low frequency, in most samples. In the Mont-13 sample *Amaurolithus tricorniculatus* and *A.* cf. *amplificus* were also detected. Discoasterids are generally rare, but *Discoaster brouweri, D. pentaradiatus* and *D. surculus* are present. *Reticulofenestra pseudoumbilica* is present in most samples, but it is missing in samples Mont-10, Mont-11 and Mont-12, close to the appearance of *Globorotalia margaritae.* This form shows a similar absence interval close to the appearance of *G. margaritae* in the ODP Site 653 in the Tyrrhenian Sea (Fig. 5 in Rio *et al.*, in press).

Mont-17, Mont-18 and Mont-21 samples yielded nannofossil assemblages in which Pliocene restricted species are missing and forms characteristic of the Pliocene but well distributed also in the Miocene (like *R. pseudoumbilica, Spherolithus abies, Calcidiscus macintyrei*) are subordinate to obviously reworked forms (like *Dictyococcites bisectus, Cyclicargolithus floridanus).* Most probably, in these samples the nannoflora is totally reworked therefore preventing any zonal assignement.

Mont-19 and Mont-20 samples contain *Helicosphaera sellii*, abundant *R. pseudoumbilica* and *S. abies. Pseudoemiliana lacunosa, Gephirocapsa* spp., *Discoaster asymmetricus* and *Discoaster tamalis* are missing. Such assemblages can be referred to the «*Ceratolithus rugosus* zone».

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Ichthyofauna of the evaporitic Messinian in the Romagna and Marche regions

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Our purpose is to provide a list of the ichthyofauna collected from the euxinic shales found at the base of or interbedded within the evaporitic Messinian sequence in selected localities of Romagna and Marche regions and to point out their palaeoecological and palaeoenvironmental characters.

SYSTEMATIC LIST

Monte Castellaro (Pesaro)
Aphanius crassicaudus
Epinephelus sp.
Cichlidae
Zeus faber
Microchirus sp.
Gobiidae (incl. *Gobius* sp.)
Spratelloides sp.
Harengula sp.
Lates sp.
Scorpaena sp.
Atherina boyeri

Rio Sgarba, SPES Quarry (Borgo Tossignano)
Aphanius crassicaudus
Gobius sp.
Atherina cf. *boyeri*
Cichlidae
Clupeidae

Monticino Quarry (Brisighella)
Clupeidae
Gobiidae
Percoids

Monte delle Formiche (Bologna)
Sardina pilchadus

The most complete stratigraphic sequence is the Monte Castellaro (Pesaro) one, which at the base consists of marls with bituminous levels containing a wealth of clearly marine ichthyofauna.

The upper part of the section, mostly made up of bituminous marls, yields a completely different ichthyofaunal association. It consists of both highly euryhaline freshwater fishes and very rare specimens of marine forms associated with *Prolagus*. Further on, a rich assemblage of birds, insects and plants are found close to the base of the overlying S. Donato (Colombacci equivalent) Fm.

In the Vena del Gesso Basin (Vai & Ricci Lucchi, 1977) associations of continental hyperhaline type have been identified in the euxinic shales of cycles 12 and 13 at Rio Sgarba; this is demonstrated by the presence of *Aphanius, Gobius* and *Atherina*, wich show macroscopic ossification (pachyostosis).

On the contrary, the association from Brisighella, collected mainly in the euxinic shales of cycles 1 and 2, though only slightly representative, indicates a different environment that is no longer hyperhaline, as can be seen in the lack of pachyostosic structures in the specimens collected.

From a climatic point of view, the presence of *Lates* and of Cichlids and *Spratelloides* indicates conditions lying between the subtropical and the tropical belts.

The presence of Cichlids possibly belonging to a few species both at Monte Castellaro and Rio Sgarba poses an interesting biogeographic problem, since these fishes, now living in the inland waters of Africa, India and central-south America, have never been found in fossil form in Europe till now.

Another interesting problem concerns certain specimens of marine species found at Monte Castellaro, such as *Zeus faber, Scorpaena* sp. and *Epinephelus* sp., to which *Sardina pilchadus* can be added. This last was found near Monte delle Formiche, Bologna (courtesy of M. Grillini) and is remarkable because of the strong development of its body, resembling the present-day populations living in the open sea. All these species, however, have been found at the very base of the Gessoso-solfifera Fm., in a stratigraphic position equivalent to the «Calcare di base» and associated marls (see Vai, this vol., Fig. 5). These data further support the opinion of non evaporitic origin of the «Calcare di base» (Vai & Ricci Lucchi, 1977).

More generally, the alternating normal marine, hyperhaline and fresh water conditions, as suggested by the ichthyofauna occurrence (see also Sorbini & Tirapelle, 1980), is an independent prove of the environmental cycle of Vai & Ricci Lucchi (1977).

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Mollusks associated with the late Messinian vertebrate remains (Monticino Quarry, Faenza)

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The present remarks are relative to the mollusks recovered within and immediately above the sedimentary dyke and hole fills containing the vertebrate fauna. These observations derive mostly by hand samples recovered during the survey for vertebrate fossils and, at a lesser degree, from personal field observations.

Mollusk fauna from *in situ* Colombacci Fm.

Greenish-grayish marls

The mollusk fauna from the slightly reduced palaeoenvironment represented by these marls is indicative of an euryhaline, brackish environment whose salinity was considerably lower than normal marine. These marls occur at the top of the evaporitic sequence and very often they form the matrix of the vertebrate-bearing sedimentary dykes (pebbly mudstone); in such a case macrofossils are often deformed.

Macrofossils are represented by mollusks, especially gastropods, and are oddly distributed but, at places, common. The dominant species appears to be *Melanopsis marzolina* (Fig. 2) D'ARCHIAC which is one of the most abundant brackish gastropods of the Mediterranean Messinian basin (Gillet, 1963). Other gastropod species found in these marls are *Theodoxus mutinensis* D'ANCONA (Fig. 2) and two unidentified species of Mesogastropods.

Grayish, weakly lithified, silty marls

These are characterized by an abundant brackish bivalve fauna (Figs. 1 and Fig. 12 in Marabini & Vai, this vol.) dominated by diversified Limnocardids (3 species at least, still under study, one belonging to *Adacna* sp.) and by *Dreissena simplex* (BARBOT). Bivalves are chalky, mostly disarticulated with single valves often relatively densely packed. The convexity is mostly upwards. However, there is no indication of significant hydraulic sorting of dead valves by size since small, tiny valves (2-3 mm) occur together with much larger (3-5 cm) ones. Gastropods are almost completely absent but this can be perhaps an artifact of selective diagenesis. More or less worn and blackened fragments and valves of Limnocardids and *Dreissena* are very often encountered in the sedimentary dykes.

Mollusks fauna from the sedimentary dykes fills

The mollusks identified from the sedimentary dykes belong to three categories.

A) Mollusk represented by casts of gastropods, mostly in the shape of microgastropods similar to the euryhaline *Hydrobia*, observed as voids in partly dolomitized pebbles of Calcare di base (pre-evaporitic Messinian).

B) Brackish elements from the overlying Colombacci Fm., as already discussed above, which are more or less worn, deformed or blackened (mostly *Dreissena*, Limnocardids and *Melanopsis*). These are quite common.

