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SYNSEDIMENTARY TECTONICS AND SEDIMENTATION IN THE TERTIARY PIEDMONT BASIN, NORTHWESTERN ITALY

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Riassunto. Questa nota concerne l'evoluzione della porzione orientale del Sottobacino delle Langhe (Bacino terziario ligure-piemontese) durante l'Oligocene superiore e la parte basale del Miocene. L'area presa in esame è situata tra Roccaverano e Mombaldone, sul versante occidentale della valle del F.Bormida di Spigno (v. carta geologica allegata). La storia geologica di questa regione è fortemente condizionata dal tettonismo sinsedimentario, i cui effetti appaiono particolarmente evidenti in tre "momenti" scelti come esemplificazione delle condizioni esistenti nell'area durante l'intervallo tempo preso in esame. Il "momento 1" (Oligocene superiore pro parte) è caratterizzato dall'individuazione di blande anticlinali, dirette WNW-ESE e NW-SE, coinvolgenti essenzialmente peliti emipelagiche. Esse danno origine a zone di alto che controllano la distribuzione areale della sedimentazione torbiditica (Alto del T.Ovrano) e di uno spesso "slump-sheet" pelitico (Alto del M.Pisone). Il "momento 2" (Aquitaniano) è contrassegnato dalla individuazione di un semi-graben (Semigraben di C.Mazzurini) separato da faglie di crescita, dirette W-E e WNW-ESE, dal contiguo Alto del T.Ovrano, sviluppato a nord, e raccordato attraverso una rampa a debole inclinazione ad una zona di alto denominata Alto di Rocchetta, collocata a sud. Entro il semi-graben si incanalano correnti di torbidità e debris flows, mentre lateralmente domina la sedimentazione di peliti emipelagiche. Durante il "momento 3" (parte inferiore del Burdigaliano) il depocentro della depressione compresa tra le due zone di alto precedentemente citate si sposta verso sud, e si assiste all'individuazione tra di esse di un'ampio truogolo (Truogolo di Piantivello) a sedimentazione torbiditica. La topografia fortemente irregolare dell'area viene in seguito progressivamente livellata e risulta definitivamente regolarizzata con l'inizio della deposizione della Formazione di Cortemilia (parte superiore del Burdigaliano).

Abstract. The Late Oligocene/Early Miocene tectonic and sedimentary evolution of the eastern sector of the Langhe Sub-Basin (Tertiary Piedmont Basin) is proposed and discussed. The area is located between the villages of Roccaverano and Mombaldone, along the western side of the Bormida di Spigno River Valley (see attached geologic map). Synsedimentary tectonics strongly influenced the geologic evolution of the region during the time span examined, being particularly evident at three specific "times" that were chosen as models. During "Time 1" (Late Oligocene) gentle anticlines, aligned WNW-ESE and NW-SE, started to form, affecting only hemipelagic mudstones and creating structural highs that controlled the areal distribution of both turbidites (i.e. T. Ovrano High) and a thick pelitic slump sheet (i.e. M. Pisone High). During "Time 2" (Aquitanian) the C. Mazzurini Half-Graben developed, separated by W-E and WNW-ESE growth faults from the M. Ovrano High to the north and gradually connecting, through a gently sloping ramp, with the Rocchetta High to the south. Turbidity currents and debris flows were channeled into the half-graben, while hemipelagic limestones were deposited onto the adjacent higher areas. During "Time 3" (Early Burdigalian) the depocenter of the depression shifted southward, while the half-graben evolved into a wide trough (Piantivello Trough) characterized by turbidites. Subsequently, the strongly irregular topography was progressively leveled to the quite homogeneous landscape on which the Cortemilia Formation (Late Burdigalian) was deposited.

Introduction.

Following the Eocene Ligurian or Mesoalpine collisional event, a wide episutural basin, the Tertiary Piedmont Basin (TPB), formed along the internal margin of the Western Alps (Northern Italy). The TPB developed on a basement made of allochthonous Alpine ("Briançonnais" and "Piemontese" Zones) and Apenninic ("Liguride Complex") units, overthrusted onto the "Insubric" Domain. Sedimentation started in the easternmost part of the TPB with a Late Eocene transgression and extended to the entire basin only during the Early Oligocene.

The tectonic and sedimentary evolution of the TPB, located at the border between the Alps and the Apennines, was studied by several authors, in particular Gelati & Gnaccolini (1984), Laubscher et al. (1992), Biella et al. (1992), Castellarin (1992), Vanossi et al. (1994), Falletti et al. (1995), Dela Pierre et al. (1995), Di Giulio & Galbiati (1995), and Mutti et al. (1995).

The area discussed presently belongs to the easternmost part of the Langhe region, which in turn represents the western part of the TPB (Fig. 1). The Langhe depositional history began during the Early Oligocene with continental to shallow-marine conglomerates and sandstones. It is only during the Late Oligocene,

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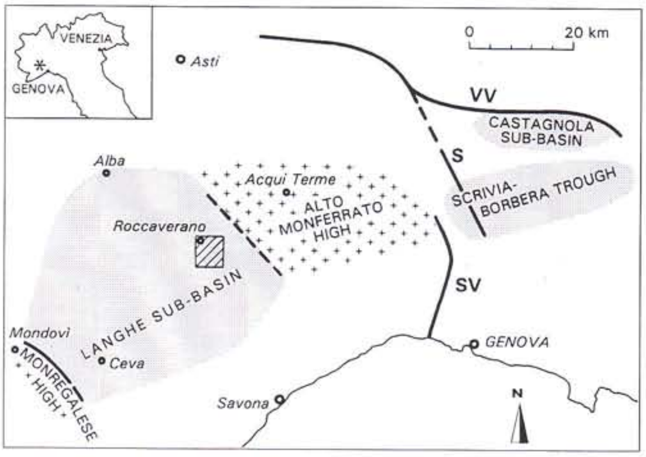

Fig. 1 - Major paleogeographic domains in the Tertiary Piedmont Basin during the Late Oligocene-Early Miocene. Inset shows the study area. VV = Villavernia-Varzi lineament; SV = Sestri-Voltaggio lineament; S = Scrivia lineament.

though, that the Langhe Sub-Basin differentiated from the Alto Monferrato High to the northeast and from the Monregalese High to the southwest, because of its higher subsidence and sedimentation rates (Gnaccolini & Gelati, 1996). In fact, the Late Oligocene succession in the Langhe Sub-Basin, made of alternating turbidite sandstones and hemipelagic mudstones, reaches 1,000 m in thickness. In contrast, the same time interval is recorded by a few tens to 150 meters of prevailing hemipelagic mudstones to the east (Alto Monferrato High) and by a succession of predominant shelf deposits, up to 200 m thick, to the west (Monregalese High) (Gelati & Gnaccolini, 1996).

Synsedimentary faults made the structure of the Late Oligocene Langhe Sub-Basin very complicated, as shown by differences in facies distribution, sediment thickness, paleocurrent direction and sandstone composition (Gelati & Gnaccolini, 1980; Cazzola et al., 1981; Cazzola & Rigazio, 1983; Cazzola et al., 1984; Cazzola & Sgavetti, 1984; Cazzola & Fornaciari, 1990; Gelati et al., 1993; Gnaccolini e Rossi, 1995).

Sedimentation was generally continuous in the Langhe region at the Oligocene-Miocene boundary, whereas a wide hiatus may be observed on the Alto Monferrato High (d'Atri, 1990; d'Atri et al., 1997; Piana et al., 1997).

A succession of very extensive turbidite units, more than 2,000 m thick, was deposited in the Langhe Sub-Basin from the Late Burdigalian to the Serravallian. During this interval a more regular basin structure is present, as indicated by facies distribution, paleocurrent direction and sandstone composition. On the Alto Monferrato High to the east, the Langhian/Serravallian interval is recorded by outer-shelf mudstones followed by shallow-marine hybrid arenites (Caprara et al., 1985; Ghibaudo et al., 1985).

Sedimentation of prevailing open-sea mudstones continued in the Langhe Sub-Basin during the Tortonian, punctuated by very important regressive and transgressive events from the Late Miocene (Sturani, 1978) up to the Pliocene.

The present study focuses on the complicated architecture and tectonic evolution of a key-area located in an episutural basin which seals the transition zone between the Alpine and Apenninic chains ("Ligurian Knot"; Laubscher et al., 1992), during a time-slice (Late Oligocene-Early Miocene) corresponding to the beginning of the Neoalpine tectonic phase. The study area is located at the eastern side od the Langhe Sub-Basin, close to the Alto Monferrato High, between the villages of Roccaverano and Mombaldone. A geologic map, scale 1:15,000 is attached.

The Oligocene/early Miocene succession of the Roccaverano-Mombaldone area: stratigraphic units, depositional setting and age.

The official geologic map (Sheet 81 "Ceva", Geologic Map of Italy, 1:100,000, 1970) which includes the area between Roccaverano and Mombaldone, in the eastern Langhe Sub-Basin, depicts a continuous and regular stratigraphic succession made from bottom to top by the Molare, Rocchetta, Monesiglio and Cortemilia formations. The units reportedly extend to the entire Langhe Sub-Basin and document the onset of sedimentation onto the pre-Cenozoic substratum, first in continental to transitional environments (Molare F., Oligocene), and subsequently in open sea hemipelagic and/or turbidite environments (Rocchetta, Monesiglio and Cortemilia formations, Late Oligocene/Early Miocene).

Extensive fieldwork in the Roccaverano-Mombaldone area highlighted a very complex geology: sudden lateral changes of facies and thickness, controlled by faults and folds related to synsedimentary tectonics, demanded a revision of the entire stratigraphic interval bracketed by the Molare and Cortemilia formations. Several informal units, which crop out in specific sectors of the study area, were introduced. These units are described according to the stratigraphic scheme of Fig. 2. The micropaleontologic analysis were carried out by M. R. Petrizzo (bio-and chronostratigraphy according to Bolli & Saunders, 1985, and Iaccarino, 1985).

The present study highlights the complexity of the Langhe Sub-Basin, particularly during the Late Oligocene/Early Miocene time span. In fact, several sectors characterized by stratigraphic successions very different in facies, thickness and sedimentation rates, were recognized in an area only 40 km² wide. The sectors, initially only faintly outlined, soon became evident and separated by systems of faults, at present sometimes still ea-

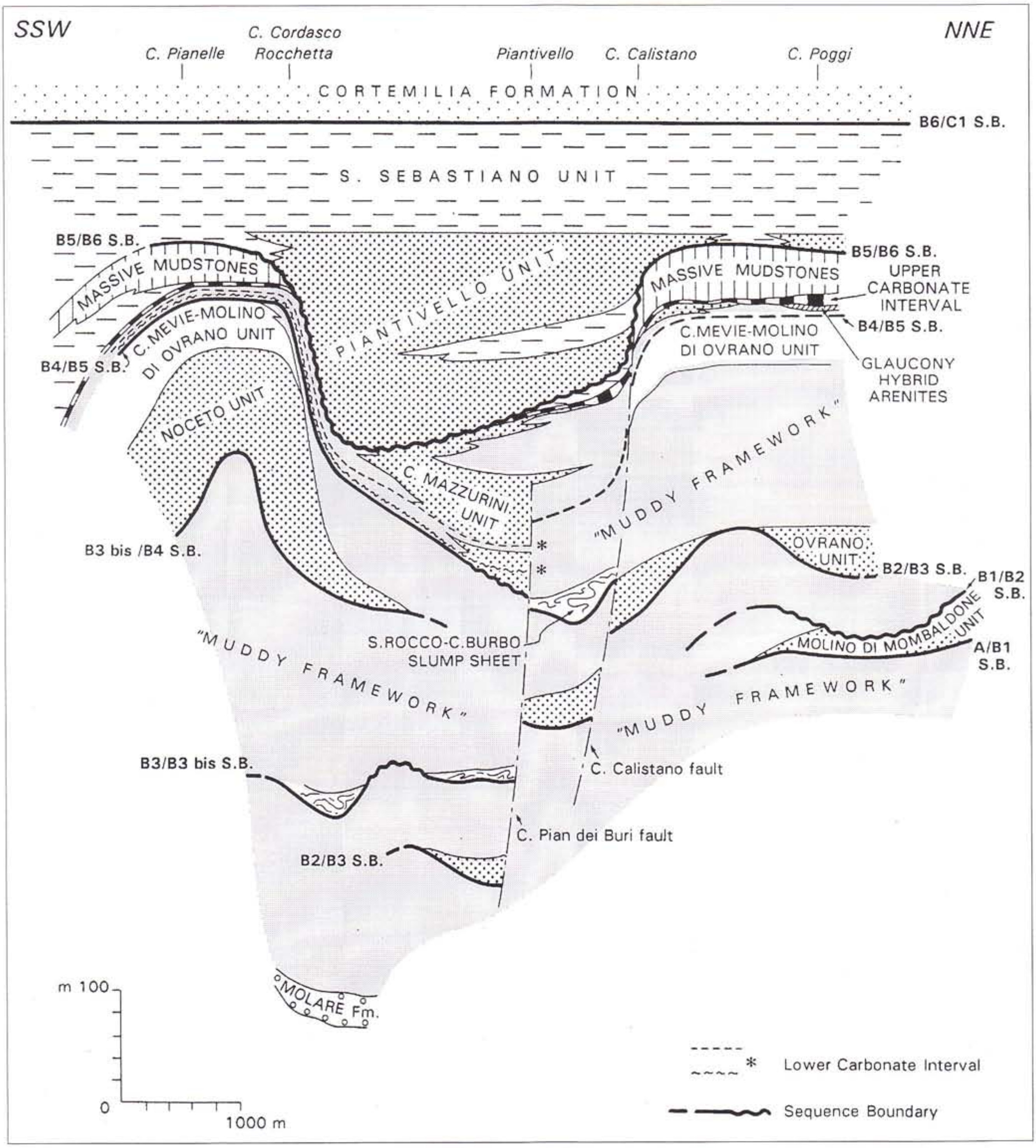

Fig. 2 - Stratigraphic scheme in which the lower limit of the Cortemilia Formation was chosen as datum. A, B1, B2, etc., refer to the depositional sequences described by Gelati et al. (1993).

sily recognizable, which created a graben or half-graben configuration. Only a detailed geologic survey, coupled with the mapping of some carbonate key-beds intercalated with the prevailing siliciclastic succession, allowed to correlate the deposits outcropping in the different sectors and to draw the stratigraphic scheme of Fig. 2.

