THE BASAL COMPLEX STRATIGRAPHY OF THE HELMINTHOID MONTE CASSIO FLYSCH: A KEY TO THE EOALPINE TECTONICS OF THE NORTHERN APENNINES

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Riassunto. Nell’ambito dell’Episolto di base del Flysch ad olistocomo superiore di M. Cassio affiorante nella sua località tipo, sono state riconosciute torbiditi ceneomaniche potenti 200 m. Queste torbiditi che in passato non erano distinte dalle Arenarie di Ostia, sono indicate nel presente lavoro come Arenarie di Case Baruzzo (CBS), consistono essenzialmente di strati siltosi marnosi-silici con stratificazione fine e rappresentano il primo apporto silicoclastico nella successione dell’Unità torrentica Cassio.

Le CBS sono intercalate da argille a palombini haute-riviano-aptiane che risultano associate a scaglie tettoniche di formazioni giurassico-cretaciche ad affinità Astralpinica (Radiolariti, Settti ad artifici e Maioliche). Sulle CBS si sovrappongono in discontinue le argille varicolore santoniano-aptiane che risultano interessate da deformazioni tettoniche precedentemente alla completa litificazione.

La composizione petrografica delle CBS mostra due petrofacies che indicano (1) la diretta provenienza dalle rocce di copertura oceanica che rappresentano il loro substrato e (2) una zona sorgente extrabasinali, impostata sul margine astroalpino, molto simile a quella delle Arenarie di Ostia coniacion-santoniane, affioranti a SW dell’Unità Cassio e tectonicamente indipendenti. Le CBS ceneomaniche si configurano quindi come un corpo tettonico di tipo silicoclastico distintivo dall’Arenaria di Ostia dell’Unità Media Val Taro che a loro volta sono tempo-equivalenti alle argille varicolore.

L’inizio degli apporti tettonici risulta Cenomanico nel Completo di base del Flysch di M. Cassio (CBS), Coniacion nell’Unità Media Val Taro (Arenarie di Ostia) e Campaniano nella piu interna Unità Gottero (torbiditi a strati sottili nella Formazione di Val Lavagna).

Per queste tre Unità che occupano una posizione strutturale alta nell’edificio appenninico tosco-emiliano si ipotizzano per il Cre-tacco superiore posizioni paleogeografiche relative simili a quelle attuali, in un contesto di evoluzione tettono-stratigrafica controllata da un prisma di accrescimento Alpino-vertente. La tettonica a polarità alpina avrebbe controllato la migrazione verso est dei depositsuni di baci-nali, dalle torbiditi argilliche campani sono indirizzate alimentate dal margine europeo.

L’assenza di apporti olistocomi nelle Unità Cassio, Media Val Taro e Gottero ne indica la sedimentazione in un porzione del Bacino Ligure dove la tettonica subduttiva eolalpina non ha prodotto ob-duzioni di litosfera oceanica. Viceversa, un cospicuo detritismo olistocomo tettonico cretaceo avrebbe potuto svilupparsi verso sud, oltre l’importante discontinuità tectonica impostata sulla traccia di una faglia trasformante giurassica che avrebbe potuto agire come fascia transpressiva durante la tettonica convergente cretaceo-paleogenica. In questo set- tore meridionale del Bacino Ligure sarebbero sedimentate le unità caratterizzate da apporti olistocomi (Ottono-Caio). Queste ultime sarebbero state sovraccariche dalle Unità Gottero, Media Val Taro e Cassio durante la chiusura dell’Eocene medio (Fase li-rino-secondario, prima della rota-zione antioraria appennincris).

Abstract. Below the Monte Cassio helminthroid Flysch of the type locality, a well exposed basal complex outcrop in which Cenomanian turbidites of up to 200 m thickness are recognized. The bulk of these turbidites, named here Case Baruzzo Sandstone (CBS), consists of thick-bedded silt and claystone with a fine arenaceous base and represents the oldest siliciclastic input within the succession of the Cassio tectonic unit.

The Case Baruzzo Sandstone lies unconformably on the Palombini shale of Haute-rivian-Aptian age and on stratified packets of Jurassic-Cretaceous formations with Astalpine affinity (Radiolarites, Artifici Shale and Maiolica). The Cenomanian CBS are unconformably overlain by Varicoloured Clay of Santonian-Campanian age and affected by soft-sediment deformations.

The petrography of the CBS shows two petrofacies indicating (1) a direct provenance from their substratum and (2) an extrabasinal source similar to the terrigenous framework of the tectonically independent Coniacian-Santonian Ostia Sandstone outcropping southwest of the Cassio Unit. Because of its Cenomanian age the CBS must be considered as a siliciclastic wedge distinct from the younger Ostia Sandstone belonging to the Media Val Taro Unit and time correlative to the Varicoloured Clay of the Cassio Unit.

The initiation of the turbidite sandstones terrigenous supply is Cenomanian into the Cassio Basal Complex (CBS), Coniacian into the Media Val Taro Unit (Ostia Sandstone) and Campanian into the more internal Gottero Unit (fine-grained turbidites interbedded within the Val Lavagna Formation).

It is proposed that the relative positions of the highest tectonic units outcropping in the Emilian Apennines (i.e. Gottero, Media Val Taro and Cassio Units) during Late Cretaceous were not very different to the present setting, and that their tectono-stratigraphic evolution was related to Alpine-vertente accretionary wedges. The Alp-ine tectonic polarity should have controlled the westward migra-

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tion of the basinal depocentres and the evolution from the Adriatic-margin supply of the Cenomanian turbidites to the European-margin supply of the Maestracian turbidites.

During the middle Eocene tectonic phase, before the counterclockwise apenninic rotation, the ophiolite-free Cretaceous Ligurian Units (i.e. Gonnem, Meda Val Taro, Cassio) overthrust the Ligurian Units characterized by late Cretaceous ophiolitic detritus, known as Ostone and Caso Units, along a significant lithospheric discontinuity which acted as a transpressive fracture zone.

Introduction.

The basic geological structure of the Northern Apennines thrust-and-fold belt results from the stacking of the oceanic crust Ligurian sequences, deposited in the Ligurian-Piedmont Ocean, on the continental crust Tuscan-Umbrian sequences of the Adriatic promontory of the African plate (Abbate & Sagri, 1982). Although the basic geometry and stratigraphy of the Northern Apennines were established some thirty years ago (Sestini, 1970; Elter, 1973), major problems remain unsolved concerning detailed regional correlation, depositional history, palaeogeography and tectonic evolution.

Two contrasting geodynamic settings have been envisaged for the subduction processes pre-dating the late Eocene-Oligocene continental collision. According to some, the whole Ligurian oceanic lithosphere subducted beneath the Sardinian-Corsican margin, as an east-verging accretionary prism (Treves, 1984; Principi & Treves, 1984). Others maintain that a large portion of the Ligurian oceanic lithosphere was first subducted beneath the African (Adriatic) margin as a west-verging accretionary prism and that the west-dipping subduction was a younger process (Gelati & Pasquer, 1970; Flacce et al., 1972; Sturani, 1973; Elter & Pertusati, 1973; Boccaletti et al., 1980; Galbiati, 1990; Elter & Marroni, 1991; Elter, 1993; Cassedi et al., 1993; Marroni & Pandolfi, 1996).