C) Truly terrestrial mollusks very probably coeval

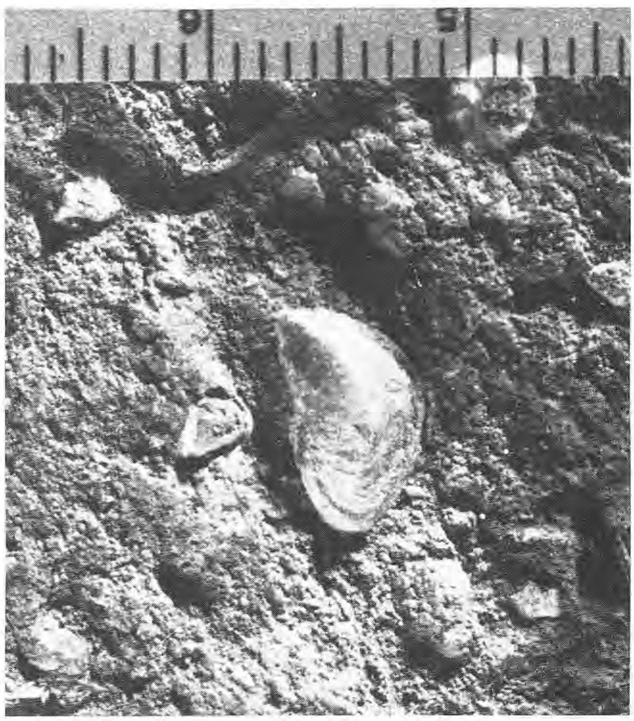

Fig. 1 – Dreissena simplex *from the Colombacci Fm.*

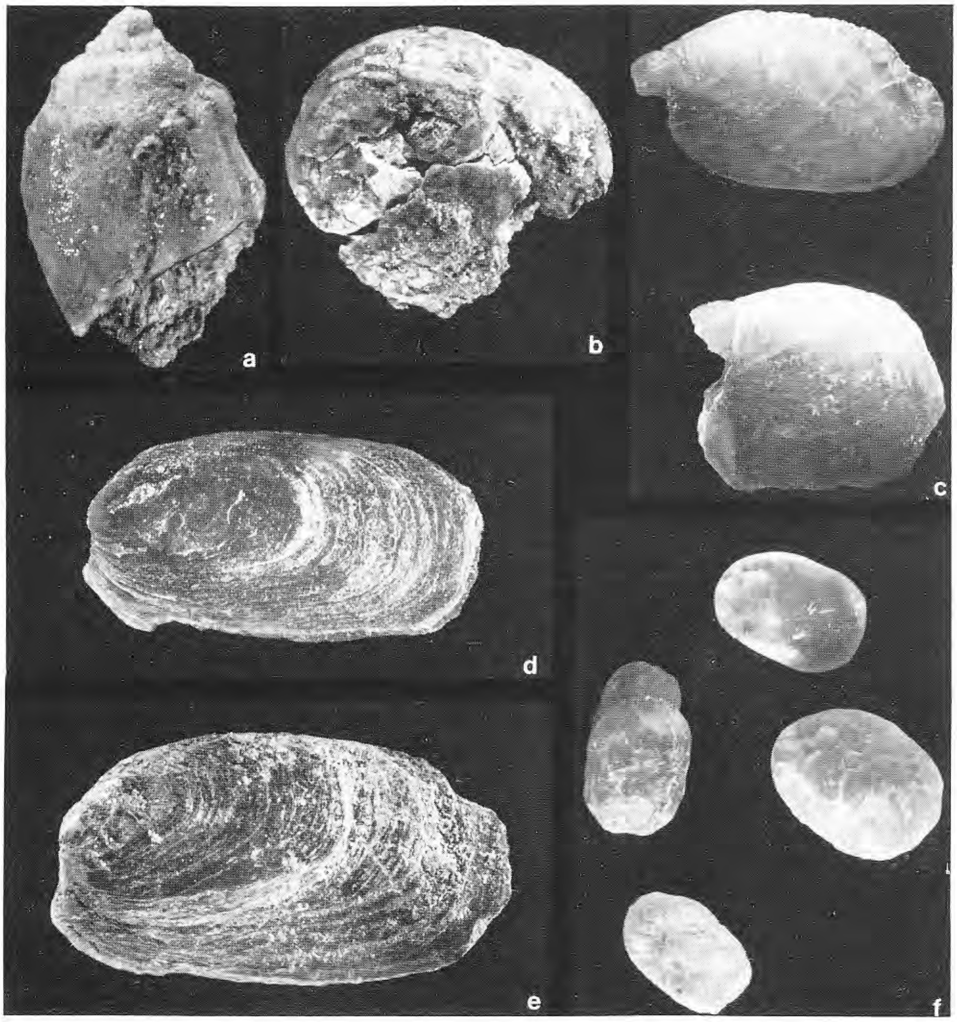

Fig. 2 – Snails and slugs from the Colombacci Fm. a, Melanopsis marzolina *4.6x;* b, Theodoxus *sp. 4.6x;* c, *Testacellidae 4.6x;* d,e, Heinemannia*? sp. 5x;* f, *Arionidae 4.6x.*

with the vertebrate fauna recovered in these dykes. Tiny shells of land snails are not present: on the other hand, rudimentary shells of slugs are surprisingly abundant. Taxonomic classification of this material is very difficult because systematics of slugs is mostly based on anatomical features of the living animal (e.g. Kerney & Cameron, 1979). However, gross morphology of the studied material reveals it belongs to three families of Pulmonate Gastropods:

1) LIMACIDAE
   Possibly *Heynemannia* sp. (cf. Sacco, 1897) (Fig. 2).
2) ARIONIDAE?
   Arionidae gen. et spec. ind.
   represented by shelled calcareous granules (Fig. 2).
3) TESTACELLIDAE?
   gen. et sp. ind.
   represented by coiled young shells (Fig. 2).

The finding of such material is of the greatest importance because:

a) the fossil record of slugs is very scarce in absolute terms;
b) as far as we know it is the first finding of similar material in Messinian sediments;
c) this terrestrial mollusks are the only invertebrates surely associated to the vertebrate fauna.

Slug shells appear to be concentrated (probably mechanically). The absence of land snails (which surely cooccurred with the slugs) is very probably imputable to the much easier dissolution of their tests.

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Magnetostratigraphy of the Monticino Section 1987 (Faenza, Italy)

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In order to determine magnetic polarity and to correlate it to the Standard Magnetostratigraphic Scale, 20 hand samples were collected along the Monticino Section at the same locations used for biostratigraphic determinations.

The strike and dip of the bedding is fairly consistent throughout the section and an averaged value of 117/30 was used as tectonic correction. The paleomagnetic measurements were carried out on a superconducting cryogenic magnetometer of Stanford University (California, USA), whose access was kindly allowed by Professor Michael McWilliams. One specimen from each hand samples was stepwise demagnetized in alternating field up 80 millitesla (mT) in steps of 10 mT. In addition the specimens were thermally demagnetized in 2-4 steps ranging between 200° and 430°C. To confirm the directions the experiments were duplicated on a second specimen of the samples Mo 5, 6, 7, 10, 12, and 16. The combined cleaning technique was preferred because the rock showed to be sensitive to temperature and after 350° it exhibits some viscosity.

The natural remanent magnetization (NRM) of the rock is weak (0.94-6.8 x 10^{-4} A/m) with lower values in the lower part of the section.

The paleomagnetic record, as can be seen in the Fig. 1, is complex with three components of magnetization that are not always completely removed. Through AF demagnetization the first component (generally aligned with the present field) is removed in peack-field of 40-50 mT. Increasing the field, the magnetic cleaning of the rock drastically increases the intensity of the remanence that in some samples exceeds that of the NRM. The characteristic magnetization of the rock (ChRM) appears after magnetic cleaning to peak-field as strong as 80mT. An additional thermal demagnetization between 200° and 430°C provided the best directions. After magnetic cleaning the samples do not always show a clear, clean paleomagnetic direction especially for scattering in the inclinations (Fig. 2). The declinations appear more consistent. A polarity pattern is well defined on the basis of declination and can be seen in Fig. 2. Only Sample Mo 5 does not fit the general magnetic pattern. During AF demagnetization this sample changed direction toward the east as did the samples with normal polarity. Thermal demagnetization of this sample exhibits an opposite component that has been interpreted as the primary one (Fig. 1). Probably a stronger normal overprint on this sample masks the true direction of the rock.

According to the age of the section, all but three samples (Mo 7, 10 and 16) are of reversed polarity that match well with the Gilbert Chron of the magnetostratigraphic scale. The correlation is shown in Fig. 2. According to this correlation, the Cochiti sub-chron appears to be missing in the section. It is possible that the section does not cover this time, but cannot be excluded that the Cochiti lies between the samples Mo18 and Mo19 where exists a gap in the sampling.

A correlation of the sample Mo16 (m 13.70) with the Nunivak sub-chron (4.10-4.24 Ma) appears in

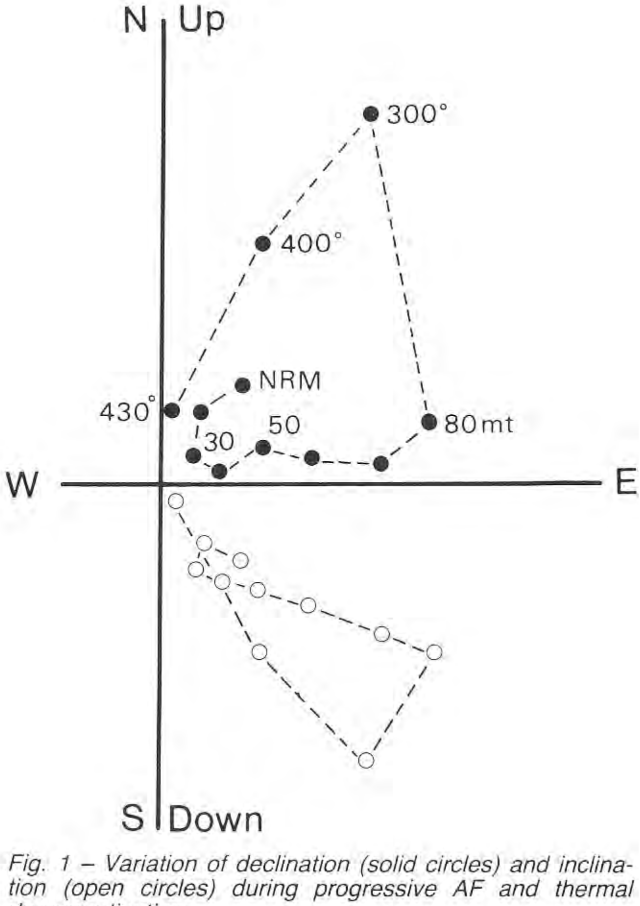

Fig. 1 – Variation of declination (solid circles) and inclination (open circles) during progressive AF and thermal demagnetization.
Numbers refer to peak field in millitesla (mT) or temperature (°C).

close agreement with the age of the sample dated biostratigraphically. This sample (Mo16) contains the first appearance of *Globorotalia puncticulata* whose estimated age is approximately 4.13 Ma.

Considering an interval of time of about 500.000 years between the Thvera and the Nunivak subchrons, the mean sedimentation rate of the section was about 1.9 cm/1000 yr.

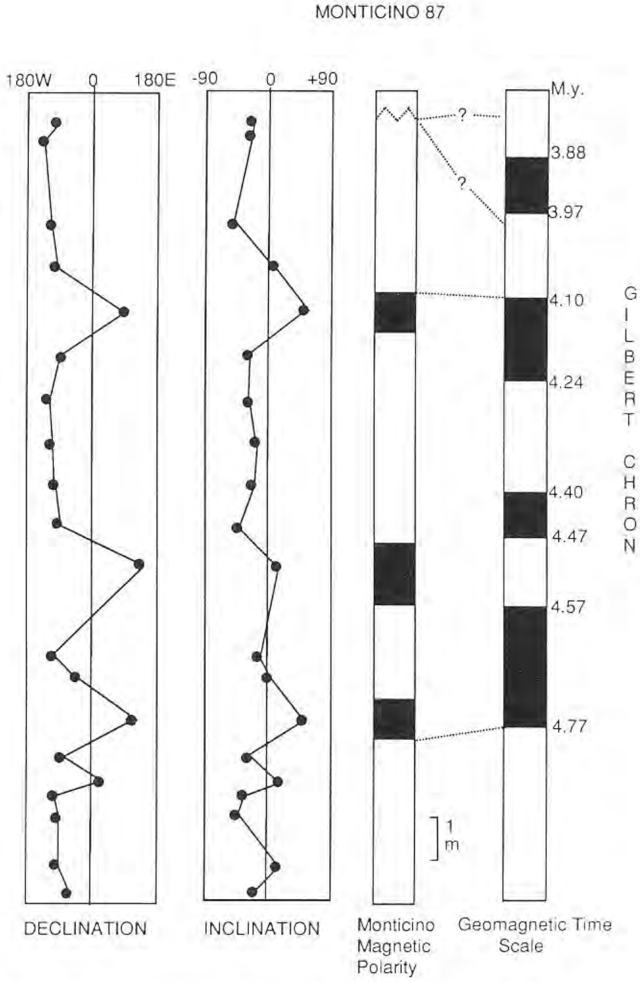

Fig. 2 – Magnetic stratigraphy of the Monticino Section 1987. Plotted points of the value of the declination and inclination are after magnetic cleaning and tectonic correction.
The Geomagnetic Time Scale for the Gilbert Chron is from Berggren et al., 1985. See Marabini & Vai (this vol., Fig. 8) for stratigraphy and thickness of the Monticino Section 1987.

