



Oligo-Miocene tectono-sedimentary evolution of the Langhe Sub-basin: from continental to basinal setting (Tertiary Piedmont Basin - Northwestern Italy)

Guido Ghibaudo^{1,*}, Francesco Massari², Igor Chiambretti³

¹ Dipartimento di Scienze della Terra, Università di Torino, Via Valperga Caluso 35, 10125 Torino, Italy

² Dipartimento di Geoscienze, Via Gradenigo 6, 35131 Padova, Italy

³ AINEVA - Associazione Interregionale Neve e Valanghe, Vicolo dell'Adige 18, 38122 Trento, Italy

ABSTRACT - The geologic and paleogeographic evolution of the Langhe Sub-basin (Tertiary Piedmont Basin) during the Oligo-Miocene was intensely controlled by synsedimentary tectonics. In Rupelian time, the Langhe Sub-basin was dominated by an extensional tectonic regime along high-angle, basement-involving faults generating differentially subsiding, fault-bounded blocks. In Rupelian times, a horst and graben paleotopography developed. From SW to NE, the major paleogeographic elements were: the Rocchetta Cairo Horst, the Borgo Graben, the Spigno Monferrato Horst and the Cartosio Graben. The grabens accommodated thick successions of continental conglomerates of the Molare Fm. A following transgression first reached the Cartosio and Borgo grabens, and only later the adjacent horsts where the marine sands of the Molare Fm rest directly on the crystalline basement. A phase of enhanced regional tectonic subsidence leading to the collapse of the entire southern margin of the Tertiary Piedmont Basin is testified by the onset of deposition of slope to base-of-slope hemipelagic mudstones (Rocchetta Fm) since late Rupelian-early Chattian. This phase of generalized subsidence was accompanied by a change into transtension, mostly along the previous faults. The most prominent intra-Oligocene structural element of the Langhe Sub-basin was the Dego-Spigno Monferrato High, a positive structure of the basement subdivided into secondary horsts and grabens, which strongly controlled thickness and facies of the Rocchetta deposits. Two depocentres, the Turpino and Rocchetta Cairo depocentres, where the Rocchetta Fm reaches thicknesses of about 1000 m, developed to the N and respectively S of the Dego-Spigno Monferrato High. The Rocchetta Fm shows common slump scars, the largest of which, about 1 km wide and up to 150 m deep, in the Molino di Mombaldone area, evolved into a submarine canyon/slope valley system. The largest turbidite bodies occurring in the Rocchetta Fm (Mogliavacca, Brovida, Cobarello and Noceto sandstone bodies) are concentrated in the southern Rocchetta Cairo Depocentre. These bodies are vertically stacked and show a trend of upward increasing width/thickness ratio reflecting a change from upper slope to base-of-slope setting. The largest and youngest is the Noceto unit (lower Aquitanian), infilling a pluri-kilometric half-graben bounded by the normal listric Rio Girona growth fault. The Rocchetta Fm is capped by hemipelagic and mainly siliceous sediments, named "Montechiaro d'Acqui Siliceous Lithozone" (LS1) (middle-upper Aquitanian) representing a regional marker horizon and interpreted as condensed deposits. This unit forms a single package in the north-eastern area and is subdivided to the SW into minor units (LS1a, LS1b, LS1c) separated by turbiditic formations. In the southern sector a system of NE-trending tectonic lines, the Uzzone Valley Fault System, was active from the middle Aquitanian to the early Burdigalian. The activation of these faults marked a change in tectonic regime, paleogeography and regional stress field of the study area. They are interpreted as growth faults repeatedly activated, showing either extensional/transensional or transpressional regimes. They generated intrabasinal highs and small-scale slope or base-of-slope basins controlling location and orientation of the turbidite sandstone bodies and their paleocurrent pattern. Specifically, in the middle Aquitanian, the Poggiolo Basin developed and was sealed by deposition of the siliceous LS1b unit. In the middle-late Aquitanian, the Scaletta Uzzone Basin developed and was sealed by deposition of the siliceous LS1c unit. During the latest Aquitanian-early Burdigalian the deposition of the hemipelagic marls of the Montechiaro d'Acqui Fm took place in a slope to base-of-slope environment. In the lowermost part of this formation resedimented glauconitic sandstones and rhodalgal calcarenites (C. Mevie, Pian Bruno and C. Poggi calcarenites), derived from coeval foramol-type carbonate platforms, were deposited. High tectonic mobility in this stage is indicated

*Corresponding author: guido.ghibaudo@unito.it

by the generation of the C. Mazzurini Half-graben, which was infilled with coarse-grained bioclastic sandstones and conglomerates. In the meantime, the Rio Giosa fault was re-activated in compression, leading to the partial inversion of the Noceto Half-graben; moreover, in the southern area strike-slip reactivation of the Uzzone Valley Fault System generated the Rio della Chiesa Basin where the Castelletto Uzzone Sottano and the Rio della Chiesa lower and upper units were deposited. A new cycle started in middle Burdigalian time, with emplacement of coarse siliciclastics (Piantivello unit) into a large base-of-slope valley followed by the widespread deposition of the thin-bedded turbidites and associated sandstone bodies of the Serole Fm. These deposits locally infilled medium- to large-scale slump scars, cut in the underlying Montechiaro d'Acqui Fm. The Serole Fm tapers gradually to the NE and is capped, with onlap relationships, by the thick basal turbidites of the Cortemilia Fm (upper Burdigalian). The tectonic evolution in the study area is characterized by a progressive change from extensional to strike-slip-dominated regime during the time span from the Early Oligocene to the Early Miocene. This changing tectonic regime is thought to reflect the transition from the early Rupelian crustal stretching which occurred in the late stage of the extensional, post-orogenic exhumation of the deep, metamorphic units of the Mesoalpine prism, to the activation, since late Rupelian, of a regional megashear zone between the left-stepping sinistral Villavernia-Varzi Line to the NE and the Stura Fault System to the SW. The wrench faulting is thought to reflect the translation of the Adriatic indenter, with progressive change of motion from NNW-wards to WNW-wards. In the studied area this megashear zone first worked in a transtensional regime from the late Rupelian to the early Aquitanian, and then in alternating transpressional/transensional regime in the middle Aquitanian-early Burdigalian. During the late Rupelian-early Burdigalian time span, the whole Tertiary Piedmont Basin probably behaved as a strike-slip basin. The upper Rupelian to middle Burdigalian large-scale sandy and conglomeratic turbidite bodies of the Rocchetta, Montechiaro d'Acqui and Serole formations were fed from NW or WNW indicating regional SE or ESE-dipping paleoslopes (in present day coordinates). All these sandstone bodies are characterized by "proximal" coarse-grained turbidite deposits. More distal coeval turbidite systems should have existed downcurrent, but are at present eroded in the uplifted domain of Ligurian Alps. The distal reaches of the Langhe Sub-basin in Chattian to early Burdigalian times are therefore unknown. In any case, it may be suggested that, at least for the largest sandstone bodies of the Rocchetta Fm, the turbidite system most probably extended onto, and possibly beyond, the present-day uplifted Ligurian Alps.

Key words: Tertiary Piedmont Basin, Oligo-Miocene, Langhe Sub-basin, continental to basinal deposits, extensional to strike-slip tectonics, tectono-sedimentary evolution, northern Italy

Submitted: 25 January 2014 - Accepted: 19 May 2014

CONTENTS

Abstract	53	4.3.3.6. Slump Sheets	69
1. GEOLOGIC SETTING	56	4.3.4. The sandstone units in the central area	69
2. INTRODUCTION	58	4.3.4.1. Piana Crixia Conglomerates	69
3. BIOSTRATIGRAPHY	59	4.3.4.2. Rodini Lower, Middle and Upper Sandstones	69
4. LITHOSTRATIGRAPHY	59	4.3.4.3. Mogliavacca Sandstones	72
4.1. Undifferentiated Crystalline Basement	59	4.3.4.4. Brovida Sandstones	73
4.2. Molare Formation	62	4.3.4.5. Bric Petacchi Sandstones	73
4.2.1. The continental conglomerates	62	4.3.4.6. Cobarello Sandstones	73
4.2.2. The marine sandstones	62	4.3.4.7. Pian del Lago Sandstones and Bric della Lasagna Sandstones	73
4.3. Rocchetta Formation	64	4.3.4.8. Noceto Sandstones	73
4.3.1. Mudstones of the Rocchetta Formation	66	4.3.5. The sandstone units in the southern area	74
4.3.2. Minor sandstone bodies, key beds	66	4.3.5.1. Sassore Sandstones	74
4.3.3. The sandstone units in the northern area	67	4.3.5.2. Vignazza Sandstones	74
4.3.3.1. Molino di Mombaldone Lower Sandstones	67	4.3.5.3. Vignaroli Sandstones	74
4.3.3.2. Ovrano Lower Sandstones	67	4.3.5.4. Altitude 524 Sandstones	74
4.3.3.3. Ovrano Middle and Upper Sandstones	67	4.3.5.5. C. Del Bric Sandstones	74
4.3.3.4. Molino di Mombaldone Erosional Depression	67	4.3.5.6. Codevilla Sandstones	74
4.3.3.5. Molino di Mombaldone Middle and Upper Sandstones	67	4.3.5.7. C. Giroso Sandstones	74
		4.3.5.8. Sorgente Alpei Sandstones	75
		4.3.5.9. Fontanelle Sandstones	75

4.3.5.10. Cian dei Grill Sandstones	75	5.4.1. North-eastern area	106
4.3.5.11. Gabutti Sandstones	76	5.4.2. South-western area	106
4.4. Montechiaro d'Acqui Siliceous Lithozone	76	5.4.2.1. Castelletto Uzzone Sottano Sandstones	109
4.5. Poggiolo Formation	77	5.4.2.2. Rio della Chiesa Glaucony	109
4.5.1. Rio Porcavio Sandstones	78	5.4.2.3. Rio della Chiesa Lower Sandstones	109
4.5.2. C. Carloni Sandstones	78	5.4.2.4. C. Ciappellano Sandstones	109
4.6. Scaletta Uzzone Formation	78	5.4.2.5. Rio della Chiesa Upper Sandstones	109
4.7. Montechiaro d'Acqui Formation	78	5.4.3. Rio della Chiesa Basin	109
4.7.1. Altitude 483 Sandstones	80	5.5. Serole Formation	118
4.7.2. Pian Bruno Calcarenites	80	5.5.1. Piantivello Sandstones	118
4.7.3. C. Poggi Calcarenites	80	5.5.2. Bric Torriente Sandstones	118
4.7.4. C. Mevie Calcarenites	80	5.5.3. Rio della Torre Lower Sandstones	118
4.7.5. C. Mazzurini Sandstones	81	5.5.4. Rio della Torre Upper Sandstones	118
4.7.6. Rio della Chiesa Glaucony	81	5.5.5. Gottasecca Sandstones	118
4.7.7. Castelletto Uzzone Sottano Sandstones	81	5.5.6. Vignazze Sandstones	119
4.7.8. Rio della Chiesa Lower Sandstones	81	5.5.7. Paleoenvironmental interpretation of the Serole Formation	120
4.7.9. C. Ciappellano Sandstones	81	5.5.8. The erosional depressions at the base of the Serole Formation	122
4.7.10. Rio della Chiesa Upper Sandstones	81	5.5.9. Bric Torriente Erosional Depression	122
4.8. Serole Formation	83	5.5.10. The C. Rocchino, Denice and Uzzone Valley erosional depressions	122
4.8.1. Piantivello Sandstones	84	5.5.11. The genesis of the erosional depressions	122
4.8.2. Denice Erosional Depression	84	6. STRUCTURAL SETTING	123
4.8.3. Bric Torriente Erosional Depression	84	6.1. The early Oligocene extensional to transtensional faults	123
4.8.4. C. Rocchino Erosional Depression	84	6.1.1. The Case Tone, Montaldo and Vico Faults and the Borgo and Cartosio continental grabens	123
4.8.5. Uzzone Valley Erosional Depression	84	6.1.2. The Dego, La Costa, Piana Crixia, C. Del Rosso, Montaldo, and Vico Faults and the Dego- Spigno Monferrato High	125
4.8.6. Bric Torriente Sandstones	84	6.2. The early Aquitanian Rio Girona synsedimentary listric fault	125
4.8.7. Vignazze Sandstones	84	6.3. The early Burdigalian Pian dei Buri synsedimentary fault and related faults	126
4.8.8. Rio della Torre Lower Sandstones	84	6.3.1. Pian dei Buri Fault	126
4.8.9. Rio della Torre Upper Sandstones	84	6.3.2. C. Bazzi Fault	126
4.8.10. C. Zabocci Sandstones	85	6.3.3. C. Gergi Fault	126
4.8.11. Gottasecca Sandstones	85	6.3.4. Rocchetta Fault	126
4.9. Cortemilia Formation	85	6.4. The middle Aquitanian and early Burdigalian transcurrent faults	127
4.10. Bubbio Siliceous Lithozone	85	7. TECTONO-STRATIGRAPHIC EVOLUTION OF THE STUDY AREA	129
4.11. Cassinasco Formation	85	7.1. The evolutionary cross-section A-A'	131
5. DEPOSITIONAL SETTING	86	7.2. The evolutionary cross-section B-B'	133
5.1. Rocchetta Formation	86	8. GEOLOGIC EVOLUTION OF THE STUDY AREA IN A REGIONAL FRAMEWORK	134
5.1.1. Sandstone bodies with lenticular geometry and small to intermediate dimensions	87	9. BIRTH AND INITIAL DEVELOPMENT OF THE TERTIARY PIEDMONT BASIN.....	136
5.1.2. Sandstone bodies with broadly lenticular geometry..	88	10. CONCLUSIONS	138
5.1.3. Sandstone bodies with lenticular geometry and large dimensions	88	Notes	139
5.1.3.1. Mogliavacca Sandstones	88	Acknowledgements	140
5.1.3.2. Brovida Sandstones	90	References	140
5.1.3.3. Rodini Upper Sandstones	94		
5.1.3.4. Cobarello Sandstones	94		
5.1.3.5. Noceto Sandstones	95		
5.1.3.6. Gabutti Sandstones	98		
5.1.4. Sandstone bodies with tabular geometry	98		
5.2. Poggiolo Formation	99		
5.2.1. Rio Porcavio Sandstones	101		
5.2.2. C. Carloni Sandstones	101		
5.2.3. The Poggiolo Basin	101		
5.3. Scaletta Uzzone Formation	104		
5.3.1. The Scaletta Uzzone Basin	104		
5.4. Montechiaro d'Acqui Formation	106		

1. GEOLOGIC SETTING

The Tertiary Piedmont Basin (TPB hereafter) (Fig. 1) developed after the Meso-Alpine Eocene collisional event (Mutti et al., 1995; Rossi et al., 2009) on both deep crustal levels belonging to the Alpine structural domain and shallow levels represented by Apenninic nappes of the "Liguride Complex" (Roure et al., 1990; Dela Pierre et al., 1995; Biella et al., 1997; Piana, 2000; Carrapa, 2002; Mutti et al., 2002). The sedimentary succession of the TPB is predominately terrigenous and forms a large homocline

gently dipping northwards to north-westwards, reaching a maximum thickness of about 6000 m. Several tectonic-driven unconformity-bounded sequences can be recognized in the TPB stratigraphic succession, and have been identified by Gelati et al. (1993), Rossi et al. (2009) and Mosca et al. (2010) on the basis of field survey, stratigraphic correlation and seismic profiles. Since the Late Eocene, after the main collisional phase, the TPB started to form as episutural basin (Gelati and Gnaccolini, 1988), comprising a number of sub-basins and structural highs.

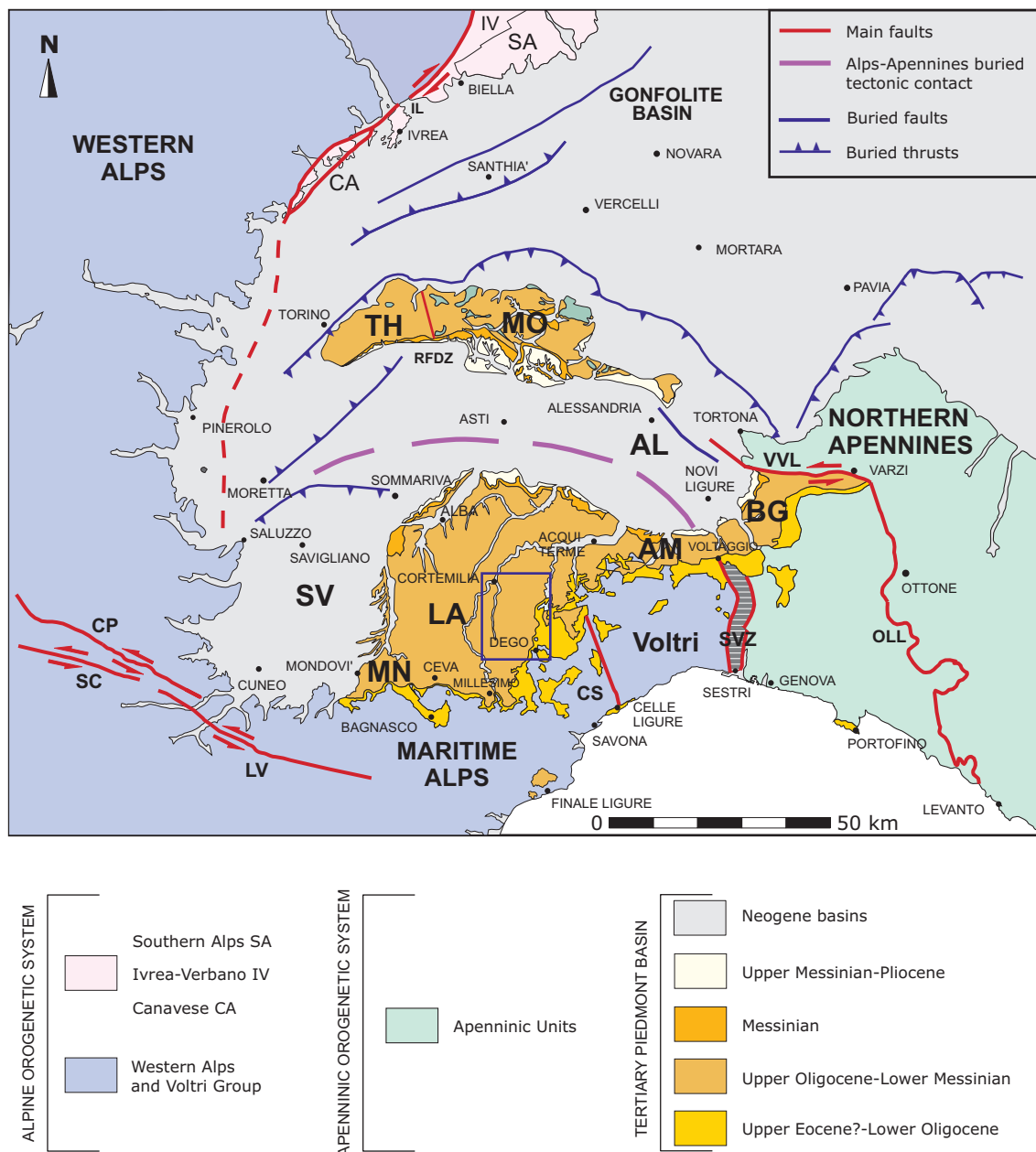


Fig. 1 - The Tertiary Piedmont Basin and the western Po plain. Simplified structural scheme (modified from Bigi et al., 1990; Rossi et al., 2009; Mosca et al., 2010). TH: Torino Hill; MO: Monferrato; MN: Monregalese; LA: Langhe; AM: Alto Monferrato; BG: Borbera-Grue; SV: Savigliano Basin; AL: Alessandria 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.

The Langhe Sub-basin is an important paleogeographic element of the TPB, extending over an area of about 1800 km² and infilled with an Oligo-Miocene sedimentary succession more than 4000 m thick (Mosca, 2006).

The geologic evolution of the Langhe area started in the Early Oligocene, with the deposition of a continental to shallow-marine transgressive succession (Molare Fm) linked to a short-lived event of lithospheric stretching, lasting no more than 4 Ma, from ca. 34 Ma (latest Priabonian) to ca. 32-30 Ma (early-middle Rupelian). This event was accompanied by a rapid post-orogenic syn-detachment exhumation of HP units of the Meso-Alpine prism in the footwall of a regional-scale extensional shear (Vignaroli, 2006; Vignaroli et al., 2008, 2010; Bernardeschi, 2009; Beltrando et al., 2010; Maino et al., 2012, 2013). The exhumation of the deep, metamorphic units of the Mesoalpine prism and the concomitant event of lithosphere stretching are the regional expression of a major change occurred in the Mediterranean region, from a compressional subduction coeval with the formation of Alpine mountain belts, to rollback subduction and backarc rifting (Jolivet et al., 2008). Handy et al. (2010) proposed that this major change was triggered by the switch in subduction polarity from a SE-dipping, "Alpine" configuration to a NW-dipping, "Apenninic" configuration at about 35 Ma, in turn requiring a vertical slab tear (see also Vignaroli, 2006), possibly nucleated along inherited lithospheric structures, such as Mesozoic transform systems. The strong surface uplift and erosional unroofing of the Voltri Massif, reflected by the coarse-textured continental facies covering the metamorphic substratum in several sectors of the TPB (the Molare Fm), are thought to have been driven by regional top-to-the-W extensional detachment tectonics coupled with buoyancy-driven exhumation processes (Vignaroli, 2006).

The Molare Fm consists of alluvial-fan and fan-delta deposits, sourced from an emerged land existing to the south of the TPB (Lorenz, 1969; Haccard et al., 1972), followed by shelf sandstones. A clastic contribution from the Voltri Massif is supported by compositional data (Gnaccolini, 1974) and is compatible with the hypothesis of the exhumation of this area as a result of an extensional episode occurred through low-angle detachment systems, and synchronous with the early stages of the TPB sedimentation (Vignaroli et al., 2006, 2009).

The depositional and probably also the former source areas were then rapidly drowned as a result of rapid subsidence leading to the deposition of hemipelagic mudstones (the upper Rupelian-lower Aquitanian 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 in the Molare-Rocchetta stage was characterized by a marked compartmentalization into a number of km-scale, differentially subsiding troughs, whose infills show highly variable thicknesses and paleocurrent patterns (Gelati et al., 1993; Mutti et al., 1995; Dela Pierre et al., 1995; Mutti et al., 2002; Rossi et al., 2009).

The Oligocene deposits of the TPB were accommodated in two complex depressions, the Molare-Rocchetta and the Savignano-Ranzano troughs, respectively located SW and NE of a major structural divide, representing the precursor of the Alto Monferrato High (Rossi et al., 2009; Mosca et al., 2010). According to Gnaccolini and Gelati (1996) and Gelati and Gnaccolini (1998, 2003) the Langhe Sub-basin was fully delineated during the Late Oligocene as a WNW-ESE-striking subsiding trough bounded to the SW by the Monregalese High and its continuation towards ESE into the Finalese High, and to the NE by the Alto Monferrato High. As pointed out by these Authors, the Upper Oligocene succession, up to about 1000 m thick in the Langhe Sub-basin, may be correlated with 150 m of hemipelagic mudstones in the Alto Monferrato High, and with ca. 200 m of shelf deposits in the Monregalese High. Rossi et al. (2009) suggested high denudation rates of the West-Alpine axial sector from latest Oligocene onwards, implying eastward shedding (in present-day coordinates) of huge volumes of coarse-textured sediments via fan-delta systems prograding from the Saluzzese-Monregalese belt.

In the Langhe Sub-basin the Rocchetta Fm is commonly overlain by siliceous sediments representing a marker horizon on regional scale. It was already recorded by Schüttenhelm (1976) as *blocky siliceous marl*, and later by d'Atri (1990) as *siliceous member of the Rocchetta Formation*, by Gelati and Gnaccolini (1998) as *C. Mevie-Molino di Ovrano unit*, and by Fava (2001) and Mutti et al. (2002), as *siliceous lithozone*.

Important sinistral motion along the Villavernia-Varzi line occurred in the Chattian-Burdigalian times, as stressed by Laubscher (1991) and Schumacher and Laubscher (1996). This major event was regarded by the authors as linked to the NW-ward translation of the Adriatic Indenter (AI) between 25 and 16 Ma (their Insubric-Helvetic phase of Alpine orogeny), in the frame of the oblique SE-NW convergence of Adria and Europa. Schumacher and Laubscher (1996) stressed that, together with the dextral motion along the Insubric Line, a concurrent, complementary sinistral motion took place along the southern margin of the indenter, i.e. along the Villavernia-Varzi line (VVL). This motion emplaced the Apennine units of Monferrato by carrying them westwards on top of the AI (Schumacher and Laubscher, 1996). Another important line regarded by Giglia et al. (1996) and Dumont et al. (2012) to be involved in the westward translation of the AI is a sinistral WNW-trending shear zone from which the recent "Stura couloir" *Auct.*, a major structural element identified by Ricou (1981) and Lefèvre (1983), could derive. The motion of the indenter occurred in concomitance with collapse and oceanization in the Provençal-Ligurian basin and counterclockwise rotation of the Sardinia-Liguria complex (Speranza et al., 2002; Maffione et al., 2008) into the roll-back gap of the eastward migrating Adriatic subduction zone beneath the proto-Apennines. Oblique convergence and associated counterclockwise rotation of Adria were partitioned between transpression along the

above mentioned fault system and thrusting in western Alps, as well as E- to SE-verging backthrusting on the internal side of the concomitantly enhancing West-Alpine arc (Schumacher and Laubscher, 1996; Mosca, 2006; Mosca et al., 2010; Malusà et al., 2009).

This phase of tectonic mobility accompanied by high rates of coarse sediment input ended in late early Burdigalian, when marly hemipelagic sedimentation occurred throughout the TPB (Dalla et al., 1992; Clari et al., 1995; Forcella et al., 1999). During the late Burdigalian, deposition of a thick and extensive, highly efficient basinal-type turbidite system (the Cortemilia Fm) took place in the Langhe Sub-basin, that became the main depocentre in the TPB, characterized by a drastic increase in subsidence rate (Dela Pierre et al., 1995; Rossi et al., 2009; Molli et al., 2010; Mosca et al., 2010). This large turbidite system and the following ones show considerably more regular paleocurrent pattern with respect to the underlying turbidites (Gelati et al., 1993). The drastic basin enlargement and abrupt deepening are thought to reflect the onset of downwarping of the basin in a piggy-back position, due to progressive involvement of the TPB area in the deformation of the Padan thrust fronts (Laubscher et al., 1992; Dalla et al., 1992; Castellarin, 1994; Piana and Polino, 1995; Dela Pierre et al., 1995; Schumacher and Laubscher, 1996; Piana and Dela Pierre, 2000; Mosca et al., 2010). The change in basin physiography starting from the late Burdigalian coincides with the beginning of development of the Apenninic foredeep in the western Padan domain, as recognized by Roure et al. (1989).

A marked differentiation between the Alto Monferrato High and the Langhe Sub-basin, accompanied by paleogeographic reorganization, took place during the Langhian. Increase in subsidence in the western sector was accompanied by pronounced uplift of the areas located east of the river Orba Valley (the Borbera-Grue sector), which underwent a true basin inversion, testified by an erosional unconformity of eastward increasing importance, cutting tilted upper Burdigalian basin-plain turbidites (Ghibaudo et al., 1985; Gelati and Falletti, 1996; Mutti et al., 2002). This sector became since then a site of shelf deposition, represented by the Cessole Marls forming a wedge which prograded SW-wards, and was then overlapped in the Langhe Sub-basin by thick turbidites of the lower part of the Cassinascio Fm (Mutti et al., 2002).

Depocentres in the TPB progressively shifted northwards since the late Burdigalian, following the northward propagation of the north-verging thrust fronts, reaching in the Serravallian the Savigliano and Alessandria basins (Mosca, 2006). The northward migration of depocentres and concomitant progressive uplift of the southernmost sectors of the TPB has been attributed to the generation of crustal folds with a width in the order of 30-60 km (Carrapa, 2002; Bertotti and Mosca, 2009).

During the Serravallian the Langhe Sub-basin accommodated the upper part of the Cassinascio turbidite system, bounded at the base by a tongue of mudstones

(the Murazzano Fm) (Gelati, 1968). In this time the Alto Monferrato area persisted as a submarine high, where a shelf sand-wave complex of hybrid arenites interfingering with resedimented fan-delta deposits were laid down (Serravalle Sandstones) (Ghibaudo, 1984; Caprara et al., 1984).

During the Tortonian tectonic instability triggered huge mass flows (e.g. the Orsara Bormida megabed, Caprara et al., 1984) and the failure of giant slide blocks (olistoliths) of Serravalle Sandstones in the Rocca Grimalda area (Bellino et al., in press a, b). Concomitantly, the Alto Monferrato area underwent a sudden drowning of the Serravalle Sandstones shelf, which led to the deposition of hemipelagic slope marls with plenty of slump scars (Clari and Ghibaudo, 1979). Moreover, small basins, regarded as half-graben-type troughs, hosting lenticular bodies of sandy conglomerates, formed in this area (Ghibaudo et al., 1985).

The intra-Messinian chaotic complex is thought to record the onset of polyphasic north-verging thrusting (Piana, 2000) which continued in the Pliocene (Piana and Dela Pierre, 2000). Since the Messinian and Early Pliocene the infill of the Langhe basin is tectonically transported northwards in a passive way, without suffering significant shortening and deformation (Piana and Polino, 1995).

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

2. INTRODUCTION

Aim of this work is to illustrate the geology of a large part of the Langhe Sub-basin which represents a key area for the comprehension of the geological evolution of the TPB. The work is based on a detailed field survey at the scale 1:10000, the measurement of several thousands of metres of detailed stratigraphic-sedimentological sections accompanied by facies analysis, and the examination of a large number of samples and smear slides for the reconstruction of the biostratigraphy on the basis of calcareous nannoplankton assemblages. The proposed stratigraphy and structural setting is largely new with respect to those previously known and their definition provided a sound basis for the disentangling of the synsedimentary tectonics.

The lithostratigraphy and the structural setting of the studied area are shown in the enclosed geological map and in the cross-section of plate I. The lithostratigraphy recently introduced by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) for the new Geological Sheet 211 Dego of the "Carta Geologica d'Italia" 1:50000 has not been followed, as the stratigraphy and structural setting resulting from our survey show substantial differences and cannot be reconciled to the ones adopted in the Sheet Dego. The stratigraphic units to which the rank of formation has been attributed correspond in some cases to the formations adopted for the Sheet 81 Ceva to scale 1:100000 of the "Carta Geologica d'Italia" (Francani et al., 1971), in other cases to informal units of new proposal.

For lower-rank lithostratigraphic units (members), we share, where possible, the corresponding denominations formerly proposed in the same area by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b). Particular specification is deserved for the siliceous unit here defined “Montechiaro d’Acqui Siliceous Lithozone”. This unit occurs as a single package of strata in the north-eastern part of the mapped area and is subdivided into minor units separated by specific terrigenous turbiditic formations in the south-western areas. This siliceous unit, represented by condensed deposits of basinal extent, has been indicated with the informal term of “lithozone” (*see also note 1).

The lithostratigraphy of the area comprises, from the base upwards, the following units:

Crystalline basement (undifferentiated)
 Molare Formation
 Rocchetta Formation
 Montechiaro d’Acqui Siliceous Lithozone
 Poggiolo Formation
 Scaletta Uzzone Formation
 Montechiaro d’Acqui Formation
 Serole Formation
 Cortemilia Formation
 Bubbio Siliceous Lithozone
 Cassinasco Formation

3. BIOSTRATIGRAPHY

The biostratigraphic zonation adopted in this paper 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 composite reference section sampled from the base of the Rocchetta Fm to the base of the Cortemilia Fm along the transect Stazione di Spigno - Rocchetta - Case Mevie - Brallo and on the Cianazzo section located a few kilometres NE of the mapped area on the right side of the Bormida di Spigno Valley (cf. Ghibaudo et al., this volume). Other sections measured in the Uzzone Valley area (Rio della Torre, Rio della Chiesa and Rio dei Germani sections) yielded additional data concerning specific stratigraphic intervals (Fig. 2).

In the section Stazione di Spigno - Rocchetta - Case Mevie - Brallo (Fig. 3), the Rocchetta Fm is attributed to the biozones MNP23 *p.p.*, MNP24, MNP25a, MNP25b, MNN1a, MNN1b, MNN1c, MNN1d *p.p.* (upper Rupelian-lower Aquitanian). Only the lowermost and uppermost parts of the Rocchetta mudstones have been sampled in this section. Some bioevents related to the middle portion of the pelitic succession of the Rocchetta Fm, therefore, could not be recognized. The Montechiaro d’Acqui Siliceous Lithozone is attributed 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 Cianazzo section, where the Montechiaro d’Acqui Siliceous Lithozone crops out with continuity, has been used as reference section for the dating of this unit. The biostratigraphic data yielded by this section support the above chronological frame for the Montechiaro d’Acqui Siliceous Lithozone, the Montechiaro d’Acqui Fm and the Serole Fm (cf. Ghibaudo et al., this volume). The dating of the sandstone bodies of the Rocchetta Fm cropping out in the northern part of the study area (Ovrano Valley and Mombaldone area) was obtained in the Ovrano section extending from the village of Mombaldone up to the base of the Montechiaro d’Acqui Siliceous Lithozone. Following Ghibaudo et al. (this volume) the Rocchetta Fm cropping out in the Ovrano Valley and Mombaldone area is attributed to the late Chattian-early Aquitanian. Biostratigraphic data from the sections measured in the Uzzone Valley area allows to date the Poggiolo Fm to the Aquitanian..

No biostratigraphic data for the Rocchetta Fm sandstone bodies cropping out in the southern part of the mapped area are at present available. Therefore, the ages of the Rocchetta Fm turbidite in such area are extrapolated assuming that the deep erosion at the base of the Mogliavacca unit (cf. Pl. I) is related to the important lowstand at the Rupelian-Chattian transition, corresponding to the Sequence Boundary Ru4/Ch1 (28.50 Ma according to Hardenbol et al., 1998 and Wornardt, 1999; 28.45 Ma according to Ogg et al., 2008) and to the isotopic event Oci-1 of Abreu and Haddad (1998). Due to the lack of precise biostratigraphic data, the ages attributed to the mentioned systems are to be considered provisional. A more exhaustive analysis of the basin fill in terms of sequence stratigraphy and tectono-stratigraphic evolution clearly needs a more complete revision of the biostratigraphy, not only for the Rocchetta Fm, but also for the overlying units which are commonly diachronous, being characterized by onlap relationships on regional scale (Ghibaudo et al., in prep.).

4. LITHOSTRATIGRAPHY

4.1. Undifferentiated Crystalline Basement

In the study area the crystalline basement is represented in a fault-bounded structural high here defined “Dego-Spigno Monferrato High” (see enclosed geologic map and Pl. I). Basement rocks are represented by metamorphic units belonging to the Piemontese Zone and, particularly, to the Voltri Group *Auct.*, respectively known as *Prasiniti di Campo Ligure* in the Sheet 81 Ceva to scale 1:100000 of the “Carta Geologica d’Italia” (Francani et al., 1971), and *Metabasiti di Rossiglione, Calcescisti del Turchino* and *Serpentinoscisti del Bric del Dente* in the Sheet 211 Dego to scale 1:50000 of the “Carta Geologica d’Italia” (Gelati et

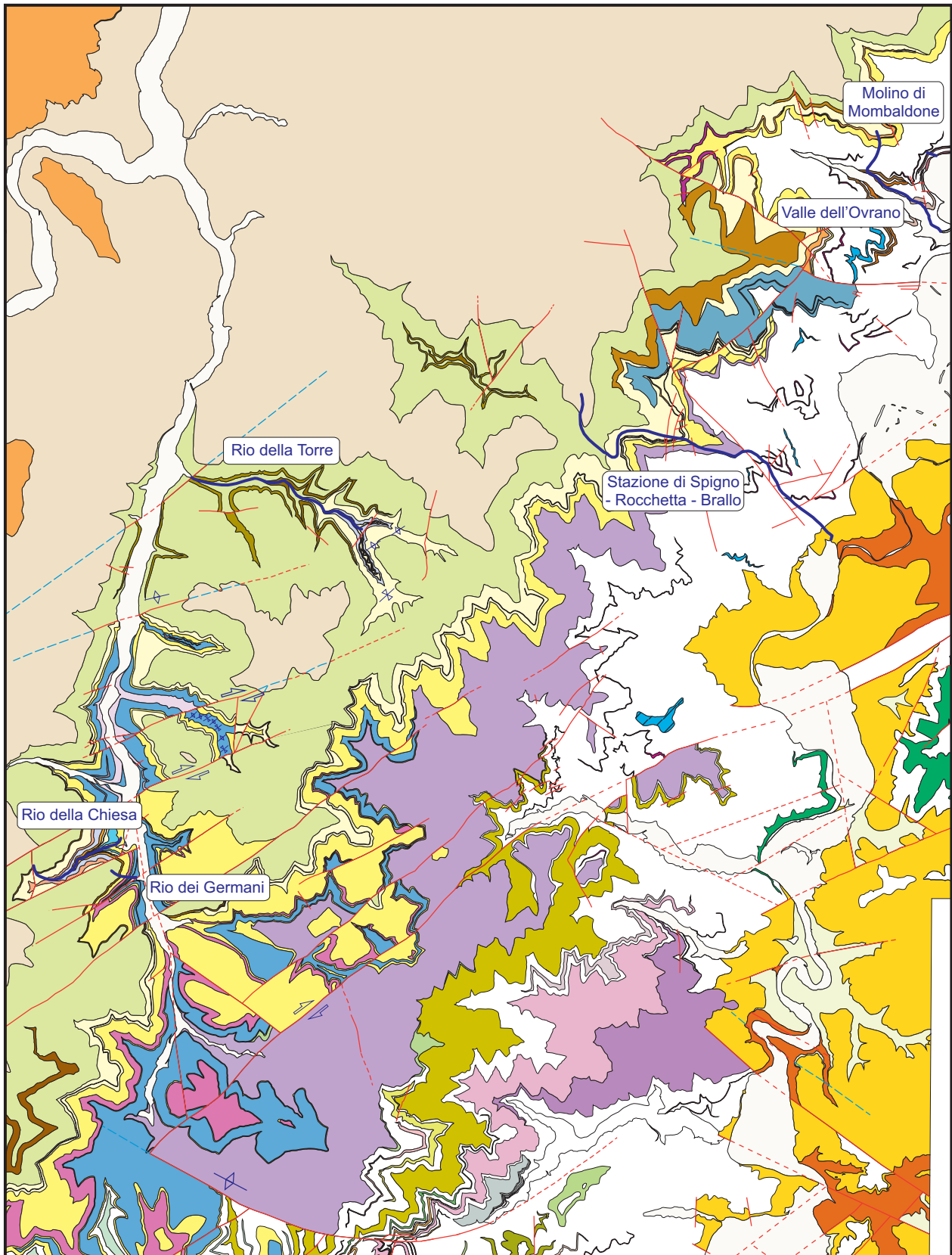


Fig. 2 - Location of the stratigraphic sections sampled for the biostratigraphy. The colours of the various stratigraphic units correspond to those adopted in the geological map.

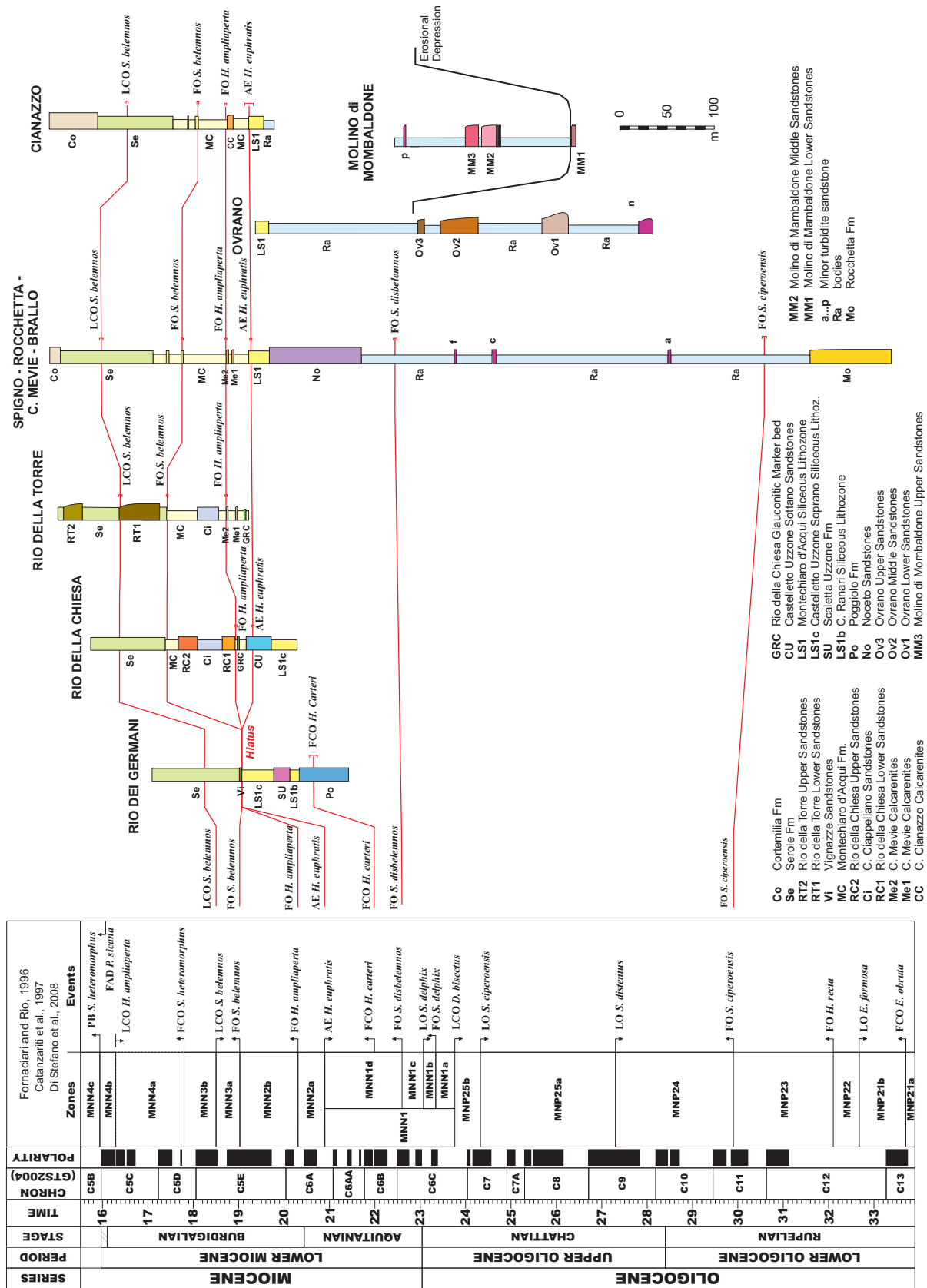


Fig. 3 - Calcareous nannoplankton biostratigraphy of the stratigraphic succession cropping out in the study area, with correlations across the sampled sections.

al., 2010a, b). In 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 and in the area surrounding the villages of Deگو and Rocchetta Cairo, where it consists of metabasites, prasinities, serpentinites and calcschists. The basement is crossed by normal, sub-vertical faults mostly oriented NW-SE and SW-NE (Vico, Montaldo, Piana Crixia, La Costa and Deگو faults, cf. Fig. 49, geological map and Pl. I). These faults bound a complex intrabasinal high, active during the deposition of the Rocchetta Fm, subdivided into minor horsts and grabens (cf. Pl. I). In particular, the above faults bound a northern horst, here defined "Spigno Monferrato Horst" and a southern horst, named "Deگو Horst", separated by an intermediate graben, here defined "Piana Crixia Graben". The basement faults predating the sedimentary cover were not reported in the enclosed geological map.

4.2. Molare Formation

The Molare Fm crops out in the eastern sector of the study area. It 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. The formation consists of continental conglomerates grading upwards into marine fossiliferous sandstones.

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 late Rupelian age of the lower part of the Rocchetta Fm. Based on the dinoflagellate biostratigraphy, Rossi et al. (2009) refer the Molare Fm to the Rupelian. We share therefore the inference of the above Authors extending the Rupelian age to the Molare Fm of the study area.

4.2.1. The continental conglomerates

Detailed mapping of the Oligocene deposits on the scale of the entire southern margin of the TPB demonstrates that the continental deposits of the Molare Fm occur as infill of complex grabens originally bounded by high-angle normal faults cutting the basement and subsequently displaced locally by transcurrent faults in pre-Burdigalian times (Ghibaudo et al., in prep.).

In the study area the basal continental conglomerates of the Molare Fm crop out only as part of the infill of a Lower Oligocene graben, here defined "Borgo Graben" (cf. Pl. IIIa). The Borgo Graben was bounded to the north by the NE-SW Montaldo Fault and the Spigno Monferrato Horst and to the south by the NW-SE Case Tone fault and an uplifted basement block extending also outside the study area, here defined "Rocchetta Cairo Horst" (cf. Pl. IIIa, panel A1). North and south of the mentioned faults the transgressive marine sandstones of the Molare Fm rest

directly onto the crystalline basement. To the NE of the Spigno Monferrato Horst (outside the study area) another Lower Oligocene graben accommodated thick continental conglomerates. 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" (cf. Pl. IIIa) (Ghibaudo et al., this volume; Ghibaudo et al, in prep.). The overall thickness of the continental conglomerates cropping out in the study area is around 50-60 metres. The stratigraphic-structural relationships highlight that the Case Tone, Montaldo and Vico faults began their activity in the Early Oligocene, probably as growth faults (Ghibaudo et al., this volume).

Best exposures of the continental conglomerates in the study area are those surrounding the village of Borgo and those facing the dammed lake of Case Tone in the Bormida di Spigno Valley. The conglomerates are coarse to very coarse, with sub-rounded to sub-angular clasts, including pebbles, cobbles, and boulders up to few metres in length; they are polymict, with a grey-brown to reddish sandy to sandy-conglomeratic matrix (Fig. 4b), and display a poorly distinct stratification. The beds lack internal organization or are characterized by a crude vertical grading. The sandstone interbeds are rare and decimetric. In the area surrounding the village of Borgo the continental conglomerates are about 50-60 m thick and wedge out rapidly southwards, in proximity to basement paleofaults sealed by marine sandstones (e. g. Case Tone faults), where the deposits become true breccias. The continental conglomerates 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. The breccias lining the faults bounding the structural lows probably represent scree deposits.

4.2.2. The marine sandstones

The marine sandstones of the Molare Fm crop out on both the continental conglomerates of the Borgo Graben and the basement highs originally bounding the graben to the N and S. It may be inferred that the Oligocene transgression which followed the deposition of the continental conglomerates encroached first upon the Borgo and Cartosio grabens depositing marine sands, and only later upon the higher adjoining areas (Rocchetta Cairo Horst and Spigno Monferrato Horst), with marine sands directly laid down on the crystalline basement. The figure 4a shows a schematic N-S cross-section passing through the village of Borgo, which highlights the above geometric and stratigraphic relationships existing during the deposition of marine sandstones.

The marine sandstones are medium- to coarse-grained, locally microconglomeratic, and fossiliferous (bivalves, gastropods, echinoderms, corals, bryozoans, larger foraminifers). The uppermost part of the formation, at the transition with the mudstones of the Rocchetta Fm,

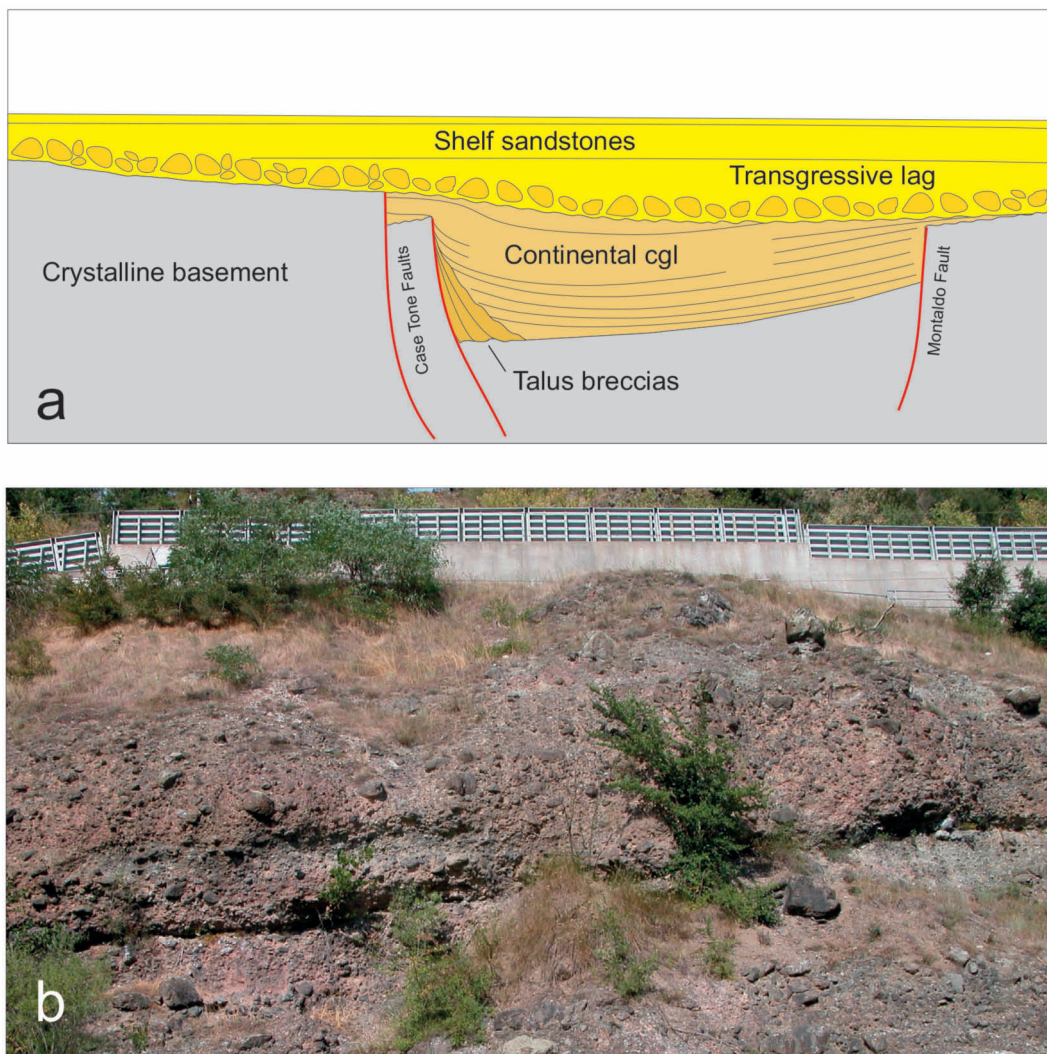


Fig. 4 - The Borgo Graben. a) Schematic representation of the Borgo Graben stratigraphical succession and structural setting. b) Thick-bedded, reddish, disorganized conglomerates interpreted as subaerial debris flow deposits cropping out on the right bank of the Bormida di Spigno River, North of the Borgo locality.

consists of heavily bioturbated fine-grained sandstones and coarse siltstones. The thickness of the marine sandstones is variable as a result of onlap on the basal nonconformity and according to the paleostructural setting. In the Spigno Monferrato fault block, for example, W of Rio Valla (Merana, Bric Monzuccaro and Spigno Monferrato areas) the marine sandstones are about 60-70 m thick. East of this valley they thin out to 30 m. Similar thickness differences in E-W direction may be recognized on the La Costa fault block bounded by La Costa and Dego faults (cf. Fig. 49 and geological map). Significant thickness changes attest to the intense intra-Molare tectonic mobility during the Early Oligocene.

Typically, the basal contact of the marine sandstones on both crystalline basement and continental conglomerates is marked by a horizon of variable thickness (up to several metres), locally discontinuous, of heterometric pebble- to boulder-conglomerates. These deposits represent a coarse transgressive lag, already recognized by Lorenz (1969). The clasts in this basal deposit are locally over 2 m in

diameter, and sub-rounded to moderately rounded. Where the transgressive marine sandstones lie directly on the basement, the basal conglomerates are monomict, with clasts reflecting the lithology of the local substratum. They are up to several m thick and represent, locally, boulder beach deposits. Where the marine sandstones transgressively overlie the continental conglomerates, the basal conglomerates usually consist of a single horizon of boulders aligned on the ravinement surface. A detailed description and paleo-environmental interpretation of this lag in the area surrounding Spigno Monferrato is provided by Ghibaudo et al. (this volume).

Textural and sedimentologic features of the marine sandstones are variable from place to place. In the area surrounding Spigno Monferrato Ghibaudo et al. (this volume) describe different paleoenvironmental settings depending on whether the marine sandstones are directly transgressive on the crystalline basement (e.g. on Spigno Monferrato Horst), or on continental conglomerates (as in the adjoining Borgo Graben). On the Spigno

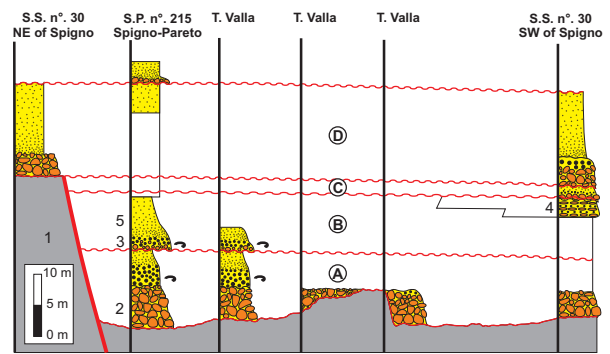
Monferrato Horst a local small-scale structural low of the basement accommodates, in the lower part of the marine sandstones, a number of small-scale, truncated T-R cycles with transgressive basal lags grading upwards into bioturbated shoreface deposits (Fig. 5a). In the northern part of the adjacent Borgo Graben (Montaldo cemetery section) a large-scale T-R cycle is recorded, with basal, transgressive, bioturbated or laminated shoreface deposits grading upwards into regressive fossiliferous sandstones and conglomerates inferred to represent a proximal fan-delta front environment (Fig. 5b).

In the central-southern sector of the Borgo Graben (north of the locality La Costa) the marine deposits are mainly represented by medium-coarse to microruditic fossiliferous sandstones, in medium and thick beds, predominantly amalgamated, characterized by small- to medium-scale erosional contacts. The beds are graded (Fig. 6a), or graded-to-laminated, with planar-parallel laminae, or low-angle oblique laminae in the upper part (Fig. 6b); metric-scale hummocky cross-stratification (Fig. 6c, 6d) or, rarely, high-angle cross-stratification (Fig. 6e) are locally present. Bioturbation pervasive or confined to the top of a laminated lower part is common (*hummocky and/or parallel laminated to burrowed shelf facies* of Bourgeois, 1980, 1984). Thoroughly bioturbated thin sandy layers, thought to represent omission events, are sometimes present (Fig. 6f). Even the Borgo Graben deposits are attributed to a fan-delta front environment (more distal with respect to the Montaldo cemetery section), where fluvial-derived materials were occasionally reworked by storm waves in a shallow-marine setting. The fan-delta probably was partly confined within the Borgo Graben.