The results obtained in the studied area show that the recognition of the geologic evolution of the Langhe Sub-Basin, and possibly of the whole TPB, need renewed, large scale geologic survey, in order to map the most significant lithosomes grouped up to now in the "traditional" formations of the TPB.

A detailed description of each stratigraphic unit, age and depositional setting will be provided in the following pages.

Molare Formation.

In the area under study the Molare F. shows variable characteristics. The most typical succession crops out at the outskirts of Spigno Monferrato, where two distinct portions, separated by an unconformity, are recognizable (Gnaccolini et al., 1990).

The lower portion, some 20 m thick, is composed of poorly sorted, generally subangular, cobble to boulder conglomerates that evolve upwards to well sorted, rounded, pebble conglomerates. A layer made of aligned coarse clasts, followed by a massive arenaceous bed with rare fossil remains, locally overlies the conglomerates, separated from them by an erosional surface.

The upper portion starts with a layer 3 to 8 m thick made of conglomerates and breccias with blocks up to 1 m in size, which unconformably lies on the massive, fossiliferous sandstone, or on the pebble conglomerates or even directly on the pre-cenozoic basement. Conglomerates and breccias are locally overlain by a small (maximum thickness 2 m) biolithite-biocalcarenite lens made of corals, corallinacean algae and ostreids, in turn covered by sandy conglomerates with coral and ostreid fragments. Mostly fine, fossiliferous (macroforaminifera), bioturbated sandstones, some 15 m thick, follow and locally overlie directly the conglomerates and breccias at the base of this interval.

Depositional setting. The lower conglomerates and breccias are interpreted as alluvial deposits that filled the incised valleys. The following deposits record a first attempt of marine ingression, with the unconformity between the pebble conglomerates and topmost sandstones interpreted as a ravinement surface. The very coarse sediments at the base of the upper portion suggest a temporary setback to the alluvial environment, followed by a new and definite marine ingression.

Age. The unit may be dated to the P20 Zone on the basis of the paleontologic content of samples from the overlying mudstones collected near Spigno Monferrato, which contain an association with *Globigerina ampliapertura*. This would limit the age of the Molare F. to the Early Oligocene.

Rocchetta-Monesiglio Group.

The sedimentary succession delimited by the Molare F. at the bottom and by the Cortemilia F. at the top is referred to the Rocchetta and Monesiglio formations in the Sheet 81 "Ceva" of the Italian Geologic Map (1970). In the study area these formations are not easily separable since the lowermost arenaceous bodies, considered in the literature as a marker for distinguishing the upper unit from the lower one, appear in different stratigraphic positions and have a very irregular lateral distribution. For the reason above stated, the forementioned succession will be indicated in this paper as Rocchetta-Monesiglio Group. One of the most interesting aspects of the Rocchetta-Monesiglio Group in the study area is the presence of two, well separated, carbonate intervals, referred to as Lower and Upper Carbonate Interval respectively, which allow the subdivision of the Group into two parts: the lower part contains the Lower Carbonate Interval and is delimited by the Molare F. at the bottom and by the Upper Carbonate Interval at the top; the upper part starts with the Upper Carbonate Interval and is delimited by the Cortemilia F. at the top.

Lower part of the Rocchetta-Monesiglio Group.

This succession is made up of a "Muddy framework" containing, at different levels, intercalations of arenaceous lenses whose lateral extension varies from some hundred metres to several kilometres and whose thickness may excede 300 metres. The "Muddy framework" consists of locally bioturbated, grey, massive mudstones, with planktonic foraminifera, forming monotonous successions up to several tens of meters thick, associated with intervals of more or less uniform alternations of mudstones and thinly bedded sandstones. The sandstone layers show a sharp base, sharp to gradual transition to the overlying pelites and often contain parallel and/or current ripple laminations.

Depositional setting. The fine texture and abundance of planktonic foraminifera indicate hemipelagic deposits that record the drowning of the shallow-water environment represented by the underlying unit. A sharp decrease in the silty fraction and the subsequent appearance of deeply carved erosional surfaces (probably submarine canyons; cf. Gelati et al., 1993, fig. 5) suggest the transition from an external platform to a slope environment.

The thin sandstone intercalations present mostly in the upper part of the succession are the product of low-density turbidity currents, in a slope-to-basin transitional environment, and might be the lateral equivalent to the mostly arenaceous units locally intercalated with the"Muddy framework".

Age. The succession extends from the Early Oligocene to the Aquitanian. The basal part is dominated by a *Globigerina ampliapertura* assemblage, representing the P20 Zone. Biostratigraphic data for the upper part come from the paleontologic content of samples collected at C. Poggi and C. Mevie. In the first locality they contain an assemblage with *Globoquadrina dehiscens, Globigerinoides trilobus, G.trilobus sacculifer, Paragloborotalia*

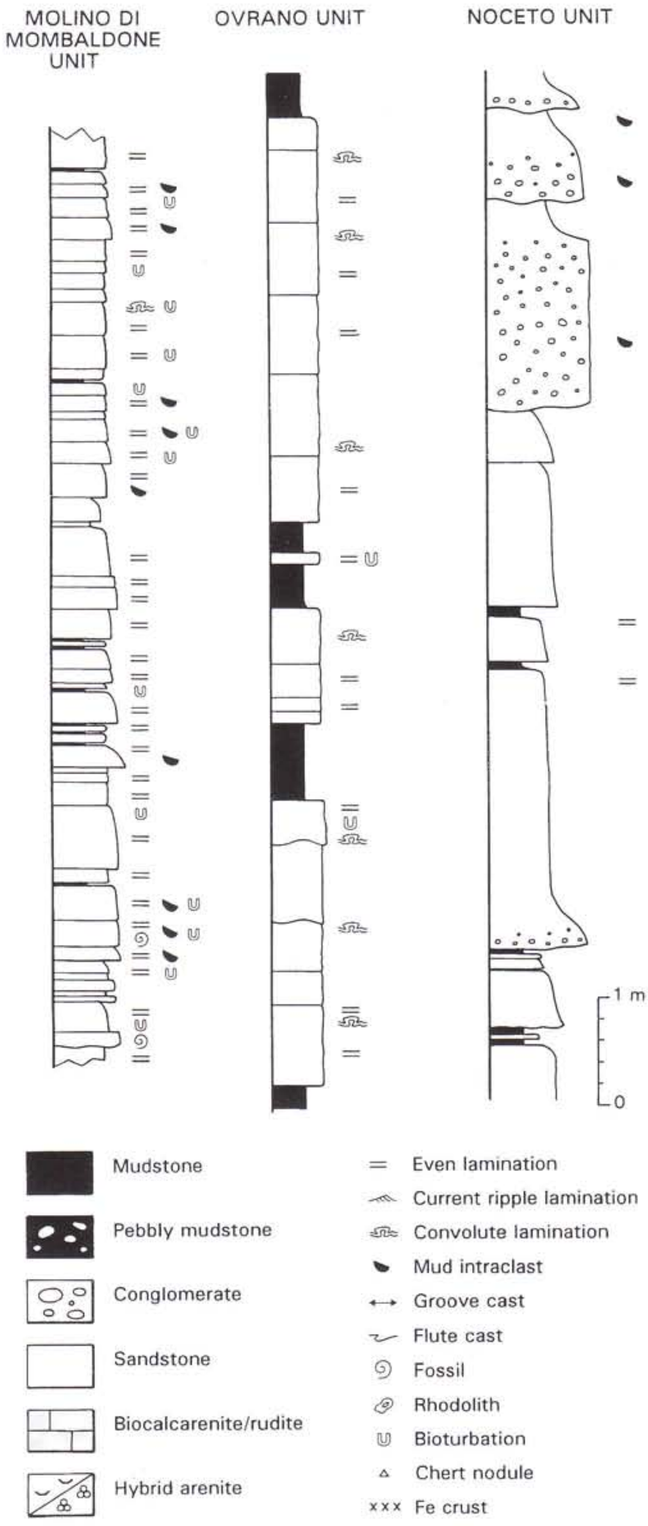

Fig. 3 - Partial stratigraphic sections of the Molino di Mombaldone, Ovrano and Noceto Units.

mayeri, and P.siakensis (N4 Zone). The second locality shows a *Globigerinoides* bloom together with *Paragloborotalia siakensis* and *Globoquadrina dehiscens.*

The following units were identified, from bottom to top, in the succession composed mostly of the "Muddy framework".

Molino di Mombaldone Unit.

The unit is composed of two sandstone bodies extending laterally for up to 1 kilometer. The lower body, up to some 40 meters thick, shows an apparently conformable contact with the underlying pelites. The dominant lithofacies is made up of fine to medium sandstones with faint, parallel to convolute, laminations, in beds from some centimeters up to 40 cm thick (Fig. 3). Strongly subordinate are sandstones made of a medium to medium/coarse basal division, more or less markedly graded, followed upwards by a division with parallel lamination. Massive, medium to fine sandstones are less frequent. Arenaceous layers are generally amalgamated. Pelitic intercalations, if present, are not more than a few centimeters thick. Mud clasts, usually smaller than 5 cm, are frequent and bioturbations are locally abundant.

At the northeast edge of the meander of Molino di Mombaldone the lower arenaceous body is overlaid by an upper arenaceous body characterized by a faint, low-angle cross stratification. This lithosome is not accessible in the field, but a maximum thickness of around ten meters may be estimated.

A deeply cut erosional surface, that reaches the basal part of the lower arenaceous body and is onlapped by a pelitic succession, represents the upper limit of the Molino di Mombaldone Unit in the central part of the meander (Fig. 4). At the northeast edge of the meander a transitional contact with pelites containing arenaceous intercalations is present, while the erosional surface lies higher and affects an entirely pelitic succession.

Depositional setting. This unit is the product of relatively low-density turbidity currents, which formed arenaceous lenses at the slope-to-basin transition. The lower arenaceous body was likely cut by shallow, meandering channels subsequently filled by the sandstones with oblique stratification of the upper arenaceous body.

The deeply-cut erosional surface that delimits the top of the unit (Fig. 4) records a submarine canyon and highlights the transition of the area to a slope environment, likely triggered by tectonic tilting.

Age. Dating to the P21 Zone (Early to Late Oligocene transition) was based on assemblages contained in the upper and underlying pelites, i.e. *Paragloborotalia opima opima* and also *Catapsydrax dissimilis, Globoquadrina tripartita* and *Globigerina venezuelana.*

Ovrano Unit.

The unit is composed of two mostly arenaceous intervals, 31 and 12 meters thick respectively in the T. Ovrano Valley, separated by a mostly pelitic intercala-

Fig. 4 - An erosional surface (e), probably related to the development of a submarine canyon, deeply cuts into the turbidite sandstones of the Molino di Mombaldone Unit (Mo) along the River Bormida di Spigno, near Molino di Mombaldone.

tion, some 10 m thick. The typical lithofacies is formed by fine to very fine sandstones, in beds from 10 cm to 1 m thick, with faint parallel laminations which often become convolute upwards and may extend to the entire thickness of the bed (Fig. 3). Locally, the sediments look massive, likely because of poor preservation that obliterates the original lamination. Bioturbation may be abundant. Arenaceous beds are often amalgamated and may be separated locally by pelitic layers from 30 cm to a few meters thick.

