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NEW OUTCROP AND SUBSURFACE DATA IN THE TERTIARY PIEDMONT BASIN (NW-ITALY): UNCONFORMITY-BOUNDED STRATIGRAPHIC UNITS AND THEIR RELATIONSHIPS WITH BASIN-MODIFICATION PHASES

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Abstract. This paper deals with the regional stratigraphy around the Alps-Apennines junction during late Eocene-Miocene. The basin-fill architecture and its relation to changes in structural style were deciphered through the integration of subsurface and outcrop data on the basis of seismic- and sequence-stratigraphy principles, respectively.

During late Eocene-Oligocene, the study area hosted a mosaic of partially interconnected sub-basins, and the Torino Hill area marked the junction towards the western apex of the Southern Alps foredeep (Gonfolite Basin). Since the latest Oligocene, the uplift of the north-verging Monferrato arc provided the separation from the adjacent Gonfolite Basin and the Tertiary Piedmont Basin behaved as a larger and more regularly subsiding thrust-top basin.

The upper Eocene-Miocene successions record a long-term, major transgressive-regressive cycle, consisting of seven large-scale unconformity-bounded stratigraphic units, whose stacking pattern was controlled by changes in the rate of tectonic subsidence and whose boundaries were generated by basin-modification phases. During the Oligocene-lower Miocene deepening-upward sequence set, the marginal marine systems show a marked diachronism associated with the SW-ward change of coastal onlap, punctuated by drowning-platform unconformities generated in relation to basinward tilting and high-angle syn-sedimentary faults. The maximum transgression coincides with the late Burdigalian tectonic space creation phase, when a basinwide, highly efficient turbidite system was deposited. The middle-upper Miocene progradation, punctuated by forced regression pulses, was driven by the inversion and uplift of the southern basin margin, so that a northward shift and progressive narrowing of the turbidite depocentre occurred.

Riassunto. Questo lavoro concerne i bacini sedimentari generati a partire dall'Eocene superiore tra il settore assiale della catena alpina e il *retroforeland*, e le modificazioni che interessarono la giunzione Alpi-Appennini dal tardo Oligocene. L'integrazione di dati stratigrafici di affioramento (cartografia geologica, sezioni stratigrafiche di dettaglio, biostratigrafia) e di sottosuolo (stratigrafia sismica, pozzi esplorativi) ha permesso di identificare sette unità delimitate da superfici di inconformità generate da fasi di modificazione tettonica.

Il Bacino Terziario Piemontese era inizialmente costituito da svariati sub-bacini parzialmente interconnessi e raccordati, in continuità fisica, all'apice occidentale dell'avanfossa sudalpina della Gonfolite verso Nord e al Bacino di Ranzano verso Est. Dal tardo Oligocene, in relazione al coinvolgimento del Monferrato nei sovrascorrimenti appenninici, il Bacino Terziario Piemontese divenne un bacino di *thrust-top* fortemente asimmetrico, caratterizzato da elevata subsidenza del settore meridionale. Dal Miocene medio, questo settore registra un'inversione tettonica che ne ha determinato il progressivo basculamento verso Nord.

Dal tardo Priaboniano al Burdigaliano si osserva una generale trasgressione, accelerata da una serie di *drowning platform unconformities* associate a faglie sinsedimentarie e ad estesa instabilità lungo pendii soggetti a *oversteepening* di origine tettonica. La variazione dell'*onlap* costiero verso le aree sud-occidentali, più prossime al settore assiale della catena alpina, è associata ad un marcato diacronismo dei sistemi marino marginali (Fm. di Molare Auct.). Nel tardo Burdigaliano si verifica la massima creazione di spazio, registrata da un sistema torbiditico ad alta efficienza esteso quasi 100 km. A partire dal Langhiano, la prevalente sottrazione di spazio determinò un elevato tasso di progradazione dei sistemi fluvio-deltizi, accompagnato da fasi di regressione forzata, *by-passing* ed estesa instabilità al margine esterno delle piattaforme.

Introduction

During the Cenozoic, a several km-thick, mainly clastic succession has been deposited in the region of the Alps-Apennines junction (Fig. 1). In this area, a number

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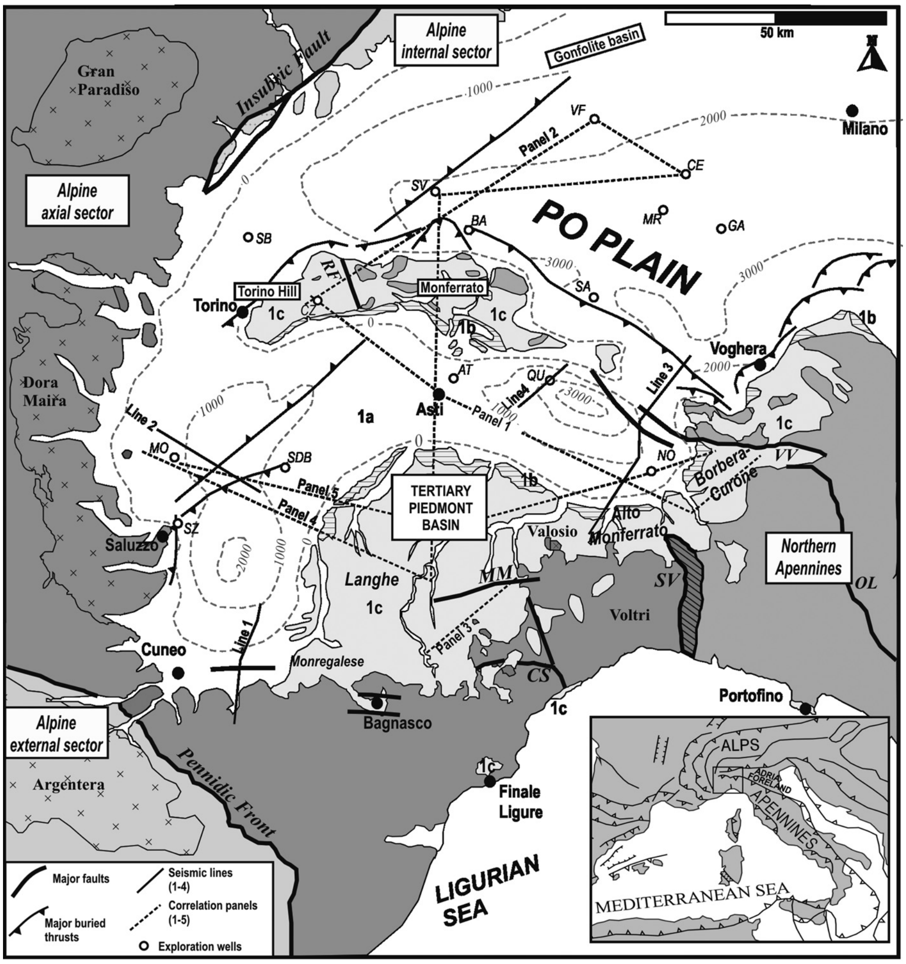


Fig. 1 - Geological sketch map of the Alps-Apennines junction area (after CNR 1983) and dataset shown in this paper. The thin black lines are traces of seismic lines (L1-L4), the dashed lines are the stratigraphic panels (Panels 1 to 5). The dashed grey lines are isobath (m) of the base of the Pliocene. 1a) Pliocene to Holocene; 1b) Messinian; 1c) Eocene to Miocene. White circles are exploration wells: AT, Asti; BA, Balzola; CE, Cerano; CZ, Cinzano; GA, Garlasco; MO, Moretta; MR, Mortara; NO, Novi Ligure; QU, Quargnento; SA, Sartirana; SB, San Benigno; SDB, Sommariva del Bosco; SV, Sali Vercellese; SZ Saluzzo; VF, Villafortuna.

of partially-independent depositional sectors are classically identified on the basis of the stratigraphy of the outcropping upper Eocene to Miocene strata: the Tertiary Piedmont Basin to the south and the Torino Hill and Monferrato to the north. As shown by the regional geological map of Fig. 1, the present relationships between the northern and southern outcropping belts are masked by the Pliocene to Holocene deposits of the Savigliano and Alessandria basins to the south and of the Po Plain to the north.

The main purpose of this paper is to attempt a regional reconstruction in order to correlate these different outcropping belts on the basis of new outcrop (geologic mapping, measured sections, biostratigraphic analyses) and subsurface (seismic profiles, logged exploration wells, bottom cores) stratigraphic and structural data. The rationale of this paper was based on the possibility of deciphering the evolution of the Alps-Apennines junction area through the detailed analysis of its sedimentary record using sequence- and seismic-stratigraphy in order to establish the timing of the major tectonic basin modification phases.

The stratigraphic and depositional history illustrated and discussed in this paper is largely based on unpublished data collected through several field campaigns and subsurface studies in the last 15 years, part of Eni R&D Projects and also used for internal field seminars. These pieces of information are here integrated with published outstanding stratigraphic syntheses (Mutti et al. 2002; Gelati & Gnaccolini 2003 with therein references) believed to be fundamental in the Tertiary Piedmont Basin. Furthermore, the importance of other papers dealing with more local datasets is acknowledged regarding the western sector (e.g. Gelati & Gnaccolini 1996), the central-eastern sector (Mutti et al. 1995), the eastern sector of Tertiary Piedmont Basin (e.g. Ghibaudo et al. 1985; Cavanna et al. 1989) and the Monferrato - Torino Hill (Dela Pierre et al. 2002a).

In detail, the subsurface data set used here consists of a grid of seismic lines variably crosscutting the Alps-Apennines junction (see also Mosca 2006 and Mosca et al. 2009 for further lines and details) and of a number of deep exploration wells (Fig. 1). According to seismic-stratigraphy principles and using the calibration provided by wireline-logs and biostratigraphy, the upper Eocene to Miocene sedimentary succession has been subdivided into a number of basinwide unconformity-bounded units (Figs 2 and 3), recording major phases of basin modification and in turn consisting of component sequences bounded by minor unconformi-

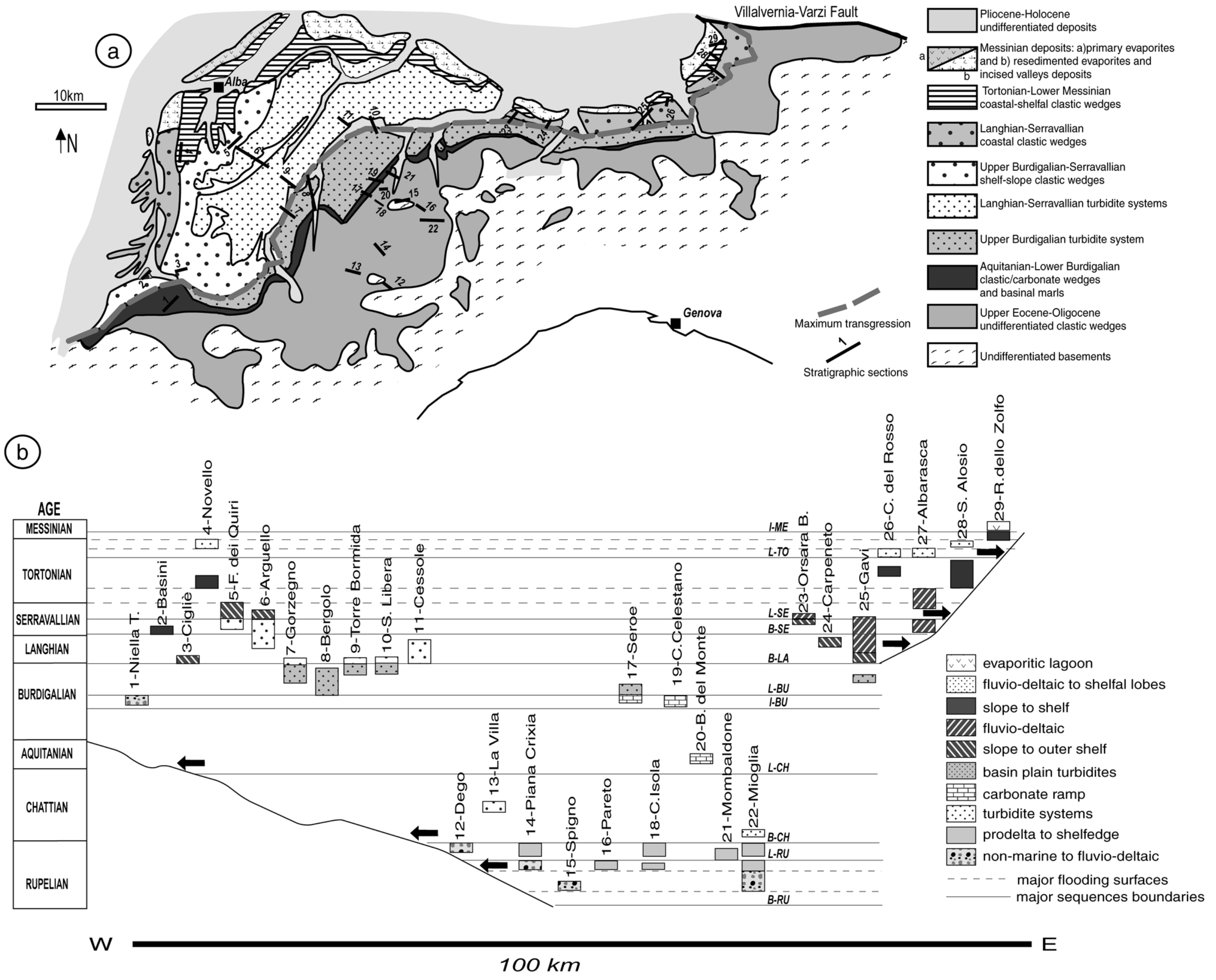


Fig. 2 - a) Simplified geological map of Tertiary Piedmont Basin showing the main lithofacies assemblages and the location of measured and sampled sections. The Upper Burdigalian basinwide turbidite system records the maximum accommodation affecting the basin, separating the overall transgressive Priabonian-Burdigalian sequence set from the Langhian-Messinian overall regressive sequence set. b) Stratigraphic scheme showing age and facies of the stratigraphic sections. Coastal onlap, major sequence boundaries and marine flooding surfaces are also indicated. Unconformities (from bottom to top): B-RU, base Rupelian; L-RU, late Rupelian; B-CH, base Chattian; L-CH, latest Chattian; I-BU, intra-Burdigalian; L-BU, late Burdigalian; B-LA, base Langhian; B-SE, base Serravallian; L-SE, late Serravallian; L-TO, late Tortonian; I-ME, intra-Messinian.

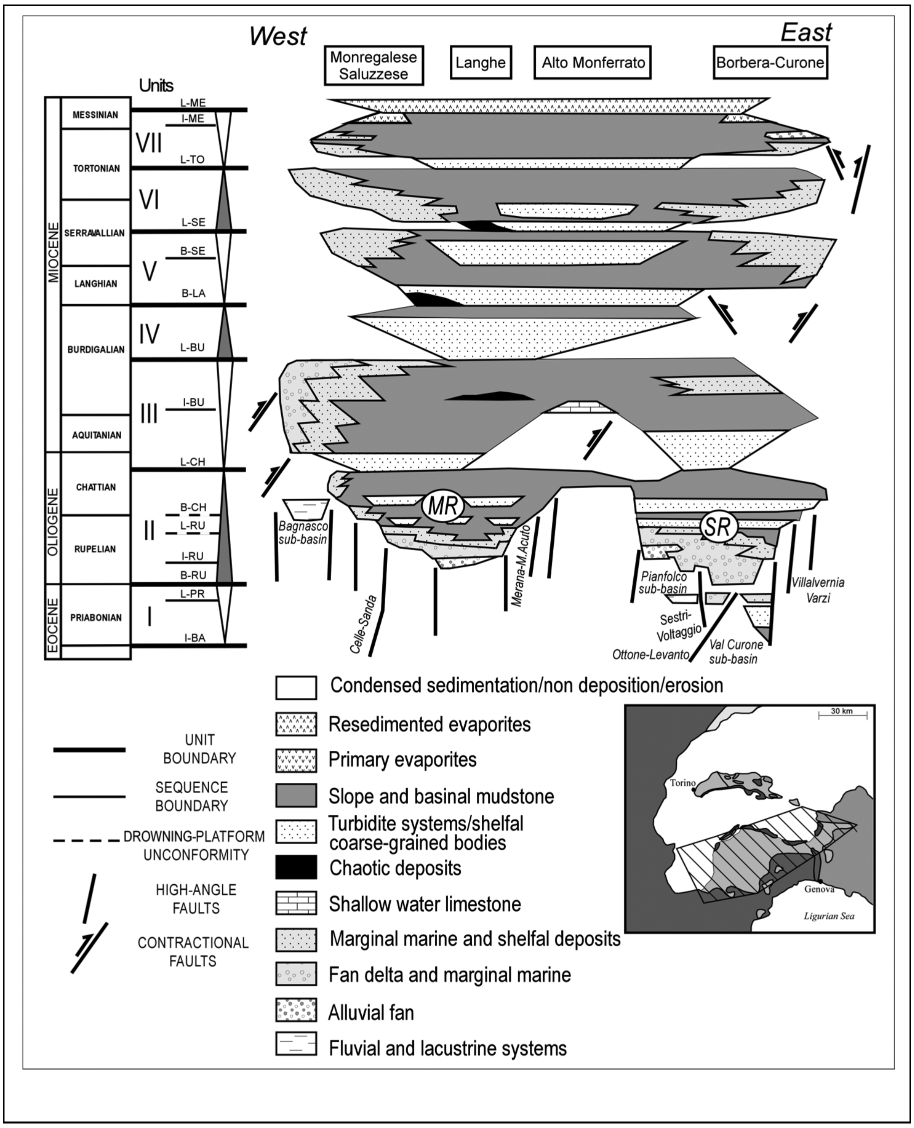


Fig. 3 - Wheeler diagram showing the stratigraphic framework of Tertiary Piedmont Basin: unconformity-bounded stratigraphic units, minor sequence boundaries, major syndepositional tectonic elements and gross facies distribution are shown. MR, Molare-Rocchetta Basin; SR, Savignone-Ranzano Basin. Unconformities (from bottom to top): I-BA, intra-Bartonian; L-PR, late Priabonian; B-RU, base Rupelian; I-RU, intra-Rupelian; L-RU, late Rupelian; B-CH, base Chattian; L-CH, latest Chattian; I-BU, intra-Burdigalian; L-BU, late Burdigalian; B-LA, base Langhian; B-SE, base Serravallian; L-SE, late Serravallian; L-TO, late Tortonian; I-ME, intra-Messinian; L-ME, late Messinian.

ties whose age was defined from outcrop literature data, integrated by new biostratigraphic analyses of well and outcrop samples (Fig. 2). This approach permitted to subdivide the basin-fill through the hierarchization of the depositional sequences, based upon the regional or local meaning of their bounding surfaces. The major bounding surfaces resulted to be driven by major changes in basin size and configuration, generated by phases of tectonic modification; they can be therefore considered the boundaries of allostratigraphic units, recognizable over the whole Alps-Apennines junction area. The minor sequence boundaries, on the contrary, are characterized by marginal unconformities passing basinward into correlative conformity surfaces.

