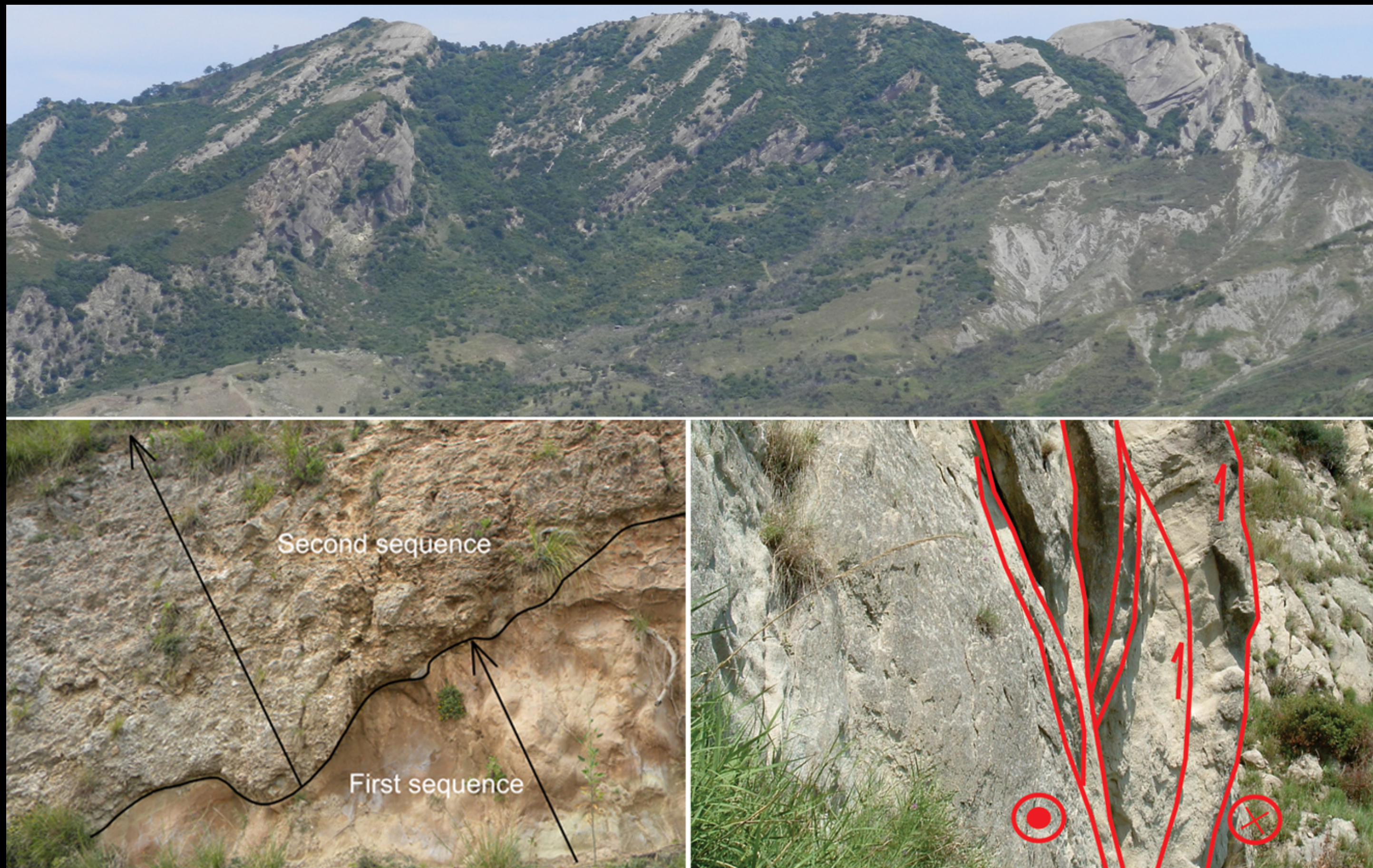
Geological Field Trips



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A Neogene-Quaternary Geotraverse within the northern Calabrian Arc from the foreland peri-Ionian margin to the backarc Tyrrhenian margin

86° Congresso Nazionale della Società Geologica Italiana, Cosenza 18-20 settembre 2012

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Abstract

The fieldtrip corresponds to a transect across the northeastern to the western Calabria. The two-days fieldtrip illustrates the Miocene to Quaternary tectono-stratigraphic features of the two distinctive Calabria margins. Sedimentary architecture and tectonic activity are testified in the infill of basins. Some structural features of the Calabrian Neogene basins cropping out in the northern sector of Calabria are exposed. The first day concerns the Neogene structural and stratigraphic evolution of the eastern Calabria margin in the peri-Ionian piedmont. The fieldtrip focus on the effects of the tectonic deformation during Neogene sedimentation in the Rossano and Crotone basins. Typical foreland-basins characterized by clastic sediments were derived from uplifted fold-thrust belts exposing sedimentary, metasedimentary and plutonic source rocks. The entire stratigraphic, structural and compositional data set are interpreted using new general models of sequential evolution of foreland basin systems. The asymmetric fold growths, are also responsible of the progressive unconformities observed in the Rossano and Crotone basins. Facies associations record strong erosion and cannibalization processes of the lower stratigraphic unit, whereas a marine clastic sedimentation persisted in the Cirò basin. The exposed stratigraphic and structural architecture are related to the offshore borehole and seismic stratigraphy, suggesting the presence of structural highs, interpreted as thrust and folds and having the main onshore evidence in the "Cariati Nappe". During the fieldtrip, some outcrops of the margin flexure and related progressive unconformities in the succession and major backthrust can be looked. Pliocene-Quaternary sedimentary architecture and tectonic activity will be observed in the Crotone basin. In the second day, the fieldtrip is mainly concentrated on the western margin of Coastal Chain along the Amantea basin. In this day other stops in the Crati basin on temporal and spatial distribution of transtensional and transpressional faulting involving the metamorphic units of the Coastal Chain and the Pliocene-Pleistocene deposits can be observed. To the north of the Amantea village, the marginal facies of the infill outcrop and the basin margin has been offset along the major fault zone. To the south of the Amantea village, tectono-stratigraphic assemblage of the second sequence and Tortonian growth faults can be observed. Panoramic view of the western Coastal Range piedmont zone will be shown during the Stop in the Fiumefreddo Bruzio village.