The major palaeogeological problems of the oceanic Ligurian Domain are the palaeogeography of the Helminthoid Flysch basins and the timing and polarity of the tectonic deformations related to subduction. A particularly intense matter of debate is represented by the original location of the basin of the Helminthoid Monte Cassio Flysch, outcropping in the northeastern side of the chain, from the Monferrato Hills to Modena Province (Zanzucchi, 1980; 1988). The composition of the Monte Cassio Flysch is characterized by the presence of coeval shallow water bioclastic detritus and the lack of ophiolitic detritus (Fontana et al., 1994). The stratigraphic substrate is characterized by the occurrence of conglomerates (Salti del Diavolo Conglomerate) with a South Alpine (Adriatic) provenance (Sames, 1967; Elter et al., 1966) and by slabs of Jurassic and lower Cretaceous rocks (Radiolarites, Apti Shale and Maiolica) derived from the Adriatic margin (Braga, 1957; Zanzucchi, 1961b; Vercesi & Cobianchi, 1998). These features led to the location of the Monte Cassio basin in the northern and external part of the Ligurian-Piedmont Ocean, close to the Adriatic margin (Elter et al., 1966; Abbate & Sagri, 1970; Monteforti, 1972; Elter, 1973; Zanzucchi, 1980; Abbate & Sagri, 1982; Sestini et al., 1986). However, the Cassio tectonic Unit occupies an elevated geometrical position in the chain which would suggest an original internal and southwestern location of its basin.

Since the facies and the depositional environment of the various Helmintoïd Flysch outcrops in the Northern Apennines are very similar, clues to their palaeogeography can be provided by the integrated study of their stratigraphic substratum, which are referred to in the literature as basal complexes. These complexes are heavily affected by tectonics, which limits their stratigraphic analysis. Today the stratigraphy of the basal complexes associated with the various Helmintoïd Flysches is sufficiently known and reflects an articulated Cretaceous palaeogeography of the Ligurian-Piedmont Ocean controlled by compressional tectonics (Zanzucchi, 1980; Labesse, 1981; Rio & Villa, 1987).

In the present work we will report data on the field stratigraphy, structural setting, calcareous nanofossil biostratigraphy, and petrography of arenites from the lower part of the Cassio Basal Complex, aiming to restore the stratigraphic succession at the base of the Monte Cassio Flysch in the type area of the unit, between the Baganza and Ceno Valleys SW of Parma (Fig. 1). In particular, we will deal with siliciclastic turbidites known as Case Baruzzo Sandstone (CBS, Scabiazz Sandstone and Ostia Sandstone of the literature). They represent the first significant input of terrigenous clastics into the Cassio basin. We compare this event with the features of other terrigenous clastic wedges present in the Ligurian Ocean in order to discuss their significance in the context of the Alpine Late Cretaceous tectonic convergence.

Regional geological framework.

Fig. 1 represents a schematic structural map essentially based on the "Carta strutturale dell'Appennino settentrionale" by Boccaletti & Coli, 1982. It shows the main tectonic units outcropping in the northwestern portion of the Northern Apennines, the stacking of which is shown in the schematic cross-section at the base of the figure. The considered segment of the Apennines can be subdivided into three wide structural sectors, characterized by specific tectono-stratigraphic features and bounded by major regional overthrusts.

The inner sector corresponds to the western portion of the chain and is characterized by widespread outcrops of Ligurian Units with Jurassic oceanic crust.
Stratigraphy of the Helmintoid Monte Cassio Flysch

INNER SECTOR
- Cretaceous ophiolite–ree succession surrounding by a helminthoid flysch (Vescovi et al., in press), corresponding to the Baganza Group (Abbate & Sagri, 1970).

MIDDLE SECTOR
- Media Val Taro Unit: Cretaceous ophiolite-free succession adjoining a helminthoid flysch (Vescovi et al., in press), corresponding to the Baganza Group (Abbate & Sagri, 1970).

OUTER SECTOR
- Cretaceous ophiolite–ree succession surrounding by a helminthoid flysch (Vescovi et al., in press), corresponding to the Baganza Group (Abbate & Sagri, 1970).


substrate (i.e. Bracco and Tavaron Units; Decandia & Elter, 1972; Abbate et al., 1988) and by the outcrop of a major turbiditic clastic wedge derived from European margin (Gottro Sandstone; Marroni & Pandolfi, 1996), overthrust by Antola helminthoid flysch; the Epi-Ligurian Succession (sensu Ricci Lucchi & Ori, 1985) is missing.

The middle sector, corresponding to the central portion of the chain, is characterized by widespread outcrops of the ophiolite bearing Ottone and Onocce (Caio) Units (Zanzucchi, 1980; Bertotti et al., 1986; Elter & Marroni, 1991). According to Piccardo et al. (1992) the ophiolitic detritus derived from transitional-to-normal MOR basalts and poorly depleted mantle ultramafics. Along the Taro Valley, the latter units are overthrust by the Middle Taro Valley Unit, that, in turn, is locally overthrust by a "spur" of the Gottro Unit characterized by polyphased tectonic deformation (Vescovi, 1991). On a wide portion of this sector, the Epi-Ligurian Succession (Muttoni et al., 1995) is preserved on top of the Middle Taro Valley Unit.

The outer sector corresponds to the eastern part of the chain, bordered by the Po River Plain. It is characterized by widespread outcrops of Paleocene to middle Eocene Flysch (Alberese), roughly similar to the Late Cretaceous Helminthoid Flysch from which they are differentiated by higher contents of sandy detritus (Abbate & Sagri, 1967). The Alberese type Flysch is overthrust by the Cassio Unit, often with the interposition of a problematic ophiolitic unit (Prinzera Unit in Zanzucchi, 1994; Groppallo complex in Marroni & Tribuzio, 1996). The Epiligurian Succession is locally paraconformable (Iaccarino & Rio, 1972; Iaccarino et al., 1974) and more complete than in the middle sector (Papani et al., 1987).

Stratigraphy of the Cassio tectonic Unit.

