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LATE MIOCENE PALEOGEOGRAPHY OF THE MONTE SOLDANO AREA, SOUTHEASTERN PART OF VOLTERRA BASIN, TUSCANY, ITALY

I.P. MARTINI(**), V. PASCUCCI (*) & F. SANDRELLI (*)

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Riassunto. Nell'area di M.te Soldano, settore sud-orientale del Bacino di Volterra (Toscana Meridionale), sono state riconosciute 5 facies sedimentarie principali aventi una età compresa tra il Tortoniano Superiore ed il Messiniano inferiore. Queste sono costituite da: a) conglomerati grossolani disorganizzati; b) conglomerati organizzati intercalati a sabbie; c) arenarie a grana da grossolana a media sia intercalate ai conglomerati organizzati che come livelli torbiditici intercalati alle argille lacustri; d) marne ricche di opercoli di *Bithynia*; e) argille lacustri con intercalati alcuni livelli di arenarie torbiditiche.

La distribuzione verticale e laterale di queste facies indica l'esistenza di un grosso complesso di conoide alluvionale. La presenza di un complesso così largo e relativamente vicino all'area sorgente (una dorsale intrabacinale), è possibile solo se i fiumi distributori sono posizionati nell'intersezione di due faglie bordiere o se sono associati ad una zona di trasferimento (transfer zone). La realizzazione di una di queste condizioni permette lo sviluppo di un ampio drenaggio e quindi, delle condizioni necessarie per la formazione di una conoide alluvionale di notevoli dimensioni.

Abstract. Several Upper Tortonian to Lower Messinian sedimentary facies were recognized and mapped in the M.te Soldano area at the southeastern end of the extensional Basin of Volterra in the Northern Apennines in Tuscany. They consist of (a) disorganized coarse conglomerates, (b) organized conglomerates interbedded with sandstone, (c) coarse to medium grained sandstone which is present both as interlayers within the organized conglomerates as well as turbidite layers interbedded with lacustrine clay, (d) marlstone rich in opercula of *Bithynia*, and (e) lacustrine clay with few sandy turbidite interlayers. The vertical and lateral distribution of these facies indicates the existence of a large alluvial fan complex. The development of such a large complex from an apparently relatively narrow sediment source area (an interbasin ridge) was possible because the feeding rivers were probably located at the intersection between a border fault and a fault associated with a transfer zone. This allowed for a much wider drainage basin.

Introduction.

The Volterra Basin is one of the large extensional, NW-SE elongated basins which formed in western Tuscany since Late Miocene (Fig. 1; Bossio et al., 1978,