Keywords: *Calabria, west-east geological transect, back-arc region, foreland region, Neogene stratigraphy, basin analysis.*

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Riassunto

L'escursione consiste in una geotraversa che unisce i margini orientale e occidentale della Calabria. Durante i due giorni di escursione vengono illustrati i caratteri tettono-stratigrafici dei bacini miocenici peri-ionici e peri-tirrenici attraverso la successione di riempimento plio-pleistocenica del bacino del Fiume Crati posto tra i due margini. I caratteri strutturali dei bacini neogenici sono ben esposti nel settore settentrionale della Calabria. La prima parte dell'escursione è dedicata ai bacini peri-ionici con particolare riferimento alla porzione neogenica del bacino di Rossano-Cirò e del Bacino crotonese. I tipici bacini di foreland caratterizzati da sedimentazione clastica derivano dall'*uplift* degli orogeni con l'esposizione delle rocce sedimentarie, metasedimentarie e plutoniche. I dati stratigrafici, strutturali e composizionali sono stati interpretati usando nuovi modelli generali dell'evoluzione sequenziale dei sistemi di bacini di foreland. La crescita di pieghe asimmetriche è responsabile delle *unconformity* progressive osservabili nei bacini di Rossano e Crotone. Le associazioni di facies registrano una forte erosione e processi di cannibalizzazione della prima unità deposizionale, mentre nel bacino di Cirò persisteva una sedimentazione clastica marina. L'architettura stratigrafica e strutturale esposta è stata correlata ai pozzi e alle stratigrafie sismiche presenti in *offshore*, suggerendo la presenza di alti strutturali, interpretati come *thrust* e pieghe aventi la maggiore evidenza a terra nella "Falda di Cariati". In alcuni stops possono essere osservati il margine deformato e le relative discordanze progressive nella successione legate ai *back-thrust* principali. L'architettura deposizionale plio-pleistocenica e l'attività tettonica sono osservabili nella successione del bacino crotonese. Durante il secondo giorno, l'escursione è principalmente concentrata sul margine occidentale della Catena costiera lungo il bacino di Amantea. Lungo l'itinerario è possibile osservare la distribuzione spazio-temporale della deformazione transtensiva e transpressiva all'interno del bacino del Crati, che coinvolge sia il substrato metamorfico della Catena costiera, sia la successione plio-pleistocenica. A nord della cittadina di Amantea, le facies marginali del riempimento miocenico del bacino di Amantea sono deformate lungo il sistema di faglia principale. A sud della cittadina, viene osservata l'architettura tettono-stratigrafica della seconda sequenza e le faglie di crescita tortoniane. Una visione panoramica generale del margine occidentale della Catena costiera è osservabile dal paese di Fiumefreddo Bruzio.

Parole chiave: *Calabria, transetto geologico ovest-est, back-arc, foreland, stratigrafia neogenico-quaternaria, analisi di bacino.*

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Program

The field trip consists in a geological transect starting from the north-eastern and eastern Ionian margin of Calabria, crossing the central area of the Crati Valley and ending in the Tyrrhenian margin of Calabria. The fieldtrip illustrates the Neogene to Quaternary tectono-stratigraphic evolution of the two distinctive Calabria margins.

The first day concerns the Neogene structural and stratigraphic outline of the eastern Calabria margin. From the Mandatoriccio village (Stop 1.1) is possible to recognize outcrops of the autochthonous Middle Miocene deposits accumulated in longitudinal wedge-top depozones and the main onland outcrop of the allochthonous succession represented by the so-called Cariati nappe. Tectonic assemblage and structural kinematics of the back-thrust and major transcurrent faults are detailed in the village of Scala Coeli (Stops 1.2) and near San Morello (Stops 1.3). After the lunch, the fieldtrip continues in the Crotone basin, where the Lower Pliocene and late Pliocene basin infill is outlined. Stratigraphic and tectonic architecture of the northern side of the basin is well documented in the Stop 1.4, near Casabona (Casabona horst and the South Casabona half-graben). The deposition of the Spartizzo clay (middle Pliocene) was controlled by the activity of the fault bounding the south Casabona half-graben, favouring the accumulation of a relatively thick succession. The Stop 1.5 concerns the western side of the Vitravo Valley where crops out prograding forced-regressive wedges of the Zinga sandstone. The architecture was controlled by the growth of a NE-trending non-cylindrical anticline (Russomanno anticline), while the Belvedere formation, within the Belvedere half-graben, was linked to the activity of NE-trending listric normal growth fault. The structures represent the effect of deformation induced by salt tectonics. The first day end with the oucrop of the Serra Mulara formation (Stop 1.6), a middle Pleistocene coarse-grained canyon fill succession.