The Ovrano Unit onlaps and levels the gently undulated topography of the underlying pelites (Fig. 5). The transition to the overlying pelites is marked by the sharp decrease of the sandstone/pelite ratio. The Ovrano Unit may be observed laterally in the study area for over 1 km, with a thickness ranging from 0 to 53 m.

Depositional setting. The arenaceous lithofacies of this unit are again the product of low-density turbidity currents. The areal distribution and geometry of the outcrops show that sedimentation was controlled by structural irregularities in the basin, such as gentle highs which became progressively leveled by turbidites.

Age. Dating to the P22 Zone (Late Oligocene) was based on *Globoquadrina praedehiscens, Globigerinoides primordius*, large *Globigerinids* and *Catapsydrax* present in the over- and underlying pelites.

S. Rocco-C. Burbo Slump Sheet.

The S. Rocco-C. Burbo Slump Sheet is contained in the "Muddy framework". It consists of packages of mudstones, with thin arenaceous intercalations, that are folded and distorted or even completely broken into isolated slabs. Thickness varies from 0 to 40 m.

The unit is easily recognizable around the little church of S. Rocco, where it forms a body 10-40 m thick and almost 1 km wide, near C. Burbo, where it extends laterally for 400 m and is up to some tens of meters thick, and on the right side of the Rio della Rocchetta Valley, where it is almost 1 km wide and 20-30 m thick.

Depositional setting. The setting of the two main outcrops appears controlled by two structural highs, located at the northern (T. Ovrano High) and southern (M. Pisone High) edge of the area, respectively (Fig. 10). Packages of mudstones slumped from these highs towards the low areas and an alignment of slump scars formed. These slump scars were overlaid by a new pelitic succession which lies on the older mudstones by means of an angular unconformity (Figs. 11, 12).

Age. The pelites overlying this unit between C. Pian dei Buri and San Rocco, were dated to the P22 Zone (Late Oligocene), based on *Catapsydrax dissimilis ciperoensis, C. unicavus, Globoquadrina tripartita*, and *Globigerina ciperoensis ciperoensis*.

Noceto Unit.

This unit is a conglomeratic-arenaceous body that represents the northeastern end of the "Noceto Turbidite System" (Cazzola & Fornaciari, 1990).

The main lithofacies are (Fig. 3): a) granule to pebble conglomerates with an arenaceous matrix and coarse-tail grading, in beds 0.5-2.5 m thick, with local mud clasts; b) medium to fine sandstones with coarse-tail grading, in beds 0.4-1.3 m thick; locally, near the base, traction carpets were observed; a division with parallel lamination may be present at the top of the beds; c) granule to pebble conglomerates, massive or with more or less evident traction carpets, in beds 1.1-1.5 m thick, passing upwards, gradually or sharply, to mostly medium sandstones; mud clasts locally present.

The unit has a sharp lower boundary which likely corresponds to an erosional surface. A rapid transition to the pelites of the C. Mevie-Molino d'Ovrano Unit

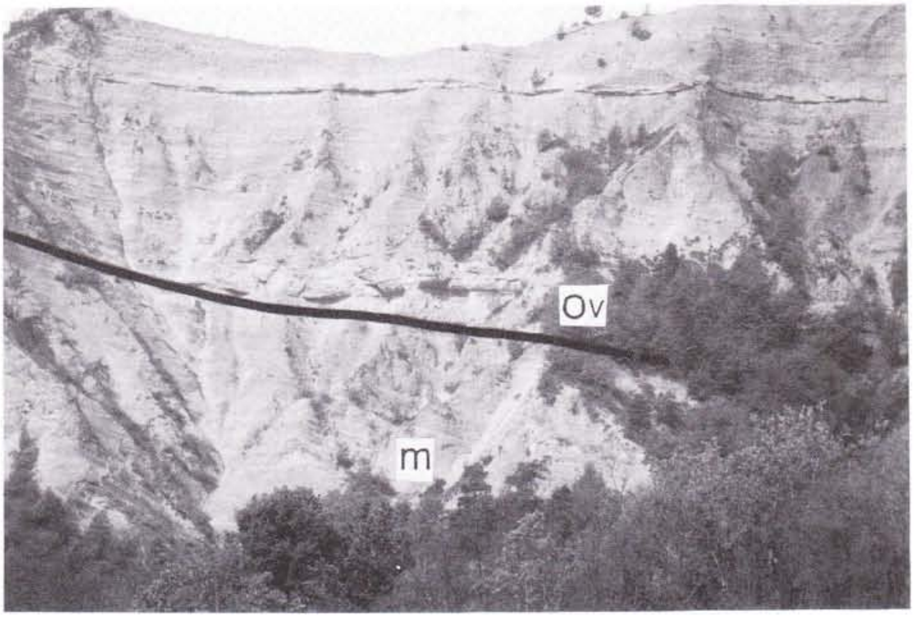

Fig. 5 - The turbidite sandstones of the Ovrano Unit (Ov) onlap the northern side of a gentle anticline developed in the underlying mudstone succession (m), near Molino di Mombaldone.

may be observed at the top. In the study area it extends laterally for about 2 km with a maximum thickness of about 90 m. In the depocenter the thickness reaches 350 m (Cazzola & Fornaciari, 1990).

Depositional setting. The dominant lithofacies in the study area indicate that the unit is the product of high-density turbidity currents. This area represents the northeastern edge of the "Noceto Turbidite System" of Cazzola & Fornaciari (1990), who interpret the system as lobes deposited in a NW-SE structural depression about 15 km wide.

Age. The unit was dated to the P22 Zone (Late Oligocene) based on material found around C. Mevie. In the underlying pelites *Globigerinoides primordius, Catapsydrax dissimilis, C. unicavus,* and *Globoquadrina praedehiscens* were identified, while the overlying pelites yielded the same assemblage, together with fairly common *Globigerina ciperoensis.*

C. Mevie-Molino di Ovrano Unit.

The unit is most typically composed of well lithified mudstones and siltstones rich in crypto- and microcrystalline quartz, rhythmically alternating with mm-to cm-thick fine to very fine sandstones, with local faint ripple laminations. According to d'Atri (1990) the silica might be biogenic.

The unit crops out for over 3 km in the T. Ovrano Valley, where it overlaps continuously the pelites of the "Muddy framework", forming a tabular body about 50 m thick. It crops out again near C. Mevie, at the southernmost edge of the study area, where it is 30 m thick and lies directly over the Noceto Unit. In the T. Ovrano Valley it is covered by a thin pelitic lithozone (uppermost part of the "Muddy framework"), which is in turn overlaid by a discontinuous arenaceous body belonging to the uppermost C. Mazzurini Unit, by the Upper Carbonate Interval or by the Glaucony Hybrid Arenites. Near C. Mevie an apparently continuous transition to mudstones with biocalcarenitic intercalations, comparable with the "Muddy framework" of the Lower Part of the Rocchetta-Monesiglio Group, is recorded.

The unit includes the succession called by d'Atri (1990) and Tateo & Dinelli (1997) "siliceous member" of the Rocchetta Formation, where a sand-size grained volcaniclastic layer was reported.

Depositional setting. The prevailing lithofacies suggest a hemipelagic setting alternating with grain-to-grain deposition by low-density turbidity currents or contour currents.

Age. The unit can be referred to the Late Oligocene. The most complete succession, sampled near C. Poggi, bears the following assemblage: *Globigerinoides primordius, Globigerina* cf.*ciperoensis, Globoquadrina praedehiscens,* and *Catapsydrax* sp. (P22 Zone). In the attached geological map the symbol for the C.Mevie-Molino di Ovrano Unit includes an overlying, thin mudstone lithozone which belongs to the uppermost part of the "Muddy framework". This lithozone contains *Globoquadrina dehiscens, Globigerinoides trilobus, G. trilobus sacculifer, Paragloborotalia mayeri,* and *P. siakensis* (N4 Zone) and can be referred to the Aquitanian.

C. Mazzurini Unit.

This unit is particularly well developed near C. Mazzurini where it reaches a thickness of about 150 m. It is formed by a succession of sandstones and conglomerates, often in amalgamated beds, locally separated by pelitic layers from a few centimeters up to 1 m thick. At least five layers of pebbly mudstones and two biocalcarenitic/biocalciruditic horizons are also observable (Fig. 6). Two tongues belonging to the "Muddy framework" intercalate in the upper part of the unit.

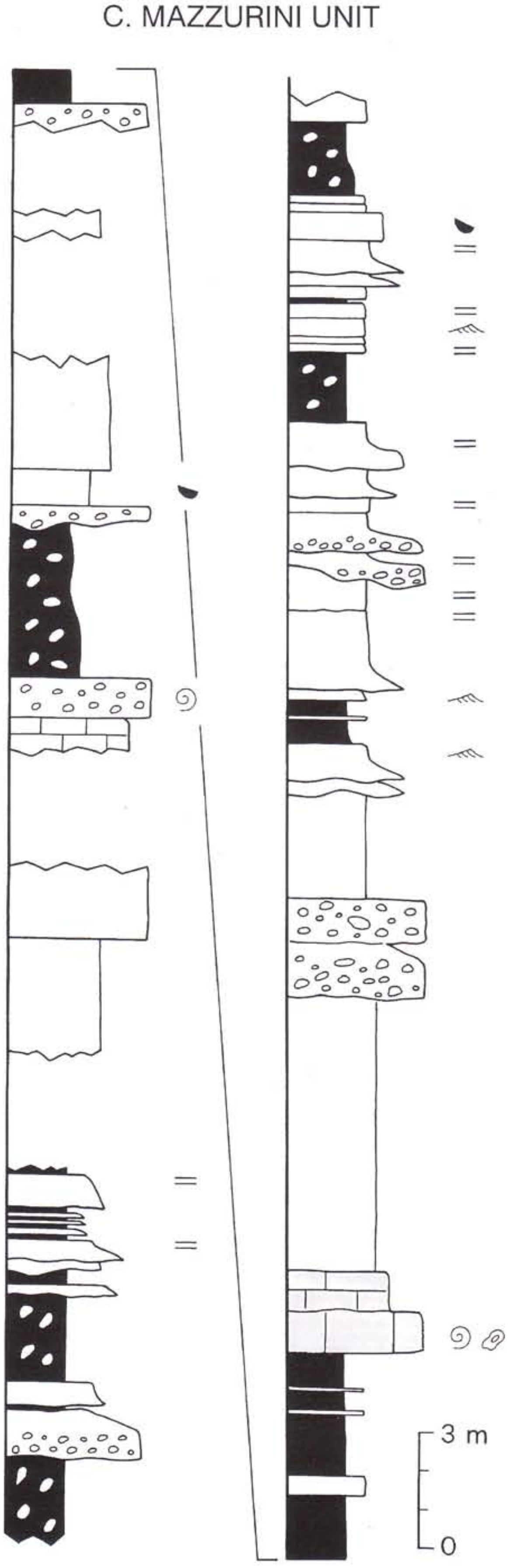

Fig. 6 - Partial stratigraphic section of the C. Mazzurini Unit. Symbols as in Fig. 3.

The dominant lithofacies, in order of importance, are: a) fine to medium sandstones, in beds 0.25-1.00 m thick, with erosional base and coarse-tail grading, highlighted, in the lower part of the bed, by granules up to a few mm in size; parallel laminations are present locally in the upper part of the beds; b) conglomerates with clasts up to 10-12 cm in size, in beds 0.7-1.2 m thick, with erosional base, passing upwards to fine/medium sandstones with local parallel laminations; c) massive, clast supported conglomerates in beds up to 1.6 m thick; d) up to 4 m thick intervals of pebbly mudstones, locally affected by synsedimentary folds; e) massive, mostly medium sandstones, in beds up to 0.7 m, with local cm-size mud clasts; f) fine sandstones in beds up to 0.2 m thick, with parallel and current ripple laminations in the lower and upper parts, respectively; g) usually massive biocalcarenites passing to biocalcirudites with rhodoliths, gastropods and bivalves, forming two layers 0.8 and 2.1 m thick, present in the basal part of the unit (see Lower Carbonate Interval).

The sandstones are locally rich in bioclasts, i.e. fragments of bivalves and occasionally rhodoliths; conglomerates entirely made of rhodoliths, supported by an arenaceous matrix, were observed.

