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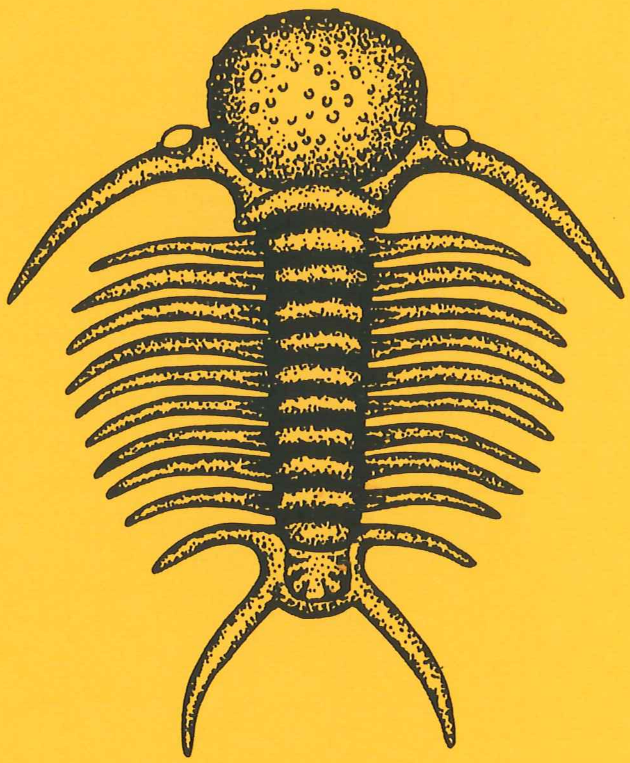

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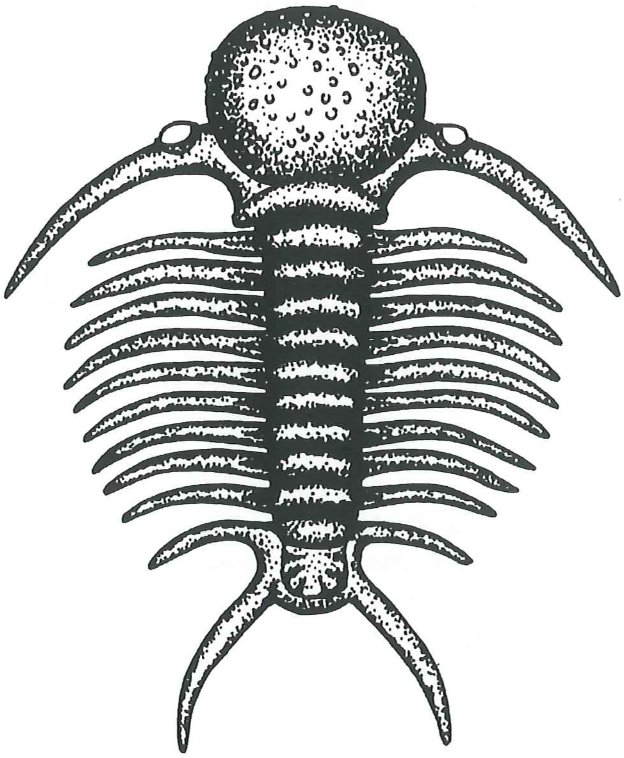

Sedimentary structures and facies of fine grained deep-water carbonate turbidites in a Paleocene-Middle Eocene flysch complex, Monte Sporno, Northern Apennines, Italy

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The Monte Sporno flysch unit consists of regularly alternating calcareous turbidites and subordinate hemipelagic clays, deposited in a basin plain environment near, but above, the calcite compensation depth (CCD). Evidence for turbidity current emplacement includes sole markings, Bouma intervals and resedimented shallow-water microfossil species in a deep-water trace fossil assemblage (*Nereites* ichnofacies). Three main compositionary facies with different provenance has been distinguished mainly on basis of terrigenous influx, sedimentary structures, trace fossils, calcium carbonate content and present microfossils. These are siliciclastic turbidite facies, where primary and secondary sedimentary structures (Bouma intervals) are well developed, and carbonate turbidite facies, where biogenic structures are common and well developed (mainly ichnogenera *Chondrites*, *Zoophycos* and *Helminthoida*). The carbonates were derived from north, while erosional structures indicate a west-southwestern source area for the clastics. The third facies is represented by hemipelagic clays. These are distinguished from turbidite derived clays in colour, thickness, micro fabric, calcium carbonate content and finally, because they represent a recurrent facies that complete Bouma intervals. It is also shown that upward decrease of calcium carbonate content through turbidites is directly related to the different depositional processes i.e. turbiditic deposition and hemipelagic settling. ❑ *Northern Apennines, Monte Sporno, flysch, calcareous turbidites, calcite compensation depth, sedimentary structures, hemipelagic clays, Bouma sequence, basin plain, provenance.*

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Introduction

The Northern Apennines correspond to an orogenic belt, partially derived from the pre-Oligocene (Alpine phase) collisional history between the European and African cratons, but also largely from their post-collisional (Apenninic phase) history (Gasperi *et al.* 1986).The geodynamic inter-action between these two cratons with the interposition of the western-most parts of the Tethys Ocean (Ligurian Ocean) has occurred through Mesozoic time (Van Wamel 1987). During Jurassic (Malm) time, sea-floor spreading took place in this ocean, which resulted in the ophiolites that now form parts of the allochthonous series of the Northern Apennines (Abbate & Sagri 1970). The beginning of the compressional stage of the two cratons took place in late Early Cretaceous (Van Wamel 1987) or in early Late Cretaceous (Ziegler 1990). This stage eventually lead to the main continent-continent collision in Middle-Late Eocene (Bernini *et al.* 1994). The mountain chain was earlier discussed in terms of a geosynclinal formation which could be divided into eu- and miogeosynclinal sequences, a late geosynclinal and a postgeosynclinal stage (Abbate *et al.* 1970). In younger literature the depositional environments of Northern Apennines series (except the Ligurian Units) or parts there of, are described as foreland basins (e.g. Ricci Lucchi 1986; Zoetemeijer *et al.* 1993).

The tectonic units of the Northern Apennines belong to two different paleogeographic domains (Fig. 1). An external mainly autochthonous domain (Umbrian - Tuscan Domain), which developed on orogenic basins rooted on continental crust, and an internal, mainly allochthonous domain (Ligurian Domain), which was deposited in the Ligurian - Piedmont Oceanic Basin, Western Tethys (Elter 1973, as referred to by Bernini *et al.* 1994). The Ligurian Units, covering 90% of the area, represent thrust nappes and gravity nappes (Bernini *et al.* 1986; Gasperi *et al.* 1986), and are composed of rock assemblages of Late Jurassic-Middle Eocene age (Abbate & Sagri 1970). Their overthrust movement started immediately after the complete closure of their basins in the Middle-Late Eocene (Bernini *et al.* 1994), and they are now superimposed on the sedimentary Umbrian-Tuscan rock sequence (Sagri & Zanzucchi 1975). Consequently, the successive tectonic superpositions of different paleogeographic domains gave the Northern Apennine structural geology a very complex nature (Bernini *et al.* 1986).

A major part of the Northern Apennines are referred to as being flysch sediments (e.g. Sestini 1970, p. 560), and at least a dozen distinct types of flysch occur in the area (Ten Haaf 1964). The Ligurian Flysch Units, in which the Monte Sporno Tertiary flysch is included (External Ligurian Units), display very low-grade metamorphism or none (Van Wamel 1987). The Monte Sporno flysch itself is highly deformed (Bernini *et al.* 1994).