The stratigraphic units constituting the Cassio tectonic Unit are reconstructed in Fig. 4 together with the successions of the Media Val Taro and Gottro tectonic Units, discussed in the following sections. The Cassio Unit is equivalent to the Baganza Group of Abbate & Sagri (1970). The upper part of the Cassio Unit corresponds to the Monte Cassio Flysch and Viano Clay formations of Zanzucchi (1961a), Abbate & Sagri (1967, 1970), Papani & Zanzucchi (1970), Iaccarino & Rio (1972) and Iaccarino et al. (1974). The Monte Cassio Flysch consists of a more than 1500 m thick succession of basin plain carbonate-rich thick-bedded turbidities, of latest Campanian to Paleocene age (Rio et al., 1983; Iaccarino & Rio, 1972; Iaccarino et al., 1974). It was deposited below the carbonate dissolution depth (CCD) (Sagri, 1973; Sagri, 1979a; Sagri & Marri, 1982). Parea (1961, 1965a, 1965b) has shown NW and SW provenances for the mud-rich turbidites and the sand-rich turbidites, respectively. Fontana et al. (1994) have shown that the tectonically input of the Monte Cassio Flysch is from the Austro-Southalpine basement. The deposition of the Monte Cassio, as well as of other Helminthoid Flysches of the Northern Apennines, has been linked to the filling of an oceanic trench during plate convergence (Sagri, 1979b; Treves, 1984; Principi & Treves, 1984; Marroni et al., 1992).

The basin-plain turbidites of the Monte Cassio Flysch rest on strongly dismembered units (Basal Complex) by Zanzucchi (1961a) and Braga (1965), that have been interpreted as an accretionary prism derived from...
Stratigraphy of the Helminthoid Monte Cassio Flysch

Fig. 2 - Schematic geologic map of the investigated area (squared in Fig. 1). A, B and C are the traces of the cross sections reported in Fig. 3. Within the Basal Complex of the Monte Cassio Flysch only the Case Baruzzo Sandstone is mapped.
the offscraping of oceanic successions (Bettelli et al., 1994). Because of the pervasive tectonic disruption, the stratigraphy of the basal complex remains controversial. There is a wide consensus, however, in considering as the basal portion of the Cassio Unit a basin plain succession of dark grey shales interbedded with fine-grained thin-bedded calcareous turbidites, referred to in this paper as the Palombini Shale of the Grontone Torrent (PS in Fig. 4). Calcareous nanofossils suggest a Hauterivian to Aptian age for the Palombini Shale unit (Villa in Vescovi et al., in press).

Plurimetric slabs of Jurassic to lower Cretaceous Radiolarites, Aptici Shale and Maiolica (R-A-M in Fig. 4) are embedded within the Palombini Shale; they have been interpreted as olistholiths (Zanzucchi, 1961a; 1982) and offscraped slices of the original oceanic sequences (Plesi et al., 1993).

Above the Palombini Shale the siliciclastic deposits focused in the present work are present. In the Baganza Valley (Fig. 2 and 3) this Unit has been referred to as "Basal Complex Sandstone" (Istituto di Geologia di Parma, 1964; Zanzucchi, 1980). It is here referred to as Case Baruzzo Sandstone (CBS). It should be noted that, on a regional scale, the siliciclastic portion of the Cassio Unit lying above the Palombini Shale, is often referred to in the literature as Scabiazza Sandstone (Ludwig, 1929; Braga, 1965; Abbate & Sagri, 1970; Bettelli et al., 1987; Ghiselli et al., 1991). Because of polyphasic deformation (Ghiselli et al., 1994) the stratigraphic relationships between the Cassio Unit and the Scabiazza Sandstone in its type area (Trebbia Valley; Piacenza Province) are not fully understood and therefore we avoid the use of this formal term in the Parma Apennines. The contact between the Palombini Shale and the CBS is poorly exposed and assumed as unconformable (Zanzucchi, 1980). On top of the CBS a pelagic varicoloured claystone unit is present (VC in Fig. 4) which contains thin-bedded arenaceous turbidites (Vescovi, 1986) and the Salti del Diavolo Conglomerate; the base of the Salti del Diavolo Conglomerate marks a major discontinuity (Zanzucchi, 1980). The conglomerates are made up of elements of Permian to Late Cretaceous age. They are very similar to those cropping out in the South-Alpine succession (Sames, 1963; 1967; Elter et al., 1966; Giam-
metti, 1966) and have been dated as earliest Campanian by Rio & Villa (1987).

The strongly deformed setting and the low carbonate content of the Varicoloured Clay have made their dating particularly difficult; they have often been ascribed to the Cenomanian, in the past (Zanzucchi, 1955; Papani, 1967; Rio & Villa, 1987). In the work area only Coniacian to Santonian ages have been documented (Rio & Villa, 1987; Perilli & Rio in Cerrina Feroni et al., 1990).

**Sampling, analytical methods.**

Laboratory work aimed to determine the age and provenance of the Case Baruzzo Sandstone and the Varicoloured Clay formations was based on calcareous nannofossil biostratigraphy and sandstone petrography.

The sampled sections are the Prelerna, Case Baruzzo and Praquarola sections depicted in Fig. 5, 6 and 7, respectively. The type section of the Ostia Sandstone near Belforte was also sampled for petrographic comparisons. Due to the dominance of the fine grain size of the deposits the samples analyzed for sandstone petrography were few. The total number of samples analyzed for nannofossil biostratigraphy was 51.

The thin-section petrographic study was made with two distinct procedures depending on the grain size of the deposits. The medium-to-coarse grained sandstones, needed for the conventional point-counting
Fig. 5 - Prelerna section. Lithostratigraphic column reconstructed along cross section A of Figure 3.
analysis, are present only in the CBS and the Varicoloured Clay turbidite beds of the Case Baruzzo section as well as in the Ostia Sandstones. Other beds, such as the CBS outcropping in the Prelerna and Praquarola sections, have a much coarser or a much finer grain size; these microconglomerates and very fine sands were treated with semiquantitative analyses of selected samples.

Quantitative modal analyses were based on point counting 250 terrigenous framework grains. Polymineralic grains were distinguished according to the dimension of their internal constituents into Coarse- and Fine-grained types using the 62 micron limit (Dickinson, 1978). According to the method used here the lithic population contains only the fine-grained rocks plus carbonate fragments of any texture. The quartzose and feldspathic populations contain the >62 micron crystals of quartz and feldspar, respectively, internal to polymineralic grains (Zuffa, 1985).

In clastic deposits the analysis of diagenetic modifications (eg. textural relations, interstitial constituents) is very informative; nevertheless diagenetic processes are not discussed here since the aim of this study is the recognition of framework petrofacies for stratigraphic purposes. In general, calcite cements of different generations are the most important authigenic phase; in particular, calcite expresses replacive patches which may obscure primary textural relations. Samples were selected for the microscopic study only if low in calcite substitutions.

The calcareous nannofossil biostratigraphy study was carried out with the polarizing optical microscope using standard techniques of preparation (smear slide). The contents in calcareous nannofossils of most of the nannofossiliferous samples is moderately high, on average 2 to 5 specimens per field of view at a magnification of approx. 1200X. However, preservation is generally poor as testified by the dominance of the dissolution resistant species of Watzenaueria (Tab. 1, 2, and 3). Confident recognition of species is often impossible and we have restricted our analysis to the index species listed in Appendix. The quantitative evaluation of the abundance of recognizable forms was made by counting 500 specimens. This count excluded the detection of the presence of rare index species and therefore, we scanned single slides for several hours looking for rare index species. Species which were detected out of the 500 counting are reported as "K" in the range charts shown in Tab. 1-3. The collected biostratigraphic data are shown in Tables 1, 2, and 3 and in Fig. 5-7, where age assignments are shown. Detailed discussion on the taxonomy of each species is beyond the scope of this study and has already been discussed in detail by many authors. Appendix 1, however, lists the references to original taxonomic descriptions, and any subsequent emendations together with brief remarks.