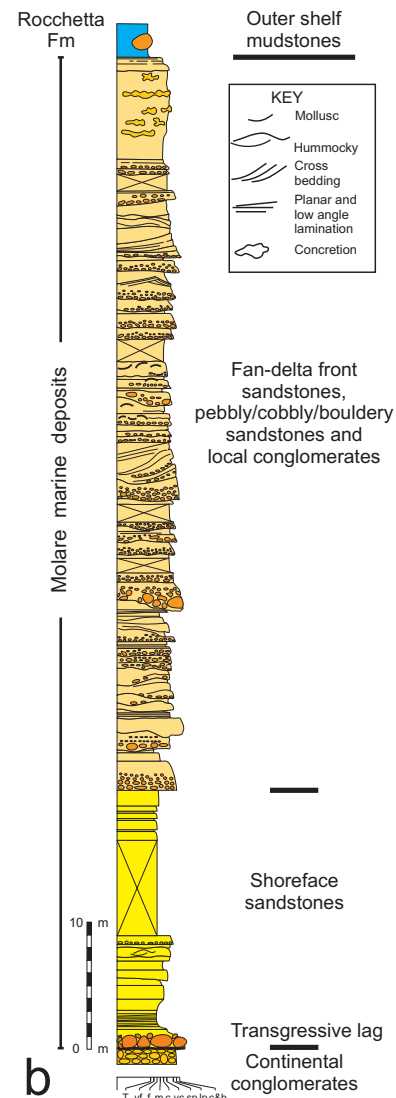
South of the Borgo Graben (Rocchetta Cairo Horst) (cf. Pl. IIIa, panel A2), the crystalline basement is covered by mostly bioturbated sandstones with poorly distinct stratification, less commonly associated with graded, graded-laminated or laminated (horizontal or low angle) sandstones collectively attributable to a shoreface-inner shelf setting. Locally (near Dego), the sandstones are discontinuously underlain by small patches of coral-bearing biolithites and/or biocalarenite/biocalcirudite beds (at most a few metres thick) with coralline red algae and large foraminifers, representing the transgressive basal deposits of the marine succession. The succession is fairly monotonous and without clearly recognizable internal cycles, suggesting an aggradational trend due to substantial compensation between sedimentation and subsidence, leading to fairly constant bathymetry and depositional setting. Only in the uppermost part the fining into massive bioturbated siltstones reflects the acceleration of subsidence resulting in the rapid transition to the slope environment typical of the overlying Rocchetta mudstones.

4.3. Rocchetta Formation

The Rocchetta Fm is a lithologically heterogeneous siliciclastic unit, mainly consisting of mudstones,



a



b

Fig. 5 - The Molare marine deposits cropping out in the Spigno Monferrato area (from Ghibaudo et al., this volume). a) Truncated small-scale T-R cycles (A to C) on the crystalline basement of the Spigno Monferrato Horst: 1) crystalline basement 2) boulder beach deposit. 3) transgressive lag 4) gravelly beachface 5) shoreface sandstones b) Large-scale T-R cycle developed atop the Molare continental conglomerates infilling the Borgo Graben.

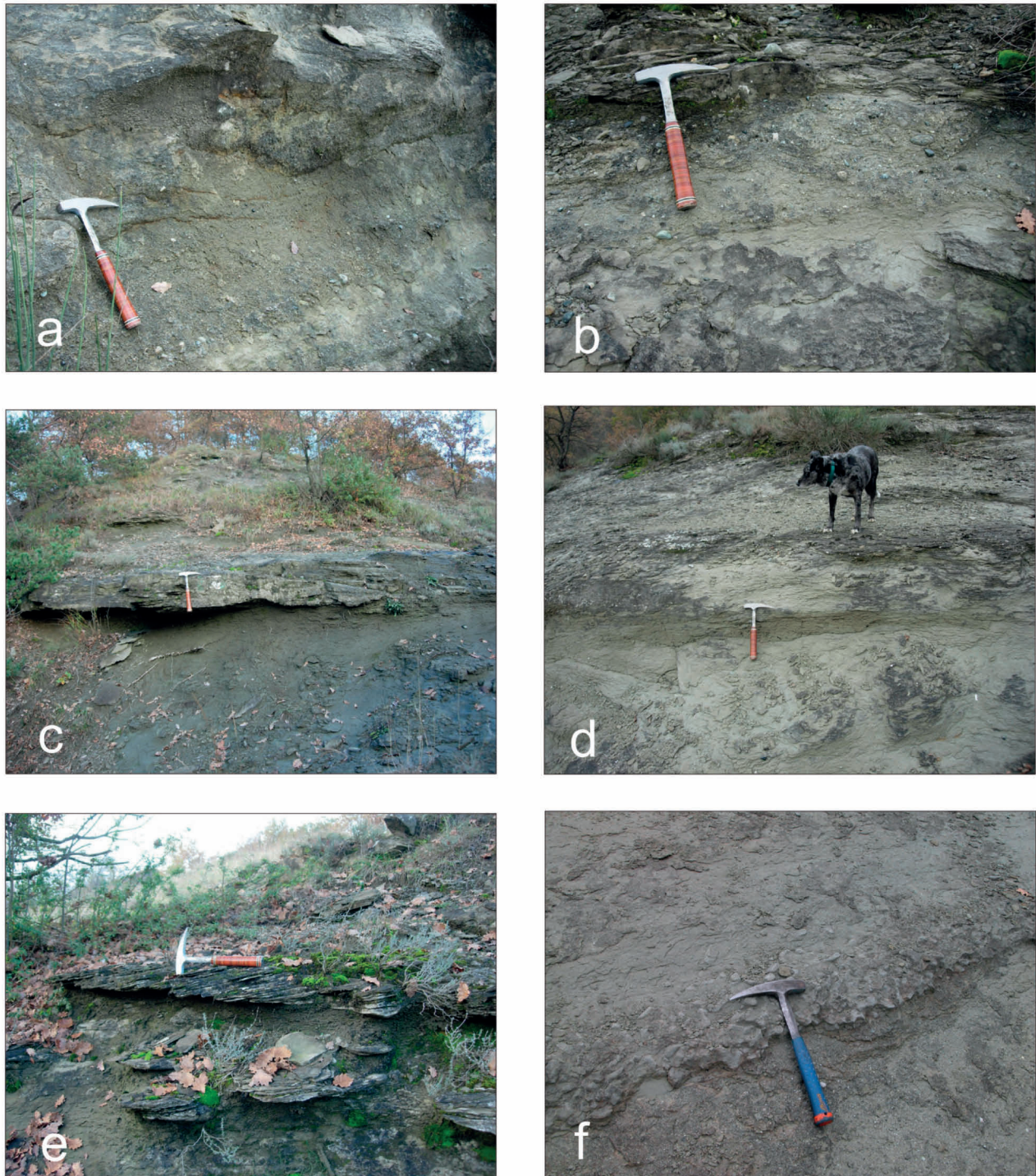


Fig. 6 - Details of the Molare shelf deposits atop the basement highs - a), b) Pebbly sandstone layers alternating with bioturbated or laminated sandstone; note normal grading in (a) and upward-convex laminae atop the pebbly sandstone layer in (b); c) Alternating bioturbated and hummocky cross-stratified sandstones; d) Low-angle cross-laminated interval underlain by thoroughly bioturbated sandstones; e) Medium-scale planar cross-laminated set; f) Detail of an omission event marked by an intensely bioturbated layer.

bioturbated siltstones and alternating mudstones and fine-grained, thin- to medium-bedded turbiditic sandstones. It encases, as members occurring at various stratigraphic levels, sandstone to sandstone-conglomerate bodies with geometry ranging from lenticular, to wedge-shaped or tabular, and minor single sandstone beds or bedsets 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”. 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 scar defined as “Molino di Mombaldone Erosional Depression” (cf. Pl. I).

The Rocchetta Fm is comprised between the Molare Fm at the base and the Montechiaro d'Acqui Siliceous Lithozone at the top. The formation shows variable thickness depending on the activity of syndepositional basement-involving faults (Ghibaudo et al., this volume). 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 Sandstone member. Both N and S of the Dego-Spigno Monferrato High, in the Turpino and Rocchetta Cairo depocentres, the formation is considerably thicker, reaching thickness of about 1000 m (cf. Pl. I). A characteristic feature, important for the interpretation of the Rocchetta Fm as a syntectonic unit, is a remarkable southward stratigraphic expansion of the mudstones intercalated between the Cobarello and Noceto units. This mudstone tongue also comprises the sandstone units named Pian del Lago Sandstones and Bric della Lasagna Sandstones (cf. Pl. I). It is bounded to the S by the Rio Giosa Fault and defines a sedimentary wedge, indicated here as "Rio Giosa stratigraphic expansion", with a maximum thickness of about 130 m against the fault, extending northwards over ca. 2.7 km, with a progressive thinning to a few tens of metres near the locality of Noceto (cf. geological map and Pl. I).

Based on the planktonic foraminiferal assemblages, the Rocchetta Fm, including the Noceto Sandstone, 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 - Rocchetta - C. Mevie section, is comprised between the late Rupelian and the early Aquitanian.

The Rocchetta Fm corresponds to the lower part (below the *Membro di C. Poggi*) of the *Formazione di Rocchetta-Monesiglio* of Gelati et al. (2010a, b). The Rocchetta Fm is time equivalent of the *Rigoroso Fm* cropping out in the adjacent Acqui Terme and Novi Ligure Sheets (Boni and Casnedi, 1970; Allasinaz et al., 1971; Bellino et al., in press, b) and to the *Rigoroso Fm* cropping out in the easternmost part of the TPB (Cavanna et al., 1989) (*note 2).

The Rocchetta Fm comprises the following lithostratigraphic units and large-scale erosional surfaces:

- Mudstones of the Rocchetta Fm
- Minor sandstone bodies (a,b, ...x)
- 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
- Slump sheets (S1, ...S6)
- Piana Crixia Conglomerates
- Rodini Lower Sandstones
- Rodini Middle Sandstones
- Rodini Upper Sandstones
- Mogliavacca Sandstones

- Brovinda Sandstones
- Cobarello Sandstones
- Noceto Sandstones
- Pian del Lago Sandstones
- Bric della Lasagna Sandstones
- Sassore Sandstones
- Vignazza Sandstones
- Altitude 524 Sandstones
- Vignaroli Sandstones
- C. del Bric Sandstones
- Codevilla Sandstones
- C. Giroso Sandstones
- Sorgente Alpei Sandstones
- Bric Petacchi Sandstones
- Fontanelle Sandstones
- Cian dei Grill Sandstones
- Gabutti Sandstones

For sake of clarity, the large number of sandstone bodies encased in the Rocchetta Fm will be briefly described with reference to separate sectors, respectively located in the northern (N of Merana), central (between Merana and the Rio Giosa - Gelosi), and southern (S of the Rio Giosa - Gelosi) areas. In the enclosed cross-section (Pl. I), these areas roughly correspond to the portions comprised between the following reference toponyms: C. Rocchino - Molino di Mombaldone (northern area), Valle - C. Rocchino (central area), Garelli - Valle (southern area).

4.3.1. Mudstones of the Rocchetta Formation

This unit consists of mudstones and/or hemipelagic siltstones, in most part delicately bioturbated, and subordinately of alternating mudstones and thin- to medium-bedded, laminated, fine-grained sandstones laid down by dilute turbidity flows. The Rocchetta Fm is interpreted, in agreement with Gelati and Gnaccolini (1998), as consisting of slope deposits grading upwards to base-of-slope deposits (Ghibaudo et al., this volume). Moreover, in the north-eastern sector of the study area the mudstones show features suggestive of a prodelta slope setting (Ghibaudo et al., 2001a).

4.3.2. Minor sandstone bodies, key beds

These are sheet-like sandstone bodies (single beds or bedsets), of decimetric to metric thickness, intercalated at various levels in the mudstones of the Rocchetta Fm, and representing excellent key beds within the monotonous pelitic succession. These bodies, indicated with the labels **a**, **b**, **c**..., consist of fine- to medium-grained turbiditic sandstones with lateral extent ranging from hundreds of metres to some kilometres.

The body **b** corresponds, *pro parte*, to the *livello Masseria* of Cazzola et al. (1981), Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b). These Authors trace the Masseria key bed both below the Noceto and Cobarello units and below the Mogliavacca unit of this paper. In our map this key bed has its termination just

below the northern closure of the Cobarello unit. Mutti et al. (2002) suggested a volcanic ash origin of the bed. Petrographic studies, however, exclude a volcanic ash origin (Ruffini, personal communication, 1991).

4.3.3. The sandstone units in the northern area

The lithostratigraphy, structural setting and sedimentary evolution of the Rocchetta Fm in the northern sector of the study area have been described in detail by Ghibaudo et al. (this volume). Here, only a brief summary is reported.

From the base upwards, the following sandstone bodies and erosional surfaces have been distinguished:

Molino di Mombaldone Lower Sandstones
 Ovrano Lower Sandstones
 Ovrano Middle Sandstones
 Ovrano Upper Sandstones
 Molino di Mombaldone Middle Sandstones
 Molino di Mombaldone Upper Sandstones

The Rocchetta Fm comprises also a number of slump sheets (S1, S2, S3, S4, S5, S6) and a large-scale scar named "Molino di Mombaldone Erosional Depression" encasing the Molino di Mombaldone Middle and Upper Sandstones (Ghibaudo et al., 2001a; Ghibaudo et al., this volume) (cf. Pl. I).

4.3.3.1. Molino di Mombaldone Lower Sandstones

This unit shows lenticular geometry with concave-up base and is in places partly eroded by the lower part of the Molino di Mombaldone Erosional Depression (Pl. I and Fig. 7). The unit has maximum thickness of 45 m and lateral extent of about 800 m. It shows a complex internal architecture resulting from the amalgamation of three stacked channels (multistorey channel-fill) (Ghibaudo et al., this volume for details). The unit consists of medium- to coarse-grained sandstones, and subordinately fine sandstones.

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, this sandstone body 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 Early Oligocene-Late Oligocene transition (Zone P21). Based on calcareous nannoplankton assemblages the unit is here referred to the late Chattian.

4.3.3.2. Ovrano Lower Sandstones

The unit shows a broadly lenticular geometry with concave-up base and is encased within the mudstones of the Rocchetta Fm. The unit is 29 m thick with a lateral extent of about 500 m (Fig. 7a, 7c). The unit is composed

of alternating medium- and thin-bedded resedimented fine sandstones and siltstones showing heavy bioturbation or parallel lamination. The unit corresponds to one of the *Corpi arenacei minori* mapped by Gelati and Gnaccolini (1998).

4.3.3.3. Ovrano Middle and Upper Sandstones

Both units show a broadly lenticular geometry and are encased within the mudstones of the Rocchetta Fm. To the NE both units are truncated by the lower part of the Molino di Mombaldone Erosional Depression (cf. Fig. 7c). To the SW they can be traced up to the surroundings of the Pian dei Buri Fault. The Ovrano middle unit has maximum thickness of 40 m and lateral extent of about 1.2 km. The Ovrano upper unit shows a maximum thickness of 12 m and lateral extent of about 1 km. Both units consist of fine-grained turbiditic sandstones occurring in thick to very thick, generally amalgamated strata. The overall internal 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 Lower, Middle and Upper Sandstones are dated by Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) to the Chattian (Zone P22). Based on calcareous nannofossil assemblages the units are dated to the late Chattian (cf. paragraph 3).

4.3.3.4. Molino di Mombaldone Erosional Depression

This characteristic erosional feature, visible along the scarp bounding the meander of the Bormida of Spigno River near the Molino di Mombaldone, was probably originated as a large-scale slump scar. Its geometry and infill are shown in figure 7 (Ghibaudo et al., 2001a; Ghibaudo et al., this volume). The depression has width of about 1 km, and maximum depth of 150 m. It truncates part of the Molino di Mombaldone Lower Sandstones and the Ovrano Middle and Upper Sandstones cropping out in the Ovrano Valley. The bulk of the infill consists of fine-grained sediments 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. We infer that an original large-scale slump scar subsequently evolved into a submarine canyon-slope valley as a result of the active bypass by dilute turbidity flows (Ghibaudo et al., 2001a; Ghibaudo et al., this volume).

4.3.3.5. Molino di Mombaldone Middle and Upper Sandstones

These units are described together, since lithologic and geometric features are similar. They form part of the infill of the Molino di Mombaldone Erosional Depression (cf. Fig. 7a and 7c). The Molino di Mombaldone middle and upper units are two broadly lenticular sandstone bodies



CROSS SECTION OF THE MOLINO DI MOMBALDONE EROSIONAL DEPRESSION (BORMIDA DI SPIGNO RIVER)

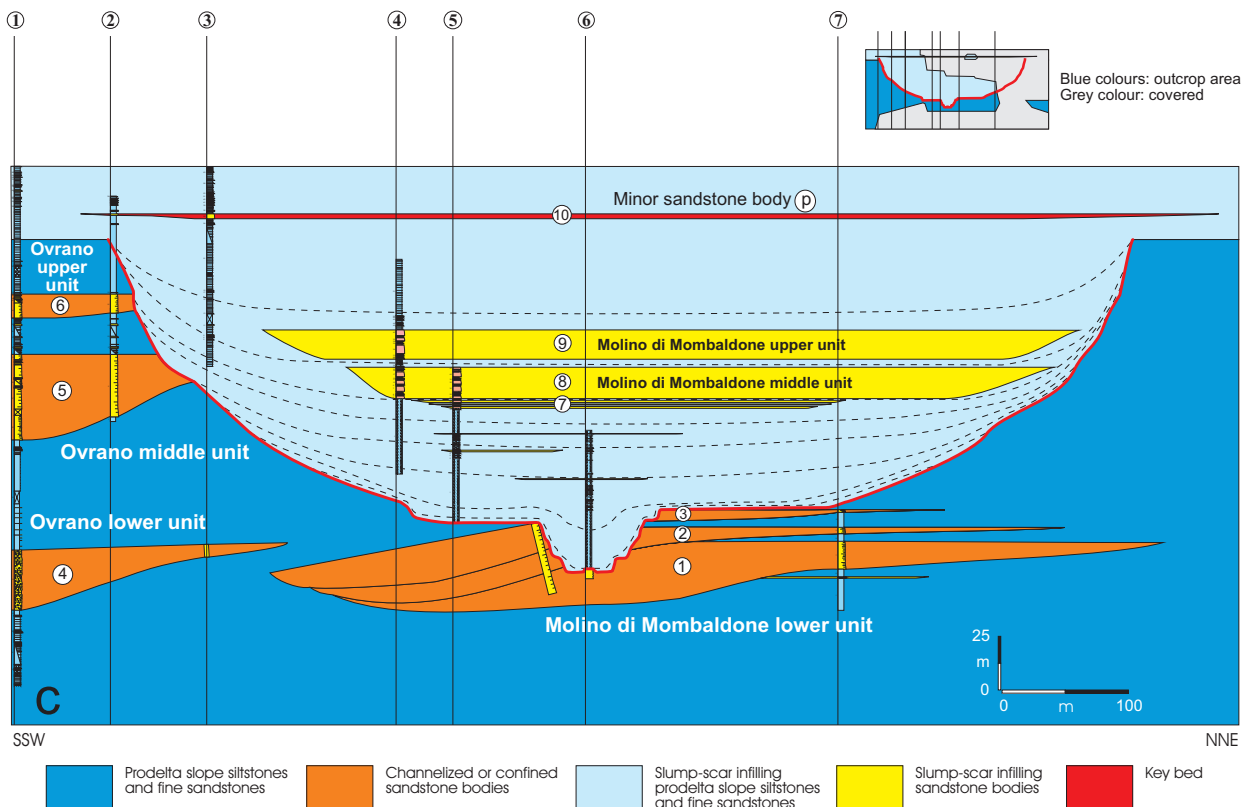


Fig. 7 - The Molino di Mombaldone Erosional Depression (from Ghibaudo et al., this volume). a) Panoramic view of the erosional depression interpreted as a large-scale slump-scar cut in prodelta slope siltstones, evolving into a canyon/slope valley system. The panoramic view shows part of the fill and of the underlying succession. b) Panoramic view showing the axial erosional thalweg related to the submarine valley stage of the depression and part of its infill. Note the irregular, metre-scale, terraced geometry of the erosional surface. c) Cross-section of the Molino di Mombaldone Erosional Depression.

encased within Rocchetta mudstones forming the bulk of the infill of the Molino di Mombaldone Erosional Depression. The lower unit has maximum thickness of 15.5 m and lateral extent of about 550 m, the upper unit has maximum thickness of 14 m and lateral extent of about 650 m. These units are made up of fine-grained turbiditic sandstones occurring in thick to very thick strata, commonly amalgamated, and subordinate intercalations of thin- to medium-bedded sandstone/mudstone couplets.

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). Both units 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 both units and the whole infill of the Molino di Mombaldone Erosional Depression are referred to the early Aquitanian (Zone MNN1d *p.p.*) (cf. paragraph 3).

4.3.3.6. Slump sheets

Six large slump sheets are intercalated at different stratigraphic levels in the mudstones of the Rocchetta Fm, and marked in the geological map with the acronyms S1, S2, S3, S4, S5, S6. All the sheets consist of base-discordant and deformed pelitic sediments of Rocchetta Fm and local portions of minor sandstone bodies. The main sheet, S6, located N of the Pian dei Buri Fault near the San Rocco small chapel, has a 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* in Gelati et al. (2010a, b). The vergence of folds and shear planes in the basal part of the slump sheet indicate an easterly transport direction (Ghibaudo et al., this volume). Gelati and Gnaccolini (1998) date this slump sheet to the Chattian (Zone P22). Actually, it is stratigraphically higher than the infill of the Molino di Mombaldone Erosional Depression and may be attributed to the early Aquitanian.

4.3.4. The sandstone units in the central area

From the base upwards they are:

Piana Crixia Conglomerates
 Rodini Lower Sandstones
 Rodini Middle Sandstones
 Rodini Upper Sandstones
 Mogliavacca Sandstones
 Brovida Sandstones
 Bric Petacchi Sandstones
 Cobarello Sandstones
 Pian del Lago Sandstones
 Bric della Lasagna Sandstones
 Noceto Sandstones

4.3.4.1. Piana Crixia Conglomerates

The unit is located about 30 m above the top of the Molare Fm and represents the lowermost unit of the Rocchetta Fm on the Deigo - Spigno Monferrato High. It crops out to the S of the village of Montaldo, on the ridge separating the Bormida di Spigno Valley from the Rio Valla Valley. It crops out, moreover, on the left bank of the Bormida River in locality Piana Crixia, where it is downthrown by a N-striking fault (Casazze Fault, see Fig. 49). The unit 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 (cf. geological map, Fig. 49 and Pl. I). Paleocurrents indicate a provenance from W-WNW (cf. also Cazzola et al., 1981). The unit has a lenticular geometry, maximum thickness of about 40 m and lateral extent of about 2.2 km. It consists of re-sedimented conglomerates, pebbly sandstones and coarse sandstones in thick to very thick strata, mostly amalgamated, with local intercalations of medium-fine sandstones and siltstones. Cazzola et al. (1981) pointed out that in the type-locality the unit is organized into plurimetric cycles thinning- and fining-upwards, confined within large-scale erosional surfaces, and forming minor sedimentary channelized bodies arranged as multistorey and multilateral fill (Fig. 8a). Typically, the individual channelized bodies are made up of conglomeratic sandstones and conglomerates in the lower and axial part (Fig. 8b) and sandstones in the upper part.

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 fill. Given its complex internal organization, this unit is here regarded as a slope channel complex confined within an elongate structural depression (Piana Crixia Graben) whose axis is followed by the paleocurrents. Cazzola et al. (1981) and Cazzola and Rigazio (1983) regard the Piana Crixia conglomeratic unit, described in the type-locality, and the Valla Sandstone unit, cropping out slightly to the E of the study area, as independent depositional systems. Unpublished field data (Ghibaudo et al., in prep.) highlight, however, that the Piana Crixia and Valla units form the proximal and respectively distal portions of a single turbiditic system. This sheds new light into the depositional setting and the sand-rich fan model that was inferred by the Authors from their field survey data (cf. Cazzola et al., 1981).

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

4.3.4.2. Rodini Lower, Middle and Upper Sandstones

These vertically stacked lenticular units crop out near the village of Rodini, in the Rio Gelosi Valley (cf. geologic



Fig. 8 - The Piana Crixia unit in the type locality. a) Stacked multi-storey channelized upward-fining units in the lower part of the Piana Crixia slope channel-complex; b) Detail of the channel axis facies association consisting of thick-bedded, erosion-based, discontinuous, resedimented coarse conglomerates and conglomerate-sandstone couplets.

map and Pl. I). The sandstone bodies are separated by about 10 m of mudstones of the Rocchetta Fm and are made up of turbiditic sandstones in thick to very thick and amalgamated strata with minor intercalations of medium- to thick-bedded alternating sandstones and mudstones

(Figs. 9, 10). These units correspond, *pro parte*, to the *Budroni unit* of Cazzola et al. (1981) and to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b). The lower and middle units are here tentatively attributed to the late Rupelian, the upper to the early Chattian.

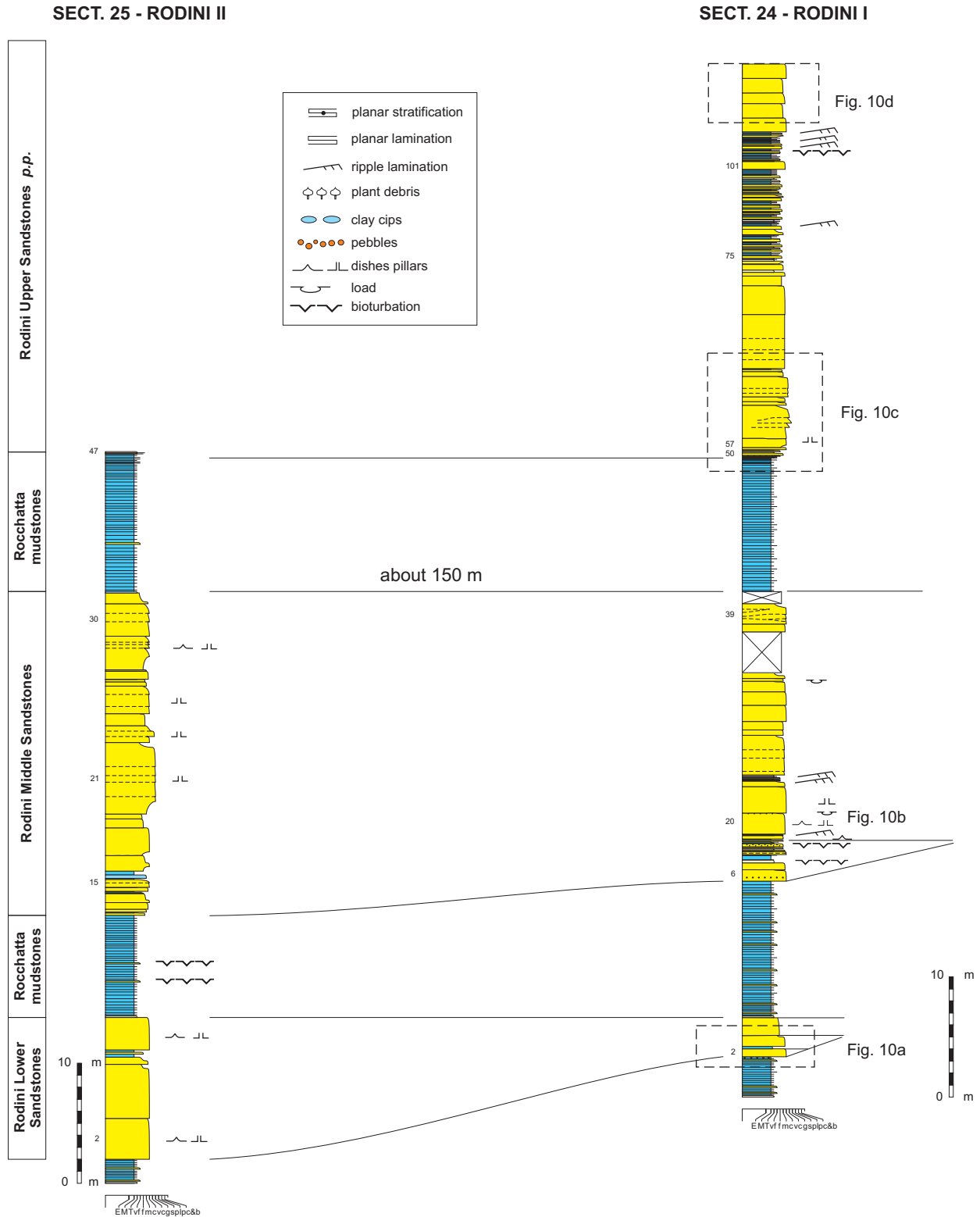


Fig. 9 - Partial cross-section of the Rodini units interpreted as slope channel-fill deposits. The cross-section shows the lateral termination of the Rodini lower and middle units and the basal part of the Rodini upper unit. Note the well developed basal upward-thinning cycle of the Rodini upper unit. Insets refer to details of figure 10.

The lower unit has lenticular geometry, maximum thickness of 12 m and lateral extent of about 480 m, the middle unit has lenticular geometry, maximum thickness of 26 m and lateral extent of about 900 m. The upper unit has marked lenticular geometry, maximum thickness of

about 100 m and lateral extent of about 1.3 km. Large-scale onlap relationships on the SW side of the bounding erosional surface are evident in the field. We cannot discard the hypothesis that the three units actually form the infill of a single, large-scale erosional surface

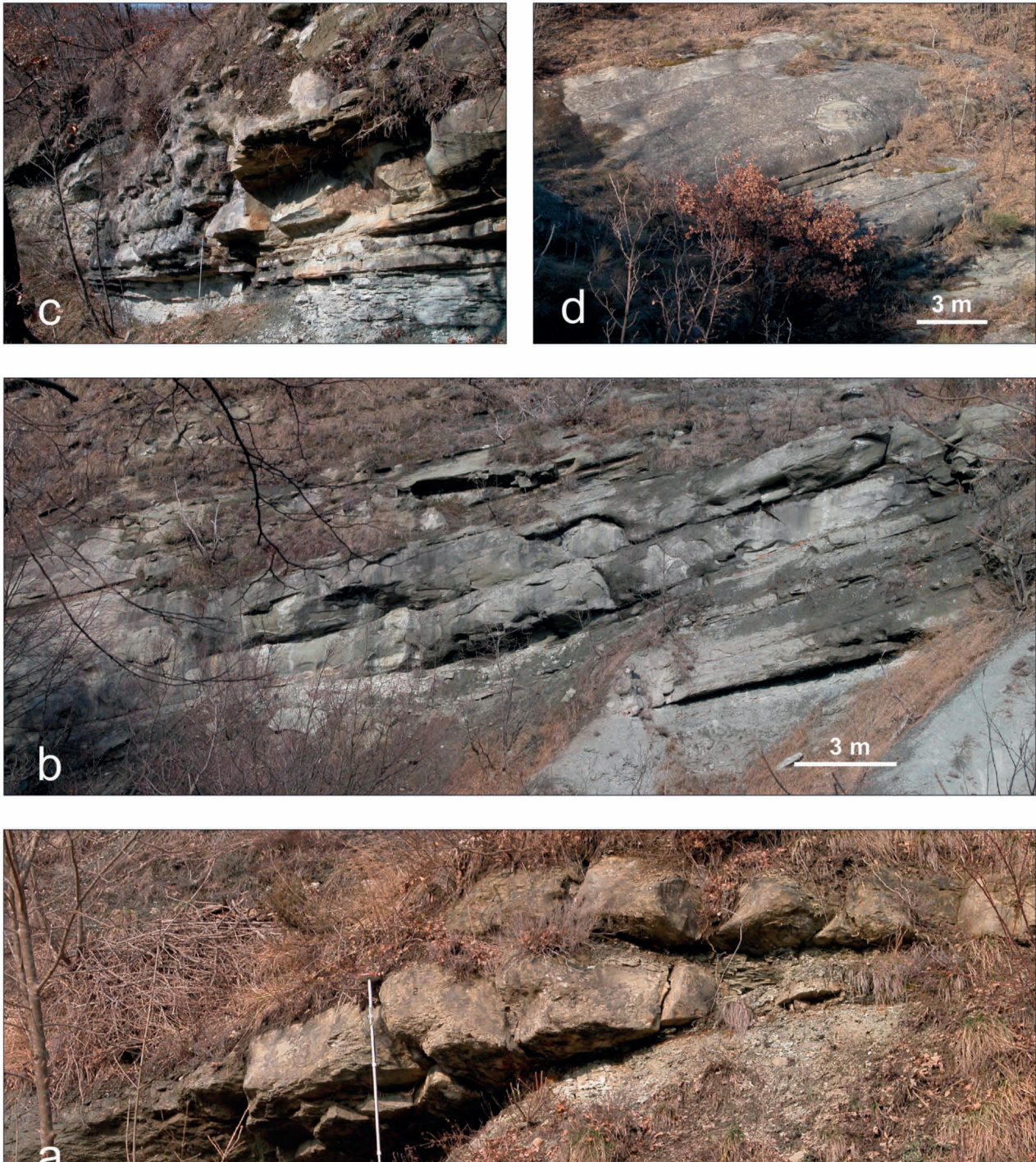


Fig. 10 - Details of the Rodini channel-fill units. a) Onlap of the basal beds of the Rodini Lower Sandstones against the lower erosional surface. b), c) Very thick-bedded and mostly amalgamated graded sandstone beds in the basal parts of Rodini Middle and Upper Sandstones. d) Very-thick-bedded, amalgamated sandstones forming the middle part of the Rodini Upper Sandstones (inset in Fig. 9).

(submarine valley or canyon), which cannot be ascertained from the available outcrops.

4.3.4.3. Mogliavacca Sandstones

The unit has marked lenticular geometry, large-scale erosional basal surface, maximum thickness of about 250 m, and lateral extent of 3.4 km. It is made up of

sandstones, conglomeratic sandstones and conglomerates in thick to very thick and amalgamated strata. Paleocurrents indicate a north-westerly provenance. The unit is enclosed in the mudstones of the Rocchetta Fm. The upper boundary is an erosional contact with the overlying Brovida Sandstones, except for the NE termination of the body, where a wedge of Rocchetta mudstones is preserved atop the unit. A fault predating,

and/or contemporaneous to, the deposition of the Mogliavacca Sandstones (La Costa Fault) puts the Rocchetta mudstones in contact with the shelf deposits of the Molare Fm (Pl. I).

The unit of Mogliavacca Sandstones corresponds, *pro parte*, to the *Lower Budroni Unit* of Cazzola et al. (1981) and Cazzola and Sgavetti (1984), to the *Sistema torbiditico di Budroni* of Cazzola and Fornaciari (1990), to the *Budroni system* of Mutti et al. (2002) and to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b).

The unit is tentatively attributed to the early Chattian assuming that the deeply erosional surface bounding the unit at its base is linked to the important lowstand of the Rupelian-Chattian transition (cf. paragraph 3). The unit was assigned by Gelati et al. (1993), Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b), to the Late Oligocene (Zone P22). It should be noted, however, that these Authors lump Mogliavacca, Brovida and Bric Petacchi units of this paper in a single unit, their *Budroni member*.

4.3.4.4. Brovida Sandstones

The unit has a thickness of 160 m in the type-section, and lateral extent of about 9 km. It erosionally overlies the Mogliavacca Sandstones. It is made up of amalgamated sandstones and pebbly sandstones in thick to very thick beds in the lower part and thin-to medium-bedded turbidites enclosing a number of thick-bedded and internally amalgamated sandstone bodies in the upper part. The unit shows a large-scale, asymmetric lenticular geometry, and, at least in its depocentral part, is characterized by a large-scale erosional contact at the base, locally highlighted by spectacular onlaps (Pl. I and Fig. 11). The contact with the underlying Mogliavacca Sandstones is erosional as demonstrated by a wedge of truncated Rocchetta mudstones separating the two units to the NE. The unit is areally more extended than the underlying unit of Mogliavacca Sandstones (Pl. I). It closes to the N over a distance of a few hundreds of metres and thins out progressively to the S, over a distance of some kilometres. In this direction the unit is offset by a listric fault (the Rio Girona Fault).

The unit corresponds, *pro parte*, to the *Upper Budroni Unit* of Cazzola et al. (1981) and Cazzola and Sgavetti (1984) and, *pro parte*, to the *Sistema torbiditico di Budroni* of Cazzola and Fornaciari (1990), to the *Budroni system* of Mutti et al. (2002) and to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b).

The unit is attributed by us to the Chattian. It was assigned by Gelati et al. (1993) and Gelati et al. (2010a, b), to the Late Oligocene (Zone P22).

4.3.4.5. Bric Petacchi Sandstones

The unit is made up of sandstones, and conglomeratic sandstones, in thick to very thick, amalgamated strata in the lower part passing upwards to alternating sandstones and mudstones in thick and medium strata, with sandstone/mudstone ratio > 1. The unit has broadly

lenticular geometry, maximum thickness of about 30 m and lateral extent of about 2 km (cf. Pl. I).

The unit is attributed to the Chattian. It corresponds, *pro parte*, to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b). These Authors assign the unit to the Late Oligocene (Zone P22).

4.3.4.6. Cobarello Sandstones

The unit is made up of sandstones in thick to very thick, amalgamated strata, with local thin intervals of interbedded sandstones and mudstones in medium and thin beds. The upper part is dominated by irregularly alternating sandstones and mudstones in medium to thick strata. On the whole, the unit shows a large-scale lenticular geometry in the axial portion and more tabular lateral terminations. The unit is laterally more extended than the underlying Brovida unit (Pl. I). To the S it is offset by the listric Rio Girona Fault. In the reference section (measured along the road Brovida-Noceto) the unit is 210 m thick. Its lateral extent is of about 10 km.

The unit corresponds, *pro parte*, to the *Unità Rapalino* of Cazzola et al. (1981) and Cazzola and Sgavetti (1984) and, *pro parte*, to the *Sistema torbiditico di Noceto* of Cazzola and Fornaciari (1990), to the lower member (*Noceto system*) of the *Noceto unit* of Mutti et al. (2002) and to the *Membro delle arenarie di Noceto* of Gelati et al. (2010a, b). The unit was assigned by Gelati et al. (1993), Gelati and Gnaccolini (1998), and Gelati et al. (2010a, b), to the Late Oligocene (Zone P22). It is referred here to the late Chattian.

4.3.4.7. Pian del Lago Sandstones and Bric della Lasagna Sandstones

These two sandstone bodies share a lenticular geometry and the lithology, are confined in the accommodation space created on the hangingwall of the listric synsedimentary Rio Girona Fault and are part of the "Rio Girona stratigraphic expansion" (Pl. I and cf. paragraphs 4.3 and 6.2). They are made up of sandstones, more rarely pebbly sandstones, in thick to very thick amalgamated strata locally separated by thin pelitic intervals, passing upwards to alternating sandstones and mudstones in thick to medium strata with sandstone/mudstone ratio ≥ 1 .

The Pian del Lago Sandstones have maximum thickness of 20 m and lateral extent of about 1.8 km. The Bric della Lasagna Sandstones have maximum thickness of 50 m and lateral extent of about 1.6 km. These units correspond, *pro parte*, to the *Membro delle arenarie di Noceto* of Gelati et al. (2010a, b). Both units are here tentatively assigned to the early Aquitanian.

4.3.4.8. Noceto Sandstones

The unit has a large-scale, wedge-shaped geometry and lateral extent of about 14.7 km and is bounded by the listric Rio Girona Fault (cf. paragraph 6.2) to the SW, where it reaches the maximum thickness of about 350 m (Pl. I). To the NE it pinches out gradually, closing near

Case Bazzi. The unit is bounded at the base 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. The upper contact with the deposits of the Montechiaro d'Acqui Siliceous Lithozone (LS1) is sharp and conformable. The unit is composed of sandstones, pebbly sandstones and rare conglomerates in thick and very thick beds, generally amalgamated. Only in the uppermost part, and in proximity to the listric fault, the unit is characterized by a plurikilometric wedge of alternating sandstones and mudstones in medium to thick strata with sandstone/mudstone ratio > 1 , and rare intercalations of conglomerates and paraconglomerates (Fig. 27a).

The unit of Noceto Sandstones corresponds, *pro parte*, to the *Unità Noceto* of Cazzola et al. (1981) and Cazzola and Sgavetti (1984), to the *Sistema torbiditico di Noceto* of Cazzola and Fornaciari (1990), to the *Unità di Noceto* of Gelati and Gnaccolini (1998), to the *Unità Noceto of Fava's Noceto Group* (2001), to the lower member (*Noceto system*) of the *Noceto unit* of Mutti et al. (2002) and to the *Membro delle Arenarie di Noceto* of Gelati et al. (2010a, b). 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.*).

4.3.5. The sandstone units in the southern area

From the base upwards they are:

Sassore Sandstones
 Vignazza Sandstones
 Vignaroli Sandstones
 C. del Bric Sandstones
 Codevilla Sandstones
 C. Giroso Sandstones
 Sorgente Alpei Sandstones
 Fontanelle Sandstones
 Cian dei Grill Sandstones
 Gabutti Sandstones
 Altitude 524 Sandstones

4.3.5.1. Sassore Sandstones

The unit has lenticular geometry, with internal large-scale erosional surfaces. It has maximum thickness of about 15 m and lateral extent of about 450 m. It consists of sandstones and conglomeratic sandstones in medium to very thick strata, systematically amalgamated. The uppermost part consists of alternating sandstones and mudstones in medium to thick strata with sandstone/mudstone ratio ≥ 1 . Age: Chattian.

4.3.5.2. Vignazza Sandstones

The unit has lenticular geometry, maximum thickness of about 30 m and lateral extent of about 350 m. The lower part is characterized by thick sandstone strata,

amalgamated or separated by thin pelitic interbeds, the upper part by alternating sandstones and mudstones in medium to thin strata with sandstone/mudstone ratio around 1. It corresponds, *pro parte*, to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.3. Vignaroli Sandstones

The unit has broadly lenticular geometry, maximum thickness of about 35 m and lateral extent of about 900 m. It consists of turbiditic sandstones in thick and locally very thick strata, amalgamated or separated by thin pelitic interbeds and minor intercalations of alternating sandstones and mudstones in medium to thin beds, with sandstone/mudstone ratio ≤ 1 . It corresponds, *pro parte*, to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.4. Altitude 524 Sandstones

The unit is confined to the NW by a fault probably active during the sedimentation (C. Vai Fault, cf. Fig. 49). It consists of sandstones and conglomeratic sandstones in thick to very thick and amalgamated strata with local intervals of alternating sandstones and mudstones in medium to thin beds. It corresponds, *pro parte*, to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b). Age: Rupelian.

4.3.5.5. C. del Bric Sandstones

The unit is composite, consisting of two stacked and amalgamated channelized sandstone bodies with lenticular geometry. The lower unit has maximum thickness of about 50 m and lateral extent of 1.2 km, the upper unit has maximum thickness of about 60 m and lateral extent of 950 m. Both units consist of sandstones, conglomeratic sandstones and minor conglomerates in thick to very thick and amalgamated strata.

The unit corresponds, *pro parte*, to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.6. Codevilla Sandstones

The unit consists of turbiditic sandstones and conglomeratic sandstones in thick to very thick, amalgamated strata, grading in the upper part to alternating sandstones and mudstones in thick to medium strata. Rare intervals of alternating sandstones and mudstones in medium beds with sandstone/mudstone ratio ≥ 1 are present. The unit has broadly lenticular geometry, maximum thickness of about 35 m and lateral extent of about 1.1 km.

The unit corresponds, *pro parte*, to the *Membro delle arenarie di Budroni* of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.7. C. Giroso Sandstones

The unit has tabular geometry, maximum thickness of about 20 m and lateral extent of about 2.6 km. The lower

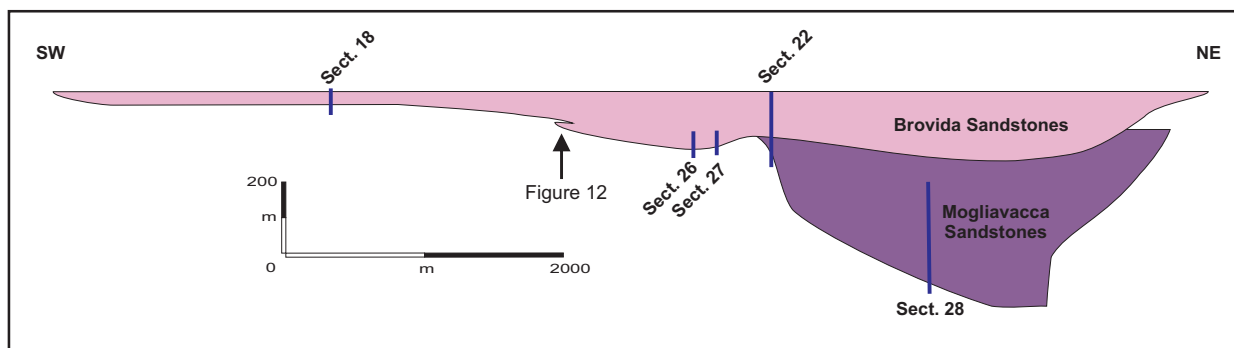


Fig. 11 - Schematic cross-section highlighting the stratigraphic and geometric relationships of Mogliavacca and Brovida units and location of stratigraphic sections. Section 18: Brovida unit - along the road crossing the Carretto village; Sections 26 and 27: Brovida unit - Vallette area (N of Rodini); Section 22 - Mogliavacca and Brovida units - along the road Brovida-Noceto; Section 28 - Mogliavacca Sandstones: left side of the Rio Casattana valley.

part is characterized by alternating turbiditic sandstones and mudstones in thick to medium strata, with sandstone/mudstone ratio ≥ 1 . In the upper part, sandstones in thick to very thick, amalgamated strata pass upwards to interbedded sandstones and mudstones in thick to medium strata with sandstone/mudstone ratio > 1 . Typically, the amalgamated interval forms a sandstone unit of plurimetric thickness, with tabular geometry, particularly evident in the present-day erosion profile.

The unit corresponds, *pro parte*, to the *Membro delle arenarie di Noceto* of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.8. Sorgente Alpei Sandstones

The unit has tabular geometry, maximum thickness of about 20 m and lateral extent of about 1.9 km. Near its north-easterly termination (Rio Costabella) the unit shows erosional base and local channelized geometry. In the lower part: alternating turbiditic sandstones and mudstones in thick to medium strata with sandstone/mudstone ratio > 1 . In the upper part: sandstones in thick to very thick and amalgamated strata passing upwards to interbedded sandstones and mudstones in thick to medium strata with sandstone/mudstone ratio > 1 . Typically, the amalgamated interval forms a tabular sandstone unit of plurimetric thickness.

The unit corresponds, *pro parte*, to the *Membro delle*

arenarie di Noceto of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.9. Fontanelle Sandstones

The unit has tabular geometry, maximum thickness of about 20 m and lateral extent of about 3.4 km. In the lower part: interbedded turbiditic sandstones and mudstones in thick and secondarily medium strata, with sandstone/mudstone ratio > 1 . In the upper part: sandstones in thick to very thick and amalgamated strata passing upwards to sandstone-mudstone couplets in thick to medium strata with sandstone/mudstone ratio > 1 . Typically, the amalgamated interval forms a tabular sandstone unit of plurimetric thickness.

The unit corresponds, *pro parte*, to the *Membro delle arenarie di Noceto* of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.10. Cian dei Grill Sandstones

The unit has broadly lenticular geometry, maximum thickness of about 40 m and lateral extent of about 2.5 km. The lower part comprises turbiditic sandstones and conglomeratic sandstones, in thick to very thick and amalgamated strata, separated by thin pelitic interbeds. The upper part is dominated by interbedded sandstones and mudstones in thick to medium strata with sandstone/mudstone ratio > 1 . The unit corresponds, *pro*



Fig. 12 - Channelized geometry of the lowermost sandstone body of the Brovida unit (left side of the Rio Serre. See Fig. 11 for location).

parte, to the *Membro delle arenarie di Noceto* of Gelati et al. (2010a, b). Age: Chattian.

4.3.5.11. Gabutti Sandstones

The unit has maximum thickness of about 100 m and lateral extent of more than 3.0 km. It has a large-scale lenticular geometry in the axial part and more tabular lateral pinchouts. The axial part consists of turbiditic sandstones, locally conglomeratic, in thick to very thick and amalgamated strata, with minor intervals of interbedded sandstones and mudstones in medium to thick and subordinately thin beds. The amalgamated intervals form sandstone units of plurimetric thickness, with approximately tabular geometry. The lateral parts consist of alternating sandstones and mudstones in medium to thick, subordinately thin beds, with minor sandstone intervals in thick to very thick and amalgamated strata. The unit appears to be composed of sub-units with decametric thickness and tabular to broadly lenticular geometry, not individually distinguished in the map.

The unit corresponds, *pro parte*, to the *Membro delle arenarie di Noceto* of Gelati et al. (2010a, b). Age: earliest Aquitanian?

4.4. Montechiaro d'Acqui Siliceous Lithozone

This unit (LS1) consists of alternating siliceous intervals 2 to 8-10 m thick and homogeneous marly intervals 2-6 m thick. Typically, the siliceous intervals tend to decrease in thickness and to become finer-grained upwards. They are made up of alternating, silica-cemented, thin-bedded, medium- to very fine-grained sandstones and dark grey siltstones, with intervals of siliceous laminites either unconsolidated or tightly lithified. The sandstone beds 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 alternating thin- to medium-bedded hard siltstones and mudstones. The sandstone beds are either parallel-laminated or characterized by form-set ripples or starved ripples. A detailed description of the sedimentary features of this unit in the northeastern part of the study area is given by Ghibaudo et al. (this volume). Locally (heads of the valleys of Rio Rocchetta and Rio Bazzi), these lithologies grade laterally into massive and homogeneous marls (LS1d). In places (head of the Ovrano Valley), the Siliceous Lithozone is more calcareous. Here, the basal part, close to the Molino d'Ovrano, is characterized by a few metres of resedimented, medium-bedded glauconitic biocalcarenes (LS1e).

The Montechiaro d'Acqui Siliceous Lithozone (LS1) is about 50-60 m thick in the NE sector of the study area (Rio d'Aprile, Ovrano Valley) (Fig. 13a). The thickness is reduced to about 30 m near the Pian dei Buri Fault, where the unit is overlain by the "Altitude 483 Sandstones", and Pian Bruno Calcarenes. In the SW sector (heads of the Rio Merana and Rio Fornaci valleys), where the Siliceous Lithozone overlies the Noceto Sandstones, the thickness is about 35 m. The contact with the underlying Rocchetta

Fm is everywhere sharp and conformable. The unit is overlain by the marls of the Montechiaro d'Acqui Fm or, locally, by the calcarenitic and siliciclastic units included in the lower part of this formation (C. Poggi Calcarenes, Pian Bruno Calcarenes, C. Mazzurini Sandstones) (cf. Pl. I). In the Costa della Feja area (S of Piantivello), the Siliceous Lithozone is truncated at the top by the erosional base of the Case Mazzurini unit (cf. Pl. I). In the SW sector of the study area, starting from the locality San Massimo towards SW, the unit splits into minor units, here defined: Bric Baraccone Siliceous Lithozone (LS1a), C. Ranari Siliceous Lithozone (LS1b) and Castelletto Uzzone Soprano Siliceous Lithozone (LS1c), overlying turbiditic units (respectively Noceto Sandstones, Poggiolo Fm and Scaletta Uzzone Fm) (Pl. I).

The Montechiaro d'Acqui Siliceous Lithozone is a marker horizon on regional scale. Towards NE the unit can be traced in the adjacent Acqui Terme Sheet, up to the Caliozna Valley, where it is unconformably truncated by the transgressive Visone Limestone (Ghibaudo et al., unpublished data). The unit crops out again several tens of kilometres to the NE, near the locality of Carrosio between the Lemme and Scrivia valleys (*Membro di C. Colombara* of Galbiati, 1976), atop the Rigoroso Fm (the latter unit being time equivalent of the Rocchetta Fm). To the SW, due to the wedging out of the turbiditic formations intercalated in it, the unit can be traced again as a single horizon in the adjoining Cairo Montenotte Sheet. The Montechiaro d'Acqui Siliceous Lithozone is particularly well exposed in the Cianazzo section (Ghibaudo et al., this volume), located a few km NE of the study area, and in the type-locality of Montechiaro d'Acqui, comprised in the adjoining Acqui Terme Sheet.

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. 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 (Ghibaudo et al., this volume).

The siliceous sediments of the Montechiaro d'Acqui Siliceous Lithozone are interpreted as condensed sections. The regional extent of this unit points to an important phase of relative sea level rise, accompanied by a drastic reduction of coarse terrigenous input in slope and basinal settings and an increase in organic productivity. The succession shows an internal cyclicity on plurimetric scale (alternating siliceous and marly intervals), particularly clear in the Cianazzo section. This is interpreted as the expression of an intra-Aquitania high-frequency cyclicity in a slope environment (Ghibaudo et al., this volume).