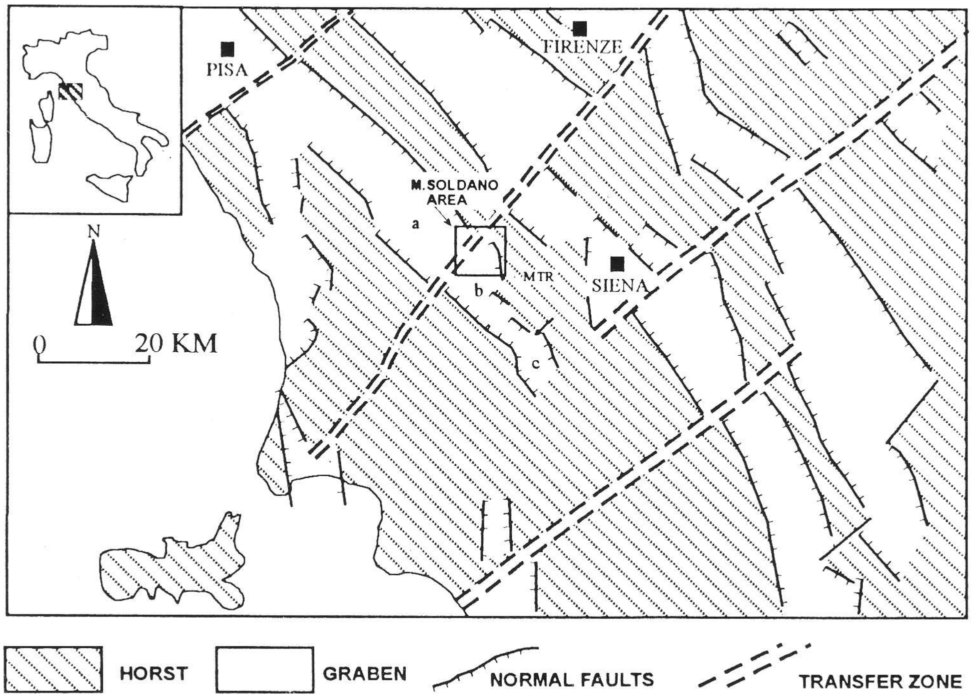

Fig. 1 - Extensional basins of the Northern Apennines, Italy. a) Volterra Basin; b) Radicondoli Basin; c) Chiusdino Basin. After Liotta (1991).

(*) Dipartimento di Scienze della Terra, Via delle Cerchia n° 3, 53100, Siena.
(**) Department of Land Resource Science, University of Guelph, Ontario, Canada.