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Palynological data on the Monticino Quarry sequence

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Palynological research was carried out in layers from the Monticino Quarry with the aim of reconstructing the old climate and environment using paleovegetational data.

The layer studied here has a thickness of about 1.5 m and is part of the Colombacci Fm., belonging to the Late Messinian. A sample collected from the overlying Argille Azzurre Fm. appeared devoid of palynomorphs. Samples from a fossil sink hole cut within the evaporites and filled with Colombacci clay proved to be rich in pollen.

The graph in Fig. 2, shows the results of our palynological analysis. *Pinus* type *haploxylon* and *Pinus* type *silvester* were present; the former had a maximums at levels D and C.

The significance of *P. haploxylon*, no longer present here today, remains undefined, but the percent ratio of *P. haploxylon* to *P. diploxylon* (or *silvester* type) increases during the hotter climatic periods. Thus *P. diploxylon* type is given the significance of cooler climate.

The climatic oscillations can be followed by means of the mediocrat curve, which takes into account the percentage of thermophilous taxa; the warmest periods are represented by its peaks. In contrast, the higher values of *Tsuga* + *Cedrus* are relat ed to the presence of cool mountain vegetation.

The values of *Hygrophyta* and *Hydrophyta*, demonstrating marshy or aquatic environments (see *Nymphaeaceae* at Level D), only have a local significance. *Alnus* + *Salix* reflect bank vegetation. *Gramineae, Chenopodiaceae, Plantaginaceae* testify to local arid substrate conditions.

The presence of coastal lagoons is related to the low but constant *Taxodium* percentages.

In short, we can state the Colombacci sequence is involved in a cool climate, as revealed by the low percentage of mediocrats and by two marked peaks of *Tsuga/Cedrus* at levels E (19.5) and C (14.6). Level E also has a certain percentage of *Picea*, that gives further importance to this peak. This spectrum also has the maximum of *Hygrophyta*, in an inspiring land having ponds with *Nymphaea*.

Globally, the sequence taken at Colombacci shows vegetational features in line with previous research, rich in «tertiary» taxa no longer present, in an overall cool climate, different overlapping vegetational belts, and coastal lagoons.

Figure 1 schematically represents the altimetric vegetational belts and the local ecological conditions, such as lagoons, etc. The climatic variations may have produced altimetric changes of the belts, but within this general representation.

The palynological data seem to indicate that the Late Messinian (Colombacci) was characterized by successive waves of climatic impairment.

The coniferous belt (*Tsuga, Cedrus, Picea*) was lowered as a consequence of the cool peaks at levels E and C. A warm dry phase at level D separates the two cool peaks. The second peak probably corresponded to a very rainy period that incremented the hygrophylous and hydrophylous vegetation. Moreover, it may have produced favourable ecological conditions for *Sciadopitys*, a taxa that today requires 6,000 mm of yearly rainfall.

The possibly slightly older pollen spectrum of the sink hole is palynologically very different. Forest cover is more important, in accord with the characteristics of tertiary woods. Ferns are abundant, but non-arboreous plants are scarce.

The mediocrats reach higher percentage values than in the upper levels. The *Tsuga/Cedrus* complex repeats the low percentage values of the Colombacci bottom.

Overall, we have here a tendentially warm climate mitigate by oceanic conditions, represented by the

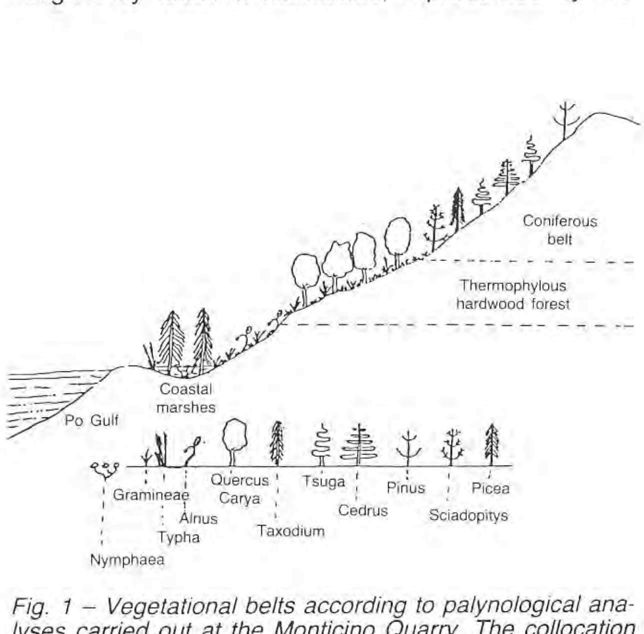

Fig. 1 – Vegetational belts according to palynological analyses carried out at the Monticino Quarry. The collocation of the taxa in vegetational belts is possible: *they are* really *present in the palynological spectra.*

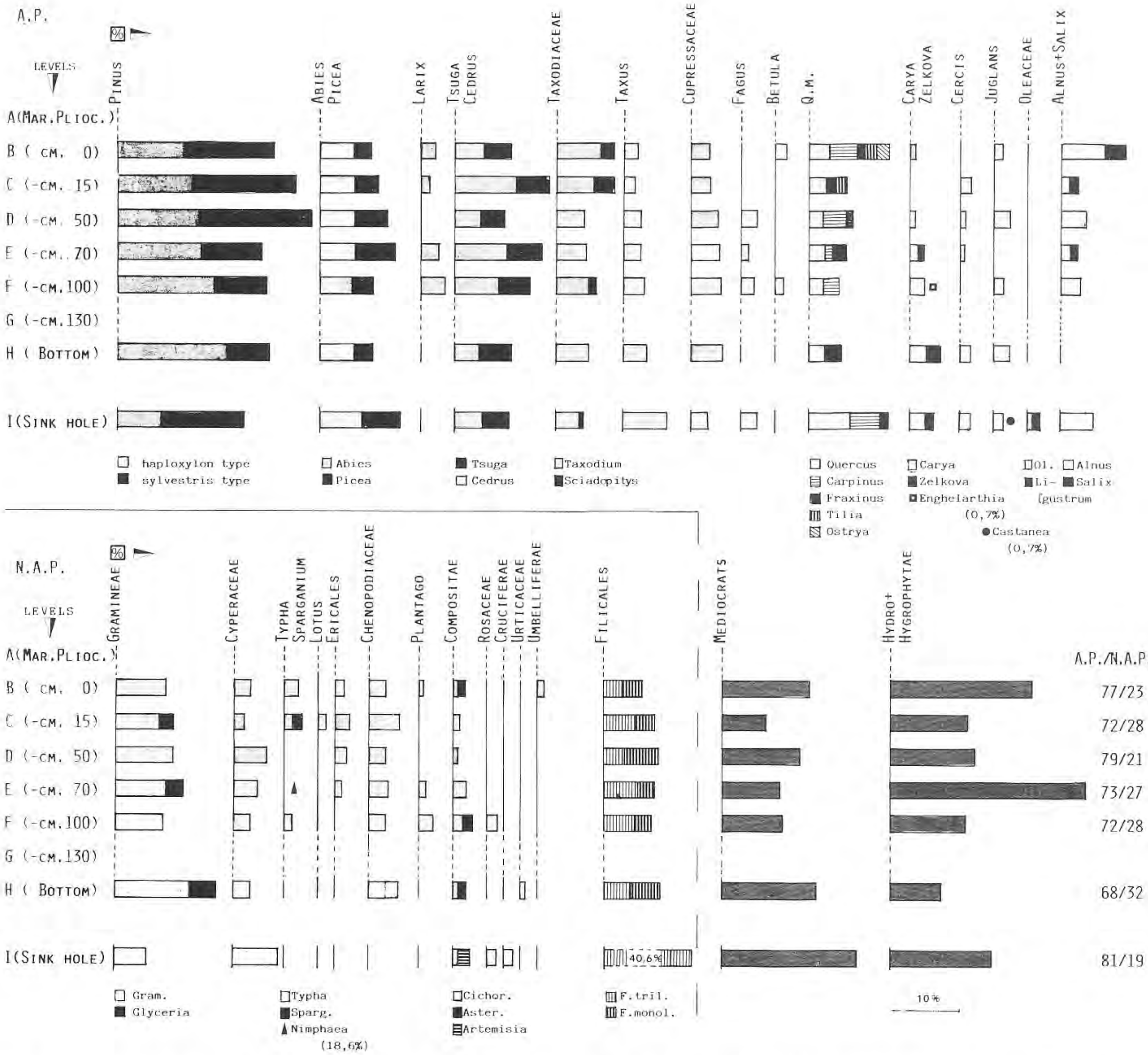

Fig. 2 – Results of palynological analysis: frequency of Arboreus Plants (A.P.) and Non-Arboreus Plants (N.A.P.) are represented.
Mediocrats = Quercetum mixtum *(Q.m.)* + Carya + Zelkova + Enghelarthia + Oleaceae + Cercis + Juglans + Castanea.
Hydro+Hygrophytae = Taxodium +Alnus + Salix + Cyperaceae + Typha +Sparganium + Nymphaeaceae.

presence of *Taxus* and *Fagus*. The abundant precipitation has favoured the formation of lagoons, ponds and marshes.

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The mammal fauna of Monticino Quarry

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FOREWORD

To date, eighteen fossiliferous sites have been found in the Monticino Quarry (Fig. 1). Most of them have been destroyed by quarrying. Their fossil content varies from a few teeth to fairly rich faunas. Some sites have yielded both large and small mammals, while others only one or the other. The sites are labeled BRS (Brisighella), followed by a number.