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), to the *Litozona*

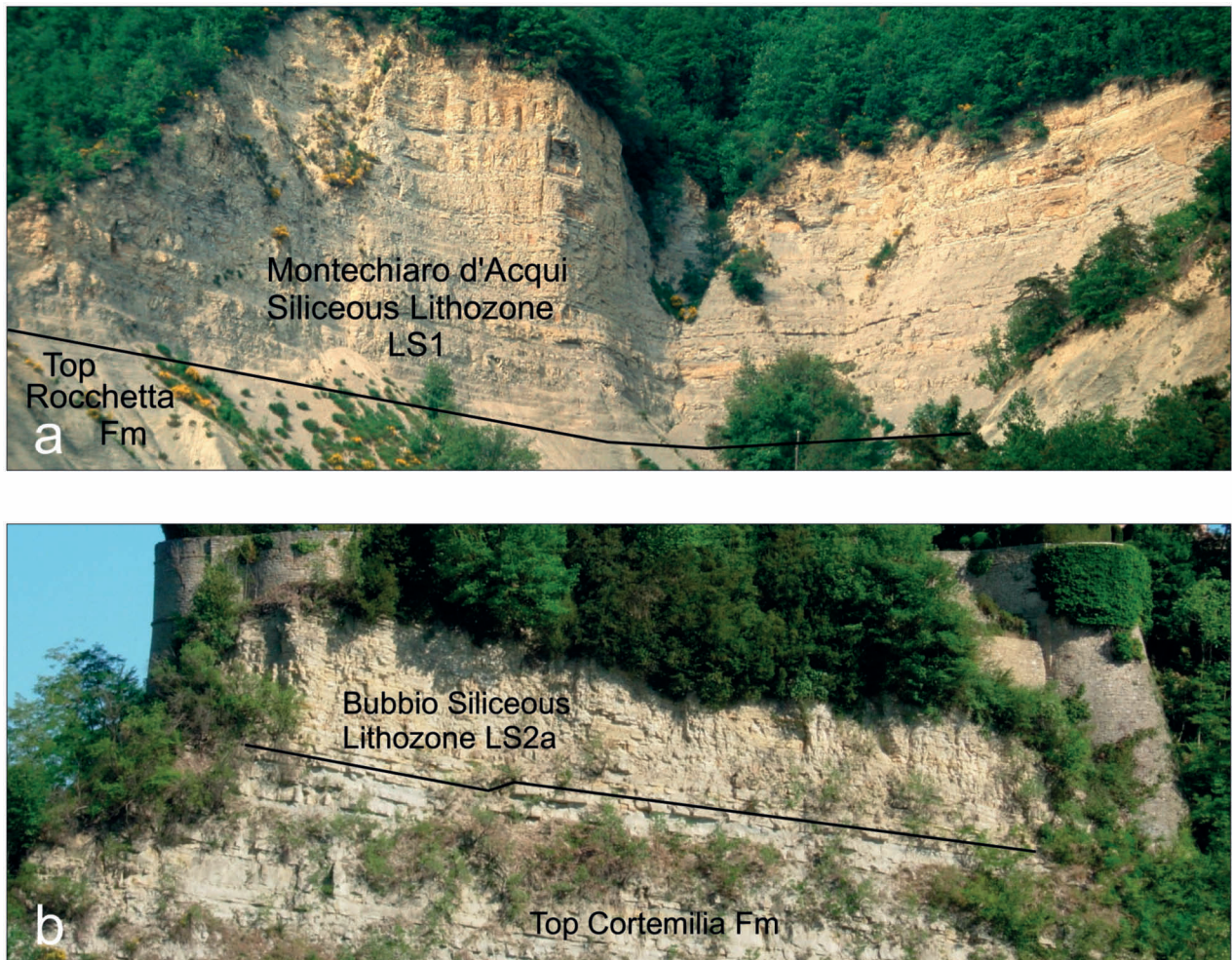


Fig. 13 - a) The Montechiaro d'Acqui Siliceous Lithozone (LS1) cropping out in the Ovrano valley atop the Rocchetta Fm. b) The Bubbio Siliceous Lithozone (LS2a) in the Bubbio type locality atop the Cortemilia Fm.

silicea of Fava (2001), to the *Siliceous Lithozone* of Mutti et al., (2002) and to the *Membro di C. Poggi* of the *Formazione di Rocchetta-Monesiglio* of Gelati et al. (2010a, b) in the Sheet 211 Deago. Fava (2001) identified a cluster of siliceous packages in the Langhe Sub-basin, and ascertained that the intervals occurring as separate units in the expanded stratigraphy of the Uzzone Valley converge in a single package in the north-eastern direction corresponding to the Montechiaro d'Acqui Siliceous Lithozone (LS1) of the present stratigraphy. The Montechiaro d'Acqui Siliceous Lithozone (LS1), moreover, corresponds to the *Membro di C. Poggi* of the *Formazione di Rocchetta-Monesiglio* of Sheet 228 Cairo Montenotte (Dallagiovanna et al., in press a, b) and to the *Membro siliceo* of the *Formazione di Montechiaro d'Acqui* of Sheet 194 Acqui Terme (Bellino et al., in press a, b) (*note 3). d'Atri (1990) and Gelati and Gnaccolini (1998) attribute the unit to a slope setting. We share this attribution, and note that the unit seems to record a more basal setting in the south-westerly direction. In the Sheet 211 Deago, Gelati et al. (2010a, b) ascribe the Montechiaro d'Acqui Siliceous Lithozone (LS1) to the Late Oligocene (Zone P22). In the adjacent Sheet 228 Cairo Montenotte

(Dallagiovanna et al., in press a, b) the same unit is attributed to the Chattian-Aquitainian transition, while in the Sheet 194 Acqui Terme (Bellino et al., in press a, b) it is attributed to the late Aquitainian-early Burdigalian. On the basis of the here adopted nannofossil biostratigraphy the Montechiaro d'Acqui Siliceous Lithozone is attributed to the middle-late Aquitainian (Zones MNN1d *p.p.* - MNN2a *p.p.*).

4.5. Poggiolo Formation

The Poggiolo Fm crops out primarily in the south-western part of the study area on both sides of the Uzzone Valley and on the heads of the Rio della Madonna, Rio Fosso di Morozzo and Rio Lodisio valleys. It is made up of alternating turbiditic sandstones and mudstones in medium to thin and subordinately thick beds. The unit also comprises two sandstone members respectively defined as Rio Porcavio Sandstones and C. Carloni Sandstones. The Poggiolo Fm is bounded by the Bric Baracone Siliceous Lithozone (LS1a) at the base and the C. Ranari Siliceous Lithozone (LS1b) at the top. Together with the underlying siliceous lithozone, this unit seals the Rio Girosa listric growth fault (cf. geological map and Pl.

I). Only SE of the locality of Valle (Uzzone Valley) the unit is in direct tectonic contact with the Noceto Unit, as a result of a late inversion of the Rio Giosa growth fault originally bounding the Noceto unit to the SW (cf. paragraph 6.2). The Poggiolo Fm crops out with continuity for about 9.4 km in direction SW-NE. The unit shows depositional closures both to the SW, on the right side of the Bormida di Millesimo Valley, NE of the Gabutti locality, and to the NE, in proximity to the village of San Massimo. It also shows a local wedging out at the Bric della Croce (W of Lodisio). The Poggiolo Fm has thickness of about 80 m in the valleys of the Rio Valloira and Rio Pilastretto (Valle area), and progressively wedges out SW-wards, NE-wards and SE-wards. In the Uzzone Valley, N of Scaletta Uzzone, the base of the Poggiolo Fm does not crop out and the unit is bounded by the C. Serra Fault to the S and the C. Lunga - Blengi Fault to the N. (Fig. 49). In this area the unit has minimum exposed thickness of about 150 m between the localities of Poggiolo and Rio Porcavio.

The Poggiolo Fm corresponds, *pro parte*, to the *Unità di Castelletto Uzzone* (N2) of the Fava's *Noceto Group* (2001) and, *pro parte*, to the *Unità Poggiolo* of his *Cartosio Group*. It corresponds, *pro parte*, to the upper member (*Castelletto Uzzone system*) of the *Noceto unit* of Mutti et al. (2002) and, *pro parte*, to the *Poggiolo system* of the *Cartosio unit* of Mutti et al. (2002). It also corresponds, *pro parte*, to the following lithostratigraphic units of the *Formazione di Rocchetta-Monesiglio* of Gelati et al. (2010a, b): a) *Membro delle arenarie di Noceto (RTM8b unit)*, b) *alternanze ritmiche di peliti e arenarie sottilmente stratificate (RTMb)* della *massa di fondo*, c) *Membro delle arenarie di Piantivello*. The Poggiolo Fm is attributed to the middle Aquitanian (Zone MNN1d *p.p.*).

4.5.1. Rio Porcavio Sandstones

This unit crops out in Uzzone Valley between the locality of Poggiolo and the Rio Porcavio. To the S the unit shows a progressive thickness reduction and ends against the S. Ilario Fault, whereas to the N it is buried by the alluvial deposits of the Rio Uzzone (Fig. 49). It has a marked wedge-shaped geometry. At its southern termination it has a thickness of 8-10 m, whereas along the Rio Porcavio it reaches a thickness of about 90 m. The unit is encased within the alternating sandstones and mudstones of the Poggiolo Fm. In the type-section of the Rio Porcavio it consists of turbiditic sandstones in thick and amalgamated strata, locally associated with alternating sandstones and mudstones in medium to thick beds and rare plurimetric pebbly mudstones and slump sheets.

The unit corresponds, *pro parte*, to the *Membro delle arenarie di Piantivello* of Gelati et al. (2010a, b).

4.5.2. C. Carloni Sandstones

This unit crops out on the thalweg of the Rio Mogliapiana, is some metres thick and shows broadly lenticular geometry. It is encased within the turbidite

couplets of the Poggiolo Fm. It consists of sandstone-mudstone turbidites, occurring in the lower part as thick to very thick and locally amalgamated strata, with sandstone/mudstone ratio > 1 and, in the upper part, as medium beds with sandstone/mudstone ratio ≥ 1 .

4.6. Scaletta Uzzone Formation

The Scaletta Uzzone Fm crops out in the south-western part of the study area, and shows approximately the same outcrop extent as the underlying Poggiolo Fm. The unit is bounded by the C. Ranari Siliceous Lithozone (LS1b) at the base and the Castelletto Uzzone Soprano Siliceous Lithozone (LS1c) at the top. In direction SW-NE it extends for about 9.3 km from the region of Contrada (Bormida di Millesimo) to the region of Morozzo Soprano and, in direction S-N, for about 7.4 km, from the Bric del Pilo to the Scaletta Uzzone area. The unit has a large-scale broadly lenticular geometry and shows maximum thickness of 50-60 m in the southern outcrop area (Bric Orso, Bric del Pilo, Bric Pendie). Toward SW, N, and NE the unit gradually wedges out. The formation has minimum thickness of about 25 m to the SW, in the Contrada area, and shows a depositional termination to the NE in the region of Morozzo Soprano. The unit thins out progressively N-wards and ends in the Castelletto Uzzone region against the S. Ilario Fault (Figs. 14 and 49). The Scaletta Uzzone Fm is made up of sandstones, conglomeratic sandstones and rare conglomerates in thick to very thick and amalgamated beds, or separated by thin pelitic interbeds. In the upper part it consists of alternating sandstones and mudstones in thick and medium beds with sandstone/mudstone ratio > 1 .

The Scaletta Uzzone Fm corresponds, *pro parte*, to the *Unità di Castelletto Uzzone* (N2) of the Fava's *Noceto Group* (2001) and, *pro parte*, to the upper member (*Castelletto Uzzone system*) of the *Noceto unit* of Mutti et al., (2002). It also corresponds, *pro parte*, to the *Membro delle arenarie di Noceto (RTM8b unit)* of Gelati et al. (2010 a, b). The unit is attributed to the middle Aquitanian (Zone MNN1d *p.p.*).

4.7. Montechiaro d'Acqui Formation

The Montechiaro d'Acqui Fm is a heterogeneous unit, consisting of homogeneous marls, with rare intercalations of siltstones and fine-grained sandstones in thin to very thin beds. The unit locally encases both carbonate and siliciclastic bodies with lenticular or wedge-shaped geometry (Pl. I). In the uppermost part two metric intervals are present, consisting of thin- to medium-bedded mudstones rhythmically alternating with competent, silica rich siltstones (not represented in the enclosed geological map) looking like the siliceous intervals of the underlying Montechiaro d'Acqui Siliceous Lithozone (LS1). In the type locality, located near the village of Montechiaro d'Acqui, about 5 km to the E of the study area, the unit is 65 m thick, and consists mostly of marls.

In the study area, the thickness of the unit is around 70-80 m in the section measured along the road C.

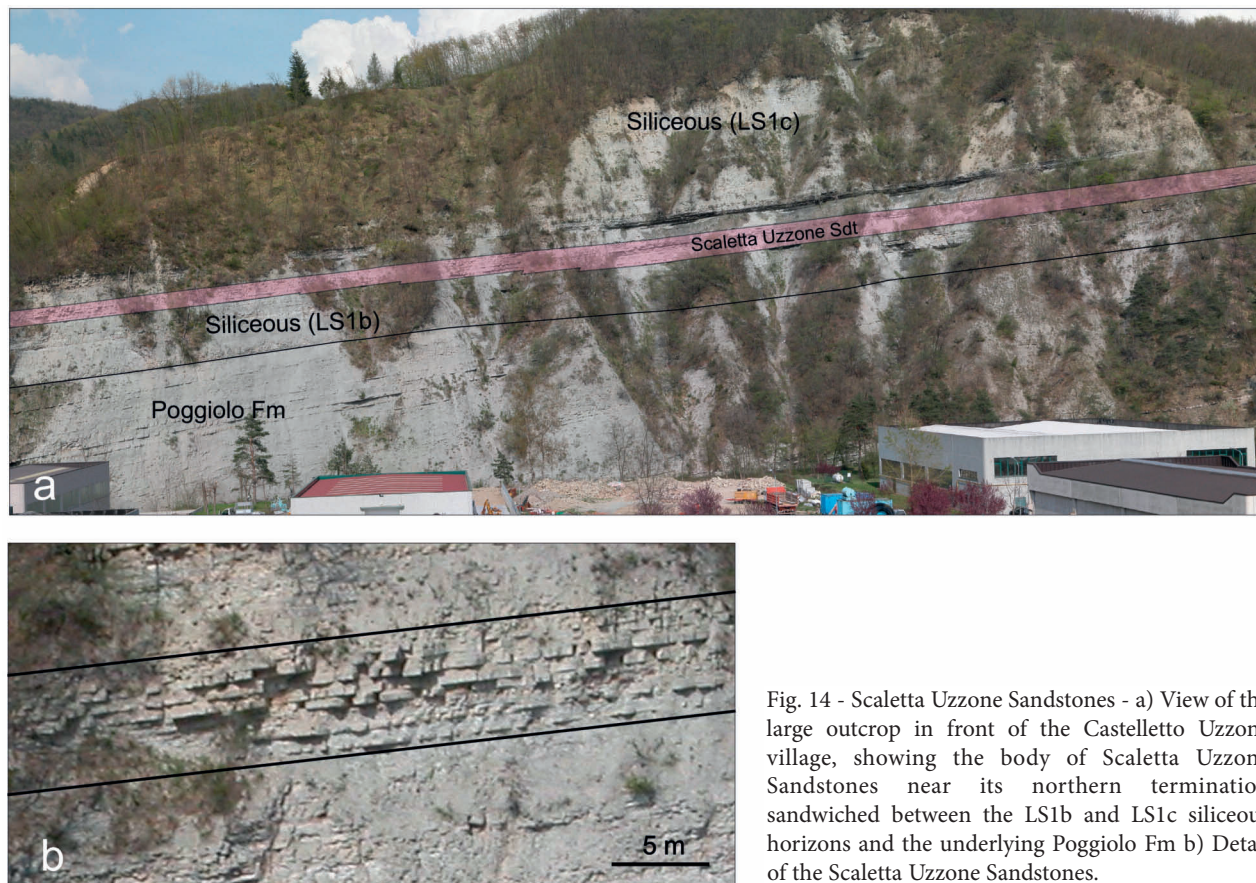


Fig. 14 - Scaletta Uzzone Sandstones - a) View of the large outcrop in front of the Castelletto Uzzone village, showing the body of Scaletta Uzzone Sandstones near its northern termination sandwiched between the LS1b and LS1c siliceous horizons and the underlying Poggiolo Fm b) Detail of the Scaletta Uzzone Sandstones.

Poggi-Roccoverano, where the lithology is essentially marly, whereas it exceeds 200 m near C. Mazzurini, where the unit encases the body of C. Mazzurini Sandstones. The formation is bounded at the base by the Montechiaro d'Acqui Siliceous Lithozone (LS1) and by the Serole Fm at the top. In part of the study area the upper contact is an erosional unconformity of pluri-hectometric extent (cf. Pl. I and paragraphs 5.5.8 to 5.5.11). Along this erosional surface variable thicknesses of the Montechiaro d'Acqui Fm have been removed and only locally the original thickness is preserved. The largest scars, liable to be mapped, were defined "erosional depressions". The base of the overlying Serole Fm is therefore irregular on large scale. Between the Bric del Mondo (W of San Massimo) and C. Mevie (Rocchetta area), and on the heads of the Rio della Torre (right-side tributary of the Rio Uzzone) the Montechiaro d'Acqui Fm is almost completely preserved. Conversely, in the Uzzone Valley the unit has been almost completely removed (Uzzone Valley Erosional Depression), except in the downthrown Rio della Chiesa fault block bounded by the Gerba and S. Ilario faults, where the unit is completely preserved (Fig. 49 and Pl. II).

The Montechiaro d'Acqui Fm shows different features in the northern and southern sectors of the study area, due to the local presence of sandstone units encased in the formation. Although some units, i.e. the Rio della Chiesa Glaucony and the C. Ciappellano Sandstones, are

represented in both areas, other units, specifically the Castelletto Uzzone Sottano Sandstones and the Rio della Chiesa Lower and Upper Sandstones, are exclusively present in the Rio della Chiesa area (Fig. 15); moreover, none of the sandstone units occurring in the Rio della Chiesa and Rio della Torre areas crops out on the left side of the Bormida di Spigno Valley, that is on the ridge dividing the Bormida and Uzzone valleys.

The formation corresponds, *pro parte*, to the *Membro superiore della Formazione di Rocchetta* of the Sheet Ceva to scale 1:100000 of the "Carta Geologica d'Italia" (Francani et al., 1971). It also corresponds to the informal unit of d'Atri's (1990) defined as *Marne di Montechiaro d'Acqui*, and to the interval defined *massive mudstones* of the *Gruppo Rocchetta-Monesiglio* of Gelati and Gnaccolini (1998), to the *white marls* of the *Carrosio unit* of Mutti et al., (2002) and to the *peliti massive (RTMa)* of the *massa di fondo* of the *Formazione di Rocchetta-Monesiglio* by Gelati et al. (2010a, b). The formation, moreover, corresponds to the *Membro marnoso* of the *Montechiaro d'Acqui Formation* of Sheet 194 Acqui Terme (Bellino et al., in press a, b). The marly sediments of the Montechiaro d'Acqui Fm have not been separated in the adjacent Sheet 228 Cairo Montenotte (Dallagiovanna et al., in press b).

Based on calcareous nannoplankton biostratigraphy, the formation is attributed to the latest Aquitanian-early Burdigalian (Zone MNN2a *p.p.*, MNN2b, MNN3a *p.p.*).

In the ensuing sections the following units occurring

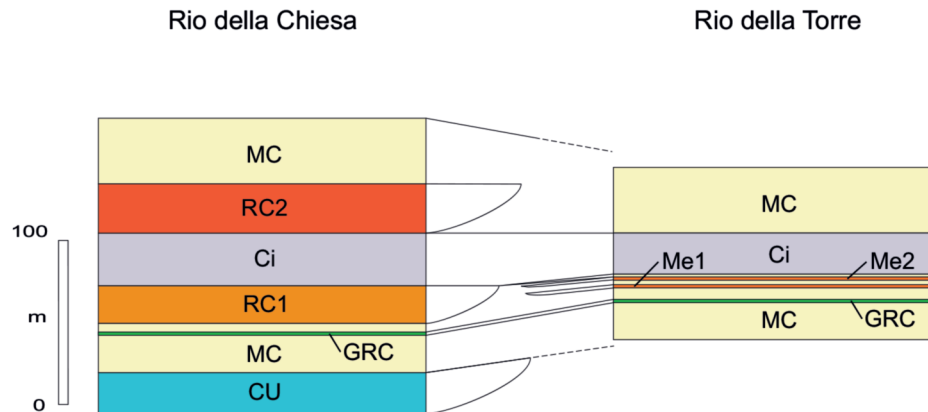


Fig. 15 - Schematic comparison between the stratigraphic successions of the Montechiaro d'Acqui Fm cropping out in the valleys of the Rio della Torre and Rio della Chiesa (both tributaries of the Uzzone stream). MC - marls of the Montechiaro d'Acqui Fm; CU - Castelletto Uzzone Sottano Sandstones; GRC - Rio della Chiesa Glaucony; RC1 - Rio della Chiesa Lower Sandstones; Me1 and Me2 - C. Mevie Calcarenites; Ci - C. Ciappellano Sandstones; RC2 - Rio della Chiesa Upper Sandstones.

within the Montechiaro d'Acqui Fm will be described:

Altitude 483 Sandstones
 Pian Bruno Calcarenites
 C. Poggi Calcarenites
 C. Mevie Calcarenites
 C. Mazzurini Sandstones
 Rio della Chiesa Glaucony
 Castelletto Uzzone Sottano Sandstones
 C. Ciappellano Sandstones
 Rio della Chiesa Lower Sandstones
 Rio della Chiesa Upper Sandstones

4.7.1. Altitude 483 Sandstones

This unit is a wedge-shaped body with maximum thickness of about 15 m, cropping out in the north-eastern sector of the study area, exclusively N of the Pian dei Buri Fault near the point of altitude 483 m, W of Bric Arborella. It is made up of turbiditic sandstone-mudstone couplets in medium strata (15-30 cm). To the S it is bounded by the Pian dei Buri Fault. To the north, away from this fault, it closes laterally in a few hundreds of metres. The unit is confined within a small submarine structural depression, which later also accommodated the Pian Bruno Calcarenites (Ghibauda et al., this volume) (see below). Based on the ages of the bounding units, the Altitude 483 Sandstones may be attributed to the early Burdigalian (Zone MNN2a *p.p.*).

4.7.2. Pian Bruno Calcarenites

This unit is a wedge-shaped carbonate body located to the N of the Pian dei Buri Fault, in the basal part of the Montechiaro d'Acqui Fm. It has lateral extent of about 2.2 km and maximum thickness of about 35 m near the Pian dei Buri Fault, with a gradual wedging out northwards. It consists of glauconite-rich, resedimented, biocalcarenites and biocalcirudites in thick to very thick graded strata, mostly amalgamated. In the Ovrano Valley, W of Molino

d'Ovrano, the unit is completely eroded along a distance of about 800 m by the Bric Torrione slump scar, which is infilled with turbiditic deposits of the overlying Serole Fm (cf. Pl. I). The unit is confined within a small submarine structural depression developed N of the Pian dei Buri Fault and bounded by the fault itself (Ghibauda et al., 2001b; Ghibauda et al., this volume). The Pian Bruno Calcarenites may be assigned to the early Burdigalian (Zone MNN2a *p.p.*).

4.7.3. C. Poggi Calcarenites

The unit crops out in the north-eastern sector of the study area. It is a lenticular body with erosional base, maximum thickness of 22 m and lateral extent of about 1.5 km. It consists of resedimented biocalcarenites and biocalcirudites in thick to very thick strata, relatively rich in glauconitic grains (1-5 %), associated with carbonate debris flows and an interval of resedimented glauconites up to 5 m thick in the lowermost part. Paleocurrents indicate transport towards ESE. The unit is interpreted as a slope or base-of-slope channel fill (Ghibauda et al., 2001b; Ghibauda et al., this volume).

The C. Poggi Calcarenites correspond, *pro parte*, to the *Intervallo carbonatico superiore* of Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b), and to the *corpo superiore carbonatico* of d'Atri (1990). The lowermost glauconitic interval corresponds to the *Areniti ibride glauconitiche* of Gelati and Gnaccolini (1998) and Gelati et al. (2010a, b) and to the *Corpo inferiore glauconitico* of d'Atri (1990). This interval is possibly equivalent to the *Livello delle arenarie glauconitiche risedimentate* cropping out in the adjacent Sheet 228 Cairo Montenotte (Dallagiovanna et al., in press a, b). The C. Poggi Calcarenites, based on the age of bounding units, may be assigned to the early Burdigalian (Zone MNN2a *p.p.*).

4.7.4. C. Mevie Calcarenites

This unit, cropping out only to the SW of the Pian dei

Buri Fault, consists of two resedimented carbonate beds, specifically a lower biocalcarenitic bed up to 0.8 m thick and an upper biocalciruditic bed up to 2 m thick, separated by some metres of hemipelagic marls. These beds are compositionally very similar to the presumably coeval deposits cropping out N of the Pian dei Buri Fault, as infill of the adjoining Pian Bruno structural depression. They are regarded as deriving from SW-ward overspill of the turbiditic currents flowing in this depression (Ghibaudo et al., this volume).

The C. Mevie calcarenites correspond to the *Intervallo carbonatico inferiore* of Gelati and Gnaccolini (1988). The unit is assigned to the early Burdigalian (Zone MNN2a *p.p.*).

4.7.5. C. Mazzurini Sandstones

This unit is a large-scale wedge-shaped body bounded to the north by the Pian dei Buri Fault. It has maximum thickness of about 150 m in proximity to this fault and closes SW-wards over a distance of about 2.5 km (cf. Pl. I). Paleocurrents indicate transport towards ESE. The unit is encased within the marls of the Montechiaro d'Acqui Fm, and is interpreted as the infill of a half-graben bounded by the Pian dei Buri Fault (Gelati and Gnaccolini, 1998; Ghibaudo et al., 2001b; Gelati et al., 2010a, b; Ghibaudo et al., this volume), here named "C. Mazzurini Half-graben"

The unit is attributed by Gelati and Gnaccolini (1998) to the Aquitanian. Based on calcareous nannoplankton assemblages, it may be assigned to the early Burdigalian (Zone MNN2b *p.p.*).

4.7.6. Rio della Chiesa Glaucony

This unit is a key horizon 0.25-1 m thick, consisting of heavily bioturbated, hemipelagic silty marls very rich in glauconite grains, either sparsely occurring or concentrated in the bioturbation galleries (Fig. 16a, 16b). The horizon is located about 20-25 m above the base of the Montechiaro d'Acqui Fm, and has been traced exclusively in the central-southern part of the study area. It has been identified in the Rio della Chiesa, Rio della Torre and Rio Vallone valleys, NE of Contrada along the road in locality Campo Asinaro, on the track descending to the SE of Gottasecca, and in localities Morozzo and Fornaci Sottane. The unit is attributed to the latest Aquitanian (Zone MNN2a *p.p.*).

4.7.7. Castelletto Uzzone Sottano Sandstones

This unit crops out exclusively in the Rio della Chiesa Valley, i.e. in the Rio della Chiesa fault block bounded by the Gerba and S. Ilario faults (Fig. 15 and Pl. II). It is sandwiched between the Castelletto Uzzone Soprano Siliceous Lithozone (LS1c) at the base and the marls of the Montechiaro d'Acqui Fm at the top. The unit is 25 m thick and consists of alternating fine- and medium-grained turbiditic mudstones and sandstones in medium strata with variable sandstone/mudstone ratio. The Castelletto Uzzone Sottano Sandstones are assigned to the late Aquitanian (Zones MNN1d *p.p.* - MNN2a *p.p.*).

4.7.8. Rio della Chiesa Lower Sandstones

This unit crops out only in the Rio della Chiesa Valley, in the Rio della Chiesa fault block (Fig. 15 and Pl. II), a few metres above the Rio della Chiesa Glaucony. It is about 24 m thick and consists of alternating fine-grained turbiditic sandstones and siltstones in medium beds, with sandstone/siltstone ratio ≤ 1 (Figs. 17a, 17c). Typically the siltstones are heavily bioturbated. The unit is assigned to the early Burdigalian (Zone MNN2b *p.p.*).

4.7.9. C. Ciappellano Sandstones

This unit crops out in the Rio della Chiesa and Rio della Torre valleys (Fig. 15 and Pl. II), atop the resedimented carbonate beds of the C. Mevie Calcarenites. It is about 25-30 m thick and consists of alternating fine-grained turbiditic sandstones and mudstones in thin to medium beds, with sandstone/mudstone ratio < 1 . The unit is assigned to the early Burdigalian (Zone MNN2b *p.p.*).

4.7.10. Rio della Chiesa Upper Sandstones

This unit crops out only in the Rio della Chiesa fault block (Rio della Chiesa Valley) and is missing in the stratigraphy of the Rio della Torre Valley (Fig. 15 and Pl. II). It is underlain by the C. Ciappellano Sandstones and overlain by about 40 m of Montechiaro d'Acqui marls. The unit is about 25-30 m thick and consists of alternating turbiditic sandstones and mudstones in thick to very thick beds, passing upwards into thick- to medium-bedded alternating sandstones and mudstones. In the middle part



Fig. 16 - The Rio della Chiesa Glaucony. a) The glauconitic level cropping out along the road near the Fornaci Sottane village. b) Detail of the glauconitic level (fallen block) cropping out in the Rio della Chiesa Valley.

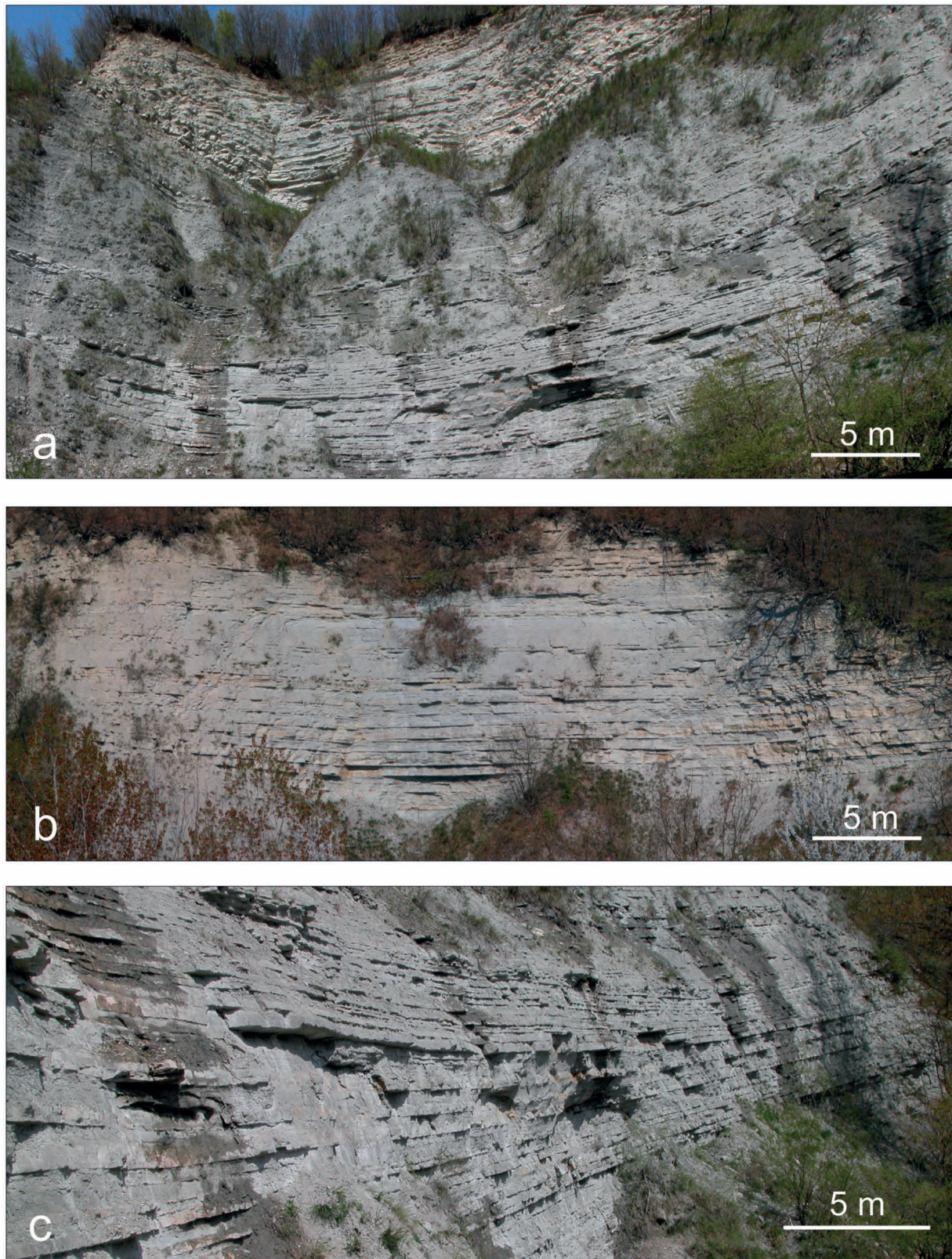


Fig. 17 - Sandstone units of the Montechiaro d'Acqui Fm cropping out in the Rio della Chiesa Valley. a) Rio della Chiesa Lower and Upper Sandstones separated by the C. Ciappellano turbidite couplets. b) Detail of the Rio della Chiesa Upper Sandstones. c) Detail of the Rio della Chiesa Lower Sandstones.

a debris-flow up to 4 m thick, is present (Fig. 17a, 17b). The unit is assigned to the early Burdigalian (Zone MNN2b *p.p.*).

4.8. Serole Formation

This is a heterogeneous unit consisting of turbiditic couplets with sandstone/mudstone ratio $\ll 1$, encasing, at different stratigraphic levels, sandstone bodies with geometry ranging from large-scale lenticular to tabular (cf. the geological map and Pls. I and IVc). Typically, the sandstone divisions of the couplets are 5-30 cm thick and the mudstone divisions 20-80 cm. In the study area the Serole Fm also comprises some large-scale erosional surfaces, named Denice, Bric Torrione, C. Rocchino and Uzzone Valley Erosional Depressions (cf. Pl. I). These surfaces are present at the base of the formation, where they remove variable thicknesses of the underlying succession. They can be observed only in limited outcrops and cannot be physically traced in the field, so that their extent and geometry are extrapolated in the map on the basis of the extent of removed sediments, or of the

presence of sandstone bodies confined within them. In particular, the sandstone bodies named Bric Torrione and Vignazze Sandstones are accommodated in the respective erosional depressions.

The Serole Fm is bounded by the Montechiaro d'Acqui Fm at the base and by the Cortemilia Fm at the top. The basal contact is conformable and rapidly transitional except where it is characterized by erosional discontinuities. The upper contact is transitional (Fig. 18a). The formation shows a progressive wedging out from SW, where it reaches a thickness of about 250 m, to the NE, where it is reduced to a few tens of metres (e.g. near Denice) (Pl. I). In the type-locality (San Sebastiano-Serole road), the formation is 115 m thick. Regionally, the formation closes to the NE within a few kilometres, on the left side of the Erro Valley (Sheet Acqui Terme), whereas it extends for many kilometres to the SW, gradually thickening in the Sheet Deigo (Ghibaudo et al., unpublished data).

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), to the *Unità Pezzolo* of the Fava's

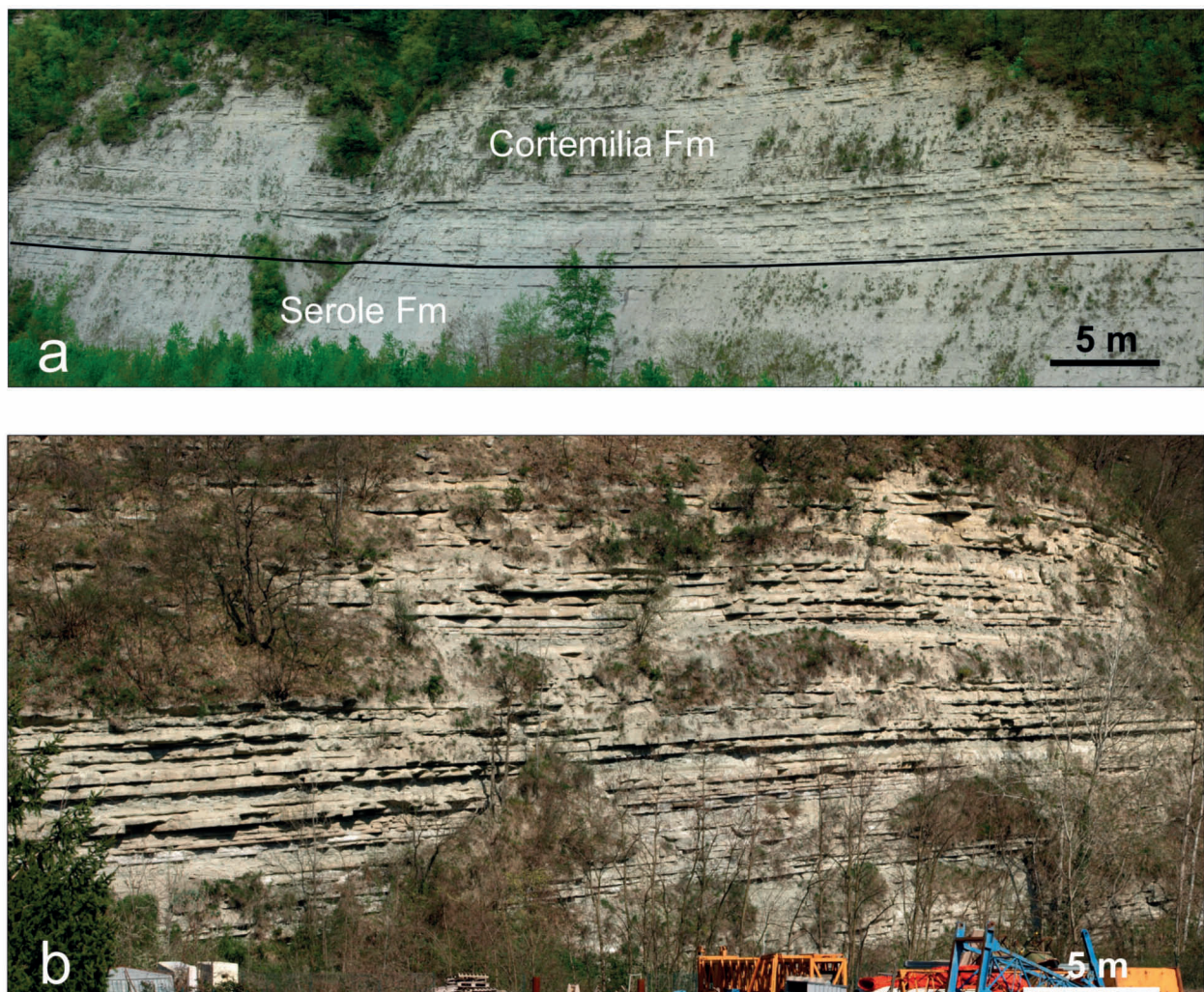


Fig. 18 - Cortemilia Fm. a) Transitional boundary between the Serole Fm and the overlying Cortemilia Fm in the Uzzone Valley; b) The Cortemilia Fm in the type locality. Note the alternation of sheet-like, thick-bedded sandy packages and medium-bedded intervals.

(2001) *Cartosio Group* and to the *Poggiolo system* of the *Carrosio unit* of Mutti et al. (2002). It also corresponds, *pro parte*, to the interval of *alternanze ritmiche di arenarie e peliti sottilmente stratificate (RTMb)* of the *massa di fondo* of the *Formazione di Rocchetta-Monesiglio* of Gelati et al. (2010 a, b). The unit may be assigned to the middle Burdigalian (Zones MNN3a *p.p.* - MNN3b *p.p.*).

The following units and erosional features identified in the Serole Fm will be described:

Piantivello Sandstones
Denice Erosional Depression
Bric Torriero Erosional Depression
C. Rocchino Erosional Depression
Uzzone Valley Erosional Depression
Bric Torriero Sandstones
Vignazze Sandstones
Rio della Torre Lower Sandstones
Rio della Torre Upper Sandstones
C. Zabocci Sandstones
Gottasecca Sandstones

4.8.1. Piantivello Sandstones

This unit is a lenticular, large-scale sandstone body with maximum thickness of about 100 m and lateral extent of about 4.6 km. The basal contact is sharp and erosional, the upper transitional in a short space. The unit is interpreted as the infill of a broad, base-of-slope submarine valley (Ghibaudo et al., this volume). The paleocurrents indicate provenance from WNW. Based on the age of bounding units, the unit is dated to the middle Burdigalian (Zone MNN3a *p.p.*).

4.8.2. Denice Erosional Depression

It is located at the extreme NE of the study area. It locally removes completely the Montechiaro d'Acqui Fm, thus resulting in the direct contact of the turbiditic couplets of the Serole Fm with the Montechiaro d'Acqui Siliceous Lithozone (LS1). The limited exposure does not allow a detailed observation of this surface, so that its extent and geometry were mostly inferred from stratigraphic relationships.

4.8.3. Bric Torriero Erosional Depression

It is a large-scale erosional surface located at the head of the Ovrano Valley. It is about 850 m wide and some tens of metres deep and truncates the Piantivello unit and the Montechiaro d'Acqui Fm. The infill mostly consists of fine-grained turbiditic couplets of the Serole Fm. In its deeper part the infill comprises the Bric Torriero unit (Ghibaudo et al., this volume).

4.8.4. C. Rocchino Erosional Depression

It is a medium-scale erosional depression developed atop the Montechiaro d'Acqui Fm in the area of C. Rocchino. The limited exposure does not allow a detailed

observation of this surface, so that its extent and geometry were mostly inferred from the stratigraphic relationships.

4.8.5. Uzzone Valley Erosional Depression

It is a plurikilometric erosional discontinuity, mostly extending in the Uzzone Valley and its tributaries, S of the village of Poggiolo and on the left side of the Bormida di Spigno Valley (Pls. I, II). Due to the scarce exposure, its extent and geometry were mostly inferred from the stratigraphic relationships. As a result of variable gravity-driven truncation, either most of the Montechiaro d'Acqui Fm has been removed, bringing the base of the Serole turbiditic couplets slightly above the Rio della Chiesa Glaucony or, in the case of more important removal, the Serole Fm was brought directly in contact with the LS1 Montechiaro d'Acqui Siliceous Lithozone. In this area the stratigraphic succession of the Montechiaro d'Acqui Fm is completely preserved only in the inferred structural low of Rio della Chiesa fault block (Pl. II) (see below).

4.8.6. Bric Torriero Sandstones

The unit crops out at the head of the Ovrano Valley and consists of turbiditic sandstones in thick to very thick strata, locally amalgamated. It is lenticular, with concave-up base, and has maximum thickness of 23 m and lateral extent of about 750 m. The unit forms part of the infill of the Bric Torriero Erosional Depression (cf. Pl. I), interpreted as a large-scale slump scar (Ghibaudo et al., this volume). The unit is dated to the middle Burdigalian (Zone MNN3a?), based on the age of bounding units.

4.8.7. Vignazze Sandstones

This unit is a sandstone body of approximately tabular geometry, cropping out in the Uzzone Valley and located at the base of the Serole Fm, in the lowermost part of the Uzzone Valley Erosional Depression. The unit has maximum thickness of about 8 m and lateral extent of about 2.9 km. Age: middle Burdigalian (Zone MNN3a).

4.8.8. Rio della Torre Lower Sandstones

This unit crops out in the valleys of Rio della Torre and Rio Rigosio in the lowermost part of the Serole Fm. In the former valley the unit has maximum thickness of about 25 m, extends over a distance of about 1.25 km in a section transverse to the paleocurrents, and shows a depositional termination to the SE. It consists of alternating turbiditic fine-grained sandstones and mudstones in medium strata, with sandstone/mudstone ratio ≥ 1 . Fine-grained sandstones in medium to thick and amalgamated strata, as well as subordinate debrite layers are present in the lower part. Age: middle Burdigalian (Zone MNN3a).

4.8.9. Rio della Torre Upper Sandstones

This unit crops out in the Rio della Torre, Uzzone and Rio Rigosio valleys. In the Rio della Torre Valley the unit

has maximum thickness of about 20 m and an almost tabular geometry. It extends over a distance of about 1.5 km in a direction transverse to the paleocurrents and closes depositionally to the SE. It consists of alternating turbiditic medium-grained sandstones and mudstones in medium to thick strata, with sandstone/mudstone ratio > 1. Medium- and coarse-grained sandstones in thick and amalgamated strata, associated with horizons with metric thickness displaying slump folds are present. The paleocurrents indicate south-westerly provenance. Age: middle Burdigalian (Zone MNN3b).

4.8.10. C. Zabocci Sandstones

The unit crops out in the south-western part of the study area and consists of sandstones in thick and amalgamated strata, grading upwards into alternating sandstones and mudstones in medium to thick strata. It is a small unit with gently lenticular geometry, slightly extending to the SW, outside the study area. Age, based on bounding units: middle Burdigalian (Zone MNN3a?).

4.8.11. Gottasecca Sandstones

The unit crops out in the south-western part of the study area. It shows an approximately tabular geometry and closes depositionally NE of Gottasecca. Near this locality it consists of sandstones in thick and very thick strata, mostly amalgamated, and subordinate thick-bedded sandstone-mudstone couplets with sandstone/ mudstone ratio > 1. Age: middle Burdigalian (Zone MNN3b?).

4.9. Cortemilia Formation

The Cortemilia Fm is bounded by the Serole Fm at the base and the Bubbio Siliceous Lithozone (LS2a) at the top (see paragraph 4.10 and Fig. 13b). Where the latter is missing, the unit grades transitionally upwards into the Cassinasco Fm. The Cortemilia Fm corresponds to the *Formazione di Cortemilia* of Gelati (1968), Francani et al. (1971), and Gelati et al. (2010a, b) and to the *Cortemilia unit* of Mutti et al. (2002). It consists in the lower part of alternating sandstones and mudstones in medium and thick strata, subordinately very thick, with sandstone /mudstone ratio ≥ 1 ; in the middle and upper parts it consists of turbiditic sandstones in thick to very thick, mostly amalgamated strata with sandstone/mudstone ratio $\gg 1$. Bed clustering is commonly observed, leading to roughly tabular bed packages a few metres to some tens of metres thick, separated by variably thick intervals of medium-bedded turbiditic couplets (Fig. 18b).

The Cortemilia Fm may be interpreted as outer-fan unchannelized deposits. Extensive field mapping of the southern margin of the TPB (Ghibaudo et al., in prep.) highlights that the unit wedges out gradually SW-wards (cf. also Pl. I), up to complete pinching out on the right side of the Belbo Valley near the locality of Bragioli (a few kilometers SW of the study area), by means of onlap relationships with respect to the underlying slope and base-of-slope wedge of the Serole Fm. Conversely, in the

easterly direction the unit is traceable up to the Lemme Valley, where it grades into the turbidites of the Costa Area Fm (see also Gelati and Falletti, 1996 and Mutti et al., 2002) interpreted as basin-plain deposits by Ghibaudo et al. (1985). No specific sedimentologic study of this formation has been performed. Age: late Burdigalian (Zones MNN3b *p.p.*-MNN4a).

4.10. Bubbio Siliceous Lithozone

The Bubbio Siliceous Lithozone (LS2a) forms a regionally widespread marker horizon located atop the Cortemilia Fm. Best exposures of this unit are below the Bubbio castle, some kms NE of the study area (Fig. 13b). The unit may be traced continuously in the adjacent Sheets Alba, Acqui Terme and Novi Ligure (Ghibaudo et al., in prep.) (*note 4). In the study area it closes slightly N of Cortemilia near the locality of C.na Lava. Regionally, the horizon separates the Cortemilia Fm from the overlying Cassinasco Fm. SW of C.na Lava, where the siliceous horizon is missing, the boundary between the two turbiditic units is transitional and hardly traceable. The Bubbio Siliceous Lithozone consists of alternating, thin- to medium-bedded, hard, parallel-laminated silica-cemented siltstones and mudstones. The deposits are quite similar to those of the uppermost part of the underlying Montechiaro d'Acqui Siliceous Lithozone (LS1). Also these deposits are regarded to represent condensed sediments.

Age: earliest Langhian (Zone MNN4c *p.p.*) (Ghibaudo et al., in prep.).

4.11. Cassinasco Formation

This unit crops out only in the north-western sector of the study area. Unpublished regional field mapping in the adjoining Sheets Alba and Acqui Terme shows that this formation is regionally separated from the underlying Cortemilia Fm by means of the Bubbio Siliceous Lithozone (LS2) (Ghibaudo et al., in prep.). In all its extent the unit is extremely sandy and consists of sandstones in thick- to very-thick and amalgamated beds (Fig. 19), locally alternating with thin pelitic layers or rare intervals of medium- and thick-bedded sandstone-mudstone couplets with sandstone/mudstone ratio around 1. Common bed clustering leads to bed packages of tabular geometry, separated by variably thick intervals of medium- to thick-bedded sandstone-mudstone couplets.

The Cassinasco Fm is here referred to an oversupplied deep-sea fan or sandy ramp setting located at the base of a submarine slope fed by sand-rich deltaic depositional systems (Heller and Dickinson, 1985). Detailed mapping in the adjoining sheets highlights that the formation wedges out progressively eastwards and closes on the right side of the Bormida Valley, near the villages of San Quirico and Scapitta (about 40 km NE of the study area), by onlap on the prograding slope wedge of the Cessole Fm (Ghibaudo et al., in prep.). The Cassinasco Fm corresponds, *pro parte*, to the *Formazione di Cassinasco* of Gelati (1968), Francani et al. (1971), Gelati et al. (2010a,



Fig. 19 - Detail of the thick- to very thick-bedded, amalgamated sandstones beds of the Cassinasco Fm cropping out along the road Torre Bormida-Cravanzana.

b) and to the *Lequio unit* of Mutti et al. (2002). No specific sedimentologic study has been performed on this formation. Age: Langhian-Serravallian.

5. DEPOSITIONAL SETTING

The following sections will be devoted to a description of the facies and paleoenvironmental setting of some of the main sandstone units constituting every formation. Given the large number of recognized sandstone bodies, the facies analysis was limited to major sandstone units, mostly cropping out in the central-southern part of the study area. For the north-eastern sector (Roccoverano-Merana area), we refer to the depositional setting already defined in former papers (Gelati and Gnaccolini, 1998; Ghibaudo et al., 2001a, 2001b, Ghibaudo et al., this volume).

Due to logistic problems, only a single stratigraphic-sedimentologic section was measured for every unit taken into account and more detailed sedimentological analysis based on specific cross-sections could not be performed. The field description of sediment gravity flows was based on the classification of turbiditic deposits proposed by Ghibaudo (1992). The main turbiditic reference facies are the following: conglomerate (Facies G - *Gravel*), conglomerate-sandstone couplet (Facies GS - *Gravel Sand couplet*), conglomeratic sandstone (Facies GyS - *Gravelly Sand*), amalgamated sandstone (Facies S - *Sand*), sandstone-mudstone and mudstone-sandstone couplet (Facies SM - *Sand Mud couplet* and Facies MS - *Mud-Sand couplet*), conglomeratic mudstone and mud-supported conglomerate (Facies GyM - *Gravelly Mud* and Facies MyG - *Muddy Gravel*).

The conglomerates, the conglomerate-sandstone couplets, the conglomeratic sandstones and the amalgamated sandstones are interpreted as deposits laid down by high-concentration turbidity currents with sandy-gravelly or coarse sandy load. These flows are typically characterized by a density bipartition during the transport or just before the deposition, due to gravity transformation of the flow, with a lower non-turbulent gravelly-sandy or coarse sandy portion and an upper

turbulent portion containing the finer fractions which are not part of the bed load (Sanders, 1965; Ghibaudo, 1992; Mutti, 1992; Mutti et al., 1999). Deposition from these flows is characterized by two stages: a) dumping of the coarse bed load at the base of the submarine slopes, while the upper turbulent portion can bypass downcurrent as residual current with medium or dilute concentration, b) deposition from the residual turbidity current in areas located downcurrent with respect to the coarse bed load. The graded to laminated sandstone-mudstone and mudstone-sandstone couplets (Bouma Ta-e, Ta-b/e, Ta/c/e) are interpreted as laid down by classic turbidity currents with intermediate concentration; the laminated sandstone-mudstone and mudstone-sandstone couplets (Bouma Tb-e, Tb/e, Tc/e, Td-e) as the product of dilute flows depositing their load in traction-plus-fallout conditions; the pebbly/cobbly mudstones as debris flow deposits.

For sake of clearness, in the ensuing review the essential characteristics of the various sedimentary units in terms of geometry and lithology are briefly retrieved from the preceding descriptive section.

5.1. Rocchetta Formation

Gelati and Gnaccolini (1998) attribute the Rocchetta Fm cropping out in the northern sector of the study area to a slope setting passing upwards into a base-of-slope setting. This attribution is matched by Ghibaudo et al. (this volume) on the basis of the facies association consisting of dominant hemipelagites encasing channelized turbiditic sandstone bodies, large-scale intraformational unconformities (slump scars) and large submarine slump sheets and slides. The presence of small- and medium-scale scour-and-fill structures (turbidite gutter casts) (Fig. 20), indicating active bypass of turbidite flows, supports a slope depositional setting for this formation. The largest turbidite bodies occurring in the Rocchetta Fm (Mogliavacca, Brovida, Cobarello and Noceto units) are concentrated in the Rocchetta Cairo

Depocentre. These bodies are vertically stacked and show a trend of upward increasing width/thickness ratio reflecting a change from upper slope to base-of-slope setting. The sandstone bodies of the Rocchetta Fm cropping out in the central and southern parts of the study area were assigned by Cazzola et al. (1981), Cazzola and Sgavetti (1984), Cazzola and Rigazio (1983), Cazzola et al. (1985) and Cazzola and Fornaciari (1990) to an essentially basal setting, in the frame of a model of sand-rich, low-efficiency deep-sea fans, with different parts of specific sandstone bodies referred to the proximal-channelized or distal unchannelized settings. Similarly, Gelati and Gnaccolini, (1980) attribute various sandstone bodies cropping out S of the mapped area to a generic deep-sea fan setting.

Four types of turbiditic sandstone bodies may be distinguished in the Rocchetta Fm, based on the geometry and dimensions (Pl. I):

Lenticular sandstone bodies of small to intermediate dimensions, with comparatively low width/thickness ratio

(thickness in the order of tens of metres and lateral extent ranging from 350 m to about 1 km in direction roughly transverse to paleocurrents);

Sandstone bodies with broadly lenticular geometry, i.e. with comparatively high width/thickness ratio (thickness in the order of a few tens of metres and lateral extent of about 1-2 km);

Sandstone bodies with lenticular geometry and large dimensions (thickness in the order of hundreds of metres and lateral extent ranging from 3 km to 10 km);

Sandstone bodies with wedge-shaped geometry bounded by growth faults;

Sandstone bodies with approximately tabular geometry (thickness of a few tens of metres and lateral extent ranging from 1.9 km to 3.4 km).

5.1.1. Sandstone bodies with lenticular geometry and small to intermediate dimensions

The lenticular sandstone bodies with small to



Fig. 20 - Rocchetta slope mudstones with scour-and-fill structures indicative of sedimentary bypass. - a), b) Small- and medium-scale turbidite gutter casts. c) Large-scale scour-and-fill structure at the base of a sandstone body a few metres thick (not visible in the photograph) pinching out laterally in some tens of meters.

intermediate dimensions include the following units: (cf. geological map and Pl. I): Piana Crixia Conglomerates, Sassore Sandstones, Vignazza Sandstones, Altitude 524 Sandstones, Vignaroli Sandstones, C. del Bric Sandstones, Rodini Lower and Middle Sandstones, Codevilla Sandstones, Bric Petacchi Sandstones, and Molino di Mombaldone Lower, Middle and Upper Sandstones. Only the Rodini Lower and Middle Sandstones have been the subject of sedimentological analysis (cf. Figs. 9 and 10).

The units are turbiditic bodies consisting of medium- to very coarse-grained sandstones in medium to thick or very thick and amalgamated strata associated with minor intervals of sandstone-mudstone couplets in medium to thick strata. The bodies are interpreted as slope to base-of-slope channelized deposits or confined unchannelized deposits (Bric Petacchi, Molino di Mombaldone middle and upper units). Paleoflow data are only available from the Piana Crixia Unit, for which Cazzola et al. (1981) report eastward paleocurrents, and from the associated large-scale lenticular bodies of the Rocchetta Fm which indicate a paleoslope dipping to SE. We believe that the data can be extrapolated to the above-mentioned smaller bodies, assuming a general feeding from source areas located to the NW or WNW. However, local provenances from SW, i.e., from the south-western margin of the Langhe Sub-basin (Monregalese High of Gelati and Gnaccolini, 1996, 2003) cannot be excluded.

5.1.2. Sandstone bodies with broadly lenticular geometry

These bodies include the Ovrano Lower, Middle and Upper Sandstones, the Pian del Lago Sandstones and the Bric della Lasagna Sandstones. These units are interpreted as confined bodies infilling accommodation space created by local synsedimentary tectonics. The Ovrano units, in particular, are interpreted to represent the sequential infill of accommodation space created as a result of the growth of a monocline developed over a buried high-angle basement fault (Ghibaudo et al., this volume). The Pian del Lago and Bric della Lasagna units, on the other hand, infilled accommodation space created on the hangingwall of the Girona listric growth fault (see also paragraph 4.3 and 6.2 dealing with the "Rio Girona stratigraphic expansion" and Pl. I).