The biostratigraphic analyses on outcrops involved foraminifera, nannofossils and palynomorphs; the original target was to establish a palynozonation, based on dinoflagellate cysts, valid for the North Italian region; subsequent studies integrated this scheme with central and southern Italy sectors, proving its overall validity for the Mediterranean area.

A total of 29 measured sections, where about 450 samples were taken, have been fully analysed using planktonic foraminifera, calcareous nannoplancton and dinoflagellate cysts (Tab. 1 and Fig. 2). The dinoflagellate cysts proved to be continuously present, and their occurrences have been correlated with the standard Foraminifera and Nannofossil Zonations; moreover, their relationships with miospores permitted to infer some paleoenvironmental considerations in the Oligocene sections (Tab. 1).

Tab. 2 provides a key for comparing the stratigraphic subdivisions proposed in this paper with those adopted by the regional syntheses of Mutti et al. (1995; 2002) and Gelati & Gnaccolini (2003).

Regional tectonic setting

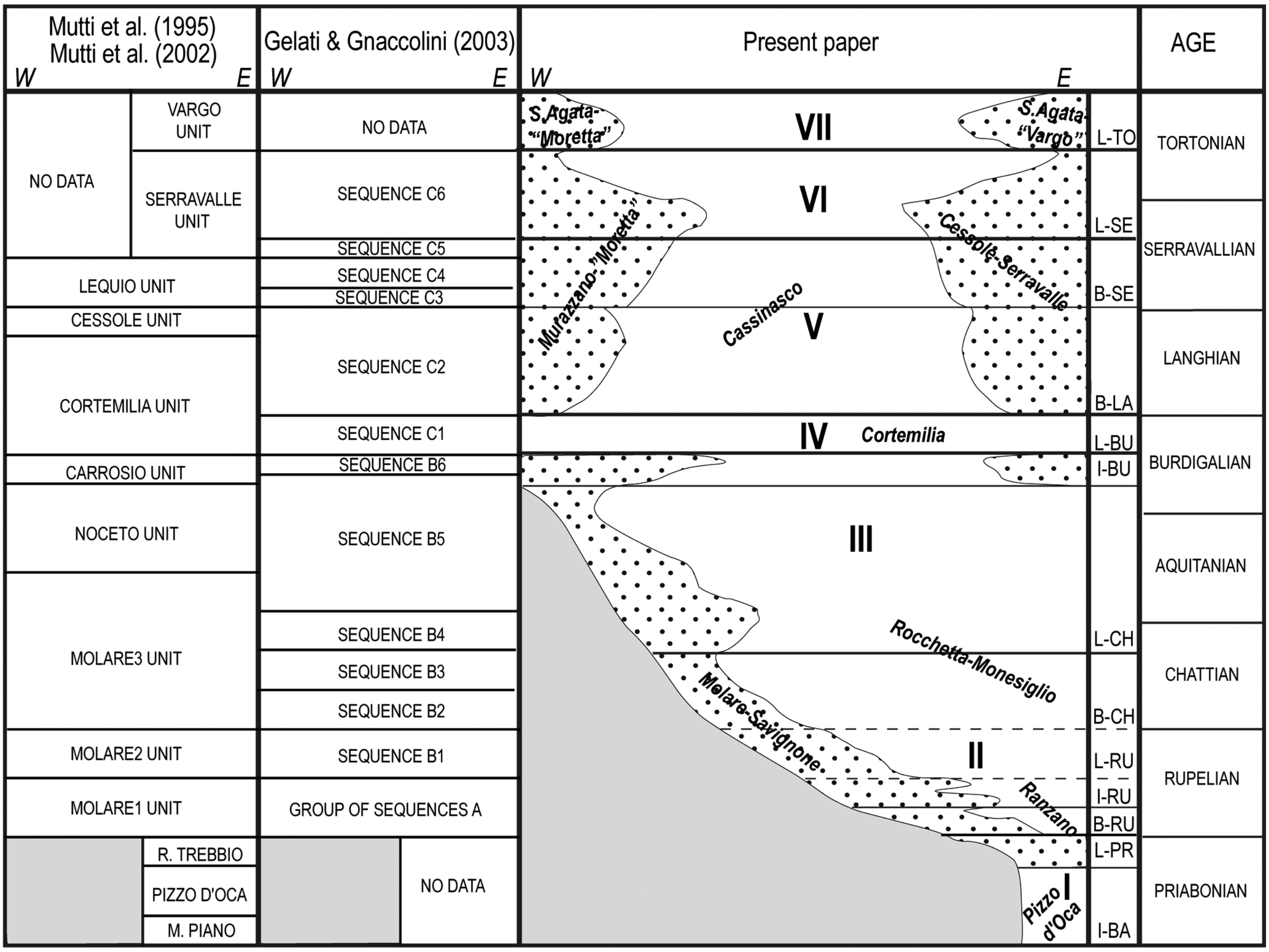
The Alps-Apennines junction is the result of complex kinematics related to the Europe-Adria continental collision (e.g. Roure et al. 1996; Mosca et al.

Section	Location	Age	Biozone	Nannozone	Palynozone	Depositional environment
1	Niella Tanaro	Burdigalian	(M2) N5	NN2 (CN2)	*S. conerae c*	Delta front to prodelta
2	Basini	E. Serravallian	(M7) N11	NN5-6 (CN5a)	*Apteodinium spp.*	Prodelta to delta front
3	Ciglië	E. Langhian	(M5b) N8	NN4 (CN3)	*P. 'striatogranulosum'*	Slope to shelf
4	Novello	Tortonian	(M12) N15 (M14)- N17	NN9 (CN7) – NN11a (CN9a)	*M. 'robustum'*	Prodelta
5	Fosso dei Quiri	L. Serravallian	(M9b-10) N12-13	NN6-7 (CN5)	*A. andalousiensis – C. 'perforocresta'*	Base-of-slope
6	Arguello	L. Langhian – Serravallian	(M6) N9 – (M9b) N12	NN5 (CN4) – NN6 (CN5a)	*C. 'powelli' – A. andalousiensis*	Turbidite lobes
7	Gorzegno	L. Burdigalian - E. Langhian	(M5) N8	NN4 (CN3)	*C. aubryae – P. 'striatogranulosum'*	Base-of-slope
8	Bergolo	L. Burdigalian	(M2-5a) N5-N8	NN3-NN4 (CN2-CN3)	*S. conerae c – C. aubryae*	Basin plain
9	Torre Bormida	L. Burdigalian - E. Langhian	(M5) N8	NN4 (CN3)	*P. 'striatogranulosum'*	Basin plain to turbidite lobes
10	Santa Libera	L. Burdigalian - E. Langhian	(M5) N8	NN4 (CN3)	*P. 'striatogranulosum'*	Basin plain
11	Cessole	Langhian	(M5b-6) N8-9	NN4-5 (CN3-4)	*P. 'striatogranulosum' – C. 'powelli'*	Basin plain
12	Dego	L. Rupelian	NP21a	Not studied	*H. pusillum a*	Lagoon / bay-fill
13	La Villa	Chattian	NP22	Not studied	*H. pusillum*	Intraslope turbidites
14	Piana Crixia	Rupelian	NP21a	Not studied	*C. lobospinosum – H. pusillum a*	Delta front to prodelta
15	Spigno	E. Rupelian	cf. NP19	Not studied	*W. gochtii*	Delta front to shelf
16	Pareto	E. Rupelian	cf. P20	Not studied	*C. lobospinosum*	Shelf
17	Serole	Burdigalian	(M2-M4) N5-N7	NN2-4 (CN1-3)	*S. conerae c*	Carbonate ramp to basin plain turbidites
18	Cappella dell'isola	Rupelian	cf. P20-p21a	Not studied	*C. lobospinosum – H. pusillum a*	Shelf
19	C. Celestano	Burdigalian	(M2) N5	NN2 (CN1)	*S. conerae c*	Carbonate ramp
20	Bric del Monte	Aquitanian	(M1) N4	NN2 (CN1)	*S. conerae a*	Carbonate ramp
21	Mombaldone	U. Rupelian	P21a	Not Studied	*H. pusillum a*	Prodelta to shelfedge
22	Mioglia	Rupelian- E. Chattian	cf. P19 – P21b	Not Studied	*W. gochtii – H. pusillum a*	From lagoon to intraslope turbidites
23	Orsara Bormida	Serravallian	(M10) N12	NN6 (CN5a)	*A. andalousiensis*	Prodelta
24	Carpeneto	Langhian	(M6) N9	NN5 (CN4)	*C. 'powelli'*	Prodelta
25	Gavi	L. Burdigalian - Serravallian	(M5a-M9) N8-N12	NN4-NN6 (CN3-CN5a)	*C. aubryae – A. andalousiensis a*	From basin plain to delta front
26	Ca' del Rosso	Tortonian	(M12-M14) N15-N17	NN9-NN11a– (CN7-CN9a)	*M. 'robustum'*	Prodelta to delta front
27	Albarasca	Serravallian – Tortonian	(M7-M14) N11-N17	NN5-NN11a- (CN4-CN9a)	*Apteodinium spp. – M. 'robustum'*	Prodelta to delta front
28	S. Alosio	Tortonian	(M11-M14) N14-N17	NN8-NN11a– (CN6-CN9a)	*M. 'robustum'*	Shelfedge to shoreface
29	Ripa dello Zolfo	L. Tortonian – Messianian	(M14) N17	NN11 (CN9)	*M. 'robustum'*	Shelf to evaporitic lagoon

Tab. 1 - Summary table of the main results of the stratigraphic analyses. For each section are reported locality and code, lithostratigraphic units, age, biozones, nannozones, palynozones and depositional environments.

2009). In the present regional configuration, metamorphic units of the Alpine axial sector are juxtaposed to non-metamorphic Ligurian units and Southalpine belts; they all are accreted on the same Adria foreland along the Monferrato fronts (see line 3 of Fig. 4). The features and timing of the major structural elements affecting the Alps-Apennines junction, briefly summarized in this chapter, are described in detail in Mosca et al. (2009), to which the reader is referred for further information and regional geodynamic implications.

The internal boundary of the Alpine axial sector has been traced from its present exposure (Insubric Fault) until the Saluzzo area (Line 2 in Fig. 4). Eastwards, it continues within a WSW-ENE trending, 100 km-long transfer zone, running between the present Monferrato to the North and the Langhe region to the South, passing in the upper Curone Valley and merging at its easternmost prosecution in the Ottone-Levanto Fault and its buried portion (Line 3 in Fig. 4) (Mosca et al. 2009). Within the southern part of the Alpine axial sector, the Celle-Sanda Fault system (Fig. 1) and its subsurface prosecution (Line 1 in Fig. 4) is the result of the interference of WSW-ENE and NNW-SSE trending faults which drove the juxtaposition of Briançonnais Units on the metaophiolitic Voltri Group. Another segment of this complex megashear zone is the Merana-Monteacuto en-echelon fault system. The Sestri-Voltaggio Fault juxtaposed in both surface and subsurface the internal Ligurian units on the nose of the Alpine axial sector. The Villalvernia-Varzi Fault system (Line 3 in Fig. 4) was a system of high-angle, mainly S-



Tab. 2 - Comparison key of the stratigraphic subdivisions proposed in this paper, permitting an easier identification of stratigraphic units through their comparison with those adopted by the regional syntheses of Mutti et al. (1995; 2002) and Gelati & Gnaccolini (2003). The major lithostratigraphic units (mainly based on Gelati & Gnaccolini 2003), meant as diachronous groups of depositional systems, are reported in a simplified stratigraphic chart in order to provide a link with the original meaning of the formations. Names in inverted commas refer to informal units, sometimes defined on the basis of exploration wells, where outcropping equivalents are not formally established. Legend for the stratigraphic chart: thick lines, major boundaries; thin lines, minor boundaries; dashed lines, drowning-platform unconformities; grey, hiatus; dotted belts, marginal wedges (from non-marine to upper slope); white background, intra-slope and basinal systems.

dipping faults accommodating the flexural tilting close to the southern edge of Adria and later reactivated as contractional during the Middle-Late Miocene outward propagation of the external Ligurian units.

The SE-verging Southalpine thrust belt was present to the north; its westernmost termination in the Torino hill area was active until the Burdigalian (Mosca 2006; Mosca et al. 2007; Mosca et al. 2009).

E- to N-verging Apenninic tectonics affected since the latest Oligocene the whole collisional system. Thrusting onto the Po Plain foredeep took place during the latest Oligocene in the Monferrato and only later, during the late Miocene, involved the Torino Hill region. Along the external Apenninic fronts a significant shortening and counter-clockwise rotation occurred, whilst in the Alps-Apennines junction a complex puzzling of nearly adjacent structures accommodated the intense crustal deformation.

Along the southern part of the Alpine arc, the amount of regional rotations suggested by paleomagnetic data could have been controlled by the activity of a crustal-scale mega-shear zone (Mosca et al. 2009) pre-dating the opening of the Liguro-Provençal basin. For this reason, paleogeographic maps discussed in this paper were not palinspastically restored. We proposed an informative 2D evolutionary sketch in Mosca et al. 2009, fig. 11, where a rough estimation of the regional shortening is suggested.

Within this tectonic framework, the outcrops of the Tertiary Piedmont Basin unconformable rest on a substratum composed of Alpine and Apenninic units. To the north, the outcrops of the Monferrato (Clari et al. 1995) rest on Apenninic units (Bonsignore et al. 1969). To the north-west, the Torino Hill consists of a siliciclastic succession exposed in form of antiform (Cita & Elter 1960; Bonsignore et al., 1969; Sturani 1973),

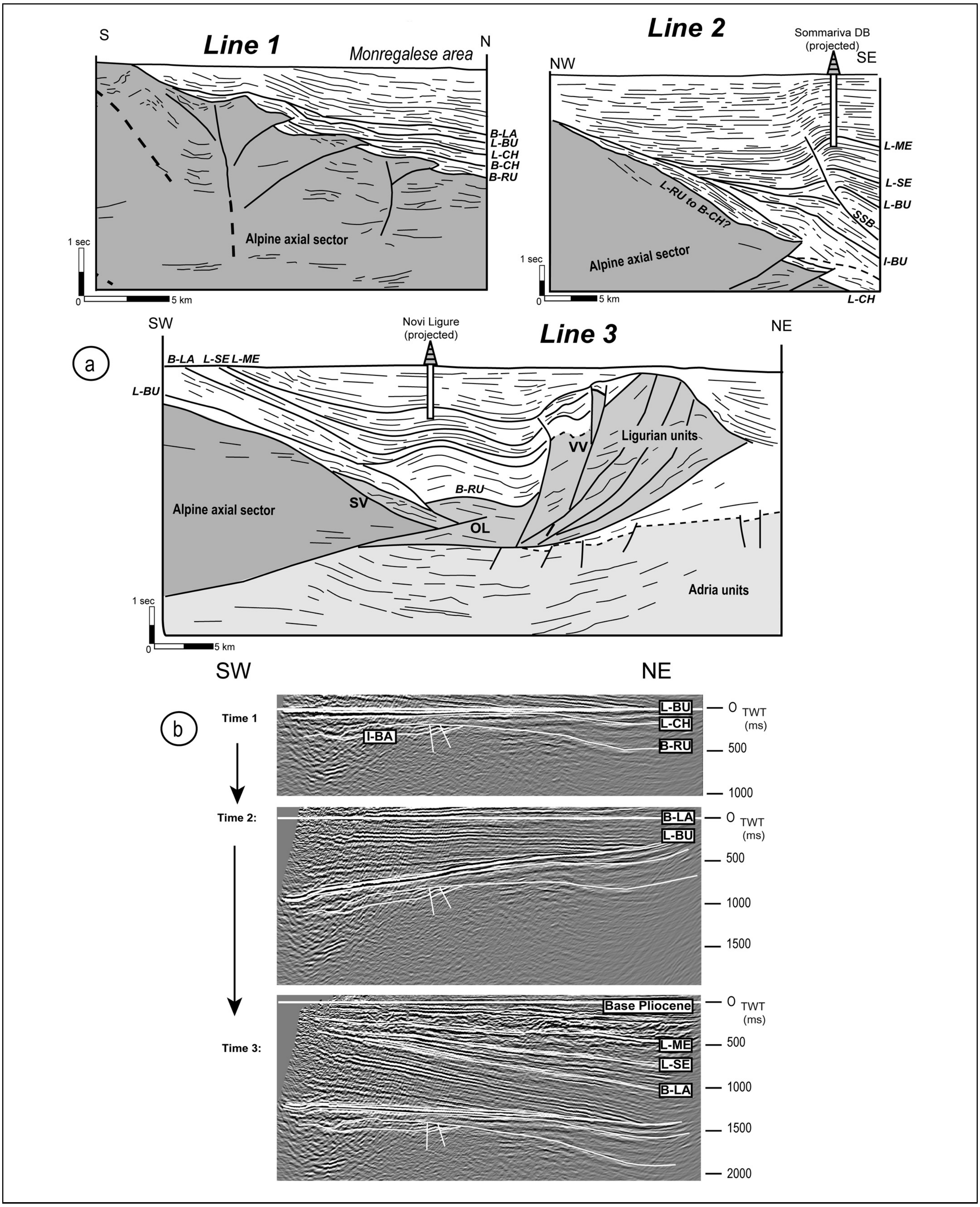


Fig. 4 - a) Seismic line drawings across different segments of Tertiary Piedmont Basin (see Fig. 1 for their location), showing the basin-fill organization in relation to the different substrata and the timing of major structural elements. Line 1 shows the western basin margin, Line 2 shows the south-western basin margin, Line 3 shows the south-eastern basin margin, the Monferrato Thrust-Fold-Belt and the major depocentre in between. b) Three successive seismic flattenings aimed at deciphering the tectono-sedimentary evolution of Tertiary Piedmont Basin in the Alto Monferrato (south-western portion of seismic line 3). The basin-forming and early basin-modification phases were controlled by a general accommodation increasing toward the structurally less elevated belt formed by the Ligurian Units, the Burdigalian space creation phase generated an asymmetric basin-fill wedging out northwards in the Monferrato area, the middle-late Miocene basin inversion phase gave way to the uplift of the previous depocentre. The ages of the unconformities are reported in Fig. 3. (From Mosca et al. 2009).

developed on a buried south-verging South-Alpine belt (Mosca 2006; Mosca et al. 2007; Mosca et al. 2009).