Individual fissures may have been encountered two or more times in the course of quarrying, though this cannot be demonstrated because data with which to reconstruct the morphologies of the fissures could not be collected. We have therefore chosen to consider each fossiliferous point as a distinct site, though we believe that sites BRS 1, 11, 12, and 13 correspond to the same fissure. Likewise, sites BRS 5 and 20 are probably from a common fissure, as are sites BRS 6 and 16. The tentative faunal list published by Costa *et al.* (1987) has been modified by studies in progress (insectivores: F. Masini, chiropters: T. Kotsakis, carnivores: D. Torre, bovids: Masini & Thomas, rodents: C. De Giuli, lagomorphs: F. Masini). The following is an updated faunal list:

INSECTIVORA
- *Galerix* sp. aff. *depereti*
- *Postpalerinaceus* sp.
- *Episoriculus* aff. *gibberodon*
- Soricidae indet.

CHIROPTERA
- *Megaderma* gr. *vireti-mediterraneum*
- Rinolophidae Sp. A
- Rinolophidae Sp. B
- Vespertilionidae indet.

PRIMATES
- Colobinae cf. *Mesopithecus*

PROBOSCIDATA
- cf. Gomphotheridae

CARNIVORA
- *Plioviverrops* n. sp.
- Hyaenidae indet.
- Canidae indet.

TUBULIDENTATA
- *Orycteropus* sp.

PERISSODACTYLA
- *Dicerorhinus* cf. *megarhinus*
- *Hipparion* sp.

ARTIODACTYLA
- *Samotragus* n. sp.
- Bovinae cf. *Parabos*
- Bovidae indet.
- Cervidae indet. (small size)
- Suidae indet.

RODENTIA
- *Hystrix* sp.
- *Stephanomys* n. sp.
- *Paraethomys anomalus*
- *Castillomys* n. sp.
- *Apodemus* cf. *gudrunae*
- *Cricetus* cf. *barrierei*
- *Ruscinomys* cf. *lasallei*
- *Eliomys* sp.
- *Atlantoxerus* cf. *rhodius*

LAGOMORPHA
- *Trischizolagus* cf. *maritzae*
- *Prolagus* n. sp.

Some reptile, bird, and fish remains are also present.

Table 1 shows the occurrence of the taxa in the different sites. BRS3, BRS5, and BRS6 are particularly rich in micromammals, while large mammals are common in sites BRS1 and BRS5.

TAPHONOMY

Fossils are for the most part concentrated in fissures, though in site BRS4 remains were scattered and embedded in sediments filling a broad superficial karst cavity in direct contact with the overlying sequence. The karst morphology of the fissures is generally evident.

Rodents form the bulk of the Brisighella Fauna. Some families are represented by a single or at most a few specimens. Murids are by far the dominant rodent family, although their diversity is moderate. Only 4 species from 4 separate genera occur. Moreover, two of the species are quite rare.

Small mammal remains are mainly concentrated in extremely rich lenses in the BRS 3, 5, and 6 sites. The high concentration of fossils can be attributed to the accumulation of pellets produced by birds of prey resting in vicinity of the fissures. This conclusion is supported by the observation that there are neither significant differences in the occurrence of left and right molars nor in the number of first and second molars (Table 2).

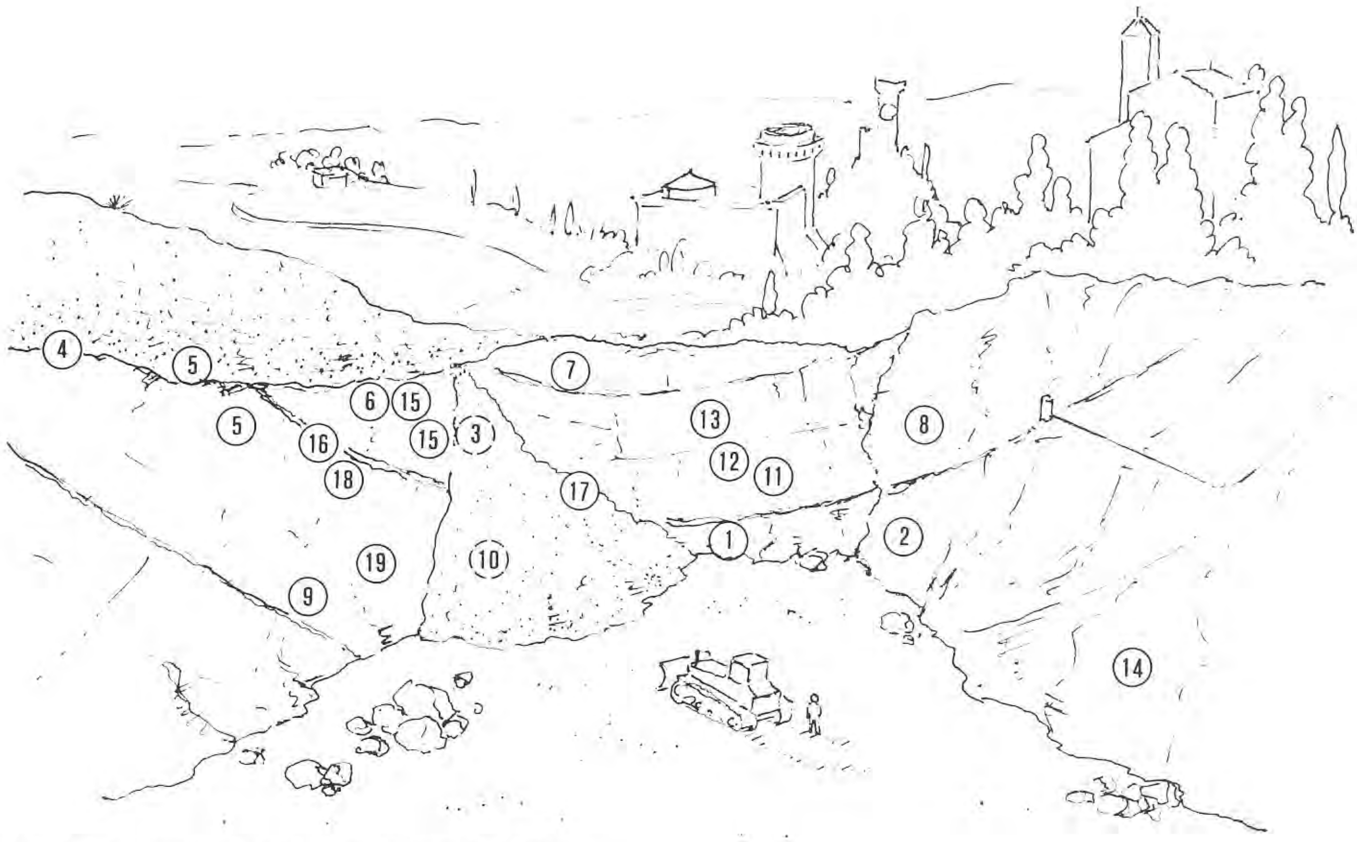

Fig. 1 – Fossiliferous sites in the Monticino Quarry.

Large mammal remains are found either as partially articulated skeletons, or as scattered, transported fragments.

In spite of the large number of fossil finds, the faunal assemblage is poorly representative of the mammal communities of the latest Turolian. Fossils from large or very large macromammals are extremely rare. For example, amongst the herbivores, proboscidians are poorly represented (only 1 find), as are rhinoceroses, hipparions, and large bovines. Carnivores are almost exclusively represented by the small sized «hyaenid» *Plioviverrops*. We think that one of the factors responsible for this selection is the small size of the fissures that have been excavated to date. Since this explanation cannot be used to account for the characteristics of the microfauna, the extreme scarcity of the cricetids and the almost total absence of the glirids seem to be an actual characteristic of the association living in the area.

The occurrence of articulated skeletons, specifically in the BRS5 site, suggest that some of the karst cavities acted as natural traps. This hypothesis is supported by the relative over-representation of carnivore remains.

TAXONOMY

Insectivores

Galerix sp. aff. *depereti*. *Galerix* is represented by single molars and lower premolars. This moon rat differs from *Galerix socialis* and the Vallesian and Early Turolian representatives of the genus because of its larger size and somewhat different dental features. The lack of upper P3 and P4 and mandibular remains prevented us from making definite conclusions. However, some similarities to the Pliocene species *G. depereti* may suggest a relationship with this species.

Postpalerinaceus sp. The hedgehog is known in the Monticino fauna only from very few, scant dental remains.

Episoriculus aff. *gibberodon*. This shrew is the most widespread insectivore in the Monticino sites. It is somewhat smaller than the Pliocene *E. gibberodon*.

Soricidae indet. Two fragments of mandible of a very small shrew were recovered in site BRS20. The lower molars are not pigmented and mesio-distally compressed, as in the Miosoricinae.

Chiropters

Bats are only represented by a few teeth that have not yet been studied. The presence of a Megadermatide belonging to *Megaderma* gr. *vireti-mediterraneus*, documented by a fragment of a lower M1 and a canine, is worth mentioning.

Primates

Colobinae cf. *Mesopithecus*. A single upper canine that displays the typical morphology of a fairly large Colobinae may be attributed to *Mesopithecus*.

Proboscidians

Cf. Gomphotheridae. A single rolled fragment of a tooth from site BRS19 can be attributed to a bunodont proboscidian.

Carnivores

Only three species are present amongst the fossils collected: a canid represented only by a premolar, a medium sized hyaenid, documented by a tooth fragment, and a new form of *Plioviverrops*, which is represented by many fossils. Judging from the characteristics of its teeth, *Plioviverrops* must have preyed on small vertebrates, although, like the larger hyaenid, it must have also eaten carrion. The high concentrations of *Plioviverrops* remains may be due to the existence of natural traps into which the animals fell, lured by the presence of carrions.

Canidae indet. It is a fox sized species possibly referable to the canid of Venta del Moro (Spain).

Hyaenidae indet. This fossil has been identified from a fragmentary lower M2 collected at site BRS3. Its features do not allow a precise determination to be made, but its size suggests a possible *Thalassictis* form.

Plioviverrops n. sp. Is mainly present in the BRS5 site, where some articulated skeletons were found. This fox-sized carnivore represents the most evolved species of the *Plioviverrops* line. Its molars display better developed pricking characteristics than do any other species of the genus.