The flysch concept

The majority of ancient turbidites are encountered in flysch or flysch-like formations. The Monte Sporno sequence is referred to as flysch (e.g. Sestini 1970) and displays many of the features regarded as typical for the term. These are amongst others sole markings, laminations, grading, small-scale current ripples and convolute laminations (Dzulynski & Walton 1965). Flysch has been a widely used, and abused term in geology during the 20th centuary, and it is therefore an important knowledge that the terms flysch and turbidite are not synonymous (Bouma 1964). According to Sestini (1970, p. 562), the term flysch should be used as a descriptive lithofacies term, while turbidite carries a genetic meaning. Mitchell & Reading (1986, p. 477) suggest that the word flysch should be used for "any thick succession of alternations of

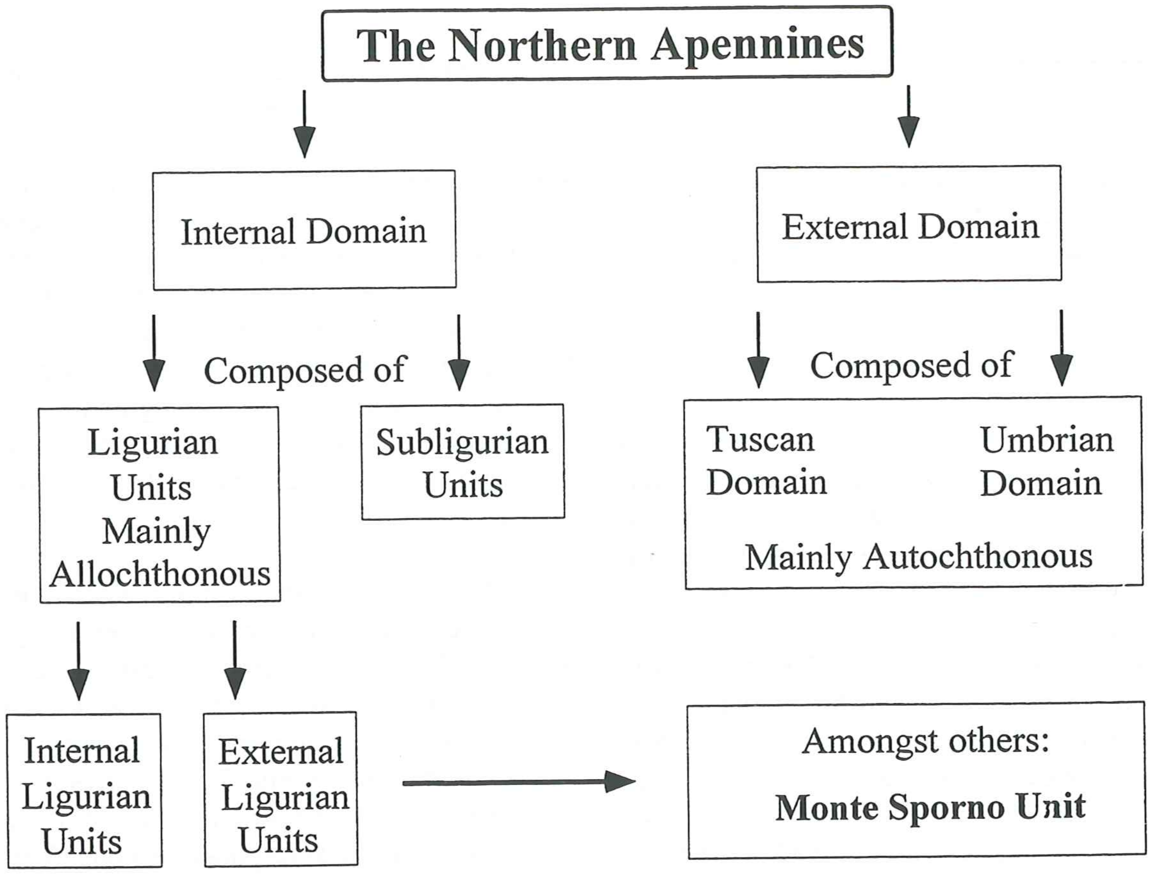

Fig. 1. Geological Framework of the Northern Apennines. Simplified after Bemini *et al.* (1994).

sandstone, calcarenite or conglomerate with shale or mudstone, interpreted as having been deposited mainly by turbidity currents or mass-flow in a deep water environment within a tectonically active orogenic belt". This definition is according to Sinha & Upadhyay (1994) probably the most common one today, and its implication is followed within this paper. Still, flysch is a controversial term. Further, Sinha & Upadhyay (1994) suggest that the term could be used for any flysch-like succession, given that it is clearly used in its sedimentary (genetic) or tectonic sense. The development of either terrigenous or mainly calcareous flysch is of course dependent of the nature and character of the source area. A short treatise on the history of flysch research is given by Hsü (1970).

Stratigraphy

As mentioned above, the Monte Sporno calcareous flysch forms part of the Ligurian Units. It was referred to the eugeosynclinal sequences of the Northern Apennine geosynclinal by Abbate & Sagri (1970), and hence is allochthonous and of oceanic affinity. The true stratigraphic position for the Monte Sporno flysch has been the subject for several discussions and are somewhat unclear. The unit is incorporated in the Mélange nappe (Van Wamel 1987). The downward relations is, however, unclear (Abbate & Sagri 1970).

The total thickness of the Monte Sporno flysch is about 1800 meter. It has been subdivided on lithostratigraphic basis into three different lithologic subunits (Petrucci & Barbieri 1966). The lower subunit is composed of about 200 meter of clays and marls, with rare sandstone intercalations. The thickest and

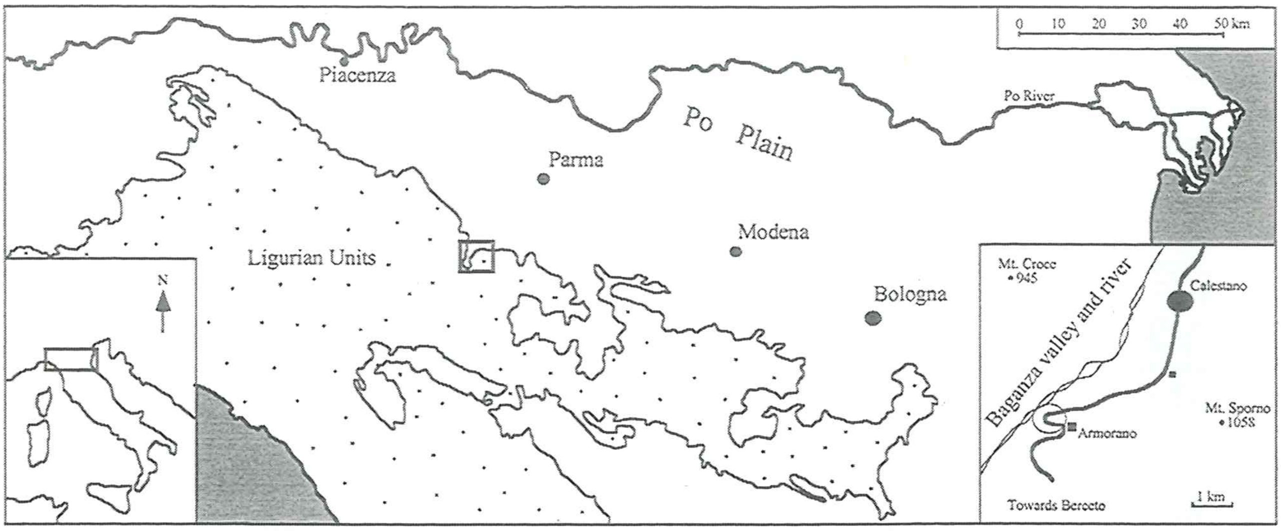

Fig. 2. Location of the Armorano road cut (encircled) and distribution of the Ligurian Units (dotted area).

best represented middle subunit is composed of calcareous marls, sandstones and calcarenites, with subordinate marls, siltstones and shales. The uppermost subunit has a thickness of about 300 meter and is mainly represented by marls and pelites. Micropaleontological studies of the rich planktonic foraminifera assemblages of the formation resulted in an biostratigraphical age assignment ranging from Paleocene for the lower subunit, Upper Paleocene to Middle Eocene for the middle one, and Middle Eocene for the uppermost subunit (Petrucci & Barbieri 1966).

