FOREWARD

The study area comprises a large part of the Langhe Sub-basin of the Tertiary Piedmont Basin. The lithostratigraphic, sedimentologic and structural information which allowed a detailed reconstruction of the paleoenvironmental setting and the tectono-sedimentary evolution of the area are based on a field survey which led to a new geological map on scale 1:20,000 covering an area comprised between the localities of Cortemilia-Denice-Rocchetta Cairo and Lignera, mostly located in the Bormida di Spigno and Uzzone valleys. The study area shows a large number of lithostratigraphic units and a complex structural, stratigraphic and paleogeographic setting. Specifically, it is characterized by significant differences and peculiarity in geologic evolution between the north-eastern (Roccaverano) area and the south-western area, which show internally homogeneous characteristics, but with distinct signatures between adjacent areas (Fig. 1). Particularly, the geology of the south-western area, presented in the second paper, displays a distinctive and characteristic geology, which cannot be compared to that of the NE area. Therefore, we opted for a presentation of two separate papers, respectively dedicated to the Roccaverano area (A in Fig. 1) and to the whole study area (B in Fig. 1). Moreover, the peculiar features of the NE area convinced us of the need of presenting the respective field results by means of a dedicated geological map on a larger scale than that of the whole area, allowing a better appreciation of the distinctive geological details. We stress that, in order to reduce the repetitions to a minimum, the main sedimentological, paleoenvironmental and structural results of the first paper have not been discussed again in the paper devoted to the whole study area, but only briefly recalled in it.

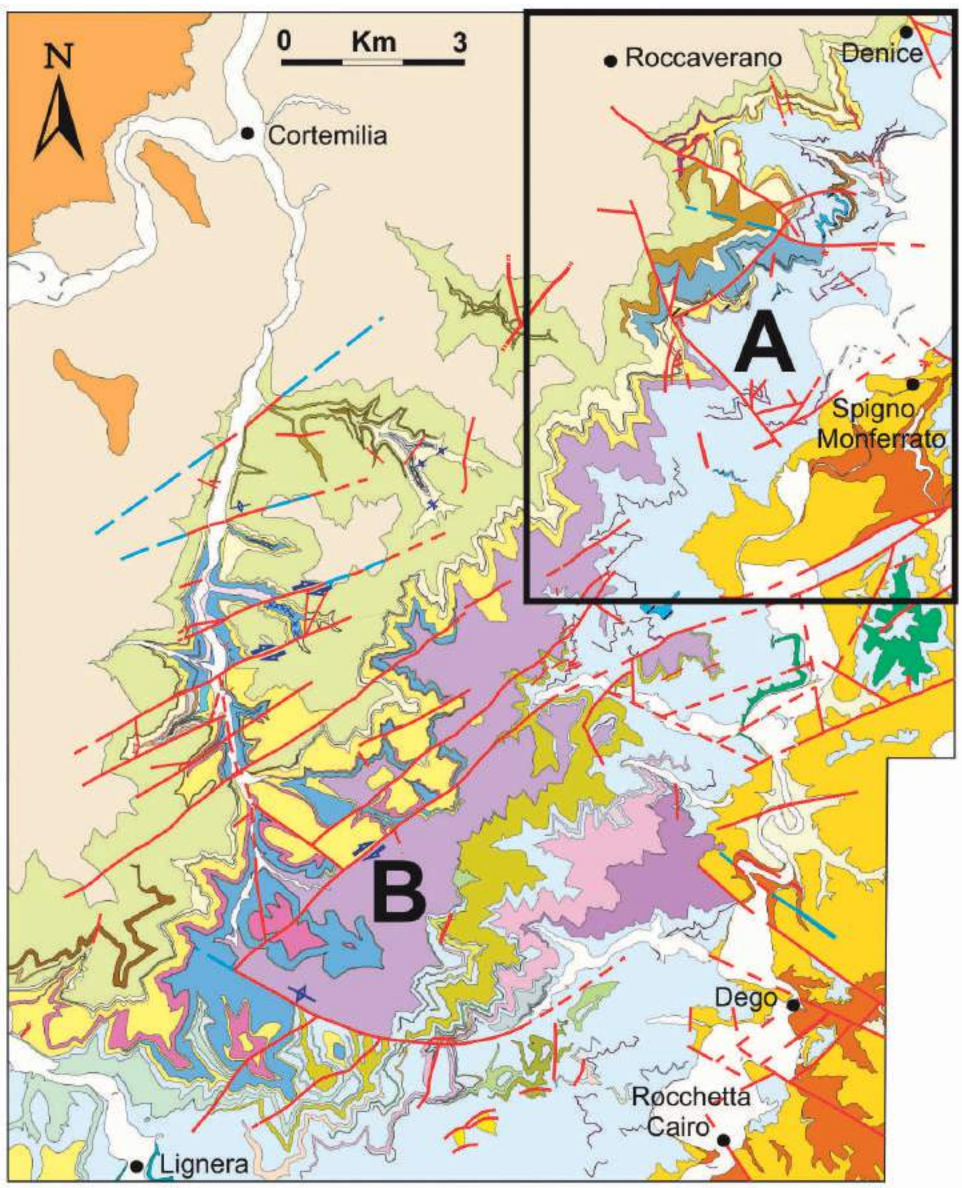

Fig. 1 - Geological sketch map showing the areas respectively investigated in the first (A) and second paper (B).

G. Ghibaudo and F. Massari are responsible for the mapping of the area and for the related geologic and sedimentologic interpretations. I. Chiambretti actively participated to all the phases of the research and was responsible for measuring of Noceto, Mogliavacca, Brovida, Cobarello, Rio della Torre and Rio della Chiesa sections and dating some of them, as well as for the informatic preparation of the geological maps and the figures of the papers. His PhD Thesis (Chiambretti, 2006), prepared in collaboration with G. Ghibaudo, highlights this contribution. A. d'Atri was responsible for the nannoplankton biostratigraphy of the Cianazzo, Stazione di Spigno-Brallo and Molino di Mombaldone sections.

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Oligo-Miocene tectono-sedimentary evolution of the Tertiary Piedmont Basin southern margin, Roccaverano area-Langhe Sub-basin (NW Italy)

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ABSTRACT - The geologic and paleogeographic evolution of the southern margin of the Tertiary Piedmont Basin (TPB) in the Roccaverano area (Langhe Sub-basin) during the Oligo-Miocene was strongly controlled by synsedimentary tectonics. During the Rupelian, the Langhe Sub-basin in the Roccaverano area was dominated by an extensional tectonic regime, expressed by an intense vertical mobility along high-angle, basement-involving faults with generation of km-scale grabens, accommodating continental conglomerates grading upwards into shelf sandstones (Molare Fm). The Molare continental conglomerates form part of the infill of the Lower Oligocene Borgo and Cartosio grabens, separated by the Spigno Monferrato Horst. A subsequent Rupelian transgression first encroached upon the Borgo Graben (and upon the northern Cartosio Graben) and only later upon the adjacent Spigno Monferrato Horst depositing marine sands directly on the uplifted crystalline basement. Since late Rupelian, inferred transtensional tectonics, mostly following the previous pattern of differentially subsiding blocks, was superimposed on a phase of enhanced regional tectonic subsidence leading to the collapse of the entire southern margin of the TPB, with the onset of deposition of slope to base-of-slope hemipelagic mudstones of the Rocchetta Fm (uppermost Rupelian-lower Aquitanian). The most prominent intra-Oligocene structural element of the area is the Spigno Monferrato Horst partly inherited from the former structure, representing the northern end of a complex positive structure (Dego-Spigno Monferrato High) which strongly controlled thickness and facies of the Rocchetta Fm. The Rocchetta Fm is commonly affected by slump scars, the largest of which, about 1 km wide and up to 150 m deep, is located in the Molino di Mombaldone area, and evolved into a submarine canyon/slope valley system. This formation encases several turbidite sandstone bodies of variable dimensions, the largest and youngest of which is the Noceto unit (lower Aquitanian) which most probably represents the infill of a submarine half-graben of pluri-kilometric scale. The Rocchetta Fm is capped by hemipelagic and commonly siliceous sediments, named "Montechiaro d'Acqui Siliceous Lithozone" (middle-upper Aquitanian). This unit represents a regional marker horizon and is interpreted as a condensed section. During the latest Aquitanian-early Burdigalian the fine-grained slope to base-of-slope sedimentation was represented by hemipelagic marls of the Montechiaro d'Acqui Fm. In the lowermost part of this formation resedimented glauconitic sandstones and rhodalgal calcarenites (C. Mevie, Pian Bruno and C. Poggi calcarenites) were deposited, probably derived from coeval foramol-type carbonate platforms. High tectonic mobility in this stage is indicated by the generation of some half-grabens attracting both siliciclastic and carbonate gravity flows. The larger of them is the C. Mazzurini Half-graben, which is infilled with coarse-grained bioclastic sandstones and conglomerates. The middle Burdigalian Serole Fm mainly consists of thin-bedded turbidites encasing a number of sandstone bodies. Such deposits are also present as the infill of medium- to large-scale slump scars developed at the top of the underlying Montechiaro d'Acqui marls. Deposition of the Serole Fm started with the infill of an inferred large-scale base-of-slope valley (Piantivello unit) followed by the widespread deposition of thin-bedded turbidites. The large-scale sandy and conglomeratic turbidite bodies of the Rupelian to middle Burdigalian succession were fed from W-WNW, supporting the presence of paleoslopes dipping E-ESE-wards (in the present-day coordinates). By the late Burdigalian the emplacement of volumetrically important, basinal turbidites of the Cortemilia Fm marks a major change in tectonic regime leading to dramatic increase in subsidence rate and accommodation space.

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Key words: Tertiary Piedmont Basin, Oligo-Miocene, rocky shore transgression, continental, shelf and slope deposits, extensional tectonics, northern Italy

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CONTENTS

1. INTRODUCTION

The aim of this work is a revision of the stratigraphy of the Oligo-Miocene succession of the Roccaverano area (Langhe Sub-basin), located on the southern margin of the Tertiary Piedmont Basin, and a reconstruction of its structural setting and tectono-sedimentary evolution. A detailed field work and facies analysis of the local succession, coupled with a revision of the biostratigraphy, allowed us to revise the local stratigraphy of the basin, in order to shed new light on its depositional and geologic evolution. Recently, a new lithostratigraphy of the area has been introduced by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) in the new Geological Sheet 211 Dego to scale 1:50000 of the "Carta Geologica d'Italia". The stratigraphy and structural setting proposed by these Authors have been significantly updated in relation to the new data provided by this work.

2. GEOLOGIC SETTING

The Tertiary Piedmont Basin (TPB) (Fig. 1), located at the junction of the Alpine and Apennine chains and in proximity of the Liguro-Provençal basin, is characterized by high tectonic mobility and frequent migrations of source areas and depocentres. The sedimentary succession of the TPB is predominantly terrigenous and forms a large homocline gently dipping northwards to north-westwards, reaching a maximum thickness of about 6000 m. The TPB formed since the Late Eocene,

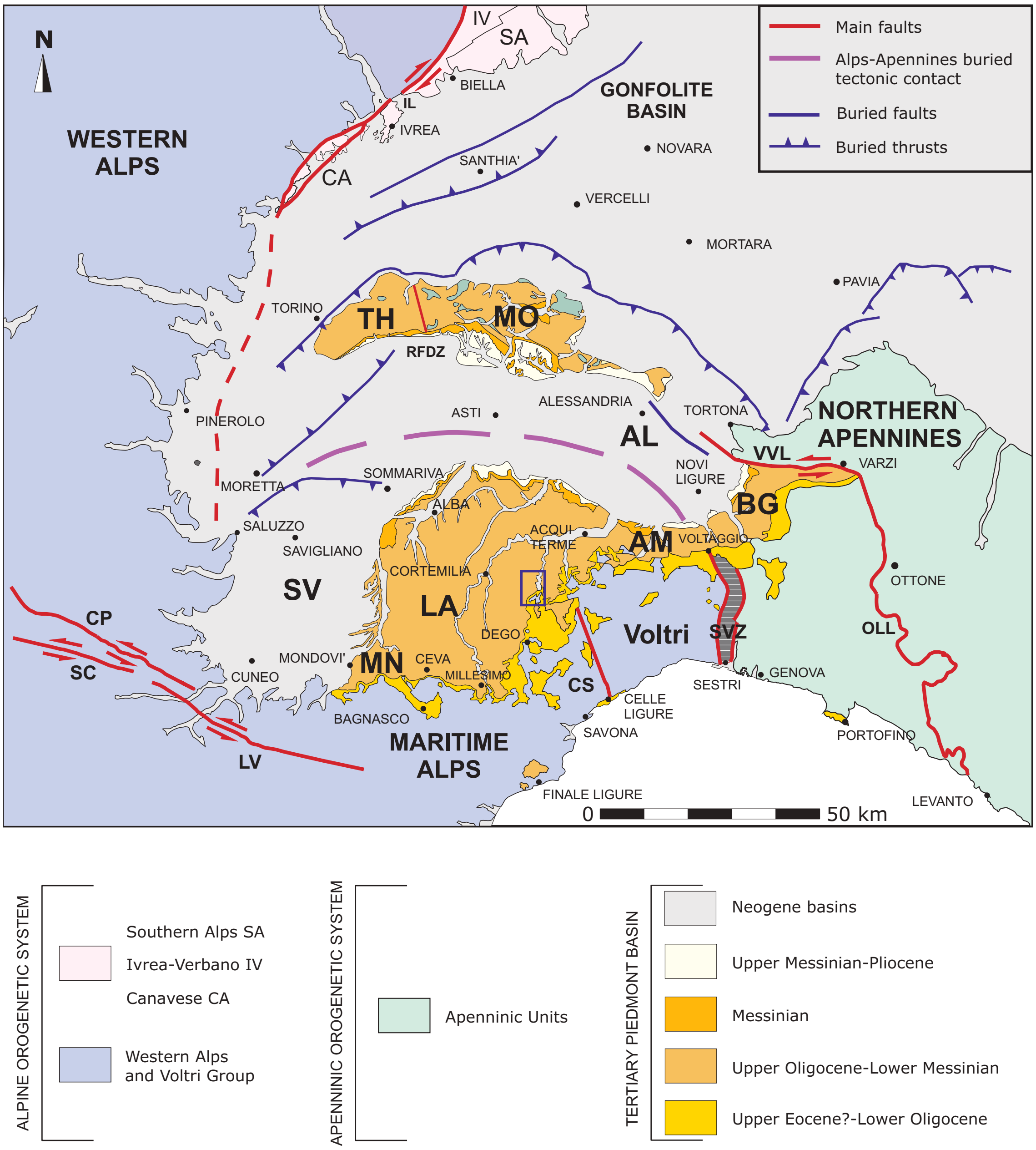

Fig. 1 - The Tertiary Piedmont Basin and the western Po plain. Simplified structural scheme (modified from Bigi et al., 1990; Rossi et al., 2009; Mosca et al., 2010). TH: Torino Hill; MO: Monferrato; MN: Monregalese; LA: Langhe; AM: Alto Monferrato; BG: Borbera-Grue; SV: Savigliano Basin; AL: Alessandria Basin; CA: Canavese Zone; IV: Ivrea-Verbano Zone; SA: Southern Alps; Major faults: IL - Insubric Line; RFDZ - Rio Freddo Deformation Zone; SVZ - Sestri-Voltaggio Zone; VVL - Villalvernia-Varzi Line; OLL - Ottone-Levanto Line; CS - Celle-Sanda Line; SC - Stura couloir; CP - Cicatrice del Preit; LV - Limone-Viozene deformation zone. The inset indicates the study area.

after the Meso-Alpine Eocene collisional event (Mutti et al., 1995; Rossi et al., 2009) and developed on both deep crustal levels belonging to the Alpine structural domain and shallow levels represented by Apennine nappes of the "Liguride Complex" (Roure et al., 1990; Piana and Polino, 1995; Dela Pierre et al., 1995; Biella et al., 1997; Piana, 2000; Carrapa, 2002; Mutti et al., 2002). Due to this geologic setting, the TPB may be regarded as an episutural basin, at least in the first stage of its development (Biella et al., 1997; Gelati and Gnaccolini, 1998; Mutti et al., 2002). Rossi et al. (2009) and Mosca et al. (2010) could identify and trace unconformity-bounded units in the whole TPB, through correlation between outcrops and seismic profiles.

The investigated area is located between the villages of Roccaverano and Spigno Monferrato, in the eastern part of the Langhe Sub-basin (Fig. 1). This sub-basin, an important paleogeographic element of the TPB extending over an area of about 1800 km^2, is infilled with an Oligo-Miocene sedimentary succession more than 4000 m thick (Mosca, 2006). Its main development is attributed by Schumacher and Laubscher (1996) to their

Insubric-Helvetic phase (Late Oligocene-Early Miocene: 25 to 16 Ma). Conversely, according to Rossi et al. (2009) and Mosca et al. (2010), a swell-and-basin topography heralding the subsequent TBP palaeogeography was already delineated in the Early Oligocene.

The geologic evolution of the Langhe area begins in the Early Oligocene, with the deposition of a continental to shallow-marine transgressive succession (Molare Fm) consisting of alluvial-fan deposits, sourced from an emerged land located south of the TPB (Lorenz, 1969; Haccard et al., 1972), followed by shelf sandstones. Rapid drowning of the area led to deposition of hemipelagic mudstones (the upper Rupelian-Chattian Rocchetta Fm), containing a number of turbidite sandstone bodies of variable thickness and geometry (Dalla et al., 1992; Mutti et al., 1995; Rossi et al., 2009). The sedimentation of Molare and Rocchetta formations was strongly controlled by an extensional to transtensional synsedimentary tectonics, with a marked compartmentalization of the sub-basin by high-angle, basement-involving faults (Gelati et al., 1993; Mutti et al., 1995; Mutti et al., 2002).

During the Late Oligocene the Langhe Sub-basin appears well delineated, being bounded to the SW by the Monregalese High possibly continuing SE-wards into the Finalese High, both dominated by continental to shallow-marine deposits, and to the NE by the Alto Monferrato High (Gnaccolini and Gelati, 1996; Gelati and Gnaccolini, 1998, 2003). The differentiation is sharp around the Oligocene-Miocene transition, with continuous sedimentation in the Langhe Sub-basin and a large hiatus accompanied by angular unconformity on the Alto Monferrato High, where the Rocchetta mudstones are overlain by lower Burdigalian carbonate ramp deposits (the Calcare di Visone) (d'Atri, 1990).

In the Aquitanian-Burdigalian times the sedimentation and geologic history of the whole TPB was strongly influenced by the counterclockwise rotation of the Corsica-Sardinia microplate and concomitant rotation of TPB rocks (Maffione et al., 2008), together with the related westward motion of the Adriatic Indenter (Schumacher and Laubscher, 1996; Piana, 2000). These important geodynamic events led to a transpression-dominated tectonic regime (Spagnolo et al., 2007; Crispini et al., 2009; Capponi et al., 2009).

In the Langhe Sub-basin the Rocchetta Fm is commonly overlain by a siliceous lithozone representing a marker horizon on regional scale, correlated with the siliceous lithozone recognized by Amorosi et al. (1995) in the northern Apennines.

The early Burdigalian sedimentation is dominated by hemipelagic mudstones (Forcella et al., 1999), locally associated with resedimented carbonate deposits and glaucarenites (Gelati and Gnaccolini, 1998; Forcella et al., 1999). Emplacement of a thick and volumetrically very important, basinal-type turbidite system (Cortemilia Fm) took place in the Langhe Sub-basin during the late Burdigalian. Rossi et al. (2009) and Mosca et al. (2010) argued that at this time the Langhe Sub-basin experienced maximum space creation in the TPB. The change in sedimentation regime, accompanied by dramatic increase in subsidence rate, is thought to reflect the progressive involvement of the TPB area in the deformation of the Padan fronts (Gelati and Gnaccolini, 2003, Rossi et al., 2009 and Mosca et al., 2010) and start of downwarping of the basin in a piggy-back position.

A marked differentiation between the Alto Monferrato High and the Langhe Sub-basin, accompanied by basin reorganization, took place during the Langhian. Increase in subsidence in the western sector was accompanied by pronounced uplift of the sector located east of the river Orba valley, (Ghibaudo et al., 1985; Gelati and Falletti, 1996; Mutti et al., 2002) which became a site of shelf deposition, with the Cessole Marl wedge prograding SW-wards, i.e. toward the Langhe Sub-basin. Conversely, in the latter, the turbiditic sedimentation becomes very thick and pervasive (lower part of the Cassinasco Fm) (Mutti et al., 2002).

In the Serravallian the Langhe Sub-basin accommodated the upper part of the Cassinasco turbidite system, bounded at the base by an eastward thinning tongue of mudstones (the Murazzano Fm). In this time the Alto Monferrato area persisted as submarine high, where the sedimentation was characterized by richly bioclastic sand-waves interfingering with resedimented fan-delta slope deposits (Serravalle Sandstone) (Ghibaudo, 1984; Caprara et al., 1984).

During Tortonian basinal hemipelagic mudstones and minor turbiditic sandstones were laid down in the Langhe Sub-basin, whereas the Alto Monferrato area underwent a sudden drowning of the Serravalle Sandstone shelf, leading to the deposition of outer shelf siltstones with plenty of slump scars passing upwards to hemipelagic slope marls (Clari and Ghibaudo, 1979). Faulting along NNE- to NE-trending systems at the western margin of the Alto Monferrato High was recorded by gravity destabilization triggering west-directed mass flows, e.g. the Orsara Bormida megabed (Caprara et al., 1984; Gnaccolini, 1989).

A general uplift of the Oligo-Miocene succession of the TPB started since the late Miocene (Forcella et al., 1999; Barbieri et al., 2003).

3. METHODS

A revision of the stratigraphy and geological setting of the local succession is based on a detailed field work including facies analysis and identification of lithostratigraphic units, and on a revision of the biostratigraphy based on calcareous nannoplankton assemblages. 26 detailed stratigraphic sections have been measured in the Roccaverano area for a total thickness of 3100 m (Fig. 2, Pls. IV, V, VI). Lithology, thickness, geometry, latero-vertical relationships, structural setting and general tectono-stratigraphic evolution of the identified units are described. The cross-section of plate I, constructed on the basis of these sections, provided the basis for the reconstruction of the tectono-sedimentary evolution of the study area during the Oligocene to

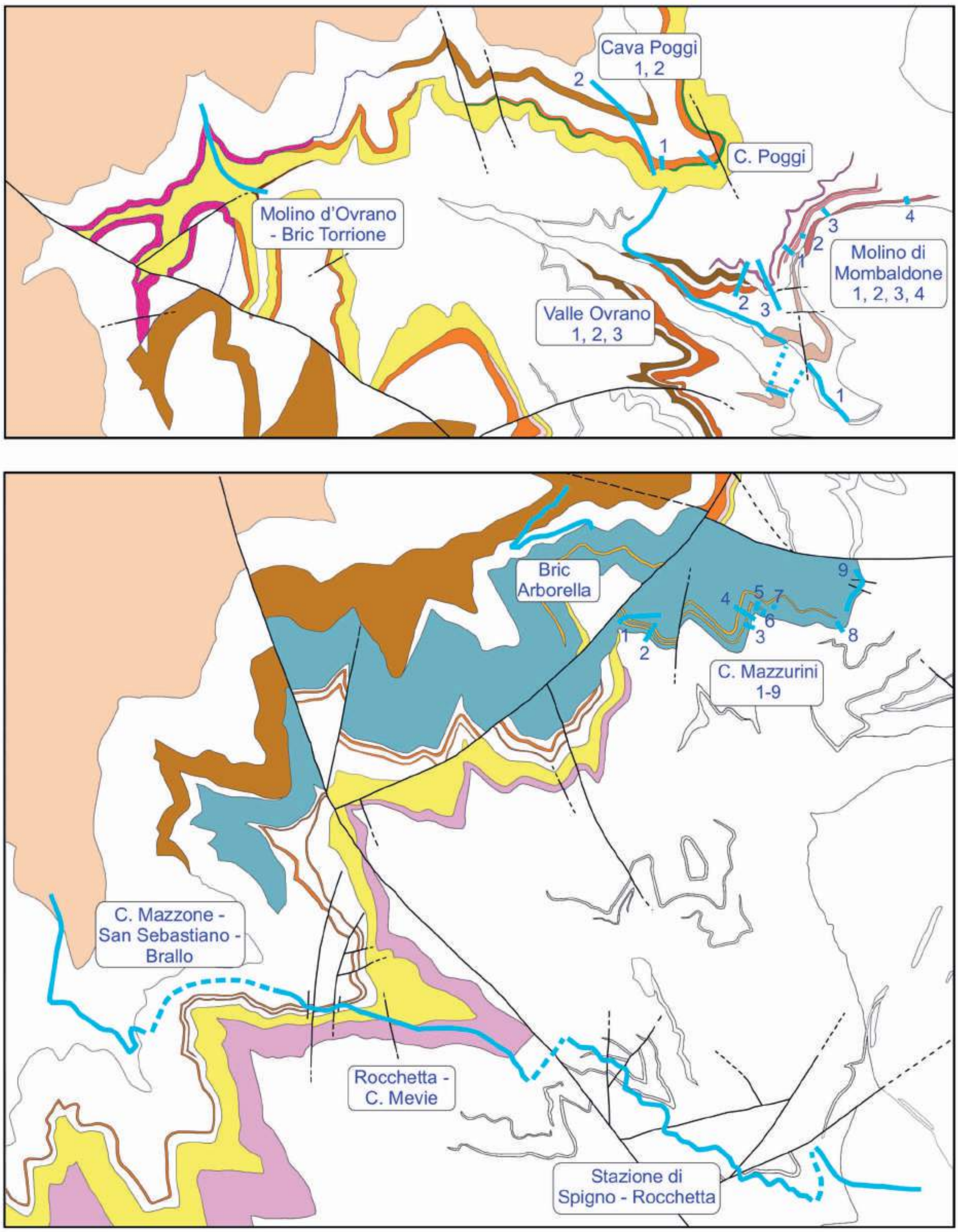

Fig. 2 - Location of measured stratigraphic sections in the Roccaverano-Merana area. Only larger sandstone units are represented with different colours (Noceto, C. Mazzurini, Piantivello, Bric Torrione, Cortemilia units, Ovrano Lower, Middle and Upper Sandstones, Molino di Mombaldone Lower, Midde and Upper Sandstones), along with the main calcarenitic units (C. Mevie, Pian Bruno and C. Poggi units). In yellow the Montechiaro d'Acqui Siliceous Lithozone. The colours of the various stratigraphic units correspond to those adopted in the geological map.

Burdigalian time span, with the steps of the evolution obtained by means of a successive flattening procedure.

Turbidite facies code for field description of detailed stratigraphic logs is after Ghibaudo (1992). The formations and members identified in the study area correspond in some cases to those of the literature, in other cases to informal units proposed here. A particular hyerarchical problem is that concerning the lithostratigraphic rank of the siliceous unit here defined "Montechiaro d'Acqui Siliceous Lithozone" (LS1). Although in the investigated area this unit occurs as a single package of strata, in the south-western neighbouring areas it is subdivided into minor units separated by specific turbiditic formations (Ghibaudo et al., this volume). This siliceous unit, represented by basinwide condensed deposits, has been indicated with the informal term of "lithozone".

4. BIOSTRATIGRAPHY

The biostratigraphy (Fig. 3) is based on the Fornaciari and Rio (1996), and Catanzariti et al. (1997) scheme of the Mediterranean calcareous nannoplankton biozonation recently emended by Di Stefano et al. (2008). The geochronology is based on Gradstein et al. (2004), Raffi et al. (2006) and Coccioni et al. (2008). Dating of various units is mostly based on a reference composite section sampled from the base of the Rocchetta Fm to the base of the Cortemilia Fm along the transect Stazione di Spigno-Rocchetta, Rocchetta-Case Mevie, C. Mazzone-Brallo (Fig. 2, Pl. V). Bioevents in the middle portion of the Rocchetta Fm could not be highlighted, as only the lowermost and uppermost parts of the formation have been sampled in this section. The dating of the Rocchetta Fm cropping out in the Ovrano Valley and Molino di Mombaldone area has been obtained in the Ovrano Valley section (Fig. 2, Pl. IVb), extending from the village of Mombaldone to the base of the Montechiaro d'Acqui Siliceous Lithozone, and in the Molino di Mombaldone section concerning the infill of the "Molino di Mombaldone Erosional Depression" (see below) (Fig. 2, Pl. VId). The Cianazzo section, located slightly NE of the study area on the eastern side of the Bormida di Spigno Valley east of the Piana village, where the Montechiaro d'Acqui Siliceous Lithozone crops out with continuity, has been used as reference section for the dating of this unit (Pl. IVa).

With reference to the composite section Stazione di Spigno-Rocchetta-Case Mevie-C. Mazzone-Brallo (Fig. 3), the Rocchetta Fm has been attributed to the biozones MNP23 p.p., MNP24, MNP25a, MNP25b, MNN1a, MNN1b, MNN1c, MNN1d p.p. (upper Rupelian-lower Aquitanian), the Montechiaro d'Acqui Siliceous Lithozone to the biozones MNN1d p.p., MNN2a p.p. (middle-upper Aquitanian), the Montechiaro d'Acqui Fm to the biozones MNN2a p.p., MNN2b, MNN3a p.p. (uppermost Aquitanian-lower Burdigalian), the Serole Fm to the biozones MNN3a p.p. - MNN3b p.p. (middle Burdigalian) and the Cortemilia Fm to the biozones MNN3b p.p. - MNN4b (upper Burdigalian). The Ovrano Valley section (Fig. 3, Pl. IVb) did not provide any specific bio-event (E. Fornaciari, personal communication), due to pervasive reworking, particularly in the lower and middle parts, dominated by resedimented deposits. It covers the uppermost part of the Rocchetta Fm and is physically correlatable with nearby sections by means of the Montechiaro d'Acqui Siliceous Lithozone, which is present at the top of the section and is confidently dated to the middle-late Aquitanian. The nannofossil assemblages in the upper part of the Ovrano section (above the sample 2138), dominated by marly hemipelagic mudstones with reliable biostratigraphic signal, suggest a latest Chattian-early Aquitanian age, in any case older than the AE of *Helicosphaera euphratis*. The upper part of the section, moreover, can be partly correlated with the Noceto unit, which may be ascribed to the early Aquitanian. The nannofossil biostratigraphic signal in the lower part (below sample 2134), instead, is very dirty due to the very high degree of reworking. The only reliable datum is represented by the presence of a few specimens of *Helicosphaera carteri* in three samples (2100, 2104 and 2130). Although the date of the first appearance of this species in unknown (the first common occurrence is currently reported in the early Aquitanian), according to E. Fornaciari (personal communication) the first specimens sparsely appear in the late Chattian. This finding, together with the fact that the Ovrano section is underlain by several hundred metres of Rocchetta Fm mudstones supports the hypothesis of the attribution of the lower part of the section to the late Chattian. The Ovrano section may therefore be attributed to the late Chattian-early Aquitanian. Similarly to the nearby Ovrano section, the Molino di Mombaldone section (Fig. 2, Pl. VId) which covers the whole infill of the "Molino di Mombaldone Erosional Depression", a large-scale slump scar cutting the Ovrano stratigraphy (see later), did not provide any specific bio-event. Despite the intense reworking, calcareous nannofossil association is characterized by very low abundance of *Dictyococcites bisectus* and absence of *Sphenolithus disbelemnos*; moreover, among the elicoliths *H. euphratis* is dominant while *H. carteri* is absent. On the basis of these data, the studied section can be ascribed to the interval between the LCO of *D. bisectus* and the FO of *S. disbelemnos*, corresponding to the Zones MNN1a-MNN1c, latest Chattian-early Aquitanian in age.