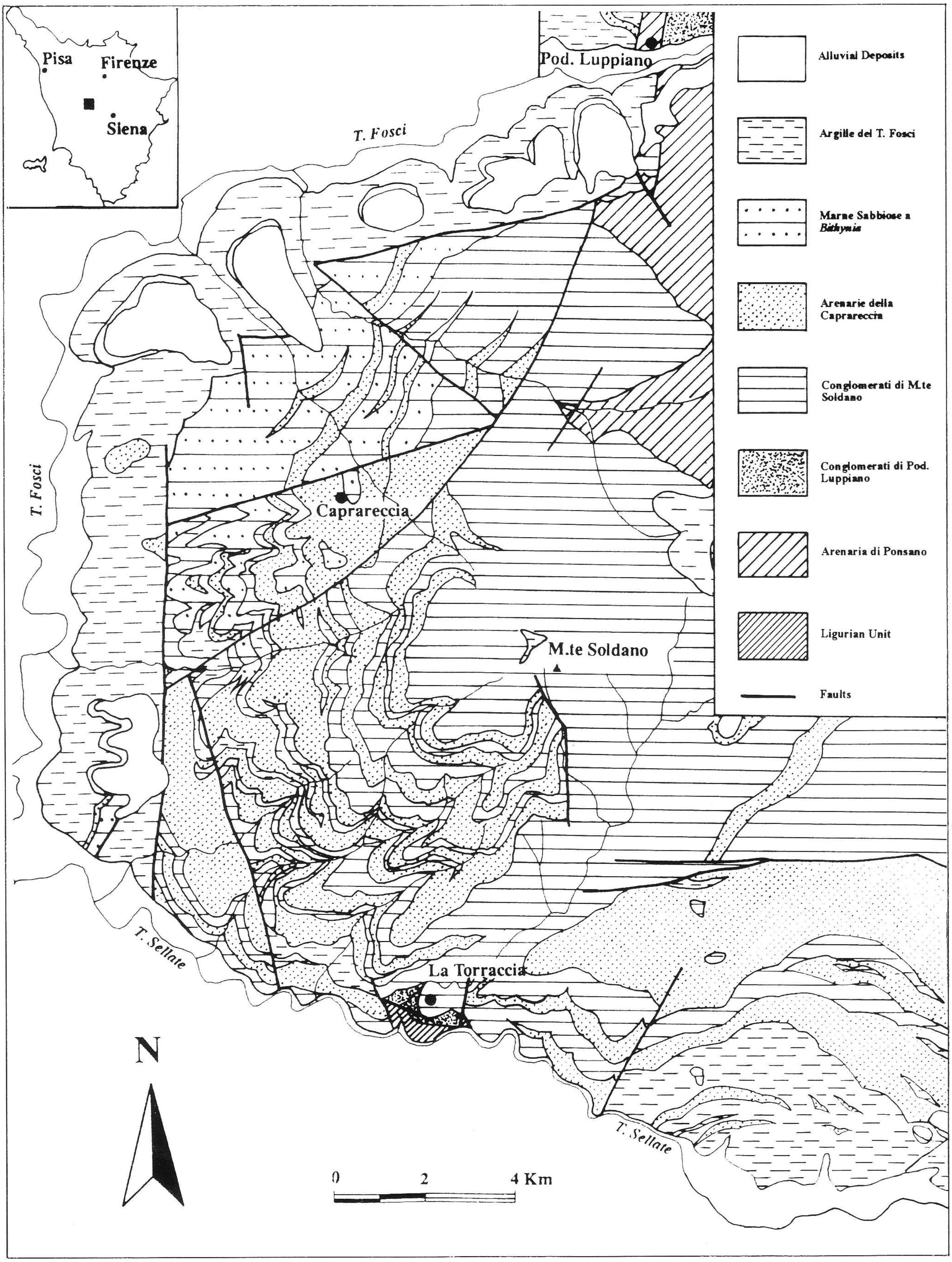

Fig. 2 - Geological map of the western flank of M.te Soldano. Argille del T. Fosci represent the clay facies; Marne sabbiose a *Bithynia* represent the marlstone facies; Arenarie della Caprareccia represent the sandstone facies; Conglomerati di M.te Soldano represent the organized conglomerates; Conglomerati di Pod. Luppiano represent the poorly organized conglomerates. The Arenaria di Ponsano and the Ligurian Unit are considered bedrock. After Pascucci (1994).

1992, 1993; Martini & Sagri, 1993; Elter & Sandrelli, 1994). These basins are separated laterally by bedrock ridges composed mainly of carbonates and sandstones. One bedrock unit, the Ligurian Unit, is composed of a varieties of lithologies (shale, carbonate, sandstone, ophiolite and chert) (Giannini, 1962; Squarci & Taffi, 1963). It is readily erodible and has provided much of the material transported into the basins. The Volterra Basin contains about 2500 m of sediments (upper Tortonian to Pleistocene), and it extends in width up to 15 km. Lengthwise this basin is subdivided into several subbasins by transversal morphological and structural highs (Bartolini et al., 1983; Liotta, 1991 has interpreted this transversal structures as transfer zones). The M.te Soldano area is located on one of these zones. It separates the main Volterra Basin from the southeastern basin of Radicondoli-Chiusdino which was implanted along the same structural depression (Fig. 1). The objective of this paper is to reconstruct the paleogeography which developed during the Late Tortonian and Early Messinian on the Volterra Basin's side of what is now M.te Soldano.

Sedimentary facies.

Five principal facies have been recognized and mapped (Fig. 2). Their diagnostic features are as follows.

1. "Poorly organized conglomerate". This facies is characterized by thickly bedded, amalgamated, coarse (clasts up to 50 cm in diameter and average size of approximately 20 cm), poorly organized conglomerates with a matrix of poorly sorted coarse sand, granules and small pebbles (Fig. 3). The composition of the clasts indicates that they derive from the Ligurian Unit, with a predominance of limestone. The clast shape varies from subangular (chert) to subrounded (limestone) and subspherical (ophiolite). No preferred orientation or imbrication is recognizable. This facies is best developed south of locality La Torraccia (Fig. 2). It lies on bedrock and constitutes the lowermost unit of the stratigraphic succession. The unit is about 50 m thick.

This facies can be interpreted primarily as a debris flow deposit. Some layers, however, may have been formed by material transported by hyperconcentrated, strong floods.