In its type-locality the C. Mazzurini Unit lies in sharp, erosive contact with the pelites of the "Muddy framework" Group and is delimited at the top by the Upper Carbonate Interval. To the north, the lower portion of the unit is interrupted by a system of faults, aligned N100 (C. Pian dei Buri fault) and N70 (Rio Bazzi fault), that place it in direct contact with the pelites of the "Muddy framework" of the Rocchetta-Monesiglio Group. The upper part of the unit is present also to the north of the fault-system, where it consists of a thin and discontinuous arenaceous body that crops out on the left side of the T. Ovrano Valley.

To the southwest, at the head of the Rio della Rocchetta Valley, the C. Mazzurini Unit thins out. A pinch-out ending is typical of the basal conglomerates and sandstones, while the two carbonate intercalations continue to the southwest intercalating with the adjacent pelitic succession.

Depositional setting. The unit is the product of high-density turbidity currents and debris flows. The lower part is confined to the C. Mazzurini Half-Graben (Figs. 13, 14), limited to the north by growth-faults which coincide with the C. Pian dei Buri-Rio Bazzi fault-system, where the deposits reach the maximum thickness. The top of the unit extends to the north beyond the fault system, leveling the preexisting topography.

Age. A prevailing Aquitanian age was established based on the paleontologic content of samples collected at Costa della Feja, where the unit reaches its maximum thickness. The pelitic layers intercalated with the sandstones contain *Globoquadrina dehiscens*, associated with *Globigerinoides primordius* and *Catapsydrax* sp. at the top of the unit. The uppermost layers of the pelites underlying this unit contain an assemblage with *Paragloborotalia* gr. *kugleri, Globigerinoides primordius, Catapsydrax dissimilis ciperoensis*, and *Paragloborotalia pseudocontinuosa,* typical of the Latest Oligocene.

Lower Carbonate Interval.

This unit consists of two moderately thick layers of biocalcarenites and/or biocalcirudites, with local mud clasts and siliciclasts, cropping out along the Costa della Feja (C. Mazzurini Half-Graben), until beyond C. Mevie (Rocchetta High).

At Costa della Feya the two layers, mostly massive biocalcarenites/biocalcirudites with rhodoliths, gastropods, bivalves, are 0.8 m and 2.1 m thick, respectively. They are intercalated within the lower part of the C. Mazzurini Unit (Fig. 6), where they are separated by about 22 m of clastic sediments, and are truncated northward by the Pian dei Buri fault.

To the west of Rio Bazzi to C. Mevie, the two layers are intercalated within the uppermost pelites of the "Muddy framework" (lower part of the Rocchetta-Monesiglio Group), where they are separated by a stack of pelites 7 to 20 m thick. The lower layer is a graded biocalcarenite/biocalcirudite, from 0.5 to 1.5 m thick; the upper layer consists of two graded and amalgamated carbonate banks, with a joint thickness between 1.9 and 2.6 m.

Further to the west one of the two layers disappears, while the other forms lenticular bodies aligned until C. Bricco.

Depositional setting. The lithofacies of the Lower Carbonate Interval are the product of high-density turbidity currents.

Age. Foraminifer assemblages contained in the pelitic intercalations allow an indirect dating of the carbonate deposits to the Aquitanian. At C. Mevie the lower carbonate layer lies on pelites bearing an assemblage with *Globigerina ciperoensis, Globoquadrina praedehiscens, Paragloborotalia pseudocontinuosa,* and *P. opima nana,* indicating the Latest Oligocene (P22 Zone). The pelites between the two layers contain a definite Miocene (N4 Zone, Aquitanian) assemblage, i.e. *Globigerinoides trilobus, G.trilobus sacculifer, Paragloborotalia siakensis,* and *P. acrostoma.*

Glaucony Hybrid Arenites.

The areal distribution of this unit is very limited and discontinuous (left side of the T. Ovrano Valley), with a maximum thickness of 5 m near C. Poggi. At this site the unit is composed of fine to very fine hybrid arenites made almost entirely of planktonic foraminifera, glaucony granules and siliciclasts, with subordinate echinoderm and bivalve fragments. Beds, 0.1 m to 0.6 m thick, are either massive or show rough normal grading, highlighted by a basal layer of mud clasts, up to 3 cm in size and coarse glaucony granules. Beds are usually separated by mm reddish crusts made of Fe-oxides, locally concentrated in layers up to 20 cm thick. Bioturbation and fossil traces are preserved locally. Results of modal analysis on three samples collected around C. Poggi show: 1) component CI- bioclasts (mostly planktonic foraminifera, often filled by glaucony, and echinoderm and bivalve fragments), 31 to 56% of total framework; 2) component NCI- glaucony granules, 20 to 37% of total; 3) component NCE made of prevailing quartz and subordinate micas and serpentinite fragments, 20 to 31%. The matrix, generally subordinate, is made of pelite.

Silty-sandy packstones with dominant foraminifera and rare, small glaucony granules, alternate locally with the main lithofacies.

The glaucony arenites were studied recently by d'Atri (1990) and Amorosi et al. (1997).

Near C. Poggi the Glaucony Hybrid Arenites lie on the pelites of the "Muddy framework" and are covered by the Upper Carbonate Interval. Around C. Colla they are overlaid by the northernmost edge of the uppermost C. Mazzurini Unit. They crop out also at the southwestern edge of the area under study, near C. delle Vigne, where they form a 2 m thick lens underlying the Upper Carbonate Interval.

Depositional setting. The Glaucony Hybrid Arenites were likely deposited on structural highs developed to the north (T. Ovrano High) and to the south (Rocchetta High) of the C. Mazzurini Half-Graben. In spite of features also peculiar to turbidites, and considering their paleogeographic setting these arenites were interpreted as local, variously amalgamated, storm-related deposits. Distinct intervals are often separated by Fe-oxides crusts, likely recording non-deposition episodes.

Age. The age of this unit is interpreted based on its stratigraphic position, bracketed by the Aquitanian uppermost "Muddy framework" pelites and the Upper Carbonate Interval, which is referred to the Burdigalian.

Upper Part of the Rocchetta-Monesiglio Group.

Biocalcarenites and biocalcirudites belonging to the informal Upper Carbonate Interval start the Upper Part of the Rocchetta-Monesiglio Group. They are followed by pelites and, subsequently, by alternations of arenaceous bodies and pelitic lithozones which contain thin bedded sandstones.

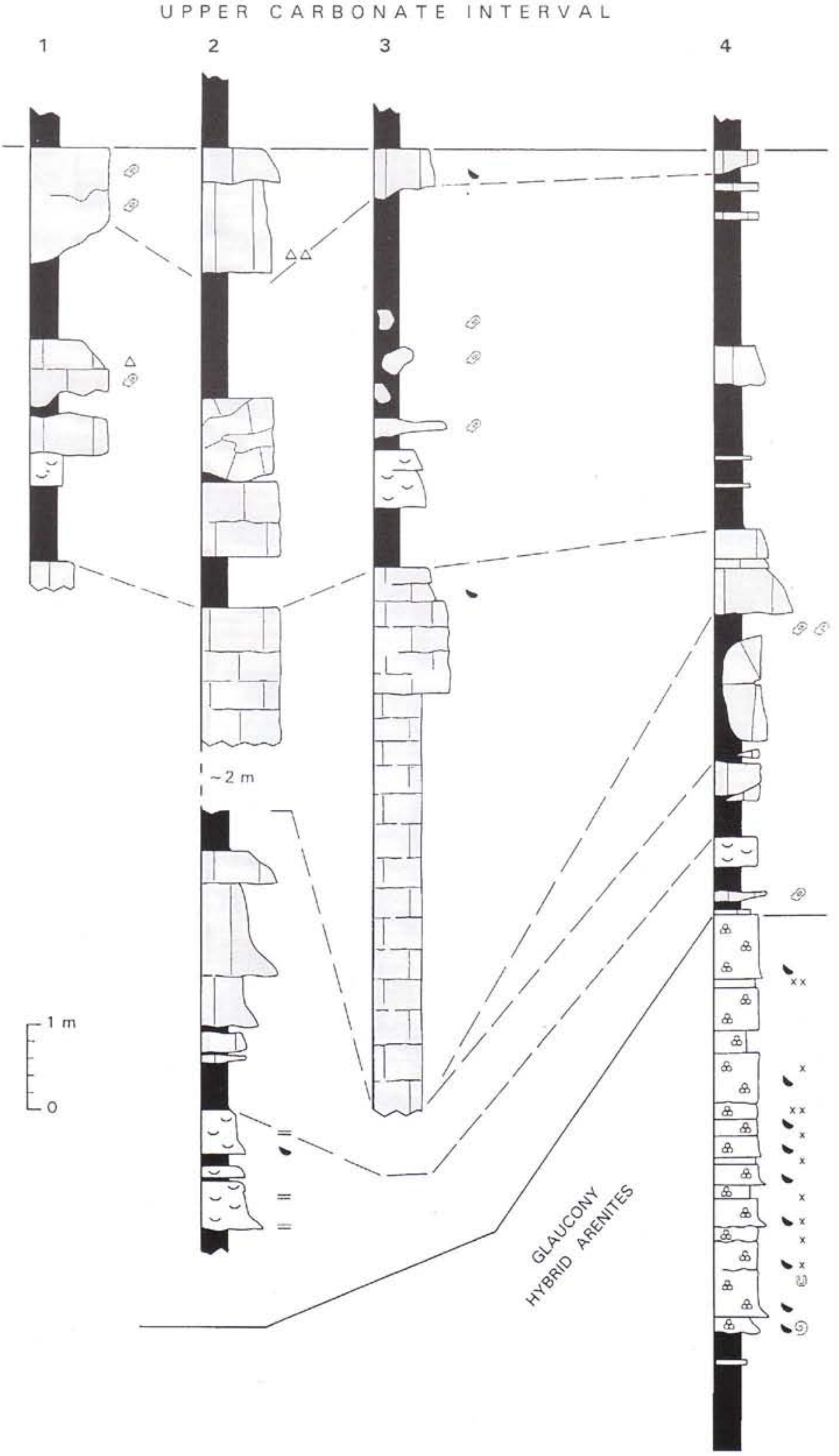

Fig. 7 - The Upper Carbonate Interval around C. Poggi. Abandoned quarry SW of C. Poggi: Section 1, west side; Section 2, central sector; Section 3, east side. Section 4, Mombaldone-Roccaverano road. Symbols as in Fig. 3.

Upper Carbonate Interval.

The unit is composed of biocalcarenitic-biocalciruditic lenses (calcareous algae, bivalves, echinoderms, bryozoans, macroforaminifera) separated at times by pelitic layers of various thickness. The best outcrop is in the abandoned quarry located 300 m southwest of C. Poggi (Fig. 7), where the unit starts with hybrid arenites, in beds 10-50 cm thick, normally graded and with local parallel or current ripple laminations. A succession of four biocalcarenitic-biocalciruditic lenses, respectively 2.5 m, 6.5 m, 1.9 m, and 1.5 m thick and separated by pelitic layers up to 1.5 m thick, follows. These lenses are still visible, even though their thickness is strongly reduced, near C. Poggi, along the Mombaldone-Roccaverano road.

Typical lithofacies are: a) graded biocalcarenites-biocalcirudites, in beds up to 1 m thick, frequently with erosional base; b) massive biocalcarenites-biocalcirudites, in beds 0.1- 1 m thick, at times amalgamated; c) biocalcirudites made of rhodoliths, in lenses up to 1.4 m thick, with strongly erosional base; d) pebbly mudstone with rhodoliths, in lenses up to 1.5 m thick. Synsedimentay folds affect these deposits locally.

The total thickness of this unit widely varies from 9 m at C. Poggi, to 17 m in the abandoned quarry. At the Molino d'Ovrano it is only 1.4 m and decreases further towards the bottom of the T. Ovrano Valley, disappearing at C. Colla. The unit crops out again around C. Pian Bruno, along the right side of the T. Ovrano Valley, and becomes about 20 m thick around C. Calistano and C. Tragna. It narrows down gradually to the southwest and disappears, due to erosion, north of C. Crose, only to crop out again 2 km to the southwest around C. Mevie, where it represents the third carbonate bed exposed on the Rocchetta-Serole road (the first two underlying carbonate layers belong to the Lower Carbonate Interval, described previously). Beyond C. Mevie, where it is 1 m

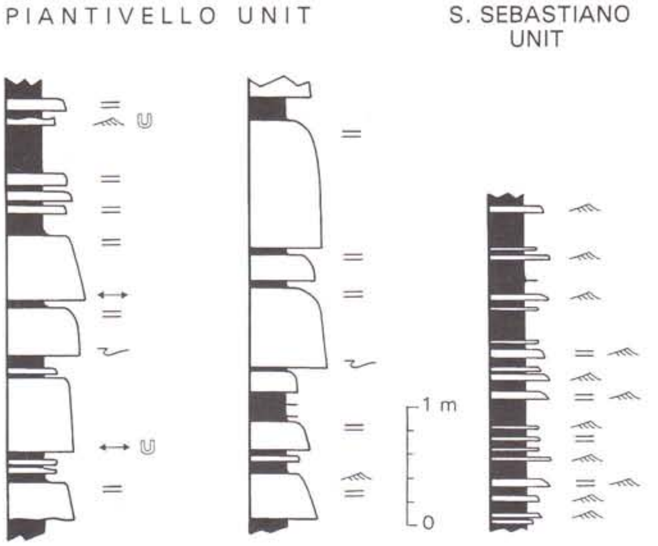

Fig. 8 - Partial stratigraphic sections of the Piantivello and S. Sebastiano Units. Symbols as in Fig. 3.

thick, the Upper Carbonate Interval continues to the southwest for 2.5 km and tapers off at C. Rocchino.