The biostratigraphic data yielded by the Cianazzo section, cropping out a few kilometres to the NE of the study area, supports the above chronological frame for the Montechiaro d'Acqui Siliceous Lithozone, the Montechiaro d'Acqui Fm and the Serole Fm (Fig. 3, Pl. IVa).

5. LITHOSTRATIGRAPHY

The lithostratigraphy is shown in the enclosed geological map and in the cross-section of plate I. It comprises, from the base upwards, the following units:

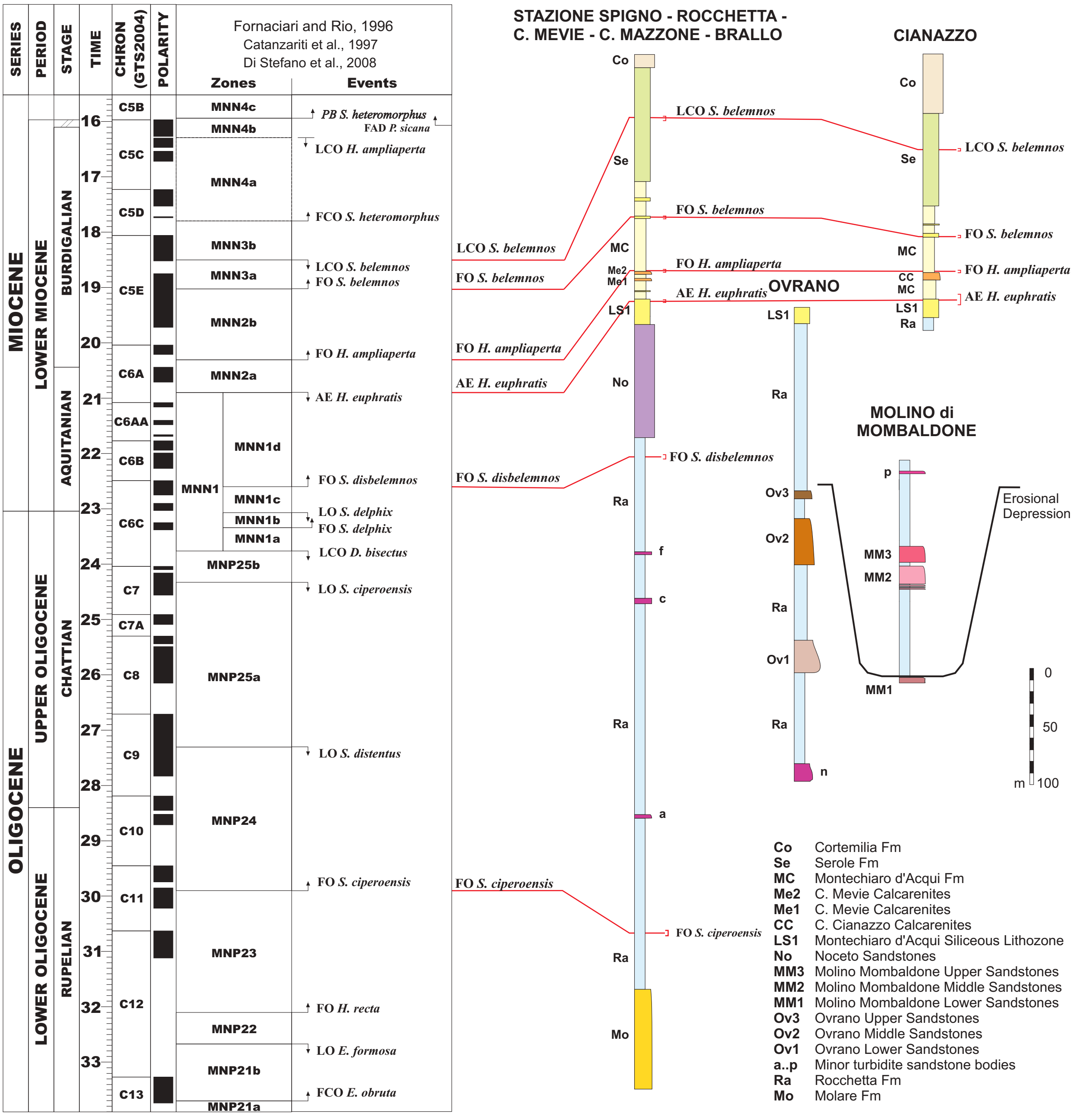

Fig. 3 - Calcareous nannoplankton biostratigraphy of the stratigraphic succession cropping out in the Roccaverano-Merana area. The Cianazzo section, located NE of the mapped area, is the reference section for the chronology of the Montechiaro d'Acqui Siliceous Lithozone and of overlying stratigraphy.

Crystalline basement (undifferentiated)
Molare Formation
Rocchetta Formation
Montechiaro d'Acqui Siliceous Lithozone
Montechiaro d'Acqui Formation
Serole Formation
Cortemilia Formation

The local stratigraphy is well exposed in the Stazione di Spigno-Rocchetta-C. Mevie-C. Mazzone-Brallo composite section along the road from Spigno Monferrato to Serole.

5.1. Undifferentiated Crystalline Basement

In the study area the crystalline basement is represented in a fault-bounded structural high here defined "Spigno Monferrato Horst" (see enclosed geologic map and Pl. I).

For the aims of this paper the crystalline basement has been regarded as undifferentiated. It crops out extensively only in the southeastern part of the mapped area, near Spigno Monferrato, where it consists of metabasites, prasinites, serpentinites and calcschists. The crystalline basement is non-conformably overlain by the Molare Fm. North and south of this area the basement is bounded by normal, sub-vertical faults (respectively Vico and Montaldo faults), and is brought in contact, together with the overlying Molare Fm, with the deep-water mudstones of the Rocchetta Fm (see also Fig. 28). The mentioned faults bound part of a complex intrabasinal high, active during the deposition of the Rocchetta Fm, which extends south of the mapped area. This structural high, characterized by minor horsts and grabens, is here defined "Dego-Spigno Monferrato High" (Ghibaudo et al., this volume). In the study area, in particular, the Vico and Montaldo faults, respectively striking ESE and NE, bound a northern horst, here defined "Spigno Monferrato Horst", and a southern graben, here defined "Piana Crixia Graben", active during the deposition of Rocchetta Fm, forming the northern part of the wider Dego-Spigno Monferrato High (cf. geological map and Pl. I). The faults which affect the basement and do not involve the sedimentary cover were not reported in the enclosed geological map.

5.2. Molare Formation

The Molare Fm lies non-conformably on the crystalline basement and grades conformably upwards to the mudstones of Rocchetta Fm with rapid transition occurring in a few metres and apparently without significant gap. Regionally, this formation consists of polygenic, coarse- to fine-grained mostly continental conglomerates grading upwards into marine bioturbated fossiliferous sandstones.

5.2.1. The continental conglomerates of the Molare Formation in the Spigno Monferrato area

Detailed mapping of the Oligocene deposits cropping out on the entire southern margin of the TPB demonstrates that the continental deposits of the Molare Fm are confined within basement complex grabens originally bounded by high-angle normal faults, subsequently offset, in places, by subvertical transcurrent faults in pre-Burdigalian times (Ghibaudo et al., in prep.). In the study area the continental conglomerates of the Molare Fm crop out only to the S of the Montaldo Fault, where they form part of the infill of a Lower Oligocene graben, here defined "Borgo Graben", also extended to the south of the study area and bounded to the north by the Montaldo Fault and the Spigno Monferrato Horst (Ghibaudo et al., this volume). North-East of the study area another Lower Oligocene graben accommodating thick continental conglomerates was present NE of the Spigno Monferrato Horst. This structural depression, highly dissected by post-Oligocene high-angle faults and bounded to the SW by the Vico Fault, is here defined "Cartosio Graben" (Ghibaudo et al., this volume).

The overall thickness of the continental conglomerates cropping out in the study area south of the Montaldo Fault is around 50-60 metres. Along all its length the Montaldo high-angle normal fault, which stretches also east of the mapped area, separates an uplifted northern sector, in which the basement is directly capped by the transgressive marine facies of the Molare Fm, from a southern subsiding sector accommodating an expanded stratigraphy of the Molare Fm, including thick continental conglomerates overlain by marine sandstones (Ghibaudo et al., in prep.). These relationships highlight that the Montaldo and Vico faults began their activity in the Early Oligocene in a phase predating, or contemporaneous to, the deposition of the continental conglomerates. It may be argued that the Oligocene transgression, which followed the deposition of the continental conglomerates, first encroached upon the Borgo Graben and the northern Cartosio Graben depositing marine sands, and only later upon the adjacent Spigno Monferrato Horst, with marine sands directly covering the crystalline basement.

The continental conglomerates cropping out in the study area are not particularly informative. Immediately east of the study area, near the Montaldo Fault, they are coarse to very coarse, with blocks up to 4 m in diameter and sub-rounded to sub-angular clasts; compositionally they are polymict, non-fossiliferous and display a poorly distinct stratification, and rare decimetric sandstone interbeds. They lack internal organization and show a grey-brown to reddish sandy to sandy-conglomeratic matrix. They are inferred to have been laid down by hyperconcentrated flows and debris flows and, subordinately, tractive flows. A depositional environment represented by alluvial fans, and/or subaerial portions of fan-deltas, may be envisaged.

5.2.2. The marine deposits of the Molare Formation in the Spigno Monferrato area

The marine sandstones of the Molare Fm crop out both above the continental conglomerates occurring south of the Montaldo Fault (Borgo Graben), and directly on the crystalline basement of the adjacent Spigno Monferrato Horst. The basal contact of the marine sandstones corresponds to a regional transgressive surface already recognized by Lorenz (1969), highlighted by a characteristic lag of coarse to very coarse conglomerate, locally discontinuous, varying in thickness from a few decimetres to some metres. Due to its limited thickness and lack of lateral continuity, it has not been distinguished as separate unit in the enclosed geological map, and has been incorporated in the sandstones. This horizon marks the position and landward migration of the coastal onlap during the Oligocene transgression.

5.2.2.1. The basal transgressive (lag) conglomerates of the Molare Formation

Where the marine sandstones lie on continental conglomerates (Borgo Graben, S of the Montaldo Fault) the transgressive lag is represented by a single horizon with well rounded pebbles to boulders aligned on the ravinement surface (Fig. 4a, 4b). The clasts are polygenic

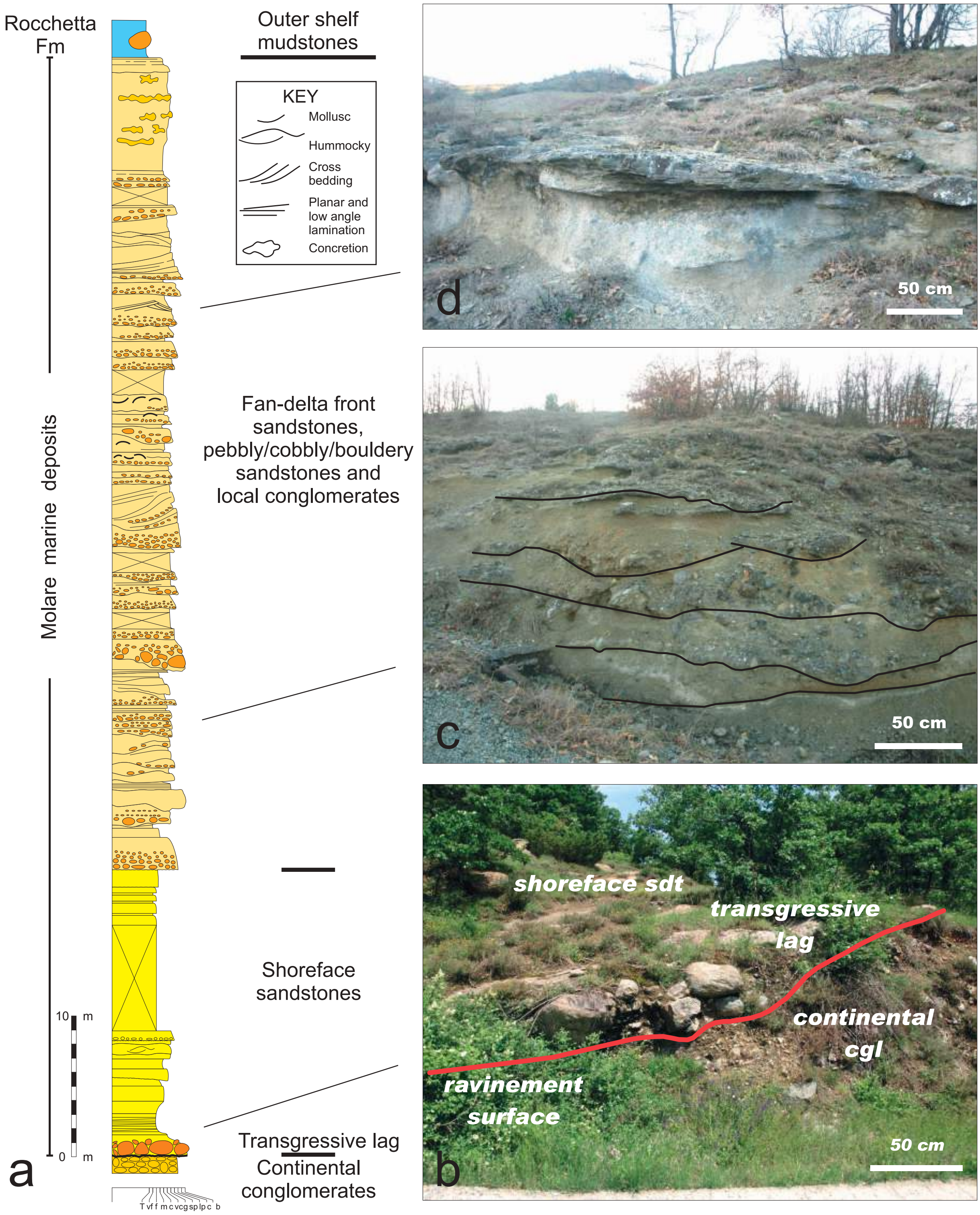

Fig. 4 - The overall transgressive-regressive cycle characterizing the marine deposits of the Molare Fm atop the continental conglomerates infilling the Borgo Graben. a) Field sketch of the succession cropping out along the track leading from Valla stream to the Montaldo cemetery. Thickness is approximate. b) Transgressive lag deposits atop the Molare continental conglomerates. c) Fan-delta front, graded conglomerate-sandstone beds with marked lenticular geometry and erosional base inferred to record flash floods of the feeding system. d) Fan-delta front, graded pebbly sandstone bed, reworked at the top by storm waves leading to development of hummocky cross-stratification.

and, as a rule, they are coarser than those of the underlying continental conglomerates. They represent the coarse residual product left on the transgressive surface by the erosive passage of wave base during the landward migration of the coastline on the previous continental deposits, accompanied by winnowing out of the medium-fine material and abandonment of coarser clasts as a transgressive lag on the surface.

Where the transgressive marine sandstones overlie the crystalline basement (Spigno Monferrato Horst, N of the Montaldo Fault) the nonconformity shows the typical features of a rocky shore transgression. In this case the basal conglomerate is thicker, locally up to several metres (Fig. 5a). The clasts range from pebbles to boulders up to 2 metres in diameter and are badly sorted. They are sub-angular to well rounded and bear a sandy-conglomeratic matrix. Typically, the composition is monomict and reflects that of the transgressed substratum. The coarsest elements are in mutual contact and locally show a close and dense packing and fitted fabric. Large broken rounds, indicating reworking in a high-energy setting, are locally present.

The upper contact with the marine sandstones ranges from sharp, with boulders protruding into the overlying sandstones (Fig. 5d), to more gradual and marked by some metres of small-pebble conglomerates and/or micro-conglomeratic sandstones with solitary corals, coralline red algae and oysters (Fig. 5e), grading upwards into heavily bioturbated sandstones. Easily accessible outcrops allowing close observations of the basal nonconformity and overlying conglomerate are located in several places of the area of Spigno Monferrato. North of this village, near the hydroelectric power plant, the nonconformity surface shows a gentle dip westwards and decimetric relief controlled by joints affecting the basement rocks (Fig. 5a). The joints are locally open and infilled with the sandy-conglomeratic matrix of the overlying conglomerate, leading to incipient neptunian dykes (Fig. 5b). Together with sub-rounded pebbles to boulders the local outcrop also shows a large angular block of basement rock some metres in length (Fig. 5c), interpretable as resulting from failure of a local cliff and escaping further reworking or, in alternative, transported by exceptional storm or tsunami waves. Such extremely energetic waves, in fact, are able to transport blocks up to several tens of tons in weight (Goto et al., 2010; Bourgeois and MacInnes, 2010; inter alia cum bibl.). On the right bank of the Valla stream, near the footbridge, the nonconformity surface is more irregular. The basement forms here a local prominence bounded to the NE by a subvertical scarp some metres high, against which big, poorly rounded metric blocks are preserved, evidently accumulated at the foot of a paleo-cliff (Fig. 6d). In general, the rocky paleo-coast of the Spigno Monferrato area should have been very irregular and characterized by a significant relief, in the order of some tens of metres, with a gentle westward dip of the nonconformity surface. In fact, from W to E, the thickness of the marine sandstones lying on the nonconformity shows a gradual decrease with minimum values on the eastern side of the dammed lake in the Valla stream valley. This thinning out probably reflects the onlap onto a paleoslope characterized, at least locally, by westward dip (see later).

In summary, the coarse basal conglomerates overlying the nonconformity are particularly characterized by: a) a monomict composition, reflecting the local substratum; b) vertical and lateral transition to transgressive, shallow-water, fossiliferous, marine facies; c) the presence of neptunian dykes as infill of joints and open fractures in the basement rocks underlying the nonconformity; d) presence of large broken rounds and fitted fabric of larger clasts. All the observed features allow an interpretation of the basal conglomerates as transgressive rocky shore deposits laid down under a wavy regime of episodic extreme energy (Johnson, 1988; Bishop and Hughes, 1989; Johnstone et al., 2006), able to rework and mobilize large blocks from the substratum (Ledesma-Vazquez et al., 2006; Fichaut and Suanez, 2011). An irregular and rugged rocky coast may be envisaged, bounding an emerged land with a relief of some tens of metres, formed by heavily fractured basement rocks. The variably sized clasts eroded and torn off from the cliffs were accumulated and reworked by storm waves in intertidal to supratidal areas, to form classic boulder beaches (Oak, 1984; McKenna, 2005). The reworking continued up to a point when the achievement of a fitted, stable fabric could prevent further mobilization. The subsequent deepening of the depositional environment led to the *in situ* fossilization of the basal conglomerates, being buried by shoreface sands. During this process the coarse sands and pebbly sands could infiltrate downwards in the wide interstices between the blocks and were preserved as coarse matrix of the conglomerate, and local infill of the open basement joints.

5.2.2.2. The marine sandstones of Molare Formation

The marine sandstones are medium-fine- to very coarse-grained, locally microconglomeratic, and occur in medium to thick layers, commonly amalgamated. Primary sedimentary structures are seldom preserved or detectable due to the common bioturbation (Fig. 6e) and pervasively weathered surfaces. The bed boundaries are discontinuous and delimit tabular to lensoid layers. Most common fossils include: bivalves (*Pecten, Clamys, Ostrea, Cardium*), gastropods, echinoderms, bryozoans and large foraminifers (*Operculina, Nummulites*). The thickness of the marine sandstones of the Molare Fm is variable even over relatively short distances, as a result of onlap on the basal nonconformity and depending on the paleostructural setting. West of Valla stream (Merana, Bric Monzuccaro and Spigno Monferrato areas) the marine sandstones have a thickness of about 60-80 m, whereas east of this stream they thin out, being reduced to about 30 m. These differences highlight a probable eastward onlap onto a basement paleorelief gently dipping westwards, represented by the Spigno Monferrato Horst.

The marine sandstones directly overlying the Spigno Monferrato basement horst show different features when compared to those capping the continental conglomerates in the Borgo Graben. In the former area the sandstones atop the crystalline basement are generally interpretable as shoreface deposits. Expeditious logging shows a subdivision into truncated transgressive-regressive small-

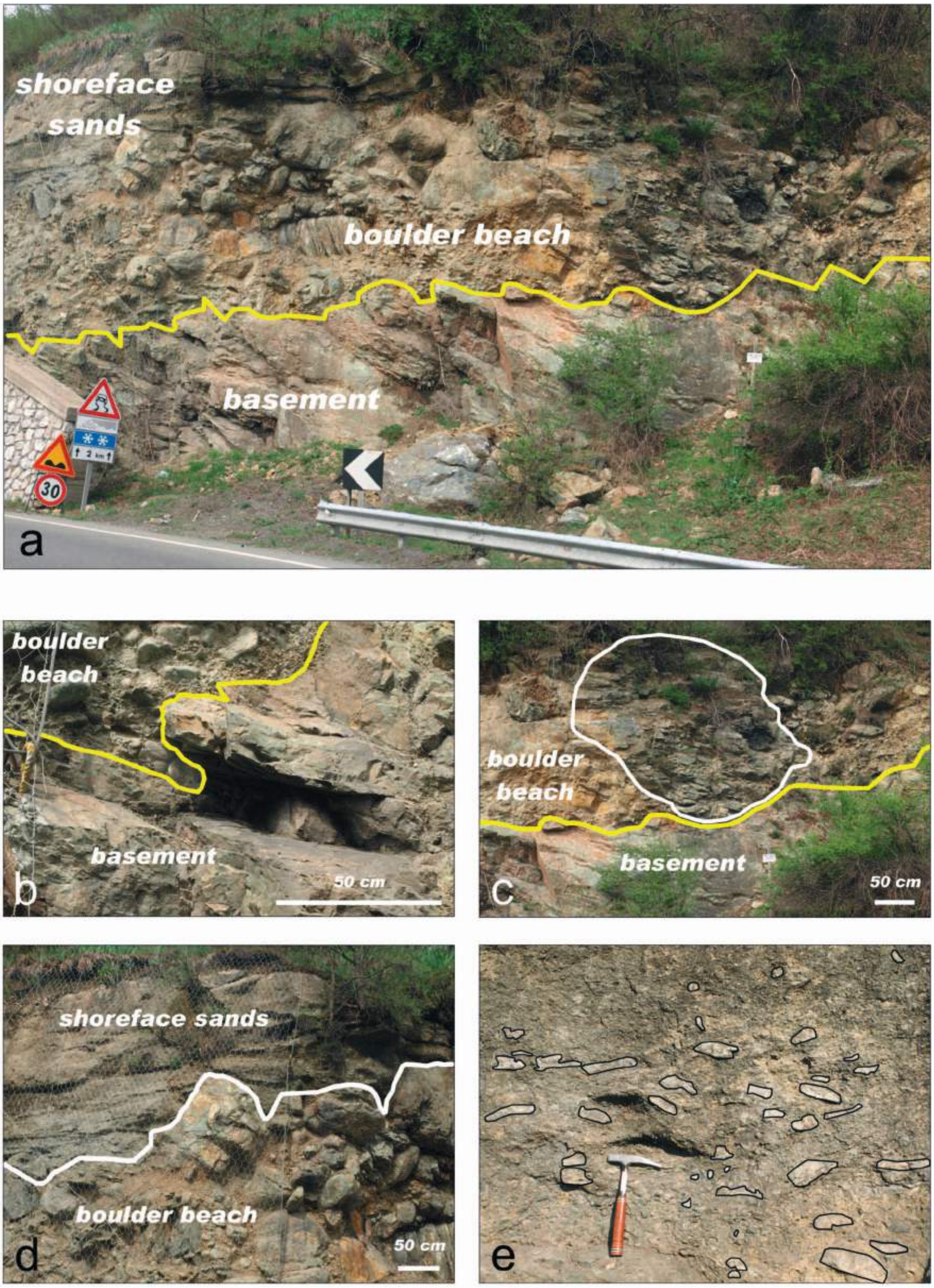

Fig. 5 - Transgressive marine deposits of the Molare Fm overlying the crystalline basement N of Spigno Monferrato near the hydroelectric power plant. The succession records a rocky shore transgression characterized by development of a transgressive boulder beach. a) Overview of the nonconformity surface and transgressive succession. Note the small-scale irregularity of the transgressive surface, due to the presence of a joint system in the basement, and the vertical transition to shoreface fossiliferous sandstones. b) Detail of the nonconformity surface showing an open fissure in the substratum infilled with coarse transgressive deposits (incipient neptunian dyke). c) Metric boulder lying on the basement interpreted as emplaced on the transgressive surface by storm or tsunami waves of exceptional energy. d) Detail of the abrupt vertical transition between the boulder beach and shoreface sandstones, characterized by large boulders protruding into the sandstones. e) Detail of the fossiliferous shoreface sandstones and microrudites. Large ostreid fragments are highlighted.

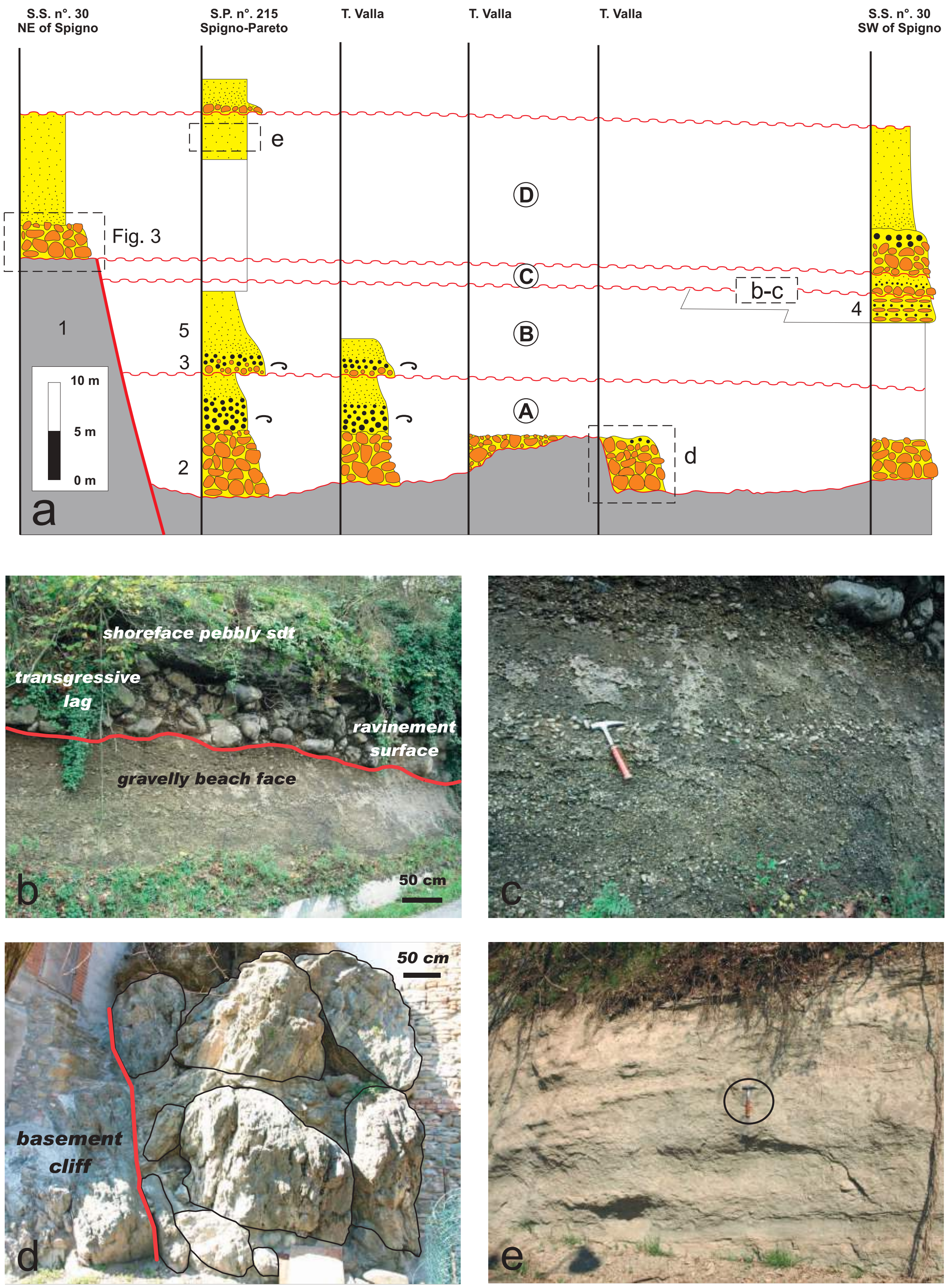

Fig. 6 - Truncated transgressive-regressive cycles in the trasgressive marine deposits of the Molare Fm overlying the crystalline basement in the Spigno Monferrato area. a) Cross section of the deposits based on expeditious observations. Thicknesses are estimated. The basal cycles are laid down in a small structural depression of the basement. 1) Crystalline basement. 2) Boulder beach deposit. 3) Transgressive lag. 4) Gravelly beachface. 5) Shoreface sandstones. b) Detail of the vertical transition between cycles B and C cropping out along the Road N. 30, S of Spigno Monferrato. c) Detail of the beachface deposits of cycle B showing crude horizontal lamination highlighted by alignments of discoidal small pebbles. d) Large blocks accumulated against a basement paleo-cliff by inferred storm waves (right bank of the Valla stream, near the footbridge, below the Spigno Monferrato post office). e) Homogenized, bioturbated, shoreface sandstones with indistinct layering.

scale cycles, ranging in thickness from a few metres to 10-15 m, characterized by basal ravinement capped by transgressive lags with pebbles to boulders, overlain by bioturbated shoreface sandstones. At least four transgressive-regressive cycles are present in the area surrounding Spigno Monferrato, the lower ones being confined in a small structural low of the basement (Fig. 6a). Details of these cycles are shown in figure 6b, 6c, 6d, 6e.

The overlying deposits, forming the bulk of the marine unit of the Molare Fm, mainly appear as a discontinuously stratified succession, upward-fining in the uppermost part, of mostly sheet-like, medium- to thick-bedded, amalgamated medium-fine sandstones and pebbly sandstones. Sandstones beds are either homogenized by bioturbation, or show planar or low-angle lamination in the lower part passing upwards to bioturbated fine sandstones. Hummocky cross-lamination is locally present. Fine-grained pebbly sandstone beds are commonly graded, graded-to-bioturbated or graded-to-laminated beds, with the laminated division consisting of planar, low angle or hummocky laminae. Such deposits may be interpreted as storm-influenced shelf deposits.

Where the marine deposits overlie the continental conglomerates (e.g. Borgo Graben), they show different facies. Along the track leading from Valla stream to the Montaldo cemetery the sandstones are about 60 m thick, organized into a transgressive-regressive cycle. A lower transgressive part, about 20 m thick, consisting of a cobble-to-boulder basal lag overlain by shoreface bioturbated or laminated sandstones, grades upwards into a regressive unit consisting of conglomeratic sandstones with pebbles to boulders, microconglomerates and very coarse fossiliferous sandstones (Fig. 4a). Layers in this interval are lenticular, bounded by strongly erosional bases; they are thick to very thick, and are commonly graded, graded-to-laminated (with the upper parts of the beds characterized by laminae ranging from planar, to low-angle oblique, to hummocky), or internally disorganized (Fig. 4b, 4c, 4d). The depositional environment may have been the proximal front of a coarse-grained fan-delta where the deposits dumped by flash floods were locally reworked by the wave action.

Gnaccolini et al. (1990) regarded these deposits as representing the first Oligocene sequence of the Langhe Sub-basin and interpreted the coarse conglomeratic deposits cropping out atop the crystalline basement in the thalweg of the Valla River and along the Spigno Monferrato national road as recording the fluvial infill of an incised valley, later transgressed by the marine sandstone. Similarly, Mutti et al (2002) interpret the boulder beach deposits of the hydroelectric power plant as fluvial deposits. These interpretations contrasts with our data. We believe that the conglomerates with well rounded spheroidal and discoidal pebbles, characterized by plane-parallel stratification, cropping out along the national road near Spigno are to be regarded as the record of a gravel beach forming the uppermost regressive interval of a transgressive-regressive cycle (lacking exposure of the lower part) truncated at the top by the transgressive lag of the following cycle (Fig. 6a, 6b, 6c). A gravel beach setting for these pebble conglomerates was envisaged also by Rossi et al. (2009).