2. "Organized conglomerate". This facies is characterized by predominantly organized, clast-supported conglomerates with few sandy interlayers which increase in number, thickness and continuity toward the top of the succession (Fig. 4 A and B). The conglomerates are composed of clasts up to 20 cm in size with average of about 10 cm. The clasts are moderately well rounded, the larger ones being also subspherical. This makes development and recognition of the imbrication difficult. Most clasts lie sub-parallel to the local depositional surface (for instance, flanks and bottom of scours), and true imbrication is seldom achieved except where pebble clusters form. The conglomerates occur (Fig. 4b) in thick amalgamated beds which internally show cuts and fills, remnants of longitudinal bars (not foresetted, coarse grained layers without cut and fill structures) and occasional transversal bars (foresetted units not specifically associated with cuts and fills) (Fig. 4a). Thin lenticular eroded remnants of coarse, poorly sorted sand are present. A few layers of poorly organized conglomerate are present as well, particularly in the lower part of the exposed succession. The structures within the amalgamated beds, have thicknesses of the order of 50 to 150 cm. Paleocurrent measurements from direction of paleochan-

Fig. 3 - Poorly organized conglomerates.

Fig. 4a - Organized conglomerates: trough (1m thick) and planar cross-beds.

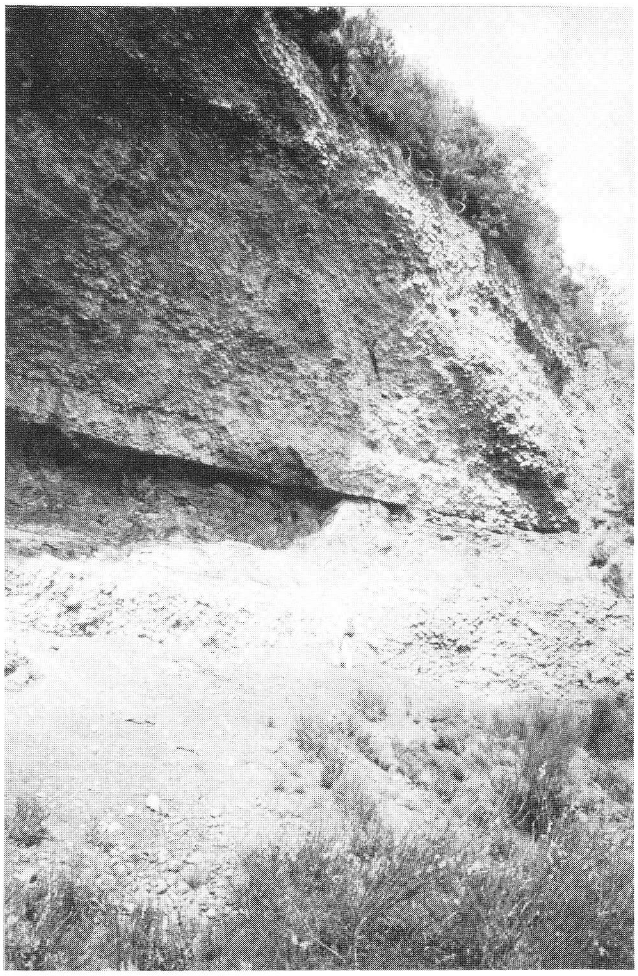

Fig. 4b - Organized conglomerates: thick amalgamated conglomerate beds and sand interlayers.

nels and clast imbrication indicate a paleoflow primarily to the southwestern quadrant and in a few places to the northwest. This facies is best developed north of La Torraccia (Fig. 2). It overlies poorly organized conglomerates, and it is interbedded with the "sandstone facies" in the upper part of the succession.

This facies records a high power fluid flow, variable in discharge and sediment load. It is a typical braided stream deposit (Scott type; Miall, 1977). Locally it experienced debris flows (or hyperconcentrated floods) as indicated by the few poorly organized conglomerate interlayers. Units with this facies have thicknesses up to 150 m.

3. "Sandstone". The sandstone facies can be subdivided into the following two subfacies.

a) Sandstone-A. This facies is characterized by coarse to medium grained, poorly sorted, yellowish brown, well cemented (calcareous cement), lithic sandstone, locally containing granules and sparse small pebbles. It occurs in medium-thick beds, seldom showing trough cross-beds, but generally plane bedded to massive. Paleocurrent data from pebble orientation indicate a southwestern direction. This facies is best developed in the proximity of Caprareccia and T. Sellate (Fig. 2). It occurs interlayered with the organized conglomerates (Fig. 5).

b) Sandstone-B. This sandstone is similar to that of sandstone-A facies, except that it is finer grained (fine to medium sand), it occurs in thin to medium-thick beds and it is interstratified with the marlstone facies (Fig. 6).