Location of outcrop

The Armorano outcrop is located to the Baganza valley, which is considered to be the type area for the Paleocene-Middle Eocene Monte Sporno flysch sequence (Bernini *et al.* 1994). This is in the outer, Po plain facing, northern parts of the Apennines, about 40 km south-west from Parma, northern Italy (Figs. 2-3). It is a rather well exposed road cut five kilometres south-west of the village of Calestano along the road towards Berceto. The section forms part of the Monte Sporno antiform (Bernini *et al.* 1994) and the strata are

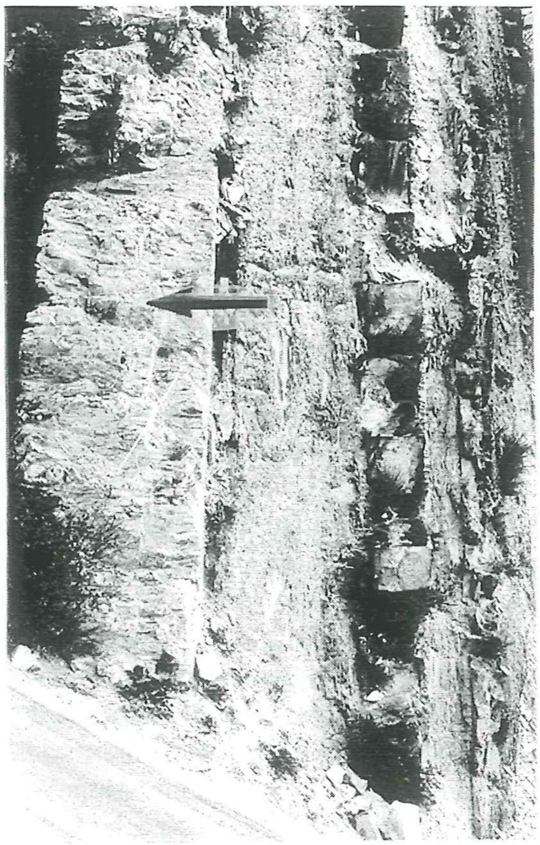

Fig. 3. The uppermost parts of the strongly tilted section at Armorano. The thick, graded carbonate turbidite to the left reaches one and a half metre in thickness. Arrow indicates stratigraphic up.

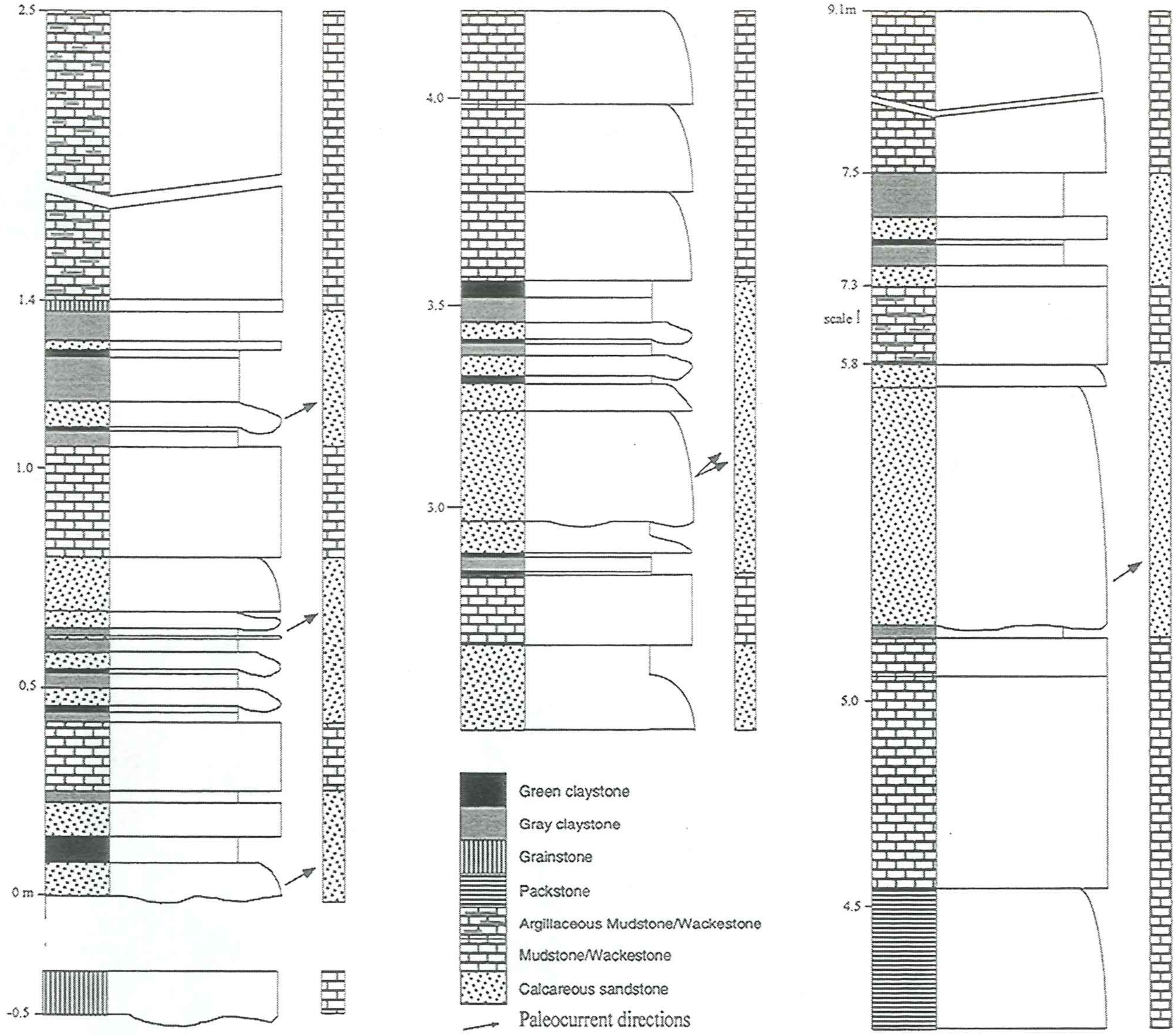

Fig. 4. The section at the Armorano outcrop. Vertical bars indicates the rhytmic alternation of siliciclastic turbidite facies versus carbonate turbidite facies.

tilted vertically with layers sub-surface facing south. As mentioned above, the Monte Sporno formation is divided into three lithological units, of which parts of the middle, more calcareous one, has been investigated.

The purpose of the present investigation is to analyze and understand the different structural and lithological facies within a flysch zone and to demonstrate their affinity with depositional processes and surronding environments. The main tasks dealt with are therefore the deposits genesis and its depositional environment as indicated by sedimentary structures and lithofacies composition.

Previous works on the Monte Sporno formation concerning sedimentology and paleontology are produced by Petrucci & Barbieri (1966), Abbate & Sagri (1970), Abbate *et al.* (1970) and Bernini *et al.* (1994).