Unconformity-bounded stratigraphic units

The identification of the bounding surfaces was based on both outcrop and subsurface criteria. The outcrop criteria rely primarily on the recognition of angular stratal relationships associated with erosional and/or non-depositional relationships, often marked by biostratigraphic gaps and/or hiatuses, respectively. They include both unconformities generated by relative sea-level falls and drowning-platform unconformities framed into long-term relative sea-level rise time intervals. The former are associated to phases of regional space subtraction generally due to low or negative subsidence and often expressed by forced regression wedges at the basin margins. The latter are associated with major space-creation phases due to increasing rates of regional subsidence and expressed by the downwarping of basin margins. This approach, not based on *a priori* models but rather relying upon objective data including the specific structural styles proper to each basin or portions of them, is believed to be the only able to permit the proper use of sequence stratigraphy principles in tectonically active basins (Mutti 1990; Vail et al. 1991). The subsurface criteria include the same concepts, but the stratal relationships and the depositional geometries were primarily recognized on seismic profiles, while their facies and biostratigraphic calibration was ensured by exploration well data and by tracing the seismic bounding surfaces toward their outcropping counterparts.

The internal organization of the major unconformity-bounded units derives from the stacking of component depositional sequences, whose boundaries are identified where anomalous facies superpositions abruptly take place, permitting to infer the presence of discontinuities, locally associated with angular stratal relationships. In turn these sequences, whose physical and temporal scales fit the 3rd order ones, were built by 4^{th} order depositional sequences; 4^{th} order systems tract have been recognized where marine flooding surfaces, ravinement surfaces or marine condensed sections occur, characterized by a well-defined signature in terms of stacking pattern and accommodation/sediment supply ratios.

The latero-vertical organization of the units identified in this paper is discussed in the following paragraphs and illustrated through stratigraphic correlation panels and seismic profiles, connecting the outcrops to their corresponding subsurface counterparts masked by Pliocene to Holocene deposits. Facies and geometry of these units permitted the reconstruction of the paleogeography of the investigated area. A set of paleogeographic sketch maps (Fig. 5) has been drawn in order to link facies and stratigraphy to the regional tectonic evolution of whole area hosting the Alps-Apennines junction. This is the only way i) to define the relationships between the different substrata and the overlying sedimentary basins and ii) to attempt a correlation between the different present outcrop belts within a regionally-coherent depositional realm.

Unit I (Priabonian)

Description. This unit comprises the Priabonian successions representing the oldest sediments discussed in this paper. Bounded at the base by a major regional unconformity of intra-Bartonian age (I-BA), the successions of the Unit I were mainly deposited and preserved in local basins, reported as the Pianfolco and Val Curone sub-basins in the scheme of Fig. 3.

The Pianfolco sub-basin consists a small fault-bounded depression lying over Alpine metaophiolitic units directly to the west of the Sestri-Voltaggio Zone, where it was filled by the Brecce di Costa Cravara and the Pianfolco Formations (Charrier et al. 1964; Franceschetti 1967; Lorenz 1969; Gnaccolini 1978a). The former consists of alluvial fan deposits whose gravels document Eocene exposure and erosion of HP metamorphic Alpine rocks, the latter is formed by fluvio-lacustrine facies.

To the east of the Sestri-Voltaggio Zone, the Val Curone sub-basin rests on Ligurian units (eastern sector of Panel 1 in Fig. 6) and shows an overall regressive stacking pattern. The lowermost depositional unit of this basin is represented by the Monte Piano mudstones and the quartz-feldspathic arenites of the Pizzo d'Oca sandstones (Mutti et al. 1995). In turn, these deposits are unconformably overlain, above the late Priabonian (L-PR) sequence boundary, by the Rio Trebbio unit that consists of marginal marine to shelfal sandstones and siltstones (Mutti et al. 1995; Mutti et al. 2002). An incised valley fill is documented (Cavanna et al. 1989), whose base shows the erosional truncation of the underlying quartz-feldspathic turbidites.

Deposits of the Unit I in the Torino Hill area are represented by mudstones, siltstones and fine-grained sandstones (Figs 7 and 8), whilst in the Monferrato mudstones prevailed (Clari et al. 1995).

To the north, volcanics and volcanoclastics occurred in small extensional basins over the Adria foreland (Fig. 7), coeval with a few tens of meters-thick mudstones deposited in the Southern Alps foredeep below the Gonfolite Group (Dalla et al. 1992).

Paleogeographic interpretation. The small depositional areas where the Priabonian successions occur are in relation to paleo-topographic depressions bounded

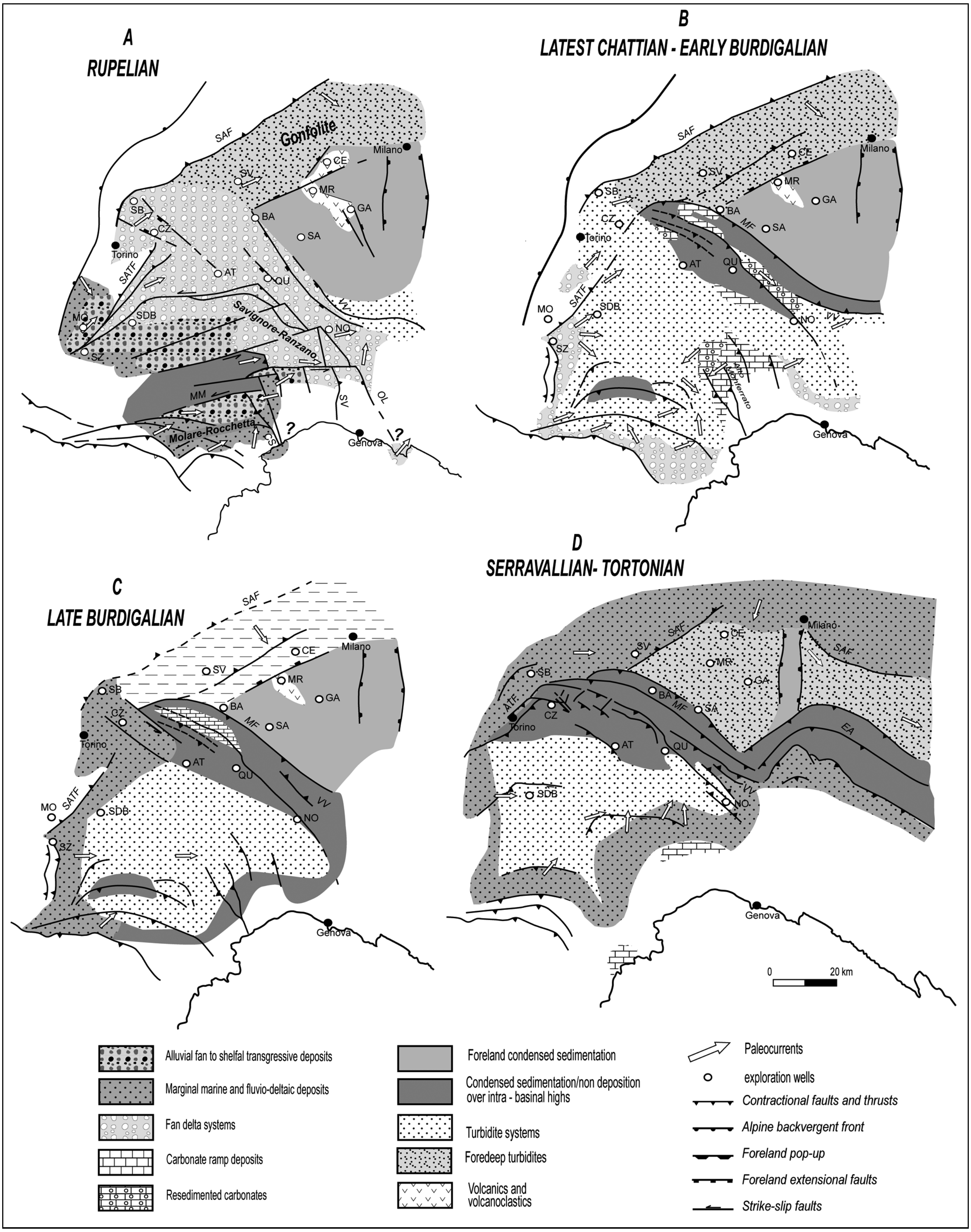


Fig. 5 - Regional paleogeographic sketch maps of the area surrounding the Alps-Apennines Junction, including: Alpine Axial Sector (Penninic Units), Ligurian Units, Southern Alps Thrust-Fold-Belt, Adria Foreland, Northern Apennines Thrust-Fold-Belt and related foredeep basins. The maps show four stratigraphic intervals marking the most significant changes in basin configuration, style and behaviour of major fault systems, and facies distribution: A) Rupelian, B) latest Chattian-Early Burdigalian, C) late Burdigalian, D) Serravallian-early Tortonian. ATF, Appenninic fronts of Torino Hill; CS, Celle-Sanda; OL, Ottone-Levanto; MF, Monferrato fronts; MM, Merana-Monte Acuto; SAF, Southalpine fronts; SATH, Southalpine fronts of Torino Hill; SV, Sestri Voltaggio; VV, Villavernia-Varzi. Acronyms of wells are reported in Fig. 1.

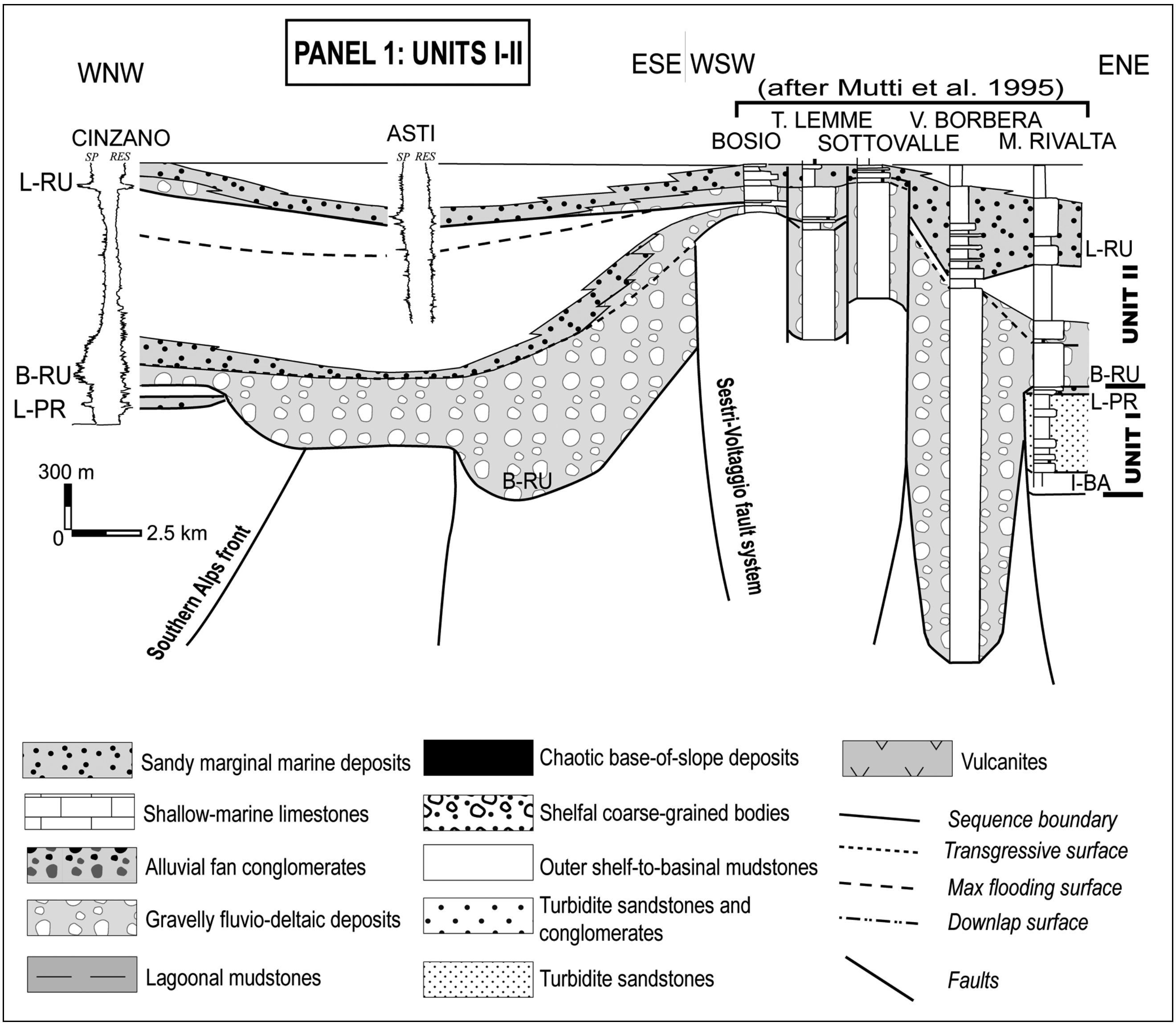


Fig. 6 - Stratigraphic correlation panel 1: correlation between measured outcrop sections (after Mutti et al. 1995) and biostratigraphically-calibrated wire-line well logs in Unit I and Unit II (p.p.). Deposits of the Unit I only occur in local fault-bounded depressions, whilst the Unit II depositional area marks a significant basin widening associated also to the inversion of some of the Priabonian border faults. Trace of the panel and location of exploration wells are shown in Fig. 1. Well-logs are Spontaneous Potential (on the left) and Induction (on the right).The ages of the unconformities are in Fig. 3.

by high-angle faults that may locally be inverted during Oligocene.

The Pianfolco sub-basin received very immature products of the erosion of surroundings high-relief zones, that gave origin to subaerial mass flow deposits of the Costa Cravara Fm. This area records a local sedimentary input at a time when the drainage system was not yet well established. The lacustrine coal-rich and fine-grained deposits of the Pianfolco Fm. are interpreted to record the basin centre facies association. In the flattened seismic profile on top of Fig. 4b, shot near the Cravara-Pianfolco sub-basin, the faulted high-amplitude reflections truncated by the Oligocene sequence set are probably originated by the strong acoustic impedance contrast between low-density coal deposits and high-velocity basement rocks and conglomerates.

In the Val Curone area (Fig. 8) slope mudstones encase quartz-feldspathic turbidite systems, recording an intra-slope basin. An incised valley fill cutting into these turbidites documents a high-magnitude relative sea-level fall of tectonic origin, as suggested also by an abrupt change in the composition, dominated by bioclastic detritus. Both the turbidites and shallow water deposits are in turn unconformably overlain by the Ranzano Fm. conglomerates, sandstones and mudstones deposited in a slope to base-of-slope setting.

On the southeast verging Southern Alps thrust of the Torino Hill (Cinzano well area) the Priabonian

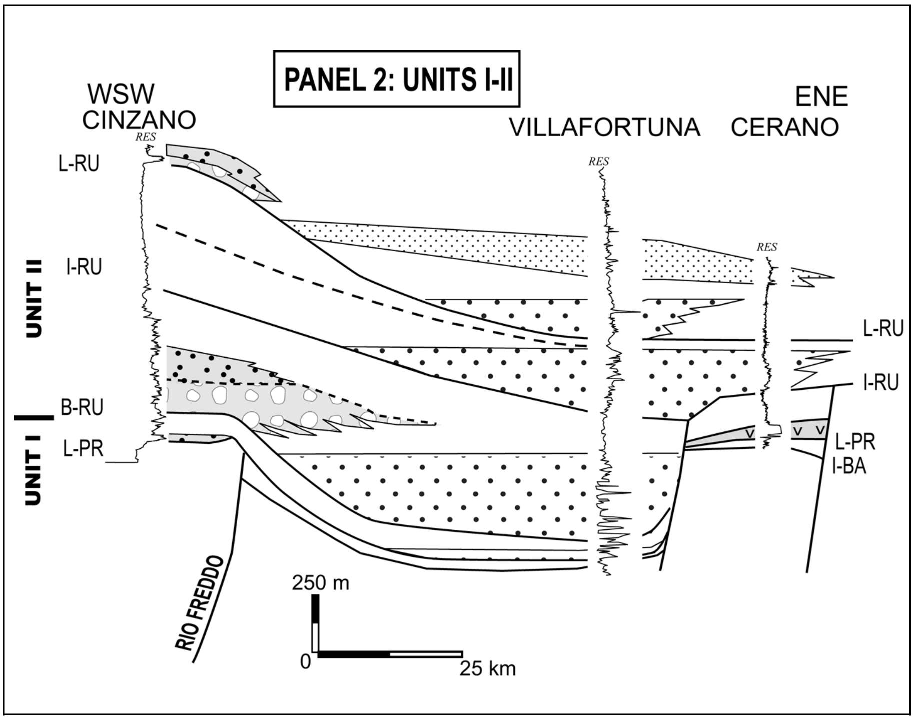


Fig. 7 - Stratigraphic correlation panel 2: correlation between biostratigraphically-calibrated wire-line well logs in Unit I and Unit II (p.p.). Deposits of the Unit I only occur in local fault-bounded depressions over both the Southern Alps Thrust-Fold-Belt and the Adria Foreland. During the Rupelian, Unit II in the Gonfolite foredeep basin was in physical continuity with the Torino Hill Southern Alps Thrust-Fold-Belt (Well Cinzano), suggesting that this latter area behaved at that time as the apex of the Southern Alps foredeep basin (cf. Fig. 4). Well-logs are Spontaneous Potential (on the left) and Induction (on the right).The ages of the unconformities are in Fig. 3. Legend in Fig. 6.