The Molare Fm in the Spigno Monferrato area is attributed to the Early Oligocene by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) mainly on the basis of the planktonic foraminiferal assemblages found in the overlying marls of the Rocchetta Fm. Our nannofossil biostratigraphy confirms the Rupelian age of the lower part of the Rocchetta Fm, to which the Molare Fm grades in apparent continuity. Based on the dinoflagellate biostratigraphy Rossi et al. (2009) refer this unit to the Rupelian. On these bases the Molare Fm of the Spigno Monferrato area is attributed to the Rupelian.

5.3. Rocchetta Formation

The Rocchetta Fm is a lithologically heterogeneous siliciclastic unit, consisting of mudstones, bioturbated siltstones and subordinate thin- to very thin-bedded turbiditic siltstones and sandstones. These fine-grained lithologies encase, as members occurring at various stratigraphic levels, sandstone to sandstone-conglomerate bodies with geometry ranging from lenticular, locally broadly lenticular, to wedge-shaped, and minor sandstone beds with tabular geometry (key beds) (cf. enclosed geological map and Pl. I). For descriptive purposes, the fine-grained deposits of the Rocchetta Fm, forming the bulk of the formation, are here defined with the informal term of "mudstones of the Rocchetta Fm". The key sandstone beds have been indicated with lower-case letters (**a**, **b**, **c**...). In the study area the Rocchetta Fm includes also a number of slumped units (S1, S2, S3, S4, S5, S6) and a large-scale erosional depression defined as "Molino di Mombaldone Erosional Depression" (cf. Pl. I). In particular, the sandstone bodies indicated as Molino di Mombaldone Middle and Upper Sandstones, are confined within this depression (cf. Pl. I).

The Rocchetta Fm, as defined in this paper, is more comprehensive than in the formal definition proposed by Gelati (1968) and adopted in the Sheet 81 Ceva to scale 1:100000 of the "Carta Geologica d'Italia" (cf. Francani et al., 1971). It includes, in fact, a large-scale sandstone-conglomerate body (Noceto Sandstones), which in the Sheet 81 Ceva is comprised in the overlying Monesiglio Fm. The attribution of the Noceto Sandstones to the Rocchetta Fm is justified by two reasons: 1) this unit shows facies similar to other sandstone-conglomerate bodies encased in the mudstones of the Rocchetta Fm and its regionally equivalent formations (cf. Andreoni et al., 1981; Ghibaudo et al., 1985; Gelati and Gnaccolini, 1998); 2) The Noceto Sandstones are overlain by siliceous and carbonate hemipelagites, here respectively indicated as Montechiaro d'Acqui Siliceous Lithozone and Montechiaro d'Acqui Formation, which extend regionally upon the mudstones of the Rocchetta Fm, beyond the depositional closure of the Noceto unit. These hemipelagites mark an important oceanographic change in a basin formerly characterized by exclusively terrigenous sedimentation. It appears consequently reasonable to include in the same lithostratigraphic unit (Rocchetta Fm) all the sandstone bodies preceding this change in sedimentary regime and to regard the overlying units as independent lithostratigraphic units, thus making the local succession consistent with the regional lithostratigraphy.

In a revision of the lithostratigraphy of the study area, Gelati and Gnaccolini (1998), regard the Rocchetta Fm as a part of a more extended unit defined as *Rocchetta-Monesiglio Group*. The latter includes all the units and sub-units extending from the Molare Fm to the Cortemilia Fm. This choice has been recently shared in the Sheet 211 Dego to scale 1:50000 of the "Carta Geologica d'Italia" (Gelati et al., 2010a, b), the sole difference being the reduction to a lower rank of the *Rocchetta-Monesiglio Group* of Gelati and Gnaccolini (1998) which has been renamed *Formazione di Rocchetta-Monesiglio*. For the above reasons the all-inclusive lithostratigraphy adopted by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) in the Sheet 211 Dego has been regarded as unsuitable to describe the local lithostratigraphy, and has not been adopted in the enclosed geological map.

The Rocchetta Fm is comprised between the Molare Fm at the base and the Montechiaro d'Acqui Siliceous Lithozone at the top. The basal contact between the mudstones of the Rocchetta Fm and the sandstones of the Molare Fm is transitional and marked by coarse bioturbated siltstones variably thick (from a few metres up to 20-30 m). The upper contact is sharp or rapidly transitional. The formation shows variable thickness depending on the activity of syndepositional faults (cf. Pl. I). In the Merana-Spigno Monferrato area (Spigno Monferrato Horst) it shows a thickness of about 540 m, of which 450 m are represented by the mudstones of the Rocchetta Fm and 90 m by the Noceto Sandstones Member. Both N and S of the Spigno Monferrato Horst, the formation is considerably thicker. The stratigraphy of the Rocchetta Fm is well exposed along the road from Stazione di Spigno to Rocchetta - C. Mevie (Fig. 2, Pl. Va, Vb).

Based on the planktonic foraminiferal assemblages, the Rocchetta Formation has been dated by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) to the Late Oligocene. On the basis of the here adopted calcareous nannoplankton biostratigraphy, the age of the Rocchetta Fm, defined in the Stazione di Spigno - C. Mevie section, is comprised between the late Rupelian and the early Aquitanian (Zones MNP23 p.p.-MNN1d p.p.).

In the next sections the following units will be briefly described within the Rocchetta Fm:

Mudstones of the Rocchetta Fm
Minor sandstone bodies of the Rocchetta Fm
Slump sheets
Piana Crixia Conglomerate
Molino di Mombaldone Lower Sandstones
Ovrano Lower Sandstones
Ovrano Middle Sandstones
Ovrano Upper Sandstones
Molino di Mombaldone Erosional Depression
Molino di Mombaldone Middle Sandstones
Molino di Mombaldone Upper Sandstones
Noceto Sandstones

5.3.1. Mudstones of the Rocchetta Formation

In the study area this unit consists of resedimented and hemipelagic mudstones, in most part delicately bioturbated, and subordinate thin to very thin, laminated or bioturbated coarse siltstone and fine to very fine sandstone layers laid down by dilute turbidity flows. Only local intercalations of medium-bedded, laminated, fine sandstone beds are present. In the Stazione di Spigno-Rocchetta type section the Rocchetta mudstones are 450 m thick (Pl. Va). The Rocchetta mudstones represent the volumetrically dominant lithology of the Rocchetta Fm, and encase, at various stratigraphic levels, several sandstone bodies. The Rocchetta mudstones correspond, *pro parte*, to the *Peliti di fondo* of the *Rocchetta-Monesiglio Group* of Gelati and Gnaccolini (1998) and to *Massa di fondo* of the Sheet 211 Dego to scale 1:50000 of Gelati et al. (2010a, b). The depositional setting is interpreted by Gelati and Gnaccolini (1998) as transitional between platform and slope (lower part of the succession) and transitional to the basin (upper part of the succession). We partly share the interpretation by Gelati and Gnaccolini (1998) and regard the formation as consisting of slope deposits grading upwards to base-of-slope deposits. This setting is particularly suggested by the hemipelagic facies association encasing channelized turbiditic sandstone bodies, large submarine slump sheets and large scale slump scars. Moreover, in the north-eastern sector of the study area the mudstones show features suggestive of a prodelta slope setting (Ghibaudo et al., 2001a). A peculiar facies is shown on structural highs (e.g., Spigno Monferrato Horst) and, particularly, in the area located to the E of Valla stream, where the lower portion of the formation is characterized by some tens of metres of homogeneous, heavily bioturbated and fossiliferous light-brown-coloured coarse siltstones, interpreted as outer-shelf/upper-slope deposits. Field mapping to the E and NE of the study area shows that an Oligocene depocentre developed NE of the Dego-Spigno Monferrato High (Turpino Depocentre), where the mudstones of the Rocchetta Fm reach an estimated thickness of about 1000 m (Ghibaudo et al., this volume) (cf. Pl. I).

5.3.2. Minor sandstone bodies of the Rocchetta Formation

These are sheet-like single or clustered sandstone layers, of decimetric to metric thickness, intercalated at various levels in the mudstones of the Rocchetta Fm. These bodies, labelled **a, b, c**…, consist of fine- to medium-grained turbiditic sandstones with lateral extent ranging from hundreds of metres to some kilometres (e.g., the body **b** corresponding, *pro parte*, to the *Livello Masseria* of Gelati and Gnaccolini, 1998 and Gelati et al., 2010a, b). They are excellent key beds within the monotonous pelitic succession.

5.3.3. Piana Crixia Conglomerates

In the study area this lithostratigraphic unit is located near the base of the Rocchetta Fm and crops out S of the village of Montaldo, on the ridge separating the Bormida di Spigno Valley from the Valla stream valley. The unit crops out only with limited extent in the study area, being mostly developed S of it. Large exposures exist on the left bank of the Bormida River in locality Piana Crixia, adjacent to the study area, where the unit is downthrown by a N-trending fault. The unit consists of resedimented conglomerates, pebbly sandstones and coarse sandstones in thick and very thick strata, mostly amalgamated, with local intercalations of medium-fine sandstones and siltstones. It is located about 30 m above the top of the Molare Fm and represents the lowermost unit of the Rocchetta Fm cropping out in the study area. It is confined within a structural low of the basement (Piana Crixia Graben), bounded to the N by the Montaldo Fault, and to the S by the Piana Crixia Fault, located slightly outside the mapped area (Ghibaudo et al., this volume). Paleocurrents indicate a provenance from W-WNW (cf. also Cazzola et al., 1981).

The Piana Crixia Conglomerates correspond to the *Piana Crixia Unit* of Cazzola et al. (1981) and to the *Conglomerato di Piana Crixia* of Gelati et al. (2010a, b). Cazzola et al. (1981) regard this unit as a slope channel. Given its complex internal organization, characterized by multistorey and multilateral channel fills (Cazzola et al., 1981), this unit is here regarded as a structurally confined slope channel complex.

The Piana Crixia Conglomerates are tentatively dated by Gelati et al. (2010a, b) to the transition Early Oligocene-Late Oligocene. Based on the dinoflagellate biostratigraphy Rossi et al. (2009) refer this unit to the late Rupelian. We share this dating.

5.3.4. Molino di Mombaldone Lower Sandstones

This unit can be extensively observed at the base of the large exposures in front of the Molino di Mombaldone along the thalweg of the Bormida di Spigno River. It shows lenticular geometry with concave-up base and is encased in the mudstones of the Rocchetta Fm (Pl. I). The basal contact is sharp and erosional, the upper is rapidly transitional. The unit is in places partly eroded by the lower part of the Molino di Mombaldone Erosional Depression, and has maximum thickness of 45 m and lateral extent of about 800 m (Figs. 7, 8a, 9a). It shows a complex internal architecture resulting from the amalgamation of three stacked secondary channels (multistorey channel-fill) (Fig. 7). In the amalgamated zone the unit is wholly made up of sandstone. Laterally, it is subdivided into the component channels, separated by a few metres of mudstones. At least in the case of the uppermost channel, a lateral-accretion pattern of deposition in a shallow meandering thalweg is indicated by the gentle south-westerly dip of strata. In its depocentral portion the Molino di Mombaldone Lower Sandstones member consists of thick and very thick amalgamated beds of medium- and coarse-grained graded sandstones in the lower part and medium-bedded, fine- to very fine-grained, mostly amalgamated, parallel-laminated sandstones in the upper part. In a post-depositional stage, moreover, the south-western portion of the unit was deformed into a monocline dipping SW-wards at 15° (Fig. 7). The Molino di Mombaldone Lower Sandstones correspond to the *Unità del Molino di Mombaldone* of Gelati and Gnaccolini (1998) and to the *Membro delle Arenarie del Molino di Mombaldone* of Gelati et al. (2010a, b). These Authors interpret the sedimentary body as a slope channel. Given its composite architecture, the unit is here interpreted as a slope-channel-complex.

The unit is dated by Gelati et al. (1993), Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) to the transition Early Oligocene-Late Oligocene (Zone P21). Based on calcareous nannoplankton the unit is here referred to the late Chattian.

5.3.5. Ovrano Lower Sandstones

This unit is located at the entry of the Ovrano Valley slightly N of the village of Mombaldone. The reference section of this unit and the overlying Ovrano middle and upper units is the Ovrano section extended from the Mombaldone village to the base of the Montechiaro d'Acqui Siliceous Lithozone LS1 (Fig. 2, Pl. IVb). The unit shows a broadly lenticular geometry with concave-up base and is encased within the mudstones of the Rocchetta Fm. The basal contact is sharp, the upper rapidly transitional. The unit is 29 m thick with a lateral extent of about 550 m (*Note 1). The unit is composed of alternating medium- and thin-bedded resedimented fine sandstones and siltstones showing heavy bioturbation obliterating to a variable extent a plane-parallel lamination. The unit corresponds to one of the *Corpi arenacei minori* of Gelati and Gnaccolini (1998), and, in particular, to the minor sandstone body "a" mapped by them at the entry of the Ovrano Valley. These authors mapped this unit only in the Ovrano Valley, where, according to them, it would be bounded by faults on both northern and southern sides. The field evidence demonstrates, however, that the unit can be traced for some hundreds of metres even on the left side of the Bormida di Spigno Valley (Fig. 8a).

Based on calcareous nannofossil assemblages the unit is dated to the late Chattian.

5.3.6. Ovrano Middle and Upper Sandstones

These units crop out primarily in the Ovrano Valley (Fig. 2, Pl. IVb). Both units show a very broadly lenticular geometry and are encased within the mudstones of the

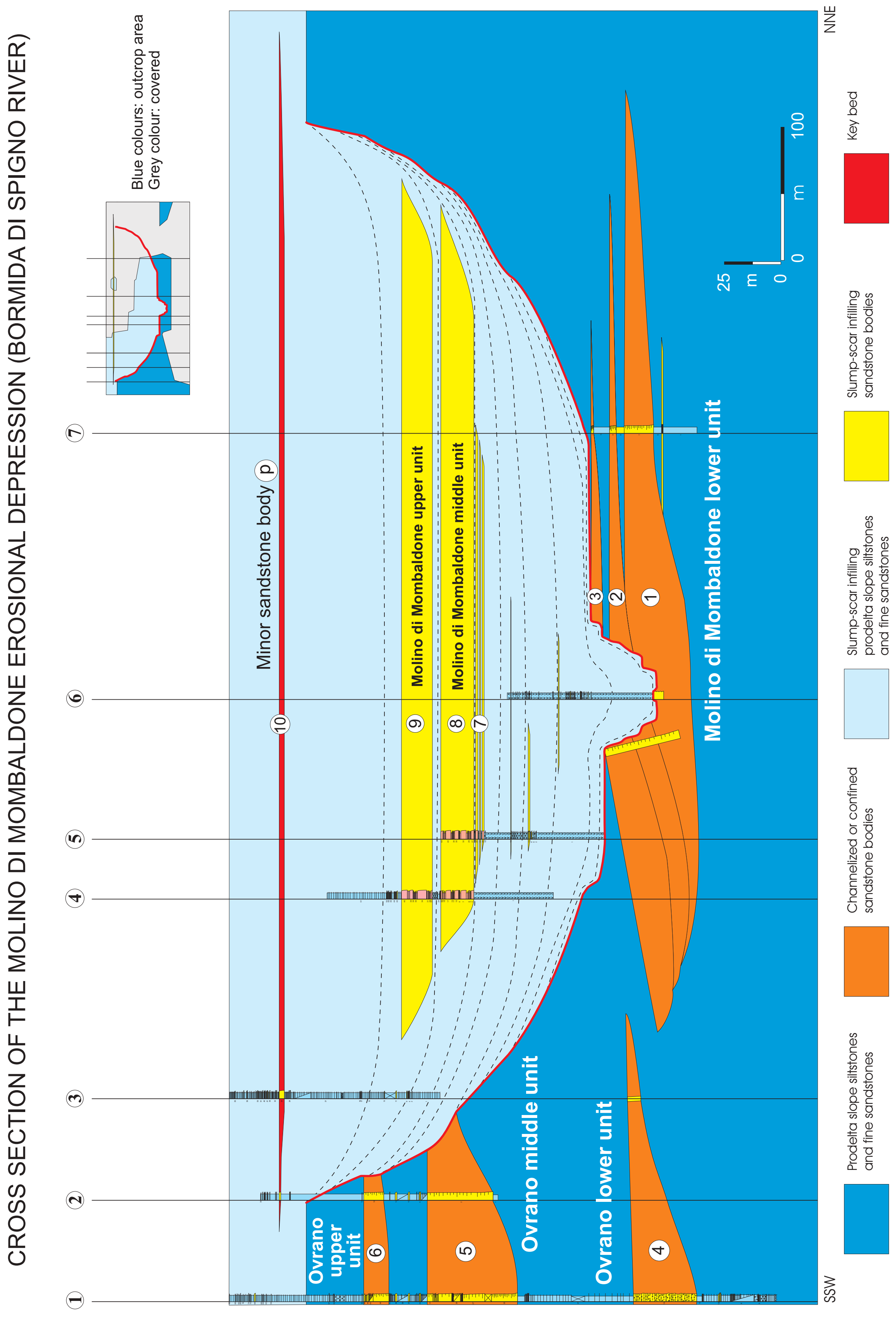

Fig. 7 - Cross section of the Molino di Mombaldone Erosional Depression (Bormida di Spigno River).

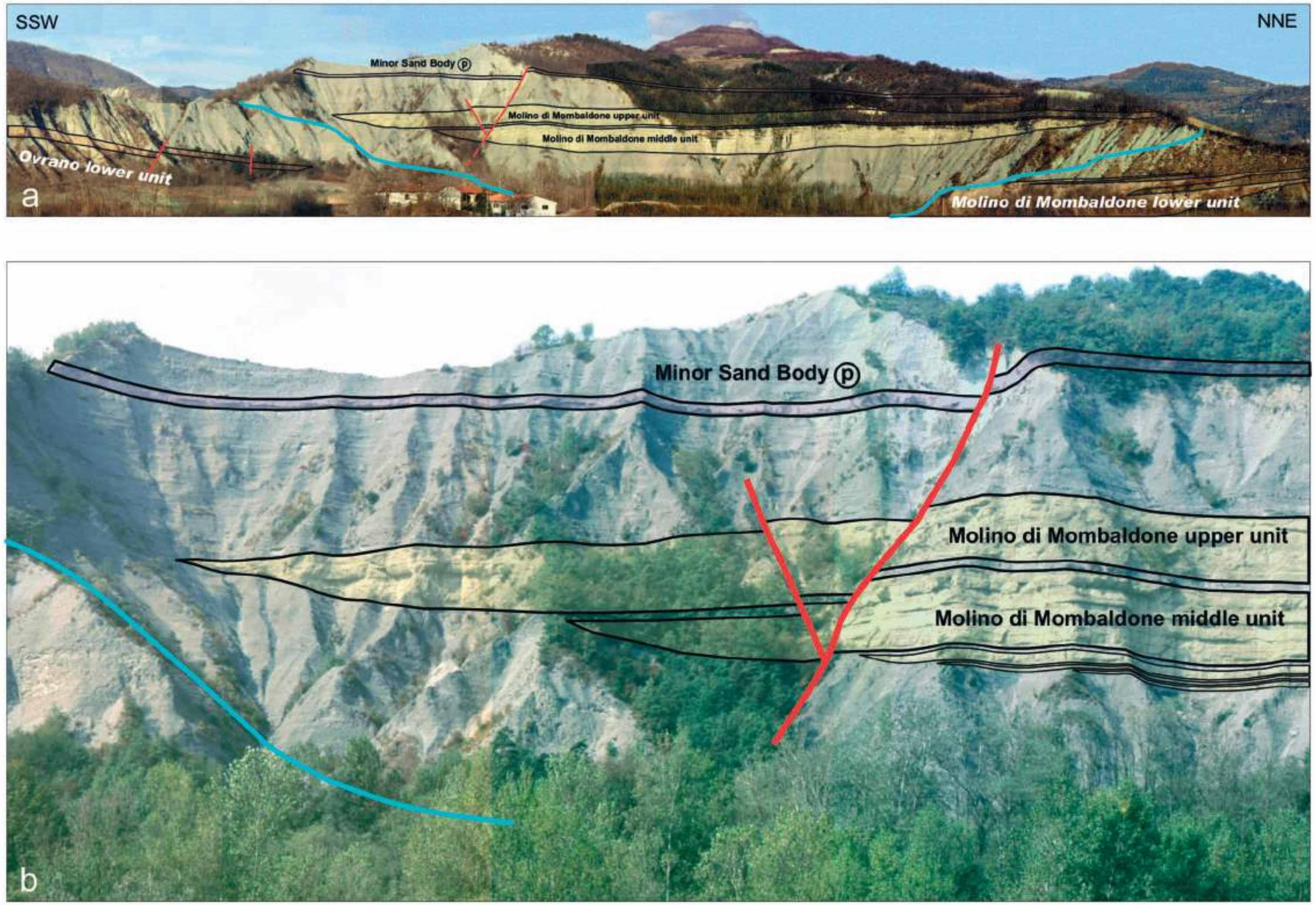

Fig. 8 - The Molino di Mombaldone Erosional Depression. a) Panoramic view of the erosional depression interpreted as a large-scale slump scar cut in prodelta slope siltstones. After the evacuation the scar temporarily acted as canyon-slope valley and was modified by erosional processes (i.e. thalweg erosion and terrace development). Total length of view is about 1 km, the outcrop is about 150 m high. The panoramic view shows part of the slump-scar fill and of the underlying succession. Note: the large-scale concave geometry of the erosional surface; the truncation of the underlying Molino di Mombaldone lower unit; the sedimentary infill consisting mostly of prodelta-slope siltstones and, subordinately, of two confined intra-scar sandstone bodies (i.e. Molino di Mombaldone middle and upper units) located in the axial part of the erosional depression; the vertical stacking and the lateral pinch-out of the Molino di Mombaldone middle and upper units onlapping onto the pelitic slump-scar fill deposits. b) Detail of the SSW flank of the Molino di Mombaldone Erosional Depression. Note: the lateral onlap termination of the Molino di Mombaldone middle and upper units onto the pelitic slump-scar fill deposits; the progressive onlap termination of the basal sandstone beds onto the axial part of the erosional depression.

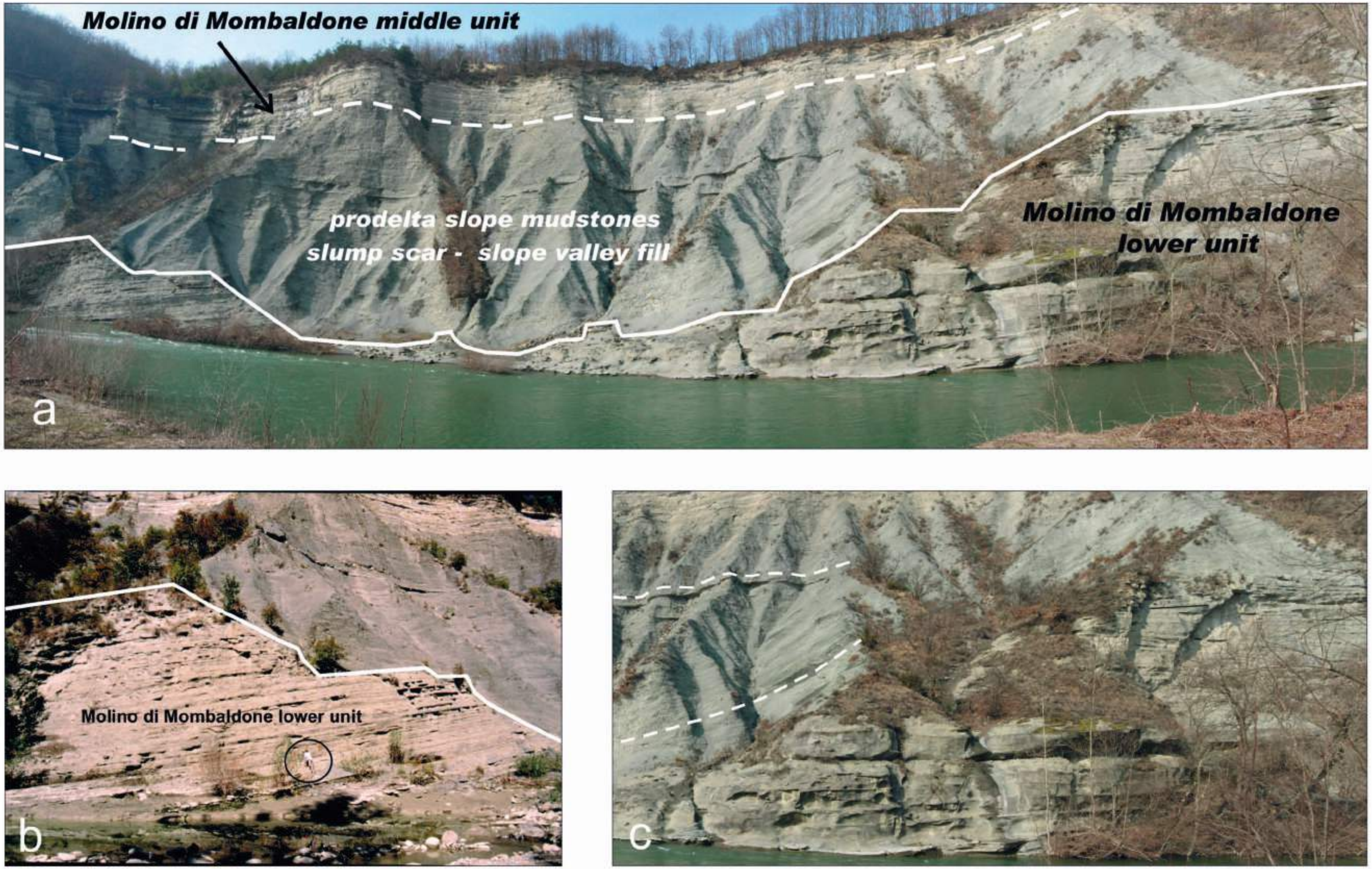

Fig. 9 - The Molino di Mombaldone Erosional Depression. a) Panoramic view of the axial erosional thalweg related to the canyon/slope valley stage and its infill. Note the irregular, metre-scale, terraced geometry of the erosional surface and the concave-up attitude of the fine-grained slump scar infill deposits draping and onlapping onto the erosional surface. b) Detail of the SSW side of the thalweg showing the terraced geometry of the erosional surface. c) Detail of the NNE side of the thalweg. Note the progressive reduction in dip angle of the infilling muddy sediments due to differential compaction.

Rocchetta Fm. The north-eastern parts of both units are truncated by the lower part of the Molino di Mombaldone Erosional Depression (Fig. 7). The unit of the Ovrano Middle Sandstones has maximum thickness of 40 m and lateral extent of about 1.2 km and ends SW-wards near the Pian dei Buri Fault. The unit of the Ovrano Upper Sandstones has maximum thickness of 12 m and lateral extent of about 1 km, and ends SW-wards near the S. Rocco small chapel. Both units consist of fine-grained turbiditic sandstones occurring in thick to very thick, graded or graded to parallel-laminated, generally amalgamated strata. The upper parts of both units contain subordinate medium- to thin-bedded intercalations of turbiditic fine-grained sandstones and mudstones. The overall trend of both units is thinning upwards.

The Ovrano Middle and Upper Sandstones correspond, *pro parte*, to the *Unità Ovrano* of Gelati and Gnaccolini (1998) and to the *Membro delle arenarie di Case Ovrano* of Gelati et al. (2010a, b). The Ovrano Middle and Upper Sandstones are dated by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) to the Chattian (Zone P22). Based on the nannofossil assemblages the units are referred to the late Chattian.

5.3.7. Molino di Mombaldone Erosional Depression

The Molino di Mombaldone Erosional Depression is a large-scale scar visibile along the scarp delimiting a meander of the Bormida di Spigno River near the Molino di Mombaldone. Its geometry and infill are shown in figures 8, 9a, 10a. The depression has a width of about 1 km, and a maximum depth of 150 m. In the deepest part it shows an erosional thalweg with well developed terraces (Figs. 7, 9a, 9b). It removes part of the Molino di Mombaldone Lower Sandstones and truncates the Ovrano Middle and Upper Sandstones, cropping out in the Ovrano Valley. The bulk of the infill consists of fine-grained sediments wholly similar to the mudstones of the Rocchetta Fm. The middle part of the infill is represented by the Molino di Mombaldone Middle and Upper Sandstones (see later).

Gnaccolini et al. (1990), Gelati et al. (1993), Gelati and Gnaccolini (1998), Gelati and Gnaccolini (2002) and Gelati et al. (2010a, b) although reporting the presence of an erosional depression, only refer to the lower part of the depression as here defined, and exclude from its infill the sandstone bodies here respectively defined Ovrano Middle and Upper Sandstones. The Molino di Mombaldone Erosional Depression is here interpreted as a large-scale slump scar which subsequently evolved into a submarine canyon/slope valley feature as a result of active bypass by dilute turbidity flows (Ghibaudo et al., 2001a). The age of the erosional surface could be referred to the transition Chattian-Aquitanian (cf. paragraph 4).

5.3.8. Molino di Mombaldone Middle and Upper Sandstones

These sandstone units are represented by two flat-lenticular sandstone bodies encased within the mudstones of the Rocchetta Fm infilling the axial part of the Molino di Mombaldone Erosional Depression (cf. Figs. 7, 8a). The basal contact with the mudstones is abrupt, the upper sharp and conformable.

The panoramic view in front of the Molino di Mombaldone shows the south-westerly termination of the two sandstone bodies (Fig. 8b). Here, they close laterally over a distance of a few tens of metres and are bounded by gently erosional basal surfaces, onto which the strata onlap, demonstrating the confined nature of the units (Fig. 10). The two units were laid down within the axial part of the ongoing infill of the slump scar, where the Rocchetta mudstones were topographically depressed due to differential compaction with respect to the inclined flanks of the depression (Pl. II, scenario j and k). The Molino di Mombaldone Middle Sandstones unit has a thickness of 15.5 m near its southwestern onlap termination where it is offset by a small fault, while it is thicker (up to 23 m) in the axial part (see Figs. 8a, 10). Its lateral extent is about 550 m. The Molino di Mombaldone Upper Sandstones unit has a thickness of 14 m and lateral extent of about 650 m. Both units close laterally in the south-westerly direction with onlapping relationships and slight angular unconformity on the mudstones draping the erosional surface (Fig. 8b), whereas in the north-easterly direction the closure of the units is masked by the detritic cover.

The Molino di Mombaldone middle and upper units are made up of fine-grained turbiditic sandstones occurring in thick to very thick strata separated by thin muddy interbeds and subordinate intercalations of thin- to medium-bedded, fine-grained, sandstone-mudstone turbidites (Fig. 10a).

The Molino di Mombaldone Middle and Upper Sandstones correspond, *pro parte*, to the *Unità Ovrano* of Gelati and Gnaccolini (1998) and, pro parte, to the *Membro delle arenarie di Case Ovrano* of Gelati et al. (2010a, b). These Authors correlate these units with the two sandstone bodies cropping out in the nearby Ovrano Valley, here respectively defined Ovrano Middle and Upper Sandstones. They hold that these units are coeval and form a single channelized system developed on both sides of a growth anticline named *Alto del T. Ovrano* (cf. Fig. 2 in Gelati and Gnaccolini, 1998). However, the stratigraphic evidence demonstrates that the mentioned units represent two sandstone bodies confined within the Molino di Mombaldone Erosional Depression and cannot be correlated with the Ovrano Middle and Upper Sandstones units. In fact, the Molino di Mombaldone Middle and Upper Sandstones show not only thickness and facies characteristics different when compared to the Ovrano sandstone bodies, but also younger age. In addition, there is no field evidence of the supposed anticline between the Molino di Mombaldone and Ovrano outcrops. The detailed cross-section of figure 7, moreover, shows that the large scar cannot be extrapolated as a regional unconformity, as supposed by Rossi et al. (2009, cf. Fig. 16, photo b).