Tubulidentata

Orycteropus sp. This peculiar ant-eater has been identified on the basis of the very typical features of a single molar from site BRS5. It is also represented by some limb bones that suggest the presence of part of an articulated skeleton. Fossil *Orycteropus* are very uncommon in Eurasia, and in Europe are only known from Samos and Perpignan (Lavocat, 1958).

Perissodactyls

Although this order is generally well represented in Late Miocene sites, at Brisighella there are only rare

Table 1 - *Distribution of taxa in the sites of the Monticino quarry.*

BRS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	19	20
Galerix sp. aff. *depereti*	–	?	X	–	X	X	–	–	–	–	–	X	–	X	–	–	–	X
Postpalaerinaceus sp.	–	–	–	–	X	–	–	–	X	–	–	–	–	–	–	–	–	–
Episoriculus aff. *gibberodon*	–	X	X	X	X	X	–	X	X	–	X	X	–	–	–	–	–	X
Soricidae indet. (small size)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	X
Megaderma gr. *vireti-mediterraneum*	–	–	X	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–
Rinolophidae indet.	–	X	–	–	X	X	–	–	–	–	–	–	–	–	–	–	–	X
Vespertilionidae indet.	–	–	X	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–
Chiroptera indet.	–	–	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–
Colobinae cf. *Mesopithecus*	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
cf. Gomphoteriidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	X	–
Plioviverrops n.sp.	–	X	X	X	X	–	–	–	–	X	–	–	–	–	–	X	X	–
Hyaneidae indet.	–	–	X	–	?	–	–	–	–	–	–	–	–	–	–	–	–	?
Canidae indet.	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–
Orycteropus sp.	–	–	–	?	X	–	–	–	–	–	–	–	–	–	–	–	–	?
Dicerorhinus cf. *megarhinus*	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hipparion sp.	X	–	X	–	X	–	–	–	X	–	–	–	–	–	X	–	–	–
Samotragus n.sp.	X	X	–	?	X	?	–	X	X	X	–	–	–	–	X	X	X	?
Bovinae cf. *Parabos*	X	–	–	–	X	–	–	–	–	–	–	–	–	–	–	X	X	–
Bovidae indet.	–	–	X	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cervidae indet. (small size)	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Suidae indet.	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hystrix sp.	–	–	–	–	X	?	–	–	–	–	–	X	–	–	–	–	–	–
Stephanomys n.sp.	X	X	X	X	X	X	X	X	X	–	X	X	–	X	X	X	–	X
Paraethomys anomalus	X	X	X	–	X	X	–	–	X	–	X	X	–	–	–	X	–	X
Castillomys n.sp.	X	X	–	X	X	X	–	X	X	–	X	X	–	–	–	–	–	X
Apodemus cf. *gudrunae*	–	–	X	X	X	X	X	?	–	–	–	–	–	–	–	–	–	X
Cricetus cf. *barrierei*	–	–	X	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–
Ruscinomys cf. *lasallei*	–	–	–	X	X	X	–	–	X	–	–	–	–	–	–	–	–	–
Eliomys sp.	–	–	–	–	–	?	–	–	–	–	–	–	–	–	–	–	–	–
Atlantoxerus cf. *rhodius*	–	–	X	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–
Trischizolagus cf. *maritzae*	–	X	–	X	X	X	–	X	X	–	–	–	–	–	X	–	X	X
Prolagus n.sp.	X	–	X	X	X	X	–	X	X	–	–	–	–	X	–	–	–	X

and isolated remains.

Dicerorhinus cf. *megarhinus*. Large rhinoceros remains probably derived from a single individual were collected from site BRS1.

Hipparion sp. This genus is only represented by some teeth and incomplete post cranial elements.

Arctiodactyls

The bovids are the best represented artiodactyls. However, as is the case in other European localities of equivalent age, the bovids from Brisighella are much less differentiated than those from Late Turolian faunas of the Balkanic peninsula and Asia Minor. The extreme fragmentation and the low number of significant specimens has in some cases reduced the possibility of specific determinations.

Samotragus n. sp. This small Oiocerini is documented by a great deal of material. Most of the remains referred to this species have been collected in site BRS5 and part of them probably belong to articulated skeletons. The morphology of an incomplete frontal with horn cores, its teeth, and its overall body size prove that this species differs with respect to the large *Samotragus crassicornis* from Samos and the older, smaller *S. praecursor* from the Ravine de la Pluie (Late Vallesian, Macedonia). It is, at present, the western-most find of this genus in Europe.

Bovinae cf. *Parabos*. The presence of a Bovinae is proven by the scant remains of a very large antelope. The morphology of a single lower molar suggests a possible relationship with *Parabos* s. l., a genus that is common in Spain in levels of equivalent age (Moyá Solá, 1983).

Bovidae indet. A number of post cranial remains and an upper third molar indicate that a bovid larger than *Samotragus* was present.

Cervidae indet. Only an upper molar for its brachyodont crown may be referred to a small species of this family.

Suidae indet. Two tarsal bones document the occurence of a suid.

Murids

The taxonomy of the murids has not yet been fully established, and it is difficult to insert new specimens into phylogenetic lineages that are valid over geographically limited areas. Because the fauna we are dealing with does not compare with any other Italian fauna, with the possible exception of the scant Baccinello V3 fauna, taxonomic terms will be used in a purely descriptive sense.

Stephanomys is represented by a new species different from and more evolved than *Stephanomys ramblensis* of Valdecebro 3, though still not as apomorphic as *Stephanomys donnezzani*. It is the most abundant species in all the sites, and is very similar to the few published specimens of Caravaca.

Paraethomys. The specimens from the BRS sites do not differ significantly from *Paraethomys anomalus*. This taxon is the second most common species in Brisighella, and indicates that there was a strong faunal connection with the site of Maritza described by De Bruijn *et al.*, 1970.

Castillomys. Though this genus is never abundant, it occurs in almost all sites. Surprisingly, it is absent from the richest site (BRS3). The specimens from Brisighella have peculiar characteristics that point to the Pleistocene genus *Orientalomys*. A new subgenus will be created to house this species.

Apodemus. The specimens which can be referred to this genus are very rare, but widespread in many sites. The scantiness of the material does not allow precise determinations to be made. At present the specimens can be attributed to *Apodemus* cf. *gudrunae* though there are probably some apomorphies in respect to the typical form described by Van de Weerd, 1976.

Cricetids

Cricetus occurs in BRS3 (one broken specimen) and in BRS6 (five specimens). On the basis of its size and morphology it can be referred to *Cricetus* cf. *barrierei*.

Ruscinomys occurs in BRS6 (eight specimens) and as single worn specimens in BRS4 and BRS9. Its hypsodonty and size suggest that it can be referred to *Ruscinomys* cf. *lasallei*.

Sciurids

Atlantoxerus. This genus is present in BRS6 (two specimens) and BRS3 (one specimen). Because of the patterns of its teeth it is referred to *Atlantoxerus* cf. *rhodius*.

Glirids

Eliomys. It occurs only in BRS6, and cannot be referred to any particular species.

Histricids.

Hystrix occurs in BRS5 and BRS12. The presence of this genus, which cannot be better determined, is indicated by a few teeth, a femur, and a humerus fragment.

Table 2 - *Occurrence of* Stephanomys *and* Paraethomys *teeth in BRS3, BRS5, and BRS6.*

		Stephanomys			Paraethomys		
		BRS3	BRS5	BRS6	BRS3	BRS5	BRS6
M1/	r	149	37	9	57	10	1
	l	137	30	12	72	4	2
M2/	r	140	42	8	46	10	3
	l	149	22	12	49	12	2
M/1	r	115	29	7	57	16	1
	l	115	29	8	55	12	4
M/2	r	149	33	4	57	17	2
	l	148	34	10	60	18	–

Lagomorphs

Trischizolagus cf. *maritzae*. This leporid, which is the most widespread and abundant lagomorph, is represented by teeth and limb bones whose morphologies are like those of the species from Maritza.

Prolagus n. sp. This ochotonid is represented mainly by teeth and is rather uncommon in the BRS sites. The recent discovery of a complete skeleton from a marly interbed in the Messinian Gessoso-solfifera Fm. near Pesaro (Italy), has allowed us to recognize a new species which has an overall similarity with *P. michauxi*, though some cranial and dental features are different. The remains from Brisighella can be referred to this new species on the basis of their dental morphologies.

CONCLUSIONS

The rodents indicate that the BRS fauna belongs to the MN13 zone. The evolutionary level reached by some species may better define the biochronological setting. For instance, the close relationships between the BRS *Paraethomys* and *P. anomanlus* from Maritza supports the hypothesis that BRS is a late MN13 fauna.

It is difficult to interpret the significance of the presence of new species of micro and macromammals, because the associations of the MN13 zone are poorly defined, especially in the case of the macromammals. Even though these species cannot be used to improve the biochronological resolution, their presence does not conflict with the assignment of BRS to zone MN13. In fact, their characteristics are more derived than those of cogeneric species from zone MN12.

Furthermore, probably we face a new biogeographical province. Some species suggest there were close connections with oriental faunas. For example, *Ploviverrops* n. sp., is phylogenetically linked to *P. orbignyi*, from Greece, and *Samotragus* n. sp., is the western most representative of this genus that has been found in the Mediterranean Area. On the other hand, the *Stephanomys* from Brisighella is the eastern-most representative of this genus.

Data on Italian faunas of similar ages are not abundant. The best known is the Bacinello V3 (Grosseto) fauna (Huerzeler & Engesser, 1976; Engesser, in preparation), and the Gravitelli Fauna from Sicily. The Gravitelly fauna was destroyed by the earthquake that struck Messina in 1908, and is therefore known only from descriptions in the literature (Seguenza, 1902, 1907). Few of its elements appear to be comparable to either those from Brisighella or from Baccinello V3.

The Brisighella fauna differs considerably from the Baccinello V3 fauna, in which suids, cervids, and hipparions are widely represented and the carnivores are more diversified. *Stephanomys*, which is apparently replaced by *Rhagapodemus*, does not occur among the rodents from Baccinello. As a matter of fact, there are too few common faunal elements to permit detailed correlations based on systematics.