This unit is overlain usually by the S. Sebastiano or Piantivello units and locally, at the southeastern and southwestern edges of the area under study, by the Massive Mudstones.

Depositional setting. The carbonate lithofacies are the product of high-density turbidity currents and debris flows that at this moment can spread over the whole study area, the irregularities of which having been completely leveled. These carbonate lithofacies intercalate a normal, hemipelagic pelitic succession.

Age. Dating to the Burdigalian was based on the over- and underlying pelites which contain *Globigerinoides altiaperturus*, in the context of the *Globigerinoides* bloom event, together with *Dentoglobigerina altispira*, *Globoquadrina dehiscens*, *Paragloborotalia mayeri*, and *P.siakensis.*

Massive Mudstones.

A more precise definition was hindered by the lack of toponyms in the area where the mudstones crop out. This unit develops above the Upper Carbonate Interval and is composed of massive, homogeneous mudstones with planktonic foraminifera. It is better defined at the northeastern and southwestern edges of the area under study, where it is heteropic with the S. Sebastiano Unit and is overlapped by the Piantivello Unit. Maximum thickness reaches 50 m.

Depositional setting. These fine sediments, rich in planktonic foraminifera, represent normal hemipelagic sedimentation and are found only on the T. Ovrano and Rocchetta Highs.

Age. Dated to the Burdigalian based on *Globigerinoides altiaperturus* and the absence of *Catapsydrax.*

Piantivello Unit.

This unit is formed by alternations of predominant sandstones and pelites.The areal distribution is likely controlled by a system of paleofaults aligned WNW-ESE and located along the T. Ovrano Valley, at the southern edge of the T. Ovrano High. In the central part of the outcropping area the succession is up to 200 m thick and is made of thick-bedded, graded sandstones and, especially at the base, conglomeratic lenses. Laterally, the unit splits into two tongues which interfinger with the pelitic-arenaceous alternations of the S. Sebastiano Unit. The dominant lithofacies is represented here by fine to medium sandstones in beds from 0.2 cm to about 1 m thick, separated by thin pelitic interlayers. Sandstones consist of a more or less evident, normally graded lower part followed by a division with parallel laminations and, at times, by a thin division with current ripple laminations (Fig. 8) and frequent flute and groove casts. Less frequent are massive, mostly fine sandstones in beds up to 0.25 m, and fine to very fine sandstones in beds from a few cm to 15 cm, with parallel and/or current ripple laminations.

The lower boundary of the Piantivello unit is erosive in the entire central-western sector of the study area, where the unit consists of a uniform sandstone body in direct contact with the Mazzurini Unit. Elsewhere, the two sandstone tongues interfinger with the S. Sebastiano Unit. Locally, the sandstone bodies onlap the Massive Mudstones, as in the area near C. Poggi.

Depositional setting. This unit is the product of generally high-density turbidity currents, mostly confined to a trough (Piantivello Trough) delimited by the T. Ovrano and the Rocchetta Highs.

Age. This unit can be dated to the Burdigalian. In fact it interfingers with the lower part of the S. Sebastiano Unit, which has been dated by means of plancktonic foraminifers.

S. Sebastiano Unit.

This unit is formed by a dense alternation of pelites and thinly bedded, fine to very fine sandstones, in beds from 1 cm to 7/8 cm thick, with parallel and/or current ripple laminations (Fig. 8). It shows tight-knit relationships with the Piantivello Unit; it is wedged between the two sandstone tongues that belong to the lat-

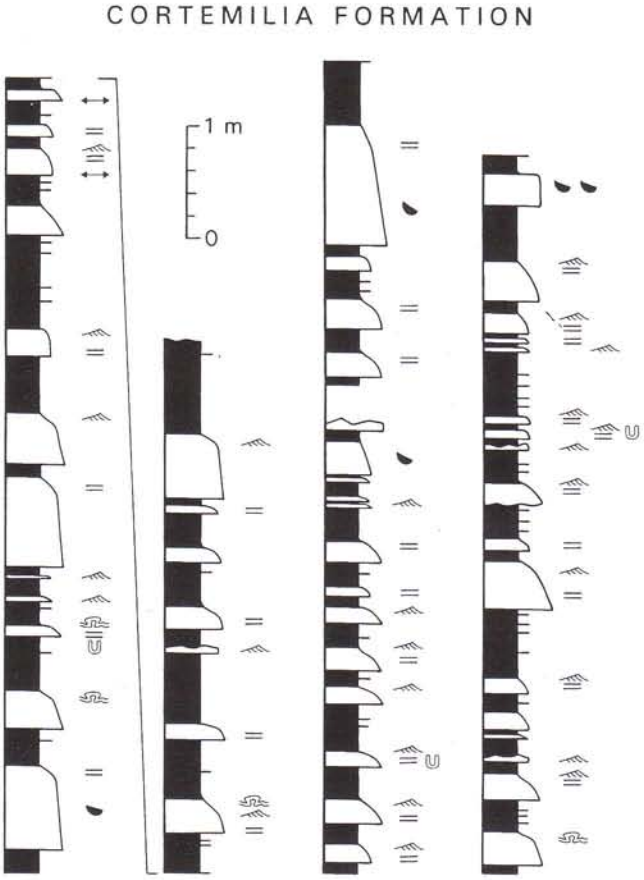

Fig. 9 - Partial stratigraphic sections of the Cortemilia Formation. Symbols as in Fig. 3.

ter in the central-western part of the area under study, replaces it in the southwestern sector and eventually covers it with tabular geometry in the entire area.

A maximum thickness of 170 m is reached in the southwestern part of the area under study, where the unit is divided by a tongue of Massive Mudstones.

A gradual increase of the arenaceous beds marks the upward transition to the Cortemilia Formation.

Depositional setting. It is a uniform succession of hemipelagic mudstones alternating with thin sandstone beds produced by low-density turbidity currents. The lower part represents the marginal facies of the Piantivello Unit, while the uniformly widespread upper part forestalls the basinal environment typical of the Cortemilia Formation.

Age. Several samples collected in different parts of the unit provided a Burdigalian assemblage (i.e. *Globigerinoides trilobus, G.subquadratus, G.sacculifer, G.altiaperturus, Paragloborotalia mayeri*, and *P. siakensis).*

In the upper part of the unit, near the contact with the Cortemilia F., the first occurrence of *Globorotalia scitula* and *Globigerinoides bisphericus* record the Late Burdigalian (N7).

Cortemilia Formation.

The Cortemilia F. delimits upwards the stratigraphic succession in the area under study, where it crops out near the watershed between the Bormida of Spigno and Bormida of Millesimo Valleys. It is a very well-known unit that outcrop both in the Langhe and in the Alto Monferrato regions. It reaches its maximum thickness (about 800 m) around the depocenter of the Langhe Sub-Basin (Gelati et al., 1993). It consists of a basin-wide succession of sandstones and pelites with an average sandstone/pelite ratio = 1. The sandstone beds, mainly 20-30 cm thick, show sequences of internal structures typical of the "classic" Bouma turbidites (complete or truncated at the base), with frequent current-related basal structures (Fig. 9).

The lower part of the Cortemilia F. contains an assemblage characterized by the presence of *Globigerinoides bisphericus* and may be ascribed to the Late Burdigalian. The upper part of this unit, outcropping westwards of the study area, can be dated to the Early Langhian.

Oligocene/Early Miocene evolution of the Roccaverano-Mombaldone area

The geologic evolution of the area will be modeled through 3 crucial "Times" chosen as examples. This chapter will focus on the most important outlines of the studied area during the Late Oligocene and Early Miocene, recognized on the grounds of the characteristics of the stratigraphic successions representative of the different sectors.

"Time 1".

"Time 1" is in the Late Oligocene (uppermost P21 /lower P22 zones) and is represented by the Ovrano Unit, the S.Rocco-C.Burbo Slump Sheet and the pelitic succession that incorporates them ("Muddy framework"). This time interval records the development of gentle folds that create structural highs and relatively lower areas. The folds affect basically only hemipelagic mudstones belonging to the lower part of the Rocchetta-Monesiglio Group and progress from the northern (T. Ovrano High) to the southern sector (M. Pisone High), aligned WNW-ESE and NW-SE respectively (Fig. 10). The turbidite sandstones of the Ovrano Unit, a 0-53 m thick body that onlaps the underlying pelites, pinch out on the north and south sides of the northern high (Fig. 5). The southern high (M. Pisone High), is located about 2.5 km from the T. Ovrano High and

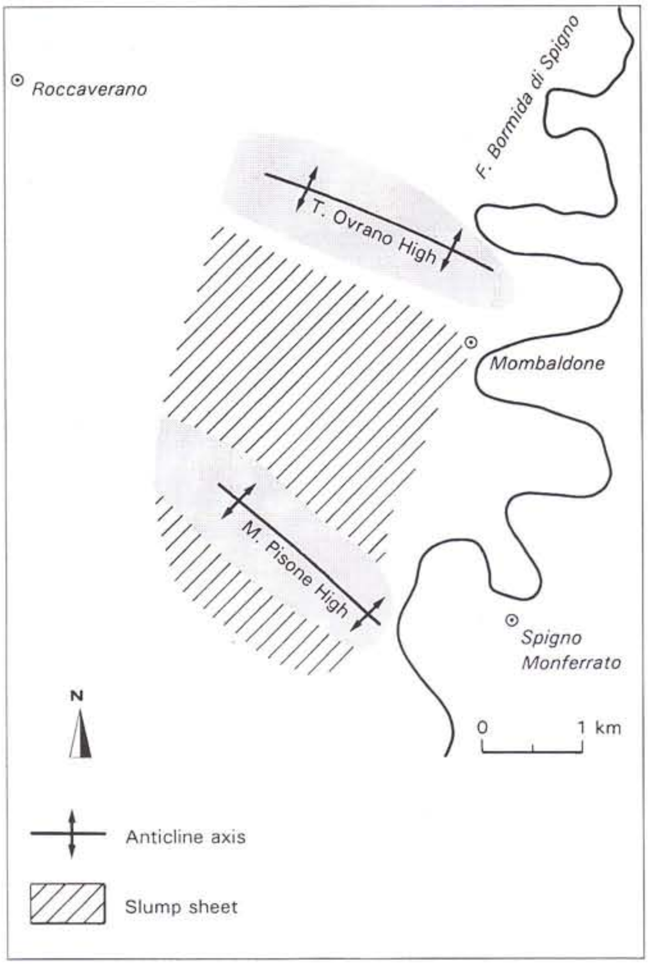

Fig. 10 - The Roccaverano-Mombaldone area during the Late Oligocene.

forms a wide anticline of pelitic sediments (Fig. 11), which is bounded at its top by an extensive slump scar overlaid by a mudstone succession (Fig. 12). A pelitic slump sheet (S. Rocco-C. Burbo Slump Sheet), derived at least in part from denudation of the sediments originally present on the top of this structure, lies on both sides of the anticline and extends northward to the base of the T. Ovrano High. Maximum thickness (30-40 m) is reached at the southern edge of both Highs.

"Time 2".