Material and methods

A section embracing about ten metres was logged and measured (Fig. 4). Representative samples were collected throughout the section from each lithotype. Bed thickness and amount of sedimentary structures judged the sample frequency, but also the alternation of recurrent facies played a role in the number of samples collected. Twenty thin sections were made for petrographical studies. Six representative claystone samples were used for x-ray diffraction (XRD) for clay mineralogic studies. This test was carried out, following Hardy & Tucker (1988), on air-dried, heated to 550° C, and ethyleneglycole treated samples of the clay fraction (<2 µm). X-ray diffraction results were also obtained from crushed whole-rock samples, for mineralogical studies on greater fractions (>2 µm). Claystone samples were also used for scanning electron microscope (SEM) analysis, concerning micro fabrics. Analysis of calcium carbonate ($CaCO_3$) content was made on all lithotypes, partly as a distinguishing character between different claystones, but also because the lithotypes could not be classified neither by limestone nor terrigenous classification systems (transitional lithologies). Instead, classification parameters used was, $CaCO_3$ content, terrigenous influx and textur. Peels were made for quick information on sedimentary structures in certain samples, while remaining samples have been cut to reveal internal structures. Orientation in space was measured for each individual bed and for erosional structures which, then could be reconstructed to their original position using a Wulff stereonet. Point-counting was made in order to statistically characterize the composition of the different lithotypes during classification. 300 points were counted on each thin section.

Results

Seven different lithofacies were found in the Armorano outcrop. They are here grouped in three lithologic sets: a) calcareous sandstones with well developed primary and secondary sedimentary structures, b) a variety of texturally different limestones and argillaceous limestones (50-75% $CaCO_3$). Both limestones and argillaceous limestones are here classified on textural basis following Dunham (1962). The third less common set, c) is represented by dark olive-green carbonate poor claystones, and grey carbonate rich claystones occurring as intercalated beds at regular distances throughout the section. Mudstones, argillaceous wackestones and wackestones are matrix rich (biomicrites), and contain reworked planktonic foraminifera only, while others (e.g. grainstone) contain smaller amounts of benthic foraminifera, echinoderm fragments and calcareous algae in a sparitic cement of blocky and occasionally of drusy character (biosparites). The different lithofacies (Fig. 5) has a rhytmic appearance and their deposits are easily recognized as being transported in a density current as they possess recurrent graded intervals, erosive well defined bases sometimes scattered by flute casts, plus reworked microfossils and orientated grains. The thickness of individual layers ranges from less than one centimetre in claystones to about one and a half meter in the thickest limestones, although, almost 70% of the beds are less than ten centimetres thick. Among biogenic structures, the ichnogenera *Chondrites*, *Helminthoida* and *Zoophycos* are common in the fine grained limestones. A detailed description of trace fossils and ichnofacies in the Armorano outcrop is given by H. Calner (in press). Based on Seilachers (1964) bathymetric ichnofacies model, and because of a rather diverse trace fossil assemblage which is morphologically dominated by fodichnial and pascichnial forms within a turbidite sequence, the ichnofauna is referred to the *Nereites* ichnofacies (H. Calner, in press).

Lithofacies description

Calcareous sandstone

Petrographical characteristics.- A greyish-brown to brown, well indurated organic rich lithology of non-mature character (poorly sorted), typically with a bed thickness ranging from 5-25 centimetres. Framework grains are dominated by fine grained (coarse silt-fine

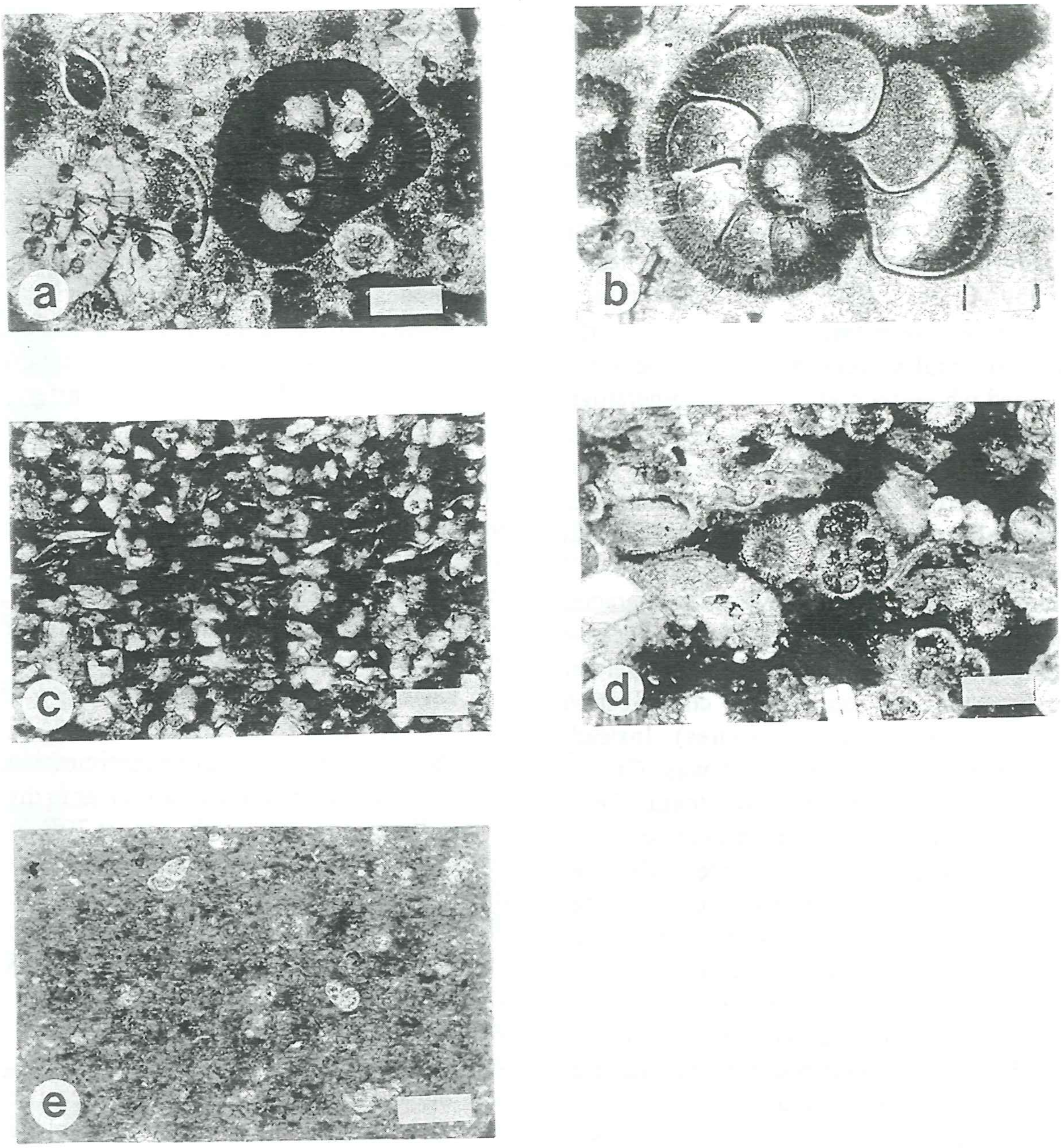

Fig. 5. Micrographs of the various lithofacies in the Armorano outcrop. Scale bars are 200 μm. a) Coarse grained grainstone. Note the assemblage of benthic and planktonic foraminifera in blocky-drusy sparry calcite (biosparite). b) Well preserved large benthic foraminifer from base of carbonate turbidite, indicating a shallow-depth provenance. c) Calcareous sandstone (calcite cement). Note horisontally orientated micas. d) Coarse grained packstone. e) Fine grained mudstone (biomicrite) only with planktonic foraminifera present. Upper parts of thick graded turbidite.

sand), angular quartz grains (40-50% of bulk composition), horizontally orientated micas, and minor amounts of feldspar. The intergrain areas are cemented by blocky sparite. Allochems are represented by small amounts of planktonic and rarely of benthic foraminifera. Cement and allochems rises the $CaCO_3$ content to 30-40%.