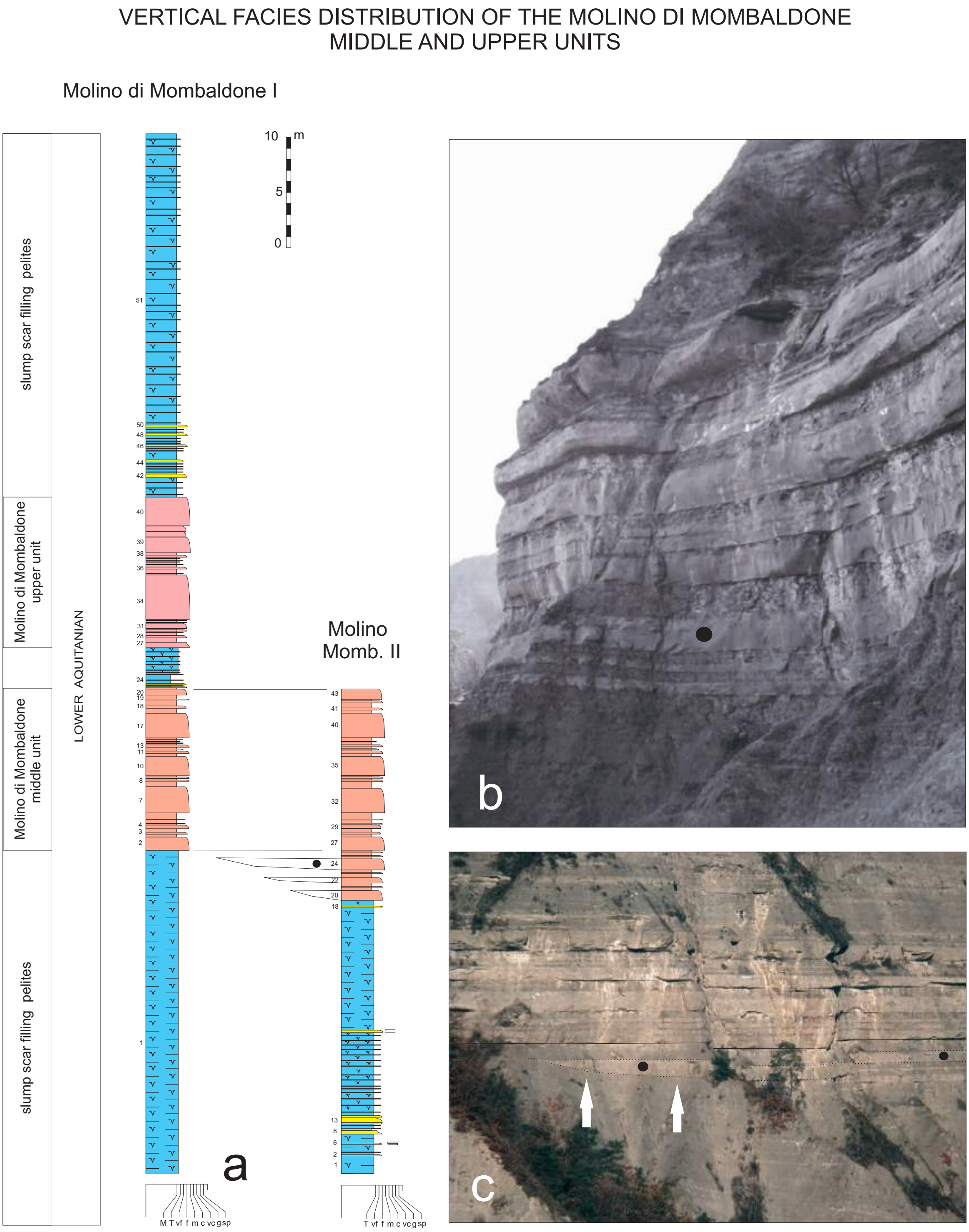

Fig. 10 - The Molino di Mombaldone middle and upper units infilling the Molino di Mombaldone Erosional Depression. a) Vertical facies distribution of the Molino di Mombaldone middle and upper units. b, c) Detail and panoramic view of the Molino di Mombaldone lower unit in section II. Note the onlap termination of the basal beds onto the gently curved mudstones infilling the erosional depression. The black spot marks the same bed both in photographs and log.

The Molino di Mombaldone Middle and Upper Sandstones are attributed to the Chattian (Zone P22) by Gelati et al. (1993), Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b). Based on calcareous nannofossil assemblages the units are dated to the early Aquitanian.

5.3.9. Slump sheets

Six large slump sheets are intercalated at different stratigraphic levels in the mudstones of the Rocchetta Fm, and distinguished in the geological map with the acronyms S1, S2, S3, S4, S5, S6 (Pl. I). All the sheets consist of displaced and commonly deformed pelitic successions of Rocchetta Fm. The main sheet, S6, is located N of the Pian dei Buri Fault near the San Rocco small chapel. It has lateral extent of about 1 km and maximum thickness of 40 m. It corresponds, *pro parte*, to the informal unit defined by Gelati and Gnaccolini (1998) *Intervallo Caotico S. Rocco-C. Burbo* and to the *Livello C. Rocco-C. Burbo* of Gelati et al. (2010a, b). This sheet is a tilted block of Rocchetta mudstone almost undeformed, forming a positive submarine topography, as evidenced by onlap relationships of the covering sediments, which progressively smoothed the sea floor (Fig. 11a). Moreover, intense deformation along the basal sliding surface resulted in metric-scale overturned folds and multiple low-angle shear planes in the lowermost part of the sheet (Fig. 11b, 11c). The vergence of the folds and the shear planes indicate an easterly transport direction. Geometric and structural features are similar to other submarine glide blocks of the literature (e.g. Ineson, 1985). This slump sheet is dated to the Chattian

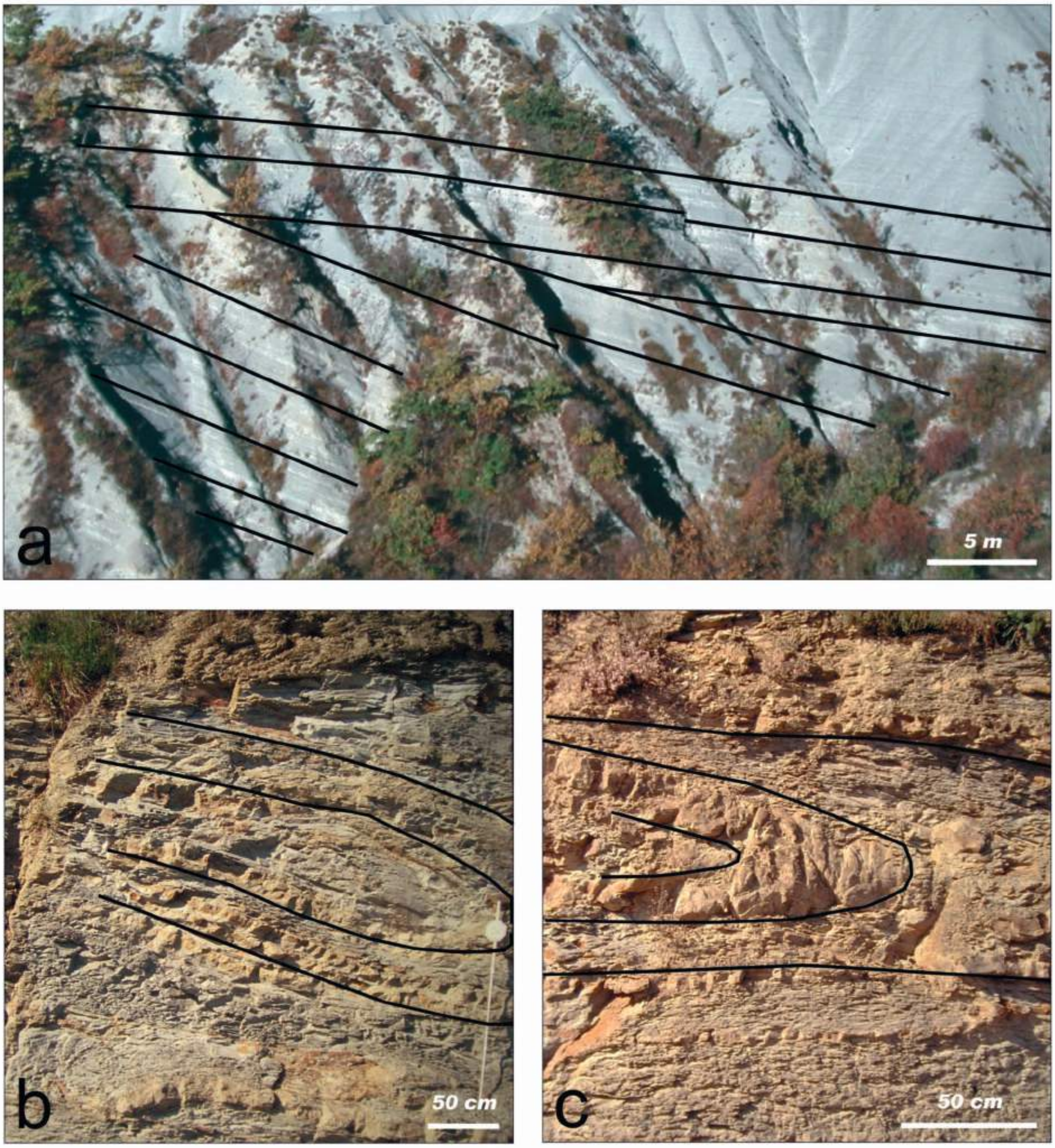

Fig. 11 - The slide sheet S6 (San Rocco-C. Tragna area). a) Upper portion of the slide sheet. Note in the lower part the inclined attitude of a tilted block of Rocchetta mudstones forming a positive submarine topography and the onlap termination of the covering sediments which progressively smooth the sea floor. b, c) Lower part of the slide sheet intensely deformed with metric-scale overturned folds and multiple low-angle shear planes indicating intense deformation along the basal sliding surface.

(Zone P22) by Gelati and Gnaccolini (1998). It is here considered slightly younger or coeval to the nearby Molino di Mombaldone Erosional Depression and is tentatively attributed to the Chattian-Aquitanian transition. Local intraformational unconformities, moreover, interpreted as slump scars of variable dimensions are common throughout the Rocchetta slope mudstones (Fig. 12a, 12b, 12c).

Gelati and Gnaccolini (1998) hold that the slump sheets are confined within structural lows developed on the sides of two growth anticlines oriented WNW-ESE, indicated as *Alto del T. Ovrano* and *Alto del M. Pisone* (cf. Figs. 2 and 10 in Gelati and Gnaccolini, 1998). The nonexistence of the former structure has been already discussed above (paragraph 5.3.8). Concerning the latter, the sole structure visible in the M. Pisone area is a flexure on the southern side of the hill, showing a progressive increase in bed dip angles from 10-12° to 20°. This flexure can be interpreted as a local drag fold linked to the probable NW-ward continuation of a NNW-trending fault, which can be traced in the field only in locality Casotto or, alternatively, it may represent a local monocline developed over a basement high-angle blind fault.

5.3.10. Noceto Sandstones

With reference to the mapped area, this member extends for about 8 km laterally, with maximum thickness of about 150 m, and has a large-scale wedging out geometry with planar top. It pinches out gradually NNE-wards and closes near Case Bazzi. In the type-locality of Noceto, SW of the study area, the unit reaches a maximum thickness of 350 m in proximity of a listric normal growth fault, later reactivated in compression, which delimits the unit on the south-western side (Ghibaudo et al., this volume). The unit is composed of sandstones, pebbly sandstones and minor conglomerates in thick and very thick beds, generally amalgamated (Fig. 13). The unit is bounded below and laterally by the mudstones of the Rocchetta Fm, and is capped by the Montechiaro d'Acqui Siliceous Lithozone (LS1).

The basal contact is sharp and, locally, large-scale erosional. Where sufficiently large-scale exposures are available, NE-ward onlap and pinch out of the basal Noceto beds can be observed (Fig. 13b). However, the stratigraphic relationships with the underlying minor sandstone body **b** show that the basal erosional surface removes, going from NE to SW, only a few tens of metres of the underlying mudstones, whereas the thickness of the Noceto unit increases of about 100 m in the same direction, indicating that the Noceto unit essentially represents the infill of a half-graben of pluri-kilometric extent rather than a true large-scale channelized body. This depositional setting is supported by the regional geologic mapping (Ghibaudo et al., this volume). The

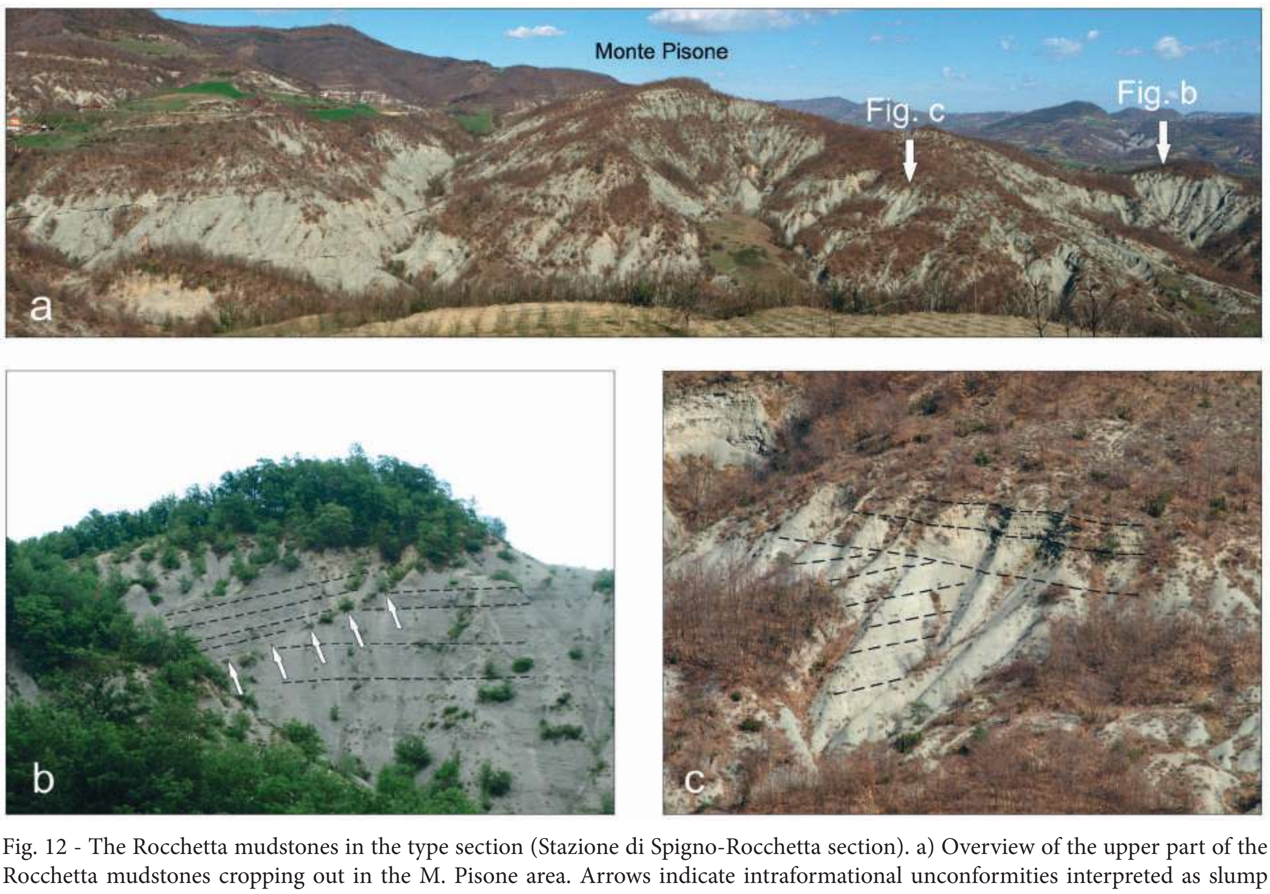

Fig. 12 - The Rocchetta mudstones in the type section (Stazione di Spigno-Rocchetta section). a) Overview of the upper part of the Rocchetta mudstones cropping out in the M. Pisone area. Arrows indicate intraformational unconformities interpreted as slump scars. b, c) Details of the intraformational discordances.

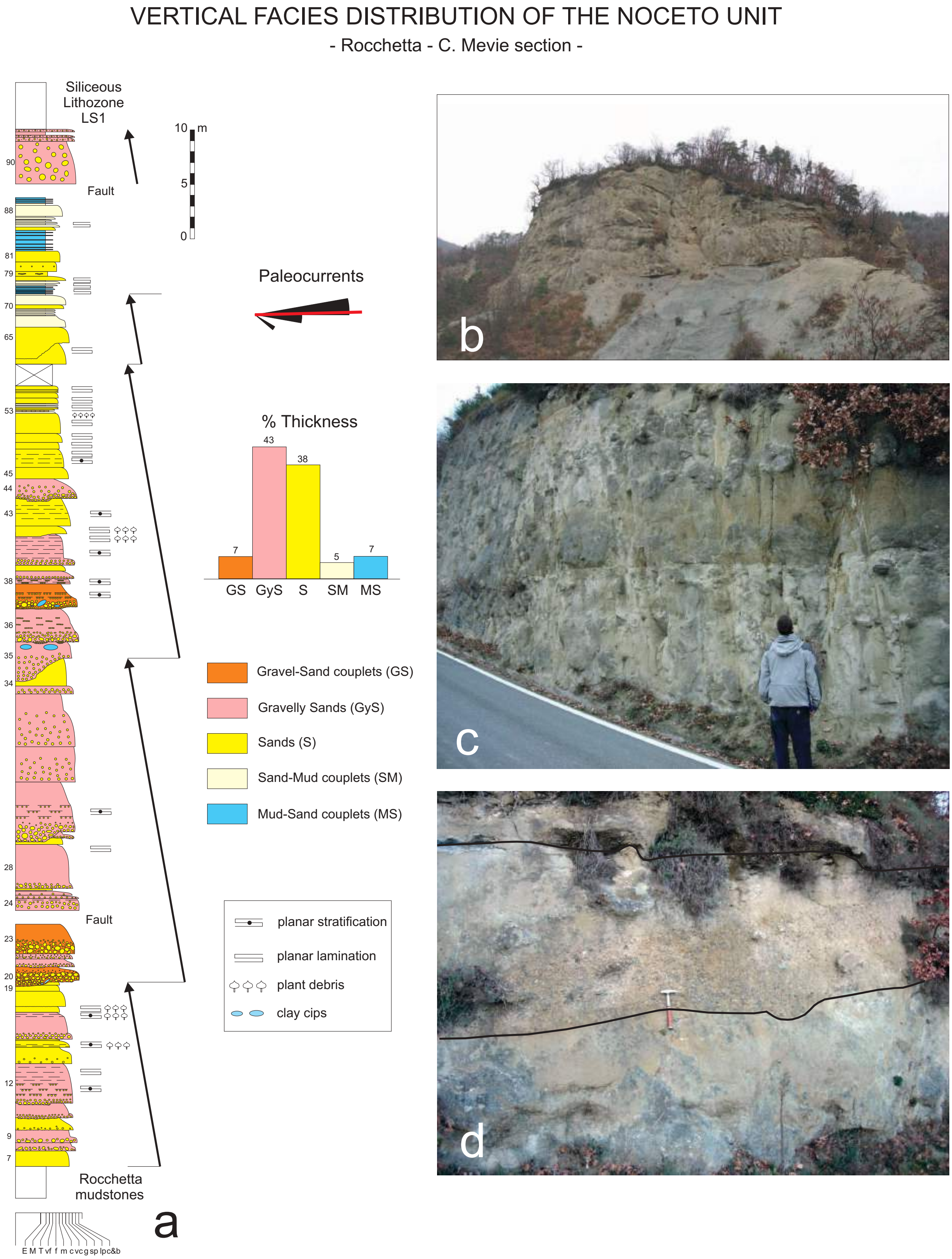

Fig. 13 - The Noceto unit in the Rocchetta-C. Mevie area. a) Vertical facies distribution of the Noceto unit in the Rocchetta-C. Mevie section. Amalgamated sandstones and conglomeratic sandstones are the dominat facies. b) Basal contact of the Noceto unit SW of C. Bertotti (C. Mevie area). Amalgamated sandstone beds onlap towards right (NE). c, d) Details of thick-bedded, amalgamated beds of sandstones and pebbly sandstones.

upper contact of the Noceto sandstone with the deposits of the Montechiaro d'Acqui Siliceous Lithozone is sharp and conformable. The paleocurrents in the study area suggest a western source area.

At least in the study area (Rocchetta - Case Mevie section) a detailed log shows that the unit is characterized by a complex infill consisting of a stack of sedimentary bodies with gently erosional bases, in turn composed of upward-fining cycles (multistorey fill) (Fig. 13a). The cycles present in the Rocchetta - Case Mevie section consist of thick and very thick strata of conglomerate-sandstone couplets and pebbly sandstones in the lower and middle parts (Fig. 13c, 13d) and of thick to medium strata of amalgamated sandstones in the uppermost part (Fig. 13a). Typically, the layers are graded or graded-laminated, with the upper division characterized by planar, centimetric traction laminae and/or upper flow regime thin planar laminae. Only the uppermost part of the Noceto unit displays metric intervals consisting of alternating sandstones and mudstones in medium to thick strata, graded or graded-laminated, laid down by turbidity flows of intermediate concentration. As a whole, the coarse lithologies (conglomerate-sandstone couplets, conglomeratic sandstones and amalgamated sandstones) form about the 88% of the overall volume of the unit (Fig. 13a). These coarser strata can be interpreted as the product of high-concentration turbidity flows with coarse load, which during the transport stage or just before the deposition became density-bipartite due to gravity transformation of the flow into a basal laminar coarse portion (very coarse sand and gravel) and a turbulent upper portion (Sanders, 1965; Ghibaudo, 1992; Mutti, 1992; Mutti et al., 1999). The flows rapidly dumped their basal coarse load at the base of the submarine slope, whereas the turbulent upper portions of the flows bypassed the depositional area of the coarse load and continued downdip as residual turbidity currents of intermediate or low concentration.

The Noceto unit is here interpreted as the infill of a large-scale, slope or base-of-slope half-graben fed by shelf coarse depositional systems (fan-deltas) located to the W or WNW of the study area. In a direction parallel to the paleo-flows, the deposits of the unit probably developed onlap relationships towards W or WNW (gradual back filling) and downlap geometry towards E or ESE in a possible base-of-slope setting. A possible source of the coarse deposits of the Noceto unit may be identified in the marginal fan-delta conglomerates occurring in the subsurface of the Saluzzo area (Rossi et al., 2009).

The unit of Noceto Sandstones cropping out in the mapped area corresponds to the *Sistema torbiditico di Noceto* of Cazzola and Fornaciari (1990), to the *Unità di Noceto* of Gelati and Gnaccolini (1998) and to the *Membro delle Arenarie di Noceto* of Gelati et al. (2010a, b). Cazzola and Fornaciari (1990) interpret the Noceto unit as submarine-fan depositional lobes fed from NW and laid down in a structural depression located in a basinal setting. The Noceto unit has been dated by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) to the Late Oligocene (Zone P22). On the basis of the here adopted nannoplankton biostratigraphy the unit is referred to the early Aquitanian. (Zone MNN1d p.p.).

5.4. Montechiaro d'Acqui Siliceous Lithozone

The Montechiaro d'Acqui Siliceous Lithozone is about 50-60 m thick in the north-eastern sector of the study area (Rio d'Aprile, Ovrano Valley). The thickness is reduced to about 30 m in proximity of the Pian dei Buri Fault, where the unit is overlain by the Altitude 483 Sandstones, and Pian Bruno Calcarenites (cf. Pl. I). In the south-western sector (heads of the valleys of Merana and Fornaci streams), where the Siliceous Lithozone overlies the Noceto Sandstones, the thickness is about 35 m. Locally (Costa della Feja area, S of Piantivello), the Siliceous Lithozone is truncated at the top by the erosional base of the C. Mazzurini unit (cf. Pl. I). The contact of the unit with the underlying Rocchetta Fm is everywhere sharp and conformable. The unit is overlain by the marls of the Montechiaro d'Acqui Fm and, locally, by the calcarenitic and siliciclastic units included in the lowermost part of this formation (C. Poggi Calcarenites, Pian Bruno Calcarenites, C. Mazzurini Sandstones), with sharp and generally erosional contact (cf. Pl. I).

This unit consists of alternating siliceous pelitic-arenaceous intervals 2 to 8-10 m thick and homogeneous marly intervals 2-6 m thick. Typically, the siliceous intervals tend to decrease in thickness upwards and to become finer-grained. The siliceous intervals are made up of alternating, thin-bedded, medium- to very fine-grained, sandstones and siltstones with siliceous cement consisting of micro- and crypto-cristalline quartz and dark grey muddy siltstones, with intercalations of siliceous laminites either unconsolidated or tightly lithified. With the exception of the fissile laminites, these lithologies, particularly the siliceous ones, are tough, competent, and characterized by closely-spaced joints normal to the stratification surfaces, resulting in rock partitioning into parallelepiped-shaped small blocks with sharp corners (Fig. 14a). The sandstone layers are particularly common in the lower part of the unit, whereas in the upper part they are virtually absent and the lithology is dominated by thin- to medium-bedded, alternating siliceous siltstone and mudstone (Fig. 14d). The sandstone layers are widespread throughout the area of the Sheet Dego to the scale 1:50000, becoming conversely sparse and very fine-grained to the NE and SW, i.e. in the adjacent Sheets Acqui Terme and Cairo Montenotte. The basal part of the unit close to the Molino d'Ovrano (Ovrano Valley) is characterized by a few metres of resedimented, medium-bedded glauconitic biocalcarenites (LS1e) of limited lateral extent (cf. geological map, Pl. I and Pl. VIa).

The sandstone beds are on average 2-8 cm thick and show a red-brown weathering patina. Internal structures have been examined in detail in a number of cut and polished slabs. In most cases strata are composite, consisting of variably laminated units of clean, fine- to

Fig. 14 - Details of the Montechiaro d'Acqui Siliceous Lithozone. a) Basal part of the siliceous lithozone cropping out in the C. Mevie area (atop the Noceto unit), characterized by alternating tough and competent red-brown silicified sandstone beds, siliceous laminites and grey marly interbeds. The former lithology is characterized by closely-spaced vertical joints, resulting in rock partitioning into parallelepiped-shaped small blocks with sharp corners. b) White, hard siliceous laminites (centre of the photograph) in the lower part of the unit. c) Detail of a polished cut of a plane-parallel laminated siliceous laminite. d) Typical aspect of the upper part of the unit characterized by thin-bedded hard silty layers and softer muddy interbeds.

medium-grained sandstone with centimetric and millimetric thickness, irregularly alternating, through a grain-size break, with muddy siltstone streaks. The sandstone units show a number of characteristic features (Fig. 15), including: rhythmic occurrence of sand and mud layers; sharp and micro-erosional upper contacts (Fig. 15a, 15b); siltstone laminae occurring as "offshoots" within sandy cross laminae or intercalated within horizontal sand laminae; horizontal lamination, low-angle cross lamination, ripple cross lamination; local form-set ripple trains or isolated and discontinuous starved ripples locally with crests showing traces of remoulding by micro-erosion (Fig. 15e); internal erosional (reactivation) surfaces (Fig. 15e); and local evidence of multiple directions of flow (Fig. 15c). The lower part of some beds consists of sharp- and erosionally-based coarser-grained units no more than 1-3 cm thick, composed of medium to coarse sandstone, sometimes granule microrudite (Fig. 15d). These units commonly show normal grading, sharp upper contacts and commonly micro-erosional and lenticular geometry with very low lateral persistence (Fig. 15f), sometimes appearing as loaded infills of small-scale scours.

Bioturbation is common, but not so intense to obliterate the physical structures. Muddy interbeds are in places pervasively burrowed by *Palaeophycus*, whereas larger tubular burrows, locally with evident *spreiten*, are common in sandy layers, as well as in siltstone layers. *Bathysiphon*, a benthic filter-feeding foraminifer living in cold- and deep-water environments, is common (Fig. 15d). All the above features point to oscillating energy conditions of the involved flows, suggesting the interpretation of the above facies as bottom-current reworked sandstone layers (e.g. Shanmugham et al., 1993; Martin-Chivelet et al., 2008).

The siliceous laminites are 1-10 cm thick, and range from unlithified to tough, lithified and parallel-laminated rocks, brown-coloured in fresh cut and weathering to whitish. When toughly lithified they are extremely competent and of whitish colour both in fresh cut and weathered surfaces (Fig. 14b, 14c).

The Montechiaro d'Acqui Siliceous Lithozone is a marker horizon on regional scale. Towards NE the unit can be traced in the adjacent Sheet Acqui Terme to scale 1:50,000, up to the Caliogna Valley, where it is unconformably truncated by the transgressive Visone Limestone (Ghibaudo et al., in prep.). The unit crops out again several tens of kilometres to the NE, near the locality of Carrosio between the Lemme and Scrivia valleys (Galbiati, 1976; Cavanna et al., 1989). Conversely, to the SW, in the whole Sheet Dego to scale 1:50000, the unit is subdivided into minor units located atop turbiditic formations laid down in a base-of-slope to basinal setting (Ghibaudo et al., this volume), attesting to the condensed nature of the succession cropping out in the study area. The presence of separate siliceous bands in the Uzzone Valley area, converging into a single package corresponding to the LS1 unit in the study area was already noted by Fava (2001). The Montechiaro d'Acqui Siliceous Lithozone is particularly well exposed in the Cianazzo section, located a few km NE of the study area, which represents the reference section for the biostratigraphic dating of this unit (Fig. 16, Pl. IVa).

The siliceous laminites are thought to represent pelagites and hemipelagites originally rich in biosiliceous component (diatoms, radiolarians), and transformed during the diagenesis following dissolution of the opaline skeletal remains and precipitation of crypto-crystalline silica. It may also be suggested that the biogenic silica is the source of the siliceous cement of the interbedded sandstone layers (e.g. Sears, 1984). The intercalated thin- to medium-bedded, silica-cemented, planar-laminated sandstone beds may be the product of turbidity flows. Conversely, the thin sandstone beds characterized by form-set ripples and/or starved ripples suggest a control of the sedimentation by bottom currents.

The Montechiaro d'Acqui Siliceous Lithozone is interpreted as a condensed section. The basinal extent of this interval attests to an important phase of relative sea level rise, accompanied by a drastic reduction of coarse terrigenous input in slope and basinal settings. The succession, on the other hand, presents a clear internal cyclicity on plurimetric scale (alternating siliceous and marly intervals), particularly evident in the Cianazzo section (Fig. 16, Pl. IVa). This is here interpreted as the expression, in a slope or base-of-slope setting, of a transgressive-regressive intra-Aquitanian cyclicity, with siliceous intervals corresponding to condensed sections (maximum flooding intervals), and marly intervals reflecting the distal reaches of highstand downlapping pelitic prograding wedges. On a larger scale, the presence of turbiditic formations intercalated within the siliceous lithozone SW of the study area, probably reflecting lowstand deposits (Ghibaudo et al., this volume), supports the assumption of multiple relative sea-level fluctuations during the deposition of the siliceous lithozone, and the condensed nature of the succession cropping out in the study area. d'Atri (1990) and Gelati and Gnaccolini (1998) attribute the unit to a slope setting. We share this attribution.