5.1.3. Sandstone bodies with lenticular geometry and large dimensions

They include the following units: Mogliavacca Sandstones, Rodini Upper Sandstones, Brovida Sandstones, Cobarello Sandstones and Gabutti Sandstones (cf. Pl. I).

5.1.3.1. Mogliavacca Sandstones

Geometry, dimensions, lithology and paleocurrents: the unit has marked lenticular geometry, large-scale erosional basal surface, maximum thickness of about 250 m, and lateral extent of 3.4 km in a section transverse to paleocurrents. It is made up of sandstones, conglomeratic

sandstones, conglomerates and debris flow deposits in thick and amalgamated strata. Paleocurrents indicate SEward transport direction.

Basal relationships: A growth fault (La Costa Fault) brings the lower part of the unit in contact with the shelf deposits of the Molare Fm (Pl. I).

Facies: the facies association and internal organization of the axial part of the Mogliavacca Sandstones are shown in plate V and figure 21. The facies association of the upper portion near the south-westerly termination of the unit is shown in Pl. VI. The location of the sections is schematically shown in figure 11. The axial portion of the unit is extremely sandy and virtually free of mudstone partings. It is made up of the following facies: conglomerates, conglomerate-sandstone couplets, conglomeratic sandstones, amalgamated sandstones and gravelly mudstones. Conglomeratic beds comprise about 49% of the axial section and are mostly developed in the lower part of the Mogliavacca unit, with conglomerate-sandstone couplets and pebbly sandstones being the most common lithologies (Pl. VI). The beds are thick to very thick (1-5 m), amalgamated and characterized by deeply erosional bases. Conglomerate beds are bouldery (clasts up to 180 cm) (Pl. Va, e, i), less commonly pebbly to cobbly (Pl. Vi) and characterized by a subtle graded bedding or a disorganized lower bouldery part passing upwards to pebbly conglomerates or pebbly sandstones. Some bouldery horizons, only a few clasts thick (Pl. Va), suggest a genesis as local residual coarse-grained material left behind by bypassing high-concentration flows. Boulders are sometimes clustered in the basal part of the bed suggesting a collective transport by sliding processes (Pl. Vf). Large intraformational sandstone or mudstone clasts up to 50-150 cm in length are abundant (Pl. Vc, e, l). Such beds, moreover, pinch out over a short distance due to their highly erosional basal contact (Tab. Vg). Conglomerate-sandstone couplets are commonly normally graded (Pl. Vb), less commonly inversely graded in the basal part (Pl. Vh, k) and are characterized by graded coarse sandstones at the top. Thick, subhorizontal traction-carpet stratification (3-20 cm thick) in the sandy upper part of the bed is common. In sections transverse to paleocurrents the conglomeratic basal parts of individual beds have less lateral extent than the upper sandy division and pinch out abruptly over a very short distance (a few metres) resulting in a lateral facies change from conglomerate-sandstone couplets to pebbly sandstone or sandstone beds. Pebbly sandstone beds are graded or inverse- to normally-graded (Pl. Vi), and commonly characterized by thick, subhorizontal stratification or planar laminae in the upper part. Some pebbly sandstone beds particularly thick (up to 3-6 m) contain large sub-rounded blocks (up to 2-3 m) of crystalline rocks isolated in the sandy matrix (Pl. Vj).

The amalgamated sandstone facies makes up about 27% of the axial section and is mostly developed in the upper part (Pl. V). The sandstones are usually very coarse to micro-conglomeratic. Beds are mostly characterized by normal grading (Pl. Vi) in the lower part and thick (2-10

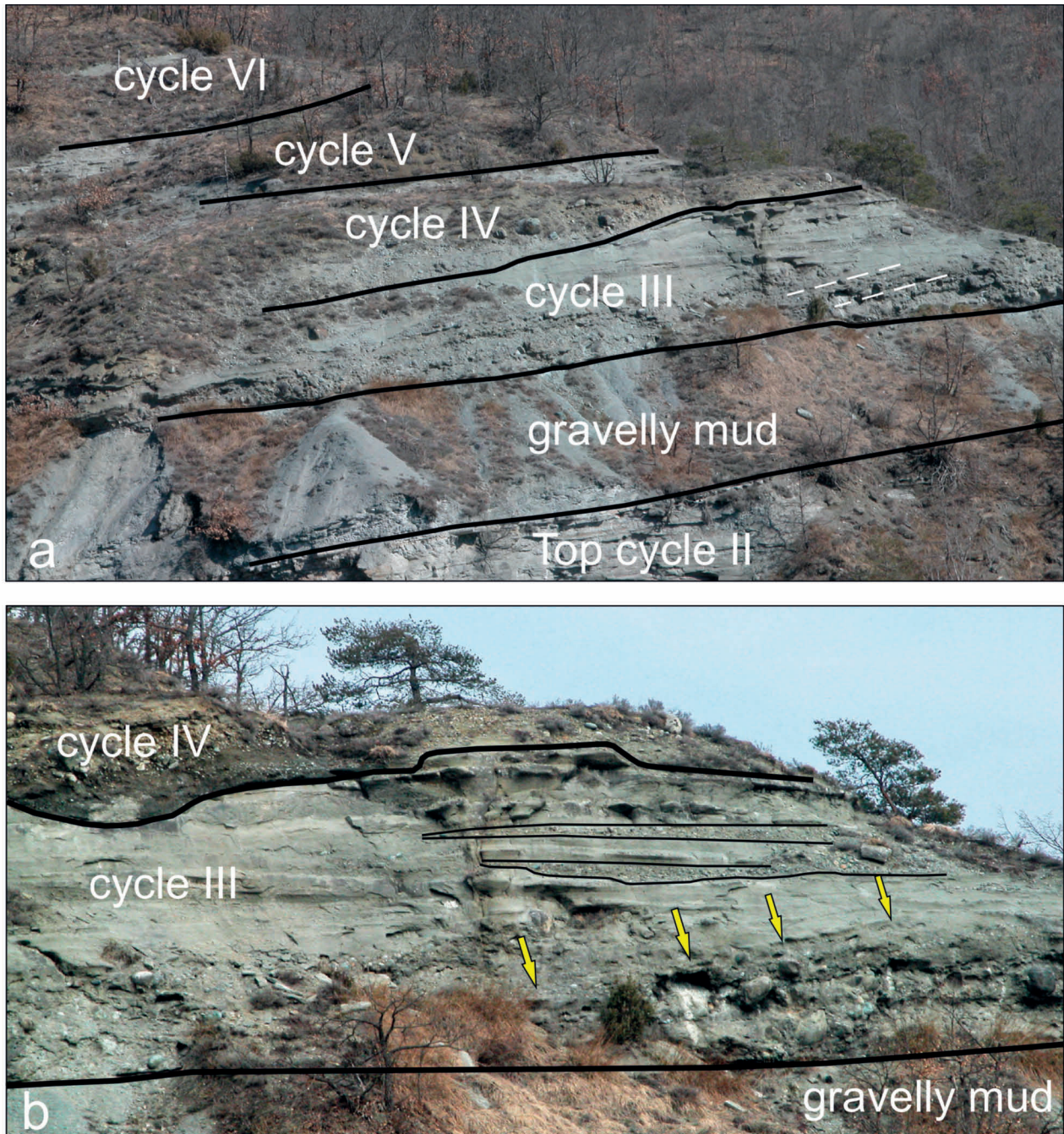


Fig. 21 - a) Lower-middle part of the Mogliavacca canyon fill cropping out on the left side of the Rio Casattana Valley (cf. Pl. V). Note the internal architecture consisting of stacked upward-fining multi-storey cycles characterized by basal pebbly to bouldery conglomerates passing upwards into thick-bedded, amalgamated pebbly sandstones and coarse sandstones. Lateral accretion surfaces in the basal conglomerates of cycle III are highlighted by white dashed. Note also the very thick (15 m) gravelly mud unit corresponding to level 52 of the stratigraphic log of Pl. V. Numbers of cycles correspond to those indicated in Pl. V (section location schematically shown in Fig. 11). b) Detail of the cycle III showing the lateral accretion pattern (yellow arrows) and the internal structure of two conglomerate-sandstone couplets, with the sandy upper part much more extended laterally than the lenticular conglomeratic lower part.

cm) traction-carpet or, less commonly, thin parallel laminae (Bouma's b division) in the upper part (Pl. VI, m). The succession also includes two gravelly mudstone layers (debris flows), respectively 6 and 15 m thick (Pl. V), the thicker one laterally extending for most part of the Mogliavacca unit. Medium- to thin-bedded, subordinately thick-bedded, sandstone-mudstone couplets are

developed in the upper part of the unit and near its SW closure (Pl. VI).

Vertical organization: the Mogliavacca Unit is characterized by a twofold vertical facies organization (Pl. V and Fig. 21): 1) an overall trend thinning- and fining-upwards with conglomeratic lithologies in the lower and middle part and sandy lithologies in the upper part, and

2) an internal subdivision into minor cycles thinning- and -fining upwards. These cycles, 10-30 m thick, show erosional, concave-up or sharp planar base at the outcrop scale, and consist of conglomerates, conglomerate-sandstone couplets and pebbly sandstones in the lower part and amalgamated sandstones in the upper part.

Interpretation: Cazzola et al. (1981) interpret the Mogliavacca Sandstones (their *Lower Budroni Unit*) as the infill of a large-scale NW-SE trending channel. Cazzola and Fornaciari (1990) interpret the same deposits as channel-lobe transition deposits laid down in a half-graben bounded to the NE by a growth fault and to the SW by a supposed intrabasinal high (the *Carretto high*). Field mapping, however, failed to reveal both the bounding fault and the intrabasinal high. Based on dimensions, latero-vertical relationships, markedly lenticular geometry, deeply erosional basal contact and extremely proximal facies association, the Mogliavacca Sandstones are here interpreted as the infill of a submarine canyon. The generation of the large-scale erosional surface and the deposition of the basal coarse deposits of the canyon fill may be interpreted as the response to relative sea level fall and lowstand stages. The subsequent base-level rise would have resulted in the progressive backstepping of the coastal depocentres and consequent decrease in grain size and volume of sediment gravity flows. The sandstone-mudstone turbidites of the upper part of the unit, cropping-out on its SW termination (Pl. VI), may be interpreted as the final deposits of the canyon fill. Such deposits were probably also present in the axial part of the canyon fill, but were later removed by the basal erosion of the overlying Brovida unit.

The La Costa Fault (cf. geological map and Pl. I) may be considered as a growth fault active during the deposition of the mudstones of the Rocchetta Fm and, probably, the basal part of Mogliavacca unit. It appears likely that, in analogy with other examples of present-day submarine canyons, the presence of this fault focused the erosion which triggered the development of the submarine canyon.

The minor cycles thinning- and fining-upwards might be attributed to a high-frequency glacio-eustatic cyclicity superimposed to the lower-frequency lowstand stage. It may be speculated that transgressive-regressive cycles in the shelf controlled the grain size and volume of the sediment gravity flows. In this context the minor cycles of the canyon fill would reflect the dynamics of local thalwegs incised and subsequently infilled with conglomerate and sandstone facies during the high-frequency lowstand and transgressive stages respectively (see also Di Celma et al., 2010). However, in absence of detailed cross-sections, the geometry and internal organization of individual cycles forming the canyon fill, as well as the latero-vertical relationships of the component facies, remain so far poorly known. The bed thickness and the very coarse and proximal nature of the deposits suggest that the canyon head was close to the coeval shelf area which, in turn, was arguably narrow and connected with a high-gradient fluvial network feeding

very coarse-textured depositional systems such as braid-deltas or fan-deltas.

5.1.3.2. Brovida Sandstones

Geometry, dimensions, lithology and paleocurrents: the unit has a asymmetric lenticular geometry and large-scale erosional basal surface in its depocentral portion. It has maximum thickness of about 200 m and lateral extent of about 9 km transverse to the average paleo-flow direction (Pl. I). Towards NE the unit wedges out over a distance of a few hundreds of metres, whereas towards SW it thins out progressively and takes on a more tabular geometry. The geometry of the erosional basal surface defines two local depocentres: one coinciding with the underlying Mogliavacca canyon and the other located to the SW, in the locality "Vallette" (sections 26 and 27 in Figs. 11, 22). The paleocurrents indicate SE-ward transport directions.

Basal contacts: the unit shows an erosional contact with the Mogliavacca Unit (Pl. I), except at the northern termination where the two units are separated by some tens of metres of Rocchetta mudstones.

Facies: the facies and internal organization are shown in the section of plate VII and figures 22, 23, 24. The location of the sections is shown in a schematic way in figure 11. The unit comprises the following facies: amalgamated sandstones, graded to laminated sandstone-mudstone couplets in medium and thick strata, laminated sandstone-mudstone and mudstone-sandstone couplets in thin to medium strata. The amalgamated sandstones are coarse to granule- and, locally, pebbly sandstones, and occur in thick to very thick beds. The beds are characterized almost exclusively by normal grading, developed in the whole bed thickness or in the topmost part (top grading) and are devoid of traction structures. The thicker beds are crowded with centimetric to decimetric intraformational mud clasts. The thick-bedded sandstone-mudstone couplets may be described as Bouma Ta/e, Ta-b/e and Ta/c/e sequences. The laminated thin- to medium-bedded sandstone-mudstone and mudstone-sandstone couplets as Tb/e, Tb-e, Tc/e and Td-e sequences.

Vertical organization: in the axial section (section 22 in Fig. 11, Pl. VII) the unit is made up of a 50 m thick basal sandy part (sandstone bodies I and II of Pl. VII) followed upwards by sandstone bodies interbedded with intervals of mudstone-sandstone turbidites (units III to VIII of Pl. VII). Eight main sandstone bodies may be identified. These show thickness ranging from 35 m to 7 m, and are mostly made up of thick to very thick, amalgamated beds (Pl. VII). Overall, the sandstone bodies show an upward decreasing thickness, whereas the intercalated mudstone-sandstone intervals increase in thickness upwards, thus defining an overall trend fining upwards. Moreover, the lower sandstone bodies are amalgamated (I and II of Pl. VII), whereas the upper ones are separated by plurimetric intervals of thin-bedded couplets. Due to extensive cover the geometry (sheet vs channelized) of such sandstones bodies could not be highlighted. Where the lateral wedging

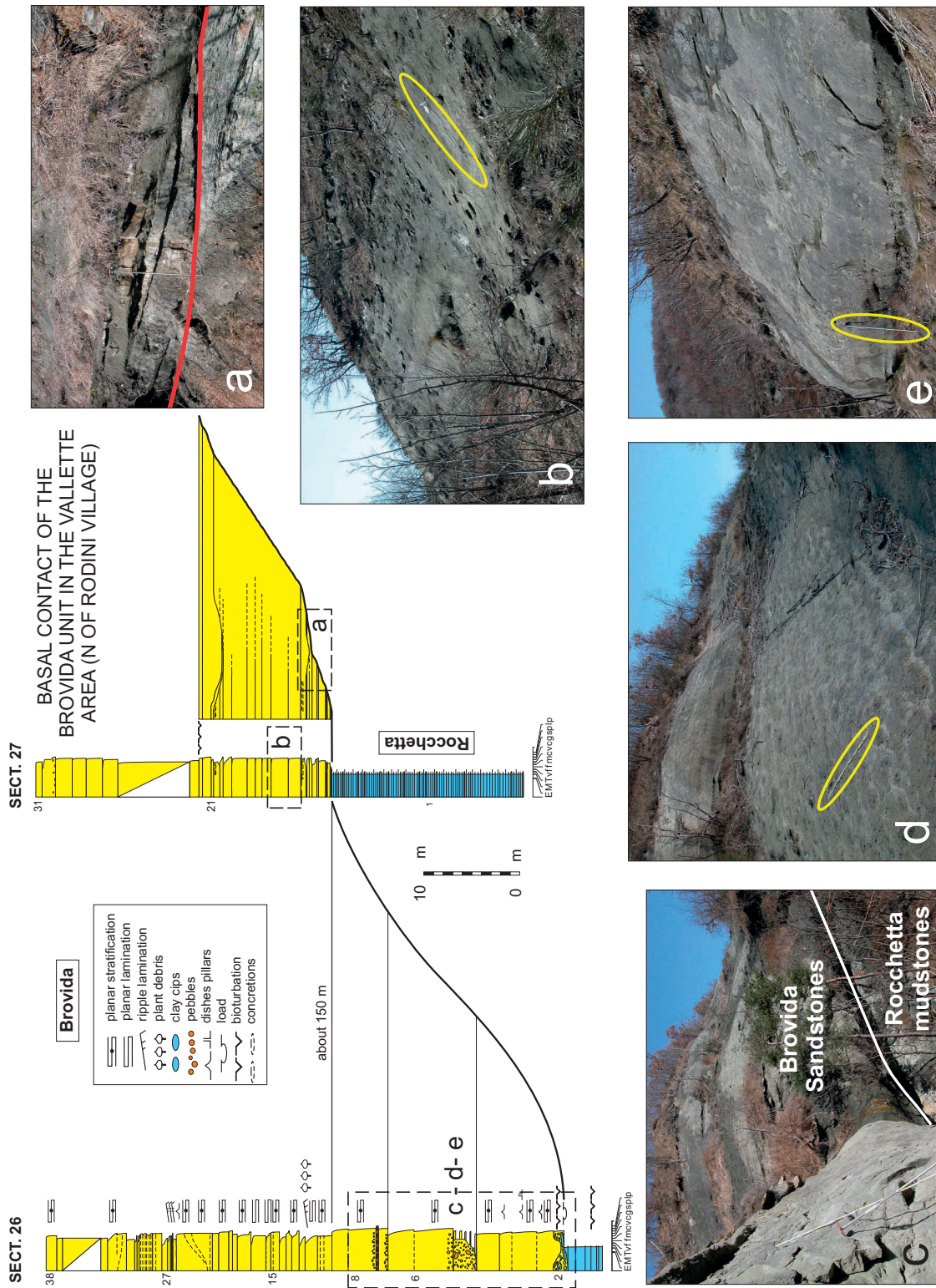


Fig. 22 - Lower part (about 50 m thick) of the Brovida unit in the Vallette area. Location of the sections in figure 11. The correlated logs illustrate the onlap of the Brovida deposits onto the basal surface and the relief of this surface. Insets indicate details shown in the photographs. a) Pinch-out of the basal beds against the basal erosional surface. c) Panoramic view of the lower part of the Brovida Sandstones virtually lacking muddy interbeds atop the Rocchetta mudstones. b), d) Very thick-bedded, amalgamated, crudely graded, coarse-grained sandstones. e) Very thick-bedded, graded pebbly sandstone unit (Jacob staff for scale).

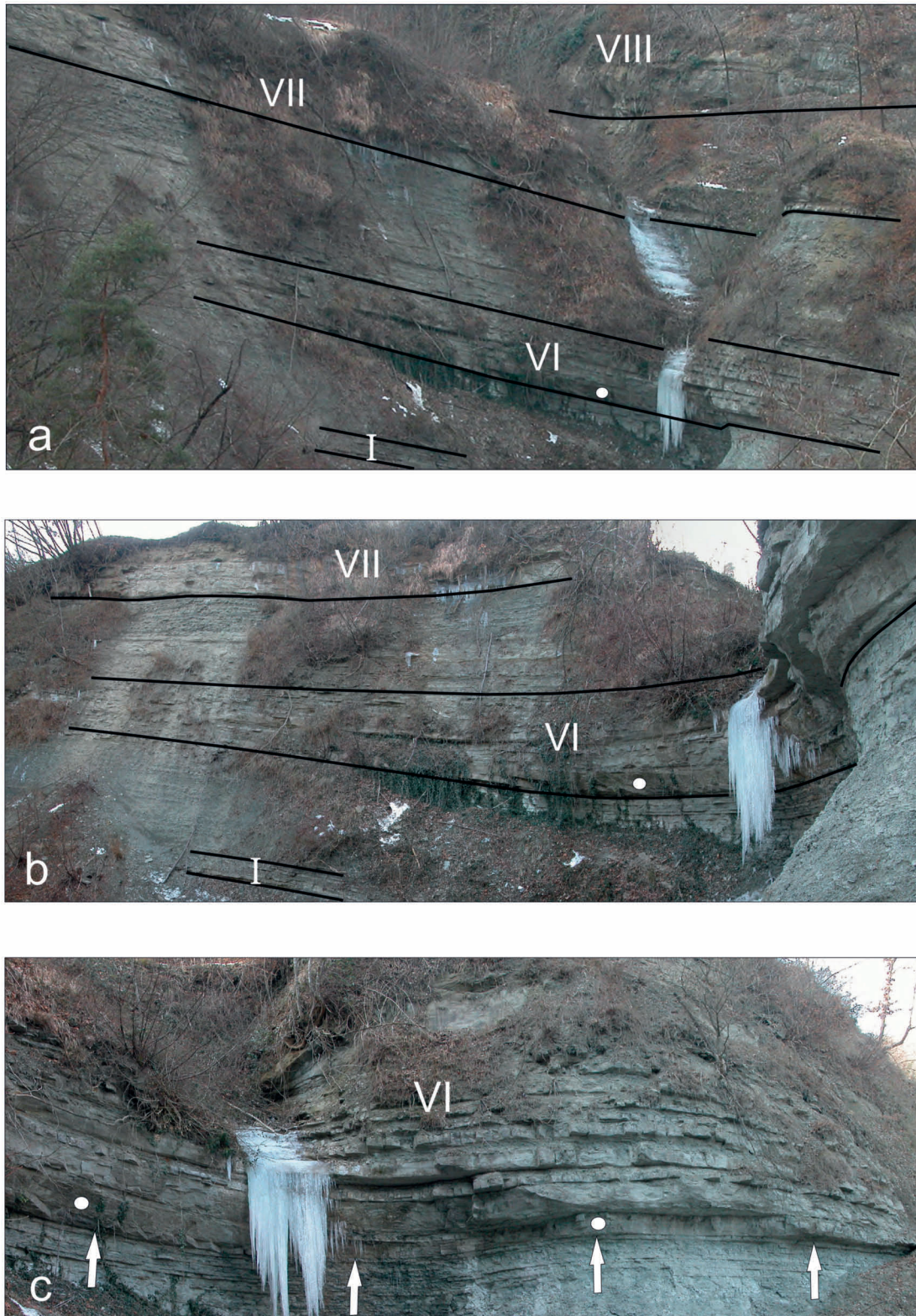


Fig. 23 - Uppermost part of the Brovida unit exposed on the right side of the Rio Casattana Valley. The outcrops are located several tens of m away from the measured section shown in Pl. VII. Roman numbers and capital letters refer to sandstone bodies and bedsets shown in plate VII. The white spot marks the same bed in the photographs; it corresponds to bed 460 in plate VII. a) From base to top the panorama illustrates: 1) dominant, thin- to medium-bedded turbidite sandstones and mudstones interpreted as overbank deposits enclosing thicker bedsets (I) representing more sandier overbanks and a slightly lenticular sandstone body (VI), about 6 m thick, showing a marked lateral facies change in a few tens of metres interpreted as crevasse splay deposits; 2) the basal part of a sharp-based, upward-thinning sandstone body (VII) (see Fig. 21 b and Pl. VII) and the basal part of an erosion-based sandstone body (VIII) both interpreted as channel fill deposit. b) Detail of the rapid lateral facies change of sandstone body VII. Note the slightly concave upward basal surface of the body and the leftward (b) and rightward (c) lateral thinning out of the basal layer (white spot) suggesting infilling of a slight basin floor depression.

VERTICAL FACIES DISTRIBUTION OF THE BROVIDA UNIT IN THE CARRETTO SECTION

SECT. 18

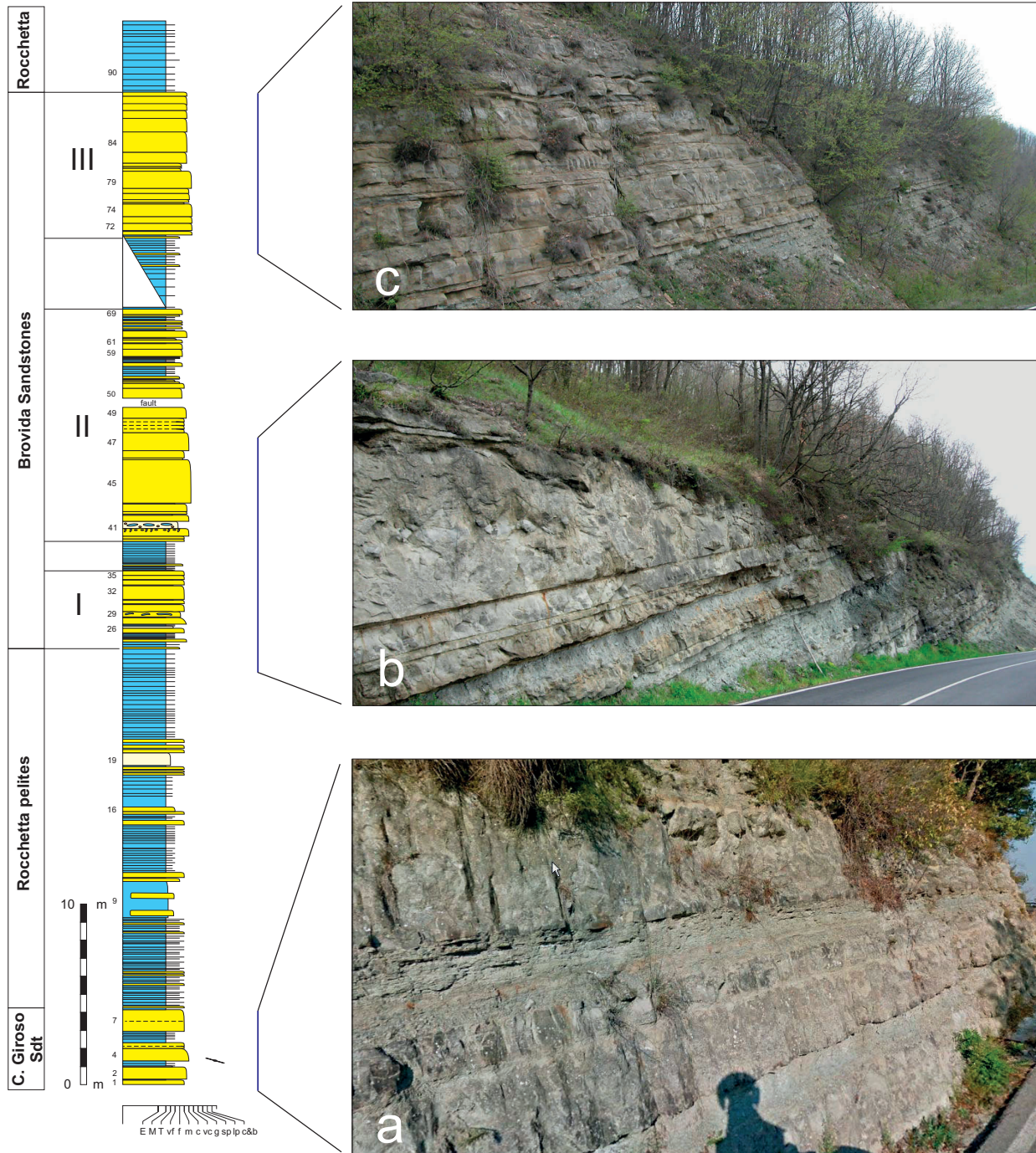


Fig. 24 - Vertical facies distribution of the marginal part of the Brovida unit in the Carretto area (section 18 in Fig. 11) located about 3 kms away from the Brovida reference section (Pl. VII). Sandstone bodies I, II and III (4 to 12 m thick) show nearly tabular geometry. Such tabular bodies may represent crevasse splays developed laterally to time-equivalent channelized units occurring in the axial part of the Brovida unit or, alternatively, nonchannelized depositional lobes representing a final retrogradational phase of the Brovida system.

out is observed (e.g. Rio Serre), the lower sandstone bodies show channelized lenticular geometry ending laterally over a few tens of metres (Fig. 12). The sandstone bodies I and II infill the deepest part of the Brovida erosional

depression. In the Brovida section (cf. section 22 in Fig. 11) these bodies are characterized by the thicker and coarser-grained beds (up to pebbly sandstones) and by internal trends thinning-upwards (Pl. VII, Figs. a, b, c). In

the Vallette area (cf. section 26 and 27 in Fig. 11), time equivalent sandstone units show marked onlap relationships against the basal erosional surface and very-thick bedded, amalgamated sandstone facies (Fig. 22). The middle-upper part of the Brovida section is characterized by sandstone bodies interbedded with variable thicknesses of thin-bedded turbidites. The individual sandstone bodies are sharp-based and show internal trends thinning- and fining-upwards (Pl. VII, bodies III, IV, V, VII, Figs. d, f, h, i). The sandstone body III, in particular, shows lateral accretion surfaces in the basal part (Pl. VII d, e). Such bodies are made up of thick- to very-thick amalgamated sandstones. Most beds are normally graded, graded to plane-stratified or graded to parallel-laminated.

The fine-grained intervals encasing the sandstone bodies mostly consist of thin-bedded, parallel-laminated, fine-grained sandstone-mudstone couplets with sand/mud ratio between 1 and 2. A number of medium-bedded and slightly coarser turbidite packets, 0.5 to 1.5 m thick, are intercalated in the succession (packets A to J in Pl. VII). The local succession also comprises a medium- to thick-bedded sandstone body 6 m thick, with planar top and slightly concave-upward basal surface characterized by a marked lateral facies change to thin-to medium bedded couplets similar to those forming the encasing fine-grained intervals (Pl. VII body VI; Fig. 23). In its SW marginal part (Carretto area, section 18 in Fig. 11) the Brovida unit has a thickness of about 30 m and different facies and sandbody geometry. In such area the unit splits into three sandstone bodies (I, II, III in Fig. 24), 4 to 12 m thick, characterized by tabular geometry and medium- to thick-bedded, amalgamated, graded or graded to laminated sandstone beds. Even if the correlation with the Brovida reference section (about 3 km apart) is uncertain these bodies should be time equivalent of the uppermost part of the Brovida section.

Interpretation: Cazzola et al. (1981) interpret the Brovida Sandstones (their *Upper Budroni Unit*) as channel-lobe transition and lobe deposits. Cazzola and Fornaciari (1990) interpret the same deposits as depositional lobes. Detailed cross-sections in this unit are not available. This prevents a certain paleo-environmental attribution. As pointed out before, however, where the lateral relationships can be observed (e.g. Rio Serre), the lower sandstone bodies of the Brovida unit show channelized lenticular geometry (Fig. 12). Based on the observed features and on the superimposition to the Mogliavacca unit, inferred to represent a canyon-fill, the unit is interpreted as the infill of residual accommodation space left atop the underlying canyon fill, which may have focused the turbiditic flows. It may be assumed that the fining- and thinning-upward sandstone bodies I, II, III, IV, V and VII cropping out in the Brovida reference section (Pl. VII) representing channelized deposits laid down on the apex of a sand-rich deep-sea fan. In such context the thin-bedded turbidites encasing the channelized units may be interpreted as overbank deposits, with the small-scale, medium-bedded bedsets (packets A to J in Pl. VII and Fig. 23) representing more sandy overbanks. The 6 m

thick unit with sharp and slightly erosional base and rapid lateral facies transition to the overbank deposits (unit VI in Pl. VII and Fig. 23), in particular, is interpretable as consisting of crevasse splay deposits. The tabular sandstone bodies cropping out at the SW termination of the Brovida unit in the Carretto area (section 18 in Figs. 11, 24) are tentatively interpreted as crevasse splays developed laterally to time-equivalent channelized units occurring in the axial part of the Brovida unit, or, alternatively, lobe deposits laid down in the final stage of backfilling of the base-of-slope depression. It may be speculated that the large-scale erosional surface and the lower amalgamated succession reflect the falling and lowstand stages, while the upper channel/overbank stratigraphy reflects the following relative sea-level rise.

5.1.3.3. Rodini Upper Sandstones

The unit has marked lenticular geometry, basal erosional surface, maximum thickness of about 100 m and lateral extent of about 1.3 km. The unit consists mostly of thick-bedded amalgamated sandstones. The lower part in the axial portion is characterized by an upward-thinning succession 30 m thick (Figs. 9, 10c), while the middle-upper part is mostly made up of amalgamated sandstones (Fig. 10d). The unit is interpreted as a slope-valley fill.

5.1.3.4. Cobarello Sandstones

Geometry, dimensions, lithology and paleocurrents: the unit has large-scale lenticular geometry with more tabular lateral portions, basal erosional surface, maximum thickness of about 200 m and lateral extent transverse to paleocurrents of about 10 km (Pl. I, Figs. 25a, 26a). Paleocurrents indicate SE-ward transport directions.

Facies: the facies and internal organization of the unit are shown in plate VIIIa. The succession is characterized by amalgamated sandstones (less commonly pebbly sandstones) in thick- to very-thick beds and subordinate sandstone-mudstone couplets in medium to thick beds. Meter-thick intervals of thin- to medium-bedded mudstone-sandstone turbidites separate the main sandstone bodies. The unit is extremely sandy with amalgamated sandstones and pebbly sandstones comprising 64 % of the total thickness (Pl. VIIIa). The amalgamated sandstones are graded, graded to plane-stratified or graded to plane-laminated. The sandstone-mudstone couplets can be described as Ta/e, Ta-b/e and Ta/c/e Bouma sequences. The sandstone/mudstone ratio as a rule is > 1.

Vertical organization: In the type-section (Brovida-Noceto road, section 28 in Fig. 11) the unit is characterized by a stack of five sandstone bodies ranging in thickness from 7 to 70 m (bodies I to V in Pl. VIIIa) The vegetation cover limits the observation of lateral relationships. Although the apparent geometry of the individual sandstone bodies on the outcrop scale is sheet-like, the presence of local channelized deposits cannot be excluded. The sandstone bodies I and II, 7 and 25 m thick

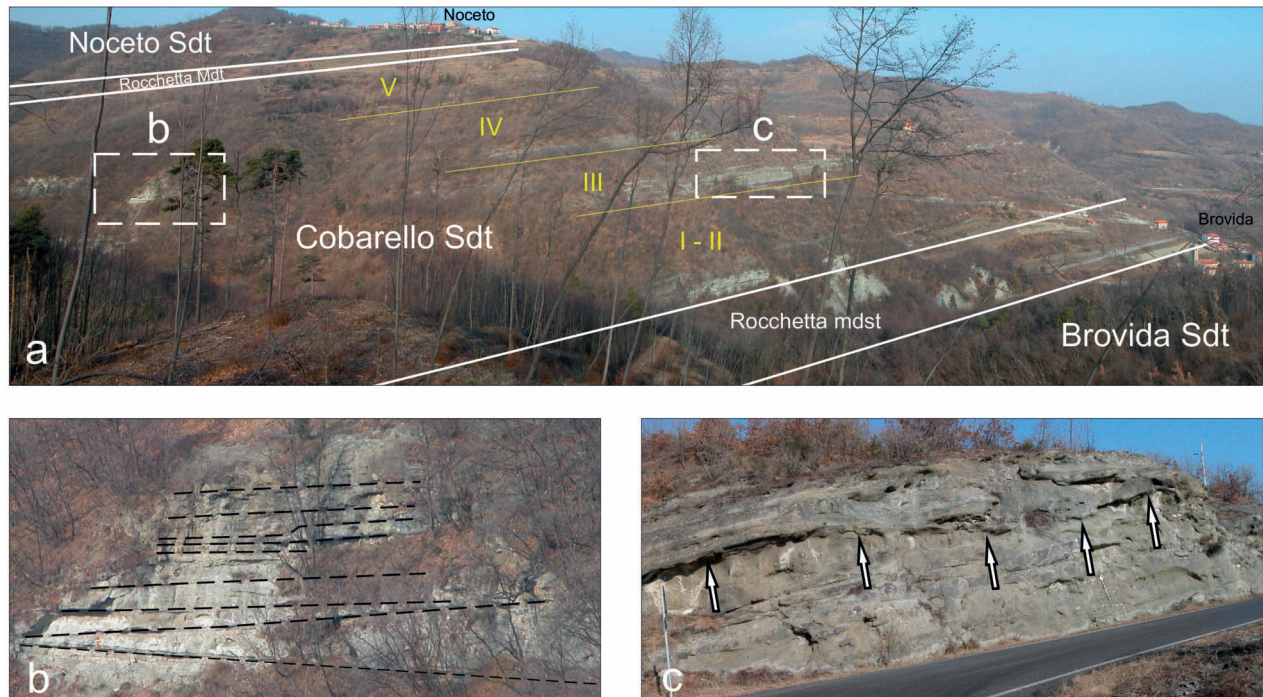


Fig. 25 - a) Panoramic view of the Cobareello Sandstones. The internal multistorey architecture of this unit consists of five stacked, sheet-like sandstone bodies (corresponding to units I to V in Pl. VIIIa) interpreted as proximal lobe deposits. b) Detail of the lower part of the sandstone body IV. Note geometric compensation of very thick basal beds and large-scale scour-and-fill structure in the upper part of the outcrop. c) Detail of the lower part of sandstone body III. Note the large-scale scour-and-fill structure. A frontal view of the same outcrop is shown in figure 26c.

respectively, do not show a clear internal vertical organization (Pl. VIIIa and Fig. 26b). The sandstone bodies III to V are thicker (up to 70 m) and characterized by thinning- and fining-upwards trends (Pl. VIIIa). Sandstone body III, in particular, is characterized, in the basal part, by coarser texture (pebbly sandstones), abundant scour-and-fill structures and large intraformational mudstone clasts up to 80 cm in length (Pl. VIIIa, Figs. 25c, 26c). Scour-and-fill structures are locally present also in other outcrops of the area together with large-scale bed compensation geometries (Fig. 25b).

Interpretation: Cazzola et al. (1981) interpret the Cobareello Sandstones (their *Rapalino unit*) as lobe and channel-lobe transition deposits. In particular, they only discuss the outcrop of figure 26c (basal part of the sandstone body III in Pl. VIIIa) and interpret such deposits as indicative of a channel-lobe transition setting. The pervasive scour-and-fill structures illustrated in figure 26c may be consistent with this interpretation, and suggest repeated erosive events generated by hydraulic jumps as a result of flow expansion occurring at the channel-lobe transition. The lack of lateral outcrop continuity prevents any reliable paleoenvironmental attribution. Based on the apparent sheet-like body geometry and predominance of thick-bedded amalgamated beds, the sandstone bodies of the Cobareello unit are here interpreted as proximal lobe deposits. The Cobareello unit, on the whole, is interpreted as a broad base-of-slope submarine depression infilled by proximal lobe deposits (*note 5). As in the case of previously

described large-scale lenticular and coarse-grained turbidite bodies of the Rocchetta Fm, the basal surface and the sandy infill of the Cobareello unit should reflect a relative sea-level fall and lowstand.

5.1.3.5. Noceto Sandstones

Geometry, dimensions, lithology and paleocurrents: the unit has a large-scale wedge-shaped geometry. It is bounded on the south-western side by a listric normal growth fault (Rio Giosa Fault, cf. paragraph 6.2). The unit is bounded below and laterally by the mudstones of the Rocchetta Fm, and is capped by the Bric Baraccone Siliceous Lithozone (LS1a). The unit has maximum thickness of about 350 m near the bounding fault and lateral extent of about 14.7 km in a direction roughly transverse to the paleocurrents (Pl. I). The general lithology is shown schematically in figure 27a. In proximity to the listric fault the uppermost part is represented by a wedge-shaped interval made up of sandstone–mudstone turbidites in medium to thick strata. Three plurimetric debrite units with pebbles to blocks are present in the basal portion (Noceto-Pian del Lago area) (No_A), and a chaotic debrite unit with pebbles to boulders, among which carbonate clasts of up to decametric dimensions (No_B), occurs at the top (Cavallini area) (Fig. 27a). The paleocurrents indicate ESE-ward transport directions, with more dispersed values near the listric fault (see also Cazzola and Fornaciari, 1990).

Facies: the location of measured sections is shown in

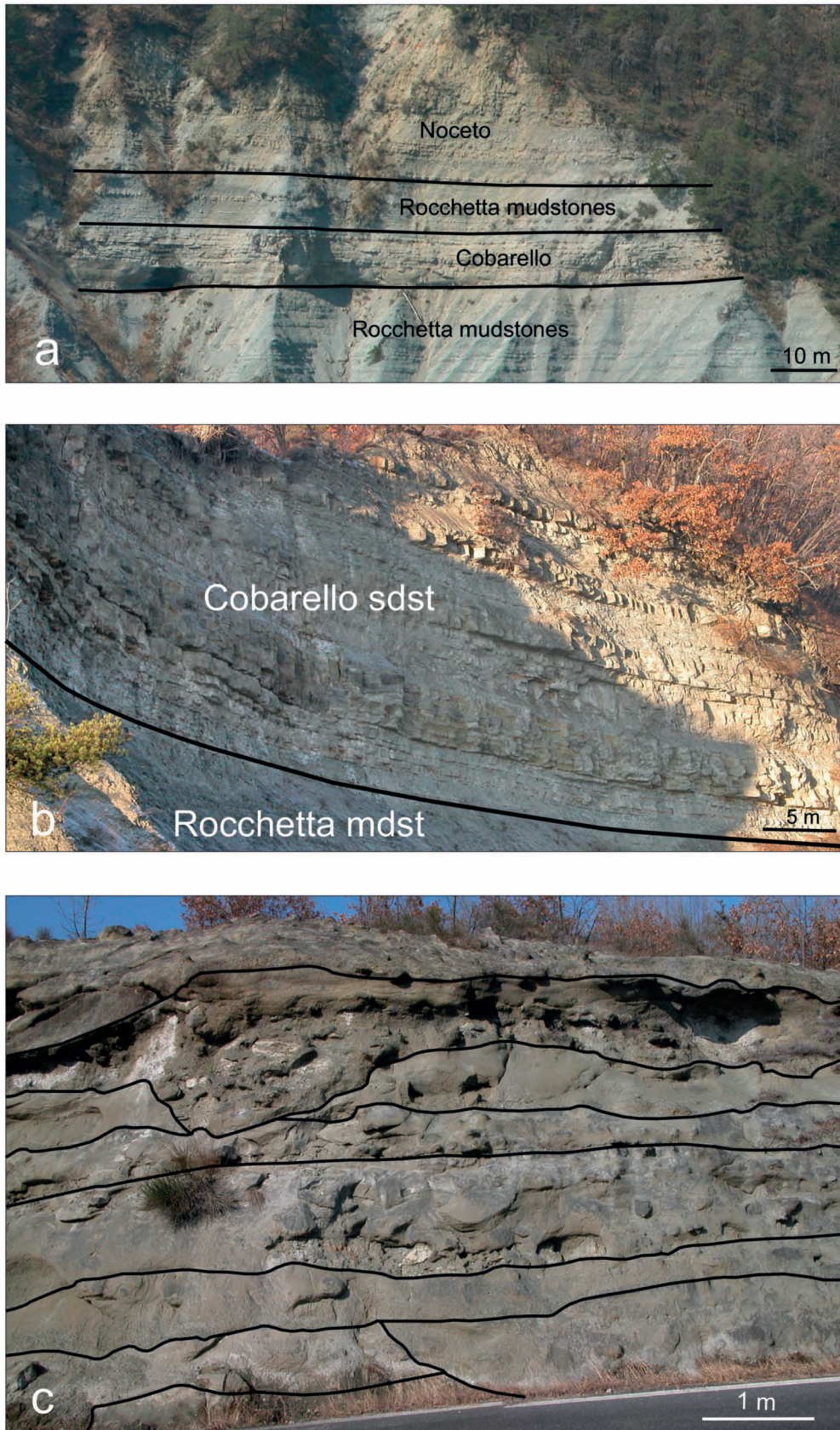


Fig. 26 - Cobarello Sandstones. a) View of the right side of the Erche Valley showing the NW thinning out of the Cobarello unit encased within Rocchetta mudstones and the lower part of the overlying Noceto unit. Note the rapid rightward pinch-out of the thicker basal layer of the Cobarello unit. b) Lower part of the Cobarello Sandstones (units I and II of Pl. VIIIa) overlying the Rocchetta mudstones. Note the sheet-like geometry of the stacked sandstone bodies. c) Detail of the basal part of unit III of plate VIII, interpreted as the record of channel-lobe transition (road between the villages of Brovida and Noceto). Note the multiple scours and the abundance of mud clasts.

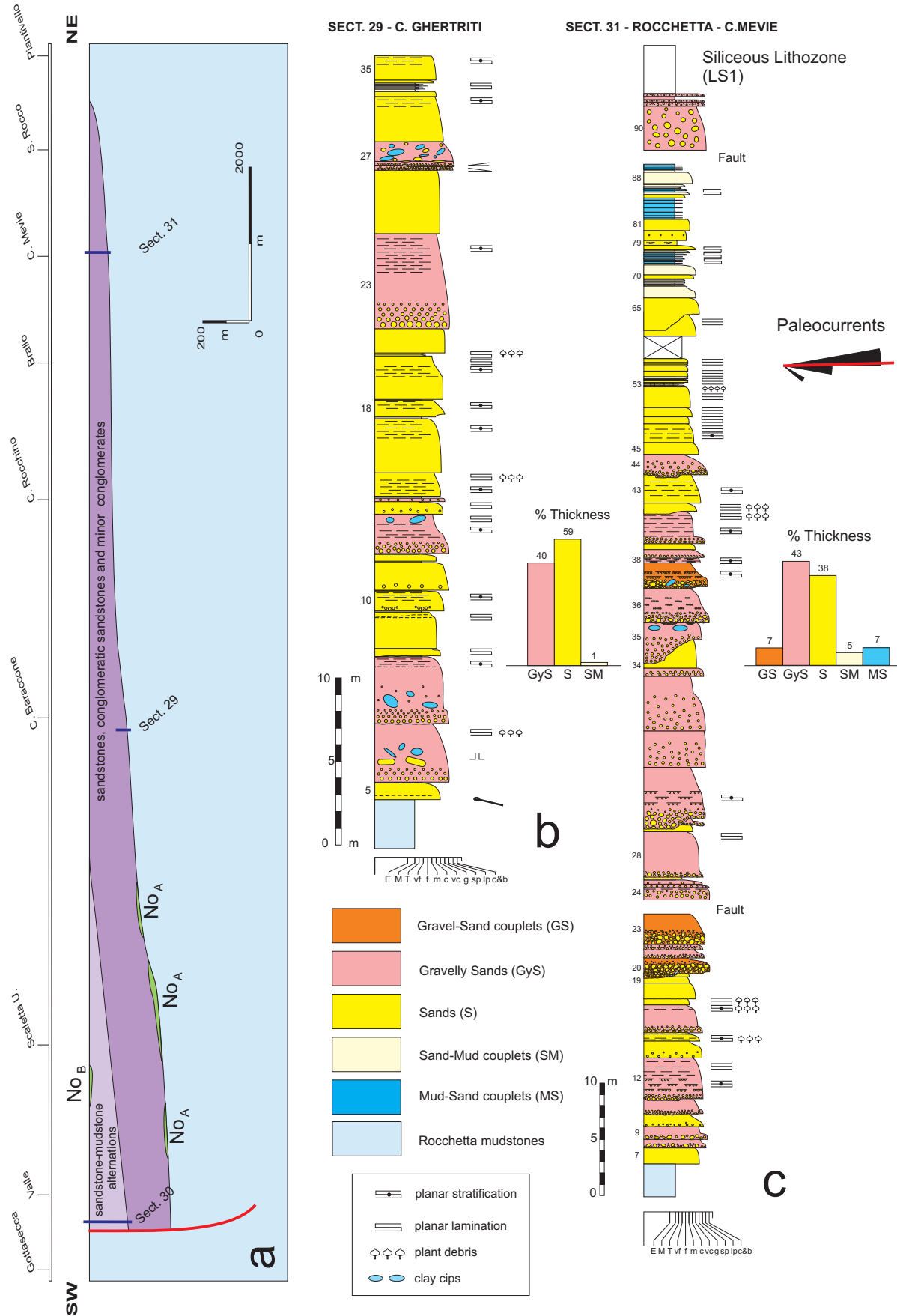


Fig. 27 - Noceto Sandstones. a) Schematic cross-section showing lithology and geometry of the Noceto unit interpreted as the infill of a submarine half-graben. Note the stratigraphic expansion near the bounding listric fault. b) Logs of the C. Ghertriti and Rocchetta-C. Mevie sections (sections 29 and 31).

figure 27a. A complete section measured near the north-eastern termination of the unit (section 31 in Fig. 27a) is shown in figure 27c and a facies sample about 60 m thick of the basal and axial parts is shown in figure 27b. The succession of the wedge-shaped upper infill of the half-graben near the listric fault (section 30 in Fig. 27a) is shown in plate VIIIb. Most common facies are represented by pebbly sandstones and amalgamated sandstones in thick- to very thick beds associated with less common sandstone-mudstone couplets in medium to thick strata and subordinate pebbly to bouldery mudstones. Particularly thick (up to 5 m) amalgamated sandstone beds are developed in axial part of the half-graben infill (Fig. 28a). The pebbly sandstones beds are normally graded with clasts ranging from 0.5 to 10 cm in diameter (on average 1-3 cm). The uppermost sandy parts of the beds are medium- to very coarse-grained, and show coarse-tail grading, or, less commonly, centimetre-thick parallel traction laminae (*flat stratification*). Large intraclasts of whitish marls (up to 50 cm in length) are common. The amalgamated sandstones occur in thick to very thick (0.40 - 5 m) beds. The strata show graded bedding, grading commonly to thick and/or thin parallel traction laminae in the uppermost part. The mud-supported conglomerates occur in very thick strata (up to several metres) and contain rounded pebbles to boulders up to 1-2 m in diameter. The sandstone-mudstone couplets may be described as Ta/e and Ta-b/e Bouma sequences, the mudstone-sandstone couplets as Tb-e, Tb/e and Tc/e sequences. The wedge-shaped succession occurring in the uppermost part of the Noceto unit near the bounding fault is made up of predominately medium- to thick-bedded, laminated or, subordinately, graded-to laminated sandstone-mudstones couplets. Amalgamated sandstones and rare conglomeratic sandstone beds and debris flow units are also present (Fig. 28b, Pl. VIIIb).

Vertical organization: the Noceto unit shows a facies association variable from place to place. In the Rocchetta-C. Mevie section (Fig. 27c), near its NNE wedging out, the unit shows an overall trend thinning- and fining-upwards. On smaller scale, the succession is apparently subdivided into a number of minor cycles thinning- and fining-upwards composed of a limited number of beds (Ghibaudo et al., this volume). They are tentatively interpreted as the infill of local shallow channels with multistorey and multilateral organization. The facies sample measured in the basal and axial parts of the unit (Fig. 27b), however, fails to show any apparent internal organization. Similarly, even the sandstone-mudstone wedge-shaped succession occurring in the uppermost part of the unit near the bounding listric fault appears relatively monotonous (Pl. VIIIb).

Interpretation: Cazzola et al. (1981) interpret the Noceto Sandstones as channel-lobe transition and lobe deposits and Cazzola and Fornaciari (1990) as depositional lobes. The Noceto unit consists of growth strata forming the infill of a submarine half-graben developed on the hangingwall of the Rio Giosa listric growth fault (cf. paragraphs 4.3.4.8 and 6.2) in a likely

slope or base-of-slope setting (Pl. I). The infill of this structural depression consists of “proximal” deposits transported by high-concentration turbidity currents and subordinate debris flows essentially linked to western sources. The half-graben was probably elongate in direction E-W, parallel to the paleocurrent directions, and its head probably intercepted to the W coarse-textured shelf depositional systems representing the source area for the sediment gravity flows. Cazzola and Fornaciari (1990) correlate a number of sections within this unit. The lack of key beds and the impossibility to physically trace bedsets laterally due to the dense vegetation cover make, in our opinion, such correlations substantially uncertain. The internal organization and detailed depositional history of the infill of Noceto Half-graben are so far poorly known. The presence of the wedge-shaped uppermost sandstone-mudstone interval of plurikilometric extent near the listric fault (Fig. 27a, Pl. VIIIb) could indicate accelerated tilting of the hangingwall in proximity of the bounding fault during the late infilling stage, leading to localized accommodation space (Schlische and Olsen, 1990). The overall fining-upwards trend of the infill, recognized both near the NE wedging out of the body (Fig. 27c), and in proximity of the listric fault, suggests that the final infilling stage was coeval to an early transgressive stage characterized by decline in concentration of the turbidity currents due to the progressive backstepping of the source areas. This stage might have followed the former falling and lowstand stages during which most of coarse deposits forming the bulk of the half-graben infill were laid down. The eventual deactivation of the turbiditic sedimentation of the Noceto Half-graben was marked by the onset of deposition, on regional scale, of the Siliceous Lithozone LS1a, which may be interpreted as a condensed section coeval to the late transgressive and highstand systems tracts in the adjoining shelf areas (Pl. I).

5.1.3.6. Gabutti Sandstones

No detailed stratigraphic-sedimentologic study has been carried out for the Gabutti unit, so that the paleoenvironmental setting of this unit is unknown. The unit has a large-scale lenticular geometry in the axial part and more tabular lateral “wings”. It is internally characterized by sandstone sub-units with approximately tabular geometry. The unit is tentatively interpreted as the infill of a broad base-of-slope depression with lobe or, locally, channelized deposits.