During "Time 2" (Earliest Miocene, i.e. Aquitanian) the area may be subdivided into 4 sectors, very different in facies, deposit thickness, and continuity of sedimentation (Fig. 3). On the T. Ovrano High, still maintained to the north, this time interval is represented by a condensed succession of a few meters of pelites, locally associated with glaucony hybrid arenites, deposited on a current-swept bottom where local, glaucony-rich deposits could form. A 3 km wide depression (C. Mazzurini Half-Graben) is present to the south, separated from the T. Ovrano High by the C. Pian dei Buri paleofault and a second lineament, likely corresponding to the C. Calistano fault. Both lineaments, aligned W-E and WNW-ESE respectively, acted as growth-faults (Figs. 13, 14). The C. Pian dei Buri paleofault, easily recognizable in the field, separates a southern sector in which the Aquitanian is basically represented by turbidite sandstones and resedimented conglomerates (C. Mazzurini Unit, maximum thickness 150 m), from a northern area where the same time span is recorded exclusively by hemipelagic mudstones. The last sector represents the transition to the T. Ovrano High from which it is separated by a synsedimentary fault, likely the C. Calistano fault. Consequently, the C. Mazzurini Half-Graben consists of two parts, namely 1) a transitional step to the T. Ovrano High, characterized by mostly pelitic sediments, and 2) a depocenter which forms the hanging wall of the C. Pian dei Buri fault, filled mainly by a conglomeratic-arenaceous turbidite succession. It is likely that additional, smaller step-like structures, such as that delimited by the C. Bazzi paleofault, affected the depocenter. The latter paleofault, aligned WSW-ENE, creates a step where the Aquitanian turbidites are much thinner than in the central portion of the half-graben.

The C. Mazzurini Half-Graben covers an area that at "Time 1" included also the M. Pisone High. The Half-Graben connects southward, through a slightly inclined ramp, with the Rocchetta High, which also formed at this time. The latter high is recorded by a suc-

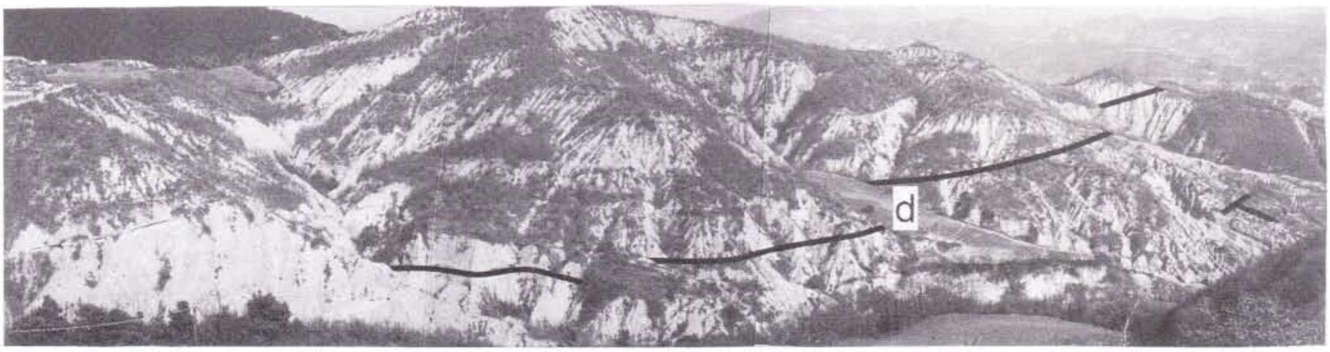

Fig. 11 - Southern side of M.Pisone: the southwestern side of a gentle anticline affecting the lower part of the "Muddy framework" (Rocchetta-Monesiglio Group) is observable. It is bounded at the top by a submarine denudation surface (d).

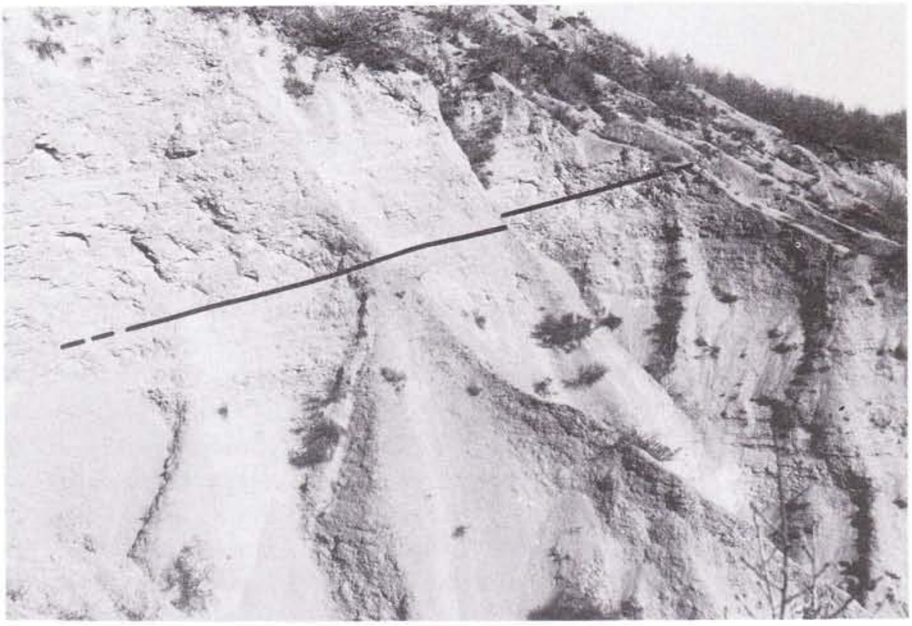

Fig. 12 - A close-up view of the denudation surface (slump scar) in the mudstones of the lower part of the "Muddy framework" (Rocchetta-Monesiglio Group). South-eastern side of M. Pisone.

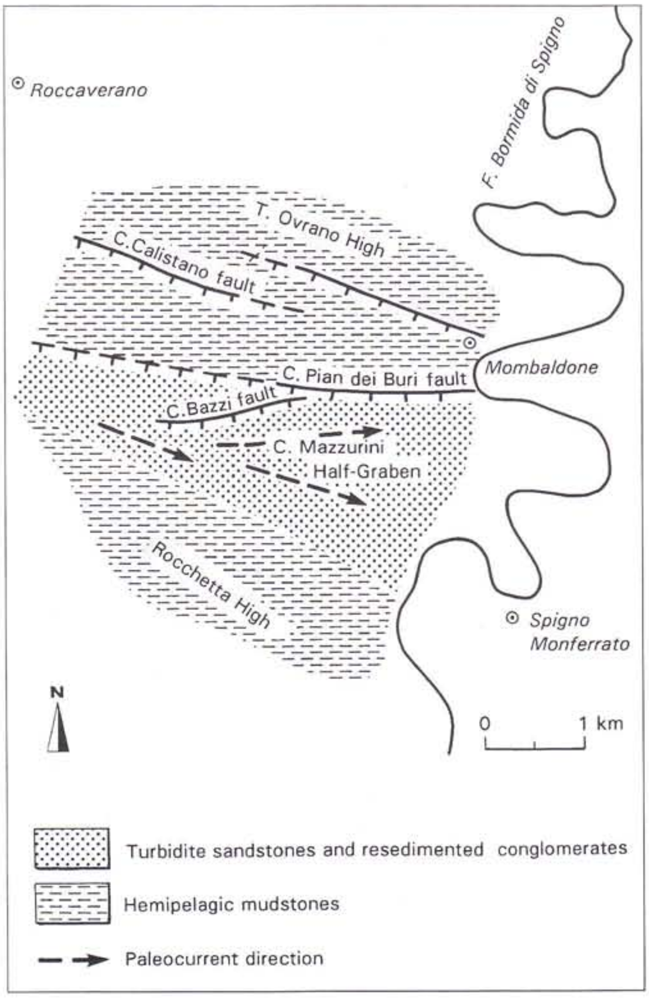

Fig. 13 - The Roccaverano-Mombaldone area during the Aquitanian.

cession of a few meters of hemipelagic mudstones, often rich in glaucony, which also includes two carbonate banks that were referred to the Lower Carbonate Interval. Glaucony hybrid arenites (maximum thickness 2 m), deposited in the same environment hypothesized for those at the T.Ovrano High, locally overlie the pelites.

"Time 3".

"Time 3" is set in the Early Burdigalian and is represented by the Piantivello and lowermost S. Sebastiano Units.

At the time, the 3 km wide Piantivello Trough, defined by the T. Ovrano and Rocchetta Highs and apparently delimited to the north by a persistent C. Calistano fault, developed (Fig. 15). The depocenter of this structure is noticeably shifted to the south in comparison with that of the C. Mazzurini Half-Graben, and is contiguous to the Rocchetta High. The Piantivello Trough is filled by the turbidite sandstones of the Piantivello Unit, which reach a maximum thickness of 200 meters.

The time-equivalent succession on the two Highs is represented by pelites and pelites alternating with thinly bedded turbidites (Massive Mudstones and the basal portion of the S. Sebastiano Unit respectively).

Composition and provenance of Arenites

Siliciclastic arenites.

Thirty-eight fine- to medium-grained samples were analyzed. Very few clasts under 0.062 mm were observed in thin section. Thin sections were 250 point-counted and a more or less coarse calcite mosaic surrounding the grains was found to represent from 25% to almost 50% of the total rock (Fig. 16). The calcite fills primary intergranular porosity and secondary porosity originated by leaching of grains, highlighted by corrosion of the clasts rims. Part of the calcite mosaic might be the product of complete recrystallization of intra and extraformational carbonate clasts, since a bottom to top trend of slight and irregular increase in the percentage

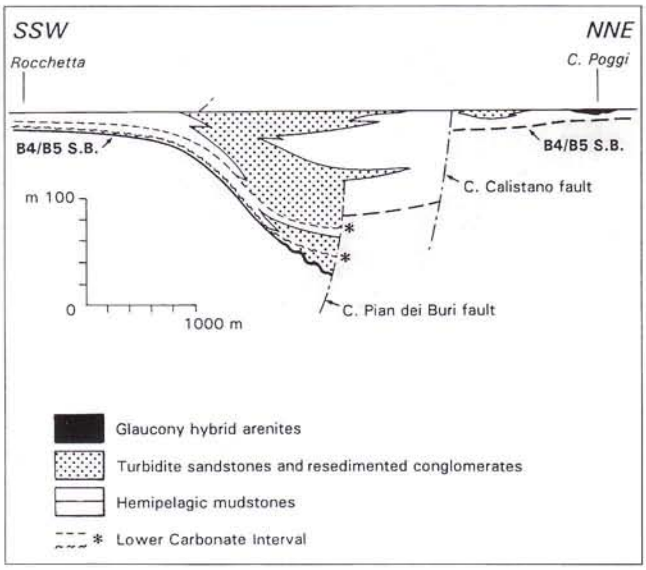

Fig. 14 - C. Mazzurini Half-Graben immediately before the deposition of the Upper Carbonate Interval.

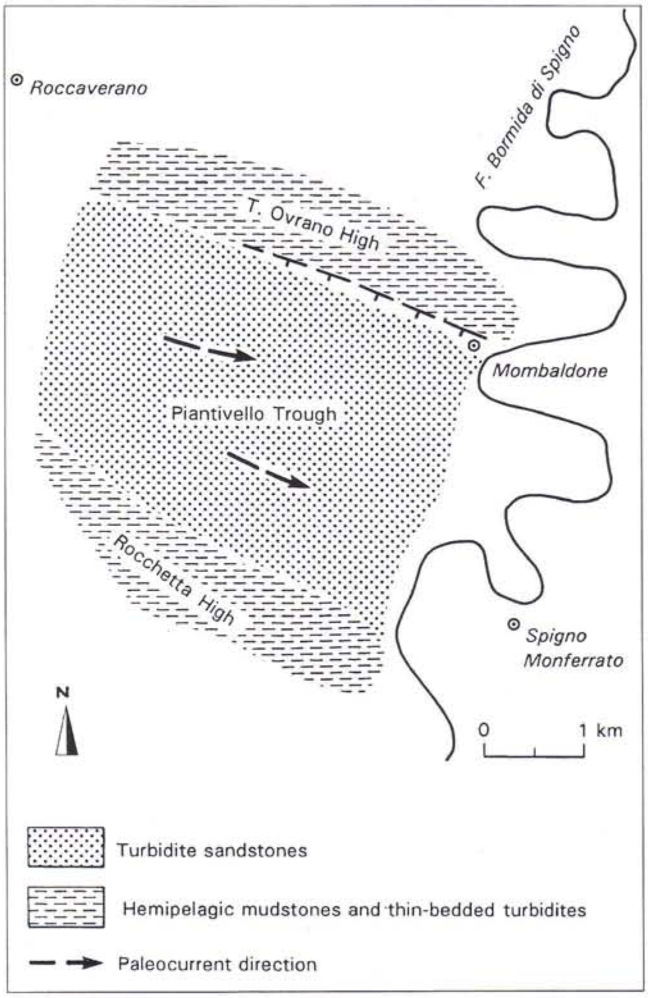

Fig. 15 - The Roccaverano-Mombaldone area during the Early Burdigalian.