A plethora of calcareous nannofossil biostratigraphic schemes have been proposed in the past years for the late Cretaceous time interval and have been reviewed by Mortimer (1987) and Bralower et al. (1995). In this paper we refer to the chronobiostatigraphic frame reported in Fig. 10, where the main calcareous nannofossil biohorizons (datum events) are correlated to the standard chronostratigraphy; the chronology of Gradstein et al. (1994) is used for stage boundaries. Correlation between calcareous nannofossil biohorizons and stage boundaries as shown in Fig. 10 is uncertain (Bralower et al., 1995) and may, therefore, undergo future revision.

Tab. 1 - Distribution of selected calcareous nannofossil species in the Prelerna section, and inferred chronostratigraphic interpretation. () counting is 0.0.

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<th>STRATIGRAPHIC UNIT</th>
<th>AGE</th>
<th>SAMPLE</th>
<th>COUNTED SPECIMENS</th>
<th>C. carinato</th>
<th>C. kennedyi</th>
<th>C. ceratium</th>
<th>H. angustifera</th>
<th>P. maria</th>
<th>C. australis</th>
<th>C. hirtus</th>
<th>F. coralliform</th>
<th>F. annulata</th>
<th>P. angustata</th>
<th>P. plicatula</th>
<th>Nannococcospora</th>
<th>Nanocystinae</th>
<th>Nanomorphinae</th>
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<td>1.0 0.2</td>
<td>0.8 0.8 K</td>
<td>2.8 1 8</td>
<td>6.8 1 6 4.2 3.6 1.6</td>
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Stratigraphy of the Helmintoid Monte Cassio Flysch
Fig. 6 - Case Baruzzo section. Lithostratigraphic column reconstructed along cross section B of Figure 3.
Case Baruzzo sandstone.

The term Case Baruzzo Sandstone was introduced by Monteforti (1972) with reference to the outcrops in the Grumione Torrent Valley (Fig. 11), regarded as the type area in which the columnar log presented in Fig. 6 were reconstructed. The CBS have also been logged in the Prelerna section (Fig. 5) where the basal and upper contacts are poorly exposed, and in the Praquarola section (Fig. 7), where only about 50 m of the CBS outcrop. It should be noted that in the previous literature only the succession of the Praquarola section (Fig. 7) was considered as belonging to the Cassio succession whereas the successions logged in the Prelerna and Case Baruzzo sections were considered as belonging to the Ostia Formation (Istituto di Geologia di Parma, 1964); because of their peculiar lithofacies the sandstones have been named Case Baruzzo Sandstone (Monteforti, 1972) and Ostia Sandstone of the Grumione (Plesi et al., 1993). As shown here, field evidence, petrographic and biostratigraphic data all suggest the correlatable aspects of the three sections and their assignment to the succession of the Monte Cassio.

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Tab. 2 - Distribution of selected calcareous nannofossil species in the Case Baruzzo section, and inferred chronostratigraphic interpretation. (,) counting is 0.0; (f) not checked.
The CBS consists of a turbidite succession with an estimated total thickness of up to about 200 m exhibiting the lithofacies listed below in order of decreasing volumetric abundance.

1) Thick and very thick-bedded (up to 10 m) turbidites showing a thin coarse-grained litharenitic sole followed by a few cm thick, fine-grained sandstone interval, with even lamination, grading into a thick interval of gray silty marlstone; the basal portion of these thick-bedded turbidites is petrographically characterized by a lithic QFL mode with the Rock Fragments population dominated by carbonate grains.

2) Thin to medium-bedded turbidite sandstones, fine to very fine-grained, horizontally laminated and often rich in coal fragments, gently grading upwards into a light gray silty marl.

3) Medium to thick-bedded turbidites, with thin soles of coarse to medium-grained whitish breccia, overlain by light gray marly limestones; as shown in the following the basal rudites have a calcilithic composition (Valloni et al., 1991), rich in biogenic chert fragments.

4) Medium to thin-bedded greenish fine-grained turbidite sandstones representing interbeds in the uppermost portion of the CBS near the contact with the Varicoloured Clay; petrographically they represent quartzofeldspathic arenites.

5) Medium to thick-bedded coarse-grained turbidites, representing intercalations in the basalmost portion of the CBS, whose framework is dominated by coeval bioclasts (Calcarenites).

**Petrography.**

With reference to the five CBS lithofacies listed above the petrographic descriptions of the Calcilithic rudite, Lithic arenite and Quartzofeldspathic arenite deposits are given below whereas the Calcarenite deposits are discussed in the next paragraph concerning the substrate of the CBS.

**Calcilithic rudites.**

Two samples from the Prelerna and one sample from the Praquarola sections representing the fine ruditic sole of thick turbiditic calcareous mudstones were analyzed; their framework compositions are very similar and grain abundances are as follows:

- Prevailing micritic limestones (sparse pelagic fauna), plus subordinate fossiliferous limestone fragments and recrystallized carbonate laminites;
- Abundant biogenic chert fragments (radiolaria common), frequently replaced by micro-cryptocrystalline calcite;
- Common siliceous shale fragments with laminated texture;
- 1 to 10 % (on total framework) accessory grains comprising quartzo-feldspathic phanerites and minor shists, sandstones and siltstones.

Lithic arenites.

Three samples, collected in the basal portion of medium to thick bedded turbidites of the Case Baruzzo Section were selected for the microscopic analysis (Fig. 6). Post-depositional changes are severe and take the form of calcite substitution patches and grain pseudomorphs; they total 14-19 % on total rock and hamper the reconnaissance of the original detrital association.

The Q-F-L+C mode is lithic with quartzose grains of the order of 40% and feldspathic grains up to 20%. Recalculation of the lithic grains (L+C) shows the dominance of sedimentary rock fragments and a characteristic 10-20% of volcanic grains with vitric, porphyric and rhyolite-like structures. Recalculation of the sedimentary grain population shows the dominance of carbonate fragments whereas siliciclastic rock fragments are almost absent. The carbonate grain varieties are essentially micritic rock fragments more or less recrystallized.

Quartzo-feldspathic arenites.

In the Case Baruzzo section (Fig. 6), in close proximity to the contact with the overlying Varicoloured Clay, fine-grained greenish sandstone interbeds occur; one of these beds was sampled for semiquantitative petrographic analysis.

The framework grains are fully interlocked by quartz and feldspar (albite?) overgrowths; also common are late-calcite replacive patches. The greenish appearance of the rock is due to the diffuse alteration of unstable (including feldspars) into chlorite-like minerals.