5.1.4. Sandstone bodies with tabular geometry

These bodies include the following units: C. Giroso Sandstones, Sorgente Alpei Sandstones, Fontanelle Sandstones, Cian dei Grill Sandstones. None of these sandstone bodies has been studied in detail. They have tabular geometry, thickness of up to some tens of metres and lateral extent ranging from 1.9 to 3.4 km. Their internal organization is characterized in many cases by sandstone-mudstone couplets in medium to thick strata

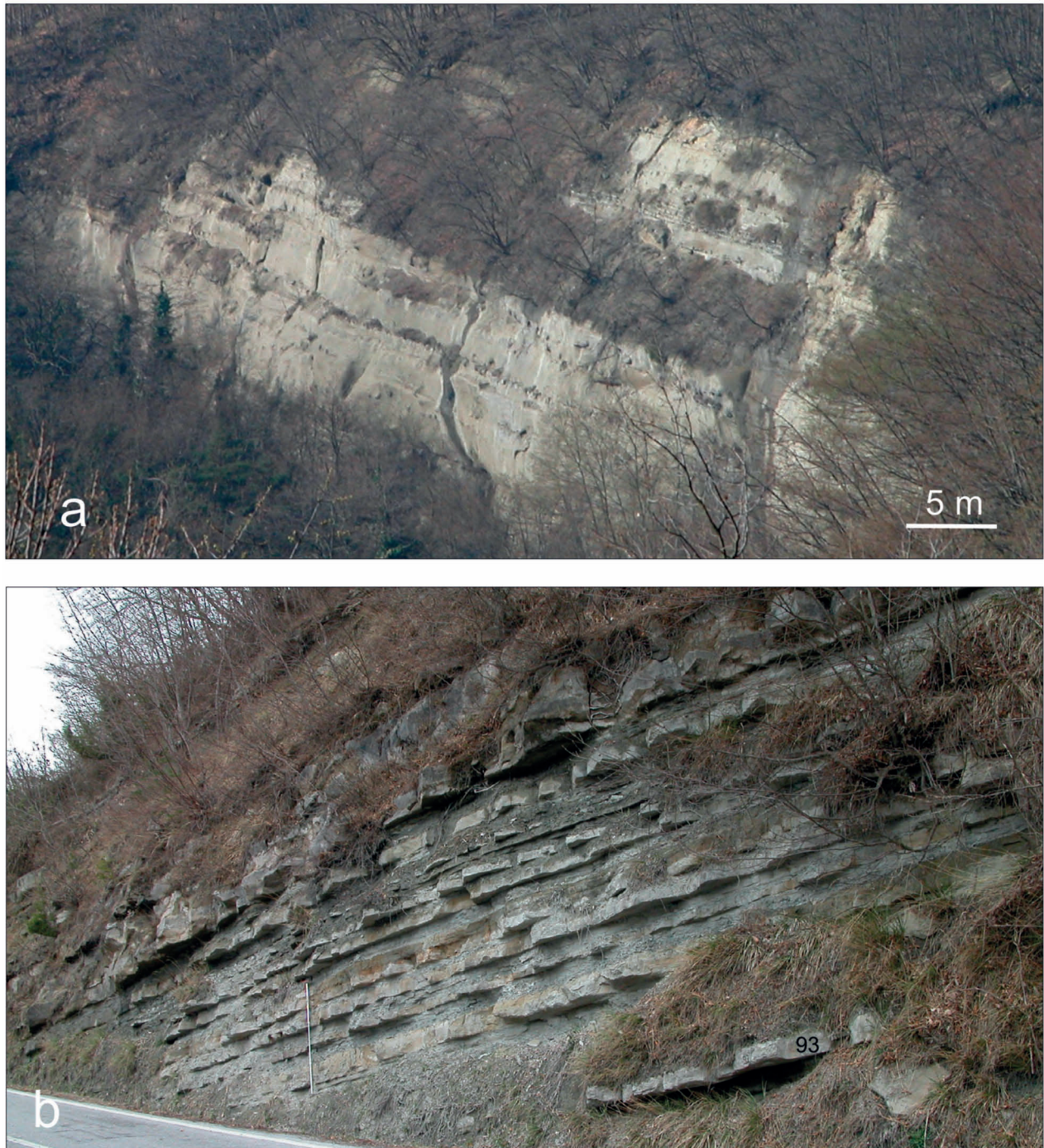


Fig. 28 - a) View of very thick and amalgamated beds in the axial part of the Noceto unit (right side of Rio Siriè Valley). b) Detail of the sandstone-mudstone turbidites comprising the wedge-shaped terminal deposits of the Noceto Half-graben infill near the bounding fault (Section 30 in Fig. 27a and Pl. VIIIb, beds 93 - 122) (Jacob staff for scale).

in the lower part, grading upwards into amalgamated sandstones in thick to very thick strata (cf. Sorgente Alpei Sandstones, Fig. 29). The interval with amalgamated beds forms tabular bodies standing out in the present-day erosion profile. The sandstone bodies are tentatively interpreted as non-channelized lobe deposits infilling local accommodation space in a possible base-of-slope setting.

5.2. Poggiolo Formation

The Poggiolo Fm consists of mudstone-sandstone and sandstone-mudstone turbidites in thin to medium, and subordinate thick strata, which encase two sandstone bodies named Rio Porcavio Sandstones and C. Carloni Sandstones (cf. paragraph 4.5). The sandstone-mudstone couplets form the dominant lithology of the formation (Fig. 31a, Pl. IX). The strata can be described as Tb/e and subordinately Ta/e and Ta-b/e Bouma sequences and

SECT. 21 - SORGENTE ALPEI

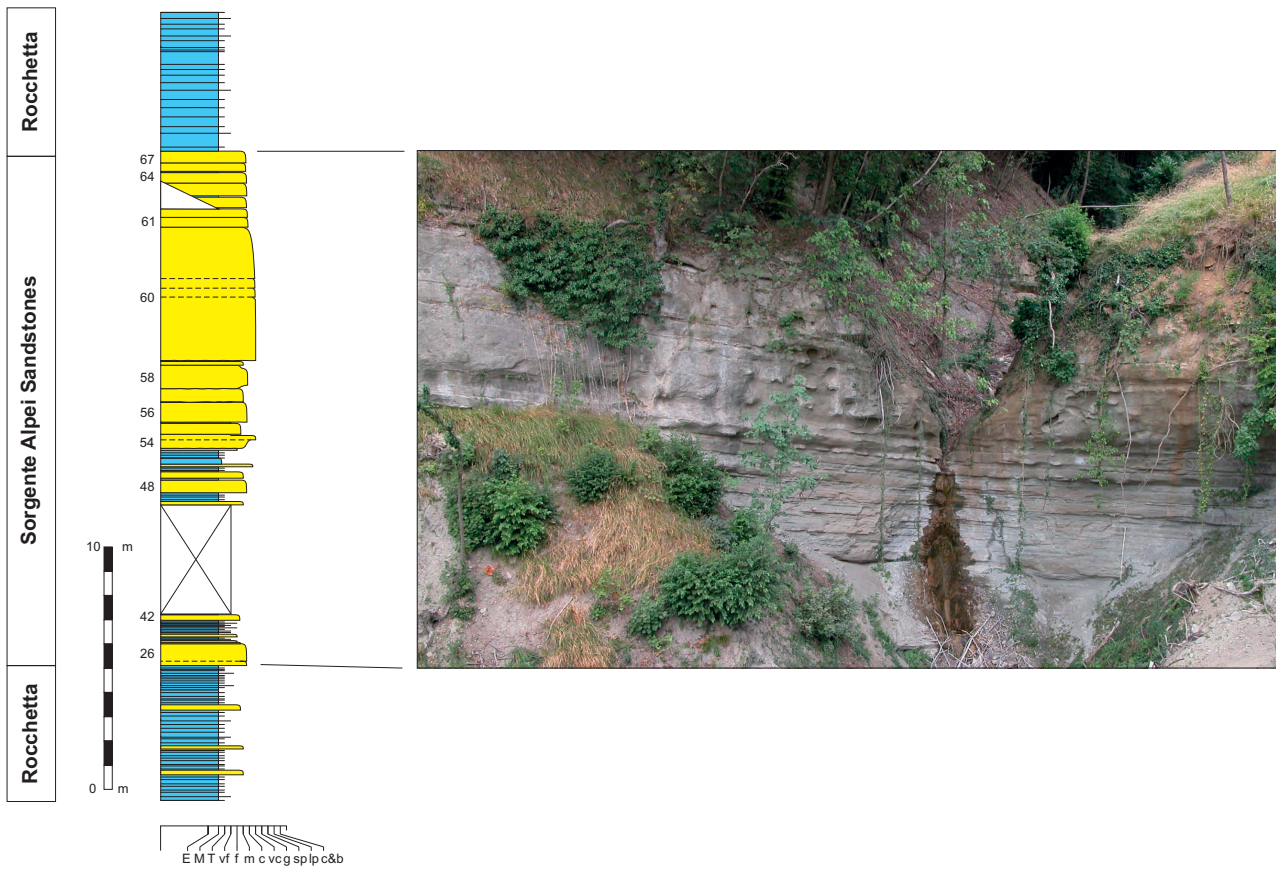


Fig. 29 - Rocchetta Fm. Vertical facies distribution and view of the Sorgente Alpei unit cropping out on the left side of the Rio Giora Valley. Note the upward-thickening trend.

SECT. 9 C. CARLONI

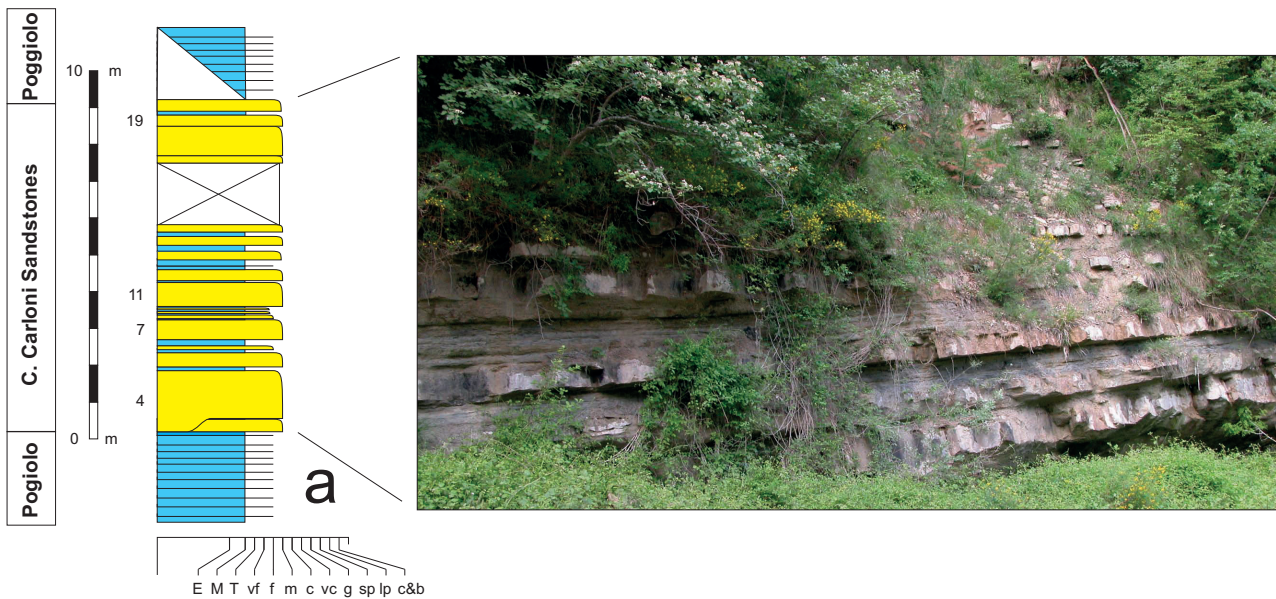


Fig. 30 - Poggiolo Fm. Vertical facies distribution and view of the C. Carloni Sandstones cropping out on the left side of Rio Moglia Piana Valley (W of Poggiolo).

laminated pelite-silt couplets in thin beds. Mutti et al. (2002) interpret the sandstone-mudstone turbidites cropping out on the left side of the Uzzone Valley (their *Castelletto Uzzone system*), shown in figure 31a, as distal delta-front deposits. The formation, however, is vertically framed by condensed siliceous hemipelagic deposits (cf. geological map and Pl. I) characterized by common deep-water benthic foraminifers (e.g. *Bathysiphon*) pointing to a deep-water setting. On the whole, the composite succession of the Poggiolo Fm is thought to have been laid down in a structurally-controlled deep-water basin (see below).

5.2.1. Rio Porcavio Sandstones

The internal organization of the Rio Porcavio Sandstones is shown in plate X. The unit has a large-scale wedge-shaped geometry. The maximum outcropping thickness is of about 90 m. Southwards, in the Poggiolo area, the unit thins out to about 10 m (Fig. 31b). The unit is characterized by mostly amalgamated sandstones, secondarily sandstone-mudstone couplets and local intercalations of pebbly mudstones and slumped beds (Fig. 31c). The paleocurrents indicate NE-ward transport direction. The sandstones are medium- to coarse-grained, mostly graded without traction structures, or display centimetric planar-parallel laminae either in the whole bed thickness or in the upper part. The mudstone-sandstone couplets are entirely laminated in their sandy portion (Bouma Tb-e, Tb/e and Tc/e). The Rio Porcavio Sandstones are formed by two sandstone sub-units separated by an interval of thin-bedded turbidites. The upper unit shows at least three stacked cycles thinning- and fining-upwards (Pl. X).

Interpretation: The unit is interpreted as the infill of an asymmetric graben (cf. paragraph 5.2.3). The unit might record high-frequency relative sea-level fluctuations, with relative lowstands expressed by the two sandstone sub-units, and the relative highstand represented by the intercalated thin-bedded turbidites.

5.2.2. C. Carloni Sandstones

This is a thin, slightly lenticular unit about 9 m thick and with lateral extent of a few hundreds of metres, consisting of turbidite beds in medium to thick strata showing Ta/e, Ta-b/e and Tb/e Bouma sequences and a trend thinning- and fining-upwards (Fig. 30). The unit is interpreted as confined in the axial part of the Poggiolo Basin (see below).

5.2.3. The Poggiolo Basin

The above units are thought to represent the infill of a basin (the Poggiolo Basin), located in the Uzzone Valley area, which is characterized by a NE-SW-striking fault system (Uzzone Valley Fault System), showing evidence of syndimentary activity. The extent and tectono-stratigraphic evolution of the Poggiolo Basin are based on the following observations:

1) The Poggiolo Fm presents depositional pinch-outs in

three directions which allow to define, at least partly, the original extent of the basin (Fig. 32).

2) The body of Rio Porcavio Sandstones is confined to the S by the S. Ilario Fault and is characterized by marked wedge-shaped geometry thickening northwards. Paleocurrents indicate NE-ward transport, i.e. in a direction approximately parallel to the NE-striking S. Ilario and Carpenetto faults (Fig. 52). This geometry suggests that the unit represents the infill of an asymmetric graben controlled by the syndimentary activity of the mentioned faults, or, to the N, by a fault located NW of the Carpenetto fault, probably with similar orientation, and at present buried below the Cortemilia Fm.

3) The Poggiolo Fm wedges out both NE-wards and SW-wards and shows maximum outcropping thickness (about 150 m) in Uzzone Valley between the S. Ilario and C. Lunga-Blenzi faults, suggesting a genetic relationship between the Uzzone Valley Fault System and the development of a structural basin.

4) The SW-NE paleocurrent directions of Rio Porcavio Sandstones and the similarly oriented strike of the Uzzone Valley faults, here interpreted as a system of growth faults controlling the development of the Poggiolo Basin, are at high angles to the presumable SE to ESE dip of the regional paleoslope, as inferred from the paleocurrents of the underlying sandstone bodies of the Rocchetta Fm and the overlying C. Mazzurini and Piantivello units. These relationships suggest that the Poggiolo Basin was an intra-slope basin oriented at high angle with respect to the regional paleoslope (Fig. 33).

5) The Poggiolo Fm is deformed by an en-echelon fold system between the S. Ilario and Rio Porcavio faults (cf. paragraph 6.4), whereas the overlying succession is apparently undeformed.

6) The Poggiolo Fm is bounded by the LS1a Siliceous Lithozone at the base and by the LS1b Siliceous Lithozone at the top, both interpreted as condensed sections.

The outcrop extent of the Poggiolo Fm and of the Rio Porcavio Sandstones member and the inferred extent of their depositional basin are shown in figure 32. Figure 33 schematically shows the inferred depositional setting of the Poggiolo Basin.

In our interpretation the development of the Poggiolo Basin was controlled by the activity of the Carpenetto Fault and secondarily S. Ilario and C. Serra Faults (Fig. 33). These faults acted as growth faults; the former two, in particular, controlled both the creation of accommodation space and the locus of deposition of the Rio Porcavio Sandstones (Figs. 33, 34). The faults acted initially as normal faults creating the accommodation for the Poggiolo Basin, and were later re-activated as strike-slip faults, together with the other faults of the Uzzone Valley Fault System, in the latest depositional stage of the Poggiolo Fm (Fig. 34). Due to this transcurrent reactivation the basin was deformed and deactivated. In the above interpretation (Figs. 32, 33, 34), the Poggiolo Basin would have had a minimum extent of about 50 km².

The tectono-sedimentary evolution of the Poggiolo

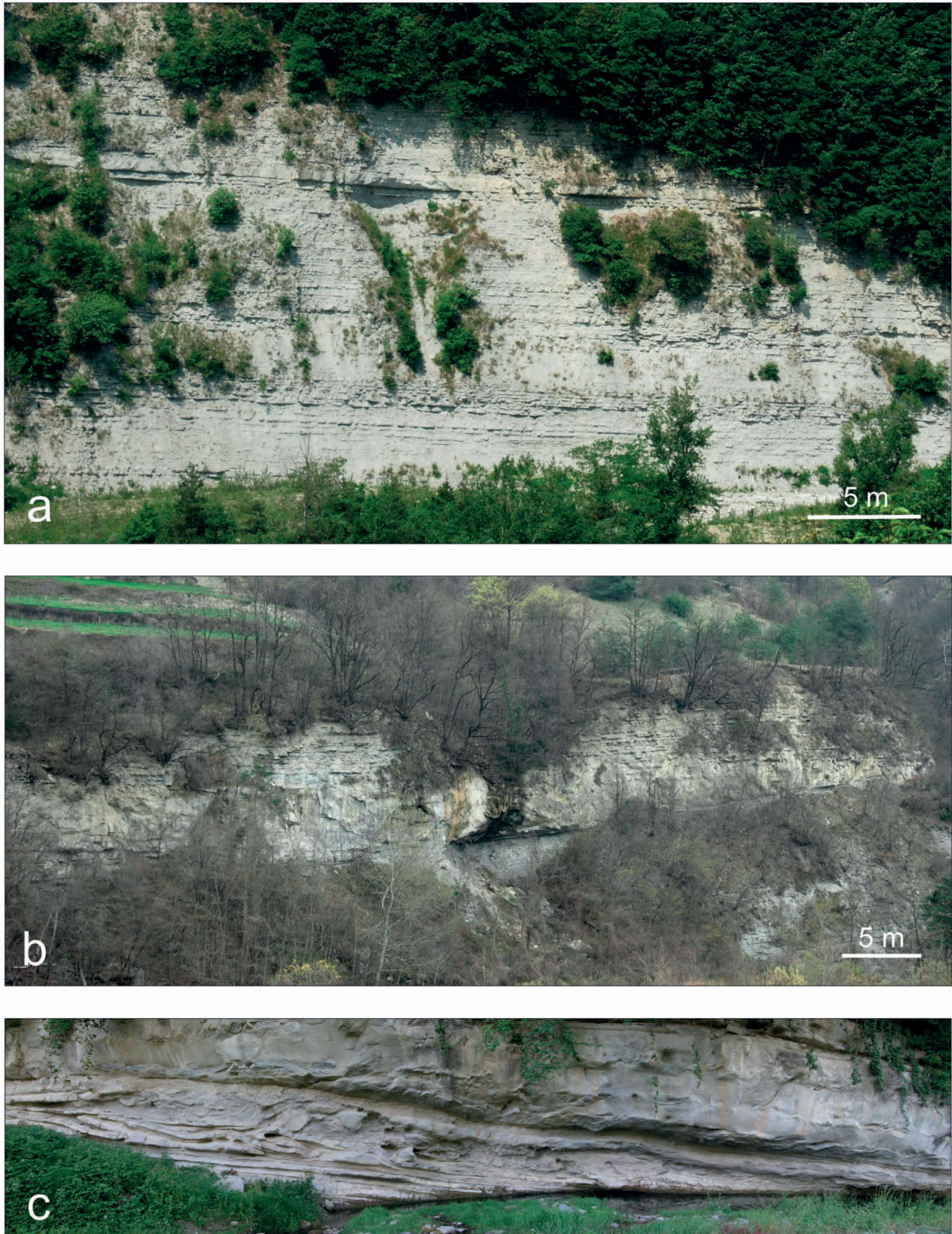
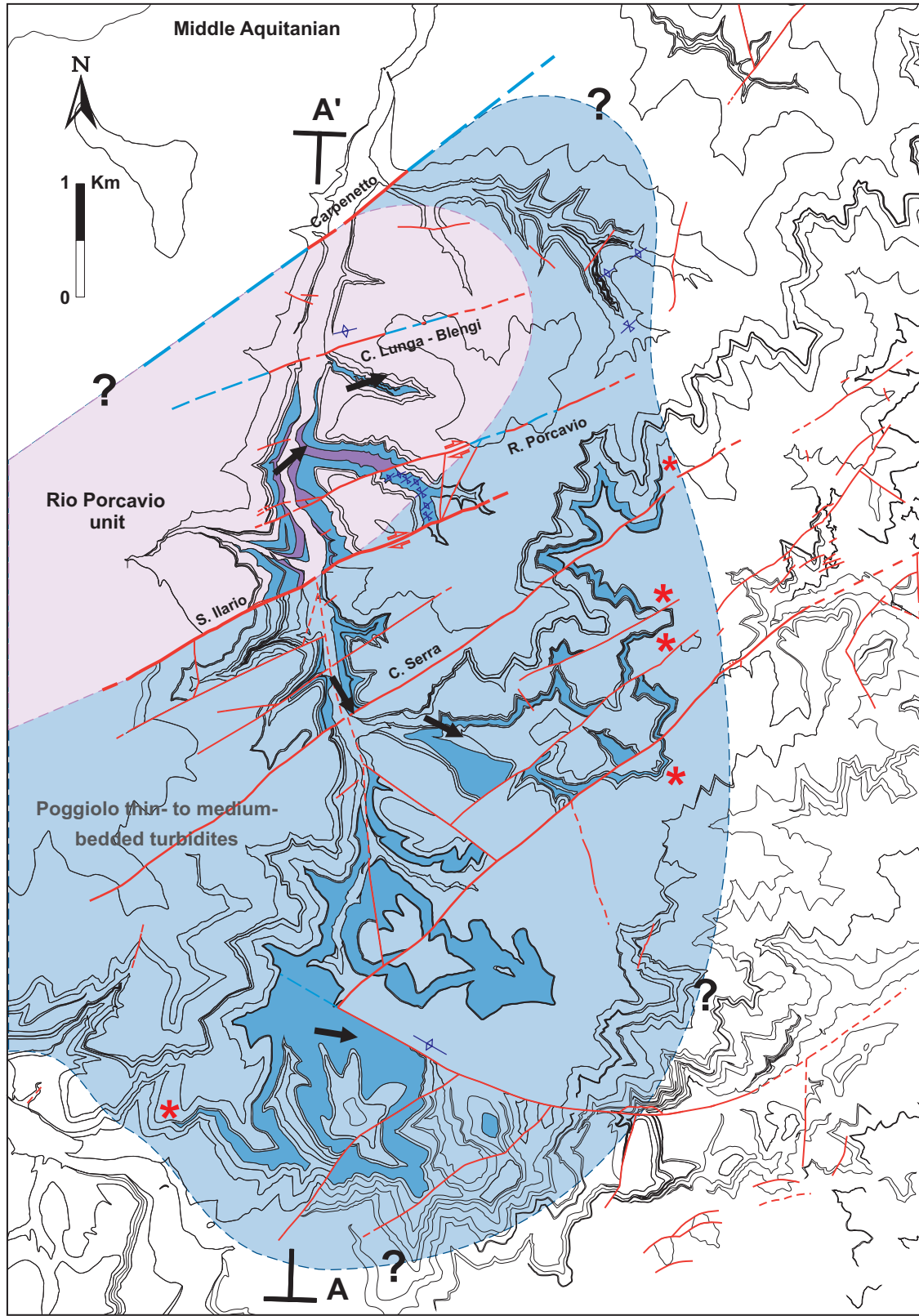


Fig. 31 - Poggiolo Fm. a) Thin- to medium-bedded sandstone-mudstone turbidites of the Poggiolo Fm cropping out on the left side of the Uzzone Valley in front of C. Demanio. Note the key bed in the upper part of the outcrop. b) The Rio Porcavio unit near its northern termination on the right side of the Uzzone Valley in front of the Poggiolo village. Note the very thick, amalgamated package near the base and the overall trend thinning upwards. The sandstone body is lateral equivalent of unit III of plate X. c) Folded slump package in the Rio Porcavio unit (left side of the T. Uzzone Valley).



The Poggiolo Basin








- | | | | | | |
|---|--|---|---|---|--------------------------|
|  | Poggiolo Fm - outcrop area |  | Rio Porcavio Sandstones - outcrop area |  | Paleocurrents |
|  | Inferred extension of the Poggiolo basin |  | Inferred extension of Rio Porcavio Sandstones |  | Trace of cross-section |
| | | | |  | Depositional wedging out |

Fig. 32 - Inferred extent of the Poggiolo Basin. Trace A-A' refers to the cross-section of figure 34.

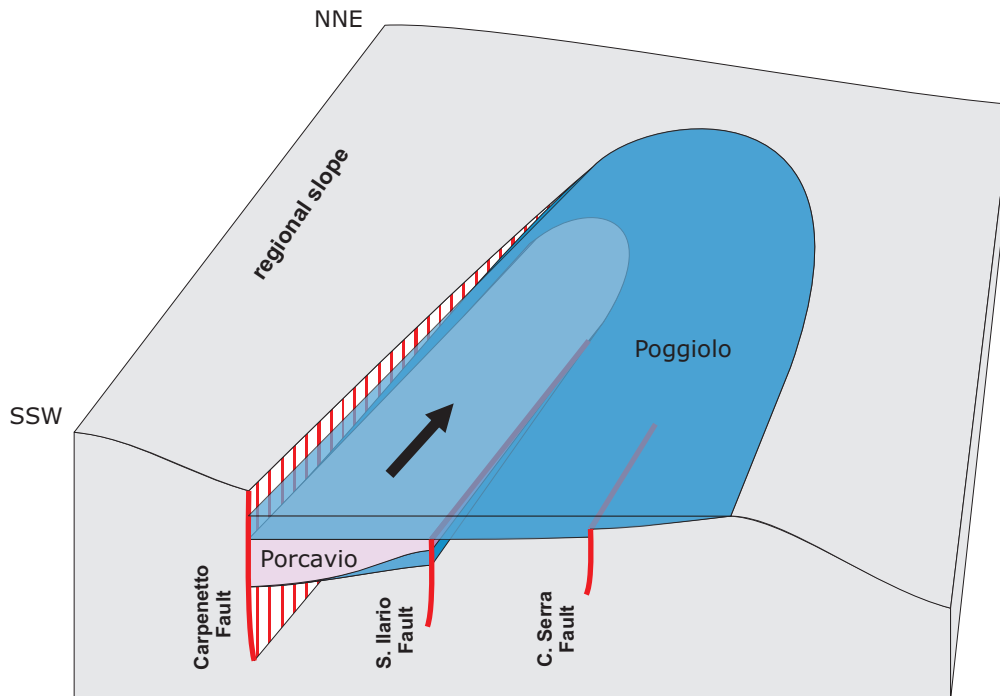


Fig. 33 - 3D interpretive sketch of the Poggiolo Basin.

Basin in a schematic N-S cross-section oriented at high angle with the Uzzone Valley Fault System is shown in figure 34. The basin substratum was represented by the infill of Noceto Half-graben and the deposits of the Rocchetta Fm. After the deposition of the LS1a Siliceous Lithozone, which seals this structure (Fig. 34, panel A), the Poggiolo Basin formed as a half-graben in the middle-late Aquitanian, probably following the activation of the S. Ilario and Carpenetto growth faults, and developed an asymmetric geometry with the depocentre in proximity of the Carpenetto Fault (Fig. 34, panel B). The basin fill mainly consists of thin- to medium-bedded turbidites laid down by dilute turbulent suspensions with relatively dispersed paleocurrent directions. The Rio Porcavio unit was deposited in the basin depocentre, between the S. Ilario and Carpenetto faults, and is interpreted as the infill of an asymmetric graben with sediments laid down by sand-laden high-concentration turbidity currents (Figs. 33, 34, panel B). The Rio Porcavio unit was then overlain by a package of thin- to medium-bedded turbidites about 50 m thick, after which the S. Ilario and Rio Porcavio faults were activated with right-lateral transpressional motion, and generated a series of en-echelon folds in the Rio Porcavio Valley (cf. paragraph 6.4) which deformed the Poggiolo Fm. Although a strike slip motion can be demonstrated only for the S. Ilario and Rio Porcavio faults, it is suggested that also the other faults of the same NE-trending system (Uzzone Valley Fault System), that displace the Poggiolo Fm result from the same kinematics (Fig. 34, panel C). The deactivation of the turbiditic sedimentation of the Poggiolo Basin coincides with the

onset of deposition, on regional scale, of the LS1b Siliceous Lithozone which may be interpreted as a condensed section inferred to record the transgressive to highstand stages in the time-equivalent shelf.

5.3. Scaletta Uzzone Formation

No complete sedimentologic sections are available for this unit. The thickness ranges from a few metres to a maximum of 50 m. The Scaletta Uzzone Fm consists of sandstones and subordinate conglomeratic sandstones laid down by high-concentration turbidity currents and organized in thick to very thick strata either amalgamated or separated by thin pelitic interbeds. Its upper part consists of sandstone/mudstone turbidites in medium to thick strata with sandstone/mudstone ratio generally > 1 , laid down by moderately concentrated turbidity currents.

5.3.1. The Scaletta Uzzone Basin

Several points of evidence indicate that the Scaletta Uzzone Fm was laid down in a basin with depocentre in the Uzzone Valley area. The reconstruction of the possible extent of the basin and its evolution is based on the following observations:

- 1) The present-day outcrop area of the Scaletta Uzzone Fm corresponds, in part, to that of the underlying Poggiolo Fm (Fig. 35). Its western margin is, however, shifted a few kilometers southwards;
- 2) The Scaletta Uzzone Fm shows depositional pinch-outs toward N and NE, that define the northern margin of the basin (Fig. 35), and thins out toward SW;

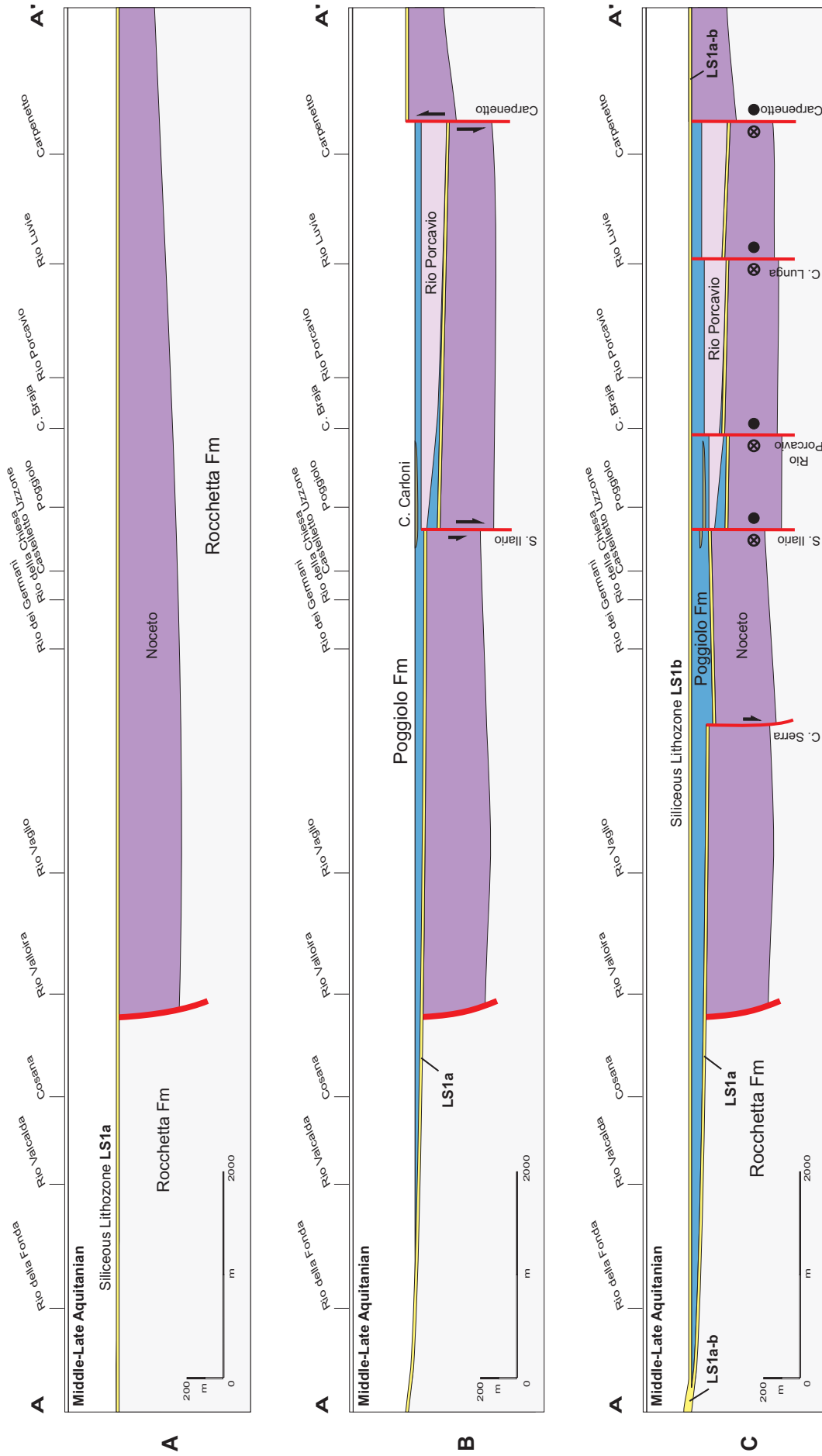


Fig. 34 - Tectono-sedimentary evolution of the Poggio Basin. Trace of the cross-section in figure 32.

3) The unit has a large-scale, broadly lenticular geometry and maximum thickness (50 m) to the SE (Fig. 35);

4) The paleocurrents, though having a certain dispersion, are mainly oriented SW-NE (with direction of transport toward NE) roughly parallel to the fault system of the Uzzone Valley (Figs. 35 and 52). No clear relationships between facies, paleocurrents and structural grain can be identified in the field;

5) The unit is bounded at the base by the LS1b Siliceous Lithozone and at the top by the LS1c Siliceous Lithozone.

The outcrop area of the Scaletta Uzzone Fm and the possible extent of its depositional basin (minimum 35 square km) are shown in figure 35. The inferred evolution of the Scaletta Uzzone Basin is outlined in a cross-section oriented N-S (Fig. 36). The substratum of the basin was represented by the former infill of the Poggiolo Basin. By the middle-late Aquitanian, after the deposition of LS1b Siliceous Lithozone which seals the underlying succession (Fig. 36, panel A), onset of differential subsidence created accommodation space for the Scaletta Uzzone Basin, whose depocentre was located to the SSE of the previous Poggiolo Basin. The constant presence of the LS1b Siliceous Lithozone at the base of the Scaletta Uzzone Fm with conformable stratigraphic relationships suggests that the turbidites have passively infilled a subsiding depression rather than being confined within a large-scale erosional surface. The cause of the subsidence is not known. Tentatively, it is attributed to differential compaction of the mudstones of the Rocchetta Fm as a result of the combined loading of the Noceto and Poggiolo units (Fig. 36, panels B and C). The deactivation of the turbiditic sedimentation in the Scaletta Uzzone Basin coincides with the onset of regional deposition of the Siliceous Lithozone LS1c, interpreted as a condensed section corresponding to the transgressive and highstand stages of the time-equivalent shelf (Fig. 36, panel C).

5.4. Montechiaro d'Acqui Formation

The Montechiaro d'Acqui Fm is a heterogeneous unit consisting of dominant homogeneous hemipelagic marls locally incorporating both carbonate and siliciclastic sedimentary bodies with lenticular or wedge-shaped geometry (cf. paragraph 4.7).

The Montechiaro d'Acqui Fm is bounded at the base by the LS1 Siliceous Lithozone and at the top by the Serole Fm. The Montechiaro d'Acqui Fm is locally truncated by erosional discontinuities, respectively defined Denice, Bric Torrione, C. Rocchino and Uzzone Valley Erosional Depressions, interpreted as single or coalesced slump scar surfaces. Due to the presence of these discontinuities, the formation shows strong changes in thickness and is locally completely missing. Only the units outcropping in the south-western part of the study area will be described in some detail (i.e. C. Ciappellano Sandstones, Rio della Chiesa Glaucony, Castelletto Uzzone Sottano Sandstones, Rio della Chiesa Lower and Upper Sandstones). These sandstone units are interpreted as filling a local slope or

base-of-slope basin called "Rio della Chiesa Basin" (see below). Concerning the units cropping out in the north-eastern area, the results of recent work will be briefly reported (d'Atri, 1990; Gelati and Gnaccolini, 1998; Ghibaudo et al., 2001b; Ghibaudo et al., this volume).

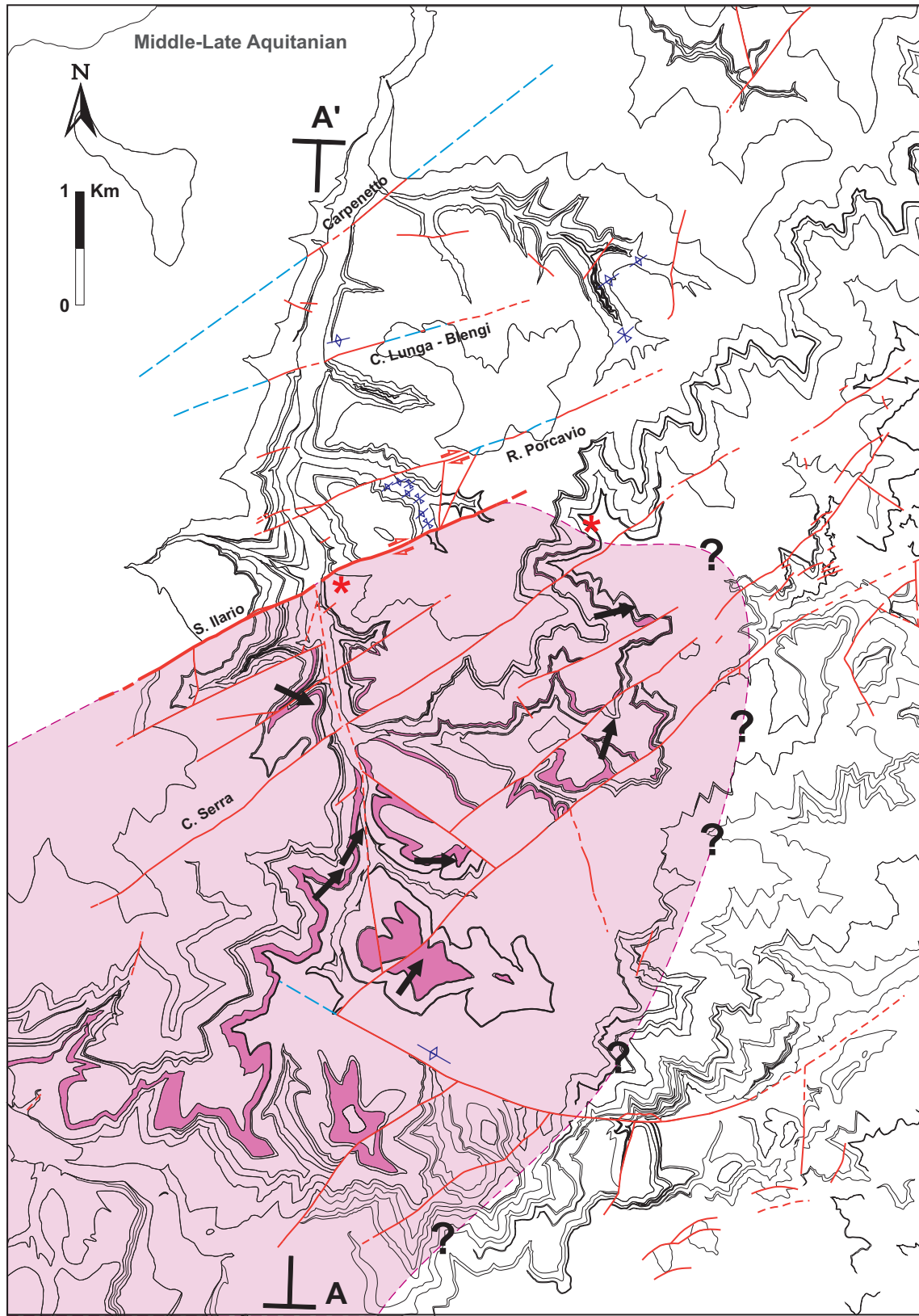
5.4.1. North-eastern area

The local stratigraphic-structural setting is shown in plate I. The Montechiaro d'Acqui Fm cropping out in the northeastern sector is interpreted by d'Atri (1990), Ghibaudo et al. (2001b) and Ghibaudo et al. (this volume) as consisting of slope or base-of-slope deposits. Active synsedimentary tectonics probably controlled the location and geometry of sedimentary bodies encased in the background marls. In particular, the C. Poggi Calcarenes are interpreted as a channelized sedimentary body. The Pian Bruno Calcarenes and the Altitude 483 Sandstones are interpreted as the infill of a small structural slope depression related to an early motion of the Pian dei Buri Fault whereas the C. Mevie Calcarenes are regarded as unconfined deposits laid down by overflows from the depression itself (Ghibaudo et al., this volume). Like Gelati and Gnaccolini (1998), the C. Mazzurini unit is interpreted as the infill of a submarine half-graben delimited by the Pian dei Buri Fault (Ghibaudo et al., this volume).

The paleocurrents in the C. Mazzurini Unit indicate transport directions from WNW, almost parallel to the bounding fault of the half-graben, and, consequently, following a regional paleoslope roughly dipping to ESE. The structural depression was probably elongate roughly in E-W direction parallel to the direction of the paleocurrents and of the bounding Pian dei Buri Fault. Its head probably intercepted to the W coarse-textured shelf depositional systems such as fan-deltas representing the source for the coarse materials involved in sediment gravity flows.

5.4.2. South-western area

The stratigraphic-structural setting of the Montechiaro d'Acqui Fm in the southwestern sector of the study area is shown in the cross-sections of plates I and II. A layer of bioturbated glauconitic marls (Rio della Chiesa Glaucony) is present throughout, at the base of the formation, and is interpreted as the record of condensed deposition with glauconite formed in situ (see below). This glauconitic layer is located some metres beneath the C. Mevie Calcarenes, as observed in the Rio della Torre Valley, where both units crop out. As discussed in paragraph 4.7, the outcrops of the Montechiaro d'Acqui Fm located in the Uzzone Valley and its tributaries present different stratigraphic organizations from those located astride the crest dividing the Uzzone Valley from the Bormida di Spigno Valley. In the former area the formation is locally removed by the Uzzone Valley Erosional Depression (Pl. II). Conversely, the formation is almost completely preserved within a structural low located in the Rio della Chiesa Valley (Pl. II). Here, the



The Scaletta Uzzone Basin

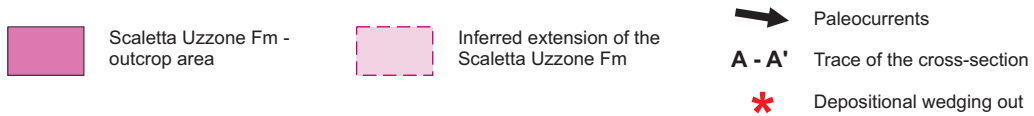


Fig. 35 - Inferred extent of the Scaletta Uzzone Basin. Trace A-A' refers to the cross-section of figure 36.

marls of the Montechiaro d'Acqui Fm encase, in the lower-middle part, a number of siliciclastic sandstone bodies (i.e., C. Ciappellano Sandstones, Castelletto Uzzone Sottano Sandstones, Rio della Chiesa Lower and Upper Sandstones) which are inferred to be part of the infill of the Rio della Chiesa Basin (see below). Moreover, the Montechiaro d'Acqui Fm shows different stratigraphic successions in the Rio della Chiesa and Rio della Torre valleys (see paragraph 4.7). Although some sedimentary bodies in the Rio della Chiesa Valley are not present in the Rio della Torre Valley, in both valleys the Rio della Chiesa Glaucony crops out, and represents a valuable marker bed allowing mutual correlation (Fig. 15). Moreover, in the Bormida di Spigno Valley, the Montechiaro d'Acqui Fm is composed only of hemipelagic marls. The NE-trending area roughly corresponding to the divide between the Uzzone and Bormida di Spigno valleys is interpreted as an intrabasinal structural high (Castelletto Uzzone High), oriented SW-NE, like the main structures of the area (Fig. 44, see below). This high was probably bounded to the W by the T. Uzzone Fault and to the N and S, respectively, by the C. Serra and St. Ilario faults; it probably confined to the E the sandstone bodies of the Montechiaro d'Acqui Fm occurring in the section of the Rio della Chiesa (Fig. 44). The need to assume the presence of an intrabasinal high to the E of the T. Uzzone Fault stems from the fact that the sandstone bodies present in the lower part of the Montechiaro d'Acqui Fm in the Rio della Chiesa (Castelletto Uzzone Sottano Sandstones, Rio della Chiesa Lower and Upper Sandstones, C. Ciappellano Sandstones), are missing to the E of the T. Uzzone Fault (Fig. 44).

The Castelletto Uzzone High, moreover, probably persisted in later times, during the deposition of the Serole Fm. This high, in particular, would have confined to the SE the sandstone bodies of the Serole Fm, named Rio della Torre Lower and Upper Sandstones. Even these sandstone bodies are in fact present only along the right-hand tributaries of the Uzzone Valley (Rio della Torre and Rio Rigosio) and wedge out SE-wards, suggesting the presence of a structural high located SE of these depositional pinch-outs (Fig. 47).

In the Valle area, another local high ("Santa Giulia High") is also envisaged on the fault block of S. Giulia, linked to the partial structural inversion of the Noceto Half-graben in times post-LS1c Siliceous Lithozone (cf. paragraph 6.2 and Fig. 44).

5.4.2.1. Castelletto Uzzone Sottano Sandstones

This unit crops out only in the Rio della Chiesa Valley, where the Montechiaro d'Acqui Fm is preserved in a graben pre-dating the formation of the Uzzone Valley Erosional Depression (see paragraph 4.7.7). The unit has a thickness of about 30 m. It is composed of mudstone-sandstone turbidite couplets in medium and thick strata, and, secondarily, of mudstone-siltstone couplets in thin and medium beds. The sandstone and siltstone divisions of turbidite beds have thickness ranging from 5 to 15 cm and are parallel-laminated (Bouma Tb/e) (Fig. 37a). This

unit is interpreted as the product of deposition from dilute turbidity currents in a confined environment (Rio della Chiesa Basin, see below).

5.4.2.2. Rio della Chiesa Glaucony

It is a marker horizon 0.25 - 1 m thick, characterized by silty hemipelagic marls intensely bioturbated, very rich in authigenic glauconitic grains, both diffuse and concentrated within the bioturbation galleries (Fig. 16). Interpretation: condensed layer recording a period of sediment starvation in a slope or base-of-slope setting (cf. Hesselbo and Hugget, 2001).

5.4.2.3. Rio della Chiesa Lower Sandstones

This unit crops out only in the Rio della Chiesa Valley, where the Montechiaro d'Acqui Fm is preserved in a graben pre-dating the formation of the Uzzone Valley Erosional Depression (cf. Pl. II and paragraph 4.7.8). The unit has a thickness of about 24 m and consists of turbiditic sandstone-siltstone couplets in medium beds with sandstone/siltstone ratio ≤ 1 (Fig. 38). Sandstone divisions are fine- and medium-grained and are parallel-laminated, or rarely rarely graded and devoid of traction structures. Typically the interbedded siltstones are intensely bioturbated. The unit shows a weak trend thinning-and fining-upwards and is interpreted as the product of deposition from dilute turbidity currents in a confined environment (Rio della Chiesa Basin - see below) with active downslope spillover of the upper, fine-grained portions of the related currents.

5.4.2.4. C. Ciappellano Sandstones

This unit is present in the Rio della Chiesa and Rio della Torre valleys. It has a thickness of about 18 m and is composed of turbiditic mudstone-sandstone couplets in medium strata (Fig. 37b). The sandstone divisions are 5-15 cm thick and are parallel-laminated (Bouma Tb/e). This unit is interpreted as the product of deposition from dilute turbidity currents in a confined environment (Rio della Chiesa Basin - see below).

5.4.2.5. Rio della Chiesa Upper Sandstones

This unit crops out only in the Rio della Chiesa Valley. The unit has an estimated thickness of about 25 m and consists of turbiditic sandstone-mudstone couplets in thick to very thick strata grading upwards into thick to medium strata (Fig. 39). In the middle part a debrite bed up to 4 m thick is present. This unit is interpreted as the product of deposition by classic turbidity currents of intermediate concentration in a confined environment (Rio della Chiesa Basin - see below).

5.4.3. Rio della Chiesa Basin

The reconstruction of the possible extent and tectono-stratigraphic evolution of the Rio della Chiesa Basin is

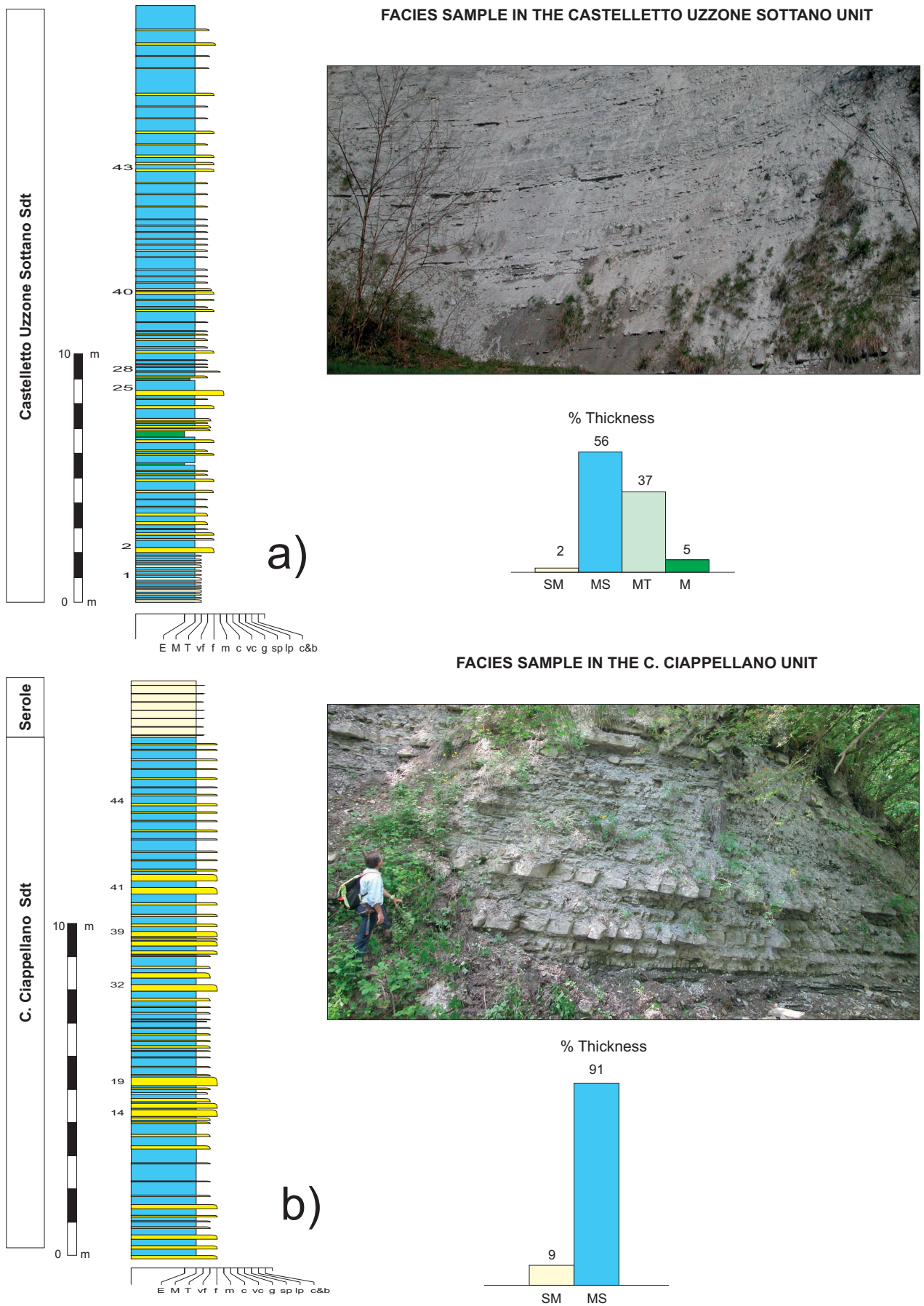


Fig. 37 - a) Facies sample of the Castelletto Uzzone Sottano Sandstones (left side of the Rio della Chiesa Valley). b) Facies sample of the C. Ciappellano Sandstones (left side of the Rio della Torre Valley).

VERTICAL FACIES DISTRIBUTION OF THE RIO DELLA CHIESA LOWER SANDSTONES

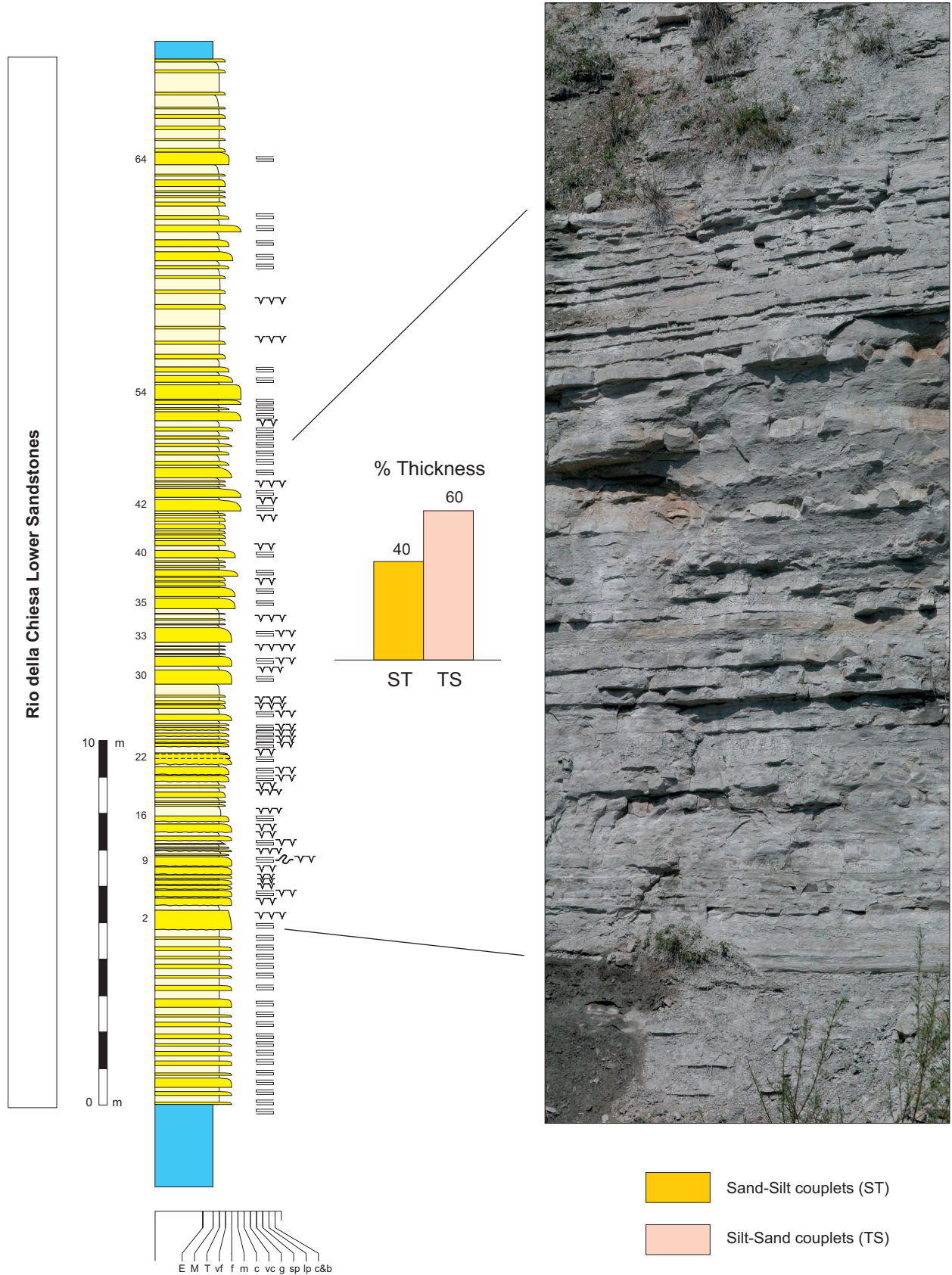


Fig. 38 - Vertical facies distribution of the Rio della Chiesa Lower Sandstones (left side of the Rio della Chiesa Valley).