The Montechiaro d'Acqui Siliceous Lithozone corresponds to the *Membro siliceo della Formazione di Rocchetta* of d'Atri (1990), to the *Unità C. Mevie - Molino d'Ovrano* of Gelati and Gnaccolini (1998) and to the *Membro di C. Poggi* of the *Formazione Rocchetta-Monesiglio* of Gelati et al. (2010a, b). Fava (2001) identified a cluster of siliceous beds in the western sector of the TPB. Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) ascribe this unit to the Late Oligocene (Zone P22). On the basis of the here adopted nannofossil biostratigraphy the Montechiaro d'Acqui Siliceous Lithozone may be attributed to the middle-late Aquitanian (Zones MNN1d p.p.-MNN2a p.p.).

5.5. Montechiaro d'Acqui Formation

The Montechiaro d'Acqui Fm is a heterogeneous unit dominated by massive homogeneous marls (carbonate

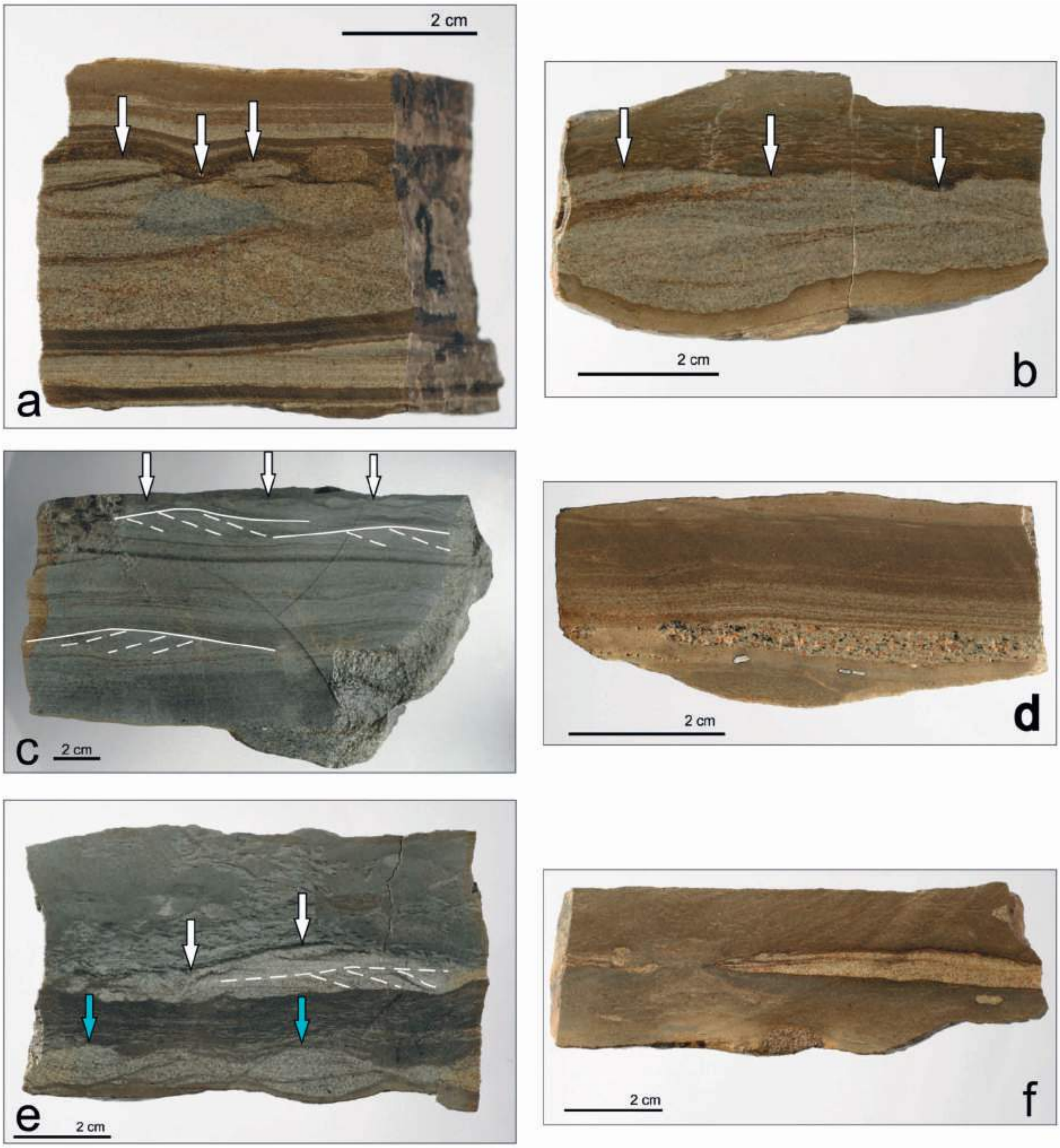

Fig. 15 - Detail of the inferred bottom-current reworked sandstone layers in the lower part of the Montechiaro d'Acqui Siliceous Lithozone. a) Rhythmically alternating thin- and very-thin bedded sandstone and siltstone layers. In the lower part a very thin-bedded sandstone layer with sharp base and top, characterized by tractive parallel laminae, is overlain by an incipient starved ripple. In the upper part a thin-bedded, current-laminated bed shows sharp base and sharp micro-erosional top (arrows). b) Thin-bedded, laminated sandstone layer with scoured base and sharp micro-erosional top (arrows). c) thin-bedded sandstone layer with bidirectional ripple laminae and sharp, micro-erosional top (arrows). d) very thin-bedded, discontinuous, coarse-grained sandstone overlain by tractive parallel laminae with a sharp grain-size break. *Bathysiphon* (white spots below the sandstone layer), a benthic filter-feeding foraminifer living in cold- and deep-water environments, is common in the siliceous lithozone. e) In the lower part: a very-thin bedded, wavy layer with sharp base and sharp, remoulded top. In the upper part: a ripple laminated, lenticular sandstone layer with internal erosional surfaces (reactivation surfaces) and sharp micro-erosional top overlain by thoroughly bioturbated fine sandstone. f) Very-thin bedded, lenticular, starved sandstone layer with sharp planar base and convex-up top. Bioturbation in most examples is common.

hemipelagites), with rare intercalations of siltstones and fine-grained sandstones in thin to very thin layers, and locally including lenticular to wedge-shaped bodies of both carbonate and siliciclastic composition. In the uppermost part of the unit two metric intervals are present, consisting of rhythmically alternating thin- to medium-bedded mudstones and competent, silica-rich siltstones (not mapped in the enclosed geological map)

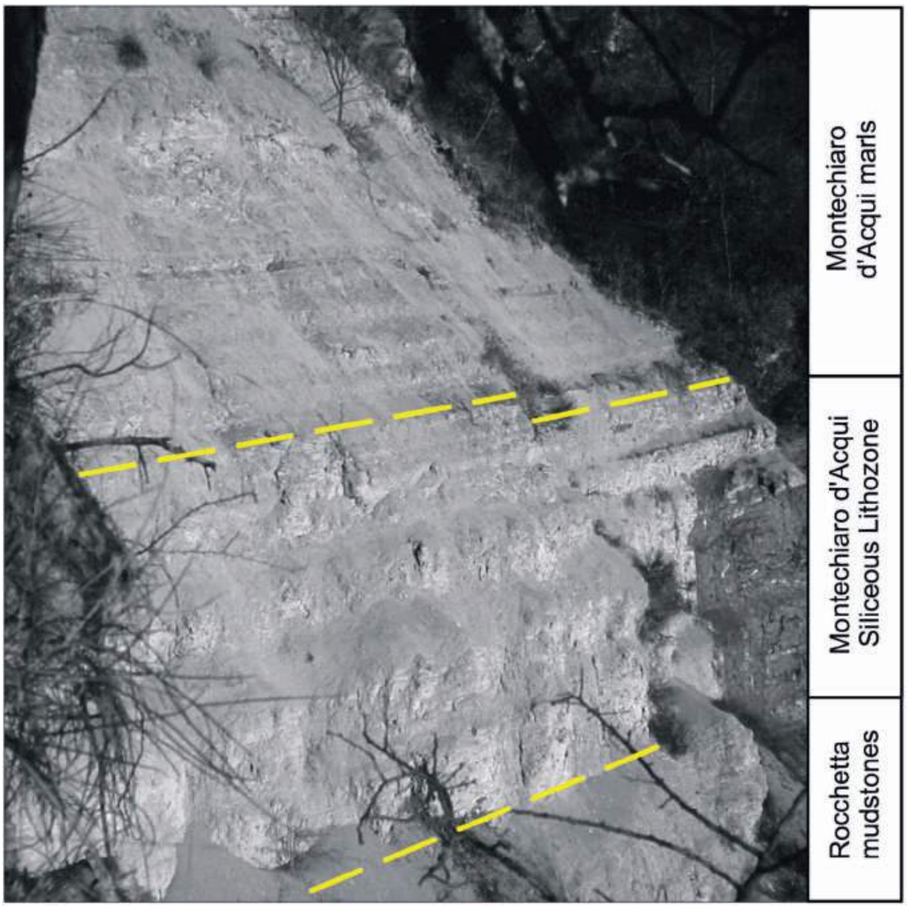

Fig. 16 - The Montechiaro d'Acqui Siliceous Lithozone cropping out in the Cianazzo section (cf. Pl. IVa). Note the alternating white, siliceous intervals, prominent in the erosion profile, and soft, grey muddy intervals.

looking like the siliceous intervals of the underlying Montechiaro d'Acqui Siliceous Lithozone. The type-locality of this unit is located near the village of Montechiaro d'Acqui, about 5 km to the E of the study area, where the formation is about 65 m thick. In the type area the unit is essentially marly, whereas in the study area the marls include sedimentary bodies made up of resedimented carbonate and siliciclastic deposits. In the study area the unit has maximum thickness of about 70-80 m in the C. Mevie - C. Mazzone - Brallo sections (Fig. 2, Pl. Vb, Vc) and in the Cava Poggi II section (Pl. VIb), where the formation is entirely marly. In the central part of the study area, where the formation includes the body of C. Mazzurini Sandstones, the local thickness exceeds 200 m. The unit is comprised between the Montechiaro d'Acqui Siliceous Lithozone (LS1) at the base and the Serole Fm at the top. The basal contact is conformable and rapidly transitional, the upper contact is rapidly transitional or sharp. The latter locally corresponds to inferred erosional discontinuities of pluri-hectometric extent, here defined as "erosional depressions" and interpreted as large-scale slump scars (cf. Pl. I). These remove in part, or in places completely, the Montechiaro d'Acqui Fm which preserves only locally its original thickness. In the central sector of the study area (S of Case Avrama), moreover, the upper part of the formation is truncated by the erosional base of the Piantivello Sandstones, here included in the Serole Fm (cf. the enclosed geological map and Pl. I).

The Montechiaro d'Acqui Fm corresponds, pro parte, to the *Membro superiore della Formazione di Rocchetta* of the Sheet 81 Ceva to the scale 1:100000 of the "Carta Geologica d'Italia" (Francani et al., 1971). It also corresponds to the informal unit designated as *Marne di Montechiaro d'Acqui* by d'Atri (1990), to the unit defined *Massive mudstone* of the *Rocchetta-Monesiglio Group* by Gelati and Gnaccolini (1998) and to the sub-unit defined *Peliti massive* of the *Massa di fondo* of the *Formazione di Rocchetta-Monesiglio* by Gelati et al. (2010a, b). The unit is here regarded as indicative of slope to base-of-slope depositional environment.

The Montechiaro d'Acqui Fm is dated to the latest Aquitanian-early Burdigalian (Zones MNN2a p.p., MNN2b, MNN3a p.p.).

In the following sections the members occurring within the Montechiaro d'Acqui Fm will be described:

Altitude 483 Sandstones
Pian Bruno Calcarenites
C. Poggi Calcarenites

C. Mevie Calcarenites
C. Mazzurini Sandstones

5.5.1. Altitude 483 Sandstones

This unit is a wedge-shaped body up to 15 m thick, only recognized to the N of Pian dei Buri Fault, with which it is in contact near the point of altitude 483 located E of Bric Arborella (cf. geological map and Pl. I). The unit shows maximum thickness in contact with the Pian dei Buri Fault and gradually closes over a distance of a few hundreds of metres away from this fault. It is bounded by the Montechiaro d'Acqui Siliceous Lithozone at the base and the Pian Bruno Calcarenites at the top. The unit consists of medium-bedded alternating turbiditic sandstones and mudstones.

The Altitude 483 Sandstones, together with the overlying Pian Bruno Calcarenites, showing similar wedge-shaped geometry and the same geometric relationships with the Pian dei Buri Fault, is here interpreted as the initial infill of a slope or base-of-slope half-graben of limited dimensions linked to the activity of the Pian dei Buri growth fault which bounds to the S both units (see below).

The Altitude 483 Sandstones, based on the age of bounding units, is tentatively referred to the early Burdigalian (MNN2a p.p.).

5.5.2. Pian Bruno Calcarenites

This unit is represented by a wedge-shaped body developed to the N of the Pian dei Buri Fault (cf. Pl. I). It has lateral extent of about 1.5 km and maximum thickness of about 35 m in contact with this fault, with gradual northward pinchout and closure near C. Colla (Fig. 18c). It is made up of resedimented biocalcarenites and minor biocalcirudites and slumped units (Fig. 18d) arranged in medium to thick, graded and graded-laminated beds similar in composition to the neighbouring C. Poggi Calcarenites and to the C. Mevie Calcarenites cropping out to the S of the Pian dei Buri Fault.

The Pian Bruno Calcarenites correspond, *pro parte*, to the *Intervallo Carbonatico Superiore* of Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b), which was mapped by them also to the SW of the Pian dei Buri Fault, for a total extent of about 8 km, as a discrete interval, locally eroded by the overlying Piantivello unit. The Pian Bruno Calcarenites, based on the wedge-shaped geometry with maximum thickness in contact with the Pian dei Buri Fault, are regarded to be confined within a small half-graben developed to the N of the Pian dei Buri Fault (Pl. I). These calcarenites share lithology and stratigraphic position with the neighbouring deposits of the C. Poggi Calcarenites and are therefore probably coeval with them. They are moreover time equivalent of the two calcarenitic horizons cropping out near C. Mevie. No paleocurrent indicators have been found in this unit. A provenance from WNW, similar to that of the adjoining C. Poggi Calcarenites is probable.

Based on the age of bounding units, the Pian Bruno Calcarenites may be attributed to the early Burdigalian (MNN2a p.p.).

5.5.3. C. Poggi Calcarenites

The C. Poggi Calcarenites form a lenticular body located to the N of the Pian dei Buri Fault. In this area the unit has lateral extent of about 1.2 km and maximum thickness of 22 m. It is bounded by the Montechiaro d'Acqui Siliceous Lithozone at the base and the marls of the Montechiaro d'Acqui Fm at the top. The unit is made up of resedimented deposits represented by glaucarenites in the lower part and biocalcirudites and biocalcarenites in the upper part (Fig. 17). Only one paleocurrent indicator has been found in the unit, showing provenance from WNW. The glaucarenites crop out near C. Poggi (Fig. 18a) with a maximum thickness of 5 m and lateral extent of about 300 m, and are locally eroded by the overlying carbonate deposits. They consist of resedimented, fine-grained, medium- to thick-bedded (10-60 cm) hybrid glauconitic arenites (glauconite 10-30%; the remaider: siliciclastic grains) and planktonic foraminifers. The glaucarenites correspond to the *Corpo inferiore glauconitico* of d'Atri (1990), to the *Areniti ibride glauconitiche* of Gelati and Gnaccolini (1998) and to the *intervallo delle areniti glauconitiche* of Gelati et al. (2010a, b). According to d'Atri (1990), the glauconitic grains would consist of slightly evolved glauconite, mechanically sorted during the transport by gravity flows. This would suggest, together with the textural and morphologic features of the grains, a cannibalization and resedimentation of older glauconitic deposits from condensed sediments formed in outer-shelf areas (Amorosi et al., 1997; Rossi et al., 2009). Gelati and Gnaccolini (1998), on the other hand, interpret this facies as *in situ* platform sediments, laid down on a structural high of very limited lateral extent defined as *Alto del T. Ovrano*. This hypothesis is excluded by the characteristics of the facies, in particular its lenticular channelized geometry.

The biocalcarenites and biocalcirudites of the middle-upper part of the unit occur in thick to very thick, graded and locally massive strata with erosional base, locally associated with rhodolithic pebbly mudstones, and contain bivalves, rhodoliths, echinoids, and other bioclastic components (Figs. 18b, 19). Some beds, moreover, are rich in resedimented glauconitic grains. This interval corresponds to the *Corpo carbonatico superiore* of d'Atri (1990) and, *pro parte*, to the *Intervallo Carbonatico Superiore* of Gelati and Gnaccolini (1998). In agreement with d'Atri (1990), both glaucarenitic and carbonate deposits are regarded as the infill of a slope or base-of-slope channel.

d'Atri (1990), Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) refer the C. Poggi unit to the Burdigalian (Zone N5-6). The C. Poggi Calcarenites, based on the age of bounding units, may be attributed to the early Burdigalian (MNN2a p.p.).

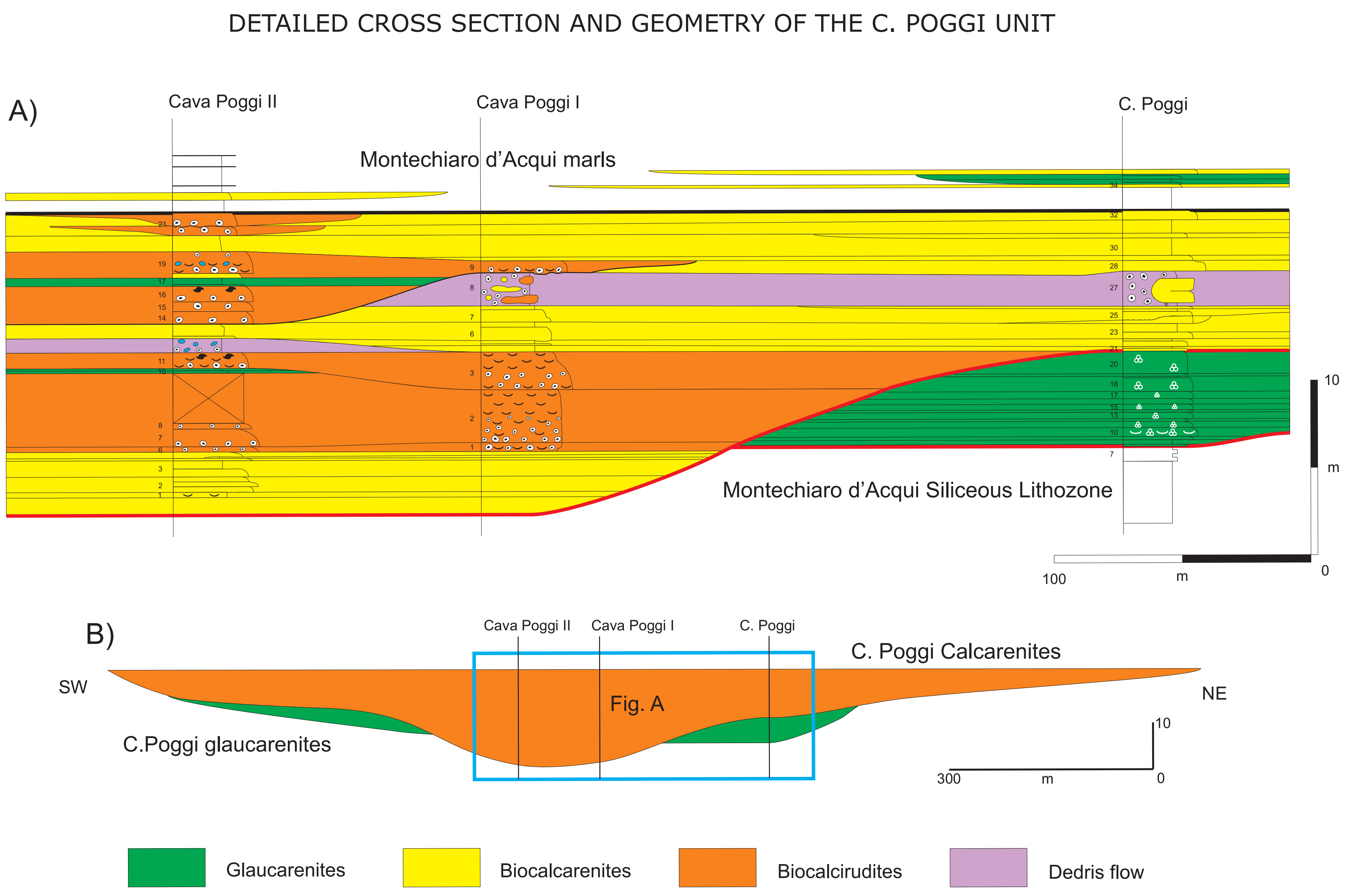

Fig. 17 - Detailed cross section and geometry of the Case Poggi unit.

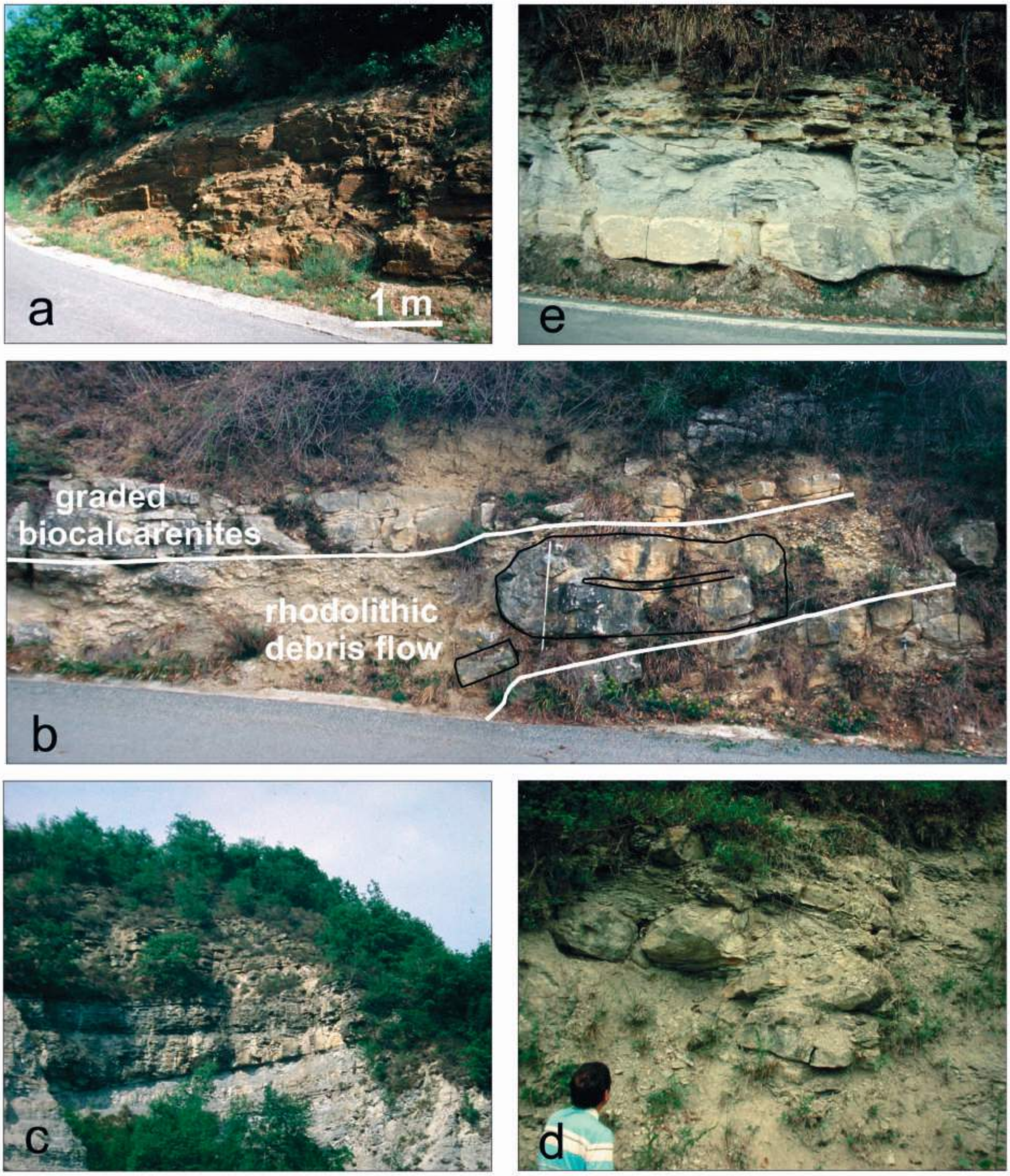

Fig. 18 - The resedimented carbonate units of the Montechiaro d'Acqui Formation. a) C. Poggi unit. Resedimented glaucarenites cropping out near C. Poggi, along the road Mombaldone-Roccaverano. b) C. Poggi unit. Rhodolithic debris flow unit capped by graded biocalcarenites. Note the folded biocalcarenite block. Jacob staff for scale. c) The Pian Bruno unit cropping out on the left side of the Ovrano Valley. The unit gradually pinches out towards NE. d) Pian Bruno unit. Slump/debris flow level capped by graded biocalcarenites. Note the folded biocalcarenite block. e) C. Mevie unit. The lower resedimented biocalcarenite bed cropping out near C. Mevie. Hammer for scale.

5.5.4. C. Mevie Calcarenites

This unit crops out to the SW of the Pian dei Buri Fault. It is represented by two horizons of graded and resedimented biocalcarenites, 0.8 m thick (lower horizon) and up to 2 m thick (upper horizon) (Fig. 18e), separated by some metres of hemipelagic marls. Both horizons thin out progressively SW-wards and close near C. Rocchino (cf. Pl. I). To the NE, both C. Mevie horizons are offset by the Pian dei Buri Fault and can be traced at the base of the C. Mazzurini unit, where they are erosionally truncated (Pl. I). The horizons show the

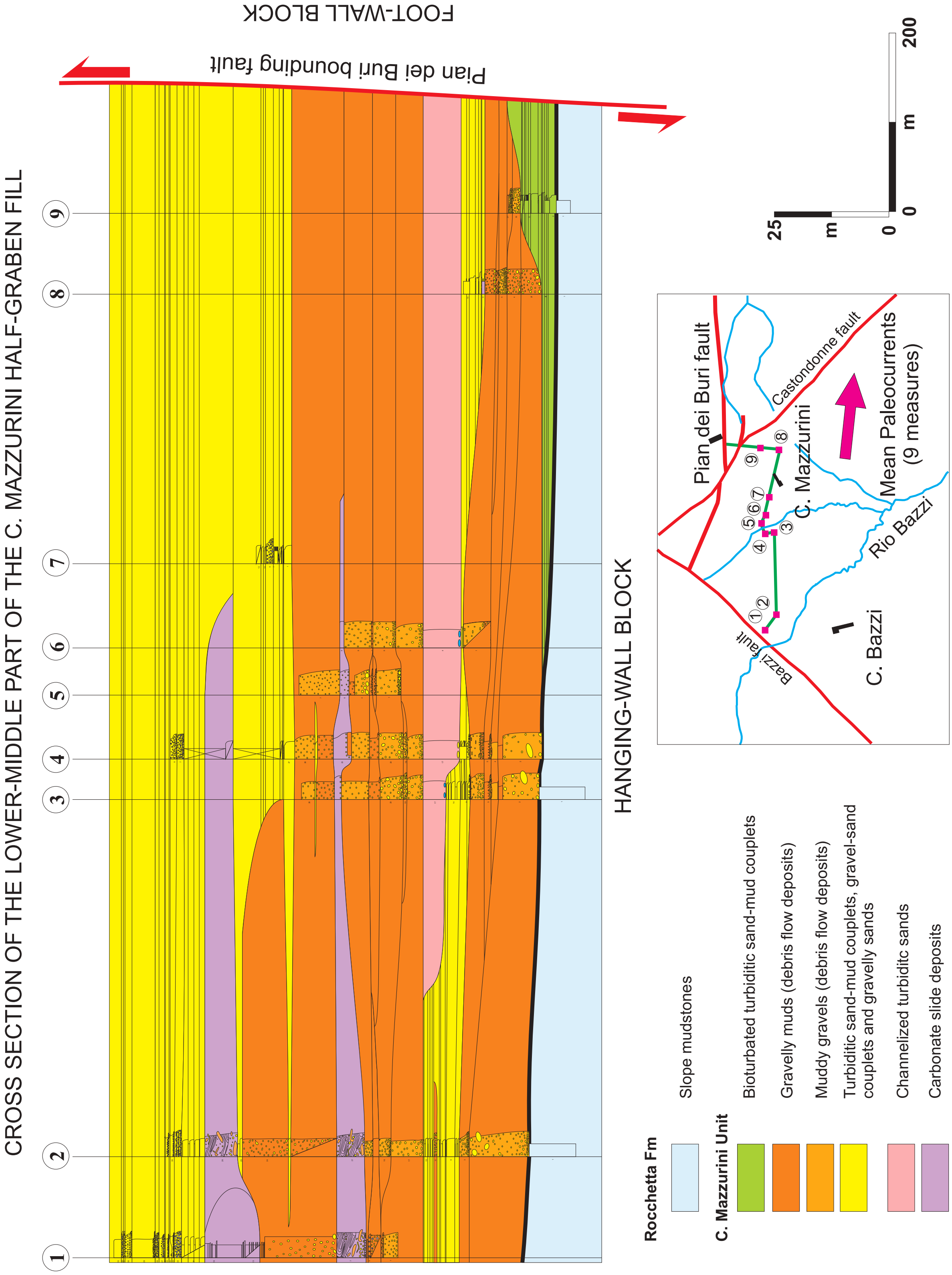

Fig. 19 - Cross-section of the lower-middle part of the C. Mazzurini Half-graben fill.

same composition as that of the Pian Bruno and C. Poggi Calcarenites, and share with them the stratigraphic position within the marls of the Montechiaro d'Acqui Fm. These carbonate horizons are therefore considered coeval to the other biocalcarenitic horizons occurring in the local succession. The two beds are here interpreted as deriving from the SW-ward overspill of turbiditic flows of carbonate composition depositing their main load in the adjacent Pian Bruno structural depression developed to the N of the Pian dei Buri Fault (Pl. III, scenario **f**).

The Case Mevie Calcarenites correspond to the *Intervallo carbonatico inferiore* of Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b). These Authors trace the two calcarenitic beds inside the C. Mazzurini unit. Hovever, mapping evidence shows that the calcarenitic beds underlie the C. Mazzurini unit and are eroded at the level of the basal surface of the same unit near C. Bazzi. The C. Mazzurini unit is therefore entirely younger than the C. Mevie unit, and, consequently, younger than all the resedimented carbonate units occurring in the lowermost part of the Montechiaro d'Acqui Fm.

The C. Mevie Calcarenites can be dated to the early Burdigalian (MNN2a p.p.).

5.5.5. C. Mazzurini Sandstones

The C. Mazzurini unit forms a large-scale sedimentary body with wedge-shaped geometry bounded to the N by the Pian dei Buri Fault (cf. Pl. I). It consists of resedimented sandstones and conglomerates arranged in thick and amalgamated strata, commonly containing an abundant coarse bioclastic fraction consisting primarily of rhodoliths and bivalves. Bioclastic-rich facies are particularly developed in the upper part of the unit. The unit has maximum thickness of about 150 m in proximity of the Pian dei Buri Fault, and wedges out SW-wards, over a distance of about 2.5 km, slightly to the N of C. Ghiazzo. The best outcrops are located on the northern side of the valley of Bazzi stream. The unit is bounded at both base and top by the marls of the Montechiaro d'Acqui Fm. In the C. Mazzurini area, however, the unit lies directly on the mudstones of the Rocchetta Fm, due to the local erosion of the underlying stratigraphy (cf. Pl. I). South of C. Avrama, moreover, the top of C. Mazzurini Sandstones is directly in contact with the erosional base of the overlying Piantivello Sandstones (Serole Fm), due to the local removal of the marly succession originally interposed between the two units (cf. Pl. I). The basal contact of the C. Mazzurini unit is everywhere sharp and, locally, erosional. A detailed cross section of the lower-middle part of the C. Mazzurini succession near the Pian dei Buri bounding fault is shown in figure 19. The above defined features allow to interpret the unit as the infill of a submarine half-graben bounded to the NE by the Pian dei Buri Fault in a probable slope or base-of-slope environment (cf. also Gelati and Gnaccolini, 1998). Paleocurrent measurements indicate provenance from WNW.

