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THE EARLY DEPOSITIONAL PHASES OF THE NORTHERN APENNINE FOREDEEP-THRUST BELT SYSTEM: IMPLICATIONS FROM THE “MACIGNO COSTIERO” (LATE OLIGOCENE, ITALY)

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ABSTRACT

The late Chattian “Macigno costiero” represents the innermost and the oldest portion of the well developed siliciclastic wedge of the migrating Oligo-Miocene foredeep-thrust-belt system of the Northern Apennine. Its stratigraphic features help to understand the early phases of the sin-collisional sedimentation and the evolution of such a thrust belt. In the turbiditic siliciclastic sequence, carbonates were found at different stratigraphic levels (chaotic-debris flow key-level, calcareous turbidites and Subligurian olistostromes and olistoliths). Stratigraphical studies of the sequence based on facies analysis, petrographical observations and biostratigraphical analysis of calcareous nannofossils allow to suggest some hypotheses of the palaeogeographic setting and the evolution of the foredeep-thrust belt system. The vertical distribution of the sediments and their sedimentological characters show a low efficiency sand-rich turbidite system (*sensu* Mutti and Normark, 1987), characterised by a prograding fan terminated by the emplacement of slices of the orogenic wedge. Olistostromes and olistoliths found in the turbidite succession were the precursor of the allochthonous nappe. The proposed hypothesis shows that turbidite sediments were probably fed transversally to the basin, from a shallow marine shelf adjacent to a crystalline basement. The “Macigno costiero” was deposited in an internal position of the foredeep system.

INTRODUCTION

The depositional system of the Northern Apennine foredeep is a good example of a turbidite basin-fill formed during the syn-postcollisional phases of orogens. The large foredeep turbidite systems of the Northern Apennine developed diachronically in foredeep basins. These basins were bounded to the hinterland by minor basins: piggy-back, satellite and thrust-top basins (Ricci Lucchi, 1986 *cum. bibl.*). The foredeep deposition started in the Oligocene and ended in the Miocene-Pliocene, with the gradual shifting of the basinal depocenter towards the foreland (Ricci Lucchi, 1986). The innermost and earliest turbiditic units of the Apennine foredeep are related to the Macigno Fm., which laterally-vertically displays a transition to the “Arenarie del M. Cervarola-Arenarie del M. Falterona” (Bortolotti et al., 1970; Ricci Lucchi, 1986), both belonging to the Tuscan paleogeographic Domain. The latter passes to the Marnoso-arenacea Fm. (Umbro-Marchean paleogeographic Domain), which in turn grades to the external and youngest “molasse” sequences (Ricci Lucchi, 1986).

The external turbiditic deposits of the Northern Apennine foredeep, cropping out on the east side of the belt, are well exposed along the chain. On the contrary, the internal turbiditic deposits are poorly known, due to the dissection during the Neogene extensional tectonics.

The westernmost Macigno units (“Macigno costiero”), exposed along the Tuscan coast, from La Spezia to Grosseto (Fig. 1), have peculiar features respect to the “Macigno s.s.” of the main Apennine belt. The study of the “Macigno costiero”, which probably represents the innermost part of the exposed foredeep system, could be useful to understand the early phases of foredeep sedimentation during Late Oligocene.

Some authors interpreted the “Macigno costiero” to be deposited in the innermost part of a wide foredeep basin (Sestini, 1970; Costa et al., 1992), others in a partially separated inner basin (Ferrini et al., 1985; Fazzuoli et al., 1985; Gandolfi and Paganelli, 1992), or in a piggy-back basin (Boccaletti et al., 1990). The “Macigno costiero” has been referred to different ages. It was firstly assigned by Tavani (1954) to a generic Oligocene on the basis of a pelecypod fauna; it was later assigned to the Late Oligocene by Dallan Nardi (1968), and to the Middle-Late Oligocene by Gasperi (1966; 1968) on the basis of foraminifers. Afterwards, Montanari and Rossi (1983), on the basis of *Lepidocyclina* con-

Fig. 1 - Upper Oligocene-Lower Miocene foredeep system turbidites of the Northern Apennines. In square the studied outcrop of Baratti-Piombino.

tent, ascribed this succession to the late Rupelian (Early Oligocene). Differently, Costa et al. (1997) suggested a time interval comprised between the Late Oligocene and the Early Miocene using nannofossils analysis.

The aims of this paper are: a) to describe the main features of the "Macigno costiero" of the well exposed sections of the Baratti-Piombino area; b) to establish the probable provenance of these sediments and their depositional mode; c) to suggest a time-space evolution of this turbidite system and its role in the foredeep-thrust belt system.

GEOLOGICAL OUTLINE OF THE NORTHERN APENNINE

The tectonic-stratigraphical units forming the Northern Apennine chain-belt are piled into a complex tectonic stack, as consequence of the convergence and collision between the European Plate and the Adria Microplate, with the development, in the collisional phases, of foredeep basins (see models of Reutter, 1968; Reutter and Groscurth, 1978; Kligfield, 1979; Boccaletti et al., 1981; 1990; Ricci Lucchi, 1986; 1990; Ciarapica and Passeri, 1994). Extensional tectonics started to affect the inner part of the Northern Apennine, such as Southern Tuscany, from the Early-Middle Miocene up to Quaternary (Fig. 2), accompanied by magmatism (Bertini et al., 1991; Decandia et al., 1994; Carmignani et al., 1995).

The orogenic east-verging stack consists of tectonic units belonging to different domains and piled up with the western onto the eastern ones (Boccaletti et al., 1981, *cum. bibl.*). From the top downwards the units are the following: a) Ligurian Units, which belong to the oceanic Ligurian Domain (Ligurian-Piedmont Basin) characterised by Jurassic ophiolites, Jurassic-Cretaceous pelagic sedimentary covers and Cretaceous-Eocene flysch; b) Subligurian Units, which belong to the Subligurian Domain (with transitional oceanic-continental crust characters), mainly represented by calcareous-shaly sequences (Paleocene-Eocene); c) Tuscan Units characterised by continental crust. These last units belong to the continental margin of the Adria Microplate. The Tuscan Nappe is the most widespread Tuscan Unit; it is characterised at the bottom by Upper Triassic evaporites, followed by Lower Jurassic-Early Cretaceous carbonates, Cretaceous-Oligocene shaly-carbonate sequence ("Scaglia toscana") and is topped by Upper Oligocene Macigno turbidite succession; d) units of the Umbro-Marchean Domain, characterised by continental crust showing Mesozoic sedimentary successions quite similar to those of the Tuscan Domain.

GEOLOGICAL SETTING OF THE MACIGNO COSTIERO

The "Macigno costiero" crops out along the Tuscany coast, from La Spezia to Grosseto (Fig. 1).

In Southern Tuscany, the relationships between "Macigno costiero" and Macigno s.s. are not well constrained due to the scattering of the outcrops. Whereas the base of the Macigno is represented by the "Scaglia toscana" Fm., but the "Macigno costiero" of Southern Tuscany, cropping out near Livorno (Calafuria Sandstones), at Baratti-Piombino and Punta Ala, is everywhere detached or not exposed. Some authors also consider the outcrops of Sassetta (Giannini, 1955), Grosseto and Scansano (Gandolfi and Paganelli, 1992) quite similar to the "Macigno costiero".

The "Macigno costiero" of Southern Tuscany tectonically rests under the Canetolo Formation (belonging to the Subligurian Units), through sinsedimentary thrusts developed from the end of the Oligocene to the beginning of the Miocene (see also Costantini et al., 1993, *cum. bibl.*). In the past the "Macigno costiero" has been differently interpretated, because of its peculiar features, different from those of the Macigno of the Apennine belt. The general massive aspect of its deposits, led Tavani (1954) and Gasperi (1968) to interpret at least some facies, as deposited in a coastal environment, and therefore they attribute the whole succession to shallow marine environment. Recently Bracci et al. (1984), Ferrini et al., (1985) and Cornamusini and Costantini (1997) have undoubtedly proved the deep turbiditic environment of the "Macigno costiero".

In the studied area, the "Macigno costiero" mainly forms the Piombino Promontory and also crops out to north of the Baratti beach, from the Lo Scivolo-Poggio San Leonardo, to the Torre Nuova, where it is exposed in a gently east-dipping monocline (Fig. 3).

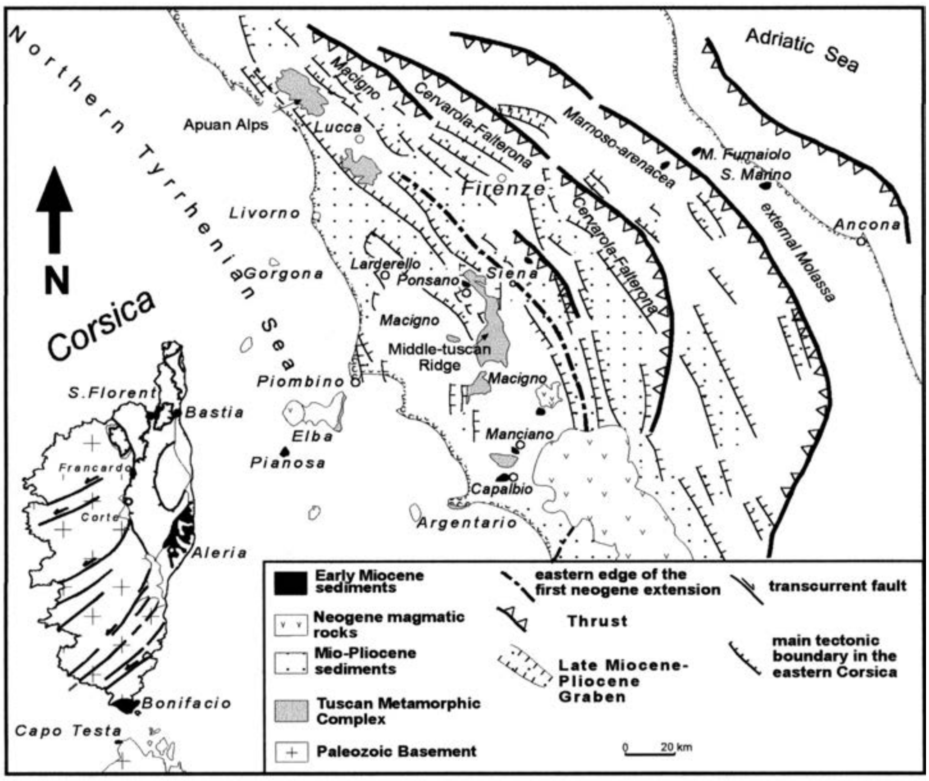

Fig. 2 - Geological sketch map of the Northern Apennines and Corsica (after Carmignani et al., 1995).

STRATIGRAPHY

The turbiditic succession

The succession of the "Macigno costiero" exposed in the Baratti area is about 470 m thick, but its stratigraphic base does not outcrop. It is tectonically overlain by Subligurian Units ("Argille e calcari" Nappe). This stack is dissected by few Neogene small normal faults with an approximate east-west orientation. The main normal fault is located in the Baratti Gulf (Fig. 3). In the field, three siliciclastic lithofacies (arenitic, arenitic-pelitic and pelitic) were distinguished and mapped within the "Macigno costiero".

The restored succession derives from the observation of five lateral correlated sections (locations in Fig. 3). It is mainly characterised by siliciclastic turbidites (Fig. 4) subdivided in hierarchical stages and substages (*sensu* Mutti and Normark, 1987), forming the turbidite system (Fig. 5). The facies recognised in the succession are classified through a genetic scheme (Table 1) (see also Cornamusini and Costantini, 1997 and Cornamusini, 1998a) following the principles of Mutti (1992). Five facies associations have been recognised and their depositional setting interpreted (Table 2) in the meaning of Mutti and Normark (1987). The vertical distribution of facies and facies associations, and their organisation and features, as shown in figure 5, allow to recognise at least five stages of deposition in the turbidite system (the lower portion of the system does not crop out). They are from bottom up (Fig. 5):

- Stage 1: characterised by facies association interpreted as channel-lobe transition environment (see in Mutti and Normark, 1987);
- Stage 2: about 60 meters thick, characterised by a thickening and coarsening upwards trend relative to a transition from fan/lobe fringe to channel-lobe transition;
- Stage 3: about 60 meters thick, characterised by a thickening and coarsening upwards trend relative to a transition from lobe/fan fringe to proximal lobe;
- Stage 4: about 160 meters thick, characterised by a thickening and coarsening upwards trend relative to a transition from lobe/fan fringe to channel-lobe transition;
- Stage 5: about 180 meters thick, characterised by facies associations referred to a major channel-levee complex with upwards increase of olistostromes coming from the adjacent slope-margin.

They are prograding lobe stages of growth in the lower-middle portion of the exposed succession (stages 2, 3 and 4) and proximal channel-levee stage (stage 5) in the upper portion up to the "Argille e calcari" Nappe.

Collected paleocurrent data (Fig. 5) show a strong dispersion of values in the NE and SE sectors (ranging between N20 and N150 with maximum concentration around N50-N115). Moreover, sedimentary facies are sometimes transformed downcurrent from section A towards section E and vice-versa.

The siliciclastic turbidite sediments have sporadically interlayered by thin bedded carbonate turbidites. These latter occur in several stratigraphic levels (Fig. 5), and are generally represented by single bed with maximum thickness of 50 cm. The lowest one, instead, is formed by a decimetre alternation of calcilutite/calcarenite turbidites and thin marly and marly calcareous intercalations.

The discovery of a chaotic layer, resulted a key level, made easier the lateral correlation of the sections. It is located in the middle-upper part of the succession (stage 4 of Fig. 5) and shows complex internal organisation (see below). Other slump and debris-hyperconcentrated flow beds are distributed in the whole succession. Generally they indicate sub-stages of sedimentation relative to tributary channel-levee complexes. In particular, few slump beds occur in the upper part of the succession (Fig. 6); they are inserted into the major channel stage (stage 5) and are relative to a proximal channel-levee environment (sometimes such slump beds show the transition from undeformed to slump-deformed up to incipient debris flow beds).

Limestone olistoliths of Ligurian-Subligurian origin, locally occur floating in the sandstone beds.

Thin black shale layers (max 10 cm thick) are locally interlayered with thin bedded turbidites, particularly in the upper portion of the succession (stage 5).

Every thin bedded turbidite, particularly in the lower-middle portion of the succession (stages 3 and 4) (relative to distal setting of the fan-lobe apparatus, facies association V) is characterised by a mudstone cap subdivided in two parts, the lower one, of grey-light brown colour, finely laminated with very little carbonate content, represents the finest unit of the turbidite, and the upper one, of grey-green colour,

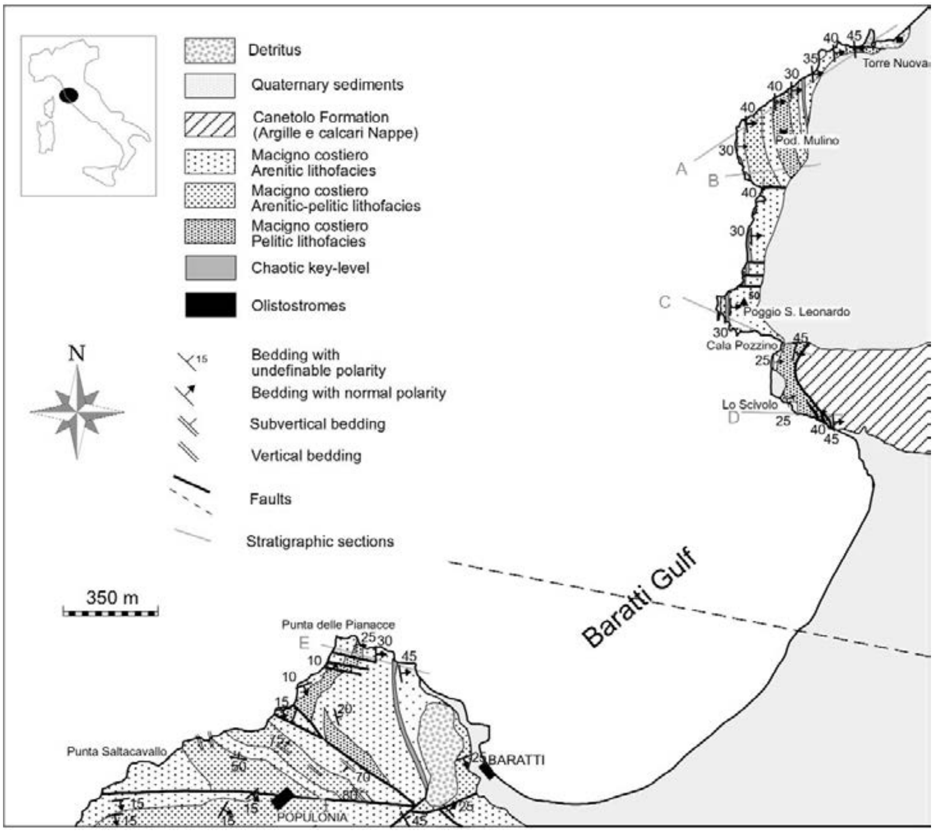

Fig. 3 - Geological map of the Baratti area.

Table 1 - Schematic description of the facies recognized in the Baratti sections of the “Macigno costiero” and of the corresponding types of flow

facies	types of flow
facies A *Slumps and slides*	Slumpings and slidings processes
facies B *Chaotic deposits*	Cohesive debris flows
facies C *Gravelly sandstones with muddy matrix*	Hyperconcentrated flows
facies D *Massive gravelly sandstones*	Very high density turbidity currents
facies E *Gravelly sandstones with traction carpets*	Very high density turbidity currents
facies F *Graded gravelly sandstones*	Very high density turbidity currents
facies G *Massive sandstones*	High density turbidity currents
facies H *Laminated and graded sandstones*	High-low density turbidity currents
facies I *Thin bedded turbidites*	Low density turbidity currents

Table 2 - Schematic description of the facies associations forming the “Macigno costiero” turbidite system of the Baratti section with the relative forming facies and the respective depositional setting

facies associations	facies	depositional setting
f.a. I - *Disorganized deposits and thin bedded turbidites*	mainly C, B, I, A and minor D, E, F	channel-levee complexes
f.a. II - *Coarse grained sandstones*	mainly D, E, F and minor G, H	channel-lobe transition
f.a. III - *Medium to coarse grained sandstones*	mainly G and minor D, E, H	proximal lobes
f.a. IV - *Medium to fine grained sandstones and pelites*	mainly G and minor H, I	intermediate-distal lobes
f.a. V - *Fine grained sandstones and thin bedded turbidites*	mainly I, H and minor G	lobe/fan fringe

without sedimentary structures and carbonate, referable to hemipelagic deposition, indicates a deep-sea environment (below the CCD) and a very slow terrigenous deposition.

Large Subligurian olistostromes and debris flow levels with interlayered conglomerate beds, are widely diffused in the upper portion of the succession (upper part of the stage 5), up to the boundary with the “Argille e calcari” Nappe. They represent the final depositional phases into a very proximal environment of the turbidite system close by the active thrusting.

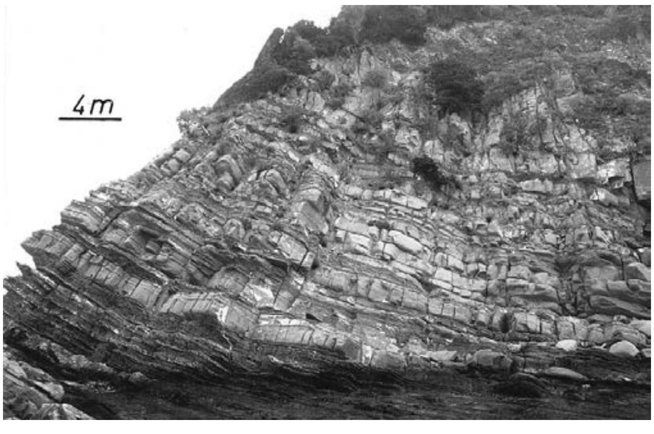

Fig. 4 - Portion of the turbidite succession of the “Macigno costiero” exposed on the coast of Poggio San Leonardo (left side of section C in Fig. 3). It represents the bottom of the Stage 4 of Fig. 5.

The chaotic debris flow key-level

A peculiar chaotic level is present in the succession. It has irregular thickness, from few centimetres to 5 meters. This level corresponds to the fossiliferous level described and dated to Middle-Late Oligocene by Gasperi (1968) and to late Rupelian by Montanari and Rossi (1983). It is composed of a microconglomerate at the bottom, overlain by a chaotic pebbly sandstone, grading upwards to a chaotic portion with slumps and slides (Fig. 7a).

The microconglomerate shows a crude normal grading with an even base and an upper transition to the chaotic pebbly sandstones, consisting of heterometric, rounded and subrounded carbonate clasts, floating into a muddy-sandy matrix. Clasts consist of dark grey fossiliferous limestones, calcarenites and macrofossils (fossils as Brachiopods, Bryozoa, Corals, Nummulites, Miliolids, Gastropods, Echinoids, Red algae, etc.). In this portion of the level, sedimentary structures are not developed, although in places a crude inverse grading is present. This portion grades upwards to a marly contorted levels through a reduction of the number of clasts and an increase of clay chips and marly-silty bed remnants. Deformed slumps, all embedded in a marly-silty matrix are also present. The upper boundary of the level can be flat or irregular. In this last case depressions are generally filled by laminated medium-coarse sandstones (Fig. 7b). Characters of the chaotic level are so typical to represent a key level. Its sedimentological features have been interpreted due to a cohesive debris flow. In particular it can be related to a single, complex, depositional event due to interaction of slides,

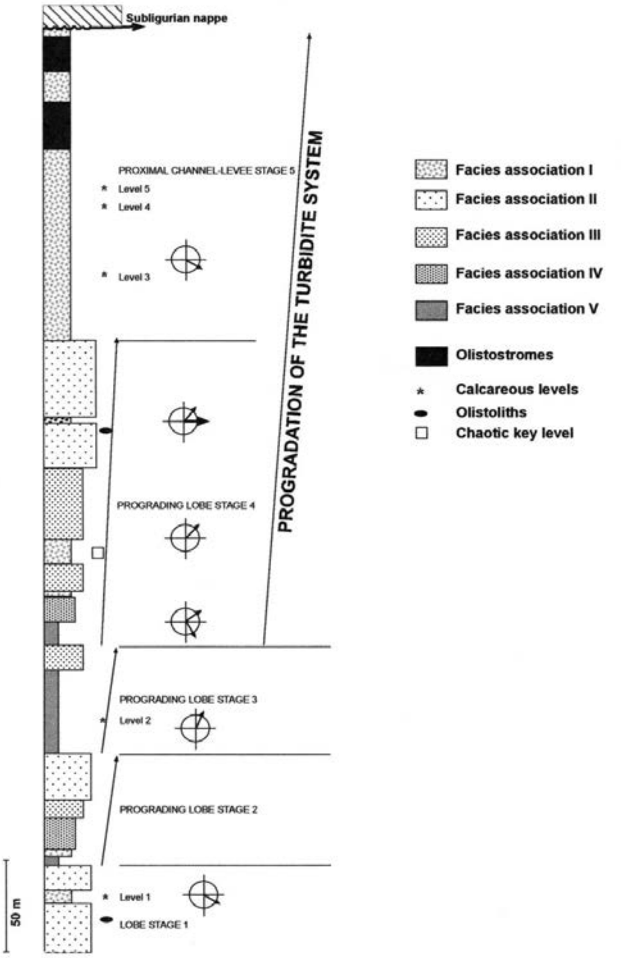

Fig. 5 - The Baratti succession: turbidite system, turbidite stages and facies associations. Paleocurrents are shown.

Fig. 6 - Slump within a thin bedded turbidite sequence. It is part of the Stage 5 of Fig. 5 and is shown near Torre Nuova (right side of section A of Fig. 3).

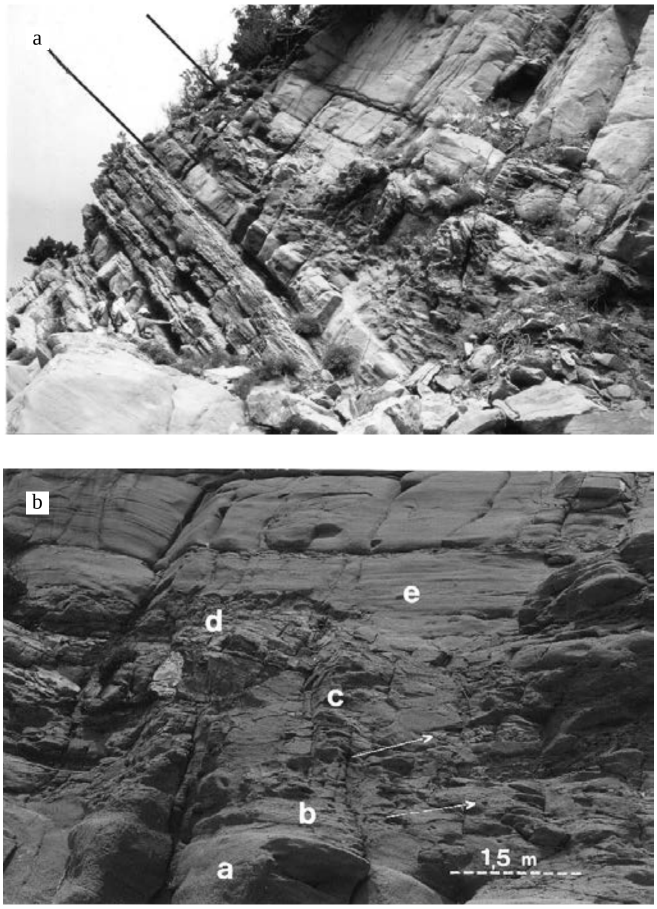

Fig. 7 - a- The chaotic debris flow key-level. Cala Pozzino (section C of Fig. 3), Stage 4, shown in Fig. 5.
b - Detail of figure 9a: “a”- microconglomerate basal part of the level; “b” - chaotic part rich in sandy-muddy matrix; “c”- highest part of the level with abundance of silty-marly slumping deformed beds; “d”- marls draping the top of the level; “e”- overlying turbidite deposits filling the irregular top surface; the lowest arrow shows a rounded clast of dark grey limestone; the highest arrow shows a slump-deformed marly remnant bed in the upper portion of the level.

slumps and cohesive debris flow. The lower portion of the chaotic level, represents a flow characterised by a very high density with the matrix strength as flow support, deposited following a high increase of cohesion up to freezing (Hampton, 1972; Enos, 1977; Lowe, 1982; Postma, 1986; Mutti, 1992). Differently, the upper portion of the level derives from slumping and sliding processes involving soft sediments, originally deposited on the slope and/or in a near structural high.

The silty-marly and calcareous lithotypes of the chaotic debris flow key-level have been sampled for biostratigraphical analysis of the nannofossils content. Samples from clay and silty-marly fragments contain nannofossil associations characterised by *Cyclicargolithus abisectus*, *Dictyococcites bisectus* and *Sphenolithus distentus,* which are indicative of the NP 24 Zone of Martini (1971) Standard Zonation relative to the early Chattian. Other silty-marls fragments contain *Cyclicargolithus abisectus* (<10 μm), *Dictyococcites bisectus*, *Sphenolithus ciperoensis*, *Sphenolithus conicus* and *Sphenolithus dissimilis*, which are referred to the MNP 25a (Fornaciari and Rio, 1996) and/or NP 25a (Aubry and Villa, 1997) subzone of late Chattian.

In the slump-deformed silty marls, generally located in the upper part of the level and in the top-draping mud, significative nannofossil association of *Cyclicargolithus abisectus*, *Dictyococcites bisectus*, *Sphenolithus conicus* and *Sphenolithus dissimilis* has been detected. This association is indicative of the MNP 25b and/or NP 25b subzones at the top of the late Chattian near the transition to the early Aquitanian.

The dark grey limestone clasts scattered in the lower part of the chaotic level, contain a poor nannofossils association characterised by *Dictyococcites bisectus*, *Reticulofenestra* sp., *Reticulofenestra umbilica*, *Zygrhablithus bijugatus*. The lacking of significative taxa can be related to a wide time-interval ranging from Late Eocene to Oligocene.

Stratigraphic features of the calcareous levels

The lowest calcareous level, labelled as 1, is located at 28 meters from the bottom of the succession (Fig. 5) and it is composed of four thin beds, which from the base up consist of: marls, calcilutites, green-brown shales, fine-grained graded calcarenites with ripple-cross lamination and plane-parallel lamination. Other limestone beds recurring in the succession have ripple-cross lamination and plane-parallel lamination.

This calcareous level contains a rich nannofossil association characterised by *Cyclicargolithus abisectus*, *Dictyococcites bisectus*, *Sphenolithus ciperoensis*, *Sphenolithus conicus*, *Sphenolithus dissimilis*, indicating the NP 25 biozone of the Martini (1971) Standard Zonation relative to the Late Oligocene, specified to the MNP 25a subzone of Fornaciari and Rio (1996) and to the NP 25a subzone of Aubry and Villa (1997).

Another calcareous level, labelled as 2 (Fig. 5), contains *Cyclicargolithus abisectus*, *Dictyococcites bisectus*, *Sphenolithus dissimilis*, *Sphenolithus ciperoensis*. This last species is very rare in this sample (low frequency), suggesting the MNP 25b subzone of Fornaciari and Rio (1996) or the NP 25b subzone of Aubry and Villa (1997). The same nannofossil association without *Sphenolithus ciperoensis* and with *Sphenolithus conicus*, has been found in a calcareous level located in the upper portion of the succession (level number 3, Fig. 5).

According to the biostratigraphic zonations of Fornaciari and Rio (1996) and of Aubry and Villa (1997), the lower part of the "Macigno costiero" of Baratti can be referred to the MNP 25a/NP 25a subzone relative to the late Chattian (Fig. 8), while the middle-upper part of the succession is referred to the MNP 25b/NP 25b subzone relative to the top of the Chattian or to Chattian-Aquitanian transition ("buffer zone" of Fornaciari and Rio, 1996).

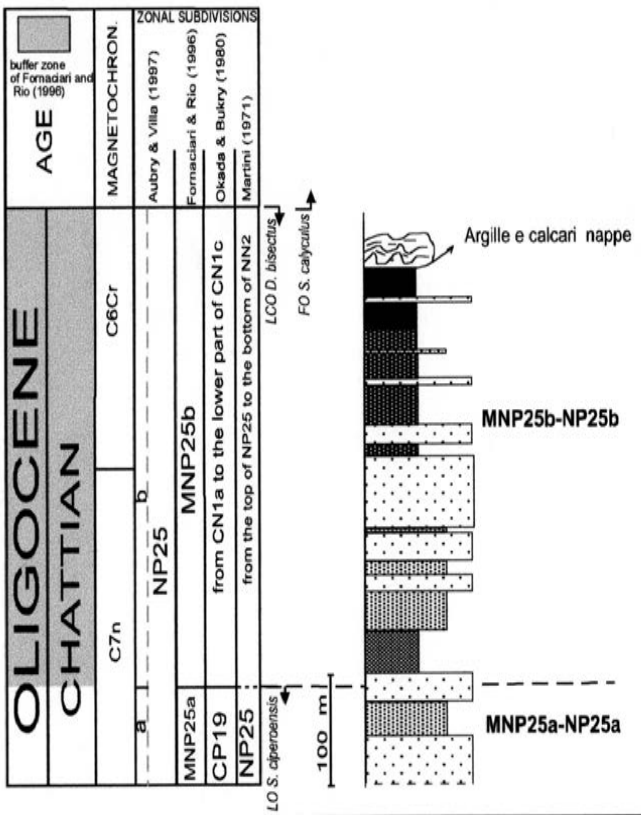

Fig. 8 - Bio-chronostratigraphic scheme of the Baratti succession.

Olistostromes and olistoliths

In the "Macigno costiero", exotic materials as olistostromes and olistoliths derived by the thrusting Subligurian Nappe are present, particularly in the upper portion of the succession (stage 5 of Fig. 5).

Olistostromes form lenticular levels interlayered into the siliciclastic succession. They are characterised by disorganised texture, generally formed by chaotic pelitic "matrix" including limestone bed-portions, without any flow features. The olistoliths are isolated blocks, of variable size, generally limestones, contained in the sandstones. These limestones derived from submarine landslides of portion of the Subligurian Units accreted to form the orogenic wedge.

The olistostromes differs from the chaotic debris flow deposits: a) composition: olistostrome clasts derive from allochthonous units, whereas debris flow clasts derive from autochthonous sedimentation; b) genesis: the formers are directly connected with the advancing and thrusting nappe, whereas the latters are relative to normal resedimentation processes. Olistostromes present in the upper part of the succession (stage 5) are alternated with chaotic debris flow and conglomerate lenticular bodies of the autochthonous sedimentation. They mark and predict the last depositional event of the "Macigno costiero" and the basin closure due to the Subligurian Nappe active thrusting.

Olistoliths (Fig. 9) occur in the succession and are represented by fine grained limestone or marly-limestone boulders floating in massive sandstone beds. The microfacies and the lithofacies of the olistoliths are similar to Subligurian limestones.

Marl samples from the olistostromes in the upper part of the succession, contain nannofossil associations formed by *Coccolithus eopelagicus*, *Dictyococcites bisectus*, *Dictyococcites scrippsae*, *Discoaster barbadiensis*, *Ericsonia formosa*, *Reticulofenestra hillae*, *Reticulofenestra umbilica*, *Sphenolithus radians* and *Zyghrablithus bijugatus*, which are assigned to the zonal interval NP 17-NP 19 relative to the Late Eocene.

Nannofossils recognised in the limestone olistoliths are represented by a generic association with *Coccolithus pelagicus*, *Cyclicargolithus abisectus*, *Dictyococcites bisectus*, *Sphenolithus moriformis*, with no markers *taxa*. They are indicative of a wide time-interval comprised between the zonal interval NP 17 and NP 25 (Late Eocene-Oligocene). The microfacies of these samples agree with the attribution of the olistostromes and olistoliths to the Canetolo Formation.

Petrography of the sandstones

The turbidite sandstones of the "Macigno costiero" succession have a homogeneous composition. The composition has been analysed with point-counting "Gazzi-Dickinson" method. Substantially grains are represented (in decreasing order) by monocrystalline quartz (undulate extinction), polycrystalline quartz, k-feldspar, plagioclase, lithic fragments, micas and bioclasts. The lithic fragments population is mainly composed of metamorphic grains (micaschists, gneisses, phyllites), plutonic grains (granites and granodiorites) (these last not included as lithic fragment in the detritic mode, see in

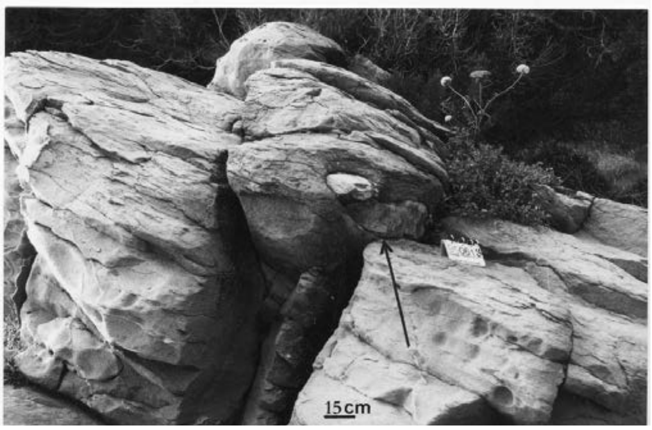

Fig. 9 - Limestone olistolith of Subligurian provenance into a sandstone bed. Cala Pozzino (right side of section C), in the Stage 4, emphasised in Fig. 5.

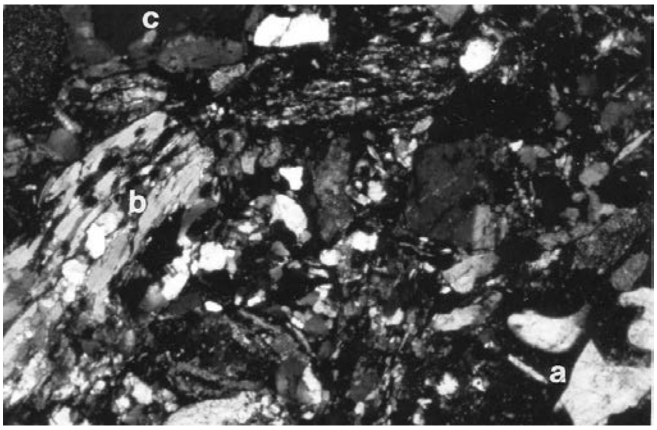

Fig. 10 - Petrofacies of the “Macigno costiero” sandstones. Photo shows three types of grains characteristic of this petrofacies: a- volcanic lithic grain; b- metamorphic lithic grain; c- carbonate grain. Crossed polars, 13x.

Di Giulio and Valloni, 1992) and subordinately, of volcanic grains (rhyolites, dacites and andesites) and sedimentary grains (limestones, shales and siltstones); bioclasts are present as well (Table 3 and Fig. 10). The main composition of the “Macigno costiero” sandstones is $Q_{56.5}\,F_{19.2}\,L{+}C_{\,24.3}$ referable to feldspathic litharenite and lithic arkose, whereas the fine-grained rock fragment composition is $Lm_{64.2}\,Lv_{20.2}$ $Ls{+}CE_{15.6}$ (carbonate extraclasts $CE_{\,7.8}$) (Table 4 and Fig. 11).

Interstitial materials, essentially related to diagenesis, are also present: calcite cement, authigenic minerals, calcite overgrowth and rare epimatrix (*sensu* Dickinson 1970). Moreover some more ductile grains (like volcanic grains, chloritic grains) have undergone re-crystallisation and changing in the textural framework and shape due to the mechanical compaction, to simulate interstitial material; this is called pseudomatrix in the meaning of Dickinson (1970).

The coarse-grained sandstones or microconglomerates, that characterise portions of the chaotic debris flow key-level, have abundant siliciclastic matrix, to be defined greywacke, with an analogous detrital composition to the above litharenites and arkoses.

In the upper part of the succession (upper part of the stage 5), sandstones and conglomerates alternate with the olistostromes, and show detrital composition slightly different to that of the below-standing sandstones, with less volcanic lithic grains, more carbonate lithic grains to do a mean fine-grained rock fragment grains composition $Lm_{72.0}\,Lv_{5.1}$ $Ls{+}CE_{22.9}$ (upper petrofacies of Fig. 11).

In the upper part of the succession (stage 5), slump beds (Fig. 6) are made of fine-grained sandstones with quartz grains and rare feldspar, mica and volcanic lithic fragments. Minor phyllosilicates and calcite are present. These rocks are texturally and mineralogically very mature (quartz arenites, but a detrital modal analysis was not possible on these rocks due to their fine grain-size).

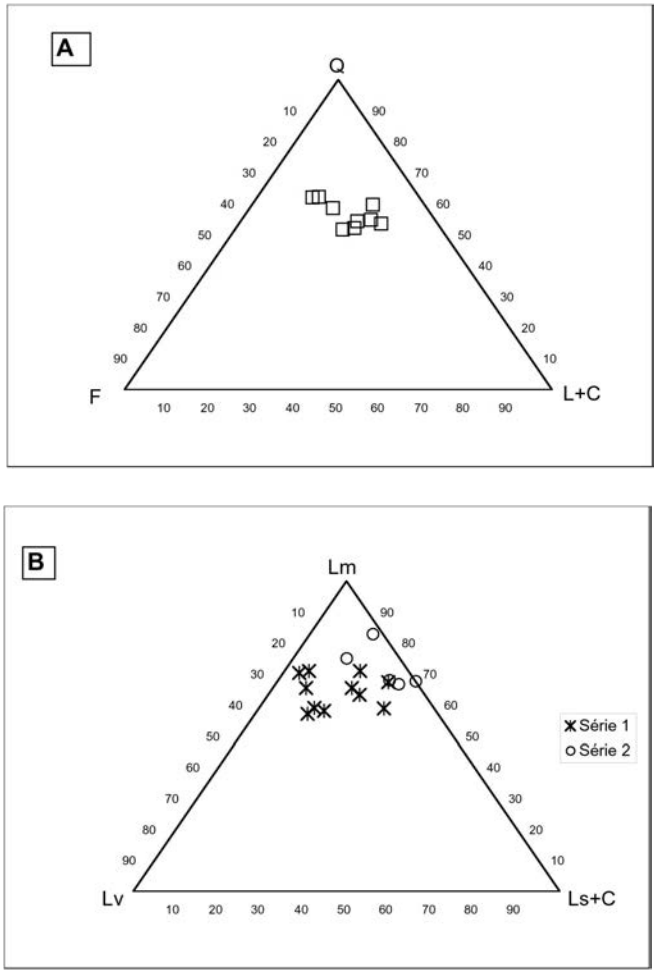

Fig. 11 - A) Main arenites composition: Q- quartz, F- feldspars, L- fine-grained rock fragments, C- extrabasinal carbonates (limestones).
B) Fine-grained rock fragments composition: Lm - fine-grained metamorphic lithics, Lv- fine-grained volcanic lithics, Ls+C- fine-grained sedimentary lithics (carbonate rock fragments are comprises). Series 1- normal “Macigno costiero” petrofacies; Series 2 - upper petrofacies.

PALAEOGEOGRAPHIC IMPLICATIONS

The vertical organisation of facies associations suggests that the lower four stages of growth of the turbidite system are relative to prograding lobes. The stage 4 marks the final progradation of the whole system, that ends at the top of the stage 5 with the overthrusting of the Subligurian tectonic Unit. Several features suggest the progradation of the turbidite system from relative distal environment to proximal fan environment close to a slope. Slope, probably represented both the inner margin of the basin and the frontal part of the orogenic wedge. Such a turbidite system, characterised by coarse-sized facies and by facies associations, mainly relative to proximal lobe or channel-lobe transition,

Table 3 - Rock modal analyses of the “Macigno costiero” arenites. Total Composition, Main Composition and Framework Composition are reported

BARATTI	Macigno costiero								
SAMPLE	**BA 34**	**BA 33**	**BA 32**	**BA 7**	**BA 5**	**BA 40**	**BA 66**	**BA 81**	**BA 82**
TOTAL COMPOSITION									
Essential extraclasts									
Quartz	**34,2**	**36,2**	**27,2**	**35,3**	**38,9**	**32,6**	**36,4**	**37,2**	**35,2**
Monocrystalline quartz (Qm)	26,4	22,3	18,7	27,7	28,5	19,1	23,9	29,9	26,5
Coarse-grained polycrystalline quartz (Qc)	4,1	10,5	4,6	4,0	3,6	6,9	8,1	3,4	3,2
Fine-grained polycrystalline quartz (Qf)	3,0	3,4	3,2	3,3	5,2	3,3	4,4	2,9	4,6
Chert (Ch)	0,7	0,0	0,7	0,3	1,6	3,3	0,0	1,0	0,9
Feldspars	**13,8**	**13,9**	**12,7**	**12,0**	**15,0**	**6,9**	**13,7**	**10,3**	**9,1**
K-Feldspar (Kf)	6,4	4,4	3,2	6,6	6,2	1,6	5,0	4,9	5,0
Plagioclase (Pf)	4,4	6,1	4,6	2,1	2,1	3,3	3,7	2,0	0,9
Undetermined feldspar (Fa)	3,0	3,4	4,9	3,3	6,7	2,0	5,0	3,4	3,2
Fine-grained rock fragments	**7,1**	**12,2**	**13,8**	**17,8**	**20,8**	**16,1**	**8,0**	**20,6**	**21,9**
Silicate lithics (Ls)	7,1	11,5	12,7	13,2	19,2	14,8	7,7	18,6	18,7
Carbonate lithics (Lc)	0,0	0,7	1,1	4,6	1,6	1,3	0,3	2,0	3,2
Accessory extraclasts	**24,7**	**16,4**	**19,4**	**5,7**	**5,9**	**10,4**	**9,4**	**4,4**	**6,5**
Micas and chlorites (M)	17,6	10,1	8,8	4,3	3,1	5,8	6,4	2,0	3,2
Heavy minerals (H)	2,0	1,7	6,7	0,7	1,0	1,5	1,0	1,4	1,4
Pseudomatrix (pm)	5,1	4,6	3,9	0,7	1,8	3,1	2,0	1,0	1,9
Intraclasts	**0,0**	**0,0**	**3,2**	**1,5**	**0,5**	**0,3**	**0,7**	**0,0**	**1,8**
Bioclasts (Bi)	0,0	0,0	3,2	1,5	0,5	0,3	0,7	0,0	1,8
Mud grains (Mc)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Glauconite (Gc)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Interstitial and patchy	**20,2**	**21,3**	**23,7**	**27,7**	**18,9**	**33,7**	**31,8**	**27,5**	**25,5**
Matrix (Ep)	0,0	2,0	2,1	3,2	1,5	6,2	2,7	1,4	2,8
Carbonate cement	1,3	3,0	2,1	5,3	1,5	3,3	3,7	3,4	4,0
Quartz cement	6,1	1,7	1,4	0,0	0,6	1,0	2,0	0,0	0,4
Chlorite and clay minerals cement	5,1	4,5	3,8	0,9	4,4	4,4	2,7	2,0	2,3
Patchy calcite	5,4	8,1	9,4	15,1	7,8	11,0	19,5	16,8	13,7
Authigen minerals	0,3	0,3	1,9	0,0	0,0	1,3	0,0	0,0	0,0
Pseudomorph replacement	2,0	1,7	3,0	3,2	3,1	6,5	1,2	3,9	2,3
ROCK TOTAL	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
FRAMEWORK COMPOSITION									
NCE	100,0	99,2	94,8	91,7	97,5	97,6	98,6	97,3	93,4
CE	0,0	0,8	1,3	6,3	1,9	1,9	0,5	2,7	4,2
CI + NCI	0,0	0,0	3,9	2,0	0,6	0,5	0,9	0,0	2,4
TOTAL	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
MAIN COMPOSITION									
Quartz (Q)	62,0	58,6	51,6	54,3	52,1	59,7	62,1	54,8	53,6
Feldspars (F)	25,1	22,0	23,2	18,4	20,2	12,1	23,5	15,0	13,2
Lithics (L+C)	12,9	19,4	25,2	27,3	27,7	28,2	14,4	30,2	33,2
TOTAL	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

is considered of low efficiency sand-rich type (Type II of Mutti, 1985), with the proximal channel-levee complex close to the lobes. The detrital composition of the sandstones shows a source area from crystalline basement rocks and from intermediate-acid volcanites in association with sedimentary rocks; such a provenance could be seen in the continental European paleomargin (as Corso-Sardinian Massif and Western Alps).

The composition of the “Macigno costiero” is slightly different from that of the “Macigno” s.s., in particular, for the former, the lithic fragment composition is characterised by a major amount of volcanic lithic grains and of lithic carbonate grains (Gandolfi and Paganelli, 1992; Costa et al., 1997; Cornamusini, 1998a).

Due to the distinctive sedimentological features of the “Macigno costiero” respect to the “Macigno” s.s., (this last is considered of high efficiency type, see in Mutti, 1992 and Cornamusini 1998a; 1998b), is possible to hyphotesise for the “Macigno costiero” a different turbidite body from that of the “Macigno” s.s.. Moreover, paleocurrent data obtained in the “Macigno costiero” suggest a source area feeding the basin transversal to the thrust belt, different from the longitudinal source of the Macigno s.s. (for this last see in ten Haaf, 1959; Sestini, 1970; Di Giulio, 1999) (Fig. 12). Such a transversal feeding agrees with the progradation of the turbidite system, as indicated by the stages of growth 4 and 5, up to the basin-closure announced by the strong arrival into the basin of Subligurian olistostromes. Moreover the facies shows downcurrent changes (*sensu* Mutti, 1992) both from the northern and southern sections, indicating a not univocal direction of the flows and the presence of several transversal entry points in the basin.

For this framework I suggest the possibility that “Macigno costiero” turbidites derive from shallow-water basin close to the Corso-Sardinian Massif, placed in the backland of the thrust belt.

In such hypothesis the Ligurian-Subligurian thrust-belt units stack had a terrigenous shelf on the top, linked to the continental margin (crystalline basement). Sediments of the shelf, periodically moved down slope, to feed the “Macigno costiero” basin (see also Sestini, 1970). Sedimentation on the shelf occurred in episutural and/or satellite basins,

Table 4 - Fine-grained rock fragment modal analysis of the “Macigno costiero” arenites

BARATTI	Macigno costiero										
SAMPLE	**BA 34**	**BA 33**	**BA 32**	**BA 7**	**BA 5**	**BA 40**	**BA 66**	**BA 81**	**BA 82**	**BA 84**	**BA 6**
FINE-GRAINED ROCK FRAGMENT COMPOSITION											
Very fine and fine-grained quartz (Qf+Ch)	18,6	7,3	12,0	8,0	6,0	10,0	0,9	22,8	17,6	19,0	15,0
Metamorphic rock fragments (Lm)	**70,9**	**58,1**	**65,4**	**67,4**	**59,1**	**65,5**	**70,9**	**57,1**	**63,2**	**70,4**	**58,8**
Gneissic	29,9	18,3	21,7	20,0	19,2	29,0	29,6	11,8	20,2	19,0	15,0
Low-grade schists	3,1	0,1	2,2	2,0	2,0	0,0	0,9	5,5	4,2	3,0	0,0
Quartz-muscovite schists	16,5	23,2	25,0	14,0	25,3	22,0	14,8	15,0	22,7	25,0	20,0
Chlorite/serpentinite	8,2	12,2	8,7	26,0	9,1	8,0	25,0	11,8	5,0	10,0	15,0
Volcanic rock fragments (Lv)	**11,4**	**26,2**	**16,1**	**6,5**	**28,0**	**26,7**	**23,4**	**30,6**	**15,3**	**25,9**	**11,8**
Acidic volcanics	2,1	8,5	5,4	6,0	10,1	10,0	7,4	15,7	2,5	14,0	5,0
Basic-intermediate volcanics	7,2	15,8	8,7	0,0	16,2	14,0	15,8	7,9	10,1	7,0	5,0
Sedimentary rock fragments (Ls+C)	**17,7**	**15,7**	**18,5**	**26,1**	**12,9**	**7,8**	**5,7**	**12,3**	**21,5**	**3,7**	**29,4**
Shales	12,4	4,9	0,0	6,0	1,0	0,0	3,7	0,0	2,5	0,0	0,0
Siltstones	2,0	7,3	5,4	0,0	6,1	2,0	0,0	0,8	3,4	1,0	5,0
Limestones	0,0	2,4	10,9	18,0	5,0	5,0	1,9	8,7	11,8	2,0	20,0
TOTAL FINE-GRAINED ROCK FRAGMENTS	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

BARATTI	Macigno costiero top portion				
SAMPLE	**BA 110**	**BA 112**	**BA 113**	**BA 114**	**BA 115**
FINE-GRAINED ROCK FRAGMENT COMPOSITION					
Very fine and fine-grained quartz (Qf+Ch)	26,3	16,3	4,0	10,7	19,0
Metamorphic rock fragments (Lm)	**75,0**	**82,9**	**67,6**	**68,0**	**66,7**
Gneissic	15,8	6,1	2,9	12,5	19,0
Low-grade schists	3,9	14,3	5,7	12,5	5,8
Quartz-muscovite schists	26,3	40,8	50,2	33,9	23,3
Chlorite/serpentinite	9,2	8,2	2,9	1,8	5,8
Volcanic rock fragments (Lv)	**12,5**	**2,4**	**0,0**	**6,0**	**4,5**
Acidic volcanics	3,9	2,0	0,0	5,3	1,5
Basic-intermediate volcanics	6,5	0,0	0,0	0,0	2,2
Sedimentary rock fragments (Ls+C)	**12,5**	**14,7**	**32,4**	**26,0**	**28,8**
Shales	0,0	0,0	0,0	3,6	1,0
Siltstones	1,3	4,1	5,7	7,2	3,0
Limestones	7,9	8,2	28,6	12,5	19,7
TOTAL FINE-GRAINED ROCK FRAGMENTS	100,0	100,0	100,0	100,0	100,0

which were probably fed by fan-delta (Paleogene clastic deposits of the eastern Corsica, see Amaudric du Chaffaut, 1973 and Carmignani et al., 1995, and of the Sardinia as Cucurru ‘e Flores Conglomerate, see Carmignani et al., 1995 and Pasci et al., 1998, developed along strike-slip tectonics structures as shown by Carmignani et al., 1995). The presence of carbonate grains and the high ratio of volcanic lithic grains within the “Macigno costiero” sandstones, allow to distinguish it from the “Macigno” s.s. (see the petrofacies of the “Macigno” s.s. in Costa et al., 1992; 1997; Valloni et al., 1992; Pandeli et al., 1994; Cornamusini, 1998a; Biserni and Cornamusini, 1999). Such a composition suggests mixed siliciclastic and carbonate sediments on the shelf, feeding the “Macigno costiero”. Comparable composition and geodynamic context, but with some differences (not a direct correlation), may be found in several Eocene-Oligocene Epiligurian formations as Loiano Fm. and Ranzano Fm. (Pizzo d’Oca Member) (Sestini, 1970; Cibin, 1989; 1993, Martelli et al., 1998), the Fontanelle-Incisa Sequence of the eastern part of Tertiary Piedmontese Basin (Di Giulio, 1991), the Mt. Senario Fm. (Merla, 1951; Sestini, 1970, Aiello, 1975), the Aveto Fm. (petrofacies A of Elter et al., 1999) and the Oligocene sandstones detected in a well located in the Elba-Pianosa Ridge in the northern Tyrrhenian Sea (Cornamusini and Pascucci, 1999). Moreover, the chaotic debris flow key-level, interlayered into the turbidite succession, contains carbonate shoal elements, this latter probably located close to a platform edge (Figs. 12 and 13). The slope of the basin was possibly draped by hemipelagic marls, which were involved in the chaotic debris flow key level of the studied succession. In additional, during the phase of full turbiditic activity, the contribution of the orogenic wedge was only represented by few olistoliths.

Finally “Macigno costiero” represents a sedimentary unit distinguished by “Macigno” of the Northern Apennine (see Fig. 1), with a different evolution in the collisional phase. However, it is difficult to define if both deposited in the same basin or in two different basins. The “Macigno costiero” is here thought deposited in an inner portion of a basin, close to the continental slope formed by the allochthonous thrust front.

CONCLUSIONS

1) The late Chattian “Macigno costiero” represents a low-efficiency turbidite system, probably fed transversally to the basin. The gradual progradation of the turbiditic apparatus moved until the emplacing of the Subligurian “Argille e calcari” Nappe originated from the orogenic wedge.
2) The shifting of the thrust-belt orogenic wedge towards the foreland, induced the progradation of the turbiditic system of the “Macigno costiero” from distal lobe environment to proximal channel environment up to the closure of the basin.
3) The sandstones composition suggests a crystalline basement source with volcanites. Sediments probably fed before a shallow-water basins located on the top of the orogenic prism and interacted with carbonate sedimentation, later fed the “Macigno costiero” basin.

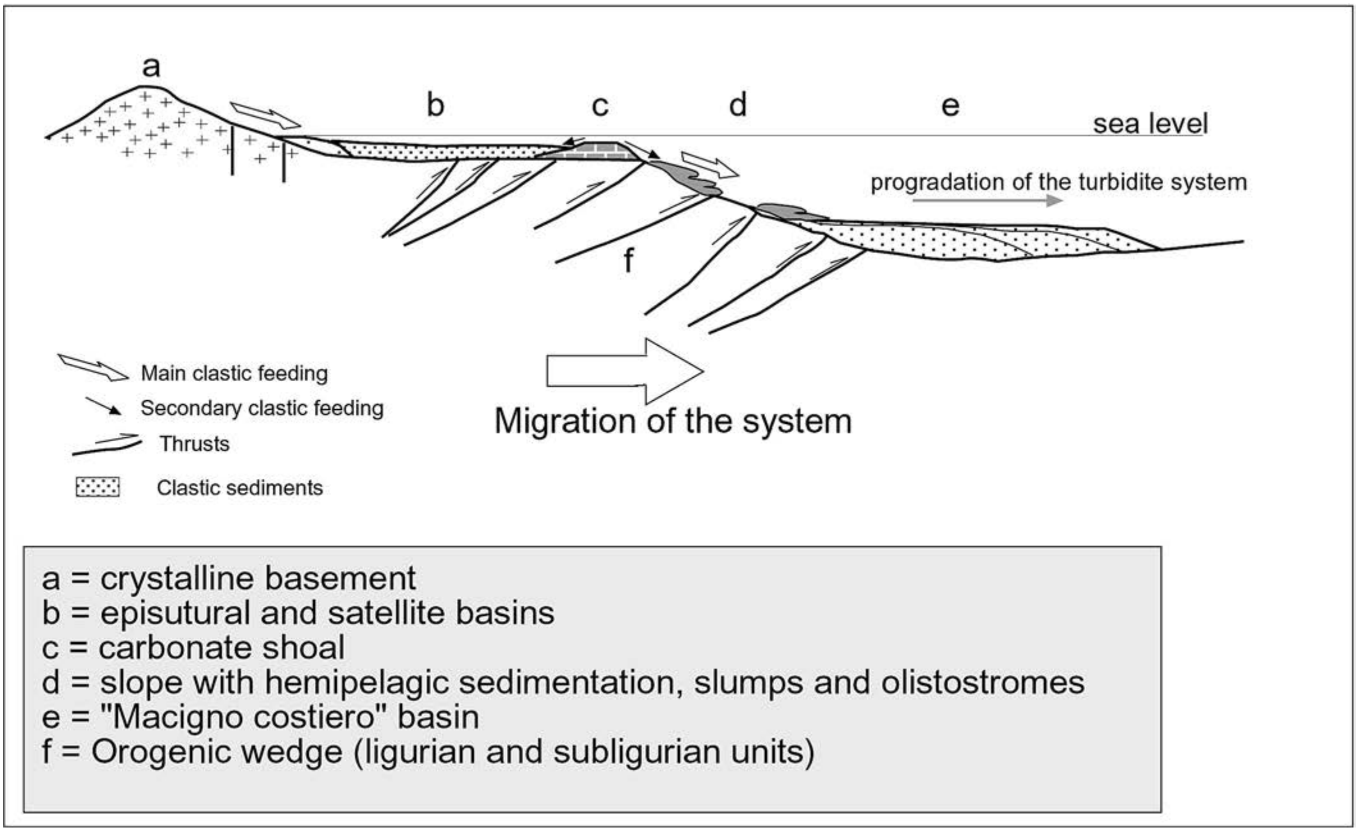

Fig. 12 - This paper suggested model for the hinterland-thrust belt-foredeep system in the late Chattian.

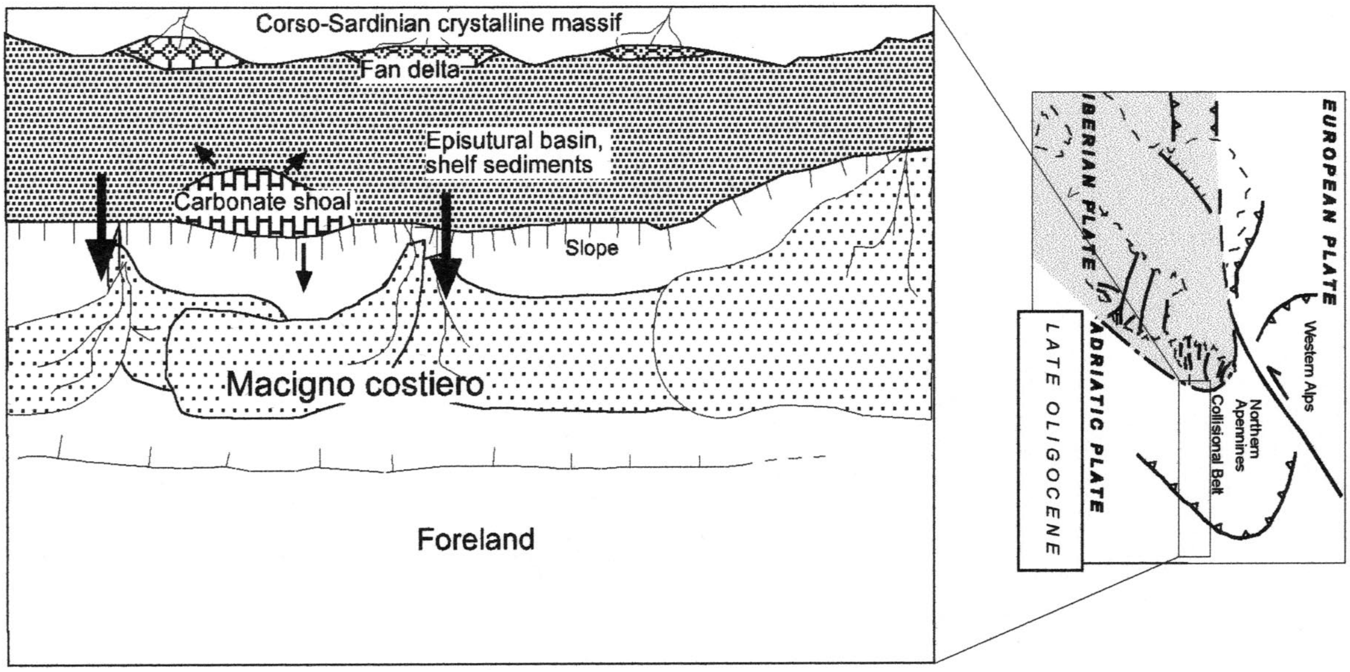

Fig. 13 - Hypotesized palaeogeographic sketch of the Tuscan foredeep system in the Late Chattian (the little figure after Carmignani et al. 1995).

4) In the shelf, mixed carbonate-siliciclastic sedimentation was active and probably also restricted carbonate shoals were present. The carbonate shelf sedimentation sporadically contributed to the “Macigno costiero” basin fed through carbonate turbidites.
5) The orogenic wedge did not directly contribute to the detrital feeding of the basin, except with olistoliths and olistostromes.
6) About the geodynamic context, the data collected in this paper and derived from literature (Sestini, 1970; Ferrini et

al., 1985; Fazzuoli et al., 1985; Boccaletti et al., 1986; 1990; Gandolfi and Paganelli, 1992) could speculate that the "Macigno costiero" was not a true part of the "Macigno" s.s. (Apennine "Macigno"), but it represents an early phase of the foredeep system structuration and deposited in an inner portion of the foredeep basin or in a restricted-basin in front of the orogenic Ligurian-Subligurian prism.

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