One factor contributing to the variations in the faunas was certainly the differences in the taphonomic conditions in the three areas, and therefore the existence of three fairly different biotypes seems reasonable.

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A new vertebrate site from late Messinian karst holes, Santerno valley, W Romagna

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INTRODUCTION

This short note is a complement to the paper by Costa *et al.*, 1986 and to the one by Vai, this volume, since it follows our recent (Feb. 1988) finding of some Upper Messinian mammal and reptyle remnants showing a strong affinity with the Monticino fauna.

Our small (a few cubic meters) bone-rich body is situated near Borgo Tossignano (Imola, Romagna, Italy), on the right side of the Santerno river-bed, 250 m downstream from the Montanara bridge: here part of the Messinian succession crops out, underneath the recently dissected alluvial cover.

Aim of this note is to give a description and a preliminary interpretation of the local geologic context around the fossiliferous body, in order to make possible the comparison between this situation and that one discovered in the Monticino Quarry (Brisighella, Romagna).

Samples for paleontological studies were recently jointly collected in the Santerno site and will be studied by De Giuli C. and Masini F. of the Department of Earth Sciences, Univ. of Florence.

STRATIGRAPHIC OUTLINE

Here follows the stratiraphic record for the studied area (key as in all of the illustrations):

1a) Marnoso-arenacea Fm. (Upper Tortonian-Lower Messinian).
1b,c,d) Gessoso-solfifera Fm. (Lower Messinian).
2a,b,c,d,3) Colombacci Fm. (Upper Messinian).
4) Argille Azzurre Fm. (Pliocene).

The lower boundary of the Gessoso-solfifera Fm. is conformable and continuous.

The lower boundary of the Colombacci Fm. is (at least here, and farther W) disconformable to angularly unconformable.

The evaporite facies analysis (Vai & Ricci Lucchi, 1976, 1977, 1978, 1981) has made possible to know, by correlating the individual Gessoso-solfifera Fm. cyclothemes, the minimum extent of stratigraphic gaps at the base of the «Colombacci» Fm. all over the W Romagna basin: our geologic map and section (fig. 1 a,b) show the Latin numeration of layers, according to the order established by Marabini & Vai, 1985, near Brisighella.

The gap we can find along the Santerno (by comparing the succession in the river-bed with measured stratigraphic sections from Paradisa Quarry and other sites) corresponds to almost all of the thinner, clastic cycles, that means comprehensively at least 55 m: the angular unconformity between Gessoso-solfifera Fm. and Colombacci Fm. is about 10-15°.

Throughout Emilia and Romagna, W of the Montone River, the Colombacci Fm. is strongly reduced: in the Santerno section, its maximum thickness is 15 m.

Another angular unconformity (up to 30° in dip), already detected by Vai & Ricci Lucchi, 1981 (pag. 223, fig. 16), takes place at the base of the layer called by the same Authors «black clay», a few decimetres under the upper, disconformable boundary with the Pliocene Argille Azzurre Fm.

TECTONIC SETTING

In the Santerno, the gypsum layers are strongly (50° or more) dipping to the NE: this is valid for the entire evaporitic belt from the old Paradisa Quarry (N of Borgo, left bank of the river), to the westernmost Tossignano houses (uphill on the right side of the river), where we find a major transversal (about N-30°) fault, probably with a component of right-lateral movement; further ESE, the Vena del Gesso homocline is gently (average about 30°) dipping to the NNE.

The Tossignano-Paradisa fold, we have just defined, is partly superimposed on (and partly contemporaneous to) other complex structures, which belong to the Upper Messinian deformational history of the western part of the Vena del Gesso: part of them likely acted in response to the «Sillaro Line» tectonic activity (Landuzzi, 1984; Marabini & Vai, 1985; Castellarin *et al.*, 1986b; Pini, 1987; Landuzzi, in prep.).

Some late transversal faults (fig. 1 a,b) offset the base of the Pliocene Argille Azzurre Fm., the dip of which is about 10° to the NNE in our site.

OUTCROP DESCRIPTION

In fig. 3(a) we present a detailed geological section, reconstructed with the help of field photographs: a fault, offsetting the base of the Argille Azzurre Fm.

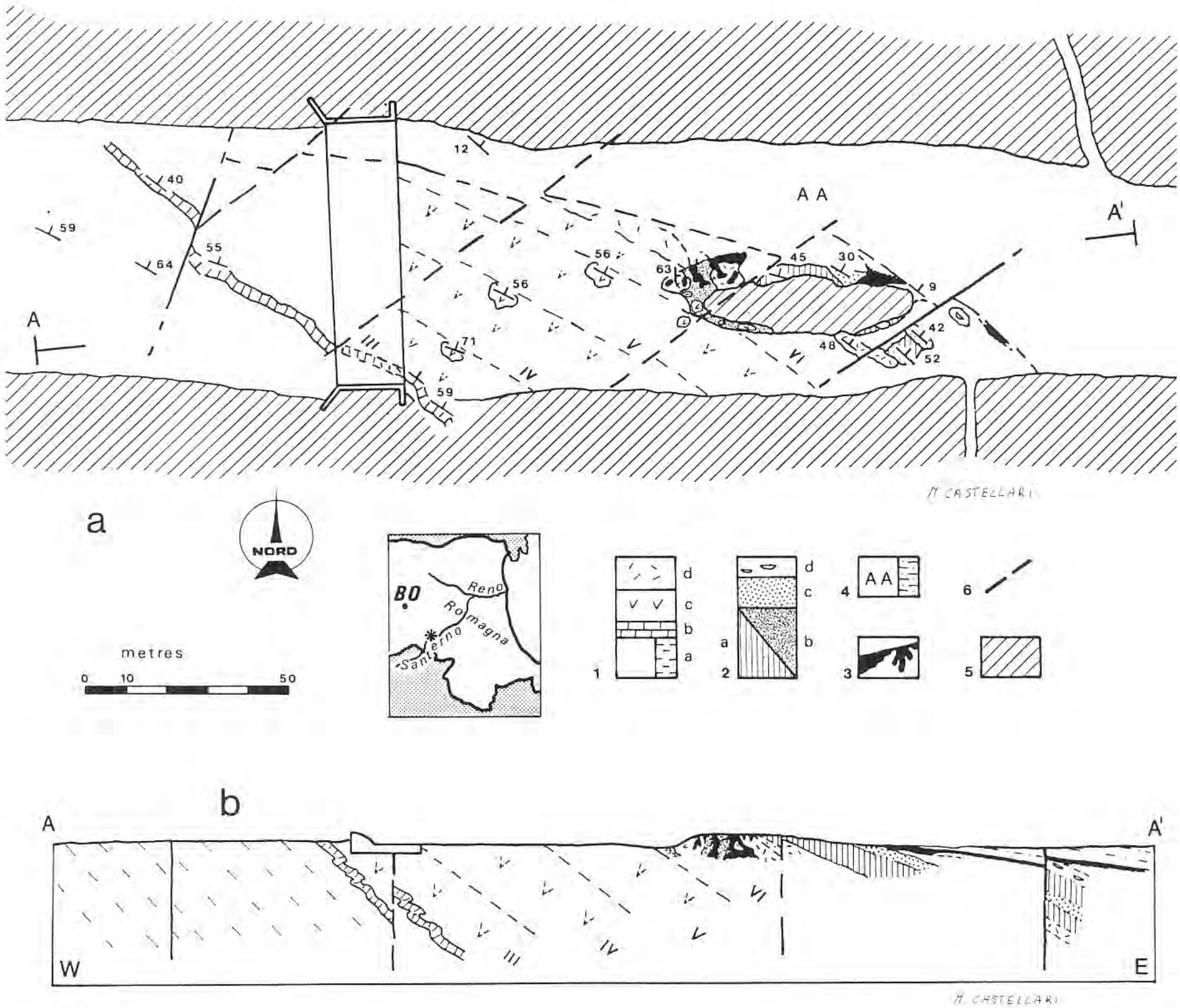


Fig. 1 – Geologic map of the Santerno river-bed (a), and corresponding cross-section (b). Key (see text for details):
1) Gessoso-solfifera Fm.: pre-evaporitic euxinic shales and carbonatic cycles (a); partly slumped «basal» limestone and calc-gypsum laminite (b); mainly «autochtonous» gypsum facies (c); mainly clastic gypsum facies (d)
2) Colombacci Fm.: blue-green «varved» mudstones (a); chaotic blue-green mudstone plus reworked and secondary gypsum (b); varicoloured laminated mudstones plus detrital vuggy limestone lenses (c); olive-green mudstones plus pebbly sandstone bodies (d)
3) Colombacci Fm.: «black layer» and equivalents
4) Argille Azzurre Fm.: glauconitic clays with abundant microfaunas
5) recent alluvial cover
6) fault (dashed if only inferred).

has been eliminated by restoring a vertical displacement of about 4 m.

The gypsum of the VI cycle, partly «autochtonous» (1c) and partly clastic (1d), appears deeply pervaded by irregular holes, some of them (2b) bearing other gypsum (as clasts or secondary crystals) and blue-green «varved » mudstones (2a); others are filled with sort of a blackish breccia (3b,c), containing rather scattered vertebrate remnants: we have not been able to find a real bone-bed concentration in the holes, as in the Monticino Quarry.

Out of the holes, a few metres E, the Gessoso-solfifera Fm. is unconformably overlain by a regular Colombacci Fm. stratigraphic column, which shows the following lithotypes:

2a) blue-green «varved» mudstones: thinly (mm) interlayered mixture of clay and carbonates: total thickness, about 5 m;

2c) varicoloured (red, green and yellow) laminated mudstones, with detrital vuggy limestone intercalations (the small voids in the limestone are prismatic moulds of dissolved gypsum crystals): minimum total thickness, about 4 m; calcareous lenses up to some dm;

2d) small (up to 50 cm thick) lensoidal sandstone bodies, with *Limnocardium* sp., plus olive-green mudstones (out of section, see geol. map., fig. 1a).