Sedimentary structures and bedding.- Primary and secondary sedimentary structures are well developed. Small scale normal(?) grading (less than 0.5 cm) can be seen in thin beds, while, in the thick beds, the graded part can reach more than 30 centimetres. Plane-parallel lamination with a laminae thickness that seldom exceeds two or three milimetres is common. Small scale ripple cross-lamination is rare and only present in a few, thin beds (<5 cm). Convolute bedding occures with a laminae thickness of three to four millimetres. Load cast structures are rare but are well developed in one thicker bed. The size of load cast display minor variation, and a diameter of 10 centimetres is the most common measure. Erosional sedimentary structures in form of flute casts and longitudinal ridges are present on soles, and the size and relief of them vary with bed thickness. They range in length from two or three centimetres in thin beds (<10 cm), to 25 centimetres in thicker beds (>50 cm), and are always distributed in a hetrogenic pattern on the sub-surface. In certain beds erosional structures are poorly developed, but even here a faint indication of paleoflow can be seen. Biogenic structures differ a lot from them in all limestones and argillaceous limestones. These sandy lithotypes are commonly not burrowed, and instead long sub-surface parallel traces are common. *Taphrhelminthopsis* sp. are long meandering traces, commonly appearing on the sole of calcareous sandstones (H. Calner, in press).

Mudstone and argillaceous mudstone

Petrographical characteristics.- Light blueish-grey with a micritic matrix (biomicrite), sometimes replaced by silica. Beds can reach a thickness of more than one metre. Allochems content is less than 10%, and is totally dominated by fragmentary planktonic foraminifera in a random appearance. Sparite occures in small amounts, commonly in the cavities of foraminifera. Quartz is very rare in this lithology.

Sedimentary structures and bedding.- Primary and secondary sedimentary structures are rare. Only a slight normal grading can be seen in cut samples. The thick, more argillaceous levels display high fissility. Among the biogenic structures (H. Calner, in press) *Chondrites* ichnogenus shows the highest abundance. Ichnogenera *Helminthoida* and *Zoophycos* are only present in the non-argillaceous mudstones, but the former is not so common. Further, small scale chaotic bioturbation can be seen in cut samples.

Wackestone and argillaceous wackestone

Petrographical characteristics.- These light blueish-grey lithologies are very similar to the mudstones of the section. They can, however, be distinguished from these by the amount of skeletal grains (10-15% in wackestones). As in the mudstone, skeletal grains are dominated by planktonic foraminifera. The matrix is sometimes replaced by silica or sparite.

Sedimentary structures and bedding.- A graded texture expressed by matrix percentage can be seen in thicker levels (>1m), where a wackestone-based layer grade into mudstone upwards, were allochems are more few and slightly finer. Biogenic structures are poorly developed in both argillaceous and non-argillaceous wackestones, and only the ichnogenus *Chondrites* was observed (H. Calner, in press).

Argillaceous packstone

Petrographical characteristics.- This lithofacies is dominated by foraminifera, both benthic and planktonic forms, but does also contains echinoderm fragments plus some angular quartz grains. Also feldspar is present in small amounts. Micas and grains with long a-axis tend to be orientated. The matrix is micritic but is often replaced by sparite of blocky character.

Sedimentary structures and bedding.- The only sedimentary structure observed was plane-parallel lamination of one to two millimetres thickness.

Grainstone

Petrographical characteristics.- All matrix is replaced by cement (blocky-drusy sparite), and sometimes by silica. Both benthic and planktonic well preserved foraminifera show high abundance (Figs. 5a-b), together with smaller amounts of echinoderm fragments, micritized bioclasts (peloids) and fragmentary calcareous algae. This lithofacies lacks micas and quartz.

Sedimentary structures and bedding.- This lithology lacks most of the internal sedimentary structures found in the lithotypes mentioned above, but displays a well defined erosional base. Small scale water escapement structures was noted in one layer. No vertical differences in grain size has been measured within grainstone beds.

Calcareous claystone (marlstone)

This lithofacies is characterized by a light yellow-grey, massive, calcareous rich claystone (>20% $CaCO_3$), which displays a high fissility in outcrop. Micro fabric has a random appearance i.e. clay particles are not aligned parallel to bedding. Among biogenic structures only *Chondrites* burrows occur. Beds are often about 5-10 cm thick.

Green claystone

Strata of this dark olive-green lithology seldom reaches greater thickness than 1-2 centimetres. It is well weathered and often displays high fissility. No biogenic or primary sedimentary structures could be observed. Except from colour it differs from calcareous claystone in three ways. The $CaCO_3$ content is only 8%. Micro fabric studies reveal a well ordered fabric, were clay particles often are aligned parallel to bedding. Further, layers are always less thick (1-2 cm) than the thickness of calcareous claystone.

Clay mineralogy

Throughout the section illite together with smectite-chlorite mixed layers occur. However, slight differences in clay mineralogy among the different lithotypes can be measured. The coarser, terrigeneous bearing parts are dominated by illite but also contain minor amounts of smectite-chlorite mixed layers. In contrast, the fine grained clayey parts contain illite and smectite-chlorite mixed layers in equal amounts.

Interpretation

The combination of different lithofacies, sedimentary structures and resedimented shallow-water microfossil species in a deep-water trace fossil assemblage (*Nereites* ichnofacies) favours an interpretation of turbidite setting to the studied area. This interpretation is also the classical one for these deposits and they are referred to as turbidites by several other authors (e.g. Abbate & Sagri 1970; Parea 1975). A vast amount of papers have been published during the late 20th century, concerning turbidites and their genesis, i.e. the turbidity current. As the most striking evidence in recognizing turbidites in field commonly is found in the vertical succession of sedimentary structures, several facies models and classification systems have been proposed for turbidites (e.g. Pickering *et al.* 1986; Ghibaudo & Vanz 1987). A widely accepted facies model for this pupose is that of Bouma (1962). His idealized turbidite sequence can be hydrodynamically interpreted as resulting from one single resedimentation event that deposited progressively finer grades of sediment and gave rise to different sedimentary structures as the flow velocity and sediment carrying power decreased (Lowe 1982). Five structural divisions, with decreasing grain size upward, form the facies model of Bouma (1962): 1) a massive to graded division (Ta), often with sharply defined, erosive or loaded base. 2) A plane-parallel laminated division (Tb), which grades into 3) a cross-laminated and/or convolute bedded division (Tc). Then follows again, 4) a plane-parallel laminated division in finer fraction (Td), and on top, 5) a pelitic interval without any sedimentary structures (Te). In Boumas (1962) facies model for turbidites no criteria were given for the distinction between the pelitic (Te) division, i.e. the fine-grained material deposited from the tail of a turbidity current, and the hemipelagic or pelagic facies, which represents the most common example of an interturbidite layer (Hesse 1975). Consequently, the Te part is sometimes subdivided (Walker 1984) in a Te_t part, which represents the mud fraction introduced by the turbidity current, and a massive to bioturbated mud, of pelagic or hemipelagic origin (Te_h). The different divisions form intervals, which could contain any, but at least two of the five divisions. A Bouma sequence referres to a complete succession of all divisions.

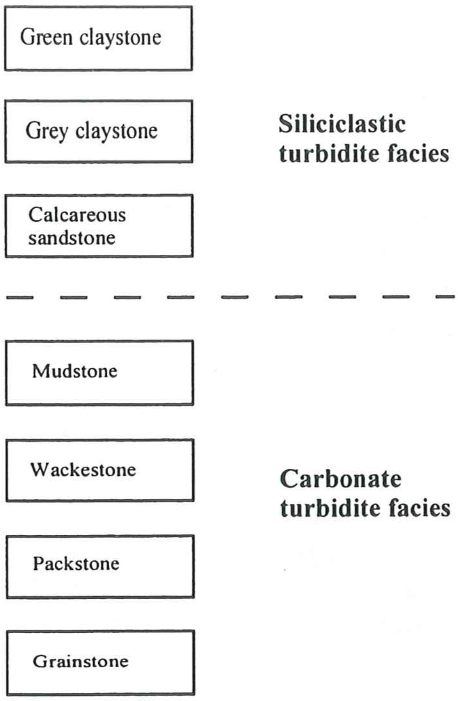

Fig. 6. The relation between the various lithofacies and the siliciclastic- and carbonate turbidite facies, in which they are the components.