The framework composition is dominated by quartz (almost 50% of total framework) and less abundant feldspars. Microcrystalline silica grains undergoing recrystallization are common and increase the quartzose character of the rock. Polymineralic grains are essentially represented by quartz-mica shists which total about

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Tab. 3 - Distribution of selected calcareous nannofossil species in the Case Praraqua section, and inferred chronostratigraphic interpretation. (i) counting is 0.0.
10% on total framework. Among accessory grains the dense minerals such as Garnet, Rutile, Sphene and Picotite are often encountered as well as sparse grains of Glauconite.

Age.

The calcareous nannofossil contents of the CBS from the Case Baruzzo (Fig. 6 and Tab. 2) and Prelerna (Fig. 5 and Tab. 1) sections are similar and can be confidently assigned to the Cenomanian because of the almost continuous presence of Corollithion kennedyi and Helenea (Microstaurus) chiastia and the absence of Quadrum gartneri and other post Cenomanian markers. The stratigraphically important Cenomanian species Libraphidites acutus and Libraphidites alatus are very rare and their occurrence has been detected only after lengthy searching. Microrhabdulus decoratus and Axopodorhabdus albianus have not been found. The absence of Microrhabdulus decoratus seems to be ecologically controlled since it is very rare even in the overlying Turonian-Coniacian sediments (Tab. 1 and 3). The presence of L. acutus makes it possible to assign the CBS of the Case Baruzzo and Prelerna sections to the late Cenomanian (see Fig. 10). A more detailed age assignment is impossible since calcareous nannofossils provide a relatively poor resolution in the time interval (Fig. 10). It should be noted that C. kennedyi is missing in the uppermost sample in the Case Baruzzo section (Fig. 6) and, with all uncertainties of the single-sample information, this might suggest a terminal Cenomanian age for the top of the unit (see Fig. 10).

The four samples collected in the CBS outcropping in the Praquarola section (Fig. 7) contain nannofossil assemblages (Tab. 3) different from those recovered in the former two sections. Corollithion kennedyi, that characterizes the CBS in the Case Baruzzo and Prelerna sections, is virtually missing and Q. gartneri and Eprolithus epipetalus are present. Helenea chiastia is present with atypical specimens and is probably reworked. These findings suggest a Turonian age for the CBS outcropping in the Praquarola section. In particular, the absence of Eifelithus eximus (well represented in the area) would suggest an early Turonian age for this portion of the CBS (Figs. 7, 10 and Tab. 3). Apparently, the CBS at Praquarola are younger than those sampled in the Case Baruzzo and Prelerna sections, although it is difficult to estimate how large the age contrast is.


The stratigraphic base of the CBS crops out in the Taro Valley, approximately 1 km SW of Prelerna (Fig. 3, section A) and in the Baganza Valley, at Praquarola (Fig. 3, section C). In the former the contact with the underlying Palombini Shale is poorly exposed. In the latter the contact with the Palombini Shale and the embedded R-A-M slabs appears unconformable, as already pointed out by Zanuzzo (1982). The presence of an unconformity between the Palombini Shale and the CBS is in agreement with the available biostratigraphic data, that suggest Hauterivian-Aptian for the Palombini Shale (Villa in Vescovi, in press) and a Cenomanian age for the CBS (present work). A hiatus of a minimum duration of 14-15 my is thus present (see time scale of Gradstein et al., 1994).

There is much evidence, however, suggesting a stratigraphic relationship between the CBS and the Palombini Shale. A granule-size sample of the Palombini Shale from the Prelerna Section (sample O18 in Fig. 5) shows a relatively distinct composition with abundant algal, briozoan and other fossiliferous limestones, abundant micritic fossiliferous and pelagic limestones and subordinate fossil fragments of probable intrabasinal origin with small amounts of rhyolite-like fragments, schist fragments of several textures, quartz, sandstone and siliceous-shale grains. Such a composition is quite similar to the one detected at the base of the CBS near Praquarola (Fig. 3, section C), close to the contact with the Jurassic Radiolirites (Fig. 7). Here, a bioclastic calcarenite located close to the contact with the underlying Radiolirites, contains limestones and fossil fragments of the same varieties and in the same relative proportions
Stratigraphy of the Helmintoid Monte Cassio Flysch

Fig. 10 - Adopted distribution model of index calcareous nannofossils species versus standard chronostratigraphy utilized for age assignments. Age of stage boundaries are after Gradstein et al. (1994). Data of distribution model of index calcareous nannofossils species after are Varol (1992), Perch-Nielsen (1985) and Bradower & Siesser (1992)

as the underlying Palombini Shale as well as 10% of the distinctive quartzose, rhyolite-like and shist grains found in the Palombini Shale sample above. At the same time, relevant amounts (about 30% on total framework) of biogenic chert and minor siliceous-shale, characteristic of the CBS Calcilithic Rudites, appear.

Other evidence of a stratigraphic relationship between the CBS and the Palombini Shale is the presence, within the coarse-grained arenites in the lowermost portion of the CBS, of numerous angular clasts of greenish chert exactly resembling the angular elements of the autoclastic breccia sampled within the Jurassic Radiolarites embedded in the Palombini Shale (Fig. 12).

The discontinuity of the Septaria-like concretion surface.

The contact between the CBS and the overlying Varicoloured Clay is well exposed in the Grontone Val-
concretions may have a duration in excess of 5-6 my, i.e., the entire Turonian and the early Coniacian are missing (Fig. 10).

Concerning the causative mechanism of this hiatus, it should be noted that the passage from the Cenomanian to the Turonian is characterized globally by a major oceanographic anoxic event (Bonarelli bed in the Adriatic foreland) and by a severe shallowing of the CCD that prompted the deposition of carbonate variegated clay in the Atlantic Ocean and caused widespread hiatuses in the oceanic realms (Kenneth, 1982). These hiatuses are also found in the Lombardy basin (Bersezio & Fornaciari, 1994), where, however, tectonics may have played a major role, since they grossly correspond with pre-Gosau Alpine tectonic phase.

Top of the CBS: Varicoloured Clay.

The Varicoloured Clay was investigated only in their basal 100 metres. Actually the entire succession shows a severe folding deformation with large-scale isoclinal folds, usually dismembered. Sometimes the deformation took place when the sediments were poorly consolidated as indicated by boudinage and hydroplastic extensional fractures.

In correspondence with the base of the Varicoloured Clay, adjacent to the Septaria-like concretions, fluid escape structures are present (Fig. 13 A). In addition, the Septaria-like concretions show fractures filled with very fine greenish chlorite sandstone (Fig. 13 D), very similar to the fine-grained beds intercalated within the uppermost portion of the CBS.

Petrography.

In the Varicoloured Clays of the Case Baruzzo section occasional sandstone turbidite beds are intercalated; in the lower portion of the CBS three coarse-grained samples (Fig. 6) were collected for point counting.

Post-depositional alteration of sandstone deposits is moderate, within 5% of the total rock; it consists of calcite in the form of grain pseudomorphs and irregular patches as well as of authigenic barite in irregular substitution patches representing the most original feature. Accessory grains are essentially represented by white and brown mica totalling 3-4 % on total rock.

Detrital modes are shown in Fig. 14. The framework composition (Q,F,L+G) is represented by 30-40 % of quartzose grains and by lithic grains in excess of the feldspathic ones.

In the quartzose grains granitoid fragments are quite common. In the feldspathic grains perthitic structures are present and the K-feldspars largely exceed plagioclases. In the lithic grains (pole L+C) all basic rock types are represented although volcanics alone total
Stratigraphy of the Helminthoid Monte Cassio Flysch

Age.

The age of the Varicoloured Clay of the Monte Cassio Unit has been partially studied by Rio & Villa (1987) and by Perilli & Rio (in Cerrina Feroni et al., 1990), who have documented Santonian and Campanian ages. In the present work we have examined the calcareous nannofossil contents of the lower part of the Varicoloured Clay outcropping in the Case Baruzzo section (Fig. 6). Results reported in Tab. 2 and in Fig. 6 indicate that this portion of the Varicoloured Clay extends from the late Coniacian to the early Santonian. Combining the present data with data in the literature, it results that a fairly regular biostratigraphic progression is present in this Formation, from the late Coniacian to the late Campanian. Unfortunately, it is impossible to evaluate the sediment accumulation rates of the Varicoloured Clay because the severe deformation prevents an estimate of the actual thickness.

CBS and Ostia Sandstone relations.

As mentioned previously, the CBS and the major packages of the arenaceous turbidites intercalated in the Varicoloured Clay have been ascribed in the literature to the Ostia Sandstones (Cerrina Feroni et al., 1990; Ghiselli et al., 1991; Elter & Marroni, 1991), a major siliciclastic wedge of the Cretaceous Ligurian-Piedmont Ocean. In particular, Costa et al., (1995) have interpreted the type Ostia Sandstone and the CBS as belonging to a unique stratigraphic succession that was dismembered and displaced by a Santonian extensional tectonic phase. In the following, we face the problem of the stratigraphic relationships between the type Ostia Sandstone outcropping in the Taro Valley (Parma Province) and the

about one half of the lithic population (Fig. 14). The volcanic fragments are frankly acid and have a structure from vitric to porphyric with quartz and alcali feldspar phenocrystals.
succession of the Monte Cassio Flysch. We will show that the CBS of the Cassio Unit and the type Ostia Sandstone have to be considered as two distinct depositional episodes with different stratigraphic evolutions.

The type Ostia Sandstone belongs to the Media Val Taro Unit, whose schematic stratigraphy is shown in Fig. 4 (Vescovi et al., in press). The succession begins with the Palombini Shale of Monte Rizzone (fairly similar and time-equivalent with the Palombini Shale of the Grontone Torrent), that is unconformably overlain by a shaly unit (San Siro Shale) containing marly turbidites (Pontolo Marl) very similar to the medium to thick-beded turbidite lithofacies of the CBS, in its turn overlain by the Ostia Sandstone with a probable unconformable contact, passing conformably to another arenaceous turbidite unit named Campi Sandstone of Campanian age (Vescovi et al., in press). The youngest formation of the Media Val Taro succession is a Campanian-Maastrichtian Helmintshoid Flysch (Testanello Flysch), similar to the Monte Caio Flysch.

The reason why in the literature the Ostia Sandstone has often been lumped with the CBS and the turbidites intercalated in the Varicoloured Clay of the Monte Cassio succession (Ghiselli et al., 1991; Elter & Marroni, 1991; Plesi et al., 1993; Costa et al., 1995) is certainly due to their similar petrographic (litharenitic) composition. However, Villa (1991) has shown that the Ostia Sandstone in the type locality is late Coniacian-Santonian in age, in sharp contrast with the late Cenomanian age of the CBS reported in this work. In the

![Fig. 13 - Concretions contained in the Varicoloured Clay, just above the stratigraphic contact with the Case Baruzzo Sandstone (Fig. 3, cross-section B).](image-url)
Monte Cassio succession the "Ostia Sandstone time" is represented by the late Coniacian-Santonian Varicoloured Clay. Former petrographic studies do not compare specifically CBS and Ostia Sandstone. Plesi et al. (1993) report Q F L compositions indicating that CBS are poorer in feldspars with respect to the Ostia Sandstone.

We have analysed the petrographic composition (Fig. 14) of the Santonian Ostia Sandstone in the type area near the village of Belforte (Taro valley) for comparison with the Cenomanian CBS and the Santonian thin bedded turbidites intercalated in the Varicoloured Clay petrographically described in the previous sections.

Petrography of the Ostia Sandstone.

Three sandstone samples with medium-coarse grain size and the lowest possible alteration were selected for point counting. The post depositional alteration of the Ostia Sandstone is strong and represented by calcite substitutions of framework and intergranular materials. Calcite substitution patches and grain pseudomorphs total 18-22 % of the total rock which implies that the detrital mode is subjected to an intrinsical error. Among the accessory grains of the framework sparse intrabasinal pelitic fragments and picotite grains are present (Mezzadri, 1964).

Modal compositions (Fig. 14) of the essential framework grains (Q,F,L+C) plot in the Lithic sandstone field of the diagram with quartzose grains ranging 20-40% and lithic grains largely exceeding feldspar grains (F/L+C > 1/3).

The lithic grains (pole L+C) constitute the most abundant framework constituent and are dominated by sedimentary types, among which carbonates strongly prevail on siliciclastics.

Petrographic comparisons.

The CBS of Cenomanian age and the Ostia Sandstone of Santonian age are petrographically very similar (Fig. 14). They represent a quite unique case in which such similarity is maintained at successive levels of analytical detail (Di Giulio & Valloni, 1992). This explains the fact that, in the past, the two deposits were considered the same formation. According to Folk's (1974) terminology both sandstones should be termed Calcilithites because of the prevalence of the carbonate grain population.

In terms of the Q,F,L+C mode the CBS and Ostia Sandstone compositional fields have some overlap although the CBS tends to be richer in quartzose and feldspathic grains. For discriminating purposes formal
point counting of the lithics population is particularly effective. The diagrams representing grain proportions within the lithic population (Fig. 14) indicate that:

(1) Santonian-age Ostia Sandstone samples have a characteristic 20-30% of metamorphic grains whereas the Cenomanian CBS samples have a characteristic 10-20% of volcanic grains;

(2) Among sedimentary lithics the Ostia Sandstone has a characteristic 10-30% of siliciclastic grains (e.g., siltite and shale) which probably represents the best parameter for its distinction from the CBS;

(3) Among carbonate grain varieties the Ostia Sandstone shows distinctive quartz-impure calcilutites and marls.

With respect to the possible compositional parentages of the sandstones intercalated in the Varicoloured Clays, it is well evident (Fig. 14) that they have no affinity with the coeval Ostia Sandstones. On the contrary a linkage can be seen with the Cenomanian CBS which contains significant amounts of the same acid volcanics which characterize the compositional mode of the Varicoloured Clay.

As far as source areas are concerned the overall composition of the Calclithites of the Santonian Ostia Sandstone and of the Cenomanian CBS indicates a wide spectrum of source rocks that is well documented in the Adriatic continental margin (cf. Fontana, 1991). The wide spectrum of exposed lithologies indicates a distant source located in the overriding plate that fed the CBS in the Cenomanian and the Ostia Sandstone during the Santonian.

The composition of the Santonian arenites intercalated in the Varicoloured Clay on top of the CBS still indicates a provenance from the Adriatic continental margin with the addition of significant exposures of the crystalline basement. This evolution towards a smaller spectrum of exposed lithologies comprising the exposure of the crystalline basement indicates that the paleo-

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**PLATE 1**

All specimens ca. 2000X

Fig. 1, 2 - Litrophilidae alatus. Fig. 1: Case Baruzzo section - 217 P3; parallel light. Fig. 2: Case Baruzzo section - 216 G220; parallel light.

Fig. 3, 5 - Litrophilidae aequalis. Fig. 3: Case Baruzzo section - 217 P3; crossed nicols. Fig. 4, 5: Preleona section - 198 G19; crossed nicols.

Fig. 6, 7 - Luciusverrahidus maliformis. Case Prarquarola section - 217 P33; Fig. 6: parallel light. Fig. 7: crossed nicols.

Fig. 8, 9 - Quadrum gottersi. Fig. 8: Case Prarquarola section - 217 P32; crossed nicols. Fig. 12: Case Baruzzo section - 217 P3; crossed nicols.

Fig. 10, 14 - Quadrum sp. Fig. 10: Case Prarquarola section - 217 P34; crossed nicols. Fig. 14: Case Baruzzo section - 217 P3; crossed nicols.

Fig. 13 - Quadrum intermedium. Case Baruzzo section - 217 P21; crossed nicols.

Fig. 11, 12, 15 - Micula deconverta. Case Prarquarola section - 217 P32; Fig. 1: parallel light. Fig. 2: crossed nicols. Fig. 3: Case Baruzzo section - 217 P21; crossed nicols.

Figs 16, 18 - Eprolisthus epiperipatus. Fig. 16: Case Baruzzo section - 217 P19; crossed nicols. Fig. 17: Case Prarquarola section. 217 P32; crossed nicols. Fig. 18: 217 P33; crossed nicols.
Stratigraphy of the Helmintoid Monte Cassio Flysch

1. L. alatus
2. L. alatus
3. L. acutus
4. L. acutus
5. L. acutus

6. L. maleformis
7. L. maleformis
8. Q. gardneri
9. Q. gardneri
10. Quadrum sp.

11. M. decussata
12. M. decussata
13. Q. intermedius
14. Quadrum sp.

15. M. decussata
16. E. eptapetalus
17. E. eptapetalus
18. E. eptapetalus
The Coniacian - Santonian age of the Gottero outcropping in the easterly areas and the petrographic composition of the Campi Sandstone, covering the Ostia sandstone in the Media Val Taro Unit being very similar to the composition of the Gottero Sandstone (Vescovi et al., in press), both indicate that the Ostia Sandstone could have been sedimented immediately to the east of the Gottero basin.

The Ostia Sandstone, in its turn, has affinities with the CBS of the Cassio Sequence which, according to the data of the previous paragraphs, was deposited in the vicinity of the Adriatic margin. From West to East, the paleogeographic positions of the three sequences is thus: Gottero, Media Val Taro (Ostia) and Cassio (CBS).

With reference to the inception of the terrigenous turbidite sedimentation we have shown that it occurred during the Cenomanian in the Cassio Basin (CBS), the late Coniacian in the Media Val Taro Basin (Ostia), and the Campanian - Maastrichtian in the Val Lavagna - Gottero Basin. Such migration should imply Alpine-verging tectonics as clearly expressed in the Gottero Sequence (Marroni & Pandolfi 1996). The reconstruction here proposed is that during late Cretaceous time, a westward prograding clastic wedge should have been present in this part of the Ligurian-Piedmont Ocean (Fig. 15).

This interpretation, however, does not explain the entire stacking of the Ligurian units. At present, the Gottero, Media Val Taro and Cassio ophiolite-free units overthrust the Bracco, Ottone and Outer Ophiolitic Complex, ophiolite-bearing successions (Fig. 1). The absence of ophiolitic detritus in the Gottero, Media Val Taro and Cassio sequences recognized here as well as in the recent literature implies that in the northern portion of the Ligurian-Piedmont Ocean the oceanic lithosphere had been completely subducted by an early Cretaceous east-dipping plane. On the contrary, in the southern portion of the Ligurian-Piedmont Ocean, large ophiolitic slices were obducted which provided detritus to the Ottone and Caio successions (Bertotti et al., 1986).

According to Vescovi (1993), these obducted ophiolites should have been oriented transversely to the Ligurian-Piedmont Ocean, probably along an ancient Jurassic transform fault zone (Fig. 16).

Only in the middle Eocene Ligurian tectonic phase, the Gottero, Media Val Taro and Cassio northern Ligurian Units, previously deformed by west-verging tectonic structures, were thrust towards south-east above the ophiolitic units and related Helminthoid flysch.

In this reconstruction, during the middle Eocene collision, the ophiolitic ridge separating the northern and southern domains of the Ligurian-Piedmont Ocean acted as a kinematic release with transpressive lateral shift (Fig. 16); after the collision, the ophiolitic ridge was strongly displaced by the well known Neogene thrusting of the Apennines.
The late Cretaceous strike-slip fault systems causing the closure of the Ligurian-Piedmont Ocean accommodate the northward motion of the Africa-Adria plate (Vandenberg et al., 1978; Savostin et al., 1986; Dewey et al., 1989; Heller et al., 1989); the oblique left-lateral convergence could have caused the tectonic slicing of oceanic fragments of the ancient transform zone (Abbate et al., 1994; Marroni & Treves, 1998).

Conclusions.

The integration of structural, lithostratigraphic, biostratigraphic and petrographic data on the helminthoid bearing Monte Cassio Flysch in its type area located between Baganza and Ceno valleys lead to the revision of the stratigraphic successions and, consequently, to new paleogeographic reconstructions.

The stratigraphic succession, extended from the lower Cretaceous to the upper Campanian, comprehends: 1) a basal carbonate-rich pelagic shaly unit (Palombini Shale of the Graontone Torrent) containing slabs of Jurassic-lower Cretaceous allochthonous material, 2) an up to 200 m thick siliciclastic turbidite unit (Case Baruzzo Sandstone) and 3) a clay-rich pelagic unit (Varicoloured Clay) containing thin-bedded terrigenous turbidites and a major coarse-grained episode (Sali del Dia-volo Conglomerate).

Contrary to previous reconstructions the Cenomanian-lower Turonian Case Baruzzo Sandstone must be considered as a distinct siliciclastic wedge from the Ostia Sandstone, dated in their type locality to the late Coniacian-Santonian (Villa, 1991) and time correlative to the Varicoloured Clay.

Field data provide evidence that the basal complex of the Monte Cassio Flysch has been affected by late Cretaceous tectonic deformations which, in the case of the Case Baruzzo Sandstone, are likely to be west (Alpine) vergent. Tectonic deformations may be related to the evolution of an alpine-vergent ligurian prism related to an east-dipping subduction zone which controlled the sedimentation of the Monte Cassio succession which shows three major stratigraphic discontinuities (Fig. 4):

1. E. cf. rarus
2. E. octopetalus
3. E. floralis
4. L. moratus
5. H. chiaiista
6. M. furcatus
7. R. asper
8. F. oblonga
9. C. kennedyi
10. C. kennedyi

All specimens ca. 2000X.

Fig. 1 - E. pseudus cf. rarus. Case Baruzzo section - 216 P236; crossed nicols.
Fig. 2 - E. pseudus octopetalus. Case Baruzzo section - 216 P236; crossed nicols.
Fig. 3 - E. pseudus floralis. Case Baruzzo section - 216 P236; crossed nicols.
Fig. 4 - L. hasianus moratus. Case Baruzzo section - 217 P21; crossed nicols.
Fig. 5 - H. monus. Case Baruzzo section - 216 P236; crossed nicols.
Fig. 6 - M. baruzzo furcatus. Case Baruzzo section - 217 P21; parallel light.
Fig. 7 - R. pseudus asper. Case Praquarola section - 217 P31; crossed nicols.
Fig. 8 - F. pseudus oblonga. Case Praquarola section - 217 P34; crossed nicols.
Fig. 9 - C. kennedyi. Fig. 9: Prelerno section - 198 G 14; crossed nicols. Fig. 10: Case Praquarola section - 217 P34; crossed nicols.
1 - at the base of the CBS, onlapping both the Palombini Shale and the Jurassic-lower Cretaceous tectonic slabs, with an angular unconformity;

2 - at the top of the CBS, where a large biostratigraphic hiatus is observed in coincidence with an interval containing barite-rich Septaria-like concretions;

3 - at the base of the Salti del Diavolo Conglomerates.

The CBS-Palombini Shale discontinuity is considered to be the result of the mid-Cretaceous tectonic accretion of the prism.

The CBS-Varicoloured Clay discontinuity corresponds to the global oceanographic shallowing of the CCD around Cenomanian-Turonian boundary. However, the timing of the CBS-Varicoloured Clay hiatus (Turonian-Coniacian) also corresponds to a major Turonian unconformity in the Lombardy Basin (Bersezio et al., 1993; Bersezio & Fornaciari, 1994) and grossly to the pre-Gosau Alpine tectonic phase.

The Salti del Diavolo Conglomerate discontinuity is well correlated to the discontinuity between the Conglomerati di Strone and the Flysch di Bergamo in the Lombardy Basin that has been connected to the intra-Gosau Alpine event (Bersezio & Fornaciari, 1994).

We have compared the depositional history of the Cassio Basal Complex with the stratigraphy of the Media Val Taro and the Gottero Tectonic Units, outcropping to the west of the Cassio Unit.

Stratigraphic and petrographic data suggest an original position of the Media Val Taro Basin in between the Cassio Basin, adjacent to the African margin, and the Gottero Basin, adjacent to the European margin. These successions contain siliciclastic turbidite wedges (CBS, Ostia Sandstone and Gottero Sandstone) the age of which is progressively younger moving from the African to the European margin (Fig. 15).

The older turbidites (Cenomanian-lower Turonian CBS) are fed by sources outcropping in the Adriatic continental margin; the large spectrum of lithologies, which is also characteristic of the compositionally very similar detritus of the Coniacian-Santonian Ostia Sandstone, indicate that these two formations are supplied by a relatively large drainage system acting on the overriding Adriatic plate.

The provenance of the Santonian arenites intercalated in the Varicoloured Clay (Cassio succession) and the Santonian-Maastrichtian Gottero Formation is from the Adriatic and from the European blocks, respectively; at this time the crystalline basement is also outcropping in both source areas.

A migration of the syntectonic elastic depocenters, from the Austroalpine-supplied Cenomanian turbidites (CBS) to the European-supplied Maastrichtian turbidites (Gottero Sandstone), linked to the alpine-verging tectonic progradation, is thus inferred.

We suggest that the paleogeographic relative positions of the CBS, Ostia Sandstone and Gottero Sandstone are located within a northern sector of the Ligurian Basin, where the offscraping of obducted oceanic lithosphere slices should not have been possible.

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APPENDIX

Calcareous nanofossil species considered in this study in alphabetic order of species.

- *Librarghildites acutus* Verbeekand and Manivit, 1977 in Manivit et al., 1977
- *Librarghildites alatus* Thierstein, 1972 in Roth and Thierstein, 1972
- *Retecapsa angustifrons* Black, 1971
- *Rhagodiscus angustus* (Stradner, 1963) Reinhardt, 1971
- *Rhegodiscus asper* (Stradner, 1963) Reinhardt, 1967 = *Peribabdiolites asper*
- *Librarghildites carnotiensis* Deflandre, 1963
- *Lucasvarabdas cayenzi* Deflandre, 1959
- *Helenea chisista* (Worsley, 1971) Bralower et al., 1989 = *Microstaurus chisistant*
- *Micula concava* (Stradner in Martini and Stradner, 1960) Verbeek, 1976
- *Cretarabdas crenilatus* Bramlette and Martini, 1964
- *Microstaurus decoratus* Deflandre, 1959

- *Micula decorata* Vekshina, 1959
- *Eptolithus epipatalus* Vanol, 1992
- *Corallithus exiguus* Stradner, 1961
- *Tetralithus exiguus* Stover, 1966
- *Quadrum gartneri* Prins and Perch-Nielsen, 1977
- *Eptolithus gorkae* Vekshina, 1959
- *Libastranus griffi* Stradner, 1962
- *Quadrum intermediatum* Vekshina, 1992
- *Corallithus kennedyi* Crux, 1981
- *Chiassozygus littorarius* (Giova, 1957) Manivit, 1971
- *Lucasvarabdas multiformis* Reinhardt, 1966
- *Libastranus monostatus* Stover, 1966
- *Eptolithus octopetalus* Varol, 1992
- *Tetralithus pseudolus* (Stover, 1966) Sissingh, 1977
- *Eptolithus rariflorus* Vekshina, 1992
- *Rhagodiscus splendens* (Deflandre, 1953) Verbeek, 1977
- *Eptolithus tenuifolius* (Deflandre in Deflandre and Fert, 1954) Reinhard, 1965