VERTICAL FACIES DISTRIBUTION OF THE RIO DELLA CHIESA UPPER SANDSTONES

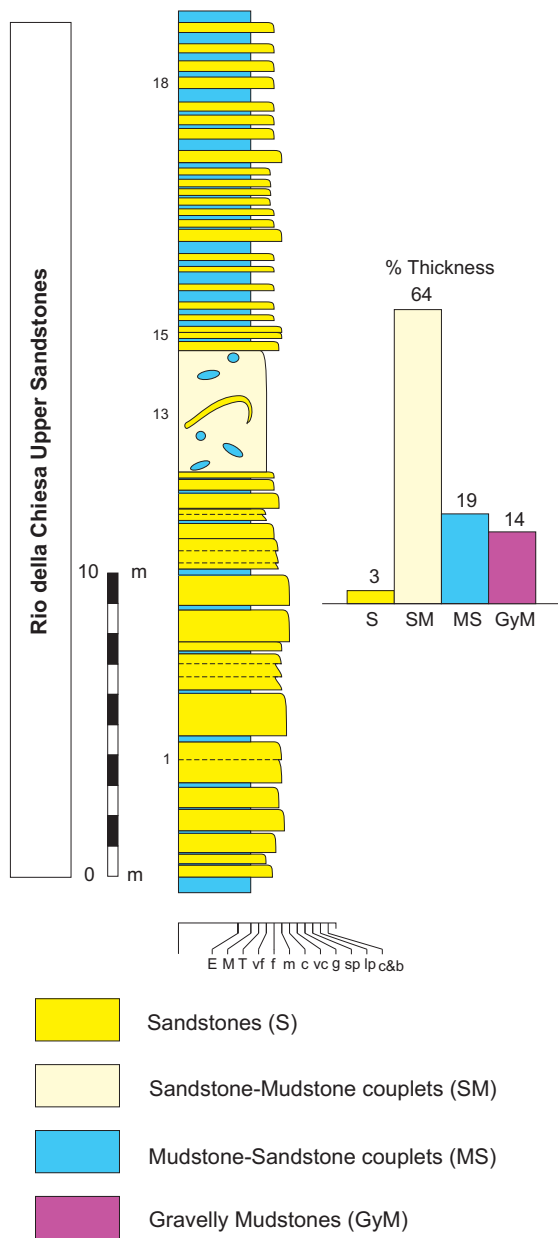


Fig. 39 - Vertical facies distribution of the Rio della Chiesa Upper Sandstones (left side of the Rio della Chiesa Valley).

based on the following arguments:

1) An active role of the C. Serra Fault can be inferred from the tectono-stratigraphic relationships highlighted by the geological map for the sandstone bodies of the lower part of the Montechiaro d'Acqui Fm cropping out in the Rio della Chiesa Valley. As discussed above, these sandstone bodies crop out only in the downthrown block bounded by the S. Ilario and Gerba Faults (cf. Fig. 49 and geological map) where the complete thickness of the Montechiaro d'Acqui Fm is preserved. In the areas located to the N and S of the structural depression the Montechiaro d'Acqui Fm is removed by the Uzzone Valley Erosional

Depression, and the Serole Fm is directly superimposed on the Siliceous Lithozone LS1c. In these areas therefore the original extent of the sandstone bodies is unknown. It seems likely, however, that the sandstone bodies did not extend southwards beyond the C. Serra Fault, because S of this fault the Montechiaro d'Acqui Fm is again partly preserved and is exclusively composed of marls.

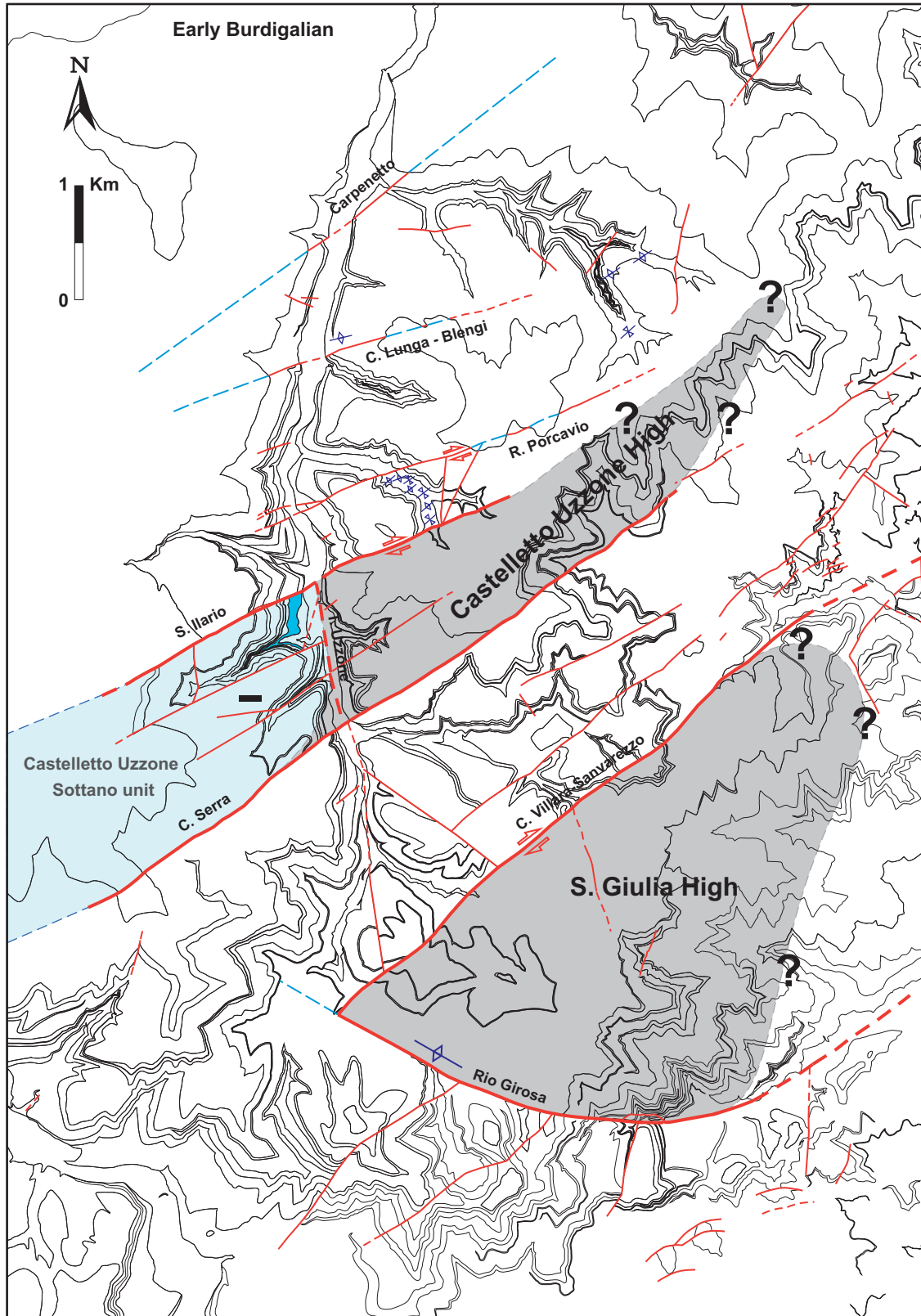
2) The reactivation of the C. Serra Fault is thought to be coeval to the rise of the Castelletto Uzzone intrabasinal high, oriented NE-SW and bounded to the W by the N-S trending T. Uzzone Fault (Figs. 40-44). In fact, the sandstone units of the Montechiaro Fm only exist on the left side of the Uzzone Valley, while they are absent, due to non-deposition, on the right side. Concurrently with the reactivation of the C. Serra Fault, the Santa Giulia Fault Block was displaced SW-wards along the NE-striking C. Sanvarezzo-C. Villara strike-slip fault, in times post-dating the LS1c Siliceous Lithozone (i.e. early Burdigalian) (cf. paragraph 6.4). This led to the local structural inversion of the Noceto Half-graben, in turn resulting in the creation of the Santa Giulia intrabasinal high (Figs. 40-44). The type of movement along the Sanvarezzo-C. Villara Fault suggests a component of strike-slip motion also for the other faults of the the Uzzone Valley Fault System.

3) It may be inferred from above that, after the deposition of LS1c Siliceous Lithozone, which marked a pause in regional tectonic activity (Pl. IVa, panel B3), the fault system of the Uzzone Valley was reactivated in the early Burdigalian during the deposition of the Montechiaro d'Acqui Fm.

These relationships suggest that a basin, here referred to as Rio della Chiesa Basin, accommodated the sandstone bodies of the lower part of the Montechiaro d'Acqui Fm and was bounded to the S by the C. Serra Fault and to the E by the T. Uzzone Fault and Castelletto Uzzone intrabasinal high (Fig. 44).

The possible tectono-sedimentary evolution of the Rio della Chiesa Basin is shown schematically in figures 40-44, and plate IVa, b, panels B4-B10.

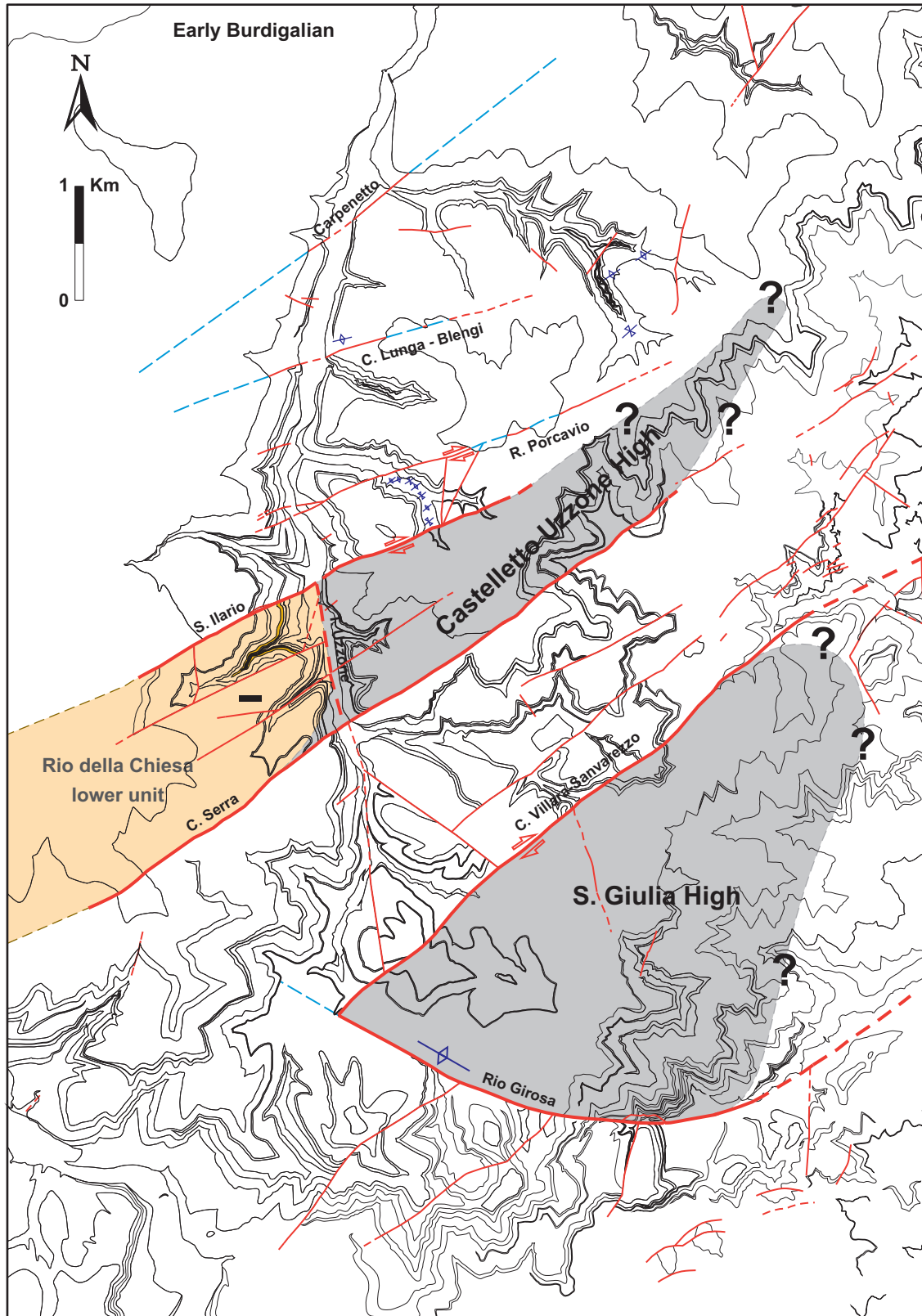
Initially, the basin was probably restricted to a graben bounded by the C. Serra and S. Ilario Faults. The Castelletto Uzzone Sottano Sandstones and Rio della Chiesa Lower Sandstones were laid down within this depression (Figs. 40, 41 and Pl. IVa, panels B4-B6). At least for the deposition of Castelletto Uzzone Sandstones, this hypothesis seems to be plausible on the basis of field data. In the Rio della Chiesa Valley, in fact, this unit is bounded by the Siliceous Lithozone LS1c at the base and the marls of the Montechiaro d'Acqui Fm at the top, while, N of the S. Ilario Fault, the LS1 siliceous unit and the Montechiaro d'Acqui marls are in contact (cf. Fig. 49 and geological map), suggesting that the northward areal extent of the sandstone unit at the time of deposition coincided with the present-day extent of the outcrops. Actually, the confinement of the Rio della Chiesa Lower Sandstones within the above mentioned graben is an interpretive choice unsupported by field evidence. Subsequently, the S. Ilario Fault would have been deactivated, while the C. Serra Fault probably remained



The Rio della Chiesa Basin - Castelletto Uzzone Sottano Sandstones



Fig. 40 - Rio della Chiesa Basin. Inferred extent of the Castelletto Uzzone Sottano Sandstones. Note the Castelletto Uzzone and S. Giulia intrabasinal highs.



Rio della Chiesa Basin - Rio della Chiesa Lower Sandstones

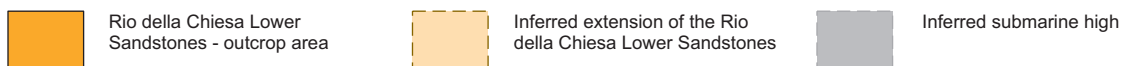


Fig. 41 - Rio della Chiesa Basin. Inferred extent of the Rio della Chiesa Lower Sandstones.

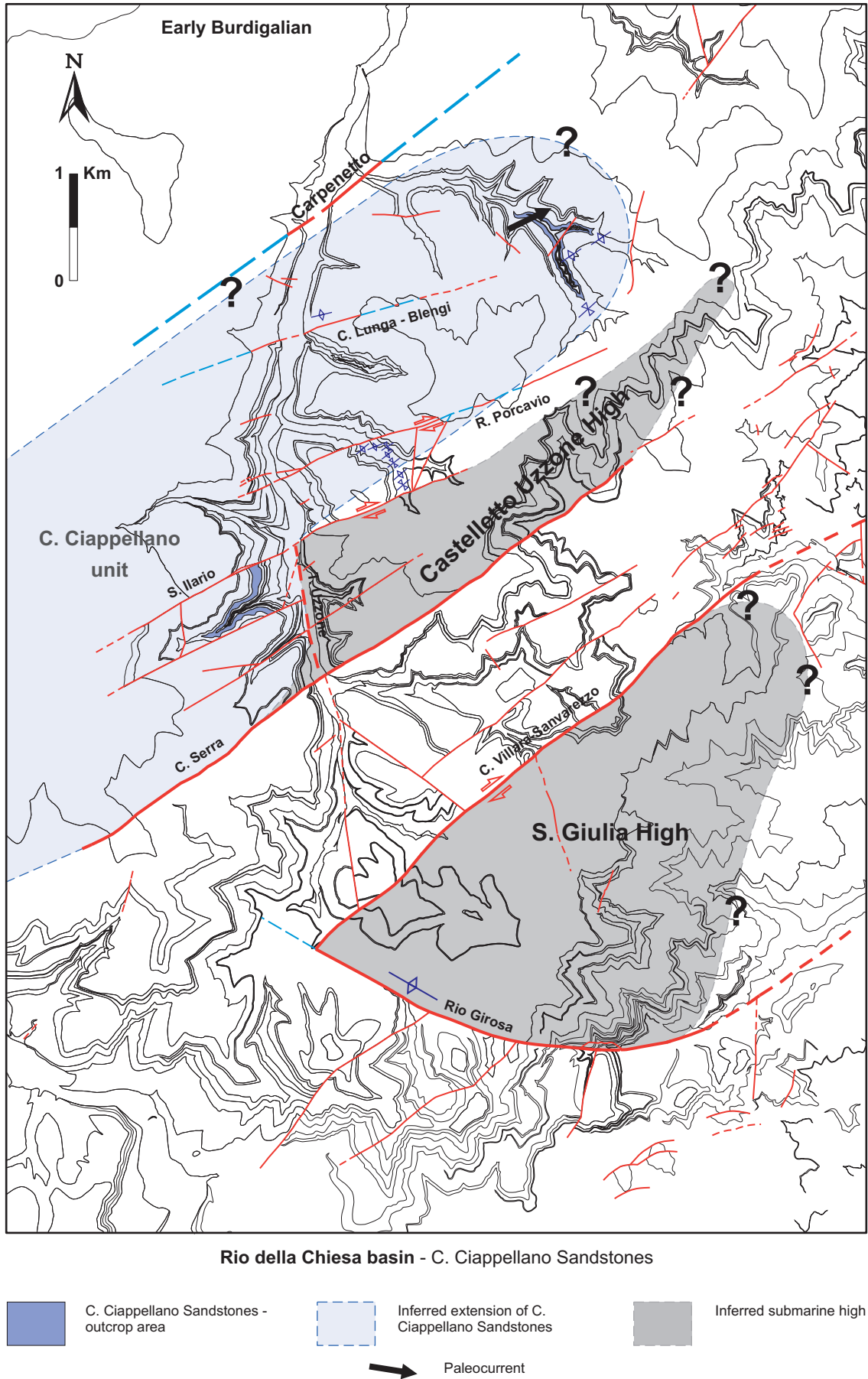


Fig. 42 - Rio della Chiesa Basin. Inferred extent of the C. Ciappellano Sandstones.

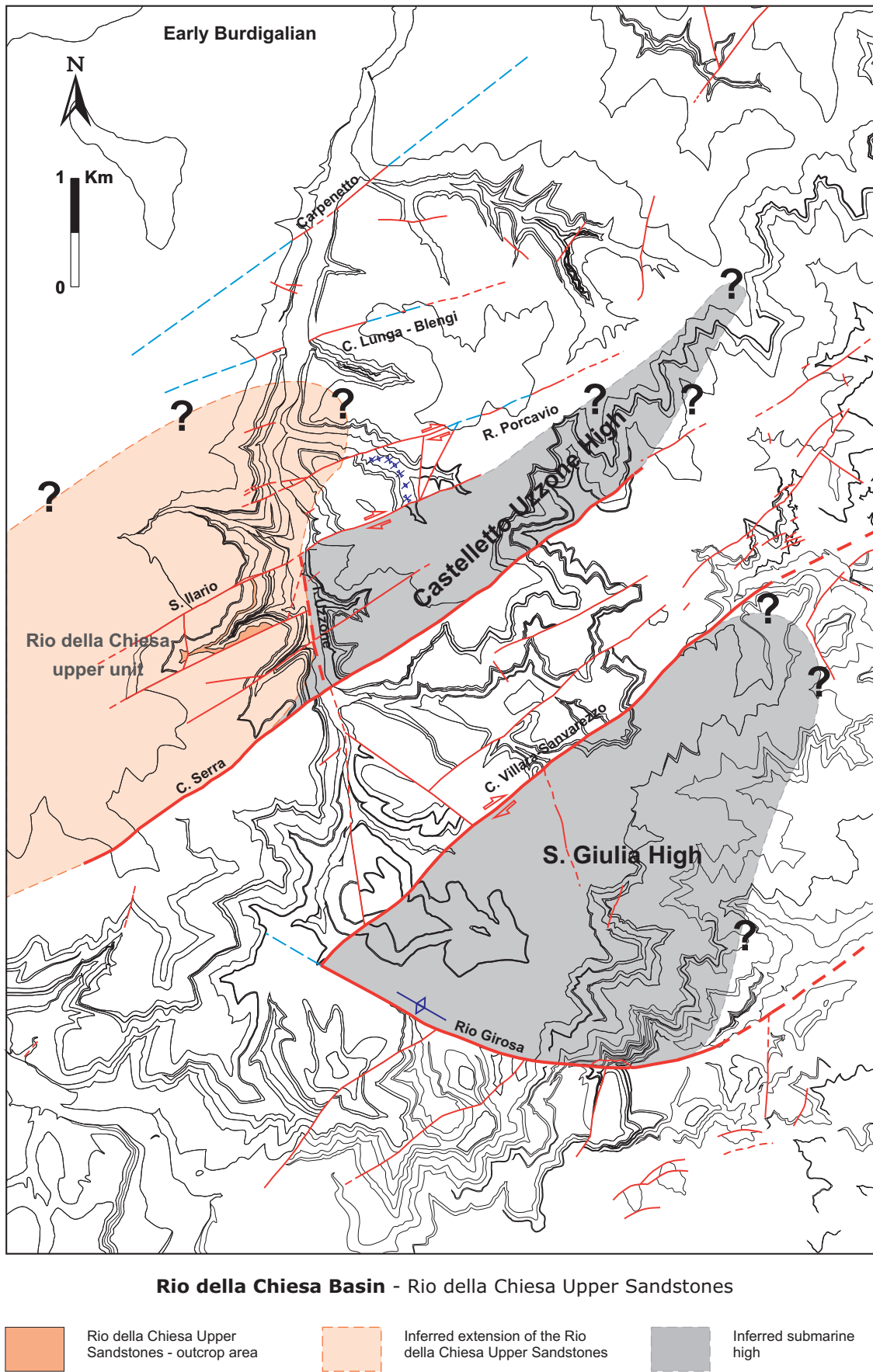


Fig. 43 - Rio della Chiesa Basin. Inferred extent of the Rio della Chiesa Upper Sandstones.

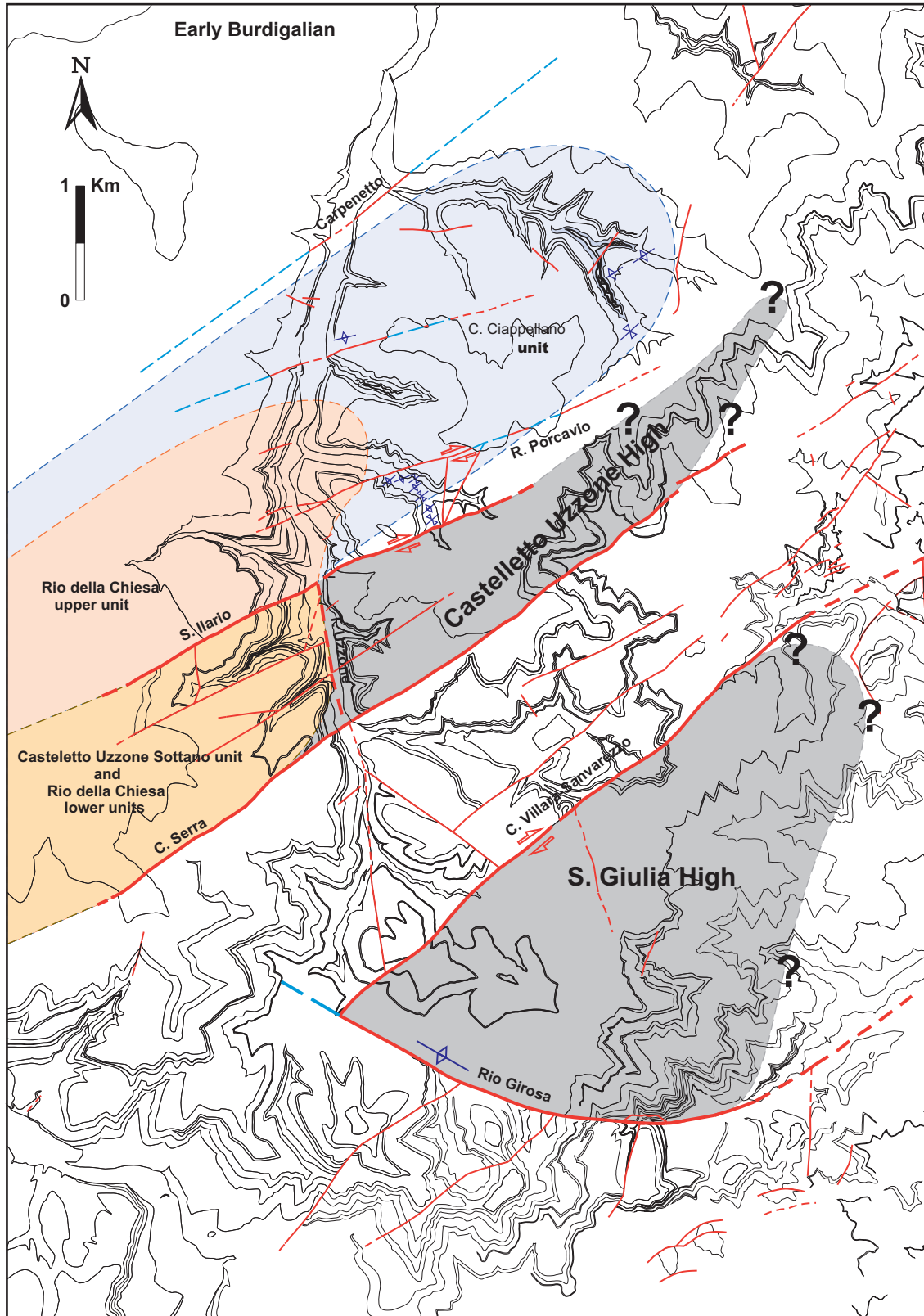


Fig. 44 - The Rio della Chiesa Basin.

active, and created a half-graben type structure accommodating the C. Ciappellano Sandstones and the Rio della Chiesa Upper Sandstones (Figs. 42, 43 and Pl. IVb, panels B8-B9). The C. Ciappellano Sandstones are present in both Rio della Chiesa and Rio della Torre areas,

while the depositional area of the Rio della Chiesa Upper Sandstones would have been only confined to the Rio della Chiesa area, as indicated by the lack of this unit in the local succession of the Rio della Torre Valley. A schematic representation of the Rio della Chiesa Basin is

shown in figure 44. Clastic sedimentation within the basin ended with the regional deposition of middle-upper part of the carbonate hemipelagites of the Montechiaro d'Acqui Fm during the early Burdigalian (Pl. IVb, panel B10).

5.5. Serole Formation

The Serole Fm has a wedge-shaped geometry tapering NE-wards and consists mainly of mudstone-sandstone couplets (mostly Bouma Tb/e) deposited by dilute turbidity currents and includes a number of sandstone bodies both on large (kilometric) and medium (hectometric) scale. Moreover, in the study area the unit is bounded at the base by some large-scale erosional surfaces defined respectively Denice, Bric Torrione, Case Rocchino and Uzzone Valley erosional depressions (cf. Pl. I). The Serole Fm passes transitionally upwards to the Cortemilia Fm.

5.5.1. Piantivello Sandstones

This unit is a large-scale sandstone body with lenticular geometry and erosional concave-up base. It has a maximum thickness of about 100 meters and lateral extent of about 4.5 km. Component facies have been described by Ghibaudo et al. (this volume). Overall, the Piantivello unit is characterized by a trend thinning and fining upwards. The paleocurrents indicate a WNW provenance.

Interpretation: The Piantivello unit is interpreted as the infill of a base-of-slope broad submarine valley roughly elongated in E-W direction and fed from the west. The trend thinning and fining upwards indicates a gradual reduction in the volume of gravity flows possibly related to a gradual rise in relative sea level (Ghibaudo et al., this volume).

5.5.2. Bric Torrione Sandstones

The unit has a maximum thickness of 23 m and lateral extent of about 750 m in a section transverse to the paleocurrents. The field evidence shows that the unit is confined within a large-scale erosional surface (Pl. I). Component facies have been described by Ghibaudo et al. (this volume). The unit mainly consists of amalgamated sandstones and sandstone-mudstone couplets in medium and thick beds. The unit was fed from W and the dip of paleoslope was to the E.

Interpretation: The unit represents a turbiditic sandstone body confined in 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 converted in a pathway for turbidite flows (slope valley) (Ghibaudo et al., this volume).

5.5.3. Rio Della Torre Lower Sandstones

The maximum outcropping thickness is 40 m. The unit shows an almost tabular geometry and is characterized by depositional pinch-out towards SE. It consists of amalgamated sandstones in medium and thick layers (Ta-

b/, Tb/); sandstone-mudstone couplets in medium and thick layers (Ta-b/e and Tb/e); laminated mudstone-sandstone couplets in thin to medium layers (Tb/e); and rare pebbly mudstones (Fig. 45). Only two paleocurrents (N60°E/S60°W, N65°E/S65°W) were found within the unit. They indicate a SW-NE transport direction, parallel to the SE-ward depositional pinch-outs of the unit. The direction of paleocurrents are, therefore, roughly perpendicular to the depositional pinch-outs.

Interpretation: based on the tabular geometry and the sedimentologic features the Rio della Torre Lower Sandstones are here tentatively interpreted as a depositional sandstone lobe developed in the lower part of the Serole inferred slope wedge (see later) (Fig. 47). The SE-ward pinchout of the unit may have been controlled by a gentle, large-scale anticline (radius of hundreds of meters) developed near the head of the Rio della Torre Valley, that deforms the Montechiaro d'Acqui Fm but does not affect the Serole Fm (cf. Fig.47).

5.5.4. Rio della Torre Upper Sandstones

The overall geometry cannot be defined on the basis of field data, as the unit is displaced by the Carpenetto Fault and does not crop out to the NW of this fault. The unit has a maximum thickness of about 35-40 m and shows, in outcrop, a tabular geometry with depositional pinch-out towards SE. Some facies samples of this unit are shown in figure 46. The unit consists mainly of thick beds of amalgamated sandstones in the lower part and thin- to medium-bedded sandstone-mudstone couplets in the upper part. The paleocurrents indicate a transport direction towards the NE, therefore normal to the SE-ward depositional pinch-out of the unit.

Interpretation: by analogy with the underlying Rio della Torre Lower Sandstones, also this unit is tentatively interpreted as a nonchannelized sandstone lobe (Fig. 47).

5.5.5. Gottasecca Sandstones

No sedimentological study was performed on this sandstone body. Expeditious observations in the Bormida di Millesimo Valley (just outside the study area), where the unit is well exposed with a thickness of about 40 m, reveal that it consists of three stacked sandstone bodies with unknown lateral continuity and upward-thinning and -fining internal trends, characterized by amalgamated turbidite sandstones in the lower part passing upwards to sandstone-mudstone couplets in thick to medium beds (Fig. 48). At least for the above mentioned outcrops, the lower sandstone body appears to thin out in a few hundred meters toward SW. Paleocurrents (two measures) indicate a transport direction toward N70°E. In the absence of detailed sedimentological data the paleoenvironmental setting of the unit is not known. Tentatively it may represent a multistorey and multilateral sandstone body made up of smaller, broad lenticular units laterally and vertically stacked to form a sedimentary body with roughly tabular overall geometry.

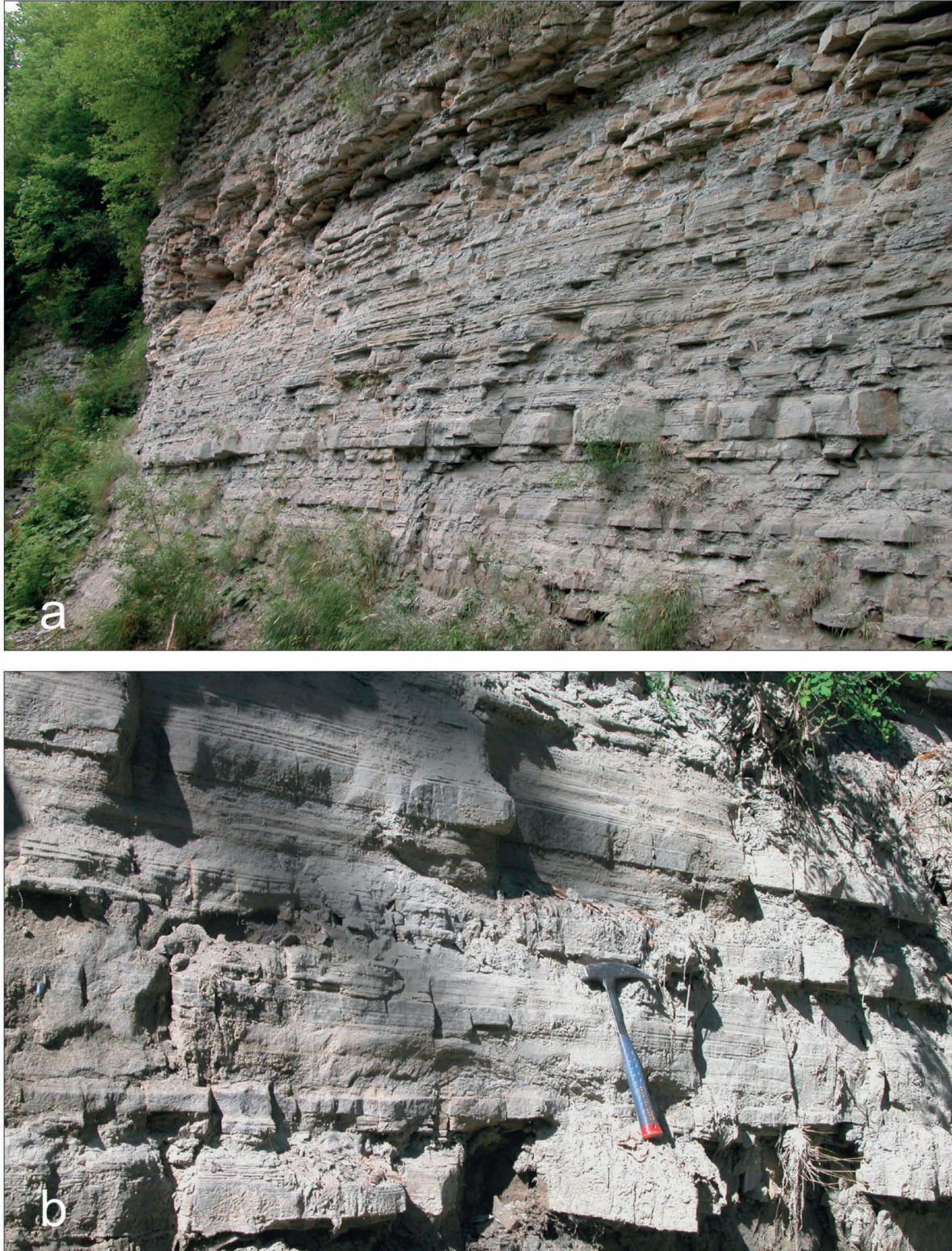


Fig. 45 - Rio della Torre Lower Sandstones. a) Lower part of the unit cropping out on the left side of the Rio della Torre Valley. Note high sandstone/mudstone ratio and pervasive parallel lamination; b) Detail of graded to parallel-laminated sandstones beds.

5.5.6. Vignazze Sandstones

This unit is a sandstone body with roughly tabular geometry cropping out in the Uzzone Valley between the villages of Scaletta Uzzone and Poggiolo and located

stratigraphically at the base of the Serole Fm, in the most depressed portion of the Uzzone Valley Erosional Depression (see below). The unit has maximum thickness of about 6-7 m.

SECT. 6 - TORRENTE UZZONE

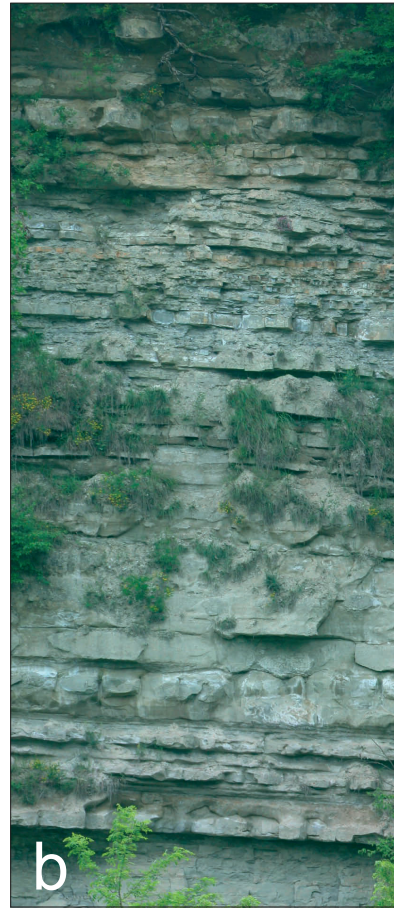
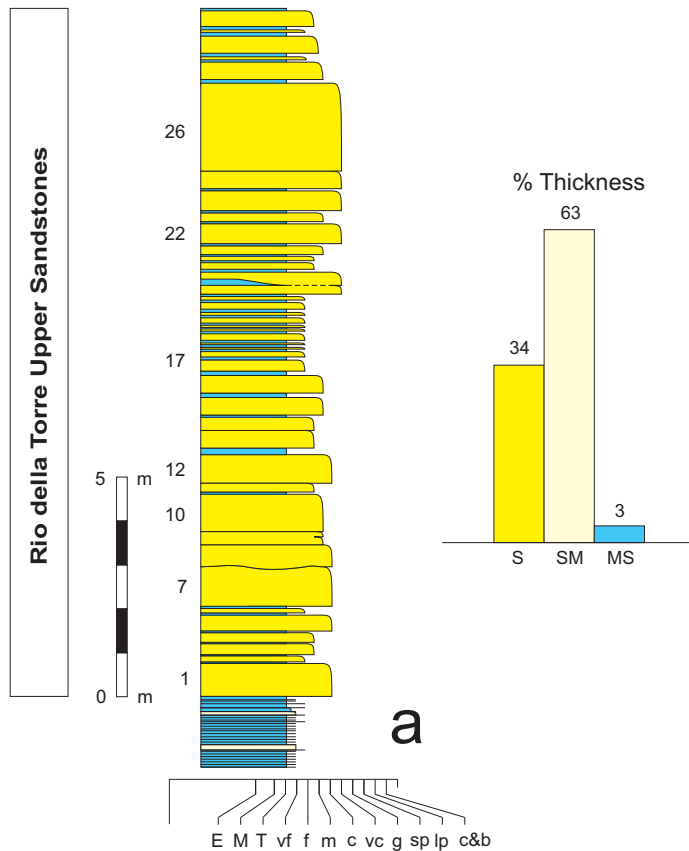


Fig. 46 - The Rio della Torre Upper Sandstones cropping out on the right side of the T. Uzzone Valley in front of the Carpenetto village, with schematic log and detail.

5.5.7. Paleoenvironmental interpretation of the Serole Formation

The presence of large-scale erosional unconformities (slump scars) at the base of the Serole Fm indicates that the succession was probably deposited on a slope. On this basis, the Serole Fm is interpreted as indicative of a deposition in a lower slope environment. Based on the fine-grained lithology and the wedge-shaped geometry

showing maximum thickness to the SW and tapering NEward the Serole Fm is interpreted as a prodelta slope wedge. In particular, this association, comprising possibly channelized sandstone bodies in its thicker part, is tentatively considered equivalent to “channel-levee complexes” or “slope fans” of the recent literature on turbidite depositional systems.

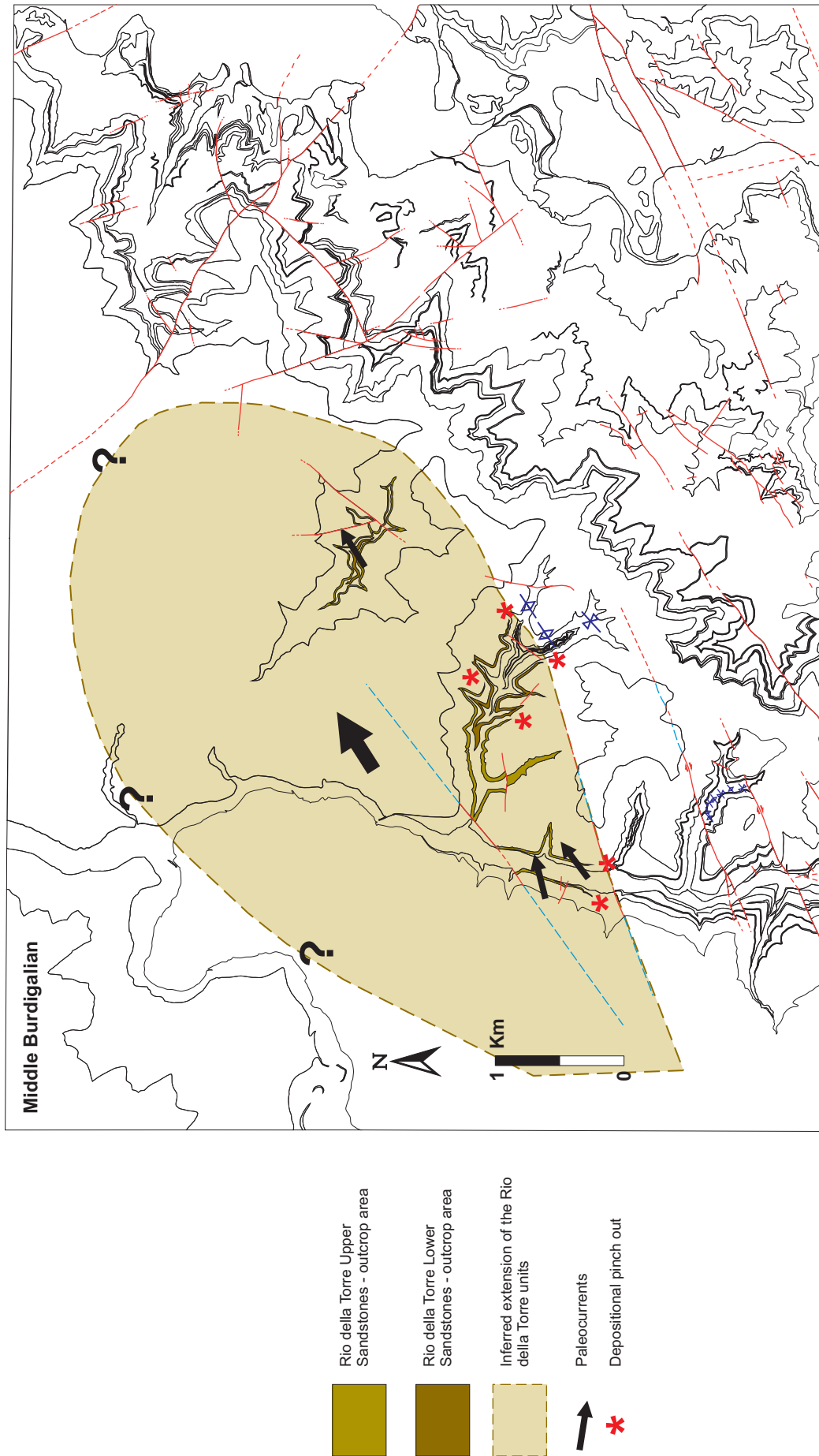


Fig. 47 - Inferred extent of the Rio della Torre lower and upper units.



Fig. 48 - The Gottasecca Sandstones cropping out along the Contrada-Monesiglio road just outside the study area. Note the complex internal organization consisting of at least three stacked upward-thinning units.

5.5.8. The erosional depressions at the base of the Serole Formation

As previously noted in paragraphs 4.7, 4.8, and 5.5, the transition between the Montechiaro d'Acqui Fm and the overlying Serole Fm is characterized locally by erosional discontinuities, interpreted as slump scars, with the partial or total removal of the marls of the Montechiaro d'Acqui Fm (cf. Pls. I and II) (see also Ghibaudo et al., this volume). With the exception of the Bric Torrione Erosional Depression, clearly evidenced by a lenticular sandstone body confined in the lower part the depression (Bric Torrione Sandstones), the other surfaces are highlighted by local thickness reductions or total absence of the underlying marls of the Montechiaro d'Acqui Fm.

5.5.9. Bric Torrione Erosional Depression

The geometry and the infill of the Bric Torrione Erosional Depression are shown in the cross-section of plate I. It has a width of about 1.5 km and an estimated maximum depth of 80 m. The scar completely removes the underlying Piantivello unit and the Montechiaro d'Acqui Fm (Pl. I). The infill is made up of the Bric Torrione sandstone turbidites in the lower part and the fine-grained turbidite deposits of the Serole Fm in the upper part (Ghibaudo et al., this volume). Paleocurrents within the Bric Torrione unit indicate transport direction from W to E.

5.5.10. The C. Rocchino, Denice and Uzzone Valley erosional depressions

These erosional surfaces developed at the top of the Montechiaro d'Acqui Fm and were infilled with the fine-grained turbidite deposits of the Serole Fm. The outcrops do not allow a detailed study of such surfaces, and their presence can only be inferred from the geological map. The C. Rocchino and Denice erosional depressions have an estimated depth of a few tens of meters and a lateral extent of several hundreds of metres (Ghibaudo et al., this volume). The Uzzone Valley Depression is a plurikilometric erosional surface some tens of metres deep. The scar removes most part of the Montechiaro d'Acqui Fm. It is especially developed in the Uzzone Valley, where the thin-bedded turbidites of the Serole Fm are locally directly superimposed on the Siliceous Lithozone LS1c, with total removal of the underlying marls of the Montechiaro d'Acqui Fm (cf. geological map and Pls. I and II). The large areal extent of this surface and local variations in thickness of the marls of the Montechiaro d'Acqui Fm preserved beneath suggest a composite origin by coalescence of slump scars.

5.5.11. The genesis of the erosional depressions

The scars occurring atop the Montechiaro d'Acqui Fm remove partially or totally this formation and are mainly located in the Uzzone Valley and its tributaries. In this area the complete thickness of the Montechiaro d'Acqui Fm is preserved only in the Rio della Chiesa graben, which presumably developed prior to the generation of the Uzzone Valley Erosional Depression (cf. Pl. II). As

discussed in paragraph 6.4, active syndepositional tectonics affected this portion of the Langhe Basin during the deposition of the Montechiaro d'Acqui Fm. Reactivation of the Uzzone Valley Fault System at the end of deposition of the Montechiaro d'Acqui Fm (see paragraph 6.4) is thought to have triggered gravity destabilization of the slope, resulting in the generation of the erosional scars. In particular, the geometry of the Uzzone Valley Erosional Depression, as inferred from the mapping evidence, is that of an irregular, composite, plurikilometric surface. However, accumulations of slumped sheets were not observed, suggesting that the sediment removal may have taken place by multiple liquefied mud flows in poorly consolidated sediments, rather than by large mass failure. Following Davies and Clark (2006), we suggest that rapid compaction of the underlying Montechiaro d'Acqui Siliceous Lithozone, due to thermochemical dehydration as a result of conversion of opal A to opal CT, generated overpressure buildup and consequent reduction of shear strength in the overlying sediments (Montechiaro d'Acqui marls), making sediments susceptible to failure, with multiple detachment units behaving as liquefied sediment masses. This mechanism may presumably have operated in concomitance with seismic tectonics, acting as immediate cause of failure.

6. STRUCTURAL SETTING

The main structural elements of the study area are shown in figure 49 and plate I. The Oligo-Miocene stratigraphic succession dips, on average, to the NW, in agreement with the attitude of the Langhe regional homocline. The average dip angles of the beds vary between 8° and 12°. The structural elements that characterize the study area consist essentially of high-angle fault systems and small- to medium-scale folds.

The structural setting is dominated by four major fault systems active in successive times: 1) a system of high-angle faults oriented NW-SE and NE-SW, active in the Rupelian *p.p.*-early Chattian, which displaced the crystalline basement and controlled the sedimentation of the Molare Fm and of the basal part of the Rocchetta Fm; 2) a listric growth fault oriented NW-SE active during the early Aquitanian (Rio Giosa Fault) which controlled the formation of the Noceto Half-graben; 3) a subvertical growth fault oriented E-W (Pian dei Buri Fault) and related faults (C. Bazzi and C. Gergi Faults) active during the early Burdigalian, which controlled the formation of the C. Mazzurini Half-graben. To this system may be associated i) the Rocchetta Fault active as synsedimentary fault in the middle-late Aquitanian and ii) the Pian dei Buri Fault during its initial synsedimentary middle-late Aquitanian activity; 4) a high-angle transcurrent faults system (Uzzone Valley Fault System) oriented NE-SW, of middle-late Aquitanian and early Burdigalian age, that displaced and controlled the deposition of Poggiolo, Castelletto Uzzone, Montechiaro d'Acqui and Serole formations, as well as the development of the large-scale

slump scars located at the top of the Montechiaro d'Acqui Fm in the Uzzone Valley area. 5) high-angle faults postdating the Cortemilia Fm.

With the exception of late faults, the tectonic lineaments may be divided into two groups: a) faults characterized by only synsedimentary evolution b) synsedimentary faults reactivated in a late, post-sedimentary stage. Synsedimentary faults strongly controlled facies, thickness, geometry and location of associated sedimentary bodies at the scale of lithostratigraphic units and sub-units.

The folds in the study area include: 1) a series of tight and small-scale *en échelon* folds (radius of the order of tens of metres) that deform the turbidites of the Poggiolo Fm in the upper part of the Rio Porcavio Valley; 2) some gentle, large-scale folds (radius of hundreds of meters) in the upper part of the Rio della Torre Valley, that deform the Montechiaro d'Acqui Fm; 3) a medium-scale anticline on the left side of the Rio Pescritta, in front of Piandolo Sottano, here called "Rio Pescritta Anticline", which deforms the Noceto unit; 4) a monocline affecting the Molino di Mombaldone lower unit (treated in detail in Ghibauda et al., this volume).

6.1. The Early Oligocene extensional to transtensional faults

This fault system includes, from S to N, the following faults (Fig. 49 and Pl. I): the NE-striking Dego, La Costa and C. Tone Faults, and the NW-striking C. Rosso, Piana Crixia, Montaldo and Vico Faults. These faults were active primarily during the Oligocene. Some of them acted as extensional synsedimentary faults during the deposition of the Molare Fm in Rupelian times (e.g. the Case Tone Faults and, *pro parte*, the Montaldo and Vico Faults). Formerly active faults and new faults were later activated in a transtensional regime and controlled facies and thicknesses of the Rocchetta Fm as well as the development of the positive intrabasinal structure called "Dego-Spigno Monferrato High" in late Rupelian-early Chattian times. Some faults, moreover, were reactivated in the early Burdigalian (e.g. C. del Rosso Fault).

6.1.1. The Case Tone, Montaldo and Vico Faults and the Borgo and Cartosio continental grabens

Activity of the faults: Early Oligocene, during the accumulation of the continental deposits of the Molare Fm.

The basement-involving, high-angle Case Tone Faults and Montaldo Fault bound the Lower Oligocene Borgo Graben, which accommodated the continental conglomerates of the Molare Fm; they are inferred to have been active in an extensional regime and are sealed by the transgressive marine deposits of the same formation (Figs. 4a, 49, Pl. I). The Montaldo Fault is a high-angle normal fault that had an initial synsedimentary activity during the deposition of the conglomerates of the Molare Fm and was subsequently reactivated during the deposition of the basal portion of the Rocchetta Fm (Ghibauda et al., this volume). The Case Tone Faults are two sub-parallel, high-

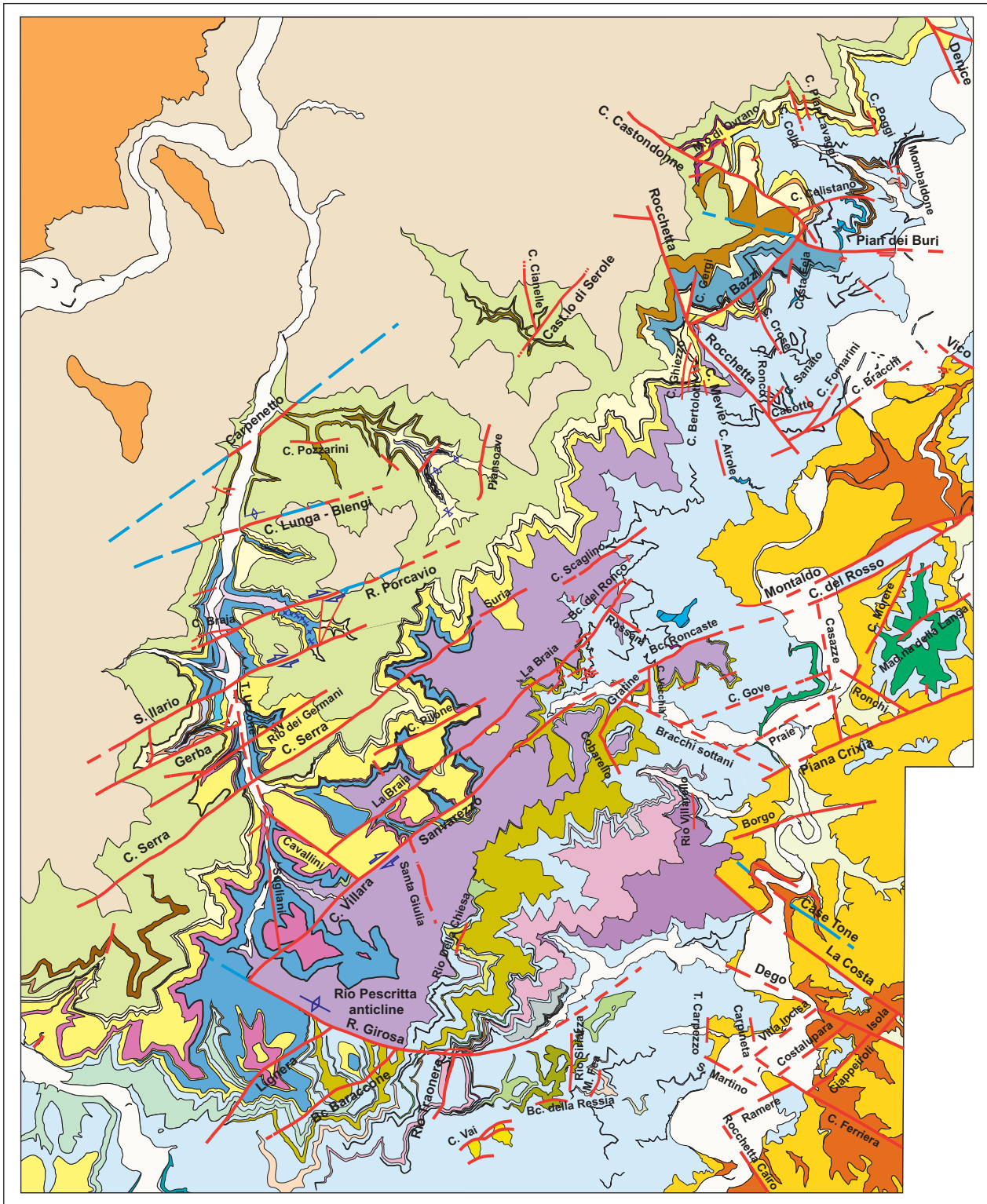


Fig. 49 - Structural map of the study area.

angle faults oriented NW-SE, characterized by a damage zone about 200 m wide, that were active during the deposition of the continental Molare Fm. A structural depression similar to the Borgo Graben, the Cartosio Graben, developed N of the Spigno Monferrato Horst, where the infilling continental conglomerates were

bounded to the S by the Vico Fault. The Borgo Graben was bounded to the S by the Rocchetta Cairo Horst and to the N by the Spigno Monferrato Horst (Pls. I, IIIa, panels A1-A2). The Case Tone, Montaldo and Vico Faults were sealed by the marine transgression which led to the general deposition of marine shelf sandstones both atop

the continental deposits of the Borgo and Cartosio Grabens and directly on the adjacent crystalline basement high (see also Ghibaudo et al., this volume).