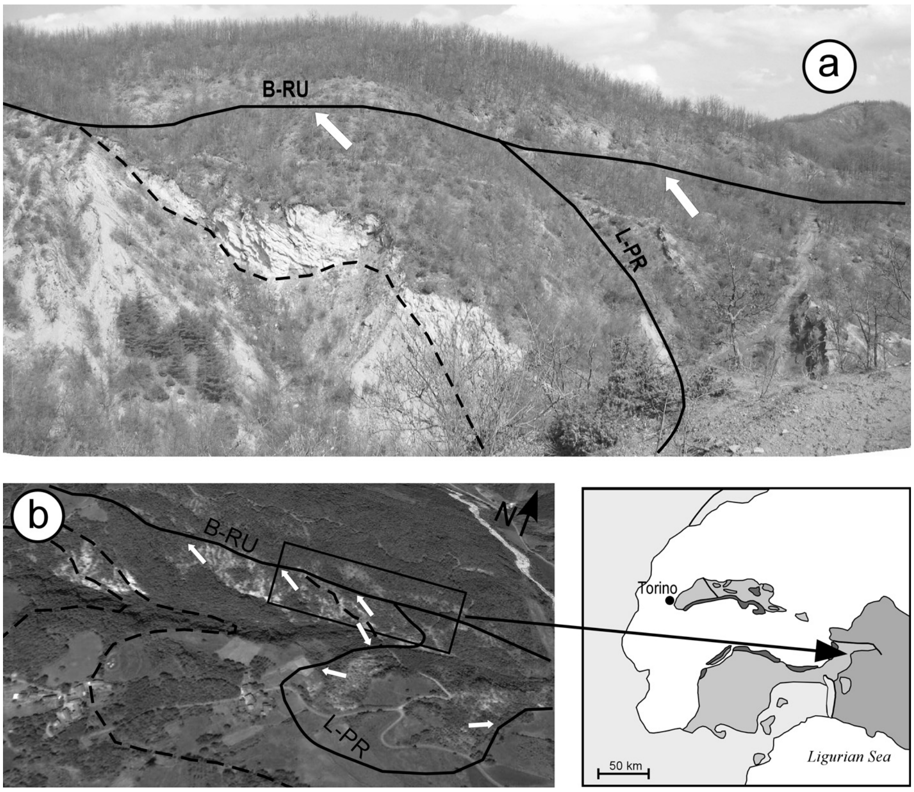


Fig. 8 - (a) The outcrop expression of the Priabonian and Rupelian sequence boundaries (Units I and II) in the Val Curone Basin near San Sebastiano Curone (in the inset, (b) the geological interpretation of a Google Earth satellite image). Whitish quartz-feldspathic turbidite bodies (whose bases are marked by dashed lines) are cut by brown-reddish lithic sandstones infilling an uppermost Priabonian-lowermost Rupelian incised valley. Both these units are unconformably overlain by the grey-coloured lower Rupelian deposits of the Ranzano Fm.

mudstones and sandstones, owing to their upward transition to open marine mudstones, possibly record a shelfal environment close to the Southern Alps margin. At that time, the Monferrato was probably separated from the southern sub-basins by a very large area, a synsedimentary high corresponding to a peripheral bulge affected by regional transfer faults, in which no sedimentation or condensation seem to have taken place.

Unit II (Rupelian-upper Chattian p.p.)

Description. This unit, consisting of Rupelian to upper Chattian sediments lying over a major sequence boundary of base Rupelian age (B-RU), is characterized by an overall transgressive stacking pattern.

Four main component sequences were identified, bounded by the base Rupelian (B-RU), the intra-Rupelian (I-RU), the late Rupelian (L-RU) and the base-

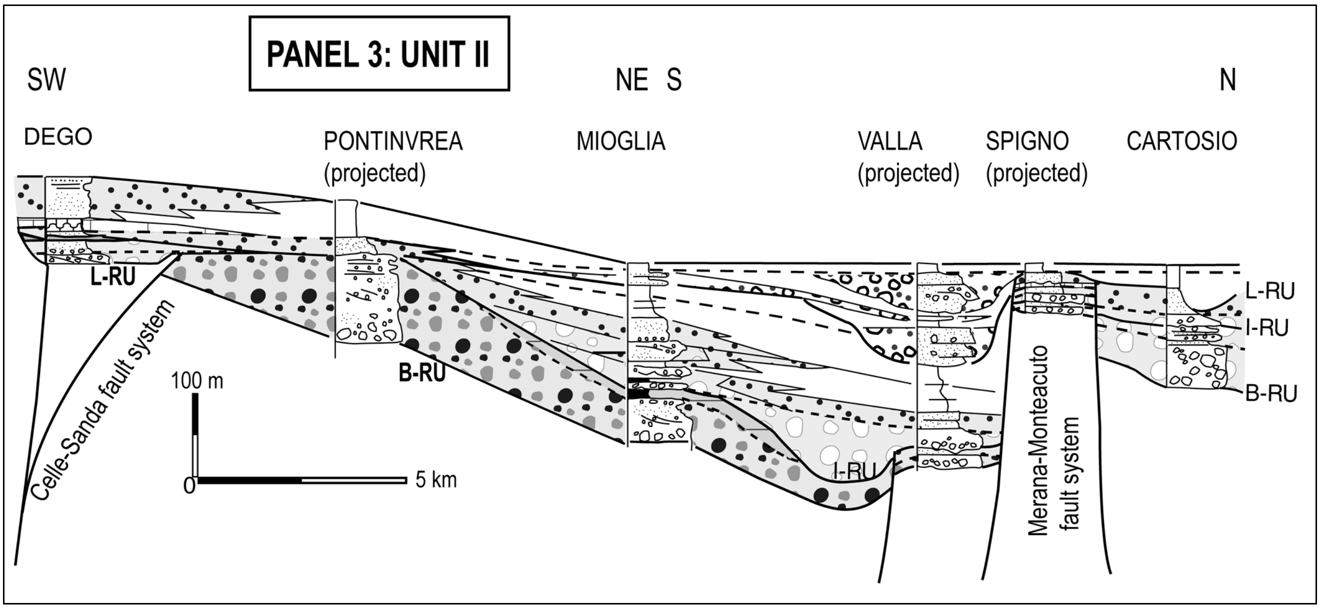


Fig. 9 - Stratigraphic correlation panel 3 (see location in Fig. 1): correlation between biostratigraphically-calibrated measured outcrop sections in Unit II (p.p.), showing a strong tectonic control on sub-basins configuration and facies distribution. The late Rupelian sequence set marks an abrupt marginward shift of the facies belts due to the Late Rupelian Drowning-Platform Unconformity. The ages of the unconformities are in Fig. 3. Legend in Fig. 6.

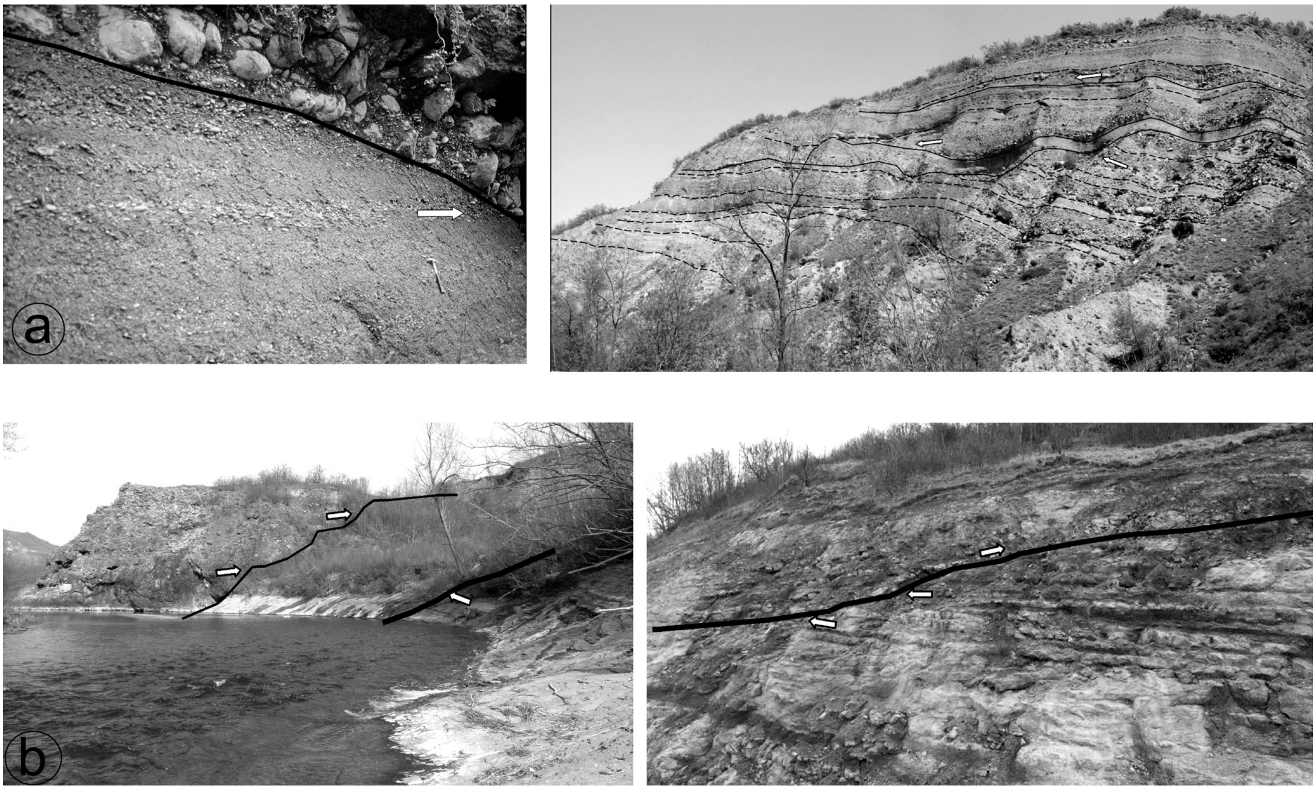


Fig. 10 - Rupelian shallow water deposits in the Molare-Rocchetta and Savignone-Ranzano sub-basins (Unit II). a) The early Rupelian sequence set. From left to right (i.e., from West to East), the intra-Rupelian sequence boundary near Spigno Monferrato, separating gravel beach deposits from the overlying wave-reworked top of an incised valley-fill; Gilbert-delta gravel-rich deposits near Carrosio, showing high-angle foresets prograding basinward (i.e., eastwards) and internal unconformities in the topsets; b) Late Rupelian sequence boundaries to the North of Spigno Monferrato. From left to right (i.e., from North to South), shelfal siltstones truncated by a subaqueous erosional unconformity overlain by slope mudstones in turn incised by a submarine canyon infilled by an ophiolitic breccia; delta front and prodelta sandstones cut by a subaqueous erosional unconformity onlapped by shelfal mudstones (local expression of a drowning-platform unconformity).

Chattian (B-CH) sequence boundaries. The successions of this unit were mainly accommodated in two major structurally-controlled depressions, here identified as the Molare-Rocchetta and Savignone-Ranzano basins (Fig. 3 and Fig. 5A).

The Molare-Rocchetta basin groups a number of sub-basins developed over the Alpine axial sector in the region extending from the Alto Monferrato to the Monregalese-Saluzzese. In these sectors (Fig. 9), the first sequence (between the B-RU and I-RU surfaces) consists of alluvial fan deposits non-conformably overlying the pre-Cenozoic substratum. The alluvial fan conglomerates, fed mainly from the south and the south-west, deposited in sub-basins controlled at the southern edge by a major uplifted belt related to the Celle-Sanda Fault System (Line 1 in Fig. 4a, see also Fig. 15). Towards the north, a set of high-angle en-echelon faults, the most representative of which is the Merana-Monteacuto Fault System (Mutti et al. 1995), fragmented the area. During the transgressive phase, foreshore gravels and sands occurred especially over structurally-high intrabasinal divides, bounding southward paralic protected environments (Fig. 9).

The deposits of the second sequence (between the I-RU and L-RU surfaces) unconformably overlie the older ones, showing erosional truncation of the underlying sequence and angular relationships, especially close to the basin margins and the synsedimentary highs (details in Fig. 10a on the left). Locally, the conglomeratic lower portion of the sequence was deposited only in the downthrown side of synsedimentary faults, permitting to define the occurrence of a non-depositional hiatus over the synsedimentary highs: structural highs bounded to the North these incised valley fill deposits, whose northward termination was controlled by abrupt lap out onto fault scarps. These sediments, locally fed from east to west, are confined in a local embayment bounded southwards by the depositional relief of the previous alluvial fans. These deposits are overlain by a complex alternation of paralic, marginal marine and shelfal facies, organized in an overall transgressive stacking pattern but punctuated by both erosional and depositional high-frequency regressions. In the first phases, structural highs were sites of sedimentation of wave-worked gravels (Fig. 9) and, occasionally, of thin coral-algal limestones (Gnaccolini 1978b) marking phases of maximum marine ingression. Elongated and protected synsedimentary lows hosted fluvio-deltaic systems showing, during high accommodation time intervals, evidences of tidal modification. In more open settings, fluvio-deltaic deposits dominated by fluvial underflows occur (Mutti et al. 1995). The paleocurrents of these two lower sequences are extremely variable (Fig. 5a), according to the structural pattern which probably was recorded by a highly irregular shoreline. However, the overall increasing in accommodation through time, nevertheless punctuated by minor sequence boundaries, determined a gradual change toward fully marine conditions and a less irregular shoreline.

The third sequence (between the L-RU and B-CH surfaces) is bounded by a drowning-platform unconformity and followed by a dramatic marginward shift, toward the south and the west, of the fluvio-deltaic systems (Fig. 9), that were replaced basinward by shelfal gravity flow-dominated coarse-grained bodies encased in the marine siltstones and mudstones of the Rocchetta-Monesiglio Fm. (Gelati et al. in press a, b). This major change is recorded by at least two 4th order sequences framed into an overall deepening-upward stacking pattern. The coarse-grained bodies of the third sequence are strongly confined, with axial paleocurrents mainly from WSW to ENE. A variety of different types of unconformable relationships occurs in the area in relation to such a change: marine onlap occurs in both shelfal and deep-water gravity flow bodies in relation to their termination against underlying tilted sequences: upcurrent (e.g., Valla System), and lateral (e.g., Piana Crixia System) terminations are common (Cazzola et al. 1981; Mutti et al. 1995). To the north of the Merana-Monteacuto Fault System, a major intrabasinal high was still present (Fig. 5a), characterized by an outer shelf to slope sedimentation, locally incised by mud-filled multiple scars and submarine canyons (Fig. 10b). Locally, slump scars were able to cut into the lower Rupelian downwarped shallow marine coarse-grained deposits (see also Figs. 16 and 17 for further details).

The fourth sequence (between B-CH and L-CH surfaces) shows a further general deepening and a marked change in paleocurrent patterns, mainly from NW to SE (e.g. Cazzola et al. 1981, 1985; Cazzola & Fornaciari 1992), except in the southern basin margin where periodic sediment flux from the south and from the west was related to the deep water expression of fluvio-deltaic systems. The base-Chattian sequence boundary is normally expressed by conformable relationships with the underlying sequence in synsedimentary lows, while the marine onlap of coarse-grained turbidites toward the flanks testifies the reactivation of the coarse-grained input after a phase of basin modification. Frontal terminations (e.g., Cengio System, Bersezio et al. 2006) commonly occur in confined systems fed from the south-western basin margin, whilst lateral terminations (e.g., Budroni System, Cazzola & Fornaciari 1992) are common in confined systems fed from the north-west.

The Savignone-Ranzano basin developed east of the Molare-Rocchetta basin and extends to the north in the subsurface until the Monferrato and Torino Hill (Fig. 5a). In this basin (eastern sector of the Panel 1 in

Fig. 6), the first (between B-RU and I-RU surfaces) and second (between I-RU and L-RU surfaces) sequences of the Unit II comprise alluvial fan deposits to the west, changing eastwards into fan-delta systems (Fig.10a on the right) with main paleocurrents from west to east (Gnaccolini 1978a, 1982, 1995; Turco et al. 1994). Near the western margin, wave reworking was responsible for the redistribution of the finer, sandy materials to form a shoreface belt lateral to the major entry points. These sequences show a rapid eastwards stratigraphic expansion, accommodated by NNW-SSE oriented faults, downstepping basinward. Eastwards (Borbera-Curone area), the fan delta systems changed basinward into a toe-of-slope setting dominated by the repeated interfingering of slope mudstones, often with abundant chaotic bodies, and gravity flow sandstone and conglomeratic bodies (Cavanna et al. 1989). The third and fourth sequences (between L-RU and L-CH surfaces) consist mainly of sand-prone turbidites (Mutti et al. 2002) onlapping the former delta slope to the southwest and the paleo Villalvernia-Varzi fault scarp (Mosca 2006; Mosca et al. 2009) to the north.

Paleogeographic interpretation. The sedimentation appears to be the record of a transgression from the NE (Lorenz 1969) giving way to a SW-ward coastal encroachment (i.e., from the low-elevation Ligurian Units toward the structurally more elevated Penninic Units) that progressively flooded exposed portions of the Alpine Axial Zone (Fig. 4b). This depositional scenario is suggested by regional NE-wards paleocurrents, coupled with a progressive southwest-wards coastal onlap, and by the regional diachronism of both the continental and marginal marine facies (Molare and Savignone Fms. of literature) becoming progressively younger SW-wards (Line 1 in Fig. 4a and top line in Fig. 4b).