The sandstone facies is interpreted as fluvial deposits formed in two different settings. Sandstone-A was for the most part deposited by poorly or shallowly channelized overland flows in a braided system. Sandstone-B was deposited by floods entering and spreading out as hyperconcentrated flows into shallow lacustrine environments.

4. "Marlstone". This facies is characterized by an irregular interbedding of three lithologies (Fig. 6, 7).

a) Gray silty clay with variable amount of sand content and, in places, disseminated granules and small pebbles.

b) Sand, fine grained with sparse granules, gray to yellowish brown, plane laminated, thin to thick bedded.

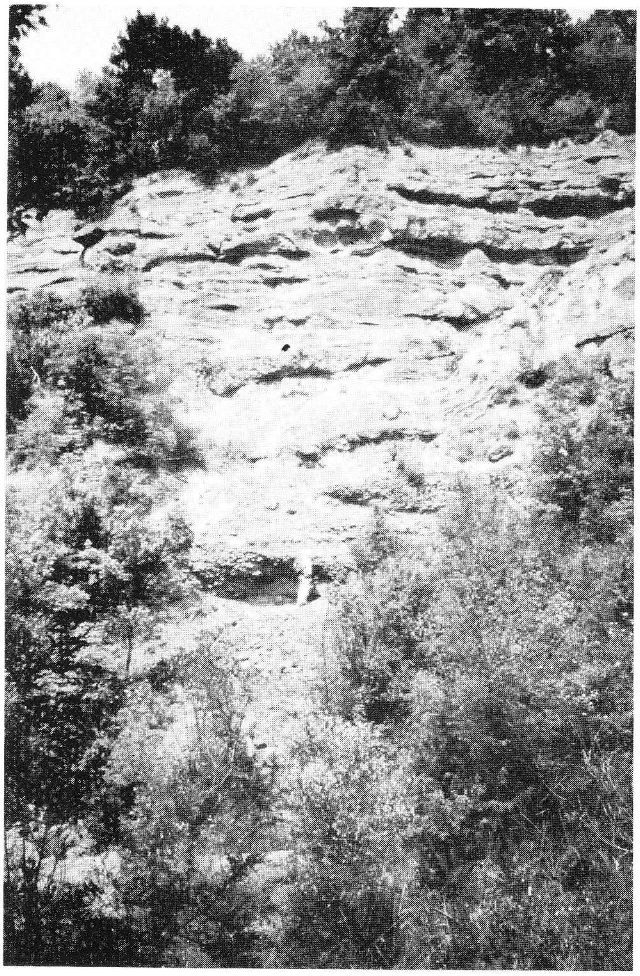

Fig. 5 - Sandstone-A: sandstone interlayered with organized conglomerates.

Fig. 6 - Sandstone-B interstratified with marlstone facies.

It contains reworked *Bithynia* opercula (caps of the gasteropod's opening, the body of the gasteropod is never found because it does not fossilize).

c) Calcareous shale (marlstone) to argillaceous limestone. The marlstone occurs in platy beds very rich in *Bithynia* opercula, the limestone in thin beds.

This facies is interpreted as a shallow, relatively low energy setting receiving clastic materials from floods.

5. "Clay". This facies is composed of gray clay, massive, with occasional reworked plant material. Local interlayers of sandstone (Fig. 8) and rare granule conglomerates are present. The clay is sparsely fossiliferous with *Limnocardium*, *Melanopsis*, oogons of *Characeae*, *Ostracoda* and rare *Bithynia* opercula (Bossio et al., 1992; Bossio et al., 1994). The sandstone interlayers are fine to medium grained, plane laminated, graded with mud pebbles toward the base. They occur in medium-thick bedded which show sharp base and gradational upper contact (Fig. 8). The paleocurrent directions obtained from clast orientation is to the northwest. This material was most likely deposited in a relatively deep lake which experienced recurring sandy turbid flows or turbidites.