Description and interpretation of turbidites and facies

The vertical sequence of internal sedimentary structures in the investigated section can easily be applied to the Bouma sequence. The turbidites are mainly of two types, with some modifications respectively. They are here divided in two different compositionary facies, namely, siliciclastic turbidite facies and carbonate turbidite facies, in which the seven lithofacies described above are divided (Fig. 6). These two turbidite facies can both be subdivided in one subfacies respectively, due to bed thickness, grain size and present Bouma divisions (siliciclastic turbidite facies) or to composition and grain size (carbonate turbidite facies). The hemipelagic clays represent a third facies but are here described within the siliciclastic turbidite facies though they together forms the best developed Bouma sequence.

Siliciclastic turbidite facies

The most striking well developed turbidites belongs to the siliciclastic turbidite facies were the lower divisions of Bouma (1962) are clearly displayed in the fine grained calcareous sandstone. This is at best of erosional character with a very small (?normal) grading (less than five millimetres), representing Bouma division A (Ta). The graded division develops upwards to plane-parallel lamination (Tb), typically with a laminae thickness of one to two millimetres. The Tb division is often the best developed part, and by far the most common internal structure of turbidites in the section. It is often continued throughout the bed without any interuptions. The parallel lamination developes upwards into small scale cross lamination (Tc). In all levels of this type, the cross lamination represent a small time interval as suggested by its mean thickness (1 cm), and then, again developes into plane-parallel lamination (Td). The structures mentioned above are very small scaled and together they embrace no more than a few centimetres. Lithology now changes to the grey, carbonate rich claystone, typically with a lesser thickness than the underlaying sandy parts. This claystone probably represents the finest fractions (pelitic interval) introduced by the turbidity current (Te_t). On top, the green claystone, interpreted as representing hemipelagic facies (Te_h), complete the turbidite sequence. The green claystone seldom exceeds more than two centimetres in thickness, and typically the thickness of the whole sequence seldom exceeds 20 centimetres. The internal divisions are much similar to eachother regarding thickness, colour and structures between different turbidites within this facies. Often, there is an abrubt, distinct boundary between the more sandy intervals (Ta-Td) and the pelitic division (Te_t). According to Stow (1986), such a break is a quite common feature in relatively pure carbonate systems, probably as a cause of lack of a specific grain size in the source material or by characteristics of the turbidity current (Bouma 1962). It does however not invalidate the idea of succession of structure intervals (Bouma 1962). However, in some siliciclastic laminated beds, laminae thickness decreases upward (fining-upward) to paper laminated, organic rich flakes, which in turn grade into the calcareous claystones (i.e. the pelitic interval). Further, most layers in this facies lack or have a reduced basal graded part (Ta). These small scale turbidites occur in several modifications and are often alinged in a repetitive pattern, typically with an upward decrease in $CaCO_3$ content (Fig. 7). The complete Bouma sequence described above is out of the ordinaries. The siliciclastic turbidite subfacies which is less represented consists of thick (maximum 0.5 m) top-absent turbidites where the graded part can extend for more than 30 centimetres. Flute casts, convolute bedding (Tc) and load casts are well developed (Fig. 8). Amalgamations of the basal division (Ta) occur. The best developed turbidite in this subfacies is an erosive Ta-Tb-Tc sequence (Fig. 9). Several modifications occur within these two facies (Fig. 10)

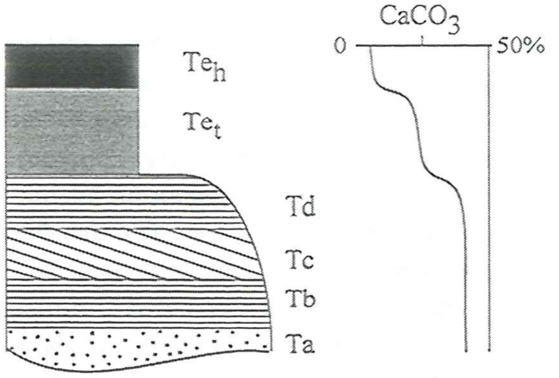

Fig. 7. Upward decrease in $CaCO_3$ content within turbidites of the siliciclastic turbidite facies as a response to the sedimentation rate, which decreases upward through one turbidite.

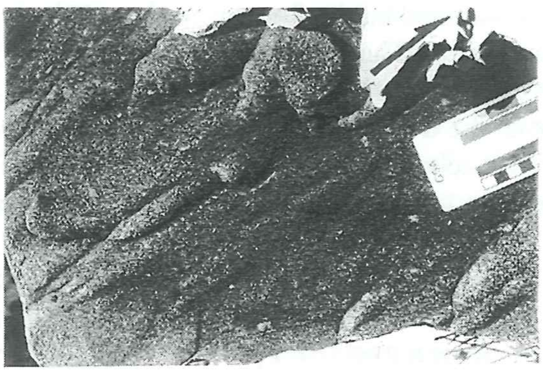

Fig. 8. Flute cast and load cast structures on the sole of coarse calcareous sandstone. Palaeocurrent direction marked by arrow. Scalebar in centimetres.

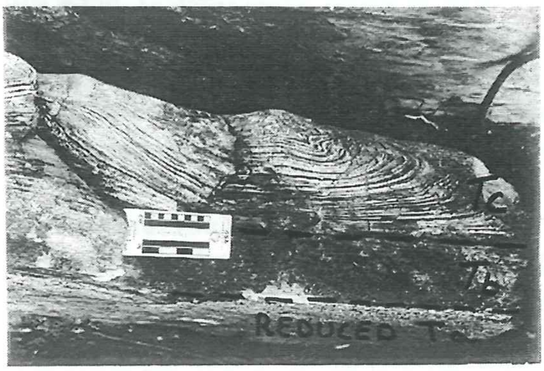

Fig. 9. Thick calcareous sandstone, within siliciclastic turbidite facies displaying a reduced Ta division and well developed laminated (Tb) and convoluted (Tc) divisions. Scalebar is 1 dm.