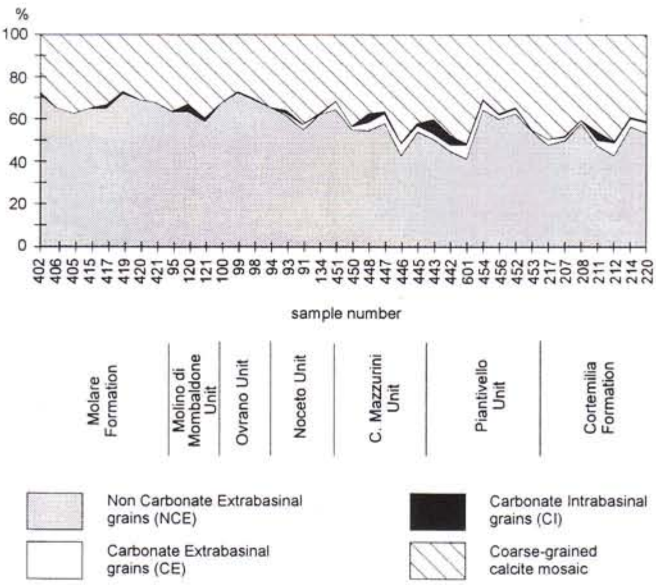

Fig. 16 - Whole composition of the siliciclastic arenites.

of calcitic "ground mass" seems to coincide with the increase of framework components CE and CI.

Data from modal analysis of the framework (grain size >0.062 mm), based on a 250 point count according to Gazzi-Dickinson (cf. Zuffa, 1980, 1985), are reported in Tables 1 and 2.

According to the QFL classification the following data emerged:

1. Samples from the basal part of the succession (Molare F.) show a very low Q component (4-18%), F varying between 2% and 10% (the only exception is sample 421, with F=24%), and L always very abundant, representing 66% to 93% of the total Q+F+L.

2. Sandstones from the overlying units show Q percentages increasing upwards, even though with remarkable variability. Q varies from 38% to 50% in the Molino di Mombaldone Unit, from 18% to 26% in the Ovrano Unit, from 41% to 58% in the Noceto Unit, from 34% to 68% in the C. Mazzurini Unit, from 55% to 72% in the Piantivello Unit and from 57% to 68% in the Cortemilia Formation. Component F does not show relevant variability, fluctuating between 3% and 13%. L percentages vary from 44% to 53% in the Molino di Mombaldone Unit, from 68% to 76% in the Ovrano Unit, from 37% to 52% in the Noceto Unit, from 28% to 55% in the C. Mazzurini Unit, from 19% to 37% in the Piantivello Unit and from 24% to 32% in the Cortemilia Formation.

The triangular diagram of Fig. 17 highlights a trend showing an irregular increase of Q towards the top of the succession, which corresponds to an irregular decrease of L percentages.

An additonal diagram (Fig. 18) highlights an irregular trend showing a sharp upward decrease of the serpentinite-metabasite lithic component, associated with a

Sample N.	402	406	405	415	417	419	420	421	95	120	121	100	99	98	94	93	91	134	451
Monocrystalline quartz	3,6	10	11,2	10,8	9,6	10,4	12,8	5,6	25,2	21,6	25,6	14,8	17,6	20,8	30,8	25,6	33,2	28	18
Polycrystalline quartz	0,4	3,2	0,8	2,4	0,8	2	1,6	0,8	3,2	1,6	2,8	1,2	2	0,4	8	7,2	9,6	12	9,6
Feldspar	1,6	6,8	2,8	6,4	6	6,8	8	17,2	4	5,2	2	4,4	2,4	5,6	6,4	4,8	4,4	4,4	8
Quartz+mica lithic	1,6	0	4	0	2,8	2	0,8	1,2	3,6	2	0	0,4	1,2	0	4	3,6	4,4	6,8	7,6
Metabasite	18,4	28	34,8	26,8	19,6	20,4	17,6	27,6	6,4	6	5,2	20	18,4	28,4	2,8	3,2	6,4	3,2	3,2
Serpentinite	62	30,4	20	32,4	40	37,2	38,4	18	16,4	24,4	21,2	44,8	33,6	30,4	27,6	34,4	17,6	26	33,2
Extrabasinal carbonate	0,4	0	0	0	0,8	1,6	0	0	0,4	0,4	0	0	0	0	0	2,4	1,2	0,4	6
Mica and chlorite	3,6	6	11,2	7,2	10,4	9,2	10	9,2	17,2	18	22,8	7,2	14,8	4,8	15,6	14,8	16	16	10,4
Heavy minerals	6	12,8	13,6	13,2	6,8	8,8	7,6	18,4	18	12,8	18	3,6	7,6	6,8	2,8	1,6	3,6	0,8	2
Bioclast	0	0	0	0	0,8	0	0,4	0	1,6	5,2	1,6	1,2	0	0,8	0	0,4	0	0,8	0
Other grains*	2,4	2,8	1,6	0,8	2,4	1,6	2,8	2	4	2,8	0,8	2,4	2,4	2	2	2	3,6	1,6	2

*Undetermined grains + glaucony grains + mud intraclasts

Tab. 1 - Framework composition of the siliciclastic arenites. Samples are listed in stratigraphic order. Samples 402 to 421: Molare Formation; 95 to 121: Molino di Mombaldone Unit; 100 to 98: Ovrano Unit; 94 to 134: Noceto Unit; 451: C.Mazzurini Unit.

Sample N.	450	448	447	446	445	443	442	601	454	456	452	453	217	207	208	211	212	214	220
Monocrystalline quartz	29	23,6	28,8	38	29,6	33,2	30,4	31,2	32,4	36	48,4	42	35,2	26,8	36,4	30,4	34,8	31,2	29,2
Polycrystalline quartz	4	13,2	12	14,8	12,4	8,4	12	20	15,2	13,2	10	16,8	8,8	11,2	10,8	12,8	12,8	15,6	15,2
Feldspar	6,8	9,2	5,2	2,4	3,2	4,8	6,4	2,8	10,4	5,6	7,2	6,4	5,2	6,8	6,8	5,2	8,4	4,4	5,2
Quartz+mica lithic	4,8	5,2	11,2	18,8	16	8	6,4	13,6	10,8	19,2	15,2	12,4	12	15,2	15,2	10,4	17,2	9,2	10,8
Metabasite	10	1,2	2,8	0,8	0,4	2,4	1,2	0,4	3,2	0,8	0,4	0,8	0	0	0	0	0	0	0,4
Serpentinite	26	25,6	11,2	2	4,4	17,6	17,2	7,2	6,8	2,8	4,4	2,4	8	6,4	7,6	5,6	8,4	8	7,6
Extrabasinal carbonate	2,8	6,4	7,6	11,2	4,8	2	2,4	7,6	6,8	2	3,6	1,2	8,8	6,4	6,8	7,6	6	11,2	8
Mica and chlorite	12	6,8	15,6	8,8	25,6	10,4	11,6	14,4	12,4	16,4	9,2	16,8	16,4	23,6	12,8	22	10,4	16,8	20
Heavy minerals	1,2	0,4	0,4	0	0	0	0,4	0	0,4	0,4	0	0	0	0,4	0	0,4	0,4	0	0
Bioclast	0,4	5,6	2	0,8	0,8	11,6	10	0,8	0,4	0,8	1,2	0	2,4	0,8	0,8	3,6	1,6	1,6	0,4
Other grains*	2,4	2,8	3,2	2,4	2,8	1,6	2	2	1,2	2,8	0,4	1,2	3,2	2,4	2,8	2	0	2	3,2

*Undetermined grains + glaucony grains + mud intraclasts

Tab. 2 - Framework composition of the siliciclastic arenites. Samples are listed in stratigraphic order. Samples 450 to 445: C.Mazzurini Unit; 443 to 453: Piantivello Unit; 217 to 220: Cortemilia Formation.

noticeable increase of Q and a less extensive, but meaningful increase of the lithics made of quartz +subordinate mica. The latter exceeds the serpentinite-metabasite component in the upper part of the C. Mazzurini Unit, in most of the Piantivello Unit and in the Cortemilia Formation.

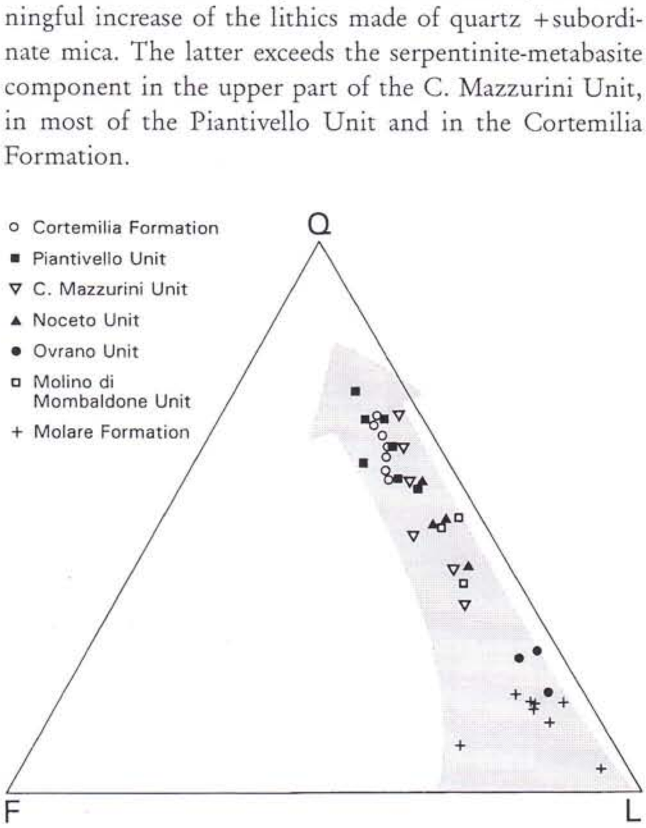

Fig. 17 - QFL diagram of the studied sandstones.

The graph in Fig. 19 highlights the trend of serpentinites versus total Q+F+L percentages. This value decreases irregularly upwards but also shows a peculiar, slight increase at the transition with the Cortemilia Formation, which is characterized by more stable values.

If the entire framework is taken into account (i.e. all the grains >0.062 mm) the following may be observed (Tables 1, 2):

1. The CE fraction is often absent or present in minimal amounts (up to a maximum of about 2% of the total frame) in the sandstones of the Molare F., of the Molino di Mombaldone, Ovrano and Noceto Units.

2. The CE fraction is always present, even if in small percentages (between 1 and 11%), from the C. Mazzurini Unit up to the Cortemilia F.

The abundance of heavy minerals (amphiboles and epidotes) also shows a peculiar trend:

1. They are always present (6-18%) in the Molare F.

2. They are particularly abundant (12-18%) in the sandstones of the Molino di Mombaldone Unit, while they vary between 3% and 7% in the Ovrano Unit.

3. They show a marked decrease starting in the Noceto Unit (from about 3% to <1%). They are often absent or present in amounts <1% in the overlying units (i.e. C. Mazzurini and Piantivello Units, Cortemilia F.).

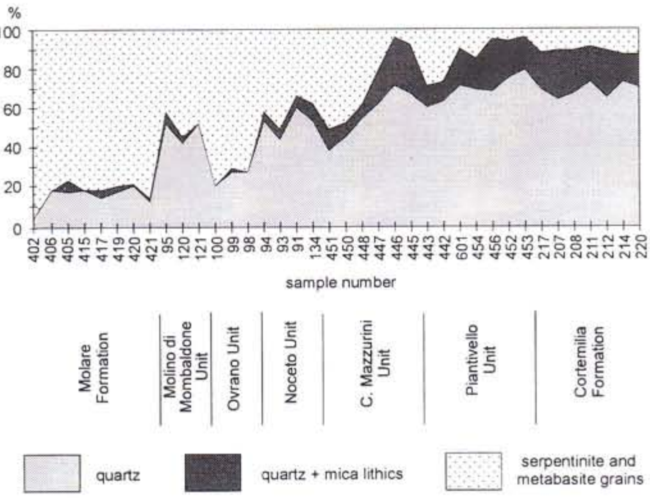

Fig. 18 - Framework-Fraction composition of the siliciclastic arenites.

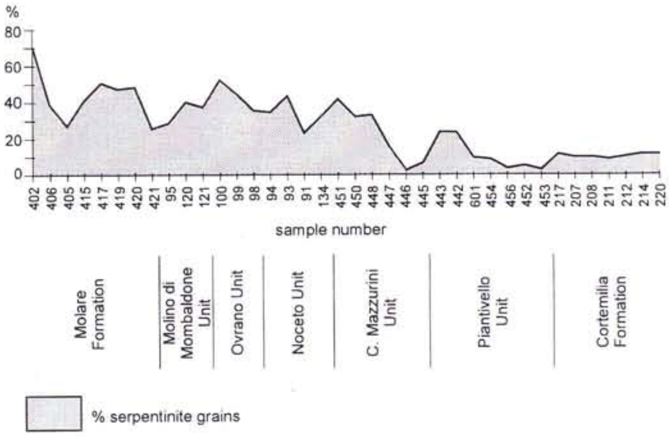

Fig. 19 - Percentage of serpentinite grains over the total Q+F+L.