The WSW-ward paleocurrents occurring in the Mioglia area merely record, in our opinion, a local effect driven by an irregular shoreline due to variously intersecting morphostructural elements. It is suggested here that they are in relation to a WSW-ENE oriented bay confined from the open sea by the Merana-Monteacuto Fault System that during early Rupelian was plunging westwards.

In the Molare-Rocchetta basin, the Monregalese and its westward subsurface continuation (Line 1 in Fig. 4) hosted sub-basins bounded by high-angle faults and filled by continental to marginal marine successions (Gelati & Gnaccolini 1996). The outcropping continental Bagnasco sub-basin (Lorenz 1969) rests on Alpine units in correspondence of a flower structure (Mosca 2006; Mosca et al. 2009). In the Saluzzese, pensile basins developed over south-east verging Alpine thrusts and are often characterized by coastal wedges or an aggradational infilling (Line 2 of Fig. 4).

The Molare-Rocchetta basin developed in front of a W-E oriented transfer zone (highlighted by the western branch of the Celle-Sanda Fault System), interplaying with NNW-SSE oriented reverse faults (such as the eastern branches of the Celle-Sanda Fault System). Such an interplay of WSW-ENE and NNW-SSE trending synsedimentary faults is well documented in Forcella et al. (1999) in a wide area comprised between Celle, Spigno and Molare. To the north, high-angle faults showing a left-lateral en-echelon arrangement, such as the Merana-Monteacuto Fault System, are part of the regional transfer zone that affects the whole study area. The I-RU sequence boundary, showing local evidences of further reactivation of the fault-bounded structural highs, can be therefore attributed to a relative sea-level fall of tectonic origin.

The thin coral-algal limestones colonizing structural highs are interpreted, in the clastic-dominated setting adjacent to the Alpine axial zone, as marking phases of clastic starvation when the increasing rate of relative sea-level rise shifted south-wards the site of deposition of the fluvio-deltaic sand-prone belt, whereas its possible basinward extent could only affect the structural depressions *via* fluvial underflows.

The L-RU sequence boundary, showing as well local evidences of further movements of the fault-bounded structural highs, is interpreted to be in relation to a drowning-platform unconformity. A sudden deepening-upward is in fact recorded in most of the basin, sometimes associated with truncation and/or onlap relationships. The upper Rupelian deposits infill areas undergoing a greater accommodation rate and experiencing common instability along slopes undergoing tectonic oversteepening.

The confinement of coarse-grained bodies seems due to the interplay of NNW-SSE and WSW-ENE trending structures. Therefore, several local entry points were generated at the intersection between these fault systems. The paleocurrents of gravity flow deposits, mainly from WSW to ENE, suggest that the axial plunging of the Merana-Monteacuto Fault System underwent an inversion in the late Rupelian, due to the scissor-like behavior of these transfer faults.

The B-CH sequence boundary shows quite clear relationships with a reorganization of the local depocentres, as inferred by the new predominant sediment dispersion of turbidite bodies, mainly from the NW quadrants, i.e., parallel to the new basin axes, controlled by the NNW-SSE structural axis such as the eastern branches of the Celle-Sanda Fault System. Further evidences derive from both the geometry of the underlying tilted beds and the instability features (sliding and slumping, cfr. Gelati & Gnaccolini 1998) affecting the tectonically oversteepened slopes.

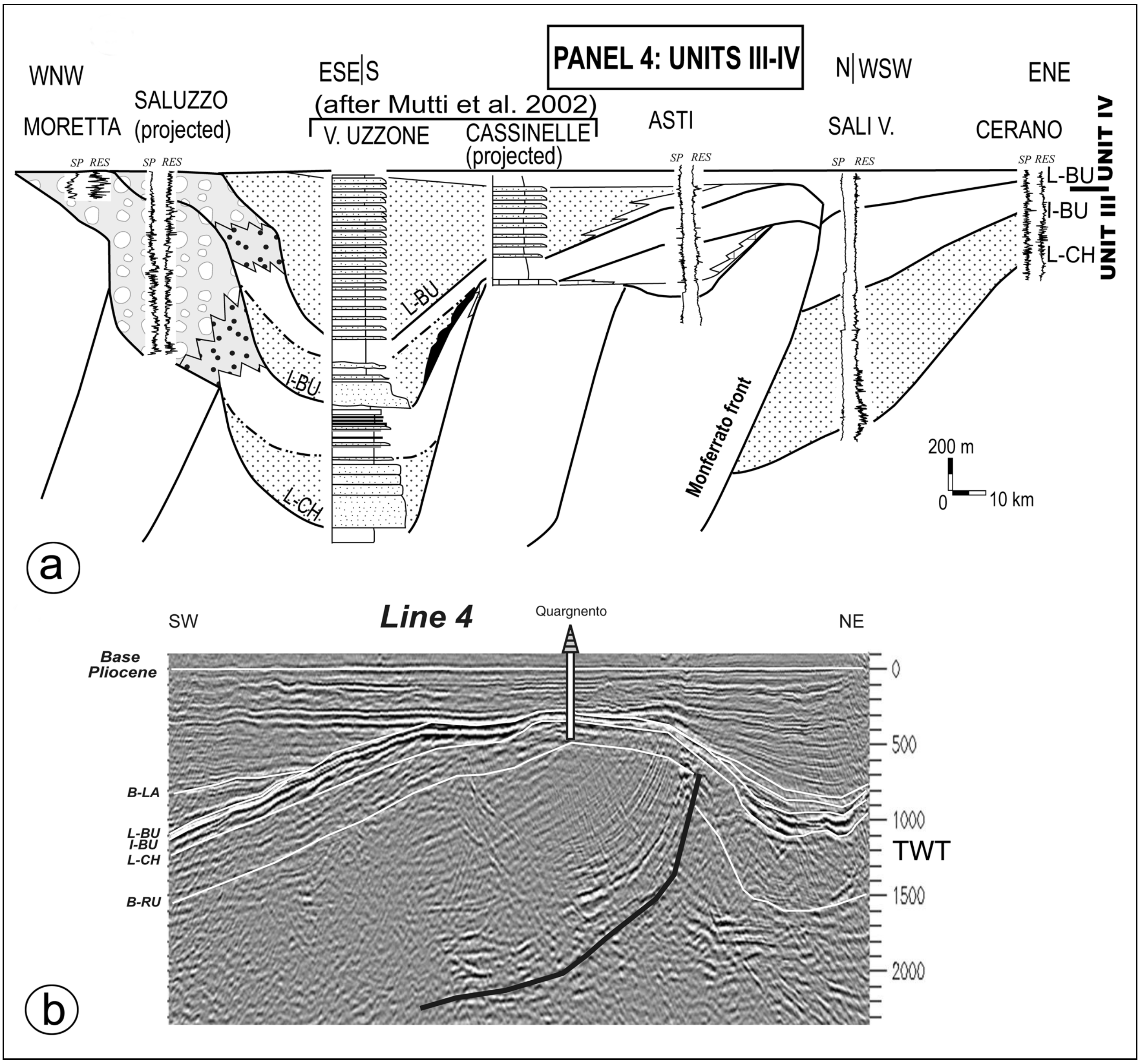


Fig. 11 - a) Stratigraphic correlation panel 4 (see location in Fig. 1): correlation between measured outcrop sections (after Mutti et al. 2002) and biostratigraphically-calibrated wire-line well logs in Unit III and Unit IV, showing that since this time the Tertiary Piedmont Basin behaved as a piggyback basin of the Po Plain Foredeep (cf. Fig. 4). Note that the shallowing-upward pulses in the uplifted western basin margin are replaced north-eastwards, where the rate of tectonic subsidence was much higher even around intrabasinal highs, by drowning-platform unconformities. Legend in Fig. 6. b) Seismic profile across an intra-basinal high showing lower Miocene high-amplitude, clinostratified carbonate platforms and ramps affected by the intra-Burdigalian and late Burdigalian drowning-platform unconformities. Well-logs are Spontaneous Potential (on the left) and Induction (on the right). The ages of the unconformities are in Fig. 3.

The separation between the Molare-Rocchetta and the Savignone-Ranzano basins can be identified to the west and to the north-east respectively of a major NNW-SSE structural divide near the Alto Monferrato (Fig. 1).

Both facies and structural data suggest that the Savignone-Ranzano basin, lying mainly over the Ligurian Units to the east of the Sestri-Voltaggio Zone, defined an area characterized by lower structural elevation and higher accommodation space. This depositional belt can be traced in the subsurface northwestwards, until the Monferrato area. Further westwards, in the present Torino Hill area, the deposits of the Unit II infill depocentres controlled by the Southern Alps fronts, implying that this area was likely to behave as a junction towards the apex of the time equivalent Gonfolite Lombarda (Gelati et al. 1988; Carrapa & Di Giulio 2001; Fantoni et al. 2004). The Gonfolite Lombarda is exposed in the Southern Alps foothills. Southwards, where it is buried below the Po Plain, it shows a dramatic stratigraphic expansion partly accommodated by a lower Oligocene wedge that is mainly missing in the northern outcropping belt (Dalla et al. 1992).

Unit III (uppermost Chattian- Burdigalian p.p.)

Description. This unit shows an overall regressive organization in the western clastic-prone basin margin of Monregalese and Saluzzese, (western sector of the Panel 4 of Fig. 11a). It consists of two component sequences separated by the intra-Burdigalian (I-BU) sequence boundary.

In the western depositional areas, the first sequence (between the L-CH and E-BU surfaces) consists of a turbidite system (the Noceto System, see Cazzola & Fornaciari 1992) with paleocurrents mainly toward SE, in turn overlain by siliceous deposits (C. Poggi Unit of Gelati & Gnaccolini 2003) and, in the westernmost sectors, downlapped by a thick gravel-rich alluvial fan to fan-delta unit prograding eastwards, i.e. the Saluzzo Conglomerate (Fig. 11a and Line 2 in Fig. 4; Mosca 2006). This body shows coastal onlap over tilted incised valley fill deposits of Unit II (Line 2 in Fig. 4) or directly over the pre-Cenozoic substratum (Line 1 in Fig. 4). Southwards, i.e., laterally to this fan delta body, incised valleys developed (see also Fig. 16), downcutting into upper Oligocene marginal marine deposits (Gelati & Gnaccolini 1996). The second sequence (between the I-BU and L-BU surfaces) was controlled by a further movement of the marginal structures in both the Saluzzese and Monregalese areas, which accelerated the progradation from the west of fluvio-deltaic prisms (Fig. 11a and Line 2 in Fig. 4) whose features (see also Fig. 16), framed into a forced regression, suggest that they were primarily built by catastrophic mouth bars generated by fluvial underflows (*sensu* Mutti et al 1996). In the upper part of the sequence, above the transgressive surface, these deposits are overlain by normal mouth bars rapidly changing upward to prodelta siltstones.

In the eastern depositional areas, the first sequence (between the L-CH and I-BU surfaces) consists of a turbidite system (Castagnola Fm.) fed from the southwest, overlain by siliceous deposits. The turbidites infill a ponded basin showing pronounced onlap in relation to an east-west oriented depression (Baruffini et

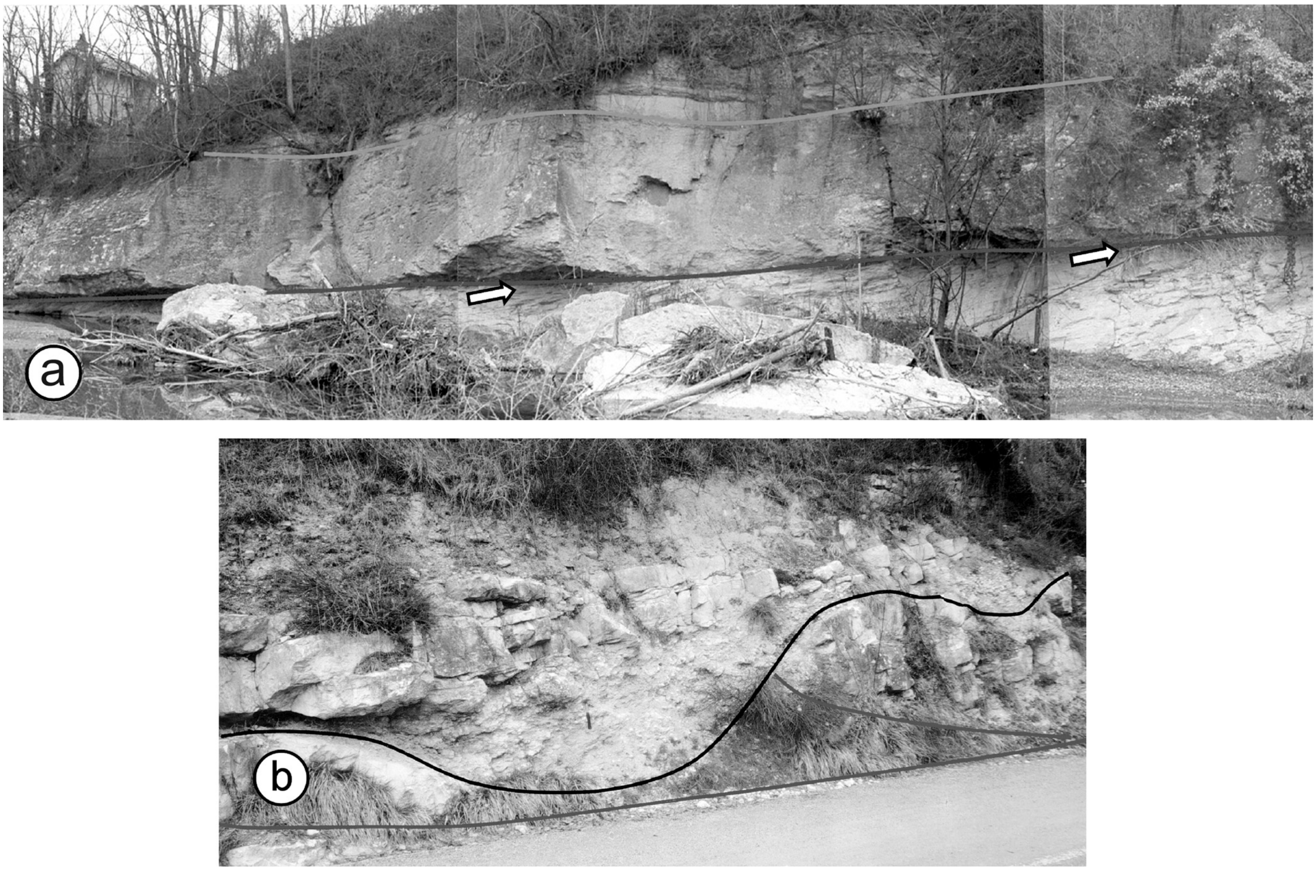


Fig. 12 - The outcrop expression of the lower Miocene shallow marine and deep-water carbonate deposits (Unit III) across the Alto Monferrato high: a) the Lower Burdigalian foramol carbonate platform outcropping along the Visone Creek, unconformably separated by deep-water upper Oligocene mudstones through the latest Chattian major sequence boundary, and topped by a glauconitic bed marking a sudden deepening (maximum flooding surface). b) The destabilization of the carbonate platform, including its deeper rhodalgal portion, near Roccaverano where slumped and resedimented limestones lie above the intra-Burdigalian drowning-platform unconformity; note the shear planes inside the chaotic body.

al. 1994; Felletti 2002, 2004). The second sequence (between the I-BU and L-BU surfaces) records the onset of a flood-dominated deltaic system (the Carrosio System of Mutti et al. 2002).

The eastern and western depositional areas were separated by the Alto Monferrato high (Fig. 5b), where the first sequence unconformably overlies tilted upper Oligocene mudstones (Fig. 12a). The erosional truncation, partly wave-cut but chiefly characterized by angular relationships with the underlying mudstones, is overlain by an overall transgressive foramol carbonate platform bounded at the top by a maximum flooding surface expressed by a glauconite-rich sandstone (D'Atri 1990, 1995; Piana et al. 1997). The carbonate platform changes basinward into a carbonate ramp, gently connecting the high with the adjacent basin to the west where local resedimented grainstones occurred at the toe of the slope (C. Mazzurini Unit of Gelati & Gnaccolini 1998). The second sequence is characterized by the tectonic destabilization of these deposits, which were accumulated in the base of slope region at the western toe of this major intrabasinal high. These deposits, onlapping eastwards onto the ramp facies, consist of resedimented glauconites overlain by slumped limestones and rhodolithic rudstones (Fig. 12b, Gelati & Gnaccolini 1998) giving way to a cannibalized succession characterized by an inverted stratigraphy with respect to the stacking of the sediments in the source area.

To the north, the deposits of the Unit II tend to thin-out in the Torino Hill and Monferrato areas. An incipient uplift of the Monferrato along north-verging thrusts (Fig. 5b) is recorded by the local development of small foramol to rhodalgal carbonate platforms rimming shallow highs, changing basinward and upward to lower Burdigalian shelf sediments (Bicchi et al. 2006). In the subsurface continuation of the Monferrato, carbonate ramps expressed by high amplitude clinoforms occur on the backlimb of the Quargnento structure, onlapped by high amplitude resedimented limestones belonging to the second sequence (Line 4 of Fig. 11b); in this figure it can also be noted that to the north-east of the Quargnento well a steeper gradient accommodated high amplitude aggradational reflectors suggesting deeper water reworked limestones similar to the outcropping resedimented rhodolithic rudstones in both the Monferrato (Falletti 1994) and the Langhe region (Gelati & Gnaccolini 1998).

In the Southern Alps foredeep, turbidites continued to fill the Gonfolite basin, encroaching southward over the foreland (eastern part of Panel 4 in Fig. 11a).

Paleogeographic interpretation. The deposition of this unit was controlled by a major change in the structural setting due to the north-westward propagation of the Apenninic thrusts. Since then, the Monferrato uplift provided a separation with the adjacent Gonfolite basin making therefore more difficult the communication between the Torino Hill area and the Gonfolite foredeep (Fig. 5b).