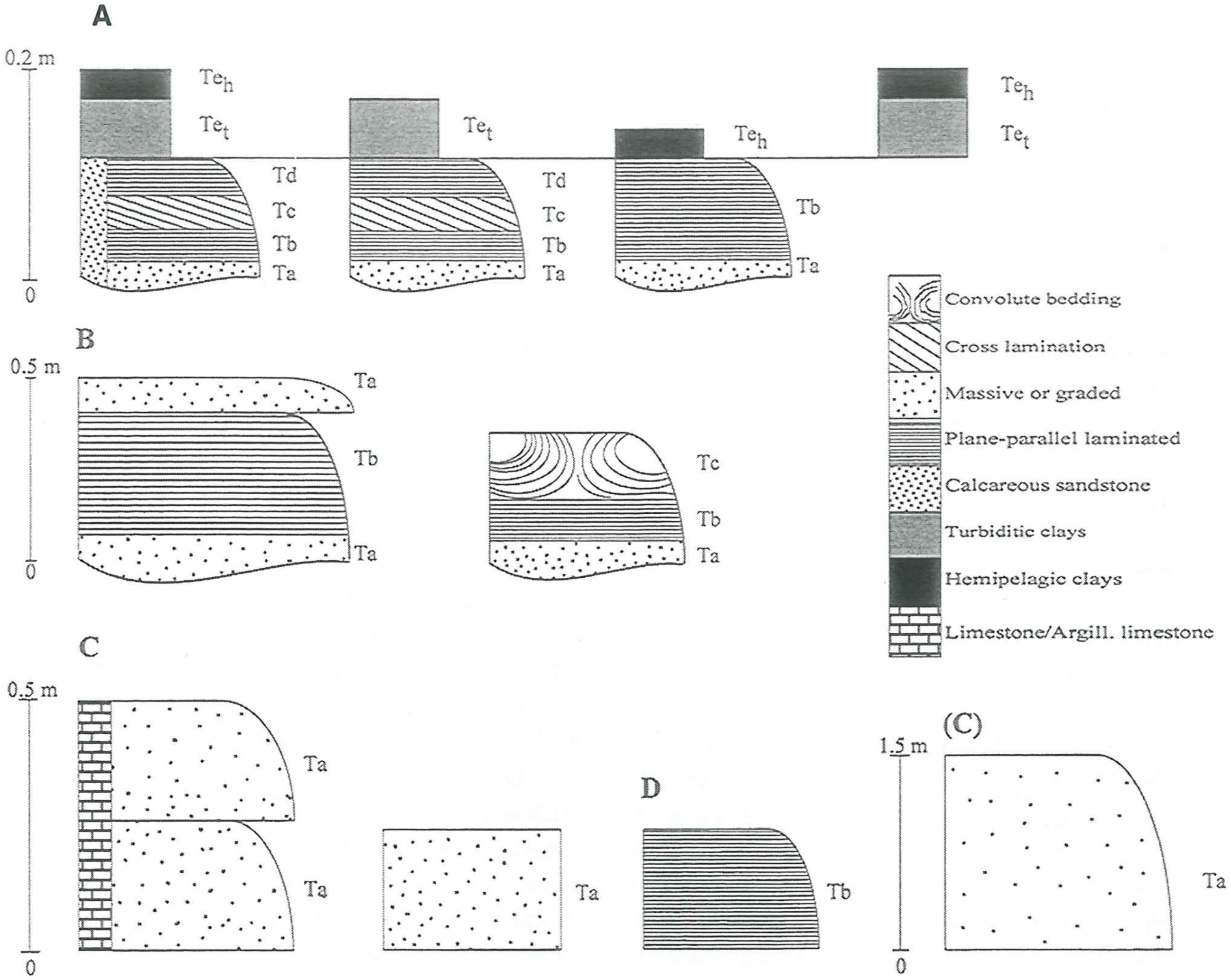

Fig. 10. Schematic illustration on variations of siliciclastic turbidite facies (A) and carbonate turbidite facies (C) and their subfacies, (B and D respectively) seen in the Armorano outcrop. Internal sedimentary structures are not to scale.

Carbonate turbidite facies

The carbonate turbidite facies (limestones and argillaceous limestones) display a more poorly developed sequence (Fig. 10), and are also less abundant compared to the siliciclastic facies in numbers of turbidites (thickness equal). It lacks the vast terrigenous influx and the erosional sedimentary structures, that characterized the siliciclastic turbidite facies. Primary sedimentary structures are much less abundant, and the facies generally displays thicker layers compared to the siliciclastic facies. The components (i.e. divisions) in carbonate turbidites are not easily distinguished. Often they appear as single thick layers (maximum thickness is 1.5 metre), which could be massive or slightly graded (Ta), and as amalgamations of these basal parts. This division are sometimes succeeded by the grey (Te$_t$) and the green (Te$_h$) claystones in the same succession as in the siliciclastic turbidite facies. However, these uppermost divisions (Te$_t$ and Te$_h$) may not be a part of the carbonate facies, but only to the siliciclastic turbidite facies. In that facies they simply would represent base-missing turbidites, while the turbidites of the carbonate turbidite facies in this case only should represent the lower divisions of the Bouma sequence. An indication that the pelitic interval are bound to the siliciclastic facies is the fact that carbonate turbidites versus siliciclastic turbidites in the Monte Sporno area are derived from different source areas (Parea 1975). The uniform thickness, colour and composition of the pelitic interval (Te_t) suggests the same provenance for all of them i.e. they should all belong to one facies. This must be the siliciclastic turbidite facies though these lithotypes apparently merge into eachother in some of the turbidites of this facies. Another consideration that favours this interpretation is that they display a very repetitive pattern together with basal divisions only in the siliciclastic turbidite facies and finally, because the thickness of claystones are well related to the thickness of underlaying sandy parts and that it therefore logically could be placed in one turbidite succession of Bouma divisions.

The carbonate turbidite subfacies differs from the carbonate turbidite facies in several aspects. Grains (bioclasts) are coarser (surprisingly well-preserved) and intergrain areas are mostly of sparitic character with a blocky and occasionally drusy texture. Further, the benthic foraminifera belong mainly to this facies, and also minor amounts of quartz are present. Finally, slight differences in provenance are assumed. Beds could be massive or plane-parallel laminated (Ta, Tb). Small scale water escape structures were found in this facies.

Discussion

The depositional environment has shown to be of importance for the distinction between the turbiditic and non-turbiditic facies in calcareous flysch sequences (Hesse 1975). Some aspects on the depositional environment for the different flysch zones as a tool for distinction between different facies is therefore needed. The flysch zones of the Northern Apennines are divided (Mutti *et al.* 1984) in typical and atypical flysch zones, where the former is the calcareous flysch and the latter represents the siliciclastic flysch. According to Mutti *et al.* (1984) and Bernini *et al.* (1994) the calcareous flysch was deposited near or below the calcite compensation depth (CCD). Another consideration is that the many units of calcareous flysch in the Northern Apennines all were deposited below the CCD (G. Parea, personal communication 1995). However, the primary geological controls on deep-sea sedimentation are sedimentary supply, the tectonic setting and sea-level fluctuations (Stow 1986), but for the biogenic sediments, the CCD could represent another controlling factor, or is at least a limitation to the distribution of biogenic facies. Carbonates transported by mass gravity flows are likely to survive below the CCD, because of the relatively quick mode of deposition, and by covering of terrigeneous material (cf. Hesse 1975). Consequently, the upward decrease of $CaCO_3$ content through turbidites in the siliciclastic turbidite facies and the overlying hemipelagic facies are directly related to, and reveal, the different depositional mechanisms. The deposition of the pelitic division (Te_t) is slow and this part of the turbidite should therefore be more affected by dissolution of $CaCO_3$, than the underlying divisions (Ta-Td). The upward decrease in $CaCO_3$ content through turbidites (Fig. 7) is so a function of the average sedimentation rate. Consequently, the hemipelagic facies has the lowest concentration of $CaCO_3$.

The hemipelagic facies in calcareous turbidite systems represents an useful tool when trying to judge whether the turbidites were deposited above or below the CCD (e.g. Scholle 1971; Hesse & Butt 1976). The discrimination by Hesse & Butt (1976) is based on a simple and obvious criterion. Accordingly, hemipelagic mudstones free from $CaCO_3$ were interpreted to indicate deposition below the CCD, while carbonate-bearing hemipelagites indicated deposition above the CCD. The green claystones in the Armorano outcrop were here in interpreted as representing hemipelagic facies for several reasons. It represents the less calcareous lithotype in the

Armorano outcrop, but its $CaCO_3$ content is not neglectible (8%). This indicates that deposition took place above the CCD. The sediments original $CaCO_3$ content is not known, and it may have been deposited below the CCD and received its $CaCO_3$ content during late diagenetic events. However, with its present composition it represents the only sediment in the section, which could have settled down to a depth near the CCD, and this is a faint indication that it is hemipelagic in origin. The more well ordered microfabric compared to the grey claystone, which is considered to be of turbiditic origin, colour, bed thickness and its role as a recurrent facies that complete Bouma sequences, form an additional support to the interpretation as representing hemipelagic facies. Further, there are differences in clay mineralogy between the hemipelagic and the turbiditic facies, which could be used as a tool for distinction between these two facies. The dominant clay mineral in the basal divisions of the siliciclastic turbidites is illite, while smectite-chlorite mixed layer only occur in minor amounts. In the overlying hemipelagic clay, there are equal amounts of illite and smectite-chlorite mixed layers. Similar conditions have been reported by Bouquillon & Chamley (1986, as referred to by Chamley 1989). Presence of quartz and feldspar in the hemipelagic clays excludes a distal pelagic origin. Interesting parallels could also be drawn to certain Cretaceous turbidite formations in the East Alps, where there is a striking resemblance to the siliciclastic turbidite facies in the Armorano outcrop, i.e. sandy basal parts displaying the Tb-Td divisions of Bouma, overlain by a grey marlstone and dark green hemipelagic claystones (Hesse & Butt 1976).