6.1.2. The Dego, La Costa, Piana Crixia, C. del Rosso, Montaldo, and Vico Faults and the Dego-Spigno Monferrato High

Activity of the faults: late Rupelian and early Chattian coeval to the deposition of the basal part of Rocchetta Fm.

This high-angle fault system oriented NW-SE (Dego, La Costa and Vico Faults) and SW-NE (Piana Crixia, C. Rosso and Montaldo Faults) displaces the crystalline basement and the Molare Fm in a series of fault blocks resulting in thickness and facies changes of the Rocchetta Fm (Fig. 49). These basement-related faults are sealed, at different stratigraphic levels, by the mudstones of the Rocchetta Fm. Only some of them, e.g. the C. del Rosso Fault, show a resumption of activity during the early Burdigalian (see below). These faults define a complex positive intrabasinal structure called “Dego-Spigno Monferrato High” (Pl. I). The Dego-Spigno Monferrato High, in turn, was subdivided into a series of horsts and grabens. These include, from S to N, the “Dego Horst”, the “Piana Crixia Graben” and the “Spigno Monferrato Horst”. The Rocchetta Fm overlying the Dego-Spigno Monferrato High is almost entirely pelitic and reaches a thickness of about 540 m. On the other hand, the Turpino and Rocchetta Cairo depocentres, developed respectively N and S of the Dego Spigno-Monferrato High, accommodated thicknesses of the Rocchetta Fm of up to about 1000 m. It should be noted that the FO of *S. ciproensis* is located about 50 m above the base of the Rocchetta Fm testifying that, at the time of this bio-event, the Dego Spigno-Monferrato High was partly leveled by the hemipelagic and turbiditic sedimentation of the Rocchetta Fm and no longer constituted a prominent intrabasinal topography. A more detailed reconstruction of the history of relative movements between adjacent fault blocks is prevented by lack of data about the age of the mudstones at the Molare-Rocchetta transition in the depocentres located SW and NE of the Dego-Spigno Monferrato High and in the Piana Crixia Graben. To the same intra-Oligocene synsedimentary activity is attributable the confinement of the Piana Crixia turbidite unit within a local graben (Piana Crixia Graben) bounded by the Piana Crixia and Montaldo Faults.

Although detailed structural data are not available, the above syndepositional tectonics is thought to record a change into transtension, after the Rupelian extension. This is suggested by the beginning of transcurrent activity at regional scale along some major tectonic lines in late Rupelian-early Chattian times (e.g. Scrivia, Villalvernia-Varzi and Stura Faults) (Molli et al., 2010, with references therein) suggesting the development of a basinwide strike-slip regime in the TPB since the late Rupelian (see chapter 9).

Some faults of this system were later reactivated. The C. del Rosso Fault, in particular, was reactivated in post-

Aquitanian times. Indeed, it displaces the Noceto unit (lower Aquitanian) at Bric Roncaste and is probably connected, to the SW, with the Sanvarezzo-C. Villara Fault for which a dextral strike-slip activity can be documented in early Burdigalian times (see below).

6.2. The early Aquitanian Rio Girona synsedimentary listric fault

Activity of the fault: growth as synsedimentary listric fault during the early Aquitanian in concomitance with the stratigraphic expansion of the uppermost mudstones of the Rocchetta Fm (cf. “Rio Girona stratigraphic expansion”, paragraph 4.3) and with the infilling of the Noceto Half-graben; b) inversion probably in the early Burdigalian times (post-Siliceous Lithozone LS1c).

This is a listric fault oriented NW-SE bounding to the S the Noceto Half-graben (cf. geological map, Pl. I and paragraph 5.1.3.5) and later inverted as high-angle reverse fault. The original listric fault that bounded to the S the Noceto Half-graben was sealed by the Bric Baraccone Siliceous Lithozone (LS1a) (cf. Pl. I). The kinematic history of the Rio Girona Fault is characterized by two distinct periods of activity: 1) long-term activity as listric growth fault sealed by deposition of the Siliceous Lithozone LS1a, and 2) later partial inversion.

The period of activity as listric growth fault is well defined in time. As shown in the cross-section of plate I, the expanded thickness includes both the stratigraphic interval called “Rio Girona stratigraphic expansion”, consisting of the uppermost mudstones of the Rocchetta Fm, encasing the Pian del Lago and Bric della Lasagna sandstones, and the overlying Noceto unit. On the hangingwall, this expanded stratigraphic interval is about 450 m thick. On the footwall, the corresponding stratigraphic interval between the top of Cobarello Unit and the Siliceous Lithozone LS1a has a reduced thickness of about 100 m. The synsedimentary activity of the Rio Girona Fault spans from the end of the deposition of the Cobarello Unit (late Chattian) and the deposition of Siliceous Lithozone LS1a (middle Aquitanian). It can therefore be referred to the early Aquitanian.

This growth fault soled out in the mudstones of the Rocchetta Fm which underlie the sandstone bodies of Mogliavacca, Brovida and Cobarello (Pl. I). A close relationship is assumed between the genesis and evolution of growth faults identified in seismic profiles of the present-day continental margins, and the presence of high pore fluid pressure in deep-seated clays (Bruce, 1973; Bradshaw and Zoback, 1988; McNeil et al., 1997). It is therefore likely that the location and evolution of the Rio Girona growth fault is related to the presence of a stratigraphic interval of poorly drained mudstones developing high pore fluid pressure at a depth where the fault soled out. The overpressure could be linked with the loading compaction due to great thickness of mudstones in this area and the high local sediment load due to the presence of the overlying Mogliavacca, Brovida and Cobarello sandstone bodies (Pl. I). The subhorizontal

soling out of the fault into overpressured mudstones would have accommodated the displacement by creep along intrastatal shear planes in a continuum of deformation resulting in the progressive creation of accommodation space for an expanded stratigraphy on the hangingwall of the fault.

The listric growth fault that bounded to the S the Noceto Half-graben was later reactivated in compression and led to partial inversion of the Noceto Half-graben. The partial inversion of the Noceto half-graben implied dextral motion along the Sanvarezzo-C. Villara Fault, which is a high-angle fault oriented SW-NE that extends for about 6.5 km from the Uzzone Valley to Rio della Madonna Valley (cf. geologic map and Fig. 49) and is part of the Uzzone Valley Fault System. This fault and the listric Rio Giosa Fault bound a fault block, here defined "S. Giulia Fault Block", that was shifted SW-wards by means of limited right-lateral motion along the Sanvarezzo-C. Villara Fault and concomitant partial inversion of the Rio Giosa Fault. The resulting SW-ward compression led to the formation of the Rio Pescritta Anticline (see below) as well as the uplifting and slight overthrusting of the stratigraphical succession located SW of the Rio Giosa.

The Rio Pescritta Anticline is well exposed on the left side of the Rio Pescritta, in front of the locality of Piandolo Sottano (cf. geological map, Figs. 49, 50a, 50b). It is a medium-scale structure, with subvertical axial plane oriented NW-SE parallel to the direction of the Rio Giosa Fault, by which it is bounded to the S. The NW-SE orientation of the axial plane of the structure suggests a shortening direction oriented NE-SW, consistent with the stress field that must have controlled the strike-slip movement of the Sanvarezzo-C. Villara Fault and the other faults of the Uzzone Valley Fault System (see below). The most recent lithostratigraphic unit displaced by the Sanvarezzo-C. Villara Fault is the LS1c Siliceous Lithozone attributable to the late Aquitanian. The reactivation in compression of the original bounding fault of the Noceto Half-graben and the subsequent structural inversion is therefore of post-late Aquitanian, probably early Burdigalian age.

6.3. The early Burdigalian Pian dei Buri syn-sedimentary fault and related faults

The faults of this system are developed in the northeastern part of the study area and have been already discussed by Ghibaudo et al. (this volume). Some of these faults (Pian dei Buri and Rocchetta faults) had an initial synsedimentary activity in the middle-late Aquitanian.

6.3.1. Pian dei Buri Fault

Activity of the fault: middle-late Aquitanian during the deposition of the Siliceous Lithozone LS1 and early Burdigalian during the deposition of the Altitude 483 Sandstones and Pian Bruno Calcarenites; main activity during the early Burdigalian with motion reversal during the deposition of the C. Mazzurini Sandstones.

This is an E-W striking, subvertical fault located to the SW of Mombaldone locality (cf. geological map, Fig. 49 and Pl. I). The Pian dei Buri Fault displaces the Rocchetta Fm and bounds entirely, to the N, the C. Mazzurini Half-graben and, to the S, the Montechiaro Siliceous Lithozone and the Pian Bruno Calcarenites (cf. paragraph 4.7.5). The Pian dei Buri Fault is sealed by the lower Burdigalian marls of the Montechiaro d'Acqui Fm. The synsedimentary character of the Pian dei Buri Fault was highlighted by Gelati and Gnaccolini (1998) with reference only to the deposition of C. Mazzurini Unit. The field evidence indicates that this 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 in the middle-late Aquitanian. In the initial stage the northern block was downthrown, resulting first in the creation of accommodation space for a thicker succession of Montechiaro Siliceous Lithozone (middle-upper Aquitanian) on the northern block, then in the confinement of the Pian Bruno Calcarenites (lower Burdigalian) into a small structural depression developed N of the fault (Pl. III, scenarios e, f). Subsequently, in the early Burdigalian, the Pian dei Buri Fault inverted the movement with downthrow of the southern block and 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.

6.3.2. C. Bazzi Fault

The C. Bazzi Fault is a subvertical fault striking NE-SW at high angle to the synsedimentary fault of Pian dei Buri (Fig. 49). It is now a high-angle reverse fault that displaces the C. Mazzurini Unit, the Montechiaro d'Acqui Siliceous Lithozone (LS1) and the mudstones of Rocchetta Fm. The fault upthrows the northwestern sector bringing the mudstones of the Rocchetta Fm in contact with the C. Mazzurini Unit. The latter unit shows reduced thickness at the northern uplifted block. The fault was synsedimentary during the deposition of the C. Mazzurini unit and was later reactivated as hypothesized by Gelati and Gnaccolini (1998).

6.3.3. C. Gergi Fault

This is a subvertical fault striking roughly N-S in the central part of the study area close to C. Gergi (Fig. 49). As this fault displaces the base of the C. Mazzurini Unit without displacing its top and causes a local increase in thickness of this unit at its downthrown side, it is interpreted as synsedimentary.

6.3.4. Rocchetta Fault

This is a subvertical fault striking NW-SE in the Rocchetta area (cf. geological map and Fig. 49) which had a synsedimentary activity in middle-late Aquitanian. The Montechiaro d'Acqui Siliceous Lithozone (LS1) (middle-

upper Aquitanian) shows facies and thickness change across this fault, as thinner siliceous deposits on the SW side are replaced by time-equivalent, thicker marls (LS1d) on the NE side. (cf. Pl. I). The Rocchetta Fault first caused the downthrow of the north-eastern side, and subsequently (in times post-Serole Fm - middle Burdigalian) was reversed, with partial reduction of the original offset of the Noceto unit and displacement of the overlying C. Mazzurini, Piantivello and Serole units.

6.4. The middle Aquitanian and early Burdigalian transcurrent faults

The faults of this system are well exposed in the Uzzone Valley and are defined here, as a whole, "Uzzone Valley Fault System" (Fig. 49). From S to N, they include: the Sanvarezzo-C. Villara, C. Serra, Rio dei Germani, Gerba, S. Ilario, Rio Porcavio, C. Lunga-Blengi, and Carpenetto

Faults. They displace the sediments pre-dating the Cortemilia Fm. Many of them are interpreted as growth faults that acted at different times, either as extensional/transensional or as transpressional faults between middle Aquitanian times post-dating the Siliceous Lithozone LS1a, and early Burdigalian times pre-dating the Cortemilia Fm (see below). The activation of this fault system represents a significant change in the tectonic regime of the study area probably resulting in a major change in the regional stress field that controlled the structural evolution of the Langhe Basin in middle Aquitanian to early Burdigalian times. These faults controlled the paleocurrents and the location of the turbidite sandstone bodies of Poggiolo Fm (middle Aquitanian), Scaletta Uzzone Fm (middle-upper Aquitanian), and Montechiaro d'Acqui Fm (uppermost Aquitanian - lower Burdigalian) cropping out in the

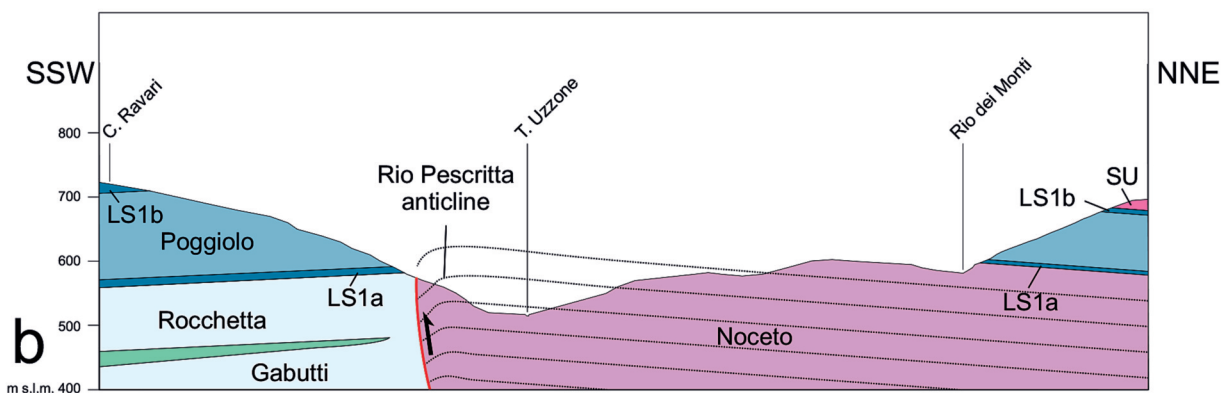
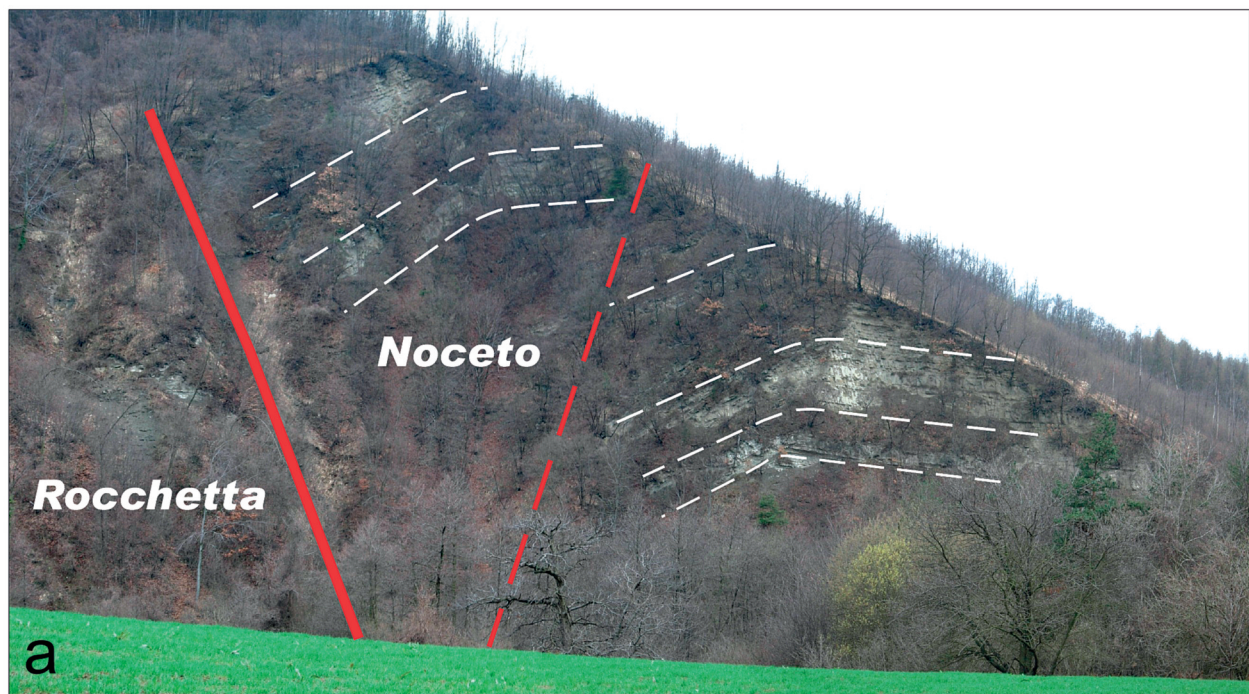


Fig. 50 - Rio Pescritta anticline at the southern termination of the Noceto body, inferred to result from partial inversion of the normal listric fault bounding the Noceto unit. a) View of the anticline from the Piandolo Sottano village. b) Geological cross-section across the T. Uzzone Valley.

south-central part of the study area. They determined also a major change in the local topography, with development of intrabasinal highs and minor extensional or transtensional basins, here respectively defined “Poggiolo Basin”, “Scaletta Uzzone Basin” and “Rio della Chiesa Basin” (see below). An important evidence of this turning point is the change in the average direction of paleocurrents of the turbidite sandstone bodies pre- and post-dating the Montechiaro d’Acqui Siliceous Lithozone LS1a, in the south-central part of the study area (Fig. 51). Paleocurrents of the Rocchetta Fm turbidite sandstone bodies, in fact, suggest a regional paleoslope dipping roughly towards SE or ESE. Conversely, turbidite sandstone bodies of the Poggiolo, Scaletta Uzzone, Montechiaro d’Acqui and Serole (post-LS1a) formations show paleocurrents directed on average towards NNE, roughly parallel to the Uzzone Valley Fault System and oblique to the regional paleoslope, suggesting a structural control in the genesis, location and orientation of these sandstone bodies. Some faults of this system were reactivated during the deposition of the Serole Fm (middle Burdigalian). Fault activity ended before the deposition of the Cortemilia Fm, which is not significantly displaced.

The most important points concerning the activity of these faults according to this interpretive scheme may be summarized as follows:

The Faults of Carpenetto, S. Ilario, Rio Porcavio and C. Serra (Fig. 49) acted probably as normal growth faults during the sedimentation of the Poggiolo Fm. They created the space for the Poggiolo Basin and, in particular, for the member of Rio Porcavio Sandstones, interpreted here as a wedge-shaped turbiditic body confined in an asymmetric graben (cf. Figs. 33, 34, panel B and paragraph 4.5.1). At the end of the deposition of Poggiolo Fm and before the deposition of the Siliceous Lithozone LS1b, these faults were reactivated as transpressional faults, displacing and deforming the Poggiolo Fm itself (cf. paragraphs 5.2.3 and Fig. 34, panel C).

The transcurrent activity of the Uzzone Valley Fault System during the middle Aquitanian, in fact, is well documented for the faults of S. Ilario and Rio Porcavio and the related system of *en echelon* folds of the Rio Porcavio (cf. geological map, Figs. 49, 52). The faults are sub-parallel, spaced about 1 km apart, and their traces show a partial overlap in the T. Uzzone and Rio Porcavio valleys, defining a “left stepover” geometry (Aydin and Nur, 1985). In the area of stepover of the two faults a system of decametric folds is present with roughly sub-parallel axes striking obliquely by about 20°-30° to the faults. These folds deform the turbidites of the Poggiolo Fm, whereas they do not affect the overlying siliceous lithozone LS1b-c. These relationships are typical of a compressional left stepover in a right-lateral transpressional regime (Segall and Pollard, 1980; Aydin and Nur, 1985; Mitra and Paull, 2011).

A period of relative tectonic quiescence followed during the deposition of the Siliceous Lithozone LS1b, the Scaletta Uzzone Fm, and the Siliceous Lithozone LS1c (cf. paragraph 5.3.1 and Fig. 36).

After the deposition of the Siliceous Lithozone LS1c the Uzzone Valley area was subject to a new reorganization. The Uzzone Valley Faults resumed activity by generating the so-called Rio della Chiesa Basin within which the Rio della Chiesa sandstone members of the Montechiaro d’Acqui Fm were emplaced. The C. Serra and S. Ilario Faults (Fig. 49), already active during the deposition of the Poggiolo Fm, were reactivated during the deposition of the Montechiaro d’Acqui Fm, defining a structurally depressed area oriented NE-SW accommodating the Castelletto Uzzone Sottano Sandstones and the Rio della Chiesa Lower Sandstones (cf. paragraph 5.4.3, Figs. 40, 41). Subsequently, the C. Serra Fault was reactivated as growth fault forming a structural depression accommodating the C. Ciappellano Sandstones and the Rio della Chiesa Upper Sandstones whose deposition would have completed the infill of the Rio della Chiesa Basin (cf. paragraph 5.4.3, Figs. 42, 43). During this period also the N-S striking T. Uzzone Fault was activated (Fig. 49). The T. Uzzone Fault was probably active during the deposition of the Montechiaro Fm, defining, together with the C. Serra and S. Ilario Faults, an intrabasinal high roughly oriented NE-SW, called “Castelletto Uzzone High” (Figs. 40-44) (cf. paragraph 5.4.2). After the deposition of the sandstone members of the Montechiaro d’Acqui Fm, the deposition of upper hemipelagic marls of the Montechiaro d’Acqui Fm took place during a period of relative tectonic quiescence (Pl. IVb, panel B10). At the end of deposition of the marls of the Montechiaro d’Acqui Fm, the C. Serra, S. Ilario and Rio Porcavio Faults (Fig. 49) were probably re-activated in a strike-slip regime together with the Gerba Fault, displacing the Montechiaro d’Acqui Fm in a series of structural highs and lows. This resumption of activity of the Uzzone Valley Fault System: i) triggered (in concomitance with inferred effects of silica diagenesis in the underlying siliceous units) gravitational instability that led to the partial or total removal of the Montechiaro d’Acqui Fm and development of the pluri-kilometric composite slump scar occurring atop the Montechiaro d’Acqui Fm in the Uzzone Valley area (Pl. IVb, panel B12); ii) allowed the preservation of the complete succession of the Montechiaro d’Acqui Fm only in the graben bounded by S. Ilario and Gerba Faults (Pl. IVb, panels B11 and B12); and iii) was indirectly involved in the generation of the gentle, large-scale folds (radius of hundreds of meters) that deform the Montechiaro d’Acqui Fm and do not affect the Serole Fm near the head of the Rio della Torre Valley; iv) was probably responsible for the partial structural inversion of the Noceto Half-Graben by means of dextral motion along the Sanvarezzo-Case Villara Fault; as a result, the intrabasinal “Santa Giulia High”, roughly oriented NE-SW, parallel to the Uzzone Valley Fault System, developed south of the Sanvarezzo-C. Villara Fault. In conclusion, the activity of the Uzzone Valley Fault System is thought to have been characterized by alternating phases of transtension and transpression during the entire interval from the middle Aquitanian to early Burdigalian. The activity ended before the deposition of the turbidites of the Cortemilia Fm.

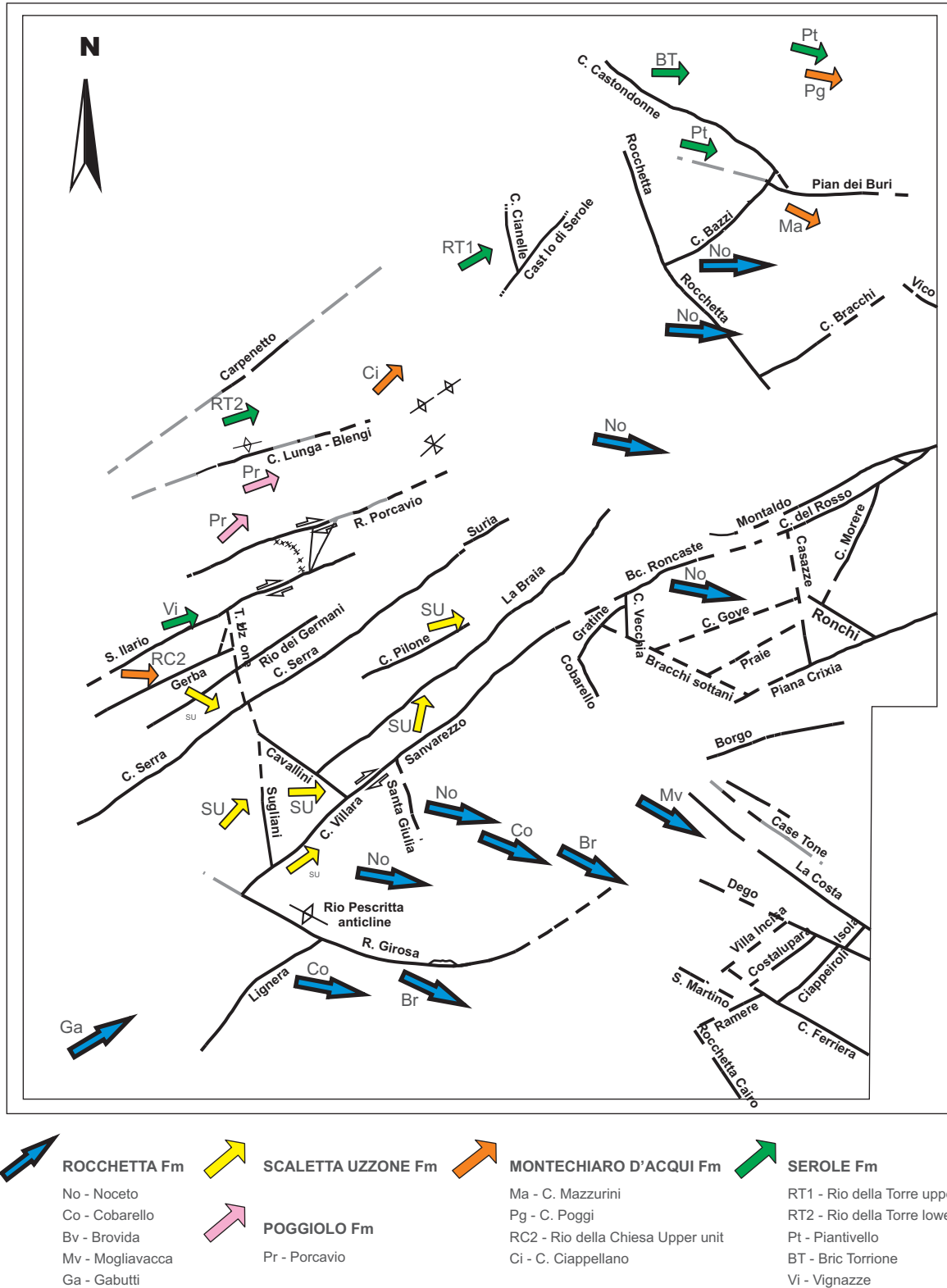


Fig. 51 - Paleocurrents of the main sandstone bodies of the study area.

7. TECTONO-STRATIGRAPHIC EVOLUTION OF THE STUDY AREA

The cross-sections of plates I and II summarize the geometries, structural setting and the latero-vertical

stratigraphic relationships of individual lithostratigraphic units. The tectono-sedimentary evolution of Oligocene-Burdigalian deposits cropping out in the study area is shown in the evolutionary cross-sections of plate III (A-A')

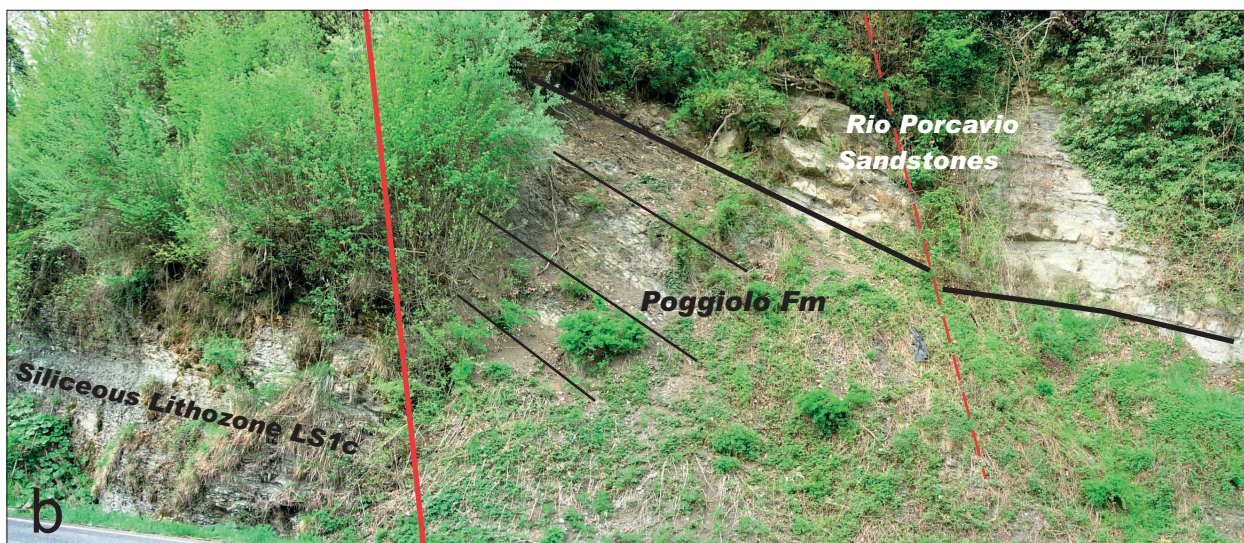
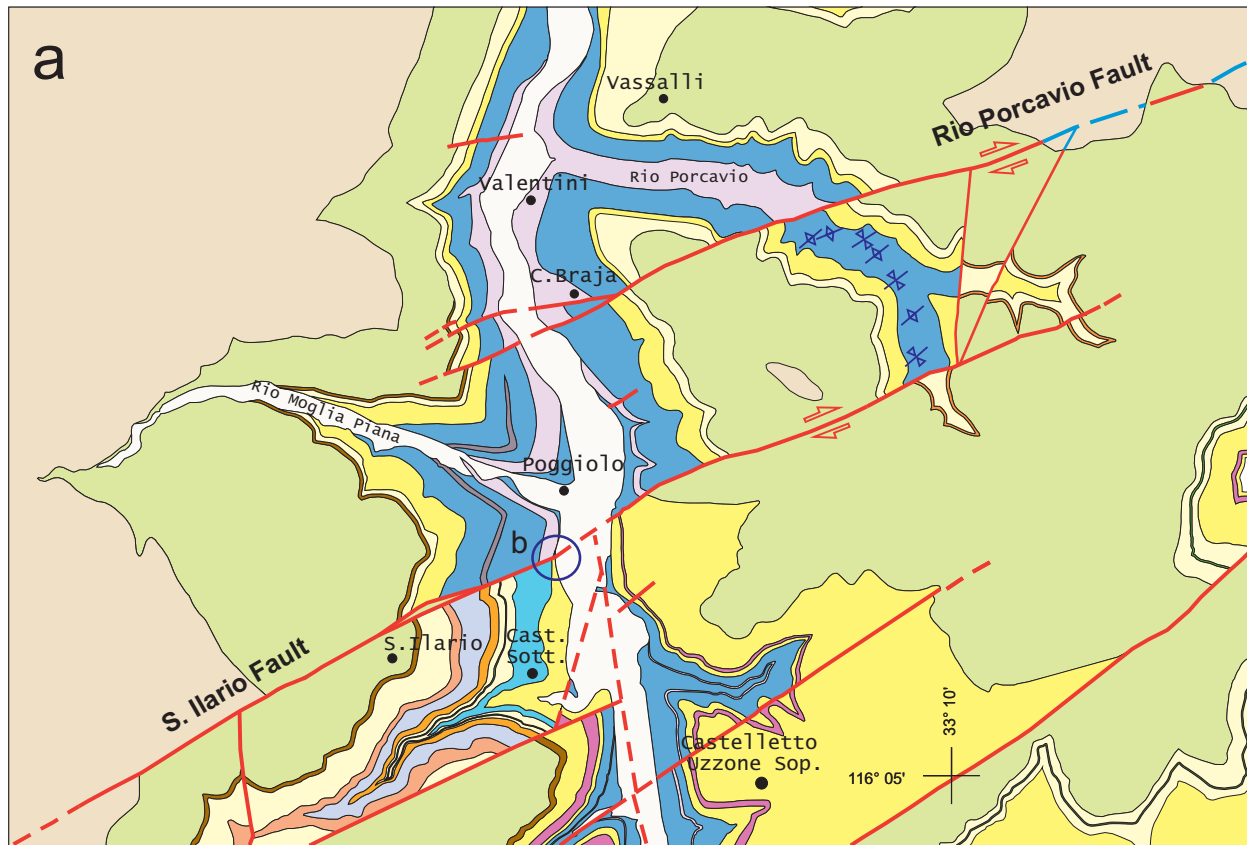


Fig. 52 - a) Left stepover between the S. Ilario and Rio Porcavio Faults and the related system of en échelon decametric folds with roughly sub-parallel axes striking obliquely by about 20°-30° to the mentioned faults (compressional left stepover in a right-lateral transpressional regime). b) Details of the S. Ilario Fault (station encircled in a).

in Fig. 53) and plate IV (B-B' in Fig. 53). The cross-sections are oriented SW-NE roughly perpendicular to the presumed dip direction of the regional paleoslope. The reconstruction of the various stages of evolution has been obtained through a progressive flattening procedure, by using, from time to time, the top of turbiditic units successively higher in the stratigraphical column as datum planes. The surfaces bounding at the base the main

turbidite units and the units themselves are considered to represent periods of falling and lowstand of relative sea level, whereas the hemipelagic intervals atop the turbiditic units, and, in particular, the siliceous units traceable on basal scale are regarded as condensed basinal deposits corresponding to periods of transgression and highstand of relative sea level in the coeval shelf areas.

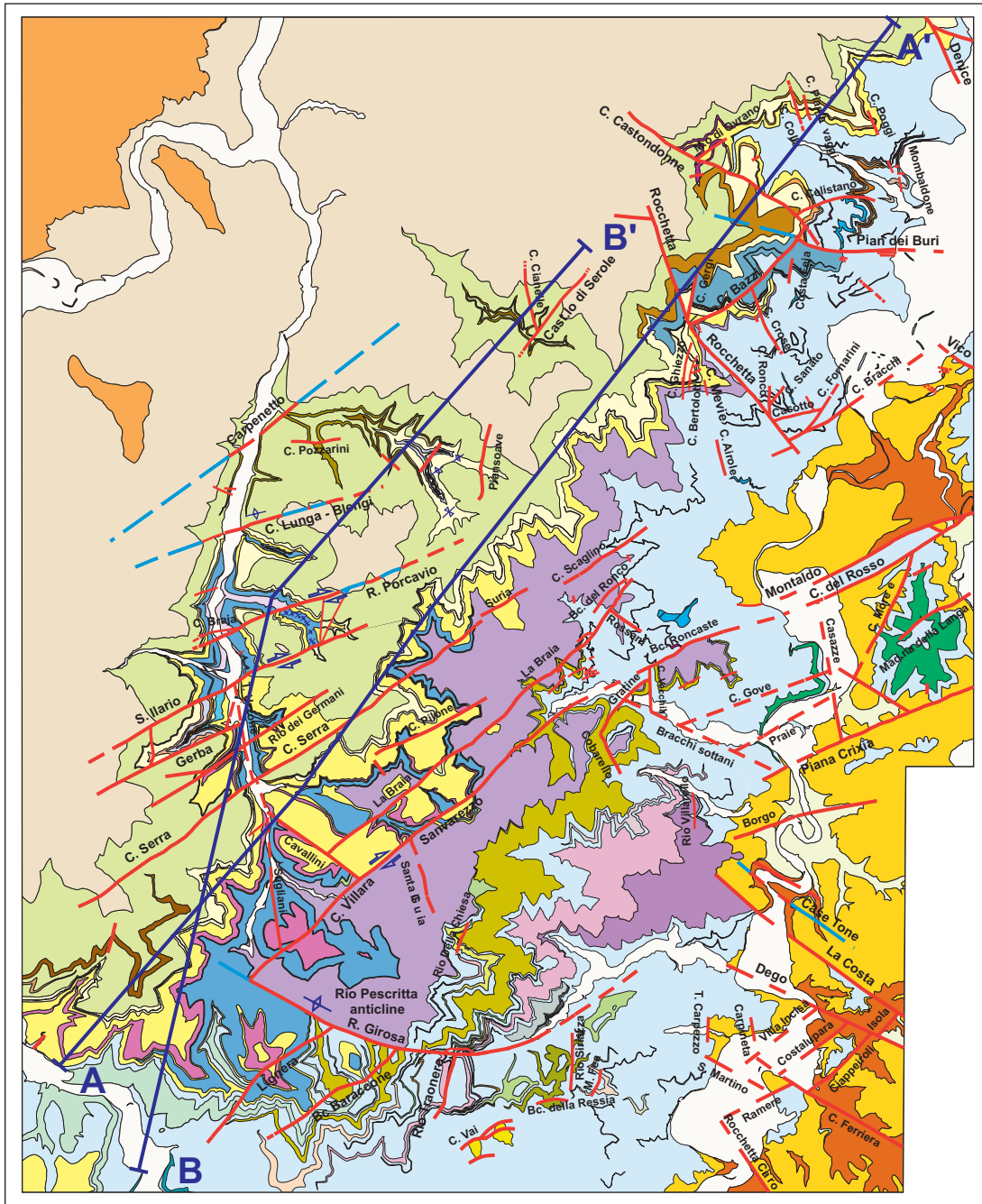


Fig. 53 - Traces of the interpretative cross-sections of plate IIIa-c and plate IVa-c.

7.1. The evolutionary cross-section A-A'

The tectono-sedimentary evolution of the study area along the stratigraphic cross-section A-A' (Fig. 53) can be summarized as follows (Pl. IIIa-c).

Rupelian p.p. (Pl. IIIa, panel A1)

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 syndepositional activity of the Vico, Montaldo and C. Tone Faults. Major structural

features include, from S to N, the Rocchetta Cairo Horst, the Borgo Graben, the Spigno Monferrato Horst and the Cartosio Graben. The Borgo and Cartosio grabens accommodated the continental conglomerates of the Molare Fm. The local landscape was entirely continental.

Rupelian p.p. (Pl. IIIa, panel A2)

Deposition throughout the study area of the transgressive shelf sands of the Molare Fm. First the structural depressions were flooded, with deposition of the Molare transgressive marine sands on the continental conglomerates. Only later the adjacent Rocchetta Cairo

and Spigno Monferrato horsts were reached by the transgression, with deposition of the marine sands directly on the crystalline basement. At the end of the deposition of the Molare shelf sandstones the Case Tone, Montaldo and Vico faults were temporarily sealed and the local landscape was characterized by a wide area of shallow shelf.

Late Rupelian - early Chattian (Pl. IIIa, panel A3)

Change into probably transtensional tectonics along both new and formerly active basement faults, with formation of differentially subsiding blocks. These movements were associated to an enhanced regional tectonic subsidence leading, since the late Rupelian, 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. The synsedimentary faults active at this time are again the Vico and Montaldo faults to the N and a series of faults (Piana Crixia, La Costa and Dego Faults) to the S. These faults bound a complex submarine intrabasinal high, the Dego-Spigno Monferrato High, active during the deposition of the Rocchetta Fm, subdivided into minor horsts and grabens. In particular, this high comprises, from south to north, the Dego Horst, the Piana Crixia Graben and the Spigno Monferrato Horst. The Piana Crixia narrow structural trough behaved as confined slope depocentre accommodating a body of resedimented conglomerates. Two major depocentres, moreover, developed to the N and respectively S of the Dego-Spigno Monferrato High, the Turpino and Rocchetta Cairo Depocentres, where thick successions of fine-grained slope deposits of the Rocchetta Fm piled up. All the faults were deactivated and sealed by the mudstones of the Rocchetta Fm during late Rupelian-early Chattian.

The stratigraphic and structural setting at the end of the deposition of Mogliavacca unit is shown in panel A3. During the late Rupelian the Dego-Spigno Monferrato High was leveled by the deposition of the hemipelagic lower-middle portion of the Rocchetta mudstones. Only in the Piana Crixia Graben coarse deposits, the Piana Crixia Conglomerates, accumulated. In this period, the turbiditic sedimentation was concentrated in the Rocchetta Cairo Depocentre where the small and medium-sized channelized bodies of the Sassore, Vignazza, Vignaroli, Lower and Middle Rodini, and C. del Bric units were deposited. The Turpino Depocentre, located NE of the Dego-Spigno Monferrato High, conversely, was characterized almost exclusively by hemipelagic sedimentation with the exception of some small channelized turbidite sandstone bodies located outside the study area and not represented in the cross-section of plate I (Ghibaudo et al., in prep.).

In a time presumably corresponding to the Rupelian-Chattian transition, a deep erosional surface marking the base of the Mogliavacca submarine canyon developed, and was subsequently infilled with the deposition of the Mogliavacca unit in the early Chattian. Medium-sized channelized sandstone bodies represented by the Upper

Rodini and Codevilla units were laid down probably at the same time.

Chattian (Pl. IIIa, panels A4, A5, A6)

In the southern sector of the study area, after the infilling of the Mogliavacca canyon, a new sedimentary cycle developed, with the deposition of Brovida unit (panel A4), tentatively interpreted as a depositional system of lower canyon/partly confined fan apex. After the deposition of this unit, the sandstone bodies of Sorgente Alpei, Bric Petacchi, Fontanelle and Cian dei Grill were laid down (panel A5). These bodies are interpreted as base-of-slope unchannelized deposits. In the northern sector, on the contrary, the sedimentation remained essentially hemipelagic, with the exception of some small sandstone bodies a few metres thick (key beds). By the late Chattian a new major phase of coarse terrigenous sedimentation characterized the southern sector of the basin, with the deposition of the Cobarello unit (panel A6) which may be interpreted as a broad base-of-slope submarine depression infilled with proximal lobe deposits, while in the northern part of the basin the channelized and confined sandstone bodies of the Molino di Mombaldone lower unit and Ovrano lower, middle and upper units were laid down.

Early Aquitanian (Pl. IIIa, panel A7; Pl. IIIb, panel A8)

In the southern sector, after the deposition of the Cobarello unit, the activity of the Rio Giosa growth fault began (panel A7). The fault displaced the Cobarello, Fontanelle, Sorgente Alpei, Brovida and Rio Giosa units and created accommodation space on the hangingwall for the deposition of a sediment wedge (i.e. "Rio Giosa stratigraphic expansion"), mainly consisting of mudstones of the Rocchetta Fm, encasing the Pian del Lago and Bric della Lasagna sandstone bodies. Meanwhile, in the northern sector the Mombaldone Erosional Depression developed and its infill began, first with the deposition of mudstones that draped and overlapped the erosional surface, and later with the deposition of the confined turbidite bodies of the Molino di Mombaldone Middle and Upper Sandstones (panel A7). These two units are tentatively considered time-equivalent of the Pian del Lago and Bric della Lasagna units, laid down on the hangingwall of the Rio Giosa listric fault. In the southern sector, after the smoothing out of the submarine topography, the Gabutti unit was laid down on the footwall, SW of the Rio Giosa Fault (panel A8). In the northern sector the slope progradation continued and the gravitational instability persisted, expressed by the emplacement of large-scale slump sheets (S5, S6) accompanied by local intraformational unconformities. On the Dego-Spigno Monferrato High, conversely, the sedimentation remained essentially hemipelagic.

Early Aquitanian (Pl. IIIb, panels A9, A10)

In the southern sector the activity of the Rio Giosa listric fault lasted throughout the early Aquitanian with

development and infilling of the Noceto Half-graben on the fault hangingwall. The deposition of the Noceto unit marked the beginning of an important new sedimentary cycle with active deposition of sandstones and pebbly sandstones in a slope or base-of-slope environment. In the meantime, deposition on the fault footwall consisted of some tens of meters of mudstones of the Rocchetta Fm. In the northern sector, during this time, the sedimentation was essentially hemipelagic (panel A9). At the end of the early Aquitanian the synsedimentary activity of the Rio Giosa listric fault ceased, and the condensed siliceous horizon LS1a was deposited throughout the area. It sealed the fault bounding the Noceto Half-graben. In the northern sector the deposition of Montechiaro d'Acqui Siliceous Lithozone (LS1) began (panel A10).

Middle Aquitanian (Pl. IIIb, panel A11)

The southern sector was characterized by the development and infilling of the Poggiolo Basin interpreted as a base-of-slope structural basin. The basin was mainly developed in the Uzzone Valley, and its genesis was closely related to the synsedimentary activity of Uzzone Valley Fault System (paragraph 6.4). Along the cross-section AA', located in a marginal position with respect to the depocentre of this basin, the deposits infilling the Poggiolo Basin are represented only by the alternating sandstone-mudstone couplets of the Poggiolo Fm, while the associated sandstone bodies are located in the basin depocentre and are not included in this cross-section. The end of deposition in the Poggiolo Basin was marked by deformation related to a transpressional episode along the Uzzone valley fault system, followed by the unconformable deposition of the condensed siliceous horizon LS1b. In the northern sector the deposition of the Montechiaro d'Acqui Siliceous Lithozone (LS1) continued. Initial synsedimentary activity of the Pian dei Buri Fault led to a thicker siliceous succession on the northern block.

Middle-Late Aquitanian (Pl. IIIb, panels A12, A13)

In the southern sector a new sedimentary cycle began with the deposition of the Scaletta Uzzone Fm (panel A12), interpreted as the infill of a base-of-slope basin genetically related to differential compactional subsidence in the area of maximum thickness of the underlying Noceto unit. The sedimentation in the Scaletta Uzzone Basin ended with the deposition of the siliceous condensed horizon LS1c (panel A13). In the northern sector the deposition of Montechiaro d'Acqui Siliceous Lithozone (LS1) continued simultaneously with the onset of the synsedimentary activity of the Rocchetta Fault, leading to the downthrow of the northern block that accommodated a thicker succession of hemipelagites.

Latest Aquitanian-Early Burdigalian (Pl. IIIb, panel A14; Pl. IIIc, panels A15, A16, A17)

Hemipelagic marls of the Montechiaro d'Acqui Fm

started accumulating in the latest Aquitanian throughout the study area. Initially, the Rio della Chiesa Glaucony, interpreted as a condensed level, was laid down in the southern sector (panel A14). Shortly after, deposition of C. Poggi, Pian Bruno and Case Mevie calcarenite units took place in the northern sector (panel A15). The Pian Bruno calcarenitic unit, in particular, was confined within a small structural depression generated to the N of the synsedimentary Pian dei Buri Fault, while the two calcarenitic levels of C. Mevie are interpreted as the product of carbonate gravity flows overspilling SW-wards from the depression itself. After the deposition of C. Mevie Calcarenites the Pian dei Buri Fault reversed its motion, generating a strong tectonic subsidence on the southern side, with the development of a large submarine half-graben (C. Mazzurini Half-graben), where the turbidite sandstones and conglomerates of the C. Mazzurini unit were laid down (panel A16). Subsequently, the hemipelagic marls of the Montechiaro d'Acqui Fm were deposited throughout the study area (panel A17).

Middle Burdigalian (Pl. IIIc, panels A18, A19, A20)

Since the middle Burdigalian a new cycle of sedimentation began, with deposition of Piantivello unit of the Serole Fm (panel A18), interpreted as the infill of a large submarine valley or base-of-slope depression corresponding to the lowstand of the Serole cycle. During this period also gravity-instability processes developed and generated erosional unconformities (large scars) atop the marls of the Montechiaro d'Acqui Fm (Denice, Bric Torrione, C. Rocchino and Uzzone Valley depressions) (panel A19) that removed, partly or wholly, the marls of the Montechiaro d'Acqui Fm. Deposition of mudstone-sandstone turbidite couplets of the Serole Fm then followed throughout the study area, accompanied by the emplacement of the C. Zabocci and Gottasecca sandstone bodies (panel A20). The Serole Fm, interpreted as a prodelta slope wedge, tapers gradually to the NE and thickens SW-wards. It is capped, with onlap relationships, by the basal turbidites of the Cortemilia Fm, that wedges out a few kms SW-wards, outside the study area.

Late Burdigalian (Pl. IIIc, panel A21)

Deposition throughout the study area of basal turbidites of the Cortemilia Fm.

7.2. The evolutionary cross-section BB'

The evolutionary cross-section BB' (Fig. 53, Pl. IVa-c) shows the tectono-sedimentary evolution of the Uzzone Valley area during the middle Aquitanian-Burdigalian, starting from the siliceous horizon LS1b sealing the deposition in the Poggiolo Basin. The panel B1 of plate IVa corresponds in time to the panel A11 of the cross-section of plate IIIb. Starting from the above panels, the tectono-sedimentary evolution of the two considered areas should be read simultaneously.

Middle-Late Aquitanian (Pl. IVa, panel B1)

This panel shows the Poggiolo Basin at the end of the transpressional tectonics that resulted in its closure, followed by sealing by the siliceous horizon LS1b.

Middle-Late Aquitanian (Pl. IVa, panels B2-B3)

After the deposition of the Poggiolo Fm and siliceous horizon LS1b, in the southern sector a new cycle started with the deposition of the Scaletta Uzzone Fm, interpreted as the infill of a base-of-slope basin. This was followed by the deposition of the siliceous horizon LS1c on a regional scale.

Latest Aquitanian-early Burdigalian (Pl. IVa, panels B4, B5, B6; Pl. IVb, panels B7, B8, B9, B10)

After the deposition of the siliceous horizon LS1c the marls of the Montechiaro d'Acqui Fm were laid down throughout the study area. Some faults active during the deposition of Poggiolo Fm were reactivated as normal or transtensional faults, creating the space for the deposition of the sandstone members of the Montechiaro d'Acqui Fm in the Uzzone Valley area (Castelletto Uzzone Sandstones, Rio della Chiesa Lower and Upper Sandstones) forming the infill of the Rio della Chiesa Basin (cf. paragraph 5.4.3). The C. Serra and S. Ilario Faults are inferred to have had alternate phases of activity, creating space for turbidite sedimentation confined within structural basins, with phases of tectonic quiescence during which the hemipelagic marls of the Montechiaro d'Acqui Fm were laid down on regional scale. In detail this evolution includes the following steps (cf. also Figs. 40-44): (1) development of a structural depression bounded by the C. Serra and S. Ilario Faults and confined deposition of Castelletto Uzzone Sottano Sandstones (panel B4); (2) onset of deposition of the Montechiaro d'Acqui marls and deposition of the condensed level of the Rio della Chiesa Glaucony (panel B5); (3) resumption of subsidence and deposition of the Rio della Chiesa Lower Sandstones (panel B6); (4) deactivation of the S. Ilario Fault and deposition of C. Mevie Calcarenites (panel B7); (5) resumption of the activity of the C. Serra Fault, with confined deposition in a structural depression of C. Ciappellano Sandstones (extended laterally up of the Rio della Torre area), and of the Rio della Chiesa Upper Sandstones (panels B8 and B9); (6) deposition in the whole area of the marls of the Montechiaro d'Acqui Fm (panel B10).

Early Burdigalian (Pl. IVb, panels B11-B12)

Inferred resumption of activity of Uzzone Valley Fault System, with gravity destabilization, and development of the Uzzone Valley Erosional Depression with local removal of the hemipelagic marls of the Montechiaro d'Acqui Fm. The complete stratigraphic succession of this formation was preserved only on the fault block of the Rio della Chiesa, structurally downthrown with respect to the surrounding areas. The Uzzone Valley Fault System was

also indirectly involved in the partial inversion of the Noceto Half-graben, by means of dextral motion of the Sanvarezzo-C. Villara Fault, and in the generation of gentle, large-scale folds (radius of hundreds of meters) near the head of the Rio della Torre Valley, that deform the Montechiaro d'Acqui Fm and do not affect the Serole Fm.

Middle and late Burdigalian (Pl. IVc, panels B13-B14)

Deposition of the prodelta slope wedge of Serole Fm and, later, of the basinal deposits of the Cortemilia Fm.

8. GEOLOGIC EVOLUTION OF THE STUDY AREA IN A REGIONAL FRAMEWORK

The main tectono-sedimentary events in the Langhe study area can be summarized as follows:

Rupelian p.p. - a) Extensional tectonic regime with generation of a horst and graben topography through the activation of large-scale, basement-involving faults. Structural lows were partly infilled with continental conglomerates (Molare conglomerates); b) Transgression with deposition of marine sandstone (Molare sandstones) atop the continental conglomerates and directly onto the basement highs.

Late Ruperlian-Early Aquitanian - Probable shift to transtensional tectonics associated with rapid regional tectonic subsidence leading to a regional collapse, with generation of a progressively deeper marine basin characterized by generalized deposition of slope to base-of-slope mudstones (Rocchetta mudstones). The Langhe Sub-basin was affected by block faulting, with generation of a complex submarine structural high (Dego-Spigno Monferrato High) separating a southern depocentre (Rocchetta Cairo Depocentre) from a northern one (Turpino Depocentre). Large-scale sandstone bodies of the Rocchetta Fm are concentrated in the Rocchetta Cairo Depocentre and are characterized by progressively finer-grained and areally more extensive turbidite bodies marking a change from upper slope to base-of-slope setting.

Middle Aquitanian-Early Burdigalian - Change in tectonic regime and in the regional stress field in the southern part of the study area with the activation of the Uzzone Valley faults interpreted as growth faults acting at different times either in an extensional/transtensional or transpressional regime. Activity of these faults generated small-scale structurally-controlled slope-basins infilled with both coarse- and fine-grained turbidites; each basin-fill was sealed by siliceous horizons (LS1a, LS1b, LS1c) converging NE-wards into a single horizon (LS1). The inferred normal motion of the Pian dei Buri Fault generates the C. Mazzurini Half-graben in the early Burdigalian.

Middle-Late Burdigalian - NE-wards progradation of the Serole prodelta slope wedge followed by regional deposition of thick basinal turbidites (Cortemilia Fm). The latter overlapped SW-wards onto the underlying Serole

slope wedge and marked a period of maximum space creation and high subsidence rate in the Langhe basin.