Paleogeographic reconstruction.

The vertical and lateral distribution of the sedimentary facies indicates a progressive change of the materials from coarse, poorly organized conglomerates at the contact with the bedrock, to finer, organized conglomerates which become interbedded with the sand facies upward and toward the west (Fig. 2). Farther to the west still, the sand is interlayered with the marlstone facies with *Bithynia*, and finally it occurs as graded beds within fine lacustrine clay. All this shows the development of a large alluvial fan merging into a lake (Fig. 9). Several parts of the fan are well defined.

a. The proximal channelized area with abundant debris flows is represented by the poorly organized conglomerate facies.

b. The mid-fan braided zone is characterized by the organized conglomerate facies as channel fills and by the sandstone-A facies, that is a deposit of overland sheet flows.

c. The shallow lacustrine environment is represented by the marlstone facies which received stream

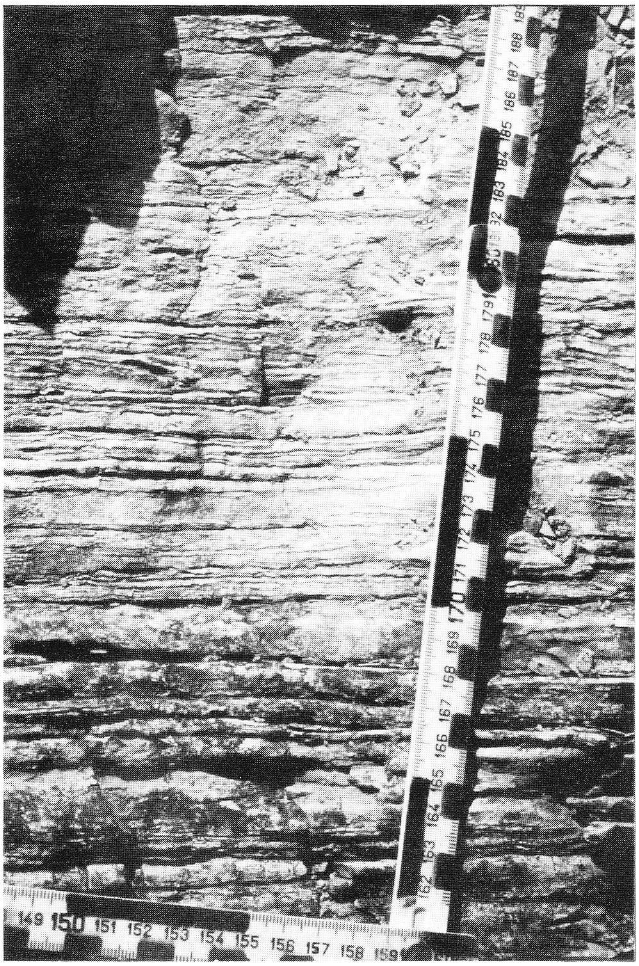

Fig. 7 - Calcareous shale (marlstone).

floods responsible for the formation of the sandstone-B facies interlayers.

d. The deep lacustrine setting is recorded by the clay facies with turbidite interbeds.

Discussion.

The distribution of sedimentary facies in the M.te Soldano area indicates the existence of a large alluvial fan which merges into a relatively deep lake during the early stages of formation of the Volterra Basin. Both the inland and the lacustrine parts of such a system are well developed and preserved. The coastal transitional parts, instead, are less well defined. Indeed there seems to be a rapid transition between the land braided part of the fan to the shallow fossiliferous areas of the lake. There is no evidence of well developed deltas or sandy shorefaces. This suggests that the rate of progradation of the fan was relatively rapid and/or that the lake had low wave energy, not sufficient to rework the river-derived sediments. Furthermore, the absence of clearly identifiable deltaic bodies indicates that the fluvio-lacustrine deposits had multiple (multichannel) sources and were redistributed into the lake through submerging turbid hyperpycnal flows.