Although Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) recognized the nature of the C. Mazzurini unit as the infill of a half-graben bounded by the Pian dei Buri Fault, the stratigraphy of this and surrounding units and their mutual relationships differ significantly from our data, as may be desumed from a detailed comparison of the two geological maps. In particular, their *Piantivello unit* and the sandstone body here named "Bric Torrione Sandstones" cannot be considered parts of the Mazzurini wedge, but are separated from it, different in composition (C. Stefani, pers. communication) and of younger age.

The C. Mazzurini unit is dated by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) to the Aquitanian on the basis of planktonic foraminifers. In our view, the unit, based on the age of bounding units, may be attributed to the early Burdigalian (MNN2b p.p.).

5.5.6. Sedimentology of the C. Mazzurini Half-graben

The C. Mazzurini unit is an outstanding example of tectonically controlled sedimentation and has been therefore the subject of a particular sedimentological analysis.

5.5.6.1. Facies analysis

The geometry and lateral distribution of the component facies are shown in the cross-section of figure 19. Such cross-section illustrates the latero-vertical facies distribution in the lower half of the half-graben infill. A panoramic view of the complete half-graben infill is shown in figure 21.

Six main facies have been identified in the unit.

Facies 1 - Thick-bedded, bioturbated, sandstone-mudstones turbidites. This facies shows an overall thickness of about 8 m. It is only present in the lowermost part of the half-graben infill, near the Pian dei Buri bounding fault, and is erosionally truncated at the top by younger deposits (Fig. 19). It consists of thick-bedded, thoroughly bioturbated (especially by subvertical escape burrows) sandstone-mudstone turbidites (Fig. 20a, 20b). The sand/mud ratio is >> 1. The sandstone layers are coarse- to medium-grained and are bounded at the base by planar or small-scale erosional base; they show distribution grading from medium-coarse to medium-fine sand. High abundance of plant debris and presence of mud intraclasts are additional features. The deposits are inferred to have been laid down by surge-type, fully turbulent, moderately high-concentration turbidity currents ("classical" turbidity currents) transporting sand from a presumably narrow shelf. The intense bioturbation is explained by the presence, in the resedimented deposits, of infaunal crustaceans that were presumably displaced from neritic environments, entrained in the gravity flow and temporarily survived transport to create burrows in the newly deposited deep-water sandy sediments (cf. Follmi and Grimm, 1990).

Facies 2 - Paraconglomerates (muddy gravels and gravelly muds). This facies is present in the lower and

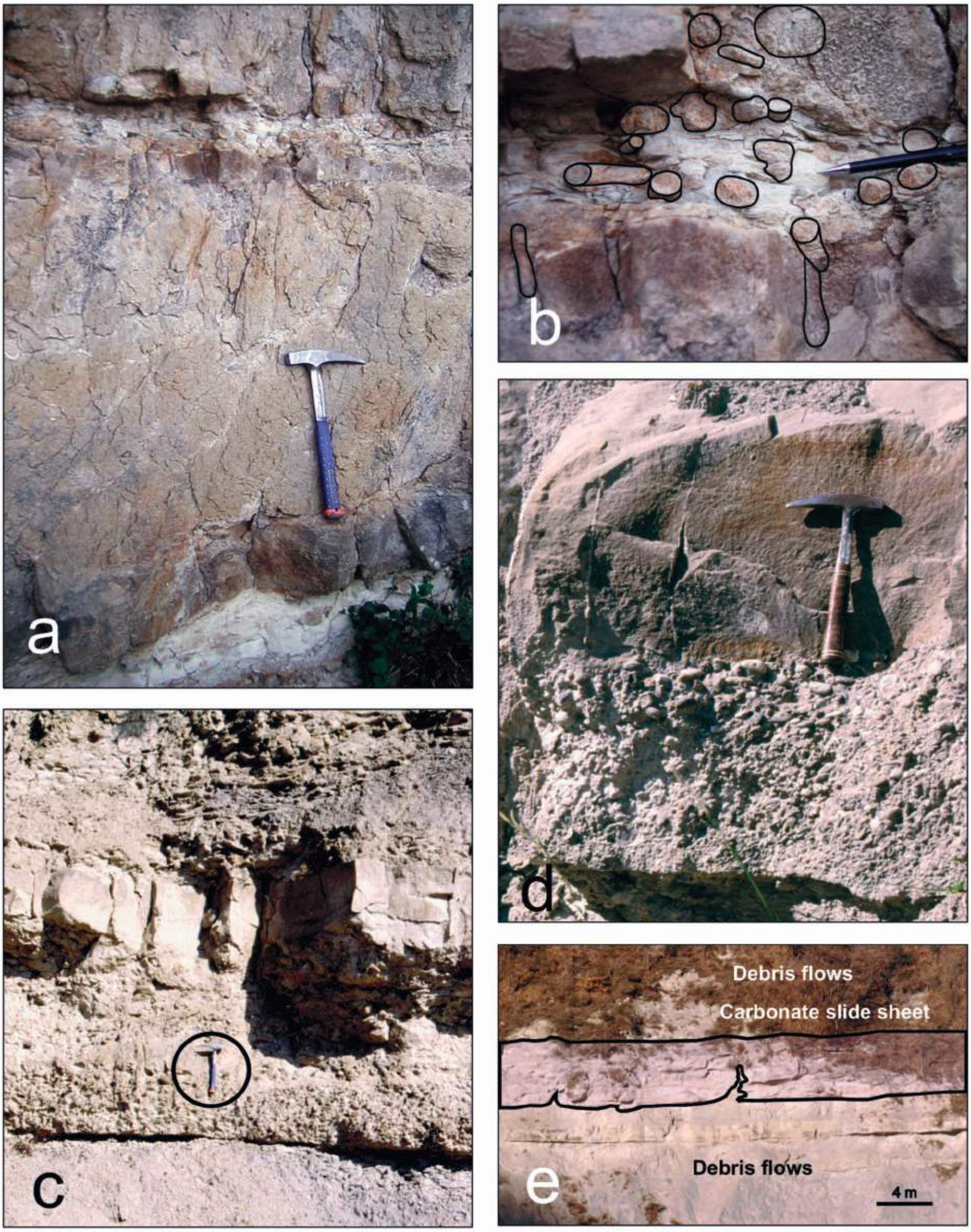

Fig. 20 - The main facies of the C. Mazzurini Half-graben fill. a, b) Bioturbated turbiditic sandstone-mudstone couplets (cf. Fig. 21). c) Pebbly mudstone capped by a graded-to-laminated turbidite unit. The non-erosional base, the tabular geometry over long distances and the presence of a sandstone-mudstone couplet at the top are interpreted as indicative of a transport mechanism related to hydroplaning subaqueous debris flow coupled with an overlying subsidiary turbulent current produced by surface transformation processes. d) Conglomerate-sandstone couplets. Note the well developed inverse grading in the conglomeratic lower part. e) The lower carbonate slide sheet with a large muddy flame protruding upwards from the base.

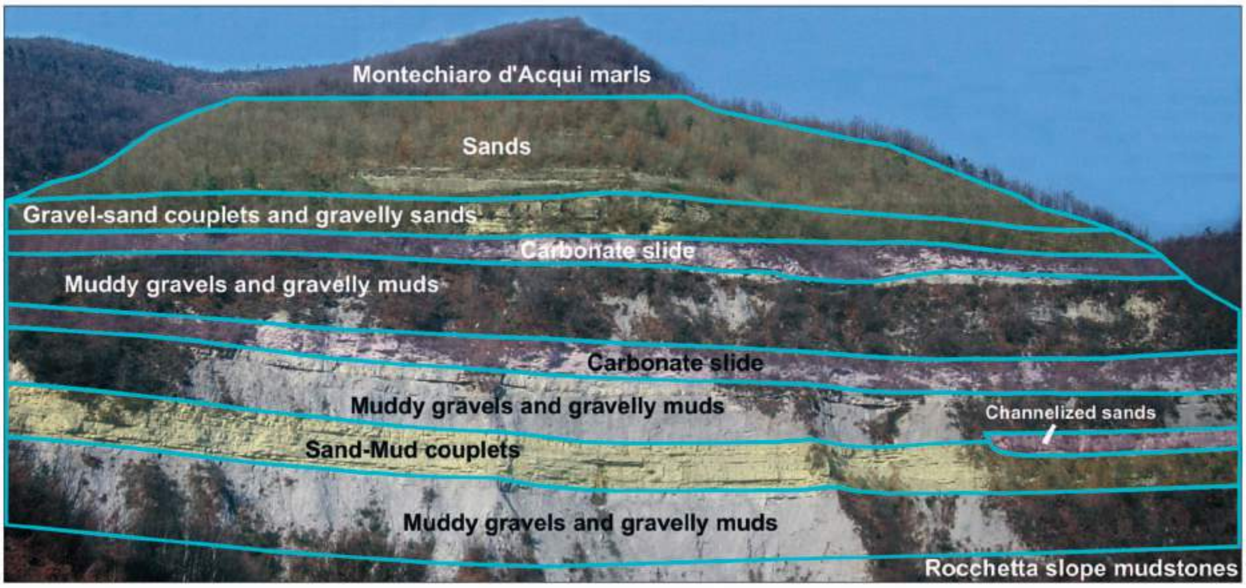

Fig. 21 - Stratigraphic architecture of the C. Mazzurini Half-graben fill (left side of Rio Bazzi Valley in front of C. Bazzi). The large-scale outcrop, about 100 m high, is oriented almost parallel to paleocurrents. It is located between sections 1 and 3 of figure 19. Note the well organized upward-fining stacking pattern of the facies, with thick- to very thick-bedded gravelly muds and muddy gravels (debris flows) and associated carbonate slides in the lower part, and gravel-sand couplets, amalgamated sands and sand-mud couplets in the upper part. Note also the lateral pinch out of the channelized sandstone body shown on the right side of the outcrop. The channelized sandstone layer is inferred to reflect the enhanced erosional power of sediment gravity flows due to lateral confinement in the deeper part of the half-graben.

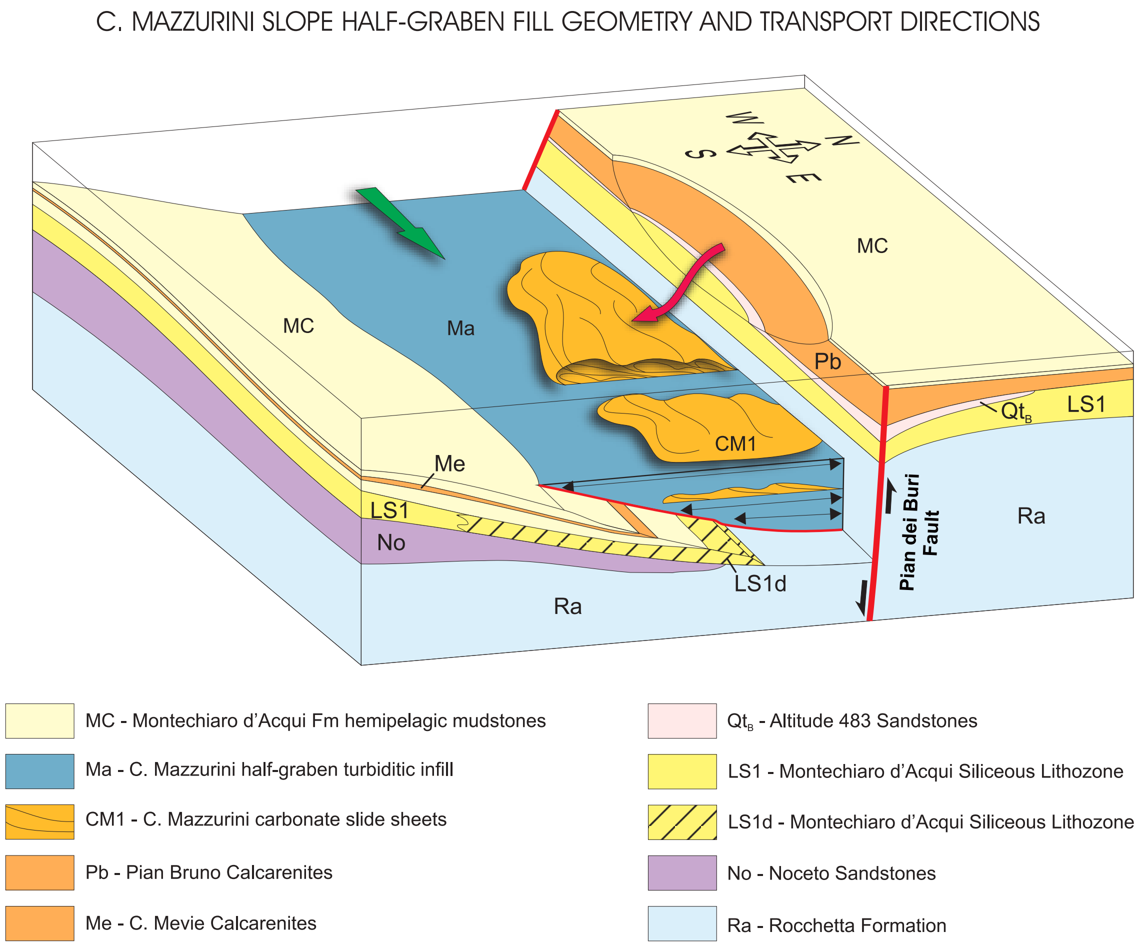

Fig. 22 - Three-dimensional reconstruction of the geometry and architecture of C. Mazzurini Half-graben fill, with indication of axial and lateral transport directions.

middle parts of the infill (Figs. 19, 21) and consists of thick- to very thick-bedded (up to 11 m) pebble to cobble gravelly muds and muddy gravels. Exotic pebbles and cobbles (serpentinites, gneiss, micaschists, quartzites, and Mesozoic limestones), 0.5 to 10 cm in diameter, are very well rounded and spherical to discoidal in shape. Large bioclasts are common and include gastropods, bivalves (pectinids, venerids and glycymerids) and less common centimetric rhodoliths. Some layers contain isolated, metric sandstone boulders and large mud clasts. Beds show lateral continuity of several hundreds of metres in both sections oblique and transverse to paleocurrents. Bed geometry is tabular to irregular. Lower surfaces are planar and mainly non-erosional, upper surfaces undulate or irregular. Upward-convex bed tops due to the preservation of the original depositional geometry are common. Beds usually show non-erosional relationships, with common mutual topographic compensation. The relief at the layer top is commonly smoothed by successive debrite or turbidite layers (Fig. 19). Many gravelly mud beds pass upwards to a normally graded sand or gravelly sand unit (Fig. 20c). Such couplets are the record of a single depositional event. The lower, gravelly mud unit is commonly characterized by a well developed content grading with larger and/or denser clasts concentrated in the basal part with, in some cases, long axes showing a relatively well developed imbrication or an orientation parallel to the stratification.

Facies 2 was laid down by subaqueous cohesive debris flows. Such flows were characterized by a relative dilution and sufficiently low internal viscosity to allow the vertical segregation of larger and/or denser clasts and a certain clast-to-clast interaction manifested by clast imbrication. A subsidiary turbulent current produced by surface transformation processes was present at the top of the flow. The described characteristics, together with the non-erosional character of the lower bed surfaces, point to a transport and depositional process related to hydroplaning subaqueous debris flows (Harbitz et al., 2003). The permeability of the hydroplaning mass was sufficiently low to maintain the hydroplaning process, but not enough to prevent a significant percolation of overpressured water into the frontal portion of the rapidly moving debris flow with consequent dilution and viscosity reduction.

Facies 3 - Thick-bedded conglomerate-sandstone couplets. This facies is present mostly in the middle - upper part of the half-graben infill (Figs. 19, 21). Beds of this facies are thick to very thick and consist of a lower, clast-supported conglomeratic part and an upper sandy one. The strata are lenticular in section normal to flow, and show persistence of some hundreds of metres along flow. Gravel/sand ratio is between 1:1 and 10:1. Exotic clasts are pebble to cobble (up to 10 cm) in size, and bioclasts, sometimes dominant, are 0.5 to 8 cm in diameter. Internally the gravelly part is crudely normally graded, sometimes inversely graded (Fig. 20d). In some cases it is characterized by thick subhorizontal internal stratification. Both long-axis and intermediate-axis imbrication are relatively common. The upper sandy part is normally graded and/or parallel-laminated. Beds almost entirely made up of resedimented bioclasts (mostly rhodoliths and, subordinately, thick-shelled bivalves) are common in the upper part of the infill.

Transport and depositional process: surge type, high-concentration turbidity currents characterized by a coarse-grained load (pebbles and sand). During transport the currents were bipartite with a lower (and frontal) coarse-grained, non-turbulent, highly concentrated gravelly portion and an upper, less concentrated turbulent sandy portion.

Facies 4 - Thick-bedded sandstones. This facies is mainly developed in the upper part of the half-graben infill. In the lower part of the infill it is only represented by a thick-bedded, scour-and-fill unit located near the bounding fault (Figs. 19, 21). The facies consists of thick-bedded (1 to 5 m), medium-grained, amalgamated sandy units of apparently tabular geometry. The lower bed contact is commonly floored by discontinuous gravel pavements concentrated in erosional scours. The units are generally massive, with normal grading confined in the bed topmost part (top grading).

Transport and depositional process: surge type, bipartite, high-concentration turbidity currents transporting a sandy load. After the *en-masse* deposition of the lower concentrated sandy portion, the upper, finer-grained turbulent part of the current bypassed the depositional area.

Facies 5 - Medium- to thick-bedded, graded to laminated sandstone-mudstone couplets (classic Bouma sequences). Bed geometry is tabular along flow, irregular in section normal to paleoflow, with marked thickness variations, partly due to onlap onto the irregular top of an underlying debrite layer, partly to erosion by an overlying channelized body. The couplets are thick (30-120 cm), with sand/mud ratio > 1. A basal, medium-grained, normally graded sand division passes into a laminated "b" Bouma division.

Transport and depositional process: surge type, turbidity currents of moderate concentration.

Facies 6 - Chaotic carbonate units. This facies consists of two chaotic carbonate units, respectively 6 and 7 metres thick, interpreted as slide deposits, which may be traced for about 350 m in the lower part of the half-graben infill (Fig. 19). They consist of deformed biocalcarenite and biocalcirudite slabs and large intraformational marly blocks (metric clasts of the Montechiaro d'Acqui marls?). Locally, the topmost part of the slide deposits is represented by a thick-bedded, normally graded, bioclastic bed possibly related to an associated upper turbulent flow. In section 1 of figure 19 the upper chaotic unit also contains a large olistolith 12 m thick of the Montechiaro d'Acqui marl. The basal contact of the chaotic units is slightly erosional and characterized by large flame structures due to upward squeezing of sediment from underlying muddy debris flow units (Fig. 20e). Locally, isolated carbonate blocks are loaded into the underlying muddy deposits. The composition of the carbonate slabs and marly blocks is similar to that of carbonate rocks occurring in the uplifted fault block (Pian Bruno Calcarenites) (Pl. I). In sections parallel to the bounding fault the lower slide mass appears to be cut by multiple, arcuate shear planes, whereas transverse sections display small-scale folds and thrusts with southward vergence.

The facies 6 is referred to gravity-emplaced submarine slides with limited plastic deformation and predominance of internal shear planes bounding rigid olistoliths. Small-scale folds and thrusts are compressional features affecting the frontal part of the sliding mass. The loading and flame structures at the base of the masses document a sudden liquefaction of the underlying pebbly mudstone.

5.5.6.2. Stratigraphic architecture and infilling model

The stratigraphic architecture of the Case Mazzurini slope half-graben infill is shown in figure 19. The infill shows a well organized, upward-fining stacking pattern of the facies, with thick- to very thick-bedded gravelly debris flow units and carbonate slide deposits in the lower part of the infill and resedimented conglomerate-sandstone couplets, amalgamated sandstones and sandstone-mudstone couplets in the upper part (see also Fig. 21). At least two large-scale erosional surfaces are present in the deeper part of the sedimentary infill near the bounding fault (Fig. 19). The first corresponds to the top surface of Facies 1 deposits, interpreted as a surface of relatively long-lasting bypass, and the second is localized at the base of a scour-and-fill sandstone unit composed of a single-event very thick bed (Figs. 19, 21). The presence of large-scale erosional surfaces localized in the deeper part of the half-graben infill, near the bounding fault, should reflect enhanced erosional power of gravity flows in the lowermost part of the half-graben, due to flow confinement. Sole marks and clasts imbrication in the coarse-grained sediment gravity flow deposits of the sedimentary infill (Facies 1 to 5) indicate an eastward, longitudinal transport direction, roughly parallel to the Pian dei Buri half-graben bounding fault. The lithology and directional structures of the two carbonate slide deposits, as well as the internal deformations and shear planes marking mutual thrusting of component blocks of the slides, point to a lateral derivation of such carbonate slide units from the uplifted block of the half graben where similar carbonate deposits (Pian Bruno Calcarenites) were exposed on the fault plane (cf. footwall degradation processes, McLeod and Underhill, 1999). The infilling model of the Case Mazzurini slope half graben is shown in figure 22. The slope structural depression was filled mainly longitudinally with west-derived sediment gravity flows (debris flows and turbidity currents of various concentration) and, subordinately, with laterally derived carbonate slides from the uplifted block (Ghibaudo et al., 2001b).

The source area may be envisaged as a fan-delta depositional system associated with a carbonate ramp, allowing coarse siliciclastics mixed with abundant skeletal debris to be shed downdip by gravity flows into the half-graben. The coastal systems are inferred to have been located near the shelf margin during a lowstand phase. Gravity destabilization first affected the muddy distal parts of the coastal systems generating debris flows; then, retrogressive liquefaction of the gravels and sands of the fan-delta front generated the turbiditic flows which fed the upper part of the half graben infill.

5.6. Serole Formation

The Serole Fm, as defined in the present paper, is a heterogeneous stratigraphic unit, mainly composed of thin- to medium-bedded mudstone-sandstone turbidites with planar-laminated sandy divisions. These background sediments encase sandstone or sandstone-conglomerate bodies at various stratigraphic levels. The turbiditic couplets, which form the bulk of the unit, will be described with the informal term of "alternating sandstones and mudstones of the Serole Fm". The sandstone bodies, on the other hand, are regarded as members of the formation. In the study area the Serole Fm also includes three erosional depressions, interpreted as slump scars (cf. Pl. I), one of which accommodated the Bric Torrione Sandstones (see below).

The Serole Fm is bounded at the base by the Montechiaro d'Acqui Fm and at the top by the Cortemilia Fm. The basal contact is rapidly transitional or erosional where it coincides with the base of the Piantivello Sandstone member and/or with the mentioned erosional depressions. The upper contact is transitional. The formation as a whole has variable thickness, with a clear tendency to progressive thinning from SW to NE. In the type-locality, on the road connecting S. Sebastiano and Roccaverano, the formation is 115 m thick. To the NE, near Denice, it is reduced to a few tens of metres. The geologic mapping in adjacent areas shows that the formation closes within a few kilometres NE-wards, on the western side of the Erro Valley (Sheet Acqui Terme). To the SW, on the other hand, the formation extends for many kilometres and gradually thickens in the Sheet Dego outside the study area, concurrently with a progressive thickness reduction of the overlying Cortemila Fm (Ghibaudo et al., this volume; Ghibaudo et al., in prep.).

The Serole Fm corresponds, *pro parte*, to the *Formazione di Serole* of Gelati (1968), to the *Unità Piantivello* and *Unità S. Sebastiano* of Gelati and Gnaccolini (1998) and to the sub-unit of the *Alternanze ritmiche di peliti ed arenarie sottilmente stratificate* of the *Massa di fondo* of the *Formazione di Rocchetta-Monesiglio* of Gelati et al. (2010a, b).

The Serole Fm is datable to the middle Burdigalian (Zones MNN3a p.p.- MNN3b p.p.).

In the following sections the units listed below with related geological features will be described:

Piantivello Sandstones
Alternating sandstones and mudstones of the Serole Fm
Bric Torrione Erosional Depression

Case Rocchino Erosional Depression
Denice Erosional Depression
Bric Torrione Sandstones
Rio della Torre Lower Sandstones
Rio della Torre Upper Sandstones

5.6.1. Piantivello Sandstones

This unit is a large-scale lenticular sandstone body with convave-up base and planar top, cropping out in the central part of the study area between C. Pian Fuoco to the NE and C. Nuova to the SW. The unit has maximum thickness of about 100 m and extends laterally for about 4.8 km (cf. Pl. I). It consists of turbiditic sandstones and pebbly sandstones, and locally pebbly mudstones, in thick and amalgamated, graded or graded-laminated beds (Fig. 23a). The uppermost part is dominated by thick- to medium-bedded turbiditic couplets (Fig. 23b, 23c). The measured paleocurrents indicate provenances from W-WNW. The unit is bounded at the base by the Montechiaro d'Acqui Fm and at the top by the alternating sandstones and mudstones of the Serole Fm.

The lower contact is sharp and erosional, the upper rapidly transitional. Locally (S of C. Avrama), where the unit is thickest, the basal surface truncates the uppermost part of the Montechiaro d'Acqui Fm, being in contact with the C. Mazzurini Sandstones (cf. Pl. I). To the NE the unit is completely eroded by the lower part of the Bric Torrione Erosional Depression for a distance of about 800 m. The depositional closure of the unit below this erosional surface can again be observed on the left side of the Ovrano Valley near the locality Pian dei Lavaggi (Pl. I). Based on its geometry, large-scale erosional nature of the basal surface and relatively proximal nature of the deposits, the unit is interpreted as the infill of a wide submarine valley in a probable base-of-slope setting.

The Piantivello unit is attributed by Gelati and Gnaccolini (1998) to the Burdigalian. Based on the age of bounding units, the Piantivello Sandstones may be referred to the middle Burdigalian (MNN3a p.p.).

5.6.2. Alternating sandstones and mudstones of the Serole Formation

A detailed section of the pelitic-arenaceous turbidites of the Serole Fm in the type-locality is shown in figure 26. This unit consists of thin- to medium-bedded sandstone-mudstone and siltstone-mudstone turbidites with sandstone or siltstone/mudstone ratio << 1 (Figs. 26, 27a). The sandy divisions are on average 5-20 cm thick. Typically most sandy layers show a parallel-laminated division directly overlain by turbidite mud (Tb/e Bouma's sequences) (Fig. 27b). Locally, in the lowermost part, packages are present of alternating turbiditic siltstones and mudstones with siltstone/mudstone ratio << 1 and silty divisions on average 3-10 cm thick. Rare decimetric layers of hemipelagites occur in the lowermost part. The alternating lithologies form the bulk of the Serole Fm and encase, at various stratigraphic levels, a number of sandstone bodies. Rare paleocurrent data collected in these lithologies suggest western provenances. The unit corresponds to the *Unità S. Sebastiano* of Gelati and Gnaccolini (1998) and to the sub-unit of the *Alternanze ritmiche di peliti e arenarie sottilmente stratificate* forming the *Massa di fondo* of the *Formazione di Rocchetta-Monesiglio* of Gelati et al. (2010a, b). The latter are interpreted by Gelati and Gnaccolini (1998) as basinal deposits. The association of these deposits with submarine erosional surfaces interpretable as slump scars developed at the top of the underlying Montechiaro d'Acqui Fm (see below) and the systematic Tb/e character of turbidite beds, indicating active bypass of the fine grain sizes along the bottom, suggest a slope or base-of-slope depositional setting.

5.6.3. Bric Torrione Erosional Depression

A large-scale erosional surface named Bric Torrione Erosional Depression has been identified at the head of the Ovrano Valley (cf. geological map and Pl. I). The erosional depression is about 850 m wide and about 50-60 m deep. It truncates the Piantivello unit and the underlying Montechiaro d'Acqui Fm. The infill mostly consists of the alternating sandstones and mudstones of the Serole Fm, and includes, in its lower part, the Bric Torrione Sandstones (see below) (Fig. 24). The Bric Torrione Erosional Depression is interpretable as a large-scale submarine slump scar subsequently acting as a pathway for turbidite flows (slope valley). The youngest sediments truncated by the surface are represented by the Piantivello Sandstones of middle Burdigalian age and the infill consists of sediments of the Serole Fm, still of middle Burdigalian age. Therefore, the erosional feature is to be hold as intra-middle Burdigalian.

5.6.4. Case Rocchino Erosional Depression

The Case Rocchino Erosional Depression is located at the extreme SW of the mapped area (cf. enclosed geological map and Pl. I), and is an erosional scar at the top of the marls of the Montechiaro d'Acqui Fm, infilled with the alternating sandstones and mudstones of the Serole Fm. Evidence of this feature is essentially based on mapping data, since poor exposures prevent a detailed investigation of the surface. Near C. Rocchino the erosional surface removes almost totally the marls of the Montechiaro d'Acqui Fm, cutting down to a level located about 20-30 m above the upper carbonate horizon of the C. Mevie Calcarenites, here showing its south-westerly termination.

5.6.5. Denice Erosional Depression

This surface is located at the extreme NE of the study area. It is wholly comparable for geometry, stratigraphic position, genesis and age to those above described. It extends to the NE, outside the study area, and shows the

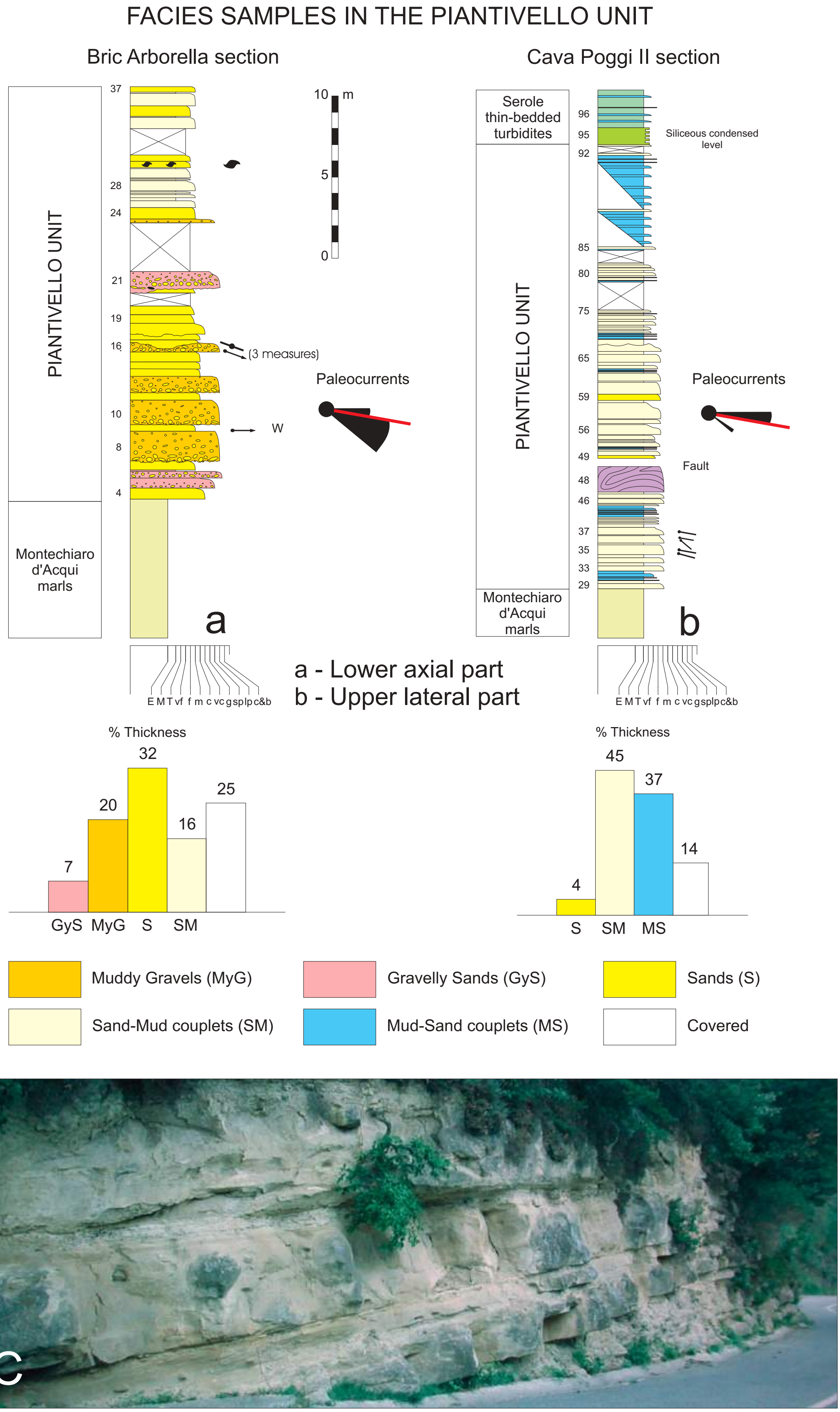

Fig. 23 - Facies samples in the Piantivello unit. a) Bric Arborella section (cf. Fig. 2 and Pl. VIc). b) C. Poggi II section (cf. Fig. 2 and Pl. VIb). c) Thick-bebbed sandstone-mudstone couplets in the basal part of C. Poggi II section.