The above described evolution can be viewed in a regional perspective.

The Rupelian extensional tectonic regime generating the horst and graben topography is thought to be induced by a regional crustal stretching phase that dissected the metamorphic substratum through normal, high-angle deep-seated faults (Phase Ligure II of Mutti et al., 1995, 2002). This block-faulting phase occurred in the late stage of the late Priabonian-early Rupelian (35-33 Ma) postorogenic extensional exhumation of the deep, metamorphic units of the Mesoalpine prism, as envisaged by Vignaroli (2006) and Vignaroli et al. (2008, 2009, 2010). The coarse continental sediments infilling structural lows (Molare conglomerates) are thought to result from the denudation of high-relief landforms created in this stage.

The rapid drowning leading to deposition of the Rocchetta Fm slope mudstones may be referred to the initial phases of the tectonic subsidence affecting the whole TPB since the late Rupelian interpreted to reflect a regional switch in tectonic regime from extensional to transtensional. This tectonics may be coeval to the phase D2 recognized in the eastern TPB by Bernardeschi (2009), recorded by the angular unconformity at the base of the middle-upper Rupelian (MNP23 *p.p.* - MNP24 *p.p.* - Marroni et al., in press) Monastero turbidites and interpreted by him as a basinwide tectonic phase, probably coeval with transpressional movements along the Villalvernia-Varzi Line, as documented in this part of the TPB (e.g. Di Giulio and Galbiati, 1993).

The switch of tectonic regime in the Langhe area from extension to transtension in late Rupelian-early Chattian times is here interpreted to be caused by the activation of a roughly E-W-oriented (in the present-day coordinates) regional megashear zone generated by the left-stepping sinistral fault system formed by the Villalvernia-Varzi Line to the NE and the Stura Fault System to the SW [the latter comprising the "Stura couloir", the "Cicatrice del Preit" and the "Limone-Viozene" fault zones (Ricou, 1981; Lefèvre, 1983; Piana et al., 2009) (Figs. 1 and 54)]. We believe that the combined activity along these important regional tectonic elements should have controlled both the birth and subsequent evolution of the Langhe Sub-basin and development of deep-water conditions in the whole TPB (see below).

Concurrently with the first delineation of the Langhe Sub-basin, the onset of development of the Alto Monferrato High, bounding to the east the Langhe Sub-basin, is thought to have similarly occurred since the late Rupelian. The Alto Monferrato High is actually characterized by a reduced thickness of the Rocchetta Fm when compared to the adjacent Langhe Sub-basin.

In middle Aquitanian-early Burdigalian times a strike-slip regime affected this part of the TPB, leading to a reinforcement of the basin-and-swell differentiation. This transcurrent activity should be related to the continuing late Oligocene-early Miocene left-lateral strike-slip

activity reported, at a more regional scale, for the Villalvernia Varzi and Stura Faults (Schumacher and Laubscher, 1996; their Insubric-Helvetic phase, 25 - 16 Ma; Giglia et al., 1996; Spagnolo et al., 2007; Capponi et al., 2009; Molli et al., 2010) coupled with the progressive westward escape of the Adriatic Indenter (i.e. change from NNW-wards to WNW-wards motion of the Adriatic Indenter accompanied by contemporaneous dextral motion along the Insubric Fault to the North, taking place from Oligocene onwards) (Dumont et al., 2011, 2012). Such translation of the Adriatic Indenter would have generated progressive transpressional conditions initially along the Villalvernia-Varzi Line in middle Rupelian times, then a progressive westward transfer of the transpression in Aquitanian times (see below).

Since the Aquitanian the Alto Monferrato High became a strongly positive structure, as documented by the important stratigraphic gap and angular unconformity at the base of the lower Burdigalian shallow-water limestones of the Visone Fm. Unpublished field-survey data in the adjacent Sheets Acqui Terme and Novi Ligure highlight that the Alto Monferrato High extended for several tens of kilometres from the Caliozna Valley (Acqui Terme area) to the Borbera Valley as a subaerial feature in late Aquitanian-early Burdigalian times. This high was later unconformably transgressed by glauconitic deposits laterally equivalent of the in situ glauconitic sediments capping the Visone Limestones and marking the drowning of the Visone platform. Such unconformity may be

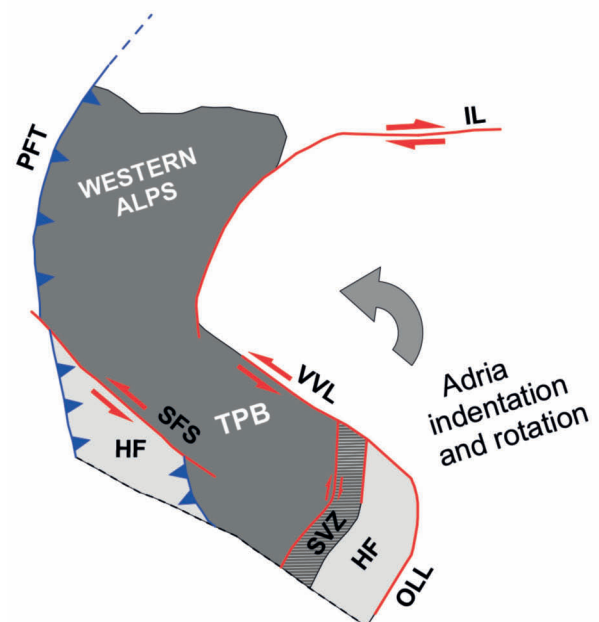


Fig. 54 - Simplified sketch of the main late Rupelian-early Miocene structural elements of the Tertiary Piedmont Basin. Redraft and modified from Capponi et al. (2009). IL - Insubric line; PFT - Penninic Front Thrust; SFS - Stura Fault System; VVL - Villalvernia-Varzi Line; OLL - Ottone-Levanto Line; SVF - Sestri-Voltaggio Fault; HF - Helminthoid Flysch and northern Apennines.

followed as far as the Borbera Valley where it is truncated, together with the overlying succession, by the angular unconformity developed at the base of the Langhian shelf deposits of Cessole Fm (Ghibaudo et al., in prep.).

The effects of the above mentioned wrench tectonics are reflected in the northern part of the study area by the generation, in early Burdigalian, of the C. Mazzurini Half-graben. In the southern part of the study area the same transcurrent regime is reflected by the inversion of the Noceto Half-graben in the early Burdigalian and the activation of the Uzzone Valley Fault System in middle Aquitanian-early Burdigalian times, resulting in continuous changes in basin geometry, facies and paleocurrent pattern. This time interval was apparently characterized by alternating transtension and transpression. Latest Aquitanian-early Burdigalian resedimented carbonates and glauconites (Pian Bruno, Case Poggi and C. Mevie units), moreover, are indicative of tectonic-driven gravity destabilization of the source platforms with cannibalization of former deposits.

The upper hemipelagic part of the Montechiaro d'Acqui Fm is thought to mark a pause in tectonic mobility, as well as a probable increment of subsidence. This event is also reported in the lower Burdigalian succession of the Monferrato (Clari et al., 1995), where the so-called Marne a Pteropodi uniformly and passively drape formerly developed basinal areas and high-standing blocks.

The overlying middle Burdigalian Serole Fm is interpreted as a downlapping prodelta slope wedge gradually thinning NE-wards. This sedimentary body may be correlated with the sequence indicated by Rossi et al. (2009) as bounded by the surfaces I-BU (intra-Burdigalian) at the base and L-BU (upper Burdigalian) at the top, and interpreted by them as controlled by movements of marginal structures in both Saluzzese and Monregalese areas, accelerating the progradation from the west of fluvio-deltaic prisms. Starting from late Burdigalian, thick basinal turbidites were regionally laid down (Cortemilia Fm), overlapping southwestwards onto the underlying Serole slope wedge and marking a period of high subsidence rate in the Langhe Sub-basin (Dela Pierre et al., 1995; Molli et al., 2010), which became in this time the main depocentre in the TPB. The base of this turbidite system appears as a clearly recognizable unconformity in the seismic lines of the TPB (Mosca et al., 2010), but in the study area is a conformable surface. The major change reflected by this turnover in the depositional history of the basin is considered to reflect the beginning of active northward thrust propagation (Dalla et al., 1992; Dela Pierre et al., 1995), with the northern margin of the TPB becoming a collision boundary. This caused the northward shift of the main subsiding depocentres, successively concentrating the sedimentation in the Savigliano and Alessandria basins (Bertotti and Mosca, 2009; Mosca et al., 2010). It is perhaps surprising, however, that during this tectonic evolution the sedimentary cover of the Langhe Sub-basin did not undergo significant shortening and deformation, being probably transported passively to the N (Piana and Polino, 1995).

9. BIRTH AND INITIAL DEVELOPMENT OF THE TERTIARY PIEDMONT BASIN

The above mentioned regional perspective shed new light on the birth and initial development of the whole TPB. After initial deposition of Priabonian deep and shallow-water sediments atop Ligurian units (Vigoponzo, Dernice, Grue and Rio Trebbio formations of Marroni et al., in press; Pizzo d'Oca Group of Mutti et al., 2002) in the easternmost part of the basin, the geologic evolution of the TPB reflects first the generalized extensional tectonics which occurred concurrently with the post-orogenic exhumation of the Mesoalpine prism (Vignaroli, 2006) and then the complex synsedimentary tectonics related to the progressive WNW-ward indentation of the Adriatic microplate (i.e. the WNW escape of the Adriatic Indenter) into the Alpine orogenic edifice. This event took place mainly from Oligocene onwards (Dumont et al., 2011, 2012), specifically, in our opinion, since the middle-late Rupelian onwards.

The generalized extensional tectonics affecting the whole TPB mainly in early Rupelian times occurred, as already pointed out, in the late stage of the late Priabonian-early Rupelian rapid post-orogenic exhumation of the Ligurian basement (Vignaroli, 2006; Vignaroli et al., 2008, 2009, 2010). This event is the regional expression of a major turnover occurred in the Mediterranean region, coinciding with the onset of the backarc rifting, in turn promoted by the active rollback of the Apenninic subduction (Jolivet et al., 2008). This major change is thought to ultimately require a vertical slab tear (Vignaroli, 2006; Vignaroli et al., 2008), possibly nucleated along inherited lithospheric structures, such as Mesozoic transform systems (Handy et al., 2010).

The crustal stretching in the TPB occurred primarily by the activation of NNW-trending (in present day coordinates), extensional, basement-involving faults with generation of a number of lower Rupelian horsts and grabens, the latter accommodating the Molare continental and marginal-marine conglomerates and the Gilbert-type fan-delta deposits of the Savignone Conglomerates (Mutti et al., 1995). This structural direction can be particularly recognized in the eastern part of the TPB from the Acqui Terme area up to Borbera Valley (Alto Monferrato and Borbera-Grue domains). SW of Acqui Terme area, in the Langhe Sub-basin, the original orientation of the extensional, basement-involving faults in Rupelian times (at present oriented NW-SE and SW-NE in the study area, see paragraph 6.1) is difficult to assess due to the pronounced basement tilting and downwarping which accommodated more than 6 km of the Langhe Sub-basin sedimentary infill (Ghibaudo et al., in prep.).

After the episode of slab tearing and related subsequent extension, continuing convergence resulted in the progressive escape of the Adriatic Indenter (AI) first to the NW, then to the WNW. Since late Rupelian times, when rapid tectonic subsidence led to generalized deep-water conditions, up to the Burdigalian, the TPB probably behaved as a strike-slip basin. Such strike-slip basin

formed, in our opinion, between the left-stepping sinistral Villavernia-Varzi Line to the NE and the sinistral Stura Fault System to the SW, defining a roughly EW-trending (in present day coordinates) megashear zone in the frame of the progressive escape of the AI (Figs. 1, 54). Beginning of motion along the Villavernia-Varzi Line in the eastern TPB is still debated. Its activity in post Middle Eocene times (Marroni and Treves, 1998) during the deposition of the Priabonian deep-marine and shelf clastic succession of the Pizzo d'Oca Group (Di Giulio, 1991; Cibin et al., 2001) is uncertain. Transpressional motion in the middle Rupelian along this line is much more documented (Di Giulio, 1991; Bernardeschi, 2009). On the other hand, the beginning of transcurrent activity along the Stura Fault System as above defined (particularly along the "Stura couloir", most probably active in concomitance with the other faults of the system) has been referred by Giglia et al. (1996) to the Rupelian-Chattian transition, since this fault system involves, in the NE sector of the Argentera massif, the Lower Oligocene Grès d'Annot Fm. Similarly, a Chattian age for the beginning of sinistral transcurrent activity along the similarly oriented Limone-Viozene deformation zone has been hypothesized by Musso et al. (2009). Although the age of the Grès d'Annot represents a lower limit for the transcurrent activation of this fault system, it may be noted that the NW translation of the rigid indenter, whose south-western boundary may reasonably be regarded as the precursor of the Stura Fault System, was indicated by Ford et al. (2006, their Fig. 5c) as already active in late Rupelian times (30 Ma) in their paleostructural reconstructions. Similarly, a lithospheric fault with comparable location, active as a sinistral lineament since late Rupelian times, was proposed by Stampfli and Marchant (1997). We may therefore assume that transcurrent activity along this major lithospheric fault system was active since at least late Rupelian times.

It may be speculated that, following the translational motion of the AI since Rupelian times (Ford et al., 2006; Dumont et al., 2011), transcurrent motion along the above mentioned fault systems in the ancestral TPB progressed in time from NE to SW (in present day coordinates). During the first translation stage of the AI, transcurrent activity might have first affected the eastern TPB in middle Rupelian times by the activation of the Scrivia and Villavernia-Varzi faults, both confining to the SW and respectively NE the deep-water Monastero (Ranzano Fm *Auct.*) basin (Ghibaudo et al., 1985; Di Giulio, 1991; Di Giulio and Galbiati, 1993, 1995). With the progressive indentation of the Adria crust into the Alpine crust, in late Rupelian times transcurrent activity would have been transferred westwards with the activation of the Stura Fault System and, since then, a large-scale left-stepping sinistral system was consequently established between the Stura and the Villavernia-Varzi lines (Fig. 54). This generated a regional E-W-trending (in present-day coordinates) megashear zone which resulted, in combination with the re-activation of formerly active extensional faults, in the generation of the Langhe Sub-

basin in a transtensional regime, and in the collapse of the Ligurian basement in the whole TPB. The importance of transpression near the eastern margin of the TPB, replaced westwards by predominance of transtension in late Rupelian-early Chattian, may reflect the position of the eastern TPB relatively closer to the retreating subduction boundary of the nascent northern Apennine system, in a setting of oblique convergence. In such a location, the effect of the boundary forces may be predominant (Carminati et al., 1998; Faccenna et al., 2002).

The collapse of the Ligurian basement since late Rupelian times was characterized by the development of the deep-water Langhe Sub-basin as well as of deep-water conditions in the whole TPB, which became, at this time, a wholly deep-marine basin extended from the Monregalese area to the West to the Borbera-Grue area to the East. The rapid basin deepening, in particular, was marked by generalized deposition of the Rocchetta Fm slope mudstones (upper Rupelian-lower Aquitanian) in the whole TPB. Such deposits, in facts, may be mapped continuously from the Tanaro Valley to the West up to the Castagnola area to the Est (Ghibaudo et al., in prep.).

The upper Rupelian to middle Burdigalian large-scale sandy and conglomeratic turbidite bodies of the Rocchetta, Montechiaro d'Acqui and Serole formations were fed from NW or WNW indicating regional SE or ESE-dipping paleoslopes (in present day coordinates). All these sandstone bodies are characterized by "proximal" coarse-grained turbidite deposits. More distal coeval turbidite systems should have existed downcurrent, but are at present eroded in the uplifted domain of Ligurian Alps. The distal reaches of the Langhe Sub-basin in Chattian to early Burdigalian times are therefore unknown. In any case, it may be suggested, at least for the largest sandstone bodies of the Rocchetta Fm, that the turbidite system most probably extended onto, and possibly beyond, the present-day uplifted Ligurian Alps. Reconnaissance field work in the Sassello basin-remnant located on the Ligurian Alps and carefully described by Lorenz (1969), highlights that the locally preserved Oligocene stratigraphy is quite similar to the lower succession of the Langhe Sub-basin, i.e. Molare continental and shelf sandstones passing upwards to some tens of metres of muddy sediments (Rocchetta mudstones) and several tens of metres of thick-bedded turbidite packages alternating with minor mudstone intervals. This succession, preserved on the uplifted Ligurian Alps, seems to support the above-mentioned hypothesis. As pointed out by Maffione et al. (2008, 2010) the TPB suffered ca. 50° of anticlockwise rotation in Aquitanian-Serravallian times. In a restored pre-rotation setting Chattian-Early Aquitanian paleocurrent directions would have been approximately N-S-oriented. It may be speculated that the distal parts of the Chattian-lower Aquitanian coarse-grained turbidite systems cropping out in the Langhe Sub-basin were laid down in an area of the present-day northern Tyrrhenian Sea, paleogeographically located in internal position with respect to the Macigno Basin. A southern extent of the Chattian Langhe turbidites

into an area located in internal position with respect to the Macigno Basin was already postulated by Boccaletti et al. (1990, their Pl. I). An attractive hypothesis is that this depositional area corresponds to the Corsica Basin (Fig. 55), which contains more than 8.5 km of Oligocene-Quaternary sediments (Mauffret et al., 1999; Pascucci, 2002). Such basin is underlain by highly deformed metamorphic and non metamorphic units of the Alpine Corsica (Helmintoid Flysch, Schistes Lustrés and ophiolites) (Mauffret and Contrucci, 1999) and may have formed in a geological context similar to that of the Langhe Sub-basin. The Corsica Basin has been interpreted by Mauffret and Contrucci (1999) as a pull-apart basin, formed before or during the opening of the Ligure-Provençal Basin, and related to the collapse of the Alpine Corsica belt along an east-dipping detachment. The basin is bounded to the West by the Solenzara and Aleria faults, which continue N-ward into the Central Corsica Fault, that was active from Oligocene to Early Miocene with left-lateral strike-slip motion (Waters, 1990; Argnani, 2012). The deep part of this huge basin is infilled with Oligocene-Early Miocene sediments (Mauffret et al., 1999) that have been assimilated by Argnani (2009, 2012), together with the time-equivalent TPB sediments, to the epi-Ligurian succession. The hypothesis that the Corsica Basin represents the distal depositional area of the Chattian-lower Aquitanian Langhe proximal turbidites, would imply a continuity of the transport path. In the interpretation of strike-slip origin of the basins this hypothesis could however be unrealistic in case of lack of connection due to basin segmentation by transverse sills generated by wrench faulting.

10. CONCLUSIONS

The tectono-stratigraphic evolution of the study area begins with an extensional phase during the early Rupelian, leading to displacement of the crystalline basement through the activation of basement-involving faults at present oriented NW-SE and NE-SW with large vertical offsets, resulting in a compartmentalization of the area into a number of differentially subsiding blocks. The initial expression of the basement tectonic mobility was the development, in Rupelian times, of a horst and graben paleotopography. From SW to NE, the major paleogeographic elements were: the Rocchetta Cairo Horst, the Borgo Graben, the Spigno Monferrato Horst and the Cartosio Graben. Such grabens accommodated thick successions of continental conglomerates of the Molare Fm. A following marine transgression first encroached upon the Cartosio and the Borgo grabens, where shelf sands of the Molare Fm were laid down on continental deposits, and only later upon the adjacent horsts depositing marine sands directly on the uplifted crystalline basement. Inferred change into predominant transtension in the late Rupelian-early Chattian, superimposed on a phase of enhanced regional tectonic subsidence, led to the collapse of the basement of the southern margin of the TPB, with the onset of deposition of slope to base-of-slope hemipelagic

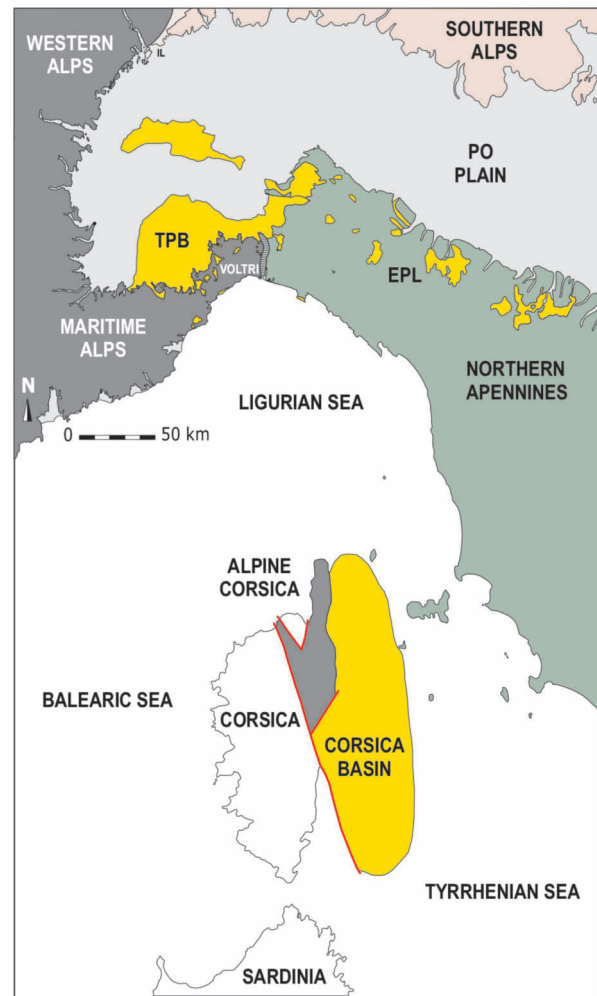


Fig. 55 - Present-day distribution of the sediments of the Tertiary Piedmont Basin, Corsica Basin and Epiligurian basin remnants of northern Apennines. Simplified, redrafted and modified from Argnani (2009).

mudstones of the Rocchetta Fm.

The most prominent intra-Oligocene structural element of the Langhe Sub-basin in the study area was the Dego-Spigno Monferrato High, a complex positive structure of the basement which strongly controlled thickness and facies of Lower Oligocene Rocchetta deposits. The Dego-Spigno Monferrato High was subdivided into secondary horsts and grabens. Two depocentres, the Turpino and Rocchetta Cairo Depocentres, developed to the N and respectively S of the Dego-Spigno Monferrato High, where the Rocchetta Fm reaches thicknesses of about 1000 m.

The Rocchetta Fm shows common slump scars, the largest of which, about 1 km wide and up to 150 m deep, in the Molino di Mombaldone area, evolved into a submarine canyon/slope-valley system. The largest turbidite bodies occurring in the Rocchetta Fm (Mogliavacca, Brovida, Cobarello and Noceto sandstone bodies) are concentrated in the Rocchetta Cairo Depocentre. These bodies are vertically stacked and show a trend of upward increasing width/thickness ratio

reflecting a change from upper slope to base-of-slope setting. The largest and youngest body is the Noceto unit (lower Aquitanian), representing the infill of a pluri-kilometric half-graben bounded by the listric Rio Girona growth fault. The Rocchetta Fm is capped by hemipelagic and mainly siliceous sediments, named “Montechiaro d’Acqui Siliceous Lithozone” (LS1) (middle-upper Aquitanian) representing a regional marker horizon and interpreted as consisting of condensed deposits. They occur as a single package in the NE and are subdivided SW-wards into minor units (LS1a, LS1b, LS1c) separated by turbiditic formations.

In the south-western sector a system of NE-trending tectonic lines, the Uzzone Valley Fault System, was active from the middle Aquitanian to the early Burdigalian. The activation of these faults marks a change in tectonic regime, paleogeography and regional stress field of the study area. They are interpreted as growth faults acting at different times either as extensional/transtensional or as transpressional faults. They generated intrabasinal highs and small-scale slope or base-of-slope basins controlling location and orientation of the turbidite sandstone bodies and their paleocurrent pattern. By the middle Aquitanian, the Poggiolo Basin developed and was sealed by deposition of the siliceous LS1b unit. By the middle-late Aquitanian the Scaletta Uzzone Basin developed and was sealed by deposition of the siliceous LS1c unit. During the latest Aquitanian-early Burdigalian the 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, derived from coeval foramol-type carbonate platforms. High tectonic mobility in this stage is indicated by the generation of the C. Mazzurini Half-graben, which was infilled with coarse-grained bioclastic sandstones and conglomerates. In the meantime in the southern area strike-slip reactivation of the Uzzone Valley Fault System generated the Rio della Chiesa Basin where the Castelletto Uzzone Sottano and the Rio della Chiesa lower and upper units were deposited.

A resumption of transpression along the Uzzone Valley Fault System in the early Burdigalian led to the partial inversion of the Noceto Half-graben, driven by dextral transpression along the NE trending Sanvarezzo-C. Villara Fault, and to the generation of large-scale folds at the head of the Rio della Torre Valley. A new cycle began in middle Burdigalian time, with emplacement of coarse siliciclastics (Piantivello unit) into a large base-of-slope submarine valley followed by the widespread deposition of thin-bedded turbidites and associated sandstone bodies of the Serole Fm. These deposits locally infilled medium- to large-scale slump scars, which partly or completely removed the marls of the underlying Montechiaro d’Acqui Fm. The Serole Fm prodelta slope wedge tapers gradually to the NE and is capped, with onlap relationships, by the thick basal turbidites of the Cortemilia Fm (upper Burdigalian).

It may be speculated, at least for the largest sandstone bodies of the Chattian-lower Aquitanian Rocchetta Fm, that the turbidite system most probably extended onto, and possibly beyond, the present-day uplifted Ligurian Alps with the distal parts of the system laid down in an area of the present-day northern Tyrrhenian Sea possibly corresponding to the Corsica Basin.

The tectonic evolution in the study area is characterized by a progressive change from extensional to transtensional and, eventually, alternating transpressional/transtensional strain regime during the time span from the Early Oligocene to the Early Miocene. This changing tectonic regime is thought to reflect the transition from the early Rupelian crustal stretching which occurred in the late stage of the extensional, post-orogenic exhumation of the Mesoalpine prism, to the activation, since late Rupelian time, of a regional megashear zone between the left-stepping sinistral Villavernia-Varzi Line to the NE and the Stura Fault System to the SW, as a result of the progressive escape of the Adriatic Indenter. During the late Rupelian-early Burdigalian time span, the whole Tertiary Piedmont Basin probably behaved as a strike-slip basin.

NOTES

(1) *The succession of the TPB is characterized by the presence, at various stratigraphic levels, of basinwide siliceous horizons, here defined “siliceous lithozones”, interpreted as condensed deposits. These siliceous intervals have the meaning of key levels and are extremely important for basin-scale correlations. The adopted LS1, LS2, LS3, etc ... notation refers to the different siliceous lithozones of the TPB succession in ascending stratigraphic order. Where the siliceous lithozones split into minor units located atop turbiditic formations they are indicated by the notation LS1a, LS1b, LS1c, LS2a, LS2b, L2c etc ... Where two lower-rank siliceous lithozones join due to the lateral pinch out of intercalated turbiditic units, they are indicated by the notation LS1a-b, LS1b-c, etc....*

(2) *With the exception of lenticular sandstone bodies (members) or of lithostratigraphic units (formations) pinching out laterally for downlapping or onlapping reasons, all the main lithostratigraphic units of the enclosed geological map can be traced laterally along the entire southern margin of the TPB (Ghibaudo et al., in prep). As far as this part of the basin is concerned, the authors disagree with the practice adopted in the new geologic sheets at 1:50000 scale of the Carta Geologica d’Italia, where the same units have different names and different lithostratigraphic hierarchy in adjacent sheets (e.g. sheets Cairo Montenotte, Dego, and Acqui Terme), thus perpetuating the flaws of the previous geological maps at 1:100000 scale.*

(3) *Bellino et al. (in press a, b) in the nearby Sheet 194 Acqui Terme to scale 1:50000 of the “Carta Geologica d’Italia” consider the Montechiaro d’Acqui Siliceous Lithozone LS1 as a member of their Formazione di Montechiaro d’Acqui. According to these Authors this formation consists of a lower Membro siliceo (i.e. Montechiaro d’Acqui Siliceous Lithozone LS1 of the present paper) and an upper Membro marnoso (i.e. Montechiaro d’Acqui Fm of the present paper). Such lithostratigraphy has not been adopted by us as it was considered not congruent with the formal lithostratigraphic rules. Both members of the above mentioned formation, in fact, comprise, on a more regional scale, lithostratigraphic units of the same or higher rank (cf. for example,*

in the enclosed geological map, the subdivision of the siliceous lithozone LS1, equivalent of the Membro siliceo of the Formazione di Montechiaro d'Acqui of these Authors, into minor units - LS1a, LS1b, LS1c - developed atop of specific turbiditic formations). It is well known that lithostratigraphic units cannot comprise other units of equal or higher rank. The same objection can be extended to the Sheet 211 Deigo (Gelati et al., 2010a, b) and to the adjacent Sheet 228 Cairo Montenotte (Dallagiovanna et al., in press a, b) where the same siliceous unit is considered as a member of the Formazione Rocchetta-Monesiglio of these Authors. It is opinion of the writers that the basinwide siliceous intervals (indispensable for regional correlations) should be considered as independent lithostratigraphic units with the meaning of key levels for which, due to their peculiar character not fitting the classic lithostratigraphic hierarchy, the term of "lithozone" seems to be appropriate (cf. Salvador, 1994 and Amorosi et al., 1995).

(4) Bellino et al. (in press a, b) in the nearby Sheet 194 Acqui Terme to scale 1:50000 of the "Carta Geologica d'Italia" lump the Bubbio Siliceous Lithozone (LS2a) of the present paper and a more recent siliceous unit (LS2b unit of Ghibaudo et al., in prep.) developed at the base of the slope wedge of the overlying Cessole Fm, into a single lithostratigraphic unit named Formazione di Bistagno. This formation also comprises a wedge-shaped sandstone unit up to 80 m thick (not mapped by the Authors), sandwiched between the above-mentioned siliceous units and having the lithology of the Cassinasco Fm. Our field surveys carried out in the nearby Alba and Acqui Terme Sheets clearly indicate that the interposed unit is to be regarded as a tongue of the Cassinasco Fm thickening westwards and pinching out eastwards (Ghibaudo et al., in prep.). The writers reiterate, for correct regional correlations, the need to assign to the individual siliceous horizons an independent lithostratigraphic rank (lithozone) with the meaning of key levels.

(5) In the legend of the geological map an incorrect environmental attribution was indicated for the Cobarello Sandstones. The correct interpretation should be "Base-of-slope broad submarine depression infilled with proximal lobe deposits".

ACKNOWLEDGEMENTS - We are deeply indebted to Pierangelo Clari and Massimo Rossi for their very careful and thoughtful revision of the manuscript. Their suggestions and comments have been very useful to improve the quality of the manuscript. Salvatore Milli is very gratefully acknowledged for is careful editorial work. Eliana Fornaciari and Cristina Stefani are acknowledged for their constructive collaboration. A special thank is due to Emilia Cianci, responsible of the Turin Geoscience Department library, for her help in providing the necessary literature. We warmly thank the family Del Cerchio, managing the Agritourism "La Molina" (Pareto) and the family Negro, managing the Agritourism "Matiein" (Vesime), for their hearty and warm welcome, friendship and honesty. G. Ghibaudo and F. Massari are also indebted to their wives for having patiently endured the long periods of absence of their husbands for field work. G. Ghibaudo is especially grateful to his dog Lea, which for 12 years accompanied him in the field and which never challenged the geologic interpretations of her master, turning out to be a perfect companion. This work was supported by University 60% to G. Ghibaudo and F. Massari.

REFERENCES

- Abreu V.S., Haddad G.A., 1998. Glacioeustatic fluctuations: The mechanism linking stable isotope events and sequence stratigraphy from the Early Oligocene to Middle Miocene. In: De Graciansky, P.-C., Hardenbol J., Thierry J., Vail P. (Eds.), *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*. SEPM (Society for Sedimentary Geology) Special Publication 60, 245-259.
- Allasinaz A., Gelati R., Gnaccolini M., Martinis B., Orombelli G., Pasquarè G., Rossi P.M., 1971. Note Illustrative della Carta Geologica d'Italia alla scala 1:100000, Foglio 82 Genova, p. 134.
- 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.
- Argnani A., 2009. Plate tectonics and the boundary between Alps and Apennines. *Italian Journal of Geosciences* 128, 317-330.
- Argnani A., 2012. Plate motion and the evolution of Alpine Corsica and Northern Apennines. *Tectonophysics* 579, 207-219.
- Aydin A., Nur A., 1985. The types and role of stepover in strike-slip tectonics. In: Biddle K.T., Christie-Blick N., (Eds.), *Strike-Slip Deformation, Basin Formation, and Sedimentation*. SEPM (Society of Economic Paleontologists and Mineralogists) Special Publication 37, 35-44.
- 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.
- Bellino F., Irace A., d'Atri A., Varrone D., Piana F., Cadoppi P., Tallone S., Spagnolo G., Fusetti E., Paro L., Piccini C., Dela Pierre F., Fioraso G., (in press) (a). Carta Geologica d'Italia alla scala 1:50000, Foglio 194 Acqui Terme. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale.
- Bellino F., d'Atri A., Irace A., Piana F., Tallone S., Varrone D., Cadoppi P., Fioraso G., Fusetti E., Morelli M., Lanteri L., Paro L., Piccini C., Trenkwalder S., (in press) (b). Note illustrative della Carta Geologica d'Italia alla scala 1:50000, Foglio 194 Acqui Terme. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale.
- Beltrando M., Lister, G.S., Rosenbaum G., Richards S., Forster M.A., 2010. Recognizing episodic lithospheric thinning along a convergent plate margin: The example of the Early Oligocene Alps. *Earth-Science Reviews* 103, 81-98.
- Bernardeschi, A., 2009. Evoluzione stratigrafico-strutturale del settore orientale del Bacino Terziario Piemontese (Appennino Settentrionale). Unpublished Ph.D. Thesis. University of Pisa, pp. 123.
- Bertotti G., Mosca P., 2009. Late-orogenic vertical movements within the arc of the SW Alps and Ligurian Alps. *Tectonophysics* 475, 117-127.
- 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 1:500000, sheet 1, SELCA, Firenze.
- Boccaletti M., Ciaranfi N., Cosentino D., Deiana G., Gelati R., Lentini F., Massari F., Moratti G., Pescatore T., Ricci Lucchi F., Tortorici L., 1990. Palinspastic restoration and

- paleogeographic reconstruction of the peri-Tyrrhenian area during the Neogene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 77, 41-50.
- Boni A., Casnedi R., 1970. Note Illustrative della Carta Geologica d'Italia alla scala 1:100000, Fogli 69 e 70, Asti-Alessandria, p. 64.
- Bradshaw G.A., Zoback M.D., 1988. Listric normal faulting, stress refraction, and the state of stress in the Gulf Coast basin. *Geology* 16, 271-274.
- Bruce C.H., 1973. Pressured shales and related sediment deformation: mechanism for development of regional contemporaneous faults. *American Association of Petroleum Geologists Bulletin* 67, 878-886.
- Bourgeois J., 1980. A transgressive shelf sequence exhibiting hummocky stratification: The Cape Sebastian Sandstone (Upper Cretaceous), southwestern Oregon. *Journal of Sedimentary Petrology* 50, 681-702.
- Bourgeois J., 1984. Late Cretaceous transgressive sedimentation: A comparison of the basal Hornbrook Formation and the Cape Sebastian Sandstone, northern California and southwestern Oregon. In Nilsen T.H. (Ed.) *Geology of the Upper Cretaceous Hornbrook Formation, Oregon and California*. Pacific Section S.E.P.M. 42, 149-158.
- 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.
- 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.
- Carminati A., Wortel M.J.R., Spakman W., Sabadini R., 1998. The role of slab detachment processes in the opening of the western-central Mediterranean basins: some geological and geophysical evidence. *Earth and Planetary Science Letters* 160, 651-665.
- Carrapa B., 2002. Tectonic evolution of an active orogen as reflected by its sedimentary record - An integrated study of the Tertiary Piedmont Basin (internal Western Alps, NW Italy). Ph.D. Thesis Vrije Universiteit, Amsterdam, The Netherlands, pp. 177.
- Castellarin A., 1994. Strutturazione eo- e meso-alpina dell'Appennino settentrionale attorno al "nodo ligure". *Studi Geologici Camerti*, Vol. spec., CROP 1-1A, 99-108.
- Catanzariti R., Rio D., Martelli L., 1997. Late Eocene to Oligocene calcareous nannofossil biostratigraphy in Northern Apennines: the Ranzano Sandstone. *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., Rigazio G., 1983. Caratteri sedimentologici dei corpi torbiditici di Valla e Mioglia, Formazione di Rocchetta (Oligocene-Miocene) del Bacino Terziario Piemontese. *Giornale di Geologia* 45, 87-100.
- Cazzola C., Sgavetti M., 1984. Geometria dei depositi torbiditici della formazioni di Rocchetta e Monesiglio (Oligocene superiore-Miocene inferiore) nell'area compresa tra Spigno e Ceva. *Giornale di Geologia* 45, 227-239.
- Cazzola C., Mutti E., Vigna B., 1985. Cengio turbidite system, Italy. In: Bouma, A.H., Barnes, N.E., Normark, W.R., (Eds.), *Submarine Fans and Related Turbidite Sequences*. Springer-Verlag, New York, 179-183.
- Cazzola C., Fornaciari M., 1990. Geometria e facies dei sistemi torbiditici di Budroni e Noceto (Bacino Terziario Piemontese). *Atti Ticinensi di Scienze della Terra* 33, 177-190.
- Chiambretti I., 2006. Tettonica e sedimentazione dei depositi oligocenici e miocenici inferiori affioranti nelle valli Bormida di Spigno e Uzzone (Margine meridionale del Bacino Terziario Piemontese). Unpublished Ph.D. Thesis. Università di Torino, pp. 232.
- Cibin U., Spadafora E., Zuffa G.G., Castellarin A., 2001. Continental collision history from arenites of episutural basins in the Northern Apennines, Italy. *Geological Society of America Bulletin* 113, 4-19.
- Clari P., Ghibaudo G., 1979. Multiple slump scars in the Tortonian type area (Piedmont Basin, Northwestern Italy). *Sedimentology* 26, 719-730.
- Clari P., Dela Pierre F., Novaretti A., Timpanelli M., 1995. Late Oligocene-Miocene sedimentary evolution of the critical Alps/Apennines junction - the Monferrato area, Northwestern Italy. *Terra Nova* 7, 144-152.
- 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.
- 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 Evolució* 24-25, 341-362.
- Dallagiovanna G., Gaggero L., Seno S., Felletti F., Mosca P., Decarlis A., Pellegrini L., Poggi F., Bottero D., (in press) (a). Carta Geologica d'Italia alla scala 1:50000, Foglio 228 Cairo Montenotte. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale.
- Dallagiovanna G., Gaggero L., Seno S., Lualdi A., Felletti F., Mosca P., Decarlis A., Pellegrini L., Poggi F., Bottero D., (in press) (b). Note illustrative della Carta Geologica d'Italia alla scala 1:50000, Foglio 228 Cairo Montenotte. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale.
- 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). Unpublished Ph.D. Thesis. Università di Torino, pp. 143.
- Davies R.J., Clark I.R., 2006. Submarine slope failure primed and triggered by silica and its diagenesis. *Basin Research* 18, 339-350.
- 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 Convegno Rapporti Alpi-Appennino, Peveragno 1994*, pp. 129-146.
- Di Celma C., Cantalamessa G., Didaskalou P., Lori P., 2010. Sedimentology, architecture, and sequence stratigraphy of coarse-grained, submarine canyon fills from the Pleistocene

- (Gelasian-Calabrian) of the Peri-Adriatic basin, central Italy. *Marine and Petroleum Geology* 27, 1340-1365.
- Di Giulio A., 1991. Detritismo della parte orientale del Bacino Terziario Piemontese durante l'Eocene-Oligocene: composizione delle arenarie ed evoluzione tettonico-stratigrafica. *Atti Ticinesi Scienze della Terra* 34, 21-41.
- Di Giulio A., Galbiati B., 1993. Escursione nell'estremità orientale del Bacino Terziario Piemontese: interazione tettonica-eustatismo nella sedimentazione di un bacino tardo post-orogenico. Guida all'escursione. 3° Convegno del Gruppo informale di Sedimentologia del C.N.R., Salice Terme, 4-6 Ottobre 1993.
- Di Giulio A., Galbiati B., 1995. Interaction between tectonics and deposition into an episutural basin in the Alps-Appennines knot. In R. Polino R. Sacchi (eds), *Atti del Convegno sul tema "Rapporti tra Alpi e Appennino"* e guida alle escursioni, Accad. Naz. Delle Scienze detta dei XL, Roma, 113-128.
- 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 biomagnetostратigraphy for the Langhian of the Mediterranean area. *Rivista Italiana di Paleontologia e Stratigrafia* 114, 51-76.
- Dumont T., Simon-Labric T., Authemayou C., Heymes T., 2011. Lateral termination of the north-directed Alpine orogeny and onset of westward escape in the Western Alpine arc: Structural and sedimentary evidence from the external zone. *Tectonics* 30, TC 5006.
- Dumont T., Schwartz S., Guillot S., Simon-Labric T., Tricart P., Jourdan S., 2012. Structural and sedimentary records of the Oligocene revolution in the Western Alps arc. *Journal of Geodynamics* 56-57, 18-38.
- Faccenna C., Speranza F., D'Aiello Caracciolo F., Mattei M., Oggiano G., 2002. Extensional tectonics on Sardinia (Italy): insights into the arc-back-arc transitional regime. *Tectonophysics* 356, 213-232.
- 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, Università di Parma, pp. 145.
- Federico L., Capponi G., Crispini L., Sgambelluri M., 2005. $^{39}\text{Ar}/^{40}\text{Ar}$ dating of high-pressure rocks from the Ligurian Alps: Evidence for a continuous subduction-exhumation cycle. *Earth and Planetary Science Letters* 240, 668-680.
- 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, pp. 339-365.
- Ford M., Duchene S., Gasquet D., Vanderhaeghe O., 2006. Two-phase orogenic convergence in the external and internal SW Alps. *Journal of the Geological Society, London* 163, 815-826.
- Fornaciari E., Rio D., 1996. Latest Oligocene to early Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology* 42, 1-37.
- Franconi V., Gelati R., Martinis B., Orombelli G., Pasquare G., Rossi P.M., Sfondrini G., 1971. Foglio 81 Ceva. Note illustrative della carta Geologica d'Italia. Nuova Tecnica Grafica, Roma, p. 100.
- Galbiati B., 1976. La successione oligo-miocenica tra Rigoroso e Carrosio (Bacino ligure-piemontese). *Atti Istituto Geologico 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., 1980. Significato dei corpi arenacei di conoide sottomarina (Oligocene-Miocene inferiore) nell'evoluzione tettonico-sedimentaria del Bacino terziario ligure-piemontese. *Rivista Italiana di Paleontologia e Stratigrafia* 86, 167-186.
- Gelati R., Gnaccolini M., 1988. Sequenze deposizionali in un bacino episuturale, nella zona di raccordo tra Alpi e Appennino settentrionale. *Atti Ticinensi di Scienze della Terra* 31, 340-350.
- Gelati R., Gnaccolini M., 1996. The stratigraphic record of Oligocene-Early Miocene events at the south-western end of the Tertiary Piedmont Basin. *Rivista Italiana di Paleontologia e Stratigrafia* 102, 65-76.
- 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., 2003. Genesis and evolution of the Langhe Basin, with emphasis on the latest Oligocene-earliest Miocene and Serravallian. *Atti Ticinensi 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., Granata P., Masi M., Piana F., Polino R., Brovero M., Drago D., Fioraso G., Mosca P., Morelli M., Sorzana P., Fontan D., 2010a. 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., 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., 2010b. Note illustrative della 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., 1992. Subaqueous sediment gravity flow deposits: practical criteria for their field description and classification. *Sedimentology* 39, 423-454.
- 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., 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., d'Atri A., (this volume). Oligo-Miocene tectono-sedimentary evolution of the continental to basinal succession of the southern margin of the Tertiary Piedmont Basin (Roccaerverano area - Langhe Sub-basin, Northwestern Italy).
- Giglia G., Capponi G., Crispini L., Piazza M., 1996. Dynamics and seismotectonics of the West-Alpine arc. *Tectonophysics* 267, 143-175.
- Gnaccolini M., 1974. Osservazioni sedimentologiche sui conglomerati Oligocenici del settore meridionale del Bacino Terziario Liguro-Piemontese. *Rivista Italiana di Paleontologia e Stratigrafia* 80, 85-100.
- Gnaccolini M., Gelati R., 1996. Anatomy of an episutural basin: the Tertiary Piedmont Basin, Northern Italy. 30th International Geology Congress, Beijing 1966, Abstracts, 3, p. 14
- 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.
- Handy M.R., Schmid S.M., Bousquet R., Kissling E., Bernoulli D., 2010. Reconciling plate-tectonic reconstructions of Alpine Tethys with the geological - geophysical record of spreading and subduction in the Alps. *Earth-Science Reviews* 102, 121-158.
- Hardenbol J., Thierry J., Farley M.B., Jacquin Th., de Graciansky P.-C., Vail P.R., 1998. Appendix to: Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. *SEPM (Society for Sedimentary Geology), Special Publication* 60, 763-783.
- Heller P.L., Dickinson W.R., 1985. Submarine ramp facies model for delta-fed, sand-rich turbidite systems. *American Association of Petroleum Geologists Bulletin* 69, 960-976.
- Hesselbo S.P., Huggett J.M., 2001. Glaucony in ocean-margin sequence stratigraphy (Oligocene-Pliocene, offshore New Jersey, U.S.A.; ODP Leg). *Journal of Sedimentary Research* 71, 599-607.
- Jolivet L., Augier R., Faccenna C., Negro F., Rimmele G., Agard P., Robin C., Rossetti F., Crespo-Blanc A., 2008. Subduction, convergence and the mode of backarc extension in the Mediterranean region. *Bulletin de la Société Géologique de France* 179, 525-550.
- Laubscher H., 1991. The arc of Western Alps today. *Eclogae Geologicae Helveticae* 84, 631-659.
- Laubscher H., Biella G.C., Cassinis R., Gelati R., Lozej A., Scarascia S., Tabacco I., 1992. The collisional knot in Liguria. *Geologische Rundschau* 81, 275-289.
- Lefèvre R., 1983. La cicatrice de Preit: une discontinuité structurale majeure au sein de la zone Briançonnaise entre Acceglio and Argentera (Alpes Cottiennes méridionales). *Comptes Rendus de l'Académie des Sciences de Paris* 296, 1551-1554.
- Lorenz C., 1969. Contribution à l'étude stratigraphique de l'Oligocène inférieur des confins Liguro-Piemontais (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.
- Maffione M., Speranza F., Faccenna C., Cascella A., Vignaroli G., Sagnotti L., 2010. A synchronous Alpine and Corsica-Sardinia rotation: new paleomagnetic evidences from the Tertiary Piedmont Basin (NW Italy). *Trabajos de Geologia, Universidad de Oviedo* 30, 28-36.
- Maino M., Dallagiovanna G., Dobson K.J., Gaggero L., Persano C., Seno S., Stuart F.M., 2012. Testing models of orogen exhumation using zircon (U-Th)/He thermochronology: Insight from the Ligurian Alps, Northern Italy. *Tectonophysics* 560-561, 84-93.
- Maino M., Decarlis A., Felletti F., Seno S., 2013. Tectono-sedimentary evolution of the Tertiary Piedmont Basin (NW Italy) within the Oligo-Miocene central Mediterranean geodynamics. *Tectonics* 32, 1-27.
- Malusà M.G., Polino R., Zattin M., 2009. Strain partitioning in the axial NW Alps since the Oligocene. *Tectonics* 28, TC3005, doi: 10.1029/2008TC002370, 2009.
- Marroni M., Ottria G., Pandolfi L., Catanzariti R., Bormioli D., Cucchi A., Moletta G., (in press). Note illustrative della Carta Geologica d'Italia alla scala 1:50000 Foglio 196 Cabella Ligure. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale.
- Marroni M., Treves B., 1998. Hidden terranes in the Northern Apennines, Italy: A record of Late Cretaceous-Oligocene transpressional tectonics. *Journal of Geology* 106, 149-162.
- Mauffret A., Contrucci I., 1999. Crustal structure of the North Tyrrhenian Sea: first result of the multichannel seismic LISA cruise. In: Durand B., Jolivet L., Horvath F., Séranne M. (Eds.) *The Mediterranean Basins: Tertiary Extension within the Alpine Orogen*. Geological Society of London, Special Publications 156, 169-193.
- Mauffret A., Contrucci I., Brunet C., 1999. Structural evolution of the Northern Tyrrhenian Sea from new seismic data. *Marine and Petroleum Geology* 16, 381-407.
- McNeil L., Piper K., Goldfinger C., Kulm L., Yeats R., 1997. Listric normal faulting on the Cascadia continental margin. *Journal of Geophysical Research* 102, 12, 123-12, 138.
- Mitra S., Paull D., 2011. Structural geometry and evolution of releasing and restraining bends: insights from laser-scanned experimental models. *American Association of Petroleum Geologists Bulletin* 95, 1147-1180.
- Molli G., Crispini L., Malusà M., Mosca P., Piana F., Federico L., 2010. Geology of the Western Alps-Northern Apennine junction area: a regional review. In: Beltrando M., Peccerillo A., Mattei M., Conticelli S., Doglioni C. (Eds.), *Journal of the Virtual Explorer* 36. doi: 10.3809/jvirtex.2009.00215.
- 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. n. 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.
- Musso A., Piana F., Bertok C., d'Atri A., Martire L., Perotti E., Varrone D., 2009. Post-Eocene transpression in Western Ligurian Alps: geometry and kinematics of the Limone-Viozene Deformation Zone (France-Italy border). *GeoItalia 2009*, Poster abstract.
- 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., Roveri M. (Eds.). Revisiting turbidites of the Marnoso-Arenacea Formation and the basin margin counterpart problems with classic models. Excursion Notes - Part II, pp. 25.
- Ogg J.G., Ogg G., Gradstein F.M., 2008. The Concise Geologic Time scale. Cambridge University Press, pp. 150.
- Pascucci V., 2002. Tyrrhenian Sea extension north of the Elba Island between Corsica and western Tuscany (Italy). *Bollettino della Società Geologica Italiana*: Vol. Spec. 1, 819-828.
- Piana F., 2000. Structural Setting of Western Monferrato (Alps-Apennines Junction Zone, NW Italy). *Tectonics* 19, 943-960.
- Piana F., Dela Pierre F., 2000. Il movimento nealpino verso NW del promontorio adriatico: vincoli posti dall'evoluzione tettono-sedimentaria post-eocenica del Monferrato. In: Carulli G.B., Longo Salvador G. (coordinatori), 80^a Riunione Estiva della Società Geologica Italiana, Trieste, Riassunti delle Comunicazioni orali e dei Posters. Edizioni Università di Trieste, pp. 361-363.
- 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.
- Piana F., Musso A., Bertok K., d'Atri A., Martire L., Perotti E., Varrone D., Martinotti G., 2009. New data on post-Eocene tectonic evolution of the External Ligurian Briançonnais (Western Ligurian Alps). *Italian Journal Geosciences* 128, 353-366.
- Raffi I., Backman J., Fornaciari E., Palike H., Rio D., Lourens L., Hilgen F., 2006. A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years. *Quaternary Science Reviews* 25, 3113-3137.
- Ricou L.E., 1981. Glissement senestre des nappes penniques le long de la bordure nord de l'Argentera; son role dans le jeu de l'arc alpin. *Comptes Rendus de l'Académie des Sciences de Paris* 292, s. II, 1305-1308.
- Rollet N., Déverchère J., Beslier M.-O., Guennoc P., Réhault J.-P., Sosson M., Truffert C., 2002. Back arc extension, tectonic inheritance, and volcanism in the Ligurian Sea, Western Mediterranean. *Tectonics* 21, 1015, doi: 10.1029/2001TC900027, 2002.
- 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., 1989. Poinçonnement, rétrochriages et chevauchements post-basculément dans les Alpes occidentales: évolution intracontinentale d'une chaîne de collision. *Comptes Rendus de l'Académie des Sciences de Paris* 309, S. II, 283-290.
- 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.
- Salvador A. (Ed.), 1994. International Stratigraphic Guide - A Guide to Stratigraphic Classification, Terminology and Procedure. Geological Society of America, Lawrence, pp. 214.
- 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. SEPM (Society of Economic Paleontologists and Mineralogists) Special Publication 12, 192-219.
- Schlische R.W., Olsen P.E., 1990. Quantitative filling model for continental extensional basins with applications to Early Mesozoic rifts of eastern North America. *Journal of Geology* 98, 135-155.
- Schumacher M.E., Laubscher H.P., 1996. 3D architecture of the Alps-Apennines join - a new view on seismic data. *Tectonophysics* 260, 349-363.
- Schüttenhelm R.T.E., 1976. History and modes of Miocene carbonate deposition in the interior of Piedmont basin, NW Italy. *Utrecht Micropaleontological Bulletin* 14, 13-207.
- Segall M.P., Pollard D.D., 1980. Mechanics of discontinuous faults. *Journal of Geophysical Research* 85, 4337-4350.
- 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.
- Speranza F., Villa I.M., Sagnotti L., Florindo F., Cosentino D., Cipollari P., Mattei M., 2002. Age of the Corsica-Sardinia rotation and Liguro-Provençal Basin spreading: new paleomagnetic and Ar/Ar evidence. *Tectonophysics* 347, 231-251.
- Stampfli G.M., Marchant R.H., 1997. Geodynamic evolution of the Tethyan margins of the Western Alps. In: Pfiffner, O.A., Lehner P., Heitzmann P., Mueller S., Steck A. (Eds.), Deep structure of the Swiss Alps: results of NRP20. Birkhauser Verlag, Basel, 223-239.
- Vignaroli G., 2006. Structural-metamorphic evolution of the Voltri Massif (Ligurian Alps, Italy). Doctorate in Geodynamics, XVIII cycle, Università degli studi, Roma 3, pp. 166.
- Vignaroli G., Faccenna C., Jolivet L., Piromallo C., Rossetti F., 2008. Subduction polarity reversal at the junction between the Western Alps and the Northern Apennines, Italy. *Tectonophysics* 450, 34-50.
- Vignaroli G., Faccenna C., Jolivet L., Piromallo C., Rossetti F., 2009. Reply to the comment by G. Capponi et al. on "Subduction polarity reversal at the junction between the Western Alps and the Northern Apennines, Italy", *Tectonophysics* 465, 227-231.
- Vignaroli G., Rossetti F., Rubatto D., Theye T., Lisker F., Phillips D., 2010. Pressure-temperature-deformation-time (P-T-d-t) exhumation history of the Voltri Massif HP complex, Ligurian Alps, Italy, *Tectonics* 29, TC6009, doi: 10.1029/2009TC002621.
- Waters C.N., 1990. The Cenozoic tectonic evolution of Alpine Corsica. *Journal of the Geological Society of London* 147, 811-824.
- Wornardt W.W. Jr., 1999. Revision of sequences boundaries and maximum flooding surfaces: Jurassic to Recent. Offshore Technology Conference (OTC) 14072, p. 18.