South of the Torino Hill and Monferrato areas, two depocentres roughly similar to the previous ones were separated to the south by the Alto Monferrato high, generated by a deep-seated antiformal ramp (Mosca 2006; Mosca et al. 2009). Eastwards, a west-east oriented depression was bounded to the north by the Villalvernia-Varzi Fault System (Fig. 5b) that was partially involved in the Apenninic deformation (Di Giulio & Galbiati 1995).

The intra-Burdigalian tectonic modification phase played a quite important role in the evolution of the backlimb of the Alto Monferrato high. After behaving initially as a carbonate ramp of structural origin, gently connecting the high with the adjacent basin to the west, its drowning and tilting gave way to a relative sea-level rise, associated with the tectonic destabilization and cannibalization of the Aquitanian-lower Burdigalian carbonates, and foreshadowing the major late Burdigalian drowning. The same evolution can also be observed in Line 4 of Fig. 11b.

Along the south-western basin margin, in the Saluzzese and Monregalese regions, the flood-dominated falling-stage deposits overlying the I-BU sequence boundary appear on the contrary to be related to the tectonic uplift of the basin margin. In the upper part of the sequence, the cessation of the catastrophic facies, replaced by normal mouth bars, suggests a strong decrease in fluvial flood volumes related to the re-adjustment of the equilibrium profile.

Unit IV (upper Burdigalian)

Description. This unit, bounded at the base by the late Burdigalian (L-BU) major sequence boundary, consists primarily of basin plain turbidites (well-known in the classical outcropping sections as the Cortemilia Formation, *sensu* Gelati & Gnaccolini 2003).

The successions of the Unit IV (Fig. 5c) were fed mainly from the south-west, where they abruptly show onlap terminations over the uplifted basin margin (lines 1 and 2 in Fig. 4a). Northwards, paleocurrents testify an eastward deflection of turbidity currents (Gelati & Gnaccolini 2003). More eastwards, this unit shows lap-out terminations and lateral shaling-out toward structurally-high areas located to the east around the Alto Monferrato, as well as toward the Monferrato and its subsurface prosecution (Fig. 11a and Line 3 in Fig. 4a). In the Monferrato, carbonate deposits prevail (Clari et al. 1995). The paleocurrents measured in this unit show a provenance from the SW, but an eastward deflection is recorded (Gnaccolini & Rossi 1994) where the flows reach the backlimb of the Monferrato high (Fig. 5c).

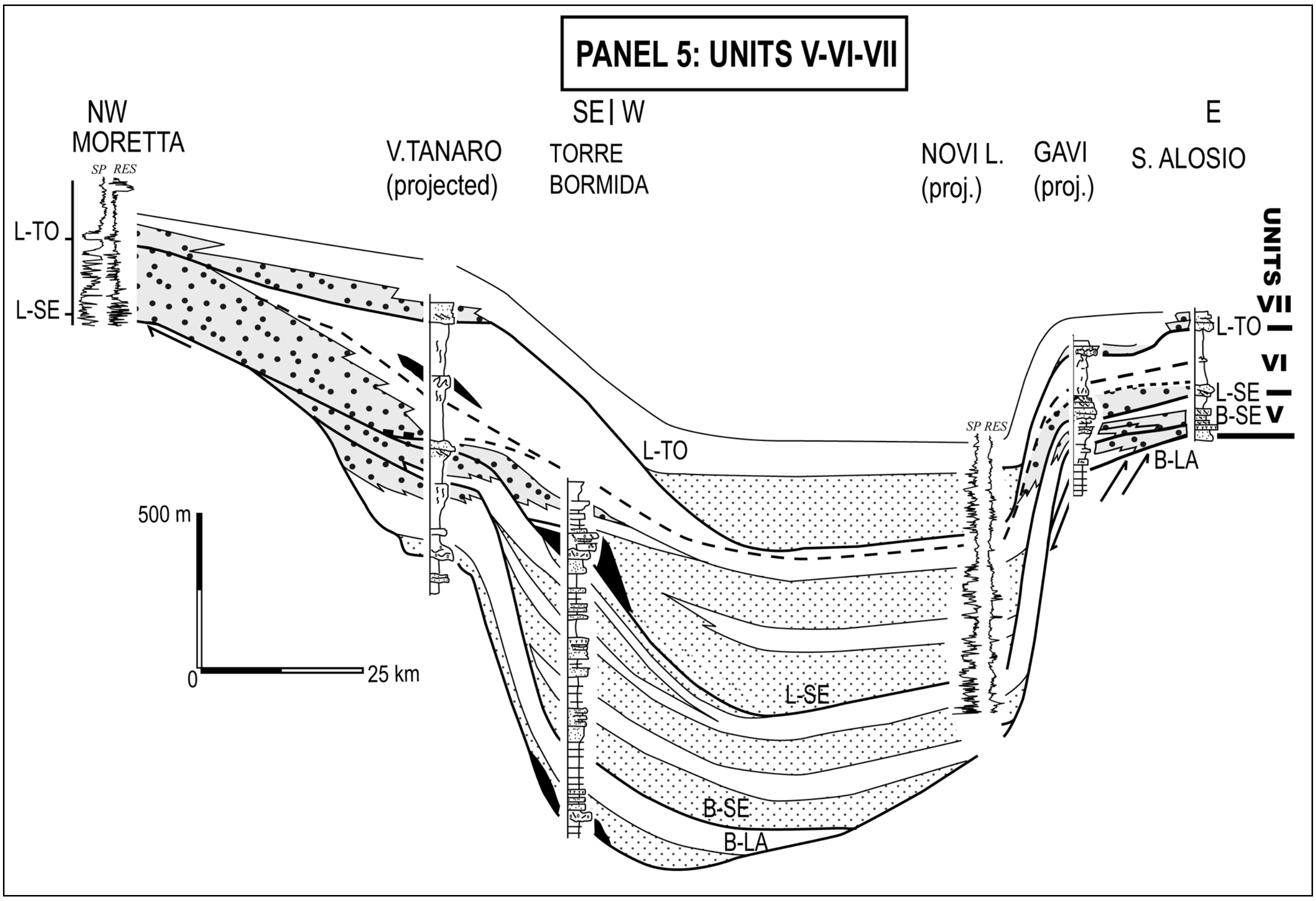


Fig. 13 - Stratigraphic correlation panel 5 (see location in Fig. 1): correlation between biostratigraphically-calibrated measured outcrop sections and wire-line well logs in Units V, VI and VII, showing the step-wise uplift of basin margins: progressive unconformities, chaotic bodies and the progressive narrowing of basin depocentre due to the combination of basinward tilting and coastal wedge progradation are shown. Well-logs are Spontaneous Potential (on the left) and Induction (on the right). The ages of the unconformities are in Fig. 3. Legend in Fig. 6.

Paleogeographic interpretation. Since the late Burdigalian, the Tertiary Piedmont Basin became characterized by a unique large depocentre. The deposition of Unit IV records a sudden deepening event related to an abrupt increase in space creation. This was related to the southward tilting of the whole basin and the incipient uplift of the south-western basin margin along a W-E trending Fault zone reactivating the former western branch of the Celle-Sanda Fault System (Fig. 5c). The evolutionary outline suggested by the flattened seismic profiles in Fig. 4b also show that the late-Burdigalian sequence boundary is a major drowning-platform unconformity driven by a major space-creation phase and recorded by the deposition of the Cortemilia system. Generally, during Oligocene the tectonic accommodation space was greater to the north and the east, i.e. in the low elevation belts; later during the latest Oligocene to early Miocene interval this structural pattern was rearranged and the major depocenter abruptly shifted to the south (Line 3 of Fig. 4a and Fig. 4b). This affects also local features like the Quargnento structure, as shown by Line 4 of Fig. 11b, where the backlimb experienced higher subsidence during early Miocene times.

Although major entry points were located in the south-west, however the uplift of the Monferrato high to the north provided an obstacle that deflected the paleocurrents eastwards along the axial plunging of the basin. The occurrence of sand-rich deposits in the Torino Hill sector (Bonsignore et al. 1969) suggests also the possibility of a local sediments supply from the northwest. This possibility is also supported by the closure of the seaway previously existing toward the Gonfolite basin (Figs. 5b and 5c).

Unit V (Langhian- Serravallian p.p.)

Description. The Unit V, resting over the major sequence boundary of base Langhian age (B-LA), consists of two component sequences separated by the base Serravallian (B-SE) sequence boundary. The stacking pattern of the Unit V is mainly characterized by a markedly regressive trend. This regression took abruptly place along the whole southern depositional belt, that previously was part of a wide turbiditic depocentre.

The first sequence, comprised between the B-LA and B-SE surfaces (Fig. 13) is marked along the south-eastern basin margins by a locally very evident angular unconformity between tilted basin plain deposits of late Burdigalian age (Unit IV) and shelfal successions of Langhian age (Cessole Fm. Auct.) occurring since the base of the Unit V. Basinward, a turbidite system was deposited (Cassinasco Fm. Auct.), well exposed in its proximal sector in the Bormida Valley near Gorzegno and Torre Bormida and showing paleocurrents mainly towards NE. In the south-western basin margin, coarse-grained turbidites and chaotic facies that can be laterally traced for at least 15 km (Gelati et al. 1993; Gelati et al. in press a, b) are downlapped by a prograding wedge, whose shelfal and upper slope portions refer to the Murazzano Fm. (Gelati & Gnaccolini 2003) (Fig. 13). To the north, in the Monferrato area, the deposition of carbonate platform facies continued (Clari et al. 1995), rimming submerged intrabasinal highs isolated from drainage basins of both the Alps and the Apennines.

The second sequence (between the B-SE and L-SE surfaces) marks an abrupt downward shift of the fluvio-deltaic deposition (lower part of the Serravalle Fm. Auct.) in the basin margin, correlating with a re-activation of turbidite sedimentation in the depocenter. Also the south-western basin margin is characterized by the progradation of shelf-slope wedges interfingering at the base of slope with turbidite systems aggrading over the basin floor (Fig. 13). In the toe-of-slope region, in the Tanaro Valley near Cigliè, the sequence boundary is recorded by the marine onlap of gravel-rich channel-fill deposits against the slope mudstones downlapping above the Cortemilia sandstone facies association (see also Fig. 16). In this area, the conglomeratic lowermost Langhian gravity flow deposits, contrasting with the much finer-grained upper Burdigalian turbidites, points out the important relief rejuvenation recorded by the base-Langhian sequence boundary.

Paleogeographic interpretation. The progradation occurring along the southern basin margin, with a rough east-west orientation, was driven by progressive uplift of this margin, that started since the Langhian from the Monregalese in the west to the Alto Monferrato in the east.

Angular unconformities to the east, where the proximity to the Apenninic frontal splays provided the direct superposition of shelfal deposits over tilted and truncated basin plain turbidites, suggest a relative sea level fall of tectonic origin in the order of at least several hundreds metres. In the Langhe region, chaotic facies (Gelati et al. 1993) occurring at the base of slope to the west (Fig. 13), point out that the uplift of the whole southern basin margin was actually significant, leading to an overall decreasing of the accommodation rate. In the south-western margin, seismic-scale outcrops where shelfal-slope deposits prograde on top of the lowermost Langhian gravity flow deposits permit to roughly estimate that the Langhian downward shift of the coastal onlap was of at least 100 m (see also Fig. 16). The evolutionary outline suggested by the flattened seismic profiles in Fig. 4b also show that the base-Langhian sequence boundary was driven by a major basin inversion related to the uplift of the southern basin margin, following the space-creation phase associated with the deposition of the underlying Cortemilia system. These data suggest an interpretation different from that proposed in previous literature (Mutti et al. 2002) as far as the meaning of the Cortemilia and Cassinasco Formations Auct. is concerned. Our data suggest that their Torre Bormida facies association (traditionally included in the Cassinasco Fm.) is genetically un-related to the Cortemilia Fm.: in our opinion, the Cortemilia and Cassinasco Formations represent two distinct systems bounded by a major discontinuity generated by a basin-modification phase.

The Monferrato area was characterized by a generalized uplift in relation to the activity of several north-verging frontal splays. Its eastward prosecution, in the Tortona area, was very close to the southern basin margin, so that the turbiditic depocentre was very narrow, recorded by the well Novi Ligure (Fig. 13). To the North of the Borbera Valley, the Langhian-Serravallian succession is progressively onlapping eastwards and northwards (Ghibaudo et al. 1985).

Unit VI (uppermost Serravallian-Tortonian p.p.)

Description. This unit consists of deposits of latest Serravallian to early Tortonian age, characterized by a predominantly transgressive stacking pattern (Fig. 3).

The lower sequence boundary is late Serravallian (L-SE) in age and culminated in a maximum regression phase, associated to the reduction of the turbidite depocenter (Fig. 13 and Fig. 5d).

In the south-western basin margin, chaotic deposits (Fig. 14a) locally occur (Fosso dei Quiri) in the base of slope region, much coarser, thicker and wider than the Langhian ones (Gelati et al. 1993). Fluvio-deltaic systems are mainly present to the west, buried in the subsurface (well Moretta). They mainly crop out in the Alto Monferrato, referred to the upper part of the Serravalle Fm. Auct., where they commonly exhibit catastrophic delta front deposits (sensu Mutti et al. 1996) characterized by large-scale water escape structures and framed in a forced regression prograding mainly toward the North-East and the North. This phase was followed by a large-scale transgression leading to the onset of normal mouth bars in the fluvio-deltaic systems and by a progressive undersupply of the turbidite depocentres. The maximum flooding surface is recorded by nodular concretions in the middle of an outer shelf muddy

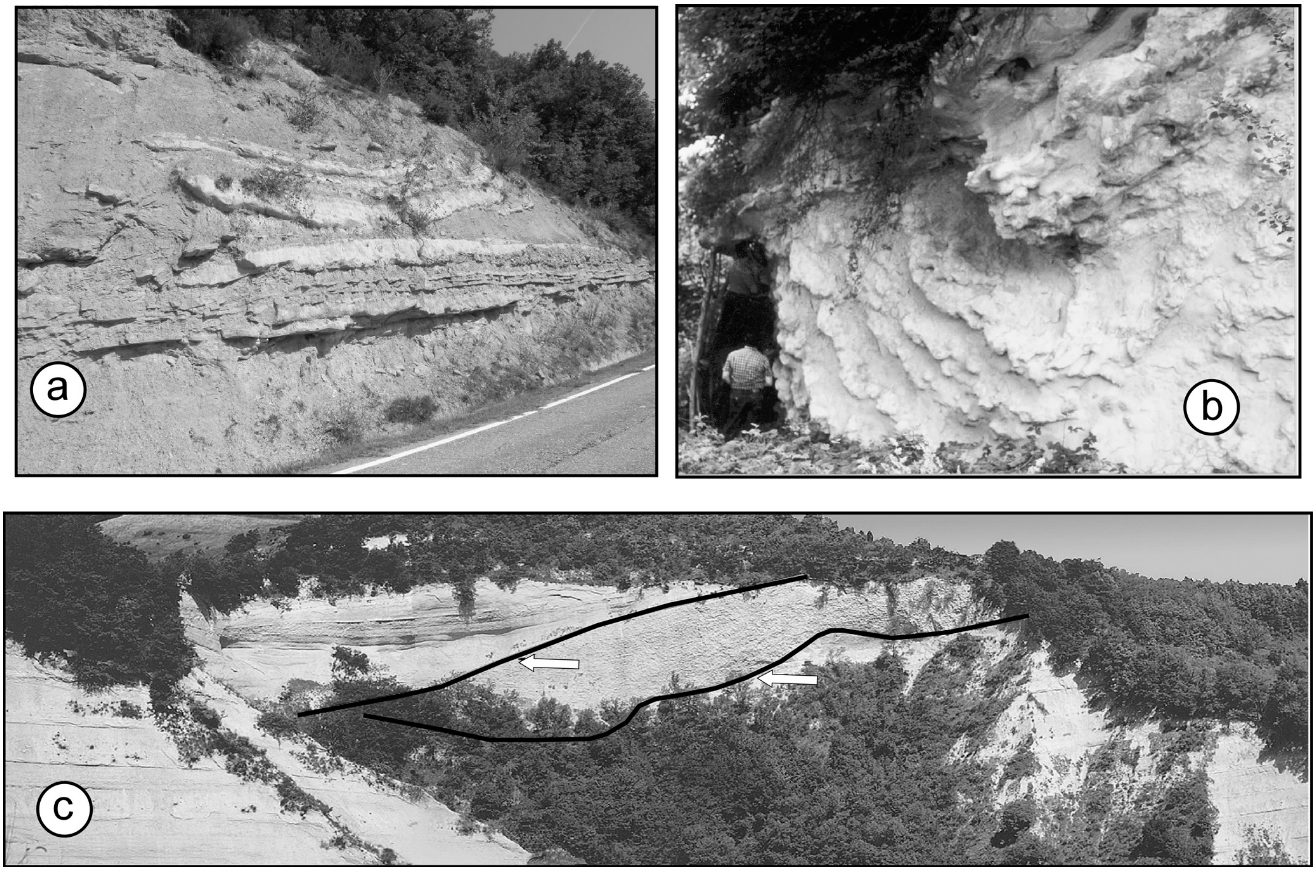


Fig. 14 - The outcrop expression of some significant features of Serravallian and Tortonian sequences. a) A portion of the Upper Serravallian chaotic complex near Sinio, the base-of slope record of the mid-Miocene maximum regression phase (Unit VI). b) A Tortonian slumped body near Stazzano, that destabilized a portion of the shelfal siltstones recording the rapid transgression at the top of Unit VI. c) The late Tortonian unconformity near San Alosio, where lower shoreface sandstones (Unit VII) unconformably cut the overall transgressive shelfal sediments present in the upper part of Unit VI; the sandstones are in turn affected by multiple slump scars recording a deepening event associated to a basin margin destabilization of tectonic origin.

lithozone; locally it is expressed by small rhodalgal platforms (Fravega & Vannucci 1982).

To the north, a widespread hiatus (Falletti et al. 1995) was related to the maximum uplift in the Monferrato, where thin condensed marly successions record the ramp connecting this high with the southern turbiditic depocenter.