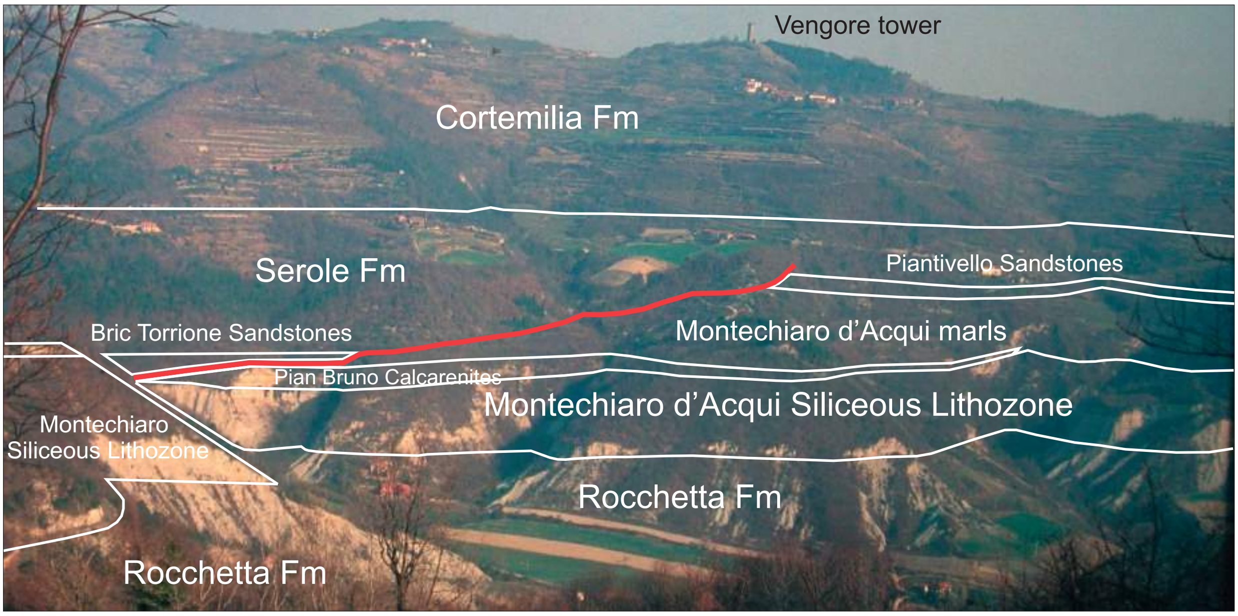

Fig. 24 - Panoramic view of the left side of the Ovrano Valley. The local succession is highlighted. Note the large-scale erosional surface infilled with Bric Torrione turbidites and Serole thin-bedded turbidites, interpreted as a slump scar surface.

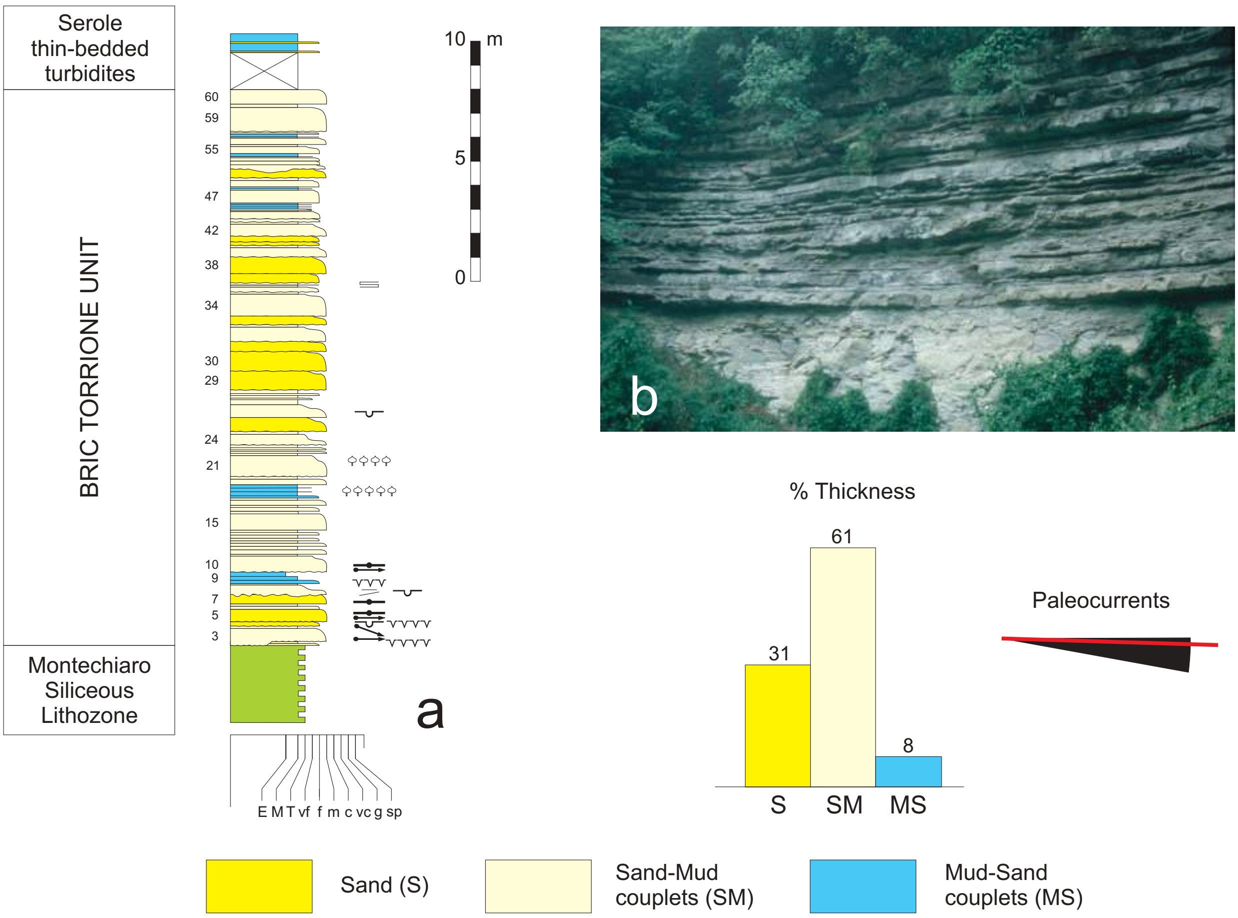

Fig. 25 - Vertical facies distribution of the Bric Torrione unit (Molino d'Ovrano - Bric Torrione section, cf. Fig. 2 and Pl. VIa). a) Facies distribution in the axial part of the Bric Torrione unit dominated by sandstone-mudstone couplets and amalgamated sandstones. b) Typical aspect of the unit at the head of the Ovrano Valley where the section was measured.

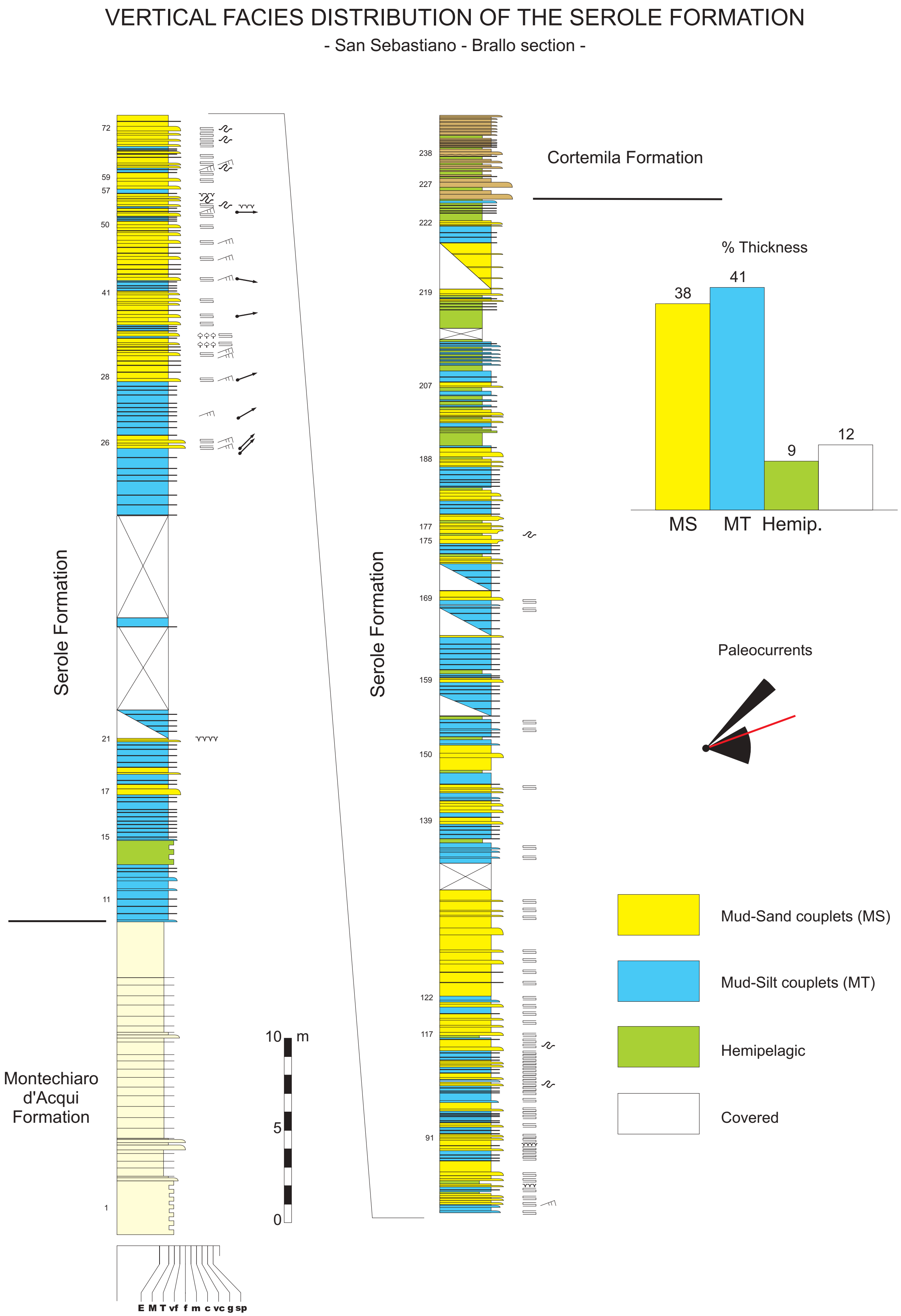

Fig. 26 - Vertical facies distribution of the Serole thin-bedded turbidites in the San Sebastiano-Brallo type section (cf. Fig. 2 and Pl. Vc), dominated by mudstone-sandstone and mudstone-siltstone couplets. Paleocurrents are only indicative, being mostly inferred from dip direction of current ripple laminae.

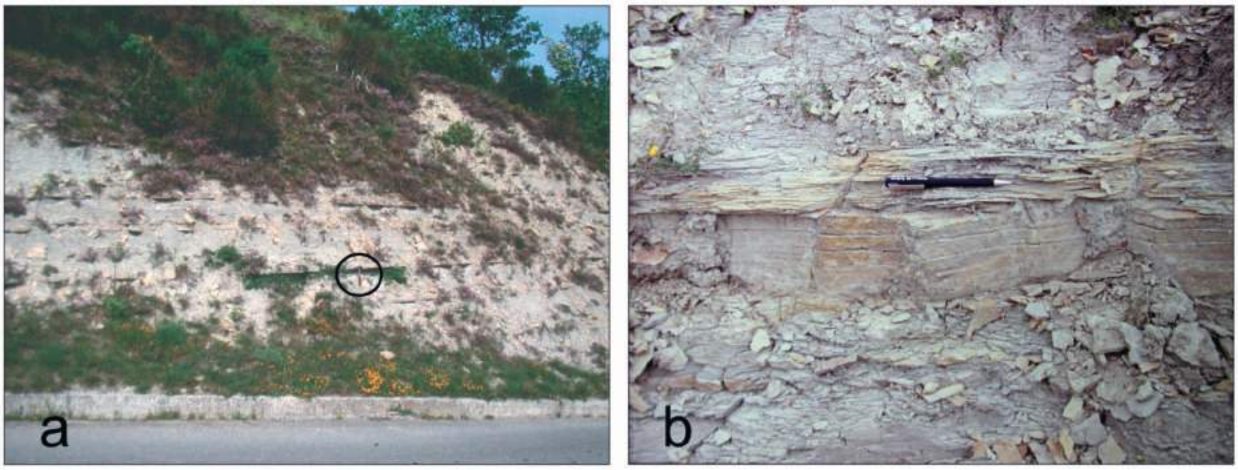

Fig. 27 - a) The Serole Fm in the San Sebastiano-Brallo type section (cf. Fig. 2 and Pl. Vc). b) Laminated mudstone-sandstone couplet characterized by Tb/e Bouma sequence typical of most turbidite beds of the Serole Fm in the type section. Such character is interpreted as indicative of a base-of-slope setting with active bypass of finer sediments (fine- to very fine-grained sands and silts).

maximum development close to the village of Denice where the alternating sandstones and mudstones of the Serole Fm directly overlie the Montechiaro d'Acqui Siliceous Lithozone.

5.6.6. Bric Torrione Sandstones

This unit crops out in a limited area at the head of the Ovrano Valley between C. Volpotto and C. Pian Fuoco. It consists of turbiditic sandstones in thick- to very thick and locally amalgamated beds. The geometry of the body is lenticular, with concave-up base and planar top. The unit has maximum thickness of 23 m and lateral extent of about 750 m, and forms part of the infill of the Bric Torrione Erosional Depression (cf. Pl. I and Fig. 24). The latter is interpreted as a large-scale slump scar which removes the whole Montechiaro d'Acqui Fm and extends downwards to the top of the underlying Montechiaro d'Acqui Siliceous Lithozone. The Bric Torrione unit is bounded at the base by the Montechiaro d'Acqui Fm and the Montechiaro d'Acqui Siliceous Lithozone, and at the top by the alternating sandstones and mudstones of the Serole Fm (cf. Pl. I, Pl. VIa, Fig. 24). The lower contact is sharp and erosional, the upper rapidly transitional. The vertical facies distribution of Bric Torrione unit is shown in figure 25. The unit shows an upward-thinning and -fining internal trend and consists of three main facies: amalgamated sandstones in medium and thick layers, sandstone-mudstone couplets in medium and thick layers and mudstone-sandstone couplets in thin to medium layers. The amalgamated sandstone facies can be described as Bouma Ta/ and Ta-b/ sequences, the sandstone-mudstone couplets as Bouma Ta-b/e and Ta/c/e and the mudstone-sandstone couplets as Bouma Tb/e and Tc-e sequences. The unit was fed from W and the dip of paleoslope was into E.

Interpretation: The unit represents a turbiditic sandstone body confined into the deepest part of a large-scale erosional surface (Bric Torrione Erosional Depression) developed in post-Piantivello times and interpreted as a large-scale slump scar subsequently acting as a pathway for turbidite flows (slope valley).

The Bric Torrione unit is referred by Gelati and Gnaccolini (1998) to the Aquitanian. Based on the age of bounding units, the Bric Torrione Sandstone could be attributed to the middle Burdigalian (MNN3a?).

5.6.7. Rio della Torre Lower and Upper Sandstones

These units are represented by two sandstone bodies separated by a few tens of metres of alternating sandstones and mudstones of the Serole Fm, and cropping out in the thalweg of the Rigosio creek, slightly SW of the village of Serole. The best outcrops are located SW of the study area in the Rio della Torre Valley (Ghibaudo et al., this volume). These bodies are a few tens of metres thick and consist of medium-coarse turbiditic sandstones in thick and amalgamated beds, grading upwards into thick to medium-bedded, alternating turbiditic sandstones and mudstones. Exposures of these units in the study area are poor, so that their definition needs an assessment of the regional frame. Facies analysis and correlation with similar sandstone bodies cropping out outside the study area allow an interpretation of these units as nonchannelized base-of-slope deposits laterally confined by the local submarine topography (Ghibaudo et al., this volume). The paleocurrent data indicate a provenance from SW.

These sandstone bodies are referred to the middle Burdigalian. The Rio della Torre Lower Sandstones may be referred to the MNN2a zone; the Rio della Torre Upper Sandstones to the MNN2b zone (Ghibaudo et al., this volume).

5.7. Cortemilia Formation

This formation is the topmost stratigraphic term of the investigated succession. The study of this unit lies outside the purposes of this work. The unit consists of alternating turbiditic sandstones and mudstones in medium- to very thick strata, locally amalgamated. These are the first basinal deposits of the local Oligo-Miocene succession of the TPB. Packages of strata forming sedimentary bodies with grossly tabular geometry, from some metres to some tens of metres thick, are separated by variable thicknesses of medium- to thick-bedded alternating sandstones and mudstones. The deposits may be regarded as indicative of an outer-fan environment.

The Cortemilia Formation is dated by Gelati et al. (2010a, b) to the Burdigalian-basal Langhian. The Cortemilia Formation is here attributed to the late Burdigalian (Zones MNN3b p.p.-MNN4b) (Ghibaudo et al., in prep.).

6. STRUCTURAL SETTING OF THE ROCCAVERANO -MERANA AREA

The main structural elements of the investigated area are shown in figure 28 and plate I. The Oligo-Miocene stratigraphical succession shows on average NW-ward dips, consistent with the regional homoclinal setting of the Langhe region. The average dip angles of the strata range from 8° to 12°. The dominant structural elements of the area essentially consist of high-angle, subvertical faults. As outlined in paragraph 5.1., the most prominent structural element of the area is the Dego-Spigno Monferrato High, which is subdivided into minor horsts and grabens. This structure, active during the deposition of the Rocchetta Fm, continues SW of the study area and only its north-eastern termination, represented by the Spigno Monferrato Horst and part of the Piana Crixia Graben, is comprised in the study area. To the NE, the Dego-Spigno Monferrato High is bounded by an important subvertical fault oriented NW-SE, here defined Vico Fault, which separates the high from a northern depocentre (Turpino Depocentre). To the SW, outside the study area, the Dego-Spigno Monferrato High is bounded by a series of normal, high-angle faults which separate it from a southern depocentre (Rocchetta Cairo Depocentre) developed in the southern part of the Dego Sheet area (Ghibaudo et al., this volume). On the Dego-Spigno Monferrato High the deep-water mudstones of the Rocchetta Fm are about 450 m thick. In the northern and southern depocentres this formation is considerably thicker.

The Spigno Monferrato Horst extends for a maximum estimated distance of about 5 km in direction SW-NE. The Piana Crixia Graben is about 2.4 km wide. It is bounded by the Montaldo Fault to the N and a normal fault (Piana Crixia Fault) slightly S of the study area. The Piana Crixia unit (Rocchetta Fm), in particular, forming the stratigraphically lower turbiditic body cropping out in the study area, is confined within this structural low. The Montaldo and Vico faults appear as important structural elements which controlled sediment thickness and facies both synchronously with the deposition of the Molare Fm, during which they bounded the continental Borgo and Cartosio grabens (cf. paragraph 5.2.1.), and during the initial deposition of the Rocchetta Fm mudstones (Piana Crixia Graben and Turpino Depocentre). Only the northern part of the Borgo Graben and Piana Crixia Graben infills are represented in the enclosed geological map and relative cross-section.

The faults present in the study area may be subdivided into three systems:

a) synsedimentary faults; b) two-stage faults with an initial synsedimentary history and a later reactivation; c) late-stage faults displacing the whole Oligo-Miocene succession without a control on sedimentation in the study area. The syndepositional faults strongly controlled facies architecture, thicknesses, geometries and localization of specific sedimentary bodies on the scale of stratigraphic units and sub-units. They include the Vico, Montaldo, Pian dei Buri and C. Gergi faults. The second group comprises the C. del Rosso, Rocchetta and C. Bazzi faults. The main faults of the third group include the Castondonne and C. Crose faults. The numerous minor faults of the study area are connected with the main faults as secondary features.

These systems, together with small-scale, drag folds, genetically related to the faults, are the only structural features of the study area.

6.1. Synsedimentary Faults

6.1.1. Vico Fault

The Vico Fault is a normal, high-angle fault striking NW-SE, bounding to the N the Spigno Monferrato Horst (Pl. I) and occurring in the study area only with its north-westerly termination. The northern block is downthrown, so that the Molare Fm and the crystalline basement are in contact with the mudstones of the Rocchetta Fm, and the fault is sealed by the middle part of the Rocchetta mudstones. The north-western end of the fault can be observed along the national road in the northern surroundings of Spigno Monferrato, where the marine sandstones of the Molare Fm (footwall) show a well developed drag fold of decametric extent. The fault extends some kilometres to the E of the study area maintaining the same displacement (Ghibaudo et al., this volume and in prep.). The Vico Fault was active during the Rupelian. Its hangingwall acted as a depocentre during the deposition of the Molare continental conglomerates (Cartosio Graben) and the lower part of the Rocchetta Fm (Turpino Depocentre) (cf. Pl. III, scenarios **a**, **b**, **c**).

6.1.2. Montaldo Fault

The Montaldo Fault is a normal, high-angle fault striking ENE-WSW, bounding to the S the Spigno Monferrato Horst. Together with the C. del Rosso Fault, it belongs to a system of ENE-striking subvertical faults occurring in the south-eastern part of the study area near the village of Montaldo. The Montaldo Fault is part of the Merana - Monteacuto fault system recently highlighted

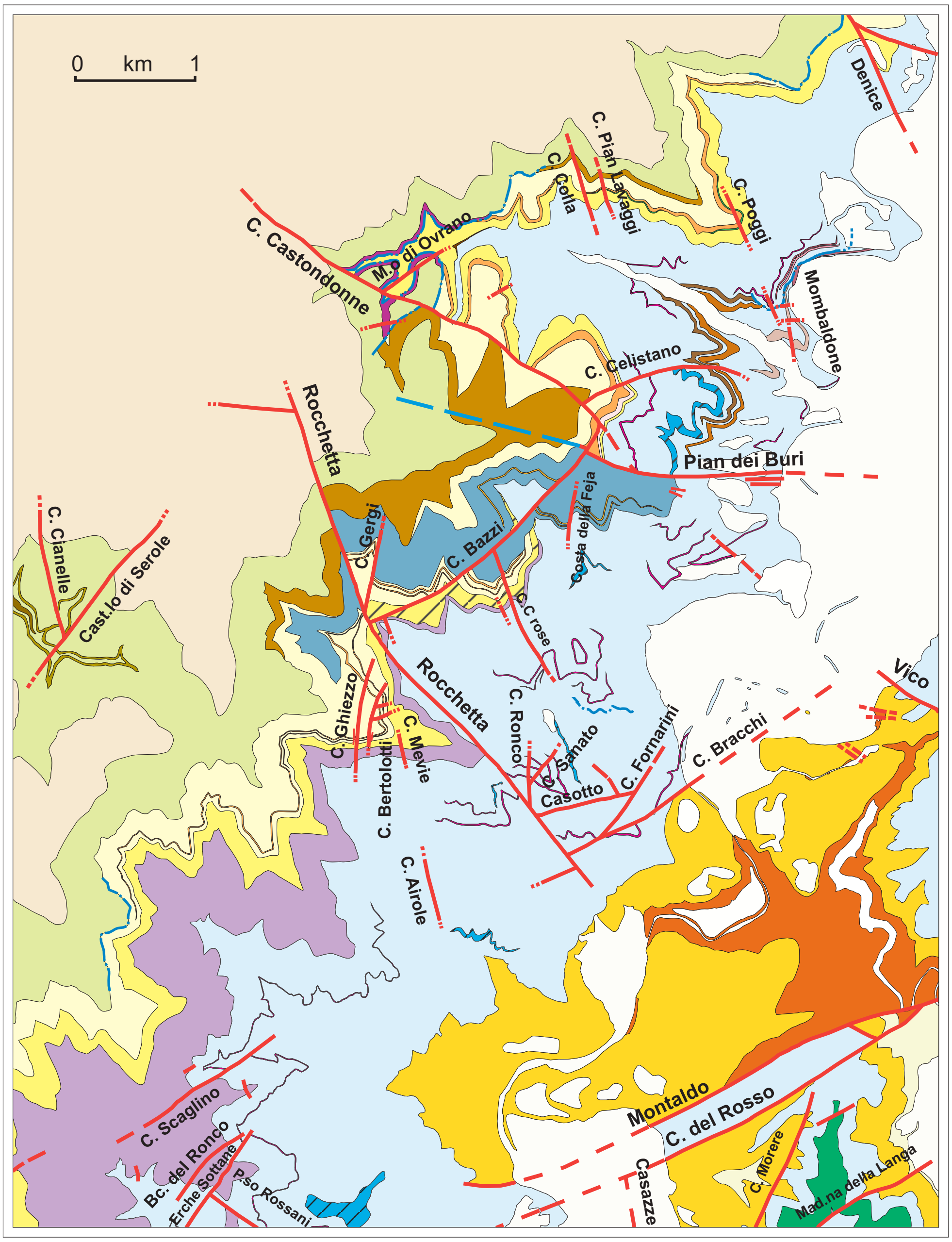

Fig. 28 - Structural map of the Roccaverano-Merana area.

by Rossi et al. (2009) and Mosca et al. (2010). During the Early Oligocene the Montaldo Fault, similarly to the Vico Fault, controlled the deposition of the Molare Fm and the lowermost part of the Rocchetta Fm. It brings in contact the crystalline basement and the Molare Fm with the mudstones of the Rocchetta Fm by downthrowing the southern sector. The fault extends several km NE-wards outside the study area, where it maintains a subvertical attitude and the same displacement as in the south-western sector (Ghibaudo et al. in prep.). In the study area the southern block is downthrown and the top of the Molare Fm is offset for 150-200 m (Fig. 29a). The fault is sealed by the lower-middle portion of the mudstones of the Rocchetta Fm. Similarly to the Vico Fault, the synsedimentary activity of the Montaldo Fault during the Rupelian took place in two successive steps: first during the deposition of the continental conglomerates of the Molare Fm, and, later, during the deposition of the lowermost part of the Rocchetta Fm. The Molare conglomerates, in fact, are confined within a graben (Borgo Graben, cf. paragraphs 5.2.1., 5.2.2) bounded to the N by the Montaldo Fault and to the S by a couple of mutually subparallel, NW-trending faults located slightly S of the mapped area (Case Tone faults) (Ghibaudo et al., this volume). The first stage of synsedimentary activity of the fault is sealed by the transgressive marine sandstones of the Molare Fm which are laid down both on the continental conglomerates infilling the Borgo Graben on the hangingwall of the fault, and directly on the crystalline basement forming the Spigno Monferrato

Fig. 29 - a) The Montaldo Fault viewed from point of altitude 331 m, looking towards Bric Calma (area located to the E of Montaldo). b) The Castondonne Fault viewed from C. Costa Mezzana looking towards Castondonne (NNW of Piantivello). Note the well developed drag fold.

Horst N of the fault (Pl. III, scenarios **a**, **b**). A resumption of activity caused a further downthrowing of the southern sector during the deposition of the lower part of the Rocchetta mudstones, concomitantly with the creation of a new structural low, here defined as the Piana Crixia Graben (Pl. III, scenario **c**). The latter is bounded to the N by the Montaldo Fault and to the S by a subparallel fault (Piana Crixia Fault) located slightly S of the study area (Ghibaudo et al., this volume). The most evident effect of this synsedimentary activity is the confinement of the Piana Crixia Unit in the above-mentioned submarine graben (Pl. I; Pl. III, scenario **c**).

6.1.3. Pian dei Buri Fault

The Pian dei Buri Fault is a subvertical fault about E-W-striking, located slightly to the SW of the village of Mombaldone. It displaces the Rocchetta Fm (upper Rupelian-lower Aquitanian), the Montechiaro d'Acqui Siliceous Lithozone (middle-upper Aquitanian) and the two horizons of resedimented calcarenites occurring in the C. Mevie area (C. Mevie Calcarenites) (lower Burdigalian). It bounds to the N the C. Mazzurini unit forming the infill of a submarine half-graben of early Burdigalian age (cf. Pl. I and paragraph 5.5.5) and, to the S, the Altitude 483 Sandstones and the Pian Bruno Calcarenites forming the infill of a small half-graben (cf. Pl. I and paragraph 5.5.2 and 5.5.3). The Pian dei Buri Fault is sealed by the marls of the Montechiaro d'Acqui Fm (lower Burdigalian). It acted therefore as synsedimentary fault during the early Burdigalian. This type of activity was already highlighted by Gelati and Gnaccolini (1998). These Authors stressed that the fault controlled the sedimentation of the C. Mazzurini unit by confining it within the homonymous half-graben. The field evidences indicate that the fault was characterized by a complex kinematic history and that the development of the C. Mazzurini Half-graben represents only the last step of this history, which started probably since the middle-late Aquitanian. This fault, in fact, apparently alternated periods of synsedimentary activity with phases of relative quiescence, and was characterized by inversion of the movement. In the initial stage the northern block was downthrown, first resulting in creation of local accommodation space for the Montechiaro Siliceous Lithozone (middle-upper Aquitanian), then in confinement of the Pian Bruno Calcarenites (lower Burdigalian) into a small half-graben developed N of the fault (Pl. III, scenarios **e**, **f**). After this first phase of activity, in the early Burdigalian, the Pian dei Buri Fault inverted the movement and downthrew the southern block causing the development of the C. Mazzurini Half-graben (Pl. III, scenario **g**). The fault was then sealed in the early Burdigalian by the deposition of the marls of the Montechiaro d'Acqui Fm.

6.1.4. C. Gergi Fault

The Case Gergi Fault is a subvertical fault striking approximately N-S, identified in the central part of the study area near Case Gergi. This fault displaces the base of the C. Mazzurini unit, whereas it does not offset its top. It caused a local increase in thickness of this unit on the hangingwall, and is interpreted as a pre- and/or syn-sedimentary lineament with respect to the deposition of the C. Mazzurini unit, active during the early Burdigalian.