Use of clay fabric (clay flake orientation) to distinguish hemipelagic from turbiditic sediments has shown to be successful as a complement to other classical distinguishing characteristica for the top divisions in the Bouma sequence (O'Brian *et al.* 1980). These characteristica are commonly microfossil content, colour, bed thickness and grain size distribution (Hesse 1975). The parallel flake orientation of the clay minerals can be the result of clay deposited in a dispersed state (pelagic/hemipelagic clay settling), because of the low clay concentration in sea water. Additionally, a random clay fabric could be due to rapid deposition in a flocculated state, i.e. of turbiditic origin (cf. O'Brian *et al.* 1980). However, it must be noted that small scale bioturbation could also cause disturbance to the clay micro fabrics.

The grey claystone is here interpreted as deposited by the turbidity current. Its high $CaCO_3$ content (20%), quartz and feldspar content and more disordered microfabric compared to the hemipelagic claystones, suggest this origin, while structurless appearance, grain size and its regular place in the vertical succession suggest that it represent the Te_t division (pelitic interval) of Bouma. The remaining lithotypes and divisions (Ta-Td) are so the result of the main turbidity current.

The rhytmic appearance of the section is obvious (Fig. 4). This means that the two different turbidite facies described above always occur as superimposed on eachother in a regular pattern (Fig. 4). The siliciclastic turbidite facies dominates and is commonly (except in the subfacies which only is rarely intercalated throughout the section) a repetitive sequence of thin-bedded turbidites, often forming rather complete Bouma sequences. The carbonate turbidite facies and subfacies on the other hand, represent relatively thick top-absent turbidites, generally intercalated in the siliciclastic facies as single beds at regular vertical intervals. Both facies describe a coarsening upward sequence with respect to bed thickness (Fig. 11). These facts give rise to several questions concerning distality and provenance for the different facies.

Facies associations and provenance

The Monte Sporno Unit has been referred as representing Basin plain facies association by Parea (1975), i.e. a distal facies. Typical for these types of deposits are thick monotonous sequences of thin bedded, fine grained turbidites, with great lateral continuation (cf. Walker 1984; Stow 1986). The lower Bouma divisions (Ta-Tb) are in general absent (Walker & Mutti 1973; Stow 1986). Other criteria useful for distinguishing distal from proximal environments were listed by Walker (1967) who stated that amalgamations of sandstones are rare and that laminations and ripples should be well developed. Consequently, the small grain size and the low sand/shale ratio (Parea 1975) of the Monte Sporno sequence are well in line with the idea of a distal facies. However, the Ta-division is rather common in the investigated section, and in the siliciclastic turbidite subfacies it reaches a considerable thickness. Thick massive or slightly graded divisions (Ta) are even more common in the carbonate turbidite facies. Amalgamations of basal parts occur in both facies and plane-parallel laminations (Tb) are well developed and are also by far the most common of Boumas divisions in the section. It is present in more than 50% of the turbidites. Finally, the alternation of turbidites from different source areas superimposed on eachother suggests a distal environment (cf. Ricci Lucchi & Valmori 1980). To summarize, both distal features and to a lesser extent, more proximal features are to be seen in the Armorano outcrop. To discover trends in distality demands studies of huge vertical sequences. The fact that some turbidites in the outcrop only displays the uppermost or the middle Bouma divisions within one facies is too weak as a base for interpretations on this scale. The thickening upward trend in bed thickness (Fig. 11) shares the same problem. The section is vertically to short to determine for example cyclicity.

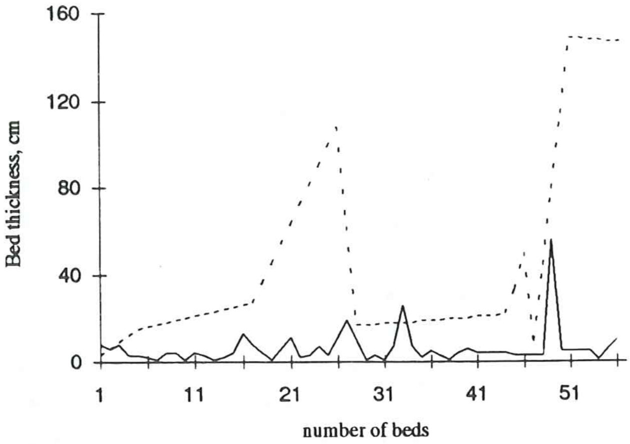

Fig. 11. Thickening upward trends in carbonate- (dashed line) and siliciclastic turbidite facies concerning bed thickness. Note the generally thicker beds of carbonates compared to the sandstone beds.

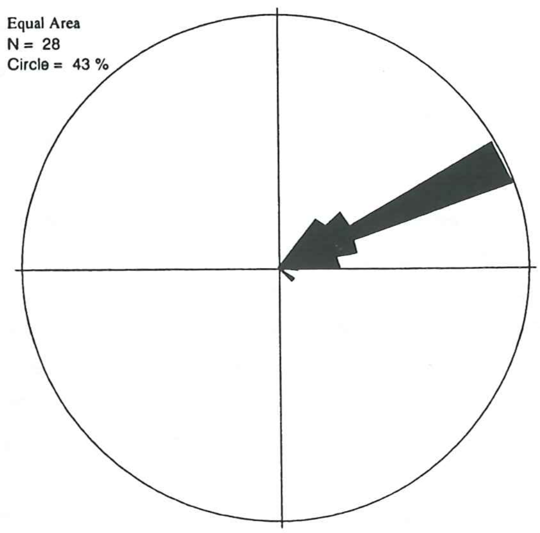

Fig. 12. Paleocurrent directions of the siliciclastic turbidite facies in the Armorano outcrop.

Provenance studies have revealed an intrabasinal source area for the typical flysch (Mutti *et al.* 1984). The paleocurrent directions in the Armorano outcrop indicates a west-southwestern source area for the siliciclastic turbidite facies (Fig. 12). This coincide well with earlier measurements (e.g. Parea 1975). The carbonate turbidites, on the other hand, indicates a source area roughly towards north for the Monte Sporno Unit (Parea 1975). However, there are differences between the carbonate turbidite facies and its subfacies, which could depend on slight differences in the location of source area. Coarse grained carbonate turbidites (subfacies) derives apparently from a shallow-water environment as they possess quartz in notable amounts, echinoderm fragments and large benthic foraminifera (e.g. *Nummelites*, *Alveolina* and *Discosyclina*). These genera were restricted to an inner shallow platform environment (Sartorio & Venturini 1988). The fine grained carbonate turbidites (Fig. 5e) have a pelagic appearance, where planktonic foraminifera only, are floting in a micritic matrix (90% micrite). This does not mean that the source area should be different between them in quarter, but the fine grained varieties probably represent resedimentated pelagic limestones, which in the first case were deposited more proximal to the receiving basin.

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