The second day starts crossing the Sila Massif and reaches the Crati Valley basin. The field trip starts in a quarry located on the eastern margin of the Crati basin. In the Stop 2.1 is well exposed the architecture of the lower Pleistocene marginal delta type deposits. Facies associations of the clastic infill with spectacular normal and strike-slip faults are exposed. Crossing the Crati Valley reach the Stops 2.2 and 2.3. In these stops the temporal and spatial distribution of transtensional and transpressional faulting, involving the metamorphic units of the Coastal Chain and the Pliocene-Pleistocene deposits, can be observed. The field trip continues crossing the Coastal Range and arriving to Fiumefreddo Bruzio for the lunch and for the visit to the Medieval

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Castle. The field trip moves for the village of Belmonte Calabro where the Serravallian-Tortonian sequences of the Amantea basin infill are well cropping out in the Stop 2.4. To the north of the Belmonte Calabro village (Regastili site, Stop 2.5) the marginal facies of the infill crops out and the basin margin is offset by a major transpressional fault zone. The last stops are located to the south of the Amantea village (Stops 2.6 and 2.7). The tectono-stratigraphic architecture of the Tortonian sequence is characterized by growth faults and roll-over anticline belonging to the opening of the Tyrrhenian back-arc basin.

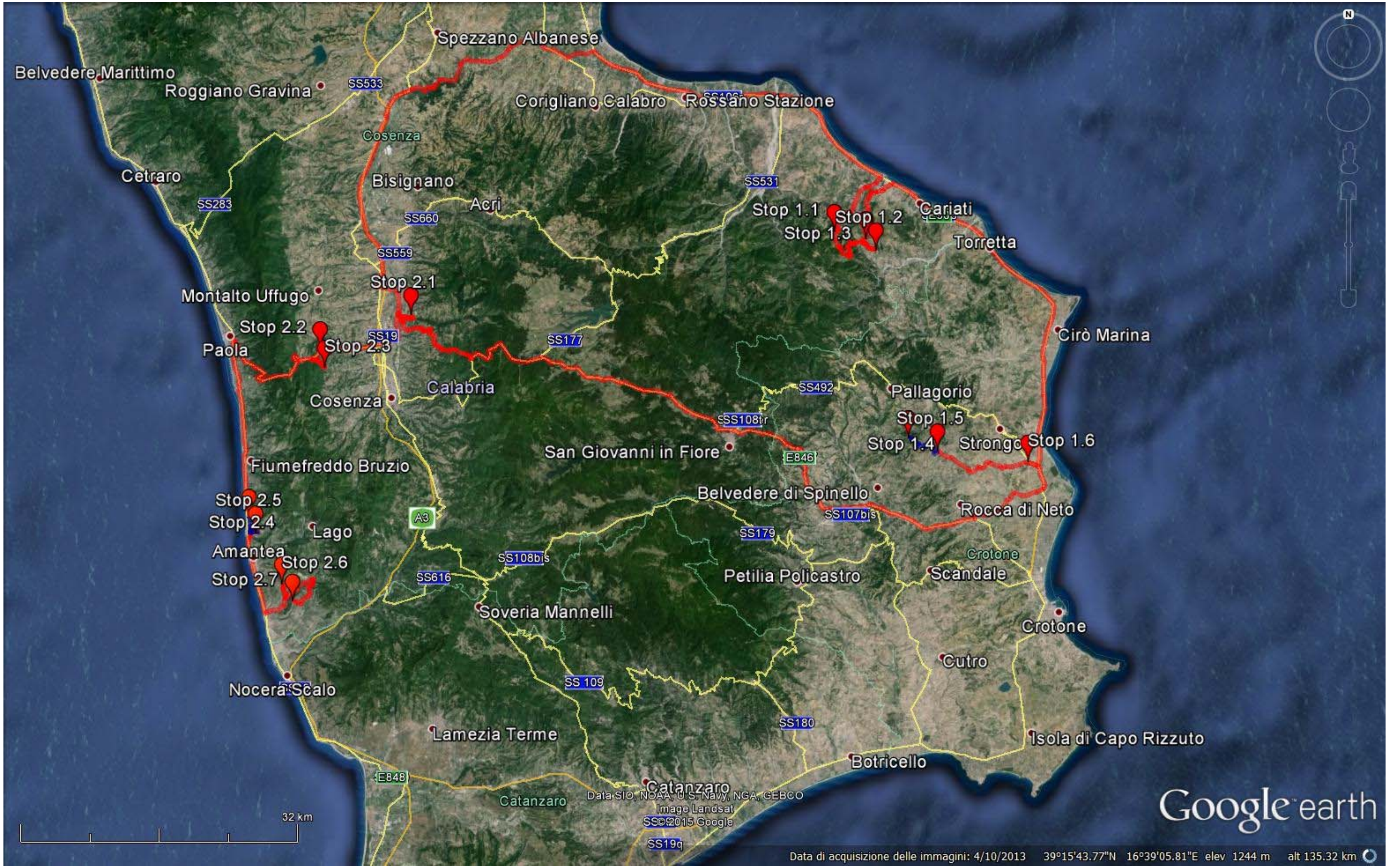

Fig. 1 – Geographical location of the field trip area, roadmap and Stops.

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Safety

Hardhat, hat, hiking shoes, sunglasses, are strongly recommended.
Depending on the weather conditions, the path in the San Morello (CS) stops could be slippery. Reflective vest for stops along the road.

Hospital

- Ospedale Civile di San Giovanni in Fiore (CS), Via Gramsci. Phone 0984 9790.
- Ospedale Annunziata, Via Migliori 1, 87100 - Cosenza. Phone 0984 6811.

Emergency Contact Numbers

- Medical Emergencies 118;
- Fire Department 115;
- State Police 113.

Accomodation

Biafora Resort & SPA in Sila, S.S. 107 - Locality Torre Garga 9, 87055 - San Giovanni in Fiore (CS)
Phone 0984 970078.
A list of farmhouse in the Crotone province is available at the website:
http://www.provincia.crotone.it/agriturismo/
The farm resort very close to the crotonese outcrops is: http://www.dattilo.it/#_=_

Visits

- Librandi (Cirò) Wine farm, SS 106 - C.da San Gennaro, 88811 - Cirò Marina (KR).
www.callmewine.com/it/cantina/librandi.html
- Medieval Castle of Fiumefreddo Bruzio (CS).
http://www.calabriaintour.it/fiumefreddo-bruzio.asp

<u>During the field trip the Stop 2.1 requires permission to enter in the Arente River quarry</u>.

Field Trip Sponsors

- University of Calabria;
- Department of Biology, Ecology and Earth Sciences;
- Librandi (Cirò Marina, KR) Wine farm;
- Hotel Biafora (San Giovanni in Fiore, CS);
- Municipality of Fiumefreddo Bruzio (CS).

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Geological setting

The Calabrian Terranes form an arcuate mountain belt that lies between the thrust belts of the Apennines to the north and the Maghrebian Chain to the south. There is a general agreement in the literature on the geometrical position of the Calabrian Arc units, and on their ages. Mesozoic carbonates, Mesozoic ophiolites, Paleozoic-Mesozoic slates and metapelites, Paleozoic orthogneisses, and Paleozoic paragneisses are observed from bottom to top; these units are frequently covered by Meso-Cenozoic sedimentary successions.

The modern physiography and geology of Calabria are the results of post-30 Ma geodynamic processes in which synchronous accretionary processes were active along the eastern flank (northern Ionian Sea), and rifting processes along the western flank (Eastern Tyrrhenian Margin).

The active frontal edge of the accretionary wedge is buried below sea-level and covered by Pliocene-Quaternary foreland deposits, whereas the main elevated ridge to the west is characterized by uplift and extensional processes. The modern basin configuration of the thrust belt includes the wedge-top depozone (the Corigliano-Amendolara basins), the marine and subaerial foredeep depozone (the Gulf of Taranto and the Bradano river basin), the forebulge (the Gallipoli basin) and the back-bulge (the southern Adriatic Sea; *e.g.,* Critelli & Le Pera, 1998). Several Pliocene-Pleistocene basins cross-cut the Apennines and northern Calabria thrust pile; among these, the Mercure basin and the Crati basin are the most important in Calabria (e.g. Turco et al., 1990; Cinque et al., 1993; Colella, 1994; Tortorici et al., 1995; Schiattarella, 1998; Tavarnelli & Pasqui, 1998).

On the back-arc area, fault-controlled Pliocene-Pleistocene basins (Tortorici et al., 1995), such as the submarine Paola basin and the Gioia basin, represent the synrift troughs of the eastern Tyrrhenian margin (*e.g.*, Savelli & Wezel, 1980; Barone et al., 1982; Sartori, 1982, 1990).

Since Middle Miocene, overthrusting combined with the progressive migration of the Calabrian Arc towards southeast was associated with the opening of the Tyrrhenian Basin (Malinverno & Ryan, 1986; Dewey et al., 1989; Decandia et al., 1998). Thick and continuous successions of Miocene basins occur in several outcrops along the Tyrrhenian margin of Calabria (Amantea, Paola and Belvedere Marittimo basins). In the same area the Pliocene-Pleistocene strata constitute the thick sedimentary succession of the Paola slope basin (Argnani

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& Trincardi, 1988; Milia et al., 2009). Since Late Miocene, the ancient reverse contacts responsible for the building of the Calabrian nappe complex were reactived by extensional tectonics (Rossetti et al., 2001; Mattei et al., 2002; Cifelli et al., 2007b).
The Calabrian orogenic belt is composed by a thrust sheet of Palaeozoic basement units, belonging to the former European-Iblean margin, over-thrusting, since Oligocene, ophiolite bearing units of the Neo-Tethys domain (Ogniben, 1973; Amodio Morelli et al., 1976; Dewey et al., 1989). Since the Middle Miocene, such tectonic edifice tectonically covered Mesozoic carbonate rocks of the Apenninic Maghrebide Chain. In particular, the Neogene to Quaternary history of the orogenic edifice is mainly controlled by the activity of NW-SE striking, sinistral shear zones (Catalano et al., 1993; Van Dijk et al., 2000), driving the differential south-eastwards migration of the Calabrian Arc Neogene foredeep and wedge-top depozones of the foreland basin system of the growing orogenic belt and flexed Adria passive margin (Critelli & Le Pera, 1998). The geodynamic evolution of the central Mediterranean is the result of complex interactions between collisional processes and extensional tectonics controlled by the Cenozoic convergence between African and Eurasian plates (Dewey et al., 1989). The main tectonic elements generated by these processes since the Neogene, are the southern Apennine-Maghrebian Chain and the Tyrrhenian back-arc Basin, both linked to the westward subduction of the Adriatic and Ionian lithospheres (Fig. 2). The back-arc extension in the Tyrrhenian area was discontinuous, with migration of the locus of extension with time, and it accompanied the shortening in the Apennine-Maghrebian fold and thrust belt (Malinverno & Ryan, 1986; Finetti et al., 2005a, b). This extension was directed toward the east from Tortonian to early Pliocene, generating the Vavilov sub-basin, and toward the SE during late Pliocene-early Pleistocene, when the Marsili sub-basin was opened (Patacca et al, 1990; Sartori, 2003). Episodicity in the Tyrrhenian back-arc extension was attributed to the interference of the retreating oceanic slab with intervening buoyant continental foreland lithosphere (Apulian and Pelagian blocks), leading to temporary stop or strong slowing-down of the subduction (Argnani & Savelli, 1999; Sartori, 2003). Slab tearing episodes accompanied by mantle lateral flow are commonly invoked for the subsequent resumption of the subduction (Faccenna et al., 2004; Chiarabba et al., 2008).

In this frame, the Calabrian Arc represents an independent arcuate terrane (the Calabria-Peloritani Terrane of Bonardi et al., 2001) that connects the NW-trending southern Apennine Chain and the E-trending Sicilian Maghrebides, and separates the Ionian and Tyrrhenian basins (Fig. 2). It is composed of a pile of pre-Mesozoic

polymetamorphic nappes comprising large sheets of an Hercynian crystalline basement (forming the Sila and Aspromonte Massifs) and local remnants of a Mesozoic to Cenozoic succession, considered by some authors as a fragment of the Alpine belt overthrusted upon the Triassic-Miocene sedimentary sequence of the Apennine-Maghrebian Chain during Miocene (Amodio Morelli et al., 1976).
The Calabrian Arc migrated south-eastward from mid-Miocene onwards in response to the subduction of the Ionian oceanic lithosphere along a deep and narrow, W-dipping Benioff zone (Malinverno & Ryan, 1986; Bonardi et al., 2001; Faccenna et al., 2001, 2004; Sartori, 2003; Finetti et al., 2005a). The diachronous collision between the Apennine-Maghrebian Chain and the Apulian foreland to the north, and the Pelagian block to the south, coupled with a different velocity of propagation of the thrust front (*e.g.*, Lickorish et al., 1999), produces the arcuate shape exhibited by the central sector of the Calabrian Arc (Fig. 2), through both clockwise (Sicily and Calabria) and counter-clockwise (southern Apennines) rotations in a "saloon-door" fashion until early Pleistocene, as testified by paleomagnetic investigations (Rosenbaum et al., 2002; Speranza et al., 2003; Cifelli et al., 2007a; Mattei et al., 2007). The movement toward the SE caused a fragmentation of the arc in individual blocks bounded by NW-trending shear zones, which controlled the development of basins located along both the Ionian and Tyrrhenian sides of Calabria (Knott & Turco, 1991; Lentini et al., 1995). These shear zones are characterized by left-lateral movement in the central and northern parts of the arc, and right-lateral movement in the south (Knott & Turco, 1991; Van Dijk, 1991, 1994; Tansi et al., 2007; Del Ben et al., 2008; Turco et al., 2012; Tripodi et al., 2013). The northernmost NW-trending shear zone is represented by the Pollino line, the major shear zone produced by continental oblique collisional processes, separating the Calabrian Arc from the southern Apennines (Fig. 2).

The offshore external region of the Calabrian Arc displays a thick and wide accretionary wedge composed of deformed Mesozoic and Cenozoic sediments belonging to the African plate, that shapes with a rugged topography the sea-floor of the Ionian Sea from the Malta to the Apulia escarpments, and is characterized by an active front in the Ionian abyssal plain (Polonia et al., 2011). The Messinian salinity crisis is inferred to have influenced the evolution of the wedge, as the basal decollement ramps up onto the Messinian salt deposits, producing a fast forward progradation of the frontal thrust and the consequent underplating of the crustal ionian sequence during trench rollback (Minelli & Faccenna, 2010).

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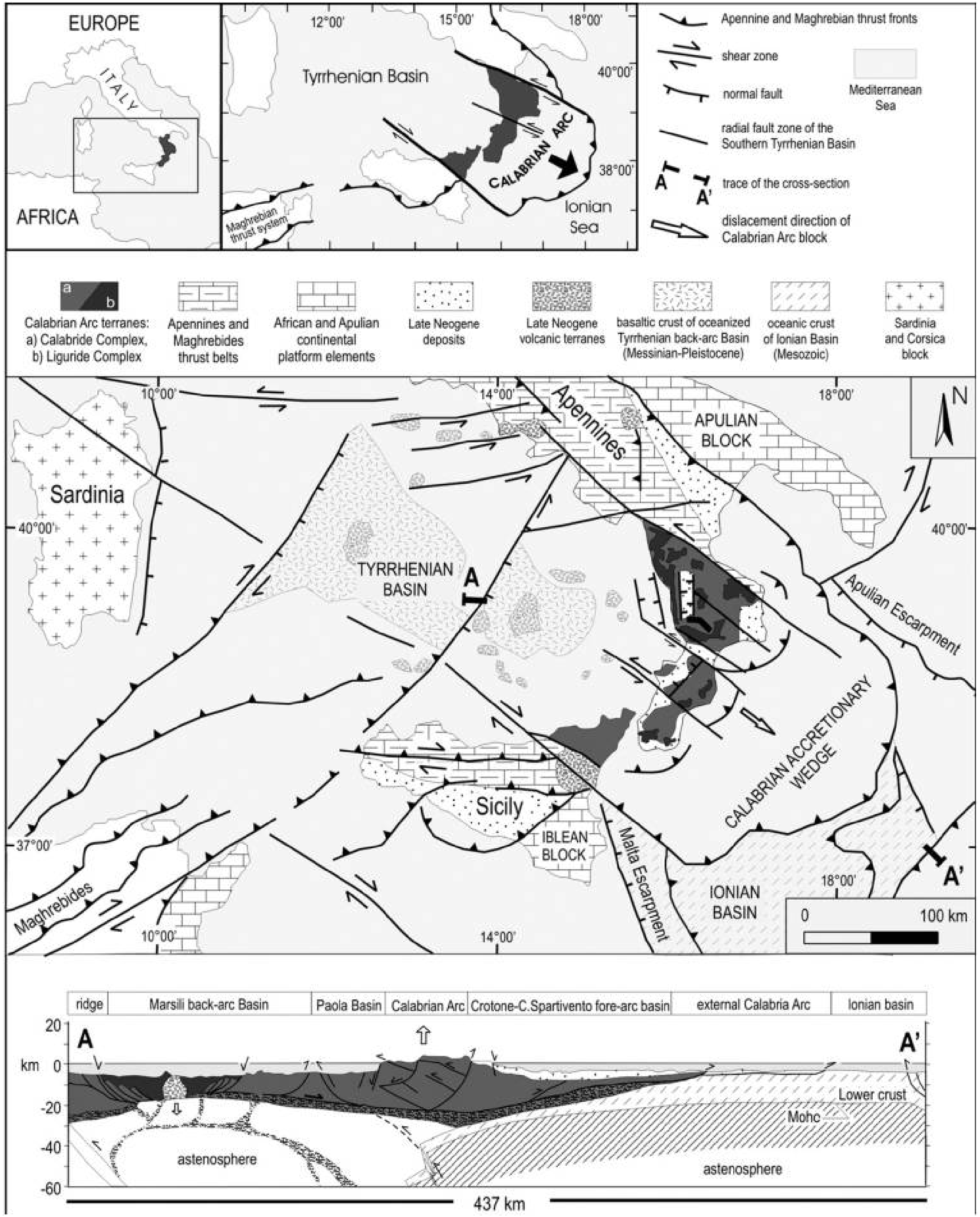

The modern physiography and geology of Calabria are the result of Miocene geodynamic processes in which synchronous accretionary processes were active along the eastern flank (northern Ionian Sea), and rifting processes along the western flank (Eastern Tyrrhenian margin). Double verging thrusts (i.e. with vergence coherent and opposite to the accretionary wedge) have been documented in the Ionian off-shore (Roveri et al., 1992, Doglioni et al., 1999; Van Dijk et al., 2000). However, similar structures are not clearly described and structurally constrained on-land. The on-shore stratigraphic and structural research better constrain the geometries and timing of deformation in the wedge-top basin. The modern setting includes two different styles of basins: A) the Corigliano basin, on the Ionian side, is a wedge-top depozone, located above thrust-sheets of the Calabrian Arc and southern Apennines terranes; B) the Paola basin, on the Tyrrhenian side, is a slope basin located on the eastern margin of the Tyrrhenian back-arc Basin (Critelli, 1999).

Fig. 2 - Geological sketch-map of the central Mediterranean area, with geological section on bottom (Tansi et al., 2007; after Van Dijk & Scheepers, 1995 and Van Dijk et al., 2000, modified).

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The tectono-sedimentary evolution of the basin successions cropping out along the northeastern Calabrian margin was investigated, describing timing, style and tectonic evolution (Critelli, 1999; Critelli et al., 2011). Middle Miocene deposits accumulated in a longitudinal wedge-top depozone of the calabrian foreland basin system, partitioned in three distinctive depocentres: Rossano, Cirò and Crotone basins. In the ionian side of the Calabrian Arc the Neogene and Quaternary basin successions overlie Paleozoic alpine units and their relative Mesozoic cover (Amodio Morelli et al., 1976). The Late Oligocene-Lower Miocene Paludi formation (Bonardi et al., 2005) unconformably overlies pre-Tertiary rocks and crops out along the eastern sector of the northern Calabria. The Paludi formation consists of alluvial conglomerates and breccias evolving to reddish and green marls and siltstones with interbedded graded calcarenites, turbiditic sandstones and silty marls with vulcanoclastic levels. On top of both crystalline rocks and Oligocene flysch, a Serravallian to Pliocene terrigenous and carbonate sequences constitute the infilling of the thrust-controlled Calabrian foreland, which can be subdivided in three main depozones.

The Amantea basin (Di Nocera et al., 1974; Colella, 1995) is one of the main Neogene basins along the Tyrrhenian margin of Calabria. The onset of the basin occurred in response to tectonic subsidence related to extensional faulting during the Serravallian-Early Tortonian (Critelli, 1999; Rossetti et al., 2001; Muto & Perri, 2002). The sedimentary infill has been subdivided into five main depositional units, bounded by stratigraphic discontinuities (Colella, 1995; Mattei et al., 2002; Muto & Perri, 2002), underlying sediments and bedrock. Middle Pliocene to Middle Pleistocene deposits, made of thick conglomerate-sand-sandstone-clay marine successions, represent the basin-fill deposits of the main tectonic depressions (Crati basin, Catanzaro trough). The Crati graben (Lanzafame & Tortorici, 1981; Tortorici, 1981; Tansi et al., 2005, 2007; Cifelli et al., 2007b; Pepe et al., 2010; Spina et al., 2011) is characterized by N-S trending transtensional quaternary faults, which separate Late Miocene-Quaternary deposits from the Paleozoic and Mesozoic rocks of the Calabrian Terranes in the Coastal Chain and in the Sila Massif, on its western and eastern margins, respectively.
The Serravallian-Tortonian stratigraphy of the Crotone basin is similar to that of the Rossano basin, at least until deposition of the Tripoli Formation. In the Crotone basin, the Tripoli Formation is overlain by clastic successions consisting of limestone breccias grading to gypsrudites–gypsarenites and gypsum-bearing sandstones (“evaporitica inferiore unit”). These successions are overlain by deposits consisting of meter-scale blocks of limestone, gypsarenite breccias, and gypsarenite slumps (“detritico-salina unit”) (Roda, 1964). In this basin, halite deposits crop out in several places and show evidence for diapiric emplacement and local salt tectonics. An Upper Messinian succession consisting of shale, sandstone, and minor gypsarenite levels (“evaporitica superiore

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unit") with a "Lago-Mare" fauna onlaps the detritico-salina unit at the top. An erosional surface marks the boundary between these uppermost Messinian deposits from the overlying deltaic sand lobes and fluvial conglomerates of the Carvane conglomerate unit. The sedimentary succession of the Crotone and Rossano basins can be subdivided into two main sedimentary cycles bounded by unconformities, a first cycle of Serravallian to Early Messinian age and a second cycle of Early to Late Messinian age (Barone et al., 2008). These cycles are capped in the Crotone basin by transgressive outer-shelf deposits of the Cavalieri marl unit and a thick Pliocene-Quaternary succession (Massari et al., 1999; Zecchin et al. 2004a, 2012). In the central area (Cirò basin) a thick siliciclastic succession, known as "Cariati Nappe" *auct.*, overthrusted on the Upper Tortonian-Messinian sequences (Muto et al., 2009; Tripodi et al., 2009, 2011). The succession was involved in oblique back thrusting related to regional oblique tectonic arrangement. The "Cariati Nappe" *auct.* includes two thinning and fining upward units, unconformably covering the Oligocene siliciclastic strata of the Paludi formation (Roda, 1967; Roveri et al., 1992; Van Dijk et al., 2000; Critelli et al., 2011). The succession starts with conglomerates and sandstones recording braided fluvial and deltaic facies associations, and passing to prodelta turbiditic bodies. The NW-SE striking shear zone led to the configuration of intrabasinal structural highs and wedge-top partitioning during the Neogene (Van Dijk et al., 2000; Barone et al., 2008). A complex network of strike-slip faults and associate thrust characterise the entire Ionian side of the northern Calabria. Huge volumes of sicilide-derived rocks composed of variegated clay matrix and large blocks of limestone and sandstones have been emplaced during Late Tortonian-Early Messinian. The latter bodies can be related to the accommodation due to out-of-sequence thrusts, or to the thrust propagation of the "Sicilide Complex". Throughout along the Ionian side of the northern Calabria, bodies of varicoloured clays ("Anti-Sicilide Complex" *sensu* Ogniben, 1969) have been observed within Late Miocene deposits. Varicoloured clays ("Anti-Sicilide Complex" *sensu* Ogniben, 1969) have been observed along the Ionian coast of the northern Calabria and are associated with basement slices composed of black slates and limestone breccias (Van Dijk et al., 2000). The Ionian fore-arc Basin develops internally with respect to the accretionary wedge since Late Oligocene along the Ionian side of the Calabrian arc (Cavazza & DeCelles, 1993; Bonardi et al., 2001; Cavazza & Barone, 2010). It is composed of some parts nowadays uplifted and cropping-out along the Ionian coast, such as the Crotone basin, and of a main active area (the Crotone-Spartivento basin). The neotectonic transcurrent activity of the transversal fault zone offsets the accrectionary front of the chain and provides structural high separating pull-apart depressions in on-shore and in off-shore zone (Amendolara, Rossano, Cariati, Cirò Ridges) (*e.g.*, Pescatore & Senatore, 1986; Romagnoli & Gabbianelli, 1990).

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Since Middle Pleistocene, the Calabrian Arc experienced a rapid uplift up to ca. 1 mm/yr (Westaway, 1993) that persists today, as documented by marine terrace flights developed along the coast. Some hypotheses have been proposed to explain this uplift, such as an isostatic rebound that follows the breaking of the subducted Ionian crust (Spakman, 1986; Westaway, 1993; Wortel & Spakman, 2000) or a convective removal of the deep root and consequent decoupling of the arc from the subducting plate (Doglioni, 1991; Gvirtzman & Nur, 2001; D'Agostino & Selvaggi, 2004). The uplift was locally accommodated by repeated displacement along the major active faults (Monaco & Tortorici, 2000; Catalano et al., 2003). Pulsating tectonics and recent and active transpressional tectonics is documented on the eastern calabrian margin by Ferranti et al., 2009. The Crotone basin is bounded to the north and to the south by two NW-trending left-lateral shear zones, called Rossano-San Nicola fault and Petilia-Sosti fault respectively (Meulenkamp et al., 1986; Van Dijk, 1990, 1991, 1994; Van Dijk & Okkes, 1991), and is currently separated from the Crotone-Spartivento basin by some thrust fronts (Fig. 2). The Crotone basin began to open between Serravallian and Tortonian time (Roda, 1964; Van Dijk, 1990), and its tectonic history was characterized by a dominant extensional tectonic regime that was interrupted periodically by relatively short compressional or transpressional phases in middle Messinian, Middle Pliocene and Middle Pleistocene times (Van Dijk, 1990, 1991; Zecchin et al., 2004a, 2012; Massari et al., 2010). Since Middle Pleistocene, a main shift from dominant subsiding conditions to generalized uplift led to the emergence of the basin (Gliozzi, 1987; Cosentino et al., 1989; Zecchin et al., 2004b, 2012). Tectonic structures strongly controlled the geometry of the Neogene basin as consequence of the progressive south-eastwards shifting of the Calabrian Arc.

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Day 1
The Cirò and Crotone basins

The San Nicola dell'Alto formation (Ogniben, 1955; Roda, 1964) and the Clypeaster sandstone formation (Cotecchia, 1963) represent the onset of the foreland basin system on advancing Calabrian thrust belt. These strata include several sedimentary facies associations, representing a depositional sequence (Roveri et al., 1992), and they are interpreted as a turbiditic system, having an overall fining and thinning upward trend, in the Crotone basin (with a thickness over 1000 m; Roveri et al., 1992).
The formations constitute the main reservoir of dry gas in the off-shore area (Roveri et al., 1992). In the other areas, these strata include also continental strata (alluvial fans), nearshore and shallow-water deposits (between Bocchigliero and Campana). These strata are overlain by fine-grained turbiditic systems and by shelfal deposits toward the thrust culminations of the Sila Massif. These strata correspond to the Ponda formation (Roda, 1964) of the Crotone basin, or the Argilloso-Marnosa formation (Ogniben, 1955) of the Rossano basin, and may represents deposition during low-stand systems tract (Roveri et al., 1992). During late Tortonian-early Messinian, the Rossano wedge-top depozone abruptly received huge volumes of sicilide-derived olistostroma "Argille Scagliose formation" (Ogniben, 1955, 1962) composed by variegated clay matrix and large blocks (olistholiths) of Cretaceous-Oligocene limestone, Miocene quartzolithic (similar to the Albanella-Colle Cappella sandstones) and quartzose sandstones (Numidian sands). These gravity flow deposits may be related to an out of sequence thrust accommodation or to a back-thrust of the sicilide unit. The Castelvetere formation has similar olistostrome layers within the foredeep depozone (Critelli & Le Pera, 1995b).

The “Cariati Nappe”, a sedimentary allochthonus succession (Roda, 1967a; Ogniben, 1973), rests tectonically on the successions of the Rossano (to the north) and Crotone (to the south) basins. This succession is made up of turbiditic bodies with thinning-upward trend of Langhian-Serravallian age, involved in backthrust starting from Late Tortonian and involving the evaporitic and post evaporitic units in the Rossano basin (Figs. 3, 4, 5). The “Cariati Nappe” includes a Middle to Upper Miocene clastic succession unconformably covering an Oligocene to Burdigalian siliciclastic flysch. The Miocene and post Messinian emplacement of the “Cariati Nappe” interrupts the lateral continuity in the central sector of the area and affects the sedimentary supply of a such configured wedge-top basin. The Messinian sequence is characterized by evaporite deposits which records the Mediterranean salinity crisis. The evaporites

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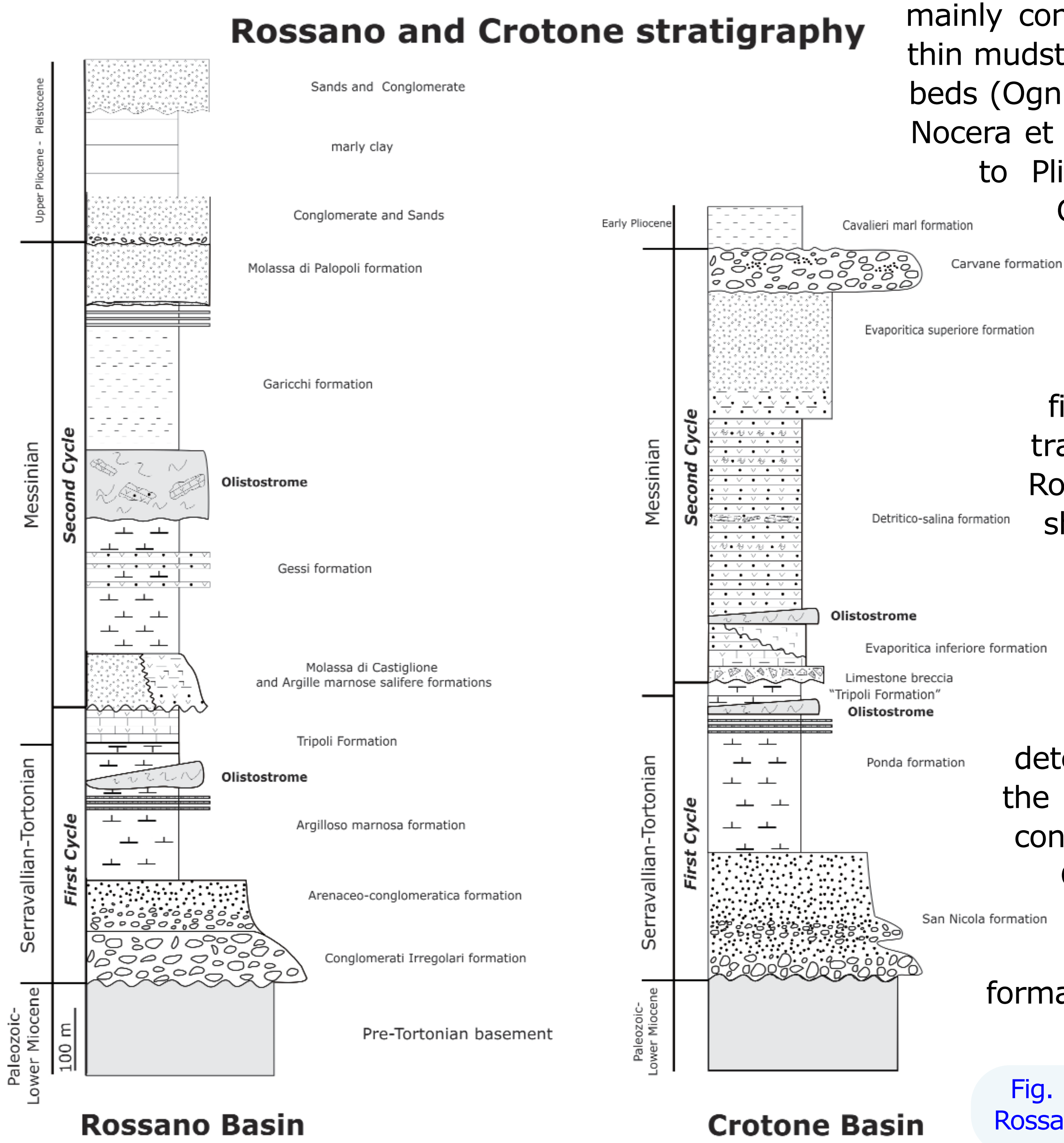