6.2. Synsedimentary faults later reactivated in a post-depositional stage

6.2.1. C. del Rosso Fault

The C. del Rosso Fault, located slightly to the S of the Montaldo Fault, is a high-angle NE-trending fault, first active as possible synsedimentary lineament during the Early Oligocene, together with the Montaldo Fault, in the creation of the graben accommodating the Piana Crixia unit, then later reactivated in a post-depositional stage. In particular, it may be regarded as directly connected with an important subvertical fault of plurikilometric extent located to the SW of the study area on the prosecution of the C. del Rosso Fault (Sanvarezzo-Bric Roncaste Fault), for which a post-Aquitanian right-lateral motion can be demonstrated (Ghibaudo et al., this volume).

6.2.2. Rocchetta Fault

The Rocchetta fault is a high-angle, NW-SE-striking fault, located in the Rocchetta area, leading to downthrowing of the south-western block with respect to the north-eastern one. This fault displaces with an offset of a few tens of metres the Noceto unit near Case Cordasco. Conversely, the overlying C. Mazzurini and Piantivello units, as well as the Serole Fm and the Cortemilia Fm, show a remarkably larger offset. Moreover, the Montechiaro d'Acqui Siliceous Lithozone, located at the top of the Noceto unit, is thicker on the north-eastern uplifted block of the fault than on the downthrown south-western block. In the first stage (middle-late Aquitanian), the downthrow of the north-eastern block would have accommodated a greater thickness of the Montechiaro d'Acqui Siliceous Lithozone (LS1d; Pl. III, scenario **e**), here showing a marly composition probabaly due to higher subsidence rate. In the second stage (post-Serole Fm) the fault would have been reactivated with an inversion of movement.

6.2.3. C. Bazzi Fault

The Case Bazzi Fault is a subvertical fault striking NE-SW, at a high angle with respect to the Pian dei Buri synsedimentary fault. At the present time it is a reverse, high-angle fault dipping to NW, displacing the C. Mazzurini Unit and the underlying succession.

The fault upthrows the north-western sector bringing the mudstones of the Rocchetta Fm in contact with the C. Mazzurini unit. This unit shows reduced thickness on the upthrown block. This observation suggests, in agreement with the assumption by Gelati and Gnaccolini (1998), that the dislocation partly predated, or was coeval to, the deposition of the C. Mazzurini unit and was reactivated only later, in a post-depositional stage. Its synsedimentary activity would have been therefore of intra-Burdigalian age.

6.3. Late Faults

6.3.1. Castondonne Fault

The Castondonne Fault strikes NW-SE and cuts the entire Oligo-Miocene succession displacing the Pian dei Buri Fault (Fig. 29b). It is a high-angle normal fault dipping SW-wards, characterized by an offset moderate (20-30 m) in its central part, and progressively decreasing towards its ends.

6.4. The monocline of the Molino di Mombaldone lower sandstones

As pointed out in paragraph 5.3.4, the unit of Molino di Mombaldone Lower Sandstones is affected by a NW-trending monocline, which leads in the south-westerly portion of the body to an increase in bed dip angle of about 15° (Fig. 7). The overlying Ovrano units show a vertical stacking pattern above the monocline and are not affected by any deformation. The monocline is most probably related to the synsedimentary activity of a basement high-angle blind fault not exposed in the field (see Withjack et al., 1990; Hardy and McClay, 1999; Patton, 2003). The local accommodation space created above the monocline would have been sequentially compensated by the deposition of the stacked Ovrano units. The subsequent development of the Molino di Mombaldone slump scar is possibly related to seismic shocks triggered by a resumption of the synsedimentary tectonic activity. The inferred tectono-sedimentary evolution of the slope deposits cropping out in the Ovrano-Mombaldone area is shown in plate II.

7. TECTONO-SEDIMENTARY EVOLUTION OF THE STUDY AREA

The cross-section of Pl. I summarizes the geometries, structural setting and latero-vertical stratigraphic relationships of the lithostratigraphic units cropping out in the study area. On the scale of depositional systems the environmental attributions of the various units can be summarized as follows: a) The Molare Fm (Rupelian) may be referred to continental and marine shelf settings, b) the Rocchetta Fm (upper Rupelian - lower Aquitanian), the Montechiaro d'Acqui Siliceous Lithozone (middle-upper Aquitanian), the Montechiaro d'Acqui Fm (uppermost Aquitanian-lower Burdigalian) and the Serole Fm (middle Burdigalian) to slope and base-of-slope depositional settings, c) the Cortemilia Fm (upper Burdigalian) to a basinal, outer-fan setting.

The slope and base-of-slope sandstone and sandstone-conglomerate bodies occurring in the Rocchetta, Montechiaro d'Acqui and Serole formations were characterized by E-ESE-ward-directed paleoflows (in the present-day coordinates) during the late Rupelian-middle Burdigalian. These bodies are generally characterized by variable geometry and dimension, and consist of resedimented deposits encased in fine-grained sediments representing the background sedimentation of the Langhe Sub-basin. During the late Rupelian-early Aquitanian (Rocchetta Fm) the slope and base-of-slope fine-grained sedimentation was essentially hemipelagic with rare and thin turbidites laid down by dilute turbidity flows. During the middle-late Aquitanian (Montechiaro d'Acqui Siliceous Lithozone) the fine-grained sedimentation records a basin-scale condensed sedimentation characterized by sediments originally rich in biogenic silica, locally associated with thin-bedded turbidites and thin sandstone layers which possibly record a reworking by bottom currents. During the latest Aquitanian - early Burdigalian (Montechiaro d'Acqui Fm) the fine-grained sedimentation was essentially represented by hemipelagic marls. During the middle Burdigalian (Serole Fm), thin-bedded alternating sandstones and mudstones were laid down by dilute turbidity flows.

The sandstone and sandstone-conglomerate bodies encased at various levels within the fine-grained sediments may be referred to different depositional settings, based on their external geometry and lithology. The possible settings include: slope and base-of-slope channels and submarine valleys (Molino di Mombaldone lower unit, Case Poggi unit, Piantivello unit), submarine half-graben (Noceto unit, Pian Bruno unit, C. Mazzurini unit), topographically confined setting (Ovrano units, Rio della Torre units), and large-scale slump-scar infilling deposits such as Molino di Mombaldone middle and upper units, Bric Torrione unit. All these sedimentary bodies, were fed from western sectors. The source areas of the gravity flows transporting basinwards the coarse-grained sediments should be characterized by coeval shelf depositional systems (most probably fan-delta or braid-delta systems) located on the western or north-western proximal margin (in the present-day coordinates) of the TPB.

The tectono-sedimentary evolution of the study area during the Oligocene to Burdigalian time span is shown in plate III. The evolutionary steps are based on geometrical and structural data of the cross-section of plate I. The successive steps were obtained by means of a successive flattening procedure, using as datum planes various surfaces at the top of units in progressively higher stratigraphic position, which may be considered horizontal at the time of deposition.

The tectono-sedimentary evolution of the study area may be summarized as follows (Pl. III):

1 - Rupelian p.p. (Scenario a). Onset of an important extensional tectonics, generating a system of horsts and grabens in the crystalline basement and the deposition of continental conglomerates of the Molare Fm in the structural depressions. The local tectonic context is characterized by the synsedimentary activity of the Vico and Montaldo faults. Major structural features formed in the study area include, from S to N, the Borgo Graben, the Spigno Monferrato Horst and the Cartosio Graben, with continental conglomerates of the Molare Fm infilling the structural depressions. The local landscape is entirely continental.

2 - Rupelian p.p. (Scenario b). Deposition throughout the study area of the transgressive shelf sands of the Molare Fm. First the structural depressions developed N and S of the Spigno Monferrato Horst are flooded, with deposition of the Molare transgressive marine sands atop the continental conglomerates. Only later the adjacent Spigno Monferrato Horst is joined by the transgression, with deposition of the marine sands directly on the crystalline basement and development of a typical rocky shore transgression, highlighted by a very irregular transgressive surface and a thick coarse lag of blocks derived from the local substratum. At the end of the deposition of the Molare marine sandstones the activity of the Vico and Montaldo faults was probably attenuated or the faults were temporarily sealed and the local landscape was characterized by a wide area of shallow shelf.

3 - Late Rupelian-Early Aquitanian (Scenario c). Change into presumably transtensional tectonics, mostly along the same, formerly active basement faults, with formation of differentially subsiding blocks developed in a progressively deeper marine setting. This local tectonics is superimposed on a phase of enhanced regional tectonic subsidence leading to the collapse of the entire southern margin of the TPB, with the rapid drowning of the former shelf deposits and the onset of a generalized slope setting. As indicated by the gradual but rapid upward transition between the shelf deposits of the Molare Fm and the mudstones of the Rocchetta Fm, the drowning of the Molare platform probably resulted from a phase of rapid regional tectonic subsidence which brought sectors of the Oligocene shelf areas formerly extended over the present Ligurian Alps to bathyal depths. The synsedimentary faults active at this time in the study area were again the Vico and Montaldo faults. These bounded a submarine block (Spigno Monferrato Horst) less subsiding than the adjacent areas (Piana Crixia Graben and Turpino Depocentre), where thick successions of fine-grained slope deposits of the Rocchetta Fm piled up. The Piana Crixia Conglomerates, in particular, appear to be confined within the homonymous graben. Both faults were apparently deactivated and sealed by the mudstones of the Rocchetta Fm during the latest Rupelian-early Chattian.
During the Chattian the study area was characterized by the generalized deposition of the deep-water mudstones of the Rocchetta Fm in a slope to base-of-slope setting. In the late Chattian the Molino di Mombaldone lower unit and the Ovrano lower, middle and upper units were laid down in the north-eastern sector. This depositional stage was followed by a gravity destabilization leading to the formation of the Molino di Mombaldone Erosional Depression (transition Chattian-Aquitanian) which may be interpreted as a large-scale slump scar later evolving into a submarine canyon/slope valley system which locally removed the formerly deposited units. Subsequently, the depression was infilled with hemipelagites and the Molino di Mombaldone Middle and Upper Sandstones units. Eventually, the slope progradation continued, concomitantly with the deposition of minor sandstone bodies (key layers) and slumped masses (S6) indicative of persisting slope instability.

4 - Early Aquitanian (Scenario d). Development and infill of the Noceto structural depression. This unit is thought to represent the infill of a large-scale submarine half-graben bounded, SW of the study area, by an important normal listric growth fault.

5 - Middle-late Aquitanian (Scenario e). Deposition on basinal scale of the condensed hemipelagic and terrigenous sediments of the Montechiaro d'Acqui Siliceous Lithozone. Onset of synsedimentary activity of the Rocchetta and Pian dei Buri faults leading to the initial downthrowing of the northern blocks accommodating a thicker succession of the siliceous lithozone. Initial deposition of the marly sediments of the Montechiaro d'Acqui Fm.

6 - Early Burdigalian (Scenario f). Deposition of the basal resedimented calcarenites of the Montechiaro d'Acqui Fm (C. Poggi, Pian Bruno and C. Mevie calcarenites). Ongoing tectonic subsidence affecting the hangingwall of the Pian dei Buri Fault resulted in the formation of a small structural depression attracting sediment gravity flows, first siliciclastic (Altitude 483 Sandstones), then carbonate (Pian Bruno Calcarenites). The episodic SW-ward overspilling of carbonate turbidity flows from the Pian Bruno structural depression led to the deposition of two horizons of resedimented, unconfined calcarenites (C. Mevie units) SW of the Pian dei Buri Fault. Eventually, incision of a slope channel and its infill with the C. Poggi Calcarenites took place NE of the mentioned depression.

7 - Early Burdigalian (Scenario g). Inversion of movement along the Pian dei Buri Fault and accelerated subsidence affecting the downthrown southern block led to the formation of a large-scale submarine half-graben and deposition of the C. Mazzurini unit (Ghibaudo et al., 2001b).

8 - Early Burdigalian (Scenario h). Cessation of activity of the Pian dei Buri Fault. Uniform deposition throughout the study area of the hemipelagic marls of the Montechiaro d'Acqui Fm sealing the Pian dei Buri Fault. In the uppermost part of the marly succession two siliceous horizons some metres thick (not mapped) marked a new short period of basinwide condensed sedimentation.

9 - Middle Burdigalian (Scenarios i, j, k). Incision and infill of the Piantivello submarine valley (scenario **i**). Gravity destabilization of the upper part of the hemipelagic marly deposits of the Montechiaro d'Acqui Fm and development of slope failures corresponding to the Bric Torrione, C. Rocchino and Denice erosional depressions (Scenario **j**). Infilling of these depressions and deposition of the alternating turbiditic sandstones and mudstones of the Serole Fm (scenario **k**).

10 - Late Burdigalian (Scenario l). Deposition throughout the Langhe Basin of the basinal turbidites of the Cortemilia Fm.

NOTES

(1) Due to the vegetation cover, in the geological map and joined cross-section, the northern termination of the body of Ovrano Lower Sandstones was incorrectly traced up to the Mombaldone Erosional Depression. A field control achieved afterwards allowed to ascertain that, most probably, the sandstone body wedges out before reaching the erosional depression.

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REFERENCES

Amorosi A., Ricci Lucchi F., Tateo F., 1995. The Lower Miocene siliceous lithozone; a marker in the palaeogeographic evolution of the Northern Apennines. Palaeogeography, Palaeoclimatology, Palaeoecology 118, 131-149.

Amorosi A., Centineo M.C., d'Atri A., 1997. Lower Miocene glaucony-bearing deposits in the SE Tertiary Piedmont Basin (Northern Italy). Rivista Italiana di Paleontologia e Stratigrafia 103, 101-110.

Andreoni G., Galbiati B., Maccabruni A., Vercesi P.L., 1981. Stratigrafia e paleogeografia dei depositi oligocenici sup.-miocenici inf. nell'estremità orientale del Bacino Ligure Piemontese. Rivista Italiana di Paleontologia e Stratigrafia 87, 245-282.

Barbieri C., Carrapa B., Di Giulio A., Wijbrans J., Murrell G.R., 2003. Provenance of Oligocene synorogenic sediments of the Ligurian Alps (NW Italy): inferences on belt age and cooling history. International Journal of Earth Sciences (Geologische Rundschau) 92, 758-778.

Biella G.C., Polino R., de Franco R., Rossi P.M., Clari P., Corsi A., Gelati R., 1997. The crustal structure of the western Po plain: reconstruction from integrated geological and seismic data. Terra Nova 9, 28-31.

Bigi G., Cosentino D., Parotto M., Sartori R., Scandone P., 1990. Structural Model of Italy 1:500,000, Sheet 1, SELCA, Firenze.

Bishop P., Hughes M., 1989. Imbricated and fitted fabrics in coastal boulder deposits on the Australian east coast. Geology 17, 544-547.

Bourgeois J., McInnes B., 2010. Tsunami boulder transport and other dramatic effects of the 15 November 2006 central Kuril Islands tsunami on the Island of Matua. Zeitschrift für Geomorphologie 54, 175-195.

Capponi G., Crispini L., Federico L., Piazza M., Fabbri B., 2009. Late Alpine tectonics in the Ligurian Alps: constraints from the Tertiary Piedmont Basin conglomerates. Geological Journal 44, 211-224. doi: 10.1002/gj.1140

Caprara L., Garzanti E., Gnaccolini M., Mutti L., 1984. Shelf-basin transition: sedimentology and petrology of the

Serravallian of the Tertiary Piedmont Basin (northern Italy). Rivista Italiana di Paleontologia e Stratigrafia 90, 545-564.

Carrapa B., 2002. Tectonic evolution of an active orogen as reflected by its sedimentary record - An integrated study of the Tertairy Piedmont Basin (internal Western Alps, NW Italy). [Ph.D. Thesis] Vrjie Universiteit, Amsterdam, The Netherland, pp. 177.

Catanzariti R., Rio D., Martelli R., 1997. Late Eocene to Oligocene calcareous nannofossils biostratigraphy in northern Apennine: the Ranzano Sandstones. Memorie di Scienze Geologiche 49, 207-253, Padova.

Cavanna F., Di Giulio A., Galbiati B., Mosna S., Perotti C.R., Pieri M., 1989. Carta geologica dell'estremità orientale del Bacino Terziario Ligure-Piemontese. Atti Ticinensi di Scienze della Terra 32.

Cazzola C., Fonnesu F., Mutti E., Rampone G., Sonnino M., Vigna M., 1981. Geometry and facies of small, fault controlled deep-sea fan systems in a transgressive depositional setting (Tertiary Piedmont Basin, Northwestern Italy). In: Ricci Lucchi F. (Ed.), Excursion Guidebook, 2nd I.A.S. Regional Meeting, Bologna, pp. 5-56.

Cazzola C., Fornaciari M., 1990. Geometria e facies dei sistemi torbiditici di Budroni e Noceto (Bacino Terziario Piemontese). Atti Ticinesi di Scienze della Terra 33, 177-190.

Clari P., Ghibaudo G., 1979. Multiple slump scars in the Tortonian type area (Piedmont Basin, Northwestern Italy). Sedimentology 26, 719-730.

Coccioni R., Marsili A., Montanari A., Bellanca A., Neri R. Bice D.M., Brinkhuis H., Church N., Makaladi A., Mcdadiel A., Dino A., Lirer F., Sprovieri M., Maiorano P., Monechi S., Nini C., Nocchi M., Pross J., Rochette P., Sagnotti L., 2008. Integrated stratigraphy of the Oligocene pelagic sequence in the Umbria-Marche basin (northeastern Apennines, Italy): A potential Global Stratotype Section and Point (GSSP) for the Rupelian/Chattian boundary. Geological Society of America Bulletin 120, 487-511.

Crispini L., Federico L., Capponi G., Spagnolo C., 2009. Late orogenic transpressional tectonics in the "Ligurian Knot". Italian Journal of Geosciences 128, 433-441.

Dalla S., Rossi, M. Orlando M., Visentin C., Gelati R., Gnaccolini M., Papani G., Belli A., Biffi U., Catrullo D., 1992. Late Eocene tectono-sedimentary evolution in the western part of the Padan basin (northern Italy). Paleontologia I Evoluciò 24-25, 341-362.

d'Atri A., 1990. Analisi sedimentologica, biostratigrafia e sequenziale della successione del Miocene inferiore tra le valli Lemme e Bormida di Spigno (margine sudorientale del Bacino Terziario Ligure-Piemontese). Unpubl. Ph.D. Thesis. Univ. Torino, pp. 143.

Dela Pierre F., Mikhailov V., Polino R., 1995. The tectono-sedimentary evolution of the Tertiary basins in the western Po plain: kinematics inferred from subsidence curves. Accademia Nazionale delle Scienze, Atti del Convegno sui rapporti Alpi-Appennino, Peveragno 1994, pp. 129-146.

Di Stefano A., Foresi L.M., Lirer F., Iaccarino S.M., Turco E., Amore F.O., Mazzei R., Morabito S., Salvatorini G., Abdul Aziz H., 2008. Calcareous plankton high resolution bio-magnetostratigraphy for the Langhian of the Mediterranean area. Rivista Italiana di Paleontologia e Stratigrafia 114, 51-76.

Fava L., 2001. Stratigrafia fisica ed analisi di facies di sistemi fluvio-deltizi oligo-miocenici nel settore occidentale del Bacino Terziario Piemontese. Ph. D. Thesis (Dottorato in sedimentologia), XIII Ciclo, Dipartimento di Scienze della Terra, Univ. Parma, pp. 145.

Fichaut B., Suanez S., 2011. Quarrying, transport and deposition of cliff top storm deposits during extreme events: Banneg Island, Brittany. Marine Geology 283, 36-55.

Forcella F., Gelati R., Gnaccolini M., Rossi P.M., Bersezio R., 1999. Il Bacino Terziario Ligure-Piemontese tra il Monregalese e la valle del Lemme: stato delle ricerche e prospettive future. In: Orombelli G., (a cura di), Studi Geografici in onore di Severino Belloni. Brigati, Genova, 339-365.

Follmi K.B., Grimm K.A., 1990. Doomed pioners: gravity-flow deposition and bioturbation in marine oxigen-deficient environments. Geology 18, 1069-1072.

Fornaciari E., Rio D., 1996. Latest Oligocene to early Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. Micropaleontology 42, 1-37.

Francani V., Gelati R., Martinis B., Orombelli G., Pasquarè G., Rossi P.M., Sfondrini G., 1971. Foglio 81 Ceva. Note illustrative della carta Geologica d'Italia. Nuova Tecnica Grafica, Roma, pp. 100.

Galbiati B., 1976. La successione oligo-miocenica tra Rigoroso e Carrosio (Bacino ligure-piemontese). Atti Istituto Geologico dell'Università di Pavia 26, 30-48.

Gelati R., 1968. Stratigrafia dell'Oligo-Miocene delle Langhe tra le valli dei fiumi Tanaro e Bormida di Spigno. Rivista Italiana di Paleontologia e Stratigrafia 74, 865-897.

Gelati R., Falletti P., 1996. The Piedmont Tertiary Basin. Giornale di Geologia 58, 11-18.

Gelati R., Gnaccolini M., 1998. Synsedimentary tectonics and sedimentation in the Tertiary Piedmont Basin, Northwestern Italy. Rivista Italiana di Paleontologia e Stratigrafia 104, 193-214.

Gelati R., Gnaccolini M., 2002. Evoluzione tettonico-sedimentaria del Bacino delle Langhe. 81a Riunione estiva Società Geologica Italiana, Torino, 10-12 settembre. Libro Guida Escursione pre-Riunione, 172-178.

Gelati R., Gnaccolini M., 2003. Genesis and evolution of the Langhe Basin, with emphasis on the latest Oligocene-earliest Miocene and Serravallian. Atti Ticinesi di Scienze della Terra 44, 3-18.

Gelati R., Gnaccolini M., Falletti P., Catrullo D., 1993. Stratigrafia sequenziale della successione oligo-miocenica delle Langhe, Bacino terziario ligure-piemontese. Rivista Italiana di Paleontologia e Stratigrafia 98, 425-452.

Gelati R., Gnaccolini M., Polino R., Mosca P., Piana F., Fioraso G. con contributi di Balestro G., Morelli M., Tallone S., Ramasco M., Fontan D., Sorzana P., Campus S., Ossella L., 2010a. Note illustrative della Carta Geologica d'Italia alla scala 1:50000, Foglio 211 Dego. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale.

Gelati R., Gnaccolini M., Granata P., Masi M., Piana F., Polino R., Brovero M., Drago D., Fioraso G., Mosca P., Morelli M., Sorzana P., Fontan D., 2010b. Carta Geologica d'Italia alla scala 1:50000, Foglio 211 Dego. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale.

Ghibaudo G., 1984. Storm controlled sand waves and sand bodies on a Serravallian inner shelf (Serravalle Formation, Tertiary Piedmont Basin, northern Italy). 5th European Regional Meeting of Sedimentology, Marseille, France, Extended abstract.

Ghibaudo G., Clari P., Perello M., 1985. Litostratigrafia, sedimentologia ed evoluzione tettonico-sedimentaria dei depositi miocenici del margine sud-orientale del Bacino terziario ligure-piemontese (Valli Borbera, Scrivia e Lemme). Bollettino della Società Geologica Italiana 104, 349-397.

Ghibaudo G., 1992. Subaqueous sediment gravity flow deposits: practical criteria for their field description and classification. Sedimentology 39, 423-454.

Ghibaudo G., Chiambretti I., Massari F., 2001a. Prodelta slope deposits of the Rocchetta Formation in the Mombaldone area (Tertiary Piedmont Basin, northern Italy): An example of structural control on channel stacking pattern and slump scar/slope valley development: IAS Regional Meeting, Davos, Switzerland, Poster abstracts, p. 200.

Ghibaudo G., Chiambretti I., Massari F., 2001b. Facies and internal architecture in a slope half graben infill. The Case Mazzurini Unit of the Montechiaro d'Acqui Marl (Burdigalian - Tertiary Piedmont Basin, northern Italy): IAS Regional Meeting, Davos, Switzerland, Poster abstracts, p. 201.

Ghibaudo G., Massari F., Chiambretti I., this volume. Oligo-Miocene tectono-sedimentary evolution of the Langhe Sub-basin: From continental to basinal setting (Tertiary Piedmont Basin - North-Western Italy).

Gnaccolini M., 1989. Il Langhiano-Serravalliano tra le valli del Tanaro e del Belbo. Confronti con i dintorni di Gavi e di Finale Ligure. Rivista Italiana di Paleontologia e Stratigrafia 95, 55-74.

Gnaccolini. M., Gelati R., Catrullo D., Falletti P., 1990. Sequenze deposizionali nella successione oligo-miocenica delle "Langhe": un approccio alla stratigrafia sequenziale del Bacino Terziario Ligure-Piemontese. Memorie della Società Geologica Italiana 45, 671-686.

Gnaccolini M., Gelati R., 1996. Anatomy of an episutural basin: the Tertiary Piedmont Basin, Northern Italy. 30th International Geological Congress, Beijing 1966, Abstracts, 3, p. 14.

Goto K., Kawana T., Imamura F., 2010. Historical and geological evidence of boulders deposited by tsunamis, southern RyuKyu islands, Japan. Earth-Sciences Reviews: 102, 77-99.

Gradstein F.M., Ogg J.G., Smith A.G. (Eds.), 2004. A Geologic Time Scale. Cambridge University Press, pp. 589.

Haccard D., Lorenz C., Grandjacquet C., 1972. Essai sur l'évolution tectogénétique de la liaison Alpes-Apennins (de la Ligurie à la Calabre). Memorie della Società Geologica Italiana 11, 309-341.

Harbitz C.B., Parker G., Helverhoi A., Marr J.G., Mohrig D., Harff P.A., 2003 Hydroplaning of subaqueous debris flows and glide blocks: Analytical solutions and discussion. Journal of Geophysical Research 108, B7, 2349. doi: 10.1029/2001JB001494, 2003.

Hardy S., McClay K., 1999. Kinematic modelling of extensional fault-propagation folding. Journal of Structural Geology 21, 695-702.

Ineson J.R., 1985. Submarine glide blocks from the Lower Cretaceous of the Antarctic Peninsula. Sedimentology 32, 659-670.

Johnson M.E., 1988. Hunting for ancient rocky shores. Journal of Geological Education 36, 147-154.

Johnstone P.D., Mustard P.S., MacEachern J.A., 2006. The basal unconformity of the Nanaimo Group, southwestern British Columbia: a Late Cretaceous storm-swept rocky shoreline. Canadian Journal of Earth Sciences 43, 1165-1181.

Ledesma-Vazquez J., Hernandez-Walls R., Villatoro-Lacouture M., Guardado-France R., 2006. Dynamics of rocky shores: Cretaceous, Pliocene, Pleistocene, and Recent, Baja California peninsula, Mexico. Canadian Journal of Earth Sciences 43, 1229-1245.

Lorenz C., 1969. Contribution à l'étude stratigraphique de l'Oligocène inférieur des confines Liguro-Piémontais (Italie). Atti dell'Istituto di Geologia dell'Università di Genova 6, 253-888.

Maffione M., Speranza F., Faccenna C., Cascella A., Vignaroli G., Sagnotti L., 2008. A synchronous Alpine and Corsica-Sardinia rotation. Journal of Geophysical Research 113, B03104, doi: 10.1029/2007JB005214.

Martin-Chivelet J., Fregenal-Martinez M.A., Chaco B., 2008. Traction structures in contourites. Development in Sedimentology 60, 159-182.

McKenna J., 2005. Boulder beaches. In Schwartz M.L. (Ed.), Encyclopedia of Coastal Sciences. Springer, Doordrecht, The Netherlands, 206-208.

McLeod A.E., Underhill J.R., 1999. Processes and products of footwall degradation, northern Brent Field, Northern North Sea. In: Fleet A.J., Boldy S.A. (Eds.), Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference (Geological Society London Publication), 91-106.

Mosca P., 2006. Neogene basin evolution in the western Po Plain (NW Italy). Insights from seismic interpretation, subsidence analysis and low temperature (U-Th)/He thermochronology. Ph. D. Thesis, Vrije Universiteit, Amsterdam, The Netherlands, Research School Geology (NSG) Publ. 20060202, pp. 190.

Mosca P., Polino R., Rogledi S., Rossi M., 2010. New data for the kinematic interpretation of the Alps-Apennines junction (Northwestern Italy). International Journal of Earth Sciences (Geologische Rundschau) 99, 833-849.

Mutti E., 1992. Turbidite sandstones. AGIP - Istituto di Geologia, Università di Parma, pp. 275. San Donato Milanese.

Mutti E., Papani L., di Biase D., Davoli G., Mora S., Segadelli S., Tinterri R., 1995. Il Bacino Terziario Epimesoalpino e le sue implicazioni sui rapporti tra Alpi ed Appennino. Memorie di Scienze Geologiche 47, 217-244, Padova.

Mutti E., Tinterri R., Remacha E., Mavilla N., Angella S., Fava L., 1999. An introduction to the analysis of ancient turbidite basins from an outcrop perspective. American Association of Petroleum Geologists Continuing Education Course Note Series # 39, p. 61.

Mutti E., di Biase D., Fava L., Mavilla N., Sgavetti M., Tinterri R., 2002. The Tertiary Piedmont Basin. In: Mutti, E., Ricci Lucchi F., M. Roveri (Eds.), Revisiting turbidites of the Marnoso-Arenacea Formation and the basin margin counterpart problems with classic models. Excursion Notes – Part II, pp. 25.

Oak L.H., 1984. The boulder beach a fundamentally distinct sedimentary assemblage. Annals of the Association of American Geographers 74, 71-82.

Patton T.L., 2003. Numerical models of growth-sediment development above an active monocline. Basin Research 16, 25-39.

Piana F., 2000. Structural setting of western Monferrato (Alps-Apennines Junction zone, NW Italy). Tectonics 19, 943-960.

Piana F., Polino R., 1995. Tertiary structural relationships between Alps and Apennines: the critical Torino Hill and Monferrato area, Northwestern Italy. Terra Nova 7, 138-143.

Raffi I., Backman J., Fornaciari E., Palike H., Rio D., Lourens L., Hilgen F., 2006. A review of calcareous nannofossil astrobiochronology enconpassing the past 25 million years. Quaternary Science Reviews 25, 3113-3137.

Rossi M., Mosca P., Polino R., Rogledi S., Biffi U., 2009. New outcrop and subsurface data in the Tertiary Piedmont Basin (NW Italy): unconformity-bounded stratigraphic units and their relationships with basin-modification phases. Rivista Italiana di Paleontologia e Stratigrafia 115, 305-335.

Roure F., Polino R., Nicolich R., 1990. Early Neogene deformation beneath the Po plain: constraints on the post-collisional Alpine evolution. Mémoires de la Société Géologique de France 156, 309-322.

Sanders J.E., 1965. Primary sedimentary structures formed by turbidity currents and related sedimentation mechanisms. In Middleton, G.V. (Ed.), Primary sedimentary structures and their hydrodynamic interpretation. S.E.P.M. (Society of Economic Geologists and Mineralogists) Special Publication 12, 192-219.

Schumacher M.E., Laubscher H.P., 1996. 3D architecture of the Alps-Apennines join - a new view on seismic data. Tectonophysics 260, 349-363.

Sears S.O., 1984. Porcelaneous cement and microporosity in California Miocene turbidites - Origin and effect on reservoir properties. Journal of Sedimentary Petrology 54, 159-169.

Shanmugham G., Spalding T.D., Rofheart D.H., 1993. Process sedimentology and reservoir quality of deep-marine, bottom-current reworked sands (sandy contourites): an example from the Gulf of Mexico. American Association of Petroleum Geologists Bulletin 77, 1241-1259.

Spagnolo C., Crispini L., Capponi G., 2007. Late structural evolution in an accretionary wedge: insights from the Voltri Massif (Ligurian Alps, Italy). Geodinamica Acta 20, 21-35.

Withjack M.O., Olson J., Peterson E., 1990. Experimental models of extensional forced folds. American Association of Petroleum Geologists Bulletin 74, 1038-1054.