Paleogeographic interpretation. The late Serravallian sequence boundary and the associated forced regression were related to the continuing uplift of the southern basin margin, determining the development of a falling stage coastal wedge. The forced regression wedge mainly was built by catastrophic fluvial underflows, as suggested by the dominance of gravity-flow deposits (Mutti et al 2002). The falling relative sea-level should have favored this process increasing the volume of sediments delivered basinward and the by-passing. The basinward occurrence of a chaotic complex testifies the increasing of the tectonic destabilization of the south-western basin margin. The reduction of the turbidite depocenter (central part of Panel 5 in Fig. 13 and Fig. 5d) was due to the combination of the basinward tectonic tilting and the deposition of the offlapping prograding wedges. The overall stratigraphic organization of the southern basin margin is determined by progressive unconformities developed since the base Langhian sequence boundary, as imaged by seismic profiles (Fig. 4b, bottom line) and correlation panel (Fig. 13).

Unit VII (upper Tortonian-Messinian p.p.)

Description. This unit is characterized by a regressive stacking pattern and is bounded upward by the late Messinian unconformity (L-ME). The unit consists of two component sequences separated by the I-ME sequence boundary, over which the deposition of primary evaporites and associated mudstones took place.

At the base of the sequence, basin floor turbidites occur in separate and reduced depocentres (Fig. 13). Flood-dominated and catastrophic fluvio-deltaic systems were present marginward, associated with delta front and shelfal gravity flow deposits. These facies are mainly sand-prone in the uplifted western margin and gravel-rich in the eastern margin (Fig. 13), where they accumulated in local depocentres, and locally

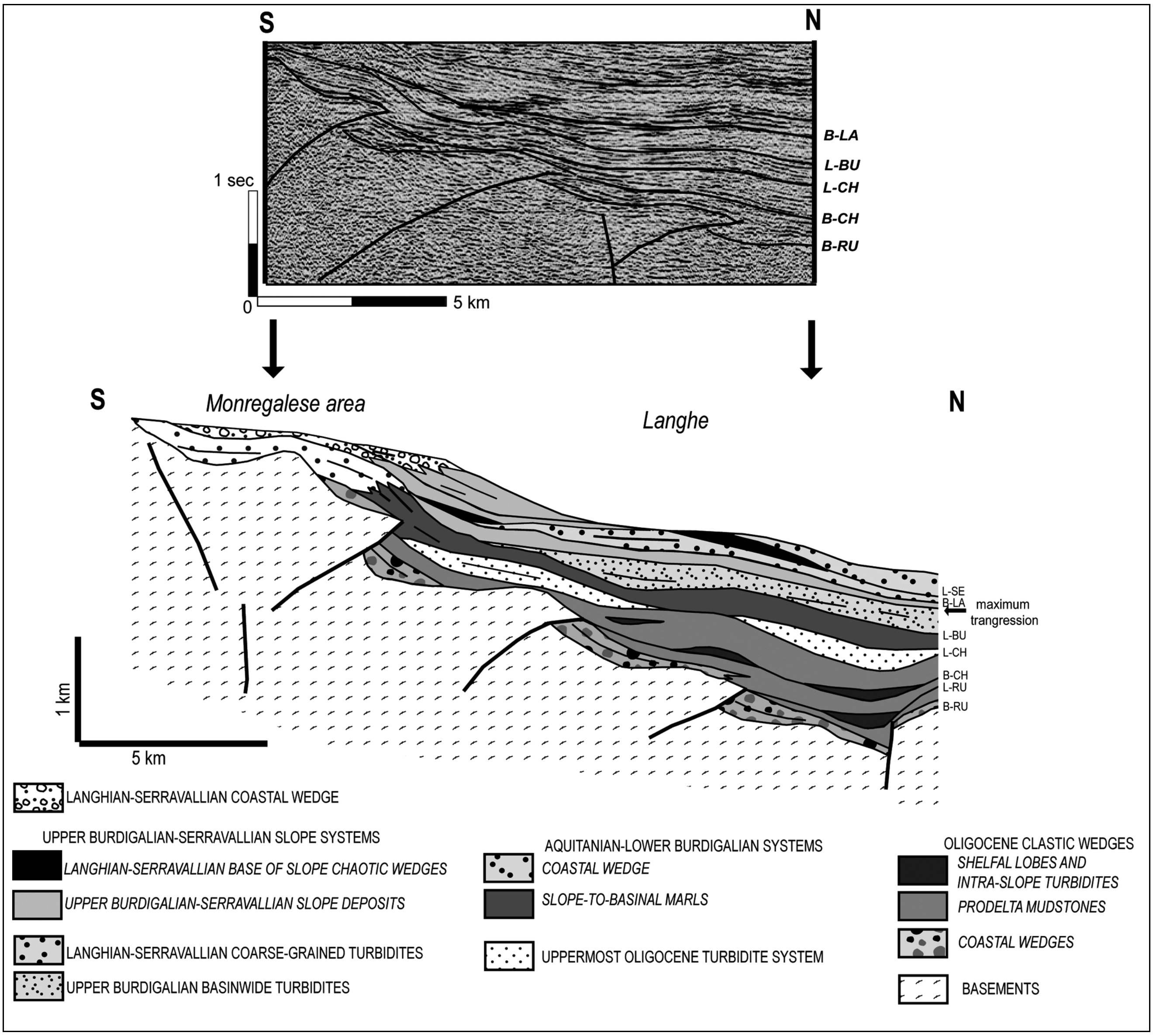


Fig. 15 - Stratigraphic relationships between basin margin and basin axis, modelled on the seismic profile L1 (see Fig. 4), and its marginward and basinward extrapolation on the basis of outcrop data. The stratigraphic summary sketch is ideally restored at the top of Serravallian deposits, and therefore the late Messinian faults visible in the seismic profile and affecting the Miocene succession, are not considered. The ages of the unconformities are in Fig. 3.

changing basinward to chaotic deposits (Fig. 14b). Laterally, strongly bioturbated shoreface sandstones locally occur, unconformably overlying the sequence boundary (Fig. 14c). These deposits are in turn cut by slump scars infilled by shelfedge deposits showing abundant instability features (Ghibaudo et al. 1985) (Fig. 14c). Above the late Messinian unconformity, most of the evaporites underwent a strong remobilization and reworking to form widespread chaotic bodies identified both in the present outcrops (Dela Pierre et al. 2002b; Irace et al. 2005) and in their subsurface continuation (Mosca 2006). Such mass flow deposits, a typical feature of the whole Apenninic margin in both outcrop and subsurface (Rossi et al. 2002), have a wide occurrence also in the Tertiary Piedmont Basin as commonly shown on seismic profiles (see the base-Pliocene flattening in Fig. 4b) and further details in Mosca 2006).

Paleogeographic interpretation. In the western part of the basin margin, thin shallow water deposits occur both buried in the subsurface (well Moretta) and outcropping in the Tanaro Valley to the North of Monchiero, marking an important downward shift of coastal onlap after the early Tortonian transgression. In the eastern part of the basin, the distribution of coarse-grained deposits was strongly controlled by the interplay between the generalized uplift of the southern margin and its involvement in the westward propagation of the Northern Apennines (Fig. 5d) accommodated near the Villavernia-Varzi Fault system (Line 3 in Fig. 4a). The tectonic interference with the frontal splays of the Emilia arc provided higher gradients and a remarkable differential subsidence between synsedimentary highs and lows. Although the deposits informally referred to the Vargo Member have been interpreted in previous literature (Ghibaudo et al. 1985) as a turbidite system confined in half grabens, in our opinion they represent shallow-water catastrophic fluvial floods deposited in sub-basins which on seismic profiles appear formed behind the Apenninic frontal splays (Line 3 in Fig. 4a). Within this framework, the older and gravel-rich portion of the eastern margin record falling stage and lowstand deposits taking place in the synsedimentary depressions, whilst the transgressive deposits are recorded by bioturbated shoreface sandstones redistributed by wave action lateral to the major entry points and rimming the structural highs.

Some regional implications and concluding remarks

Transgressive-regressive cycles and component sequences

A long-term, major transgressive-regressive cycle is recorded in the late Eocene to Miocene succession in the study area. The maximum transgression took place in the late Burdigalian and coincides with the maximum rate of tectonic space creation. This is recorded by the deposition of a 1 km-thick basinwide and highly efficient turbidite system (Cortemilia Fm. of literature). This system separates the older southwestward coastal onlap and aggradation from the younger outbuilding related to the middle Miocene uplift recorded along both the southwestern and southeastern basin margins, sometimes punctuated by forced regression pulses (Figs. 15 and 16).

Within the major T-R Cycle, changing shoreline trajectories point out 2nd order peak-regressions, often associated with forced regressions, occurring during latest Priabonian, early Burdigalian and late Serravallian, and 2nd order peak-transgressions occurring in late Chattian, late Burdigalian and early Tortonian times.

The transgressive-regressive wedge consists of seven large-scale unconformity-bounded stratigraphic units, whose location, development and internal organization were controlled by major changes in the rate of tectonic subsidence and by the shift of sedimentary depocentres in relation to basin reorganization and changes in tectonic style. This resulted in the alternation of phases of accommodation space subtraction and creation along the basin margins, respectively leading to regressive and transgressive cycles, with average duration of 5 my and characterized by thickness on the order of 2 km in the depocentres. The overall trend in each unit is recorded by the stacking pattern of component 3rd – to – 4th order depositional sequences bounded by marginal unconformities and correlative continuity surfaces towards the depocentre, whose average time span approximates 2.5 and 1 my, respectively.

A different behavior may occur between marginal belts and intrabasinal highs during the early Miocene. A reduction of the accommodation space is usually imposed along uplifted marginal belts, as recorded by forced regression occurring in the fluvio-deltaic wedges of the Monregalese and Saluzzese regions. By contrast, the prevalence of space creation or subtraction over intrabasinal highs of the Monferrato and Alto Monferrato was controlled just by local tectonic structures generating progressive unconformities.

This was initially recorded by carbonate platforms rimming significantly uplifted subaqueous intrabasinal highs, and by their subsequent tectonic tilting and stratal convergence with an overall deepening-upward stacking pattern (Line 4 in Fig. 11b).

Changes of coastal onlap and sediment composition

The latest Priabonian-to-Burdigalian overall transgression, framed within a regional southwest- to west-ward change of coastal onlap, caused the progressive flooding of the Alpine basements. The biostratigraphic age of the coastal onlap from the Alto Monferrato to the Monregalese and Saluzzese areas (located nearly 80 km apart) spans from the Priabonian to the early Burdigalian, implying an average coastal encroachment of about 4 km/my (Fig. 16).

The transgressive evolution was characterized by a large-scale diachronism of both paralic and fluvio-deltaic deposits (Molare Fm. of literature). It was nevertheless punctuated by higher frequency sequence boundaries and marine transgressions associated with minor regressions and ravinement surfaces or carbonatic marine condensed sections, respectively.

From the Priabonian to the early Rupelian (Fig. 17), syndepositional structural highs and depositional reliefs determined the occurrence of E-W oriented tidal-influenced embayments south of the Merana-Monteacuto Fault system, where an eastward transgression was temporarily recorded, until a gradual increasing in accommodation provided a more regular shoreline and the re-establishment of the regional SW-ward transgression.

In the late Rupelian (Fig. 17), a drowning-platform unconformity led to an abrupt southward shift of the facies belts, so that the shoreline moved more southwestward. Generally, during Oligocene time, both the location of marine onlap and the development of coastal wedges seem in close relation to structural elements providing high paleomorphological gradients. Then, from the latest Chattian to the Burdigalian the

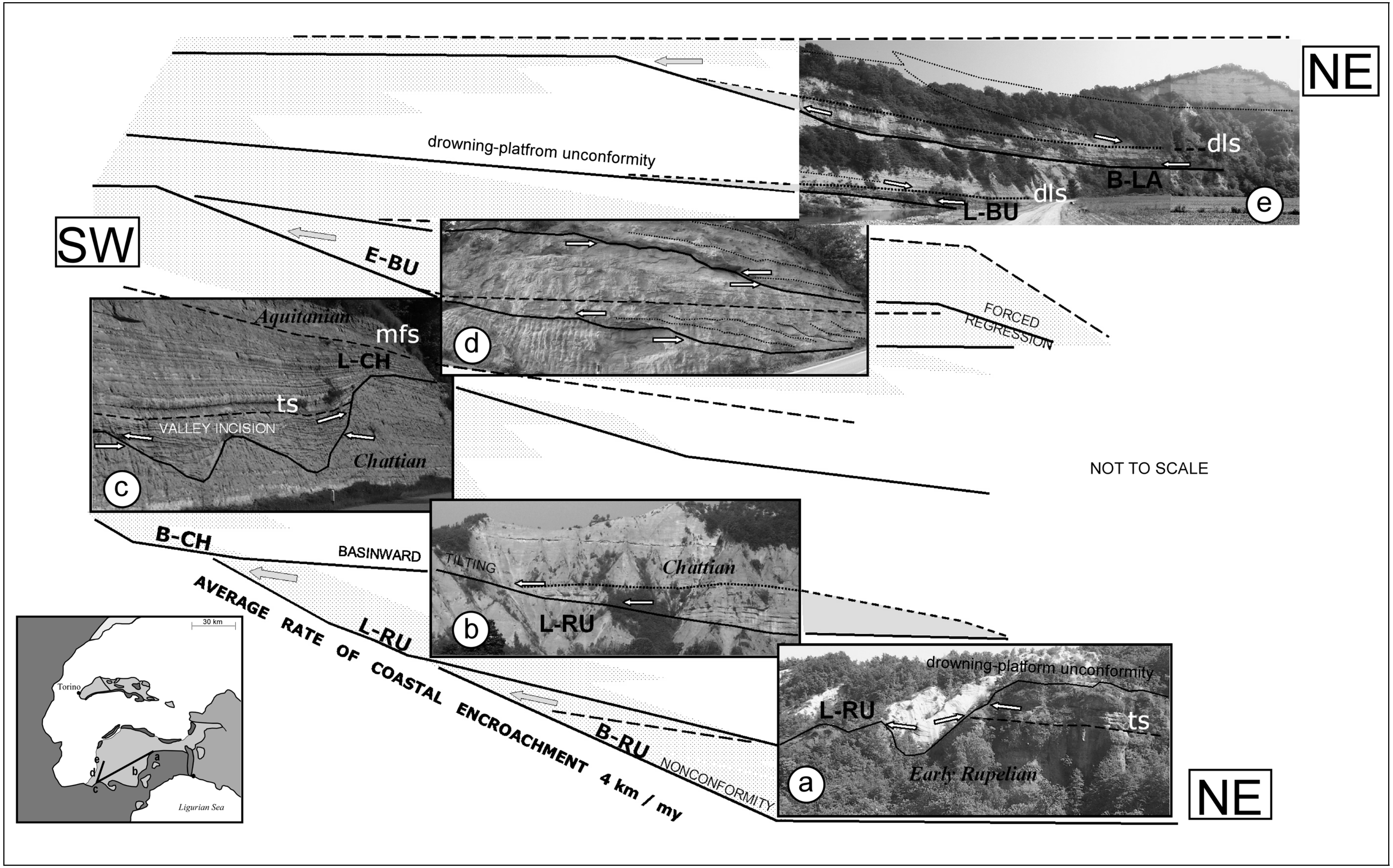


Fig. 16 - The most significant outcrop records of the major Oligocene-middle Miocene Transgressive-Regressive Cycle in the Langhe and Monregalese regions. Location of the photographs is reported in the inset. The major Cycle is subdivided in two minor T-R Cycles by the early Burdigalian peak regression. The average rate of coastal encroachment was 5 km/my during the Oligocene overall transgression, whilst the average rate of the Miocene overall regression was 2 km/my, increasing to 3 km/my from the middle Miocene onwards. The ages of the unconformities are in Fig. 3.

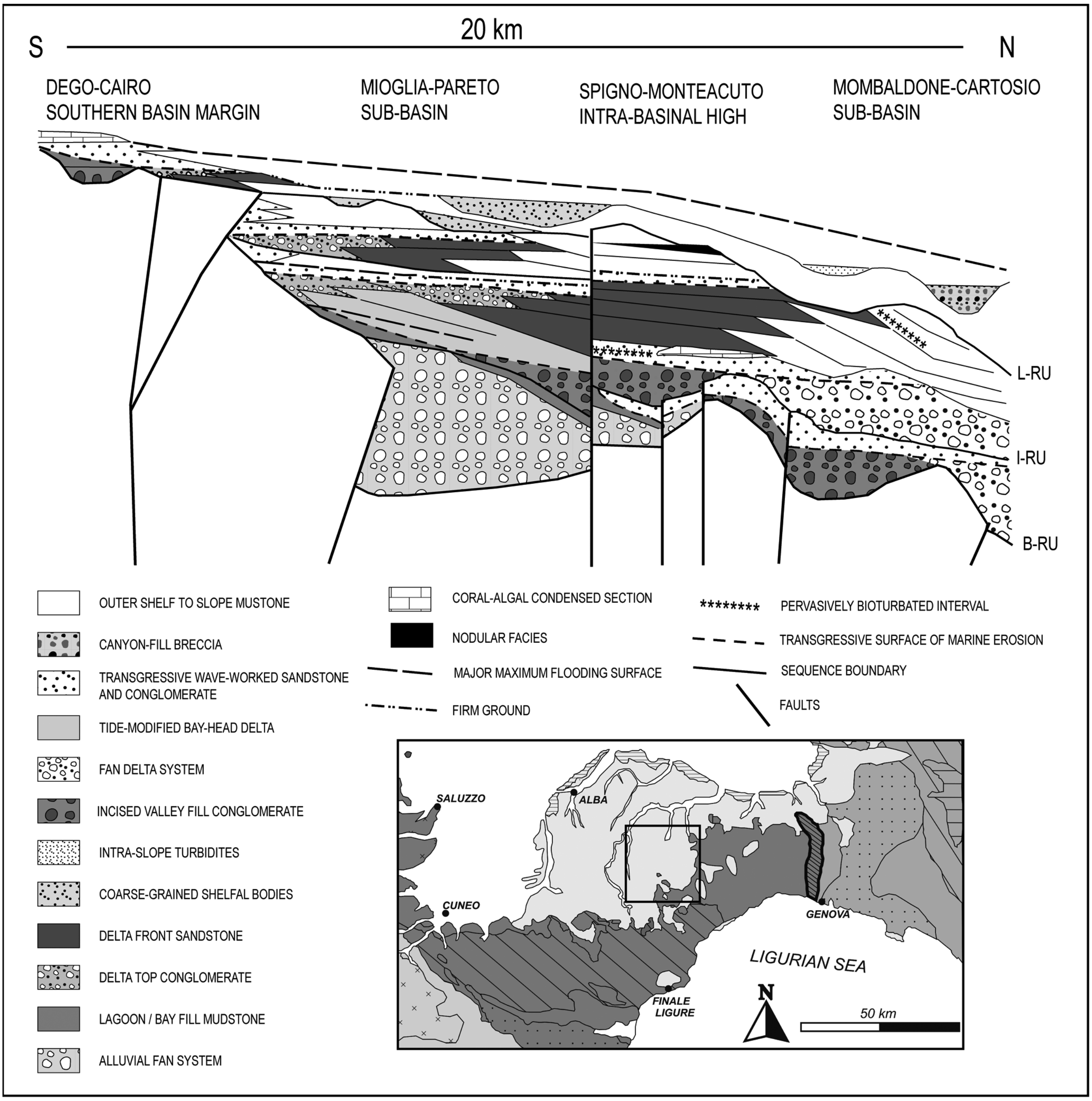


Fig. 17 - Stratigraphic organization of the Rupelian deposits (lower part of Unit II) in the Molare-Rocchetta sub-basin, showing an overall transgressive stacking pattern affected since the late Rupelian by large subaqueous erosional surfaces induced by drowning-platform unconformities. The stratigraphic complexity derives from the combination of morphostructural setting, depositional geometries and higher-frequency (4^{th} order) cyclicity defined by minor sequence boundaries, transgressive surfaces and condensed intervals.

previous irregularities were smoothed and/or filled, the coastal wedges had a simpler internal organization and a more regular distribution, and the shoreline reached the Monregalese and Saluzzese areas (Figs. 15 and 16).

Although this study is lacking of new data about sediments composition, changes of major source areas as documented by literature (e.g. Cazzola et al. 1981; Di Giulio 1989; 1991; Gnaccolini & Rossi 1994; Barbieri et al. 2003) fit very well with the paleotectonic and paleogeographic reconstructions here proposed (see also further details in Mosca et al. 2009). Since late Eocene, the collisional scenario was characterized by the exposure of different basements and by average paleocurrents from the SW, locally complicated by the tectonically-controlled paleotopography. The Alpine axial sector made different rock types available for erosion, i.e. ophiolitic, quartz-feldspathic, and carbonatic. Sources for upper Eocene sediments can be located both in me-

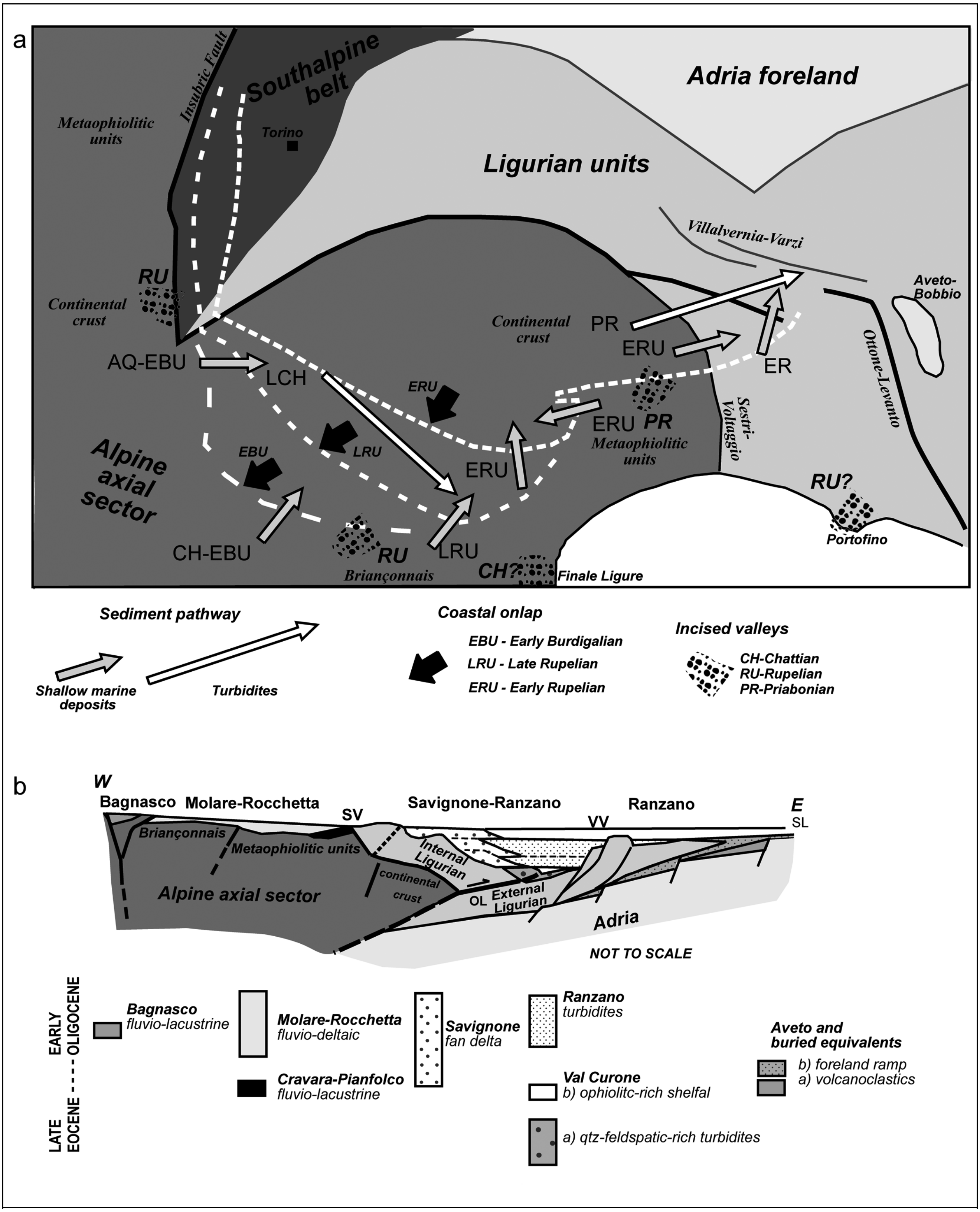


Fig. 18 - a) upper Eocene-lower Miocene coastal onlap and major paleocurrents superimposed over the combined outcrop/subcrop map of the pre-Cenozoic substrata. b) 2-D simplified reconstruction of the overall basin organization and its relation to the tectonic juxtaposition of the different substrata at the end of early Rupelian. Note that sediment composition changes known in literature fit both the substrata subcrop map and the transport pathway implied by the considered paleogeography. Note also the foreland deposits outcropping in the Aveto-Bobbio tectonic window (eastern sector of profile, cf. Rossi et al. 2007), thus implying a relative stability of this area with respect to the blocks to the west.

tamorphic oceanic units (such as the Voltri Group) and in underlying or adjacent continental crust units (Fig. 18a and 18b), similar the Valosio Unit. The facies characteristics of the turbidites and the E-W transfer branch of the internal boundary of the Alpine axial sector support the possible presence of continental crust buried to the north of the present outcrops of the Valosio unit. This could explain the quartz-feldspathic composition of the deposits of the Val Curone basin (Fig. 18a and 18b). During the Rupelian, the southward coastal onlap made the sediments to be mainly sourced by erosion of ophiolitic units of the Voltri Group (Gnaccolini & Rossi, 1994). Since late Oligocene, the north-verging thrusts controlled further accommodation on their backlimb and forced an acceleration of the coastal aggradation and transgression toward the south. This favoured additional sources from the Briançonnais rocks (Gnaccolini & Rossi 1994) exposed southwest of the Voltri Group.

From the latest Oligocene onwards, the NE-verging Monferrato thrusts caused a regional tilting to the south: an increasing of accommodation space in the westernmost part of the Tertiary Piedmont Basin was coupled with a further westward coastal onlap. As a consequence, a higher amount of quartz-feldspathic detritus was available by erosion of continental crust units of the Alpine axial sector (e.g. Dora Maira). This could feed, *via* the fan deltas presently buried in the Saluzzese region, the structurally confined latest Chattian turbidite depocentres in the Langhe, where axial flows were running from NW to SE parallel to the synsedimentary depressions.

Since the late Burdigalian, a very high subsidence occurred south of the Monferrato fronts in the alto Monferrato region. This led to the development of a large and simpler basin, in which the shallow water facies belt shifted marginward in relation to a strongly increased rate of relative sea-level rise. Highly efficient turbidites were fed mainly from the south-western apex, and the subaqueous Monferrato ramp merely continued to act as a morphological obstacle deflecting paleocurrents eastwards.

Appendix: integrated biostratigraphic data

Dinoflagellate cysts are quite abundant and diverse in the Tertiary Piedmont Basin: they represent the basis for the present Oligocene and Miocene palynozonation (Fig. 19), and its framing into the Ogg et al. (2008) chronostratigraphic scheme. The Biozone and Nannozone chronostratigraphy calibration derives from unpublished data (2006) and from the Gradstein's Norlex website.

A total of 29 measured sections, where about 450 samples were taken, have been fully analysed using planktonic foraminifera, calcareous nannoplancton and dinoflagellate cysts (Tab. 1 and Fig. 2a); the dinoflagellate cysts proved to be continuously present and their relationships with miospores permitted some palaeoenvironmental remarks in the Oligocene sections. The palynological data have been correlated with the standard Foraminifera and Nannofossils Zonations, on the basis of original analyses (Fig. 2b).

Most of the Oligocene data derive from original analyses carried out both in the Piedmont Basin and central Italy, integrated with data published by Powell (1986a,b) and Brinkhuis et al. (1992). Concerning the Miocene data, many of recovered dinocysts resulted undescribed, mainly at species level. In the original analyses the nomenclature have been left open or an informal name has been assigned. The name here in ' ' must be considered yet formally undescribed: these names derive from the thesis of Zevenboom (1995), in which most of Miocene new species have been described, but not validly published. In the subsequent ten years many papers from northern hemisphere Miocene have been published and some species have been validated with new specific names (cf. De Verteuil & Norris 1996; Head & Norris 2003; Louwye 1999, 2000, 2001, 2004; Versteegh & Zevenboom 1995; Warny & Wrenn 1997). The aim of this paper does not concern with dinocysts' taxonomy, so we leave at open nomenclature the species which are worth to be deeply discussed in a dedicated paper.

The Palynozone Scheme (Fig. 19) relies upon original analyses and represents the result of many years of work in the Mediterranean area, at least since 1991 (summarized in Biffi et al. 1995). It represents a relatively "new" stratigraphic tool in this study and it's here very briefly discussed in its original elements.

In the study area, the Oligocene outcrops (Fig. 2b) start with non marine/paralic conditions passing to fluvio-deltaic conditions, from Rupelian to lower Chattian (*W. gochtii* Zone to *H. pusillum* Subzone a; P19-P21 Zones); the assemblages recovered from all the sections yielded assemblages dominated by spores, passing to rare dinocysts and to relative blooms of *Deflandrea* spp., marking incipient marine incursions. The subsequent appearance of the zone markers, as *Chiropteridium lobospinosum* and *Hystrichokolpoma pusillum* points out marine conditions mainly recording prodelta to shelf edge conditions.

The upper Oligocene samples are concentrated in its lower portion. Concerning its upper portion, the palynozone scheme is based on the biostratigraphic and palynological study of the Lemme section, where the Oligocene/Miocene transition has been defined (Powell 1986a; Biffi personal observation)

The lower Miocene samples are mainly concentrated in the Burdigalian; the Burdigalian – Serravallian (N5-N13; NN4-NN6) time span is well defined by dinoflagellate cysts as shown in Fig. 2b; the Palynozones *Coustodinium aubriae*, *Palaeocystodinium 'striatogranulosum'*, *Cerebrocysta 'powelli'* and *Achomosphaera andalousiensis* appear well defined by the First Appearance, Last Appearance and Frequency datum of different species. Other than the zone markers, in particular we can highlight the FA of *Impagidinium patulum, Cerebrocysta poulsenii, Labyrinthodinium truncatum, Unipontidinium aquaeductum, Invertocysta tabulata, Hystrichosphaeropsis pontiana*. The earliest Tortonian is characterised by the *Cerebrocysta 'perforocresta'* Zone; the bulk of the Tortonian is represented by the *Mendicodinium robustum* Zone; the samples studied resulted quite rich in dinoflagellate cysts, but no markers were evident other than this peculiar cysts, formerly named *robustum* by Zeevenboom (1995) and formally established by Fensome et al. (2008), due to its thick, heavily incised wall. This zone has been recognised also in the early Messinian. The upper Messinian 'lagomare' facies is dominated by *Galeacysta etrusca* and its suite; no sediments of this age have been studied in this area.

In conclusion, few remarks on the present zone markers, whose specific name has been reported by the Index of Fensome & Williams (2004) as 'NAME NOT VALIDLY PUBLISHED', referring to the thesis of Zevenboom (1995). No species with the peculiar characteristic of *Palaeocystodinium 'striatogranulosum'* (striae and granules on the pericyst) have been published in these last years; *Cerebrocysta 'powelli'* is very similar to *Pixidinopsis elliptica* Biffi & Manum (1988), but it appears definitely larger in size; *Cerebrocysta 'perforocresta'* is very

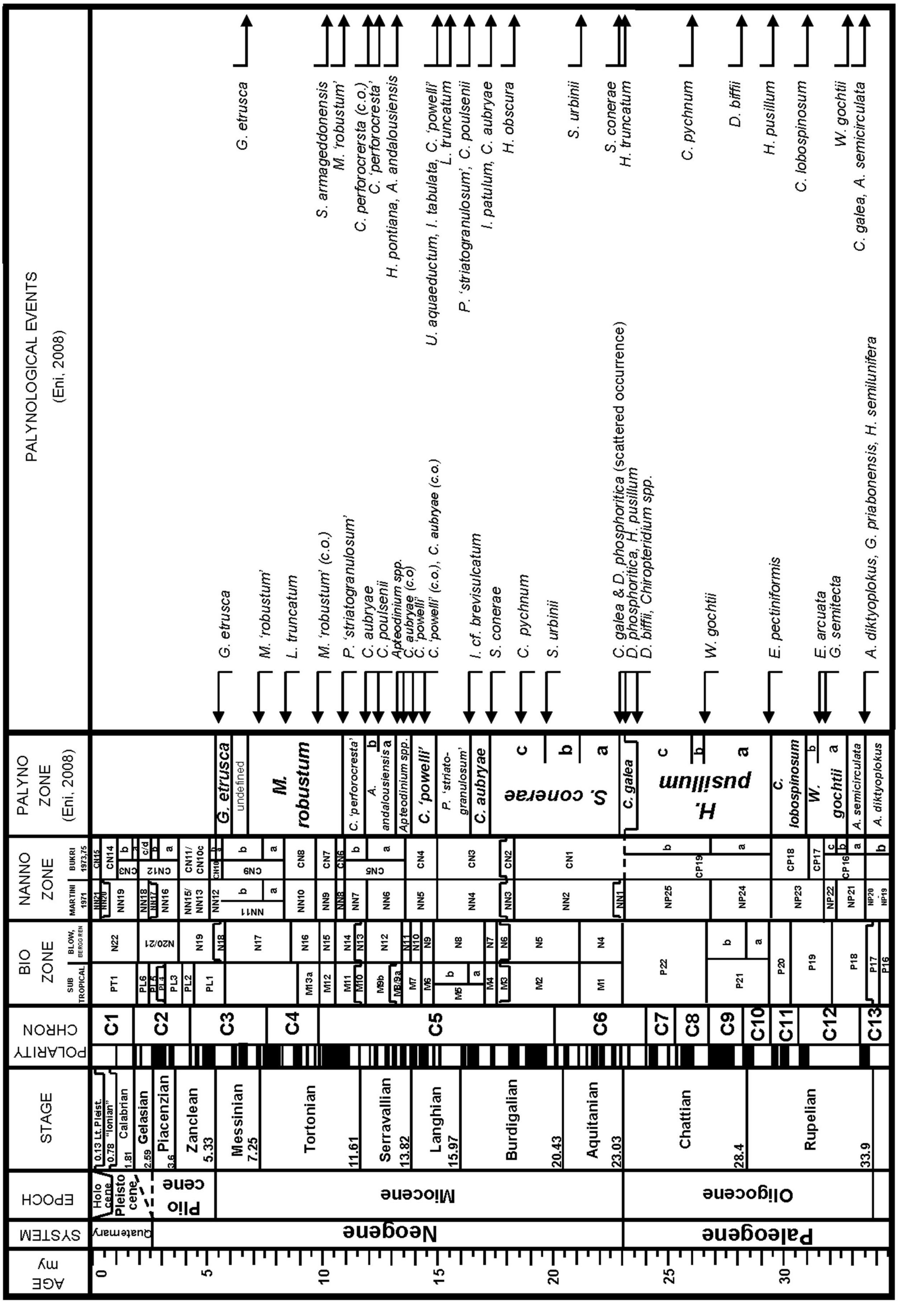


Fig. 19 - Biostratigraphic scheme showing biozones, nannozones, palynozones and the related palynological events tied to the geochronogical time scale of Ogg et al. (2008). The palynozonation has been correlated with the standard Foraminifera and Nannofossils Zonations on the basis of original analyses in the Mediterranean area.

similar to *Corrudinium devernaliae* Head & Norris (2003), which is remarkably smaller in size. For these reasons we here maintain the open nomenclature, waiting for a next paper, aimed to a taxonomic revision and description of new species.

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