3) «black clay»: dark, 50-60 cm thick clay-rich layer, containing reworked calcareous and arenaceous

clasts as well as fragments of calcretes and lignitified plant debris. Not far from this site, a small outcrop of this layer has given us an impressive number of *Dreissena* sp. shells. The fabric of the «black layer» is often confusingly brecciated (3b); its lower contact can appear either as a real erosional one (if marked by pockets with pebbly filling), or, on the contrary, as a fringing transition: we think that this second possibility could be due to intense bio-(rhizo-?)turbation or other disturbing synsedimentary phenomena. We stress that the local attitude of this layer is strongly unconformable on the underlying beds. We can also see in our section a lateral substitute of the «black layer», i.e. a chaotic (max 2 m thick) unsorted deposit of angular Colombacci Fm. clasts (including «black clay») supported by a greenish, clayey matrix (3a): we are tempted to interpret it as a small debris-flow.
This latter deposit, and the «black layer» as well, are sharply and disconformably covered by Pliocene glauconitic clays (4), with frequent burrows.

KARSTIC EVENTS

We can demonstrate that the holes in the gypsum are related to two separate phases of karstic development (at least two local emersion episodes).

— *1st phase*: as said before, some of the holes (absolutely devoid of fossils and calcareous clasts) are filled with blue-green «varved» mudstones (from the basal part of the Colombacci Fm. unit 2a), which are strongly deformed, often in a semiductile fashion, with irregular folding of the laminae and some microfracturing. Laminae in the mudstones have been also deformed by displacive growth of big secondary gypsum crystals (fig. 2): this could have happened after the emplacement of the mudstones in the hole.
The presence of big primary gypsum blocks, embedded in the deformed green mudstones, is probably a key for the interpretation of the deposit as resulting from the collapse (fig. 3b) of a large preexisting karstic vug during the sedimentation of the basal Colombacci Fm. mudstones: a tectonic trigger, like the one proposed in the paper by Costa *et al.*, 1986, can neither be excluded nor proved, because of the very small exposure available: we have not been able to see any of the even and parallel walls which are so characteristic of the Monticino neptunian dykes.

— *2nd phase*: the holes (properly karstic ones, with plenty of dissolution features and extreme shape irregularity; see fig. 3d) were gravitationally (with some direct grading) filled with dark, extremely heterometric breccia (3b,c), largely made up of more or less angular clasts from the «black clay»: it contains almost all of the local Colombacci Fm. lithotypes, including olive-green and blue-green mudstones, calcareous clasts, some sandstone clasts and reworked calcretes: the calcareous paraconglomerates (so bone-rich in the Monticino bodies) are not represented, even though they do exist in several outcrops nearby. The composition of the materials inside the karsts lead us to correlate this filling phase with the «black layer» atop the Colombacci Fm.

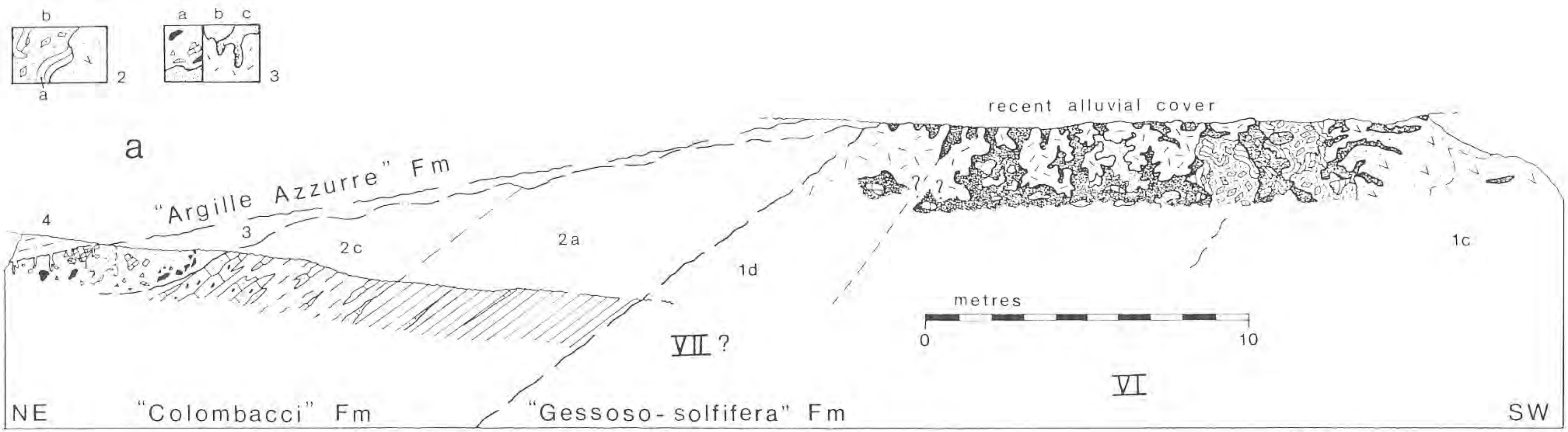
The proposed time sequence can be checked on the basis of the following relationships:

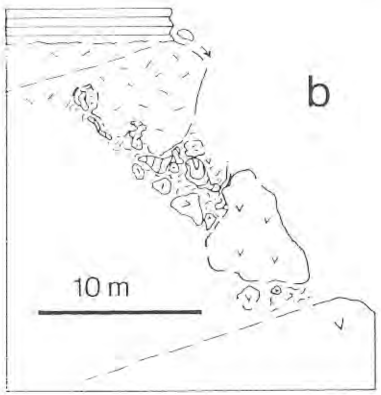
1) consolidated blue-green mudstone (2a) clasts are included in the blackish breccia (3b) along with more recent lithotypes, as the vuggy limestones (2c), which are absent in the first filling.
2) brittle cracks, crossing after consolidation the greenish chaotic mudstone (2b) of the first stage, were subsequently filled by the blackish breccia (3b,c).
3) the rare gypsum crystals in the blackish breccia (3b,c) appear smooth and rounded (because of dissolution), while in the greenish fills (2b) they were more abundant and growing displacively.

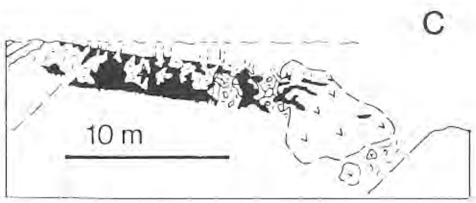
CONCLUSIONS

The Santerno site clearly shows three major

Fig. 2 – The photograph, taken from above, shows part of the abrupt, erosive contact between the earlier, blue-green fill and the more recent, blackish one.
Displacive growth of big secondary gypsum crystals occurred in a blue-green deformed mudstone spot, included in the earlier fill.







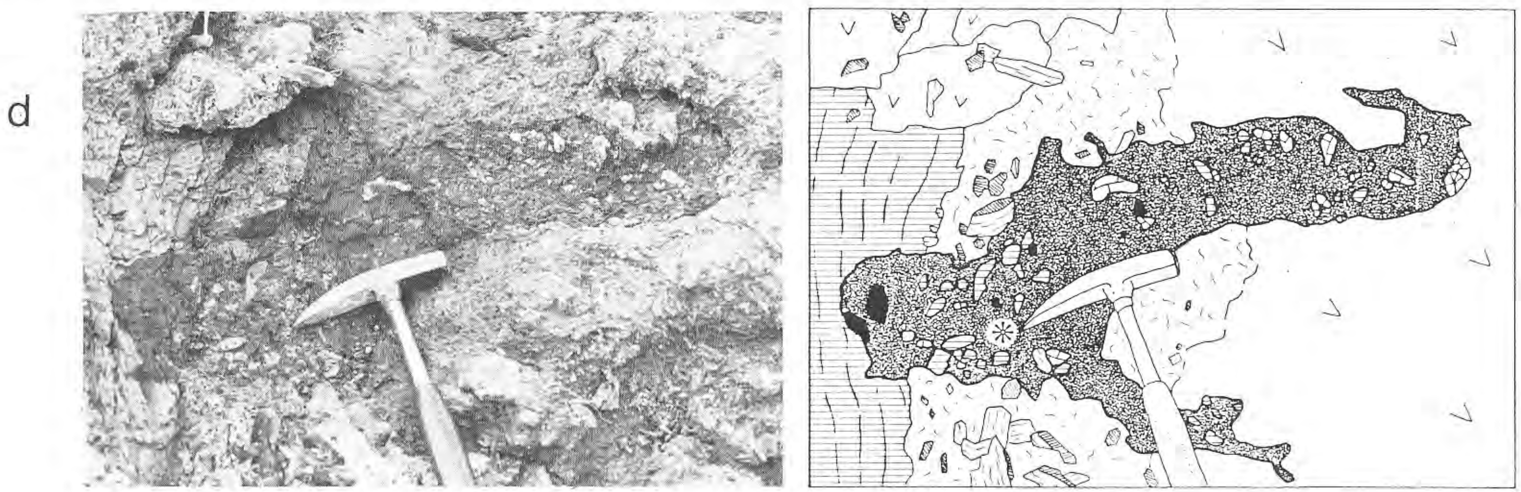


Fig. 3(a) – detailed cross-section from the eastern part of the studied site. Key (refer to fig. 1):
(2b) first karst fill, containing deformed blue-green mudstone (2a) plus primary gypsum blocks and secondary gypsum crystals
(3) «black layer» equivalents: chaotic, debris-flow deposit (a); 2nd phase karst fill, with lighter olive-green portions (rich in calcrete fragments), included in blackish breccia (c).

Fig. 3(b) – Interpretation of the first phase fill as a collapsing vug.

Fig. 3(c) – Second phase karsts superimposing on the first phase ones.

Fig. 3(d) – Bone fragment (*) in a 2nd phase karst, affecting «autochtonous» gypsum as well as the gypsiferous chaotic 1st phase fill (mid-upper part of the photograph).

discontinuities: the first one between the Gessoso-solfifera Fm. and the Colombacci Fm., the second one a few dm under the top of the Colombacci Fm., and the third one at the base of the Argille Azzurre.

The first and the second of them are well-documented angular unconformities, summing up about a 45° Upper Messinian tilting. Their emersive nature is testified by the two-phase development of karstic phenomena in the evaporites.

The former phase fill composition shows that it was emplaced after the end of the first emersion episode, by subaqueous synsedimentary collapse involving gypsum and partly unconsolidated «varved» mudstones from the lower part of the Colombacci Fm.