The relatively large (about 10 km wide), thick (350 m) fan system of M.te Soldano developed in a relatively small (15 km wide) basin, deriving the sediments from the emerging Middle Tuscany Ride (Bossio et al., in press). Such a ridge had, and still has, a relatively limited areal extension. This suggests that the rivers responsible for the construction of this fan were implanted at the junction of two faults intersecting at high angle. This would allow for a wider catchment area hence for the production of a sufficiently large amount of sediments. Similar conditions have been reported from the Valley and Ridge area of the western United States (Leeder & Gawthorpe, 1987; Leeder at al., 1988) and in African rifts (Crossley, 1984; Rinet et al., 1988; Smale et al., 1988).

Fig. 8 - Sandy turbidite interlayer in the clay facies.

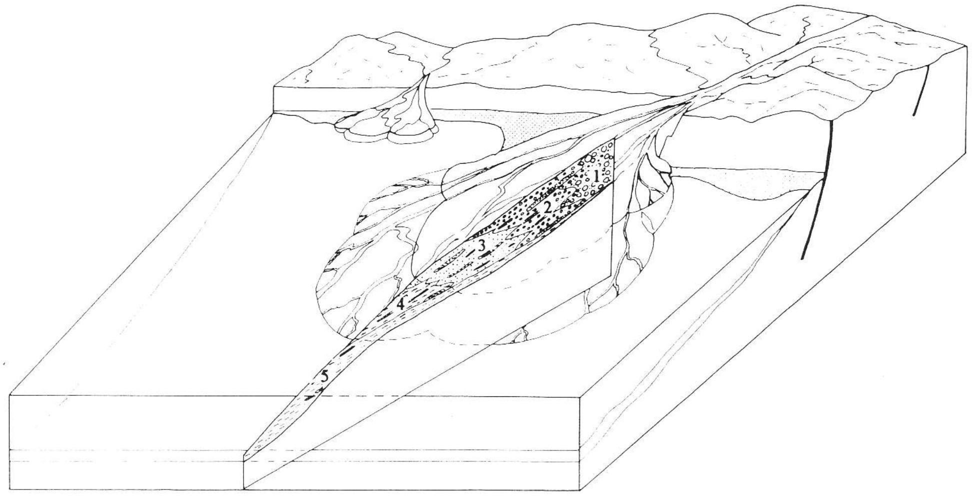

Fig. 9 - Model of the alluvial fan complex of M.te Soldano. 1) Poorly organized conglomerate facies; 2) organized conglomerates facies; 3) sandstone-A facies; 4) marlstone facies with sandstone-B facies associated; 5) clay facies. Dotted area stands for the hypothetical shore.

Conclusions.

1. Sedimentological observations and mapping of various facies have demonstrated the presence of a large Upper Tortonian to Lower Messinian alluvial fan complex in the M.te Soldano area in the southeastern part of the Volterra Basin.

2. Such a complex is characterized by: a) a subaerial alluvial fan which is comprised of a channelized proximal facies of poorly organized conglomerates mostly formed by debris flows and/or hypoconcentrated strong floods, and a gravelly braided mid-fan system which grades into a progressively sandy lower fan; b) a subaqueous fluvio-lacustrine system characterized by (i) a relatively shallow area with sand, clay and calcareous clay to argillaceous limestone with *Bithynia*, and (ii) a deeper lacustrine setting characterized by clay with interstratified graded turbidite sandstone layers, probably formed by fluvial derived hyperpycnal flows.

3. Such a large alluvial fan complex indicates the relatively rapid evolution of the receiving basin and of an emerging Middle Tuscany Ridge to the north. Furthermore, the large amount of sediment for the alluvial fan complex may have been provided by rivers implanted at the intersection of faults parallel to the Mid Tuscany Ridge and to a transfer zone perpendicular to it.

4. Rather than the exception, alluvial fan like those of M.te Soldano located in similar structural settings, may be common and form significant portion of the filling of other extensional basins of Tuscany.

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