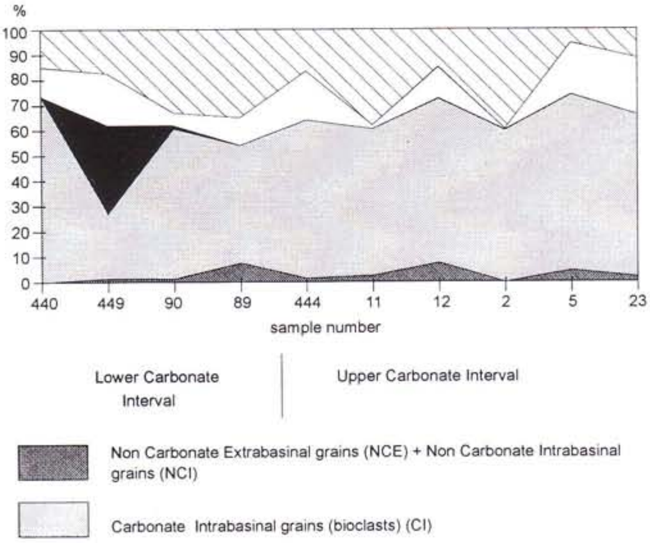

Fig. 20 - Whole composition of the carbonate arenites.

Provenance. The composition of the sandstones of the Molare F. reflects the lithology of the pre-cenozoic basement exposed in the neighbourhood of the study area. Mutti et al. (1995) proposed a northern provenance for the Molare F. cropping out around Mioglia (about 8 km southeast of the eastern edge of the area under study). A northern origin, possibly from the extension of the Alto Monferrato High (Fig. 1), may not be excluded for the sandstones of the units examined in this study, although data from different parts of the Tertiary Piedmont Basin suggest a southern provenance for the siliciclastics of the Molare F. in region adjacent to the studied area studied (Lorenz, 1969, Gnaccolini, 1978).

The composition of sandstones from the Molino di Mombaldone, Ovrano and Noceto Units, cannot exclude repeated recycling and resedimentation of sands sharing initially the same composition of those of the Molare F.. Basal current structures were not observed in the sandstones of the Molino di Mombaldone and Ovrano Units. A moderately thick sandstone interval overlying the Ovrano Unit bears flute casts indicating southwest and south paleocurrent directions. Paleocurrents directed southeast or southwest were reported from the Noceto Unit in outcrops adjacent to the area under study (Cazzola & Fornaciari, 1990). These observations would exclude a provenance from the southern margin of the basin for the forementioned turbidite sandstones. According to Gnaccolini & Rossi (1995) high areas under erosion during the Oligocene and composed of rocks similar to those presently cropping out in the neighbourhood of the study area, might have been located north to northwest of the Bormida di Spigno Valley and represented the source area of the clastic deposits.

Sedimentary structures in the C. Mazzurini and Piantivello Units and in the Cortemilia F. always record paleocurrents directed essentially to the east. The constant presence of component CE, albeit in low percentages, the increasing importance of lithics (L) made of quartz+micas, and the abundance of Q, suggest that starting with the C. Mazzurini Unit, source areas are probably different from those of the sandstones belonging to the older units.

Based on sandstone composition, a source area for the oldest sandstone units may be hypothesized to consist primarly of rocks similar to those that presently crop out in the Gruppo di Voltri and the Montenotte/Erro-Tobbio Thrust Sheet, as well as the continental to coastal deposits deriving from these rocks (Gnaccolini & Rossi, 1995). A composite source area, formed by rocks belonging to the basement and cover of Briançonnais Units, seems to be likely for the more recent sandstone deposits.

Carbonate arenites.

Modal analysis was performed on ten thin sections from samples belonging to the Lower and Upper Carbonate Interval. Results on composition, based on 250 point count, are reported in Fig. 20.

Component CI, made mostly of bioclasts (i.e. corallinacean algae, bivalves, echinoderms, macroforaminifera, bryozoans) and at times of intraclasts, prevails among grains. A very low NCE and/or NCI fraction (the latter made of glaucony granules) is present at times. The "ground mass" is composed by a mosaic of micrite and/or microspar, and by pseudospar, the latter likely derived from neomorphism of bioclasts and of part of the micrite.

Provenance. Bioclasts indicate a shallow marine environment and are obviously reworked. The areal distribution of the Lower Carbonate Interval is sharply interrupted to the north by the C. Pian dei Buri paleofault, which represents the northern edge of the C. Mazzurini Half-Graben. To the southwest the two carbonate layers that form this interval become discontinuous at first, to disappear shortly thereafter. Considering this distribution, and the close connection to the siliciclastic wedge of the C. Mazzurini Unit, an essentially west-east direction may be assumed for the sediment gravity flows that produced the Lower Carbonate Interval. However, the location of the source areas remains problematic.

The areal distribution of the Upper Carbonate Interval in the area under study does not seem to be controlled by the C. Pian dei Buri and C. Calistano paleofault systems. This interval tapers off to the southwest and also crops out discontinuously northeast of the area under study. Source area and flow direction are consistent with those of the Lower Carbonate Interval, even though the sediment gravity flows of the Upper Carbonate Interval extend beyond the C. Mazzurini Half-Graben which at the time was totally filled.

Stratigraphic units and depositional sequences

The stratigraphic succession described in the previous chapters fits in the sequence stratigraphy outline proposed for the Langhe Sub-Basin (Gelati et al., 1993). The succession spans the stratigraphic interval in which six depositional sequences, referred to as B1 to B6, were identified. Local geologic conditions provided additional data to improve the definition of sequences B5 and B6 (Fig. 2).

Depositional sequence B1. (Early Oligocene-Late Oligocene transition). It is well exposed only in the northern sector of the study area, where it is composed of the turbidite sandstones of the Molino di Mombaldone Unit and of the overlying pelites.

Depositional sequence B2. (Late Oligocene). In the study area it is represented only by mudstones limited at the base by an erosional surface that cuts into the slightly bent underlying deposits for more than 30 m (Fig. 4). At the top gently folded pelites are onlapped by turbidite sandstones marking the beginning of sequence B3.

Depositional sequence B3. (Late Oligocene). It is composed of the turbidite sandstones of the Ovrano Unit which onlap the slightly folded pelites of the underlying sequence (Fig. 5), leveling the former topography. Hemipelagic pelites are present at the top of the sequence.

Depositional sequence B3bis. (Late Oligocene). It was observed to date only in the study area, contained in the "Muddy framework" of the Rocchetta-Monesiglio Group. The mudstones of sequence B3 appear to be involved in tectonic movement which are responsible of the individualization of structural highs. Packages of mudstones slumped from these highs towards the low areas. An alignment of submarine slump scars formed: this denudation surface has been chosen as a boundary between sequence B3 and sequence B3bis. This last depositional sequence begins with mudstones which lie on the forementioned denudation surface (by means of an angular unconformity), or with the related slump sheets (Figs. 11, 12).

Depositional sequence B4. (Latest Oligocene). It is represented by the turbidite sandstones and conglomeratic sandstones of the Noceto Unit and by the overlying pelitic succession ("Muddy framework" p.p. of the Rocchetta-Monesiglio Group, C. Mevie-Molino d'Ovrano Unit).

Depositional sequence B5. (Aquitanian-Burdigalian). It is composed of successions strongly different in each of the sectors distinguished in the study area. The lower limit of this sequence is clearly visible at the C. Mazzurini Half-Graben, where it is marked by the beginning of the deposition of the turbidite sandstones and conglomeratic sandstones of the C. Mazzurini Unit, which includes, at the bottom, the Lower Carbonate Interval. Southward, particularly on the Rocchetta High, the lower limit may be placed at the contact between the Lower Carbonate Interval and the underlying mudstones. To the north, on the T. Ovrano High, it supposedly lies in the pelites just below the Glaucony Hybrid Arenites and/or the Upper Carbonate Interval.

In the C. Mazzurini Half-Graben sequence B5 is represented by the C. Mazzurini Unit, which includes the Lower Carbonate Interval, by the overlying "Muddy framework", by the Upper Carbonate Interval and by the overlying pelites. On the Rocchetta High it is represented by the Lower and Upper Carbonate Intervals, together with the intercalated pelites, and by the Massive Mudstones. On the T. Ovrano High the sequence consists of a mostly pelitic succession which includes the Upper Carbonate Interval and local lenses of Glaucony Hybrid Arenites.

Depositional sequence B6. (Burdigalian). In the Piantivello Trough it is marked by the beginning of the deposition of the turbidite sandstones of the Piantivello Unit. It is limited locally by an erosional surface that cuts into the underlying sequence (basically Upper Carbonate Interval and C. Mazzurini Unit). On the highs adjacent to the Piantivello Trough the sandstones pinches out, onlapping the pelites of the underlying sequence. The upper part is composed of mudstones with thin-bedded turbidites of the S. Sebastiano Unit, and it is limited at the top by the turbidites of the Cortemilia Formation (Sequence C1, Gelati et al., 1993).

The sequence stratigraphy proposed for the Oligocene-Miocene succession of the Langhe Sub-Basin (Gelati et al., 1993) showed both the possibility that the area had recorded the global eustatic signal (Haq et al., 1988) and that strong synsedimentary tectonics had interacted with eustatic fluctuations. The importance of synsedimentary tectonics in a crucial area located at the transition between the Langhe Sub-Basin and the Alto Monferrato High is confirmed. The sequence of events extends from the base of the Late Oligocene to the Burdigalian. It starts with gentle folding, which seems to control the deposition of sequences B1, B2, B3 and B3bis, followed by tensional events, with prevailing normal synsedimentary faults, that influence the development of sequence B5 and B6.

Conclusions.

Stratigraphic and sedimentologic analysis, together with large scale geologic mapping of the region between the villages of Roccaverano and Mombaldone, provided a clear view of the geologic evolution of a crucial area, located at the transition between the western margin of the Langhe Sub-Basin and the Alto Monferrato High (Tertiary Piedmont Basin) (Fig. 1).

Seven depositional sequences, strongly controlled by synsedimentary tectonics, mark the geologic evolution of the area between the Late Oligocene and Early Miocene (Fig. 2).

Sequences B3 and B3bis in particular, result from the development of anticlines that produced two high areas, located at the northern (T. Ovrano High) and southern (M. Pisone High) edge of the study area. The scenario at the time of the beginning of sequence B3bis (Late Oligocene) is shown in Fig. 10. The low area bounded by two highs is characterized by a widespread and thick muddy slump sheet derived from sliding of the topmost portion of the mudstones belonging to the underlying succession. The source area of the slump sheet is marked locally by a denudation surface, clearly visible at the M. Pisone High. The T. Ovrano High is maintained over time and becomes even more marked during the Aquitanian. At this time it is limited southward by growth-faults that cause the development of a depressed area (C.Mazzurini Half-Graben) where the turbidity flows of the lower portion of sequence B5 are channeled (Figs. 13, 14). To the south, a gently inclined ramp connects the half-graben to the Rocchetta High.

During the Early Burdigalian the depocenter of the depression shifts to the south and causes the formation of a trough (Piantivello Trough) in which the turbidite sandstones of the lower portion of sequence B6 are deposited (Fig. 15). The highly irregular topography of this area, progressively leveled during the deposition of the mostly pelitic upper portion of sequence B6, becomes rather homogeneous at the beginning of the following depositional sequence, i.e. the Cortemilia Formation.

A direction from the NW seems prevalent for the paleocurrents that deposited the turbidite sandstones of sequences B1 to B4, while a direction mostly from the west is recognizable in sequences B5 and B6. Based on sandstone composition, a source area for the oldest sequences may be hypothesized to consist primarily of rocks similar to those that presently crop out in the Gruppo di Voltri and the Montenotte/Erro-Tobbio Thrust sheet, as well as the coastal to continental deposits deriving from these rocks. This area was located presumably northwest or possibly also north of the study area. A composite source area, formed by rocks belonging to the basement and cover of Briançonnais Units, seems to be likely for the more recent sequences, particularly B5 and B6.

The considered time interval (Late Oligocene - Early Miocene) can be placed between the end of the mesoalpine phase and the beginning of the phases responsible of the uplifting of the Northern Apennines. The illustrated geologic events not only represent a significant case history, but can also give a contribution to the highlighting of the role of the TPB at the Alps-Apennines knot.

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