The overlying vuggy (ex-gypsum-bearing) limestones seem to suggest the persistence of emerged areas nearby (Landuzzi, 1984).

We don't find large collapse structures in the filling phase which follows the second emersion episode: a rough direct grading of some portions suggests gravitational settling of the blackish mixture, accompanied by faint sorting.

A full understanding of the second filling event would require some more information about the enigmatic «black layer» and its stratigraphic equivalents: most of the literature data about it (Iaccarino & Papani, 1979; Sturani, 1976; Casati *et al.*, 1976; Cremonini & Farabegoli, 1977; Colalongo *et al.*, 1976; Cremonini & Marabini, 1982) support an oligohaline, non-alcaline, largely detrital sedimentation under very shallow-water, marshy conditions. Furthermore, in our own opinion as well as in that of some references, a transgressive setting is particularly welcome (see, for instance, Colalongo *et al.*, 1978): it would be marked by angular unconformity, in areas (like ours) of very late Messinian tectonics, or by simple disconformity elsewhere (as perhaps in the Monticino Quarry).

If we consider the «black layer» as part of the Colombacci cyclotheme, by analogy with the E Romagna stratigraphic record, it would mark (where preserved) the transgressive beginning of the modal cycle, whereas the required conditions of continental water input were probably achieved by means of climatic control.

As consequence, the last Colombacci cycle (corresponding to the unique «black layer» we see here) would result incomplete: it would have been interrupted close to its own base, because of the sudden «over-regional» (Cremonini & Ricci Lucchi, 1982) Pliocene transgression.

According to this view, an explanation for our second filling phase would be a more or less rapid «drowning» of the karsts under marshy transgressive deposits.

ACKNOWLEDGEMENTS

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Recent land vertebrate discoveries in the surroundings of Faenza (Romagna Apennines): description of stops

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In the country around Faenza, the chronology of continental vertebrate fossil findings is extremely recent.

1984 Olmatello di Faenza (Algery – Italy gas pipeline trench)
A proximal portion of elephant tusk (Vai, 1984; Giusberti & Peretto, 1987), and a fragment of deer mandible (Giusberti, pers. com.) were found in middle Pleistocene strata.

1985 Brisighella (Monticino Quarry)
Discovery of a rich Messinian fauna in karst holes of the «Gessi di Brisighella» – Vena del Gesso romagnola (Costa *et al.*, 1986).

1986 Oriolo di Faenza («Salita» Quarry)
A *Crocuta* sp. tooth and a deer (?) rib were collected in the middle Pleistocene «Sabbie gialle».

1987 Discovery of a *Mammuthus* sp. skull and an occipital portion from a bison skull (Marabini *et al.*, 1987).

At least the Brisighella and Oriolo situations can provide us opportunities to check the geological-stratigraphical contexts of the various findings, unless the very short time lapses since their respective discovery dates.

These schematic notes are only intended to give a local framing to the proposed stops (Fig. 1). For further details, other works in this volume are referred to, as well as all of the illustrations and photos.

Stop 1 — Oriolo di Faenza, 105 m a.s.l.

The «Salita» Quarry is digging the hill right W of Oriolo (a small village, dominated by the XIV-XV century Torre del Castello). The exploited sands belong to the stratigraphic unit «Sabbie gialle», resting on the Pliocene-Pleistocene Argille Azzurre. Both of the most significant specimens, actually undergoing restoration (*Mammuthus* sp., from the eatern border of the quarry front, and a bison, from the western one), were collected not far from the topographic surface, although well within the sands.

Digging around the elephant skull, evidence was found about storm episodes, that repeatedly influenced the inhumation of remnants.

These «catastrophic» high-energy events are marked by thin layers of stranded shells and imbricated pebbles.

Stratigraphical-sedimentological observations are in favour of the «Sabbie gialle» being locally deposited near a river mouth in a shore environment, sheltered by sand barriers: here over-bank sedimentation was occasionally allowed (more clayey, discontinuous and partly disturbed layers, rich in

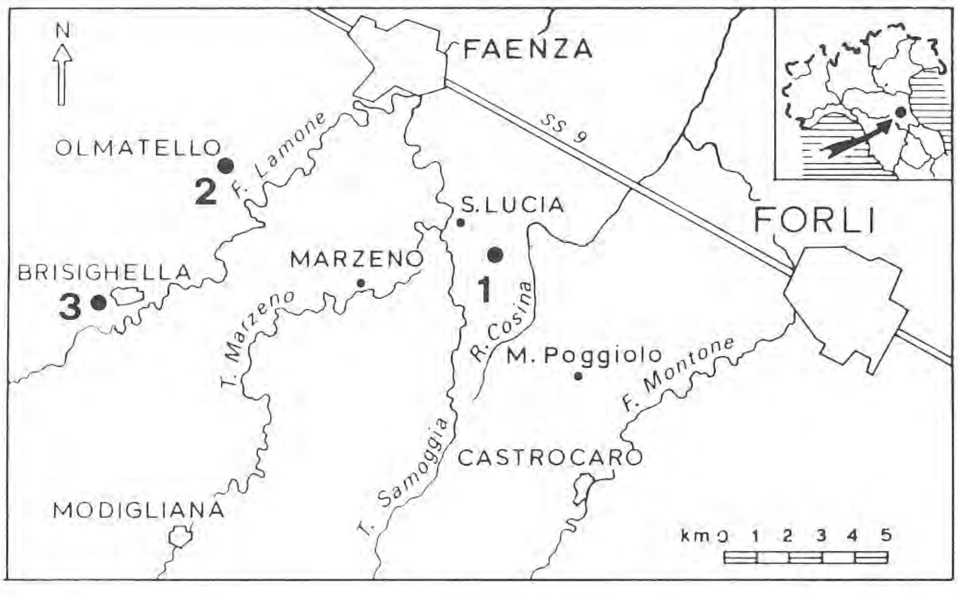

Fig. 1 – Excursion stops: 1 - «Salita» Quarry, 2- Olmatello, 3 - Monticino Quarry.

plant debris and leaves, occur in several parts of the quarry) (Marabini *et al.*, 1987).

Stop 2 — Olmatello di Faenza, 190 m a.s.l.

Since the end of the works on the Algery-Italy gas pipeline, the site where the afore-mentioned remants were found is not visible.

The Olmatello Fm. lies angularly unconformable on the Plio-Pleistocene Argille Azzurre. A fine-grained alluvial plain sequence, resting on coarse fluvial gravels, was exposed by the 1984 trench.

A volcanic ash layer (tephra) was recognized near the top of this succession: actually, it is undergoing radiometric age determination.

A few tens of meters SW of the finding site, a steep, hardly accessible wall probably displays the same stratigraphic succession as it was observable in the trench. At present, the Olmatello Fm. is considered as overlying the «Sabbie gialle» Vai (this vol.).

Stop 3 — Monticino di Brisighella, 215 m a.s.l.

A gypsum quarry is situated on the third hill near Brisighella, not far from the Monticino Sanctuary. Here, in 1985, the presence of some sub-vertical, tectonically-reactivated karstic holes was recognized for the first time, their clastic fill being clays, brown-blackish marls, grey and olive-green clays, pebbles and subordinate thin fine-grit layers.

In most of the holes (Figs. 2 and 3), a number of bones, many of them fragmentary, some in anatomic connection, were collected along with hundreds of teeth from macro- and micromammals. Mining works repeatedly discovered and subsequently destroyed many of the holes; at the present state of the works, significant karstic structures are not visible. On the other hand, it is easy to see the contact Messinian «Gessi» – Colombacci Fm. (Messinian, corrispondent to the described fills) – Pliocene Argille Azzurre.

In the quarry area several sections of more recent karsts do exist, their various ages of fitting being not easily determinable.

Worth noting: near the adit to the lower square of the quarry, on the contact Marnoso-Arenacea Fm./ Gessoso-solfifera. Fm., an interesting pseudo-diapiric structure is responsible for a local, strong deformation in the gypsum beds attitude (Marabini & Vai, this vol).

Fig. 2 – «Plioviverrops Hole» (site 5).

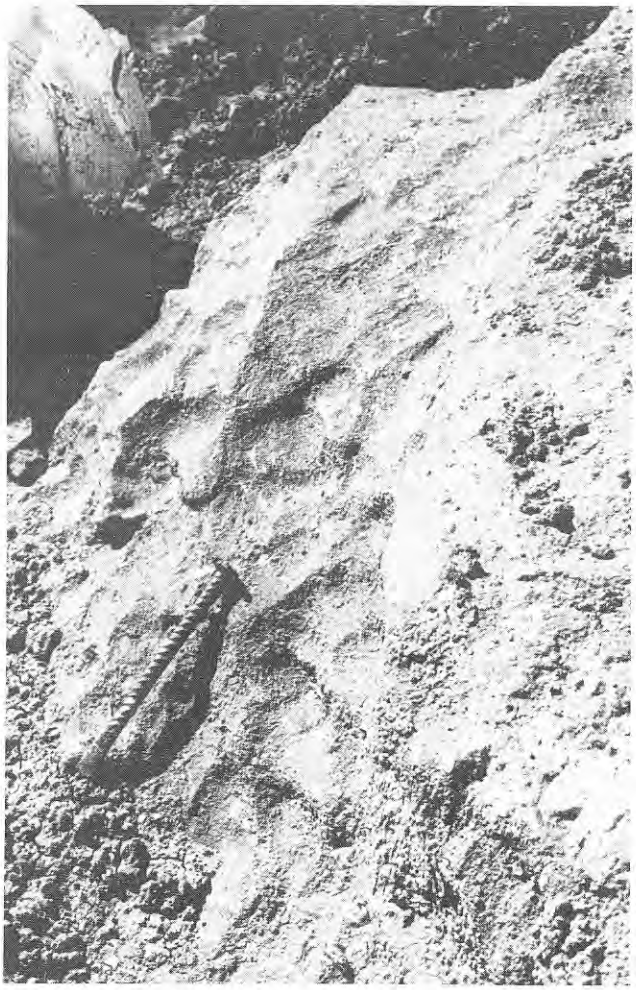

Fig. 3 – Karstic erosions in the area of «Plioviverrops Hole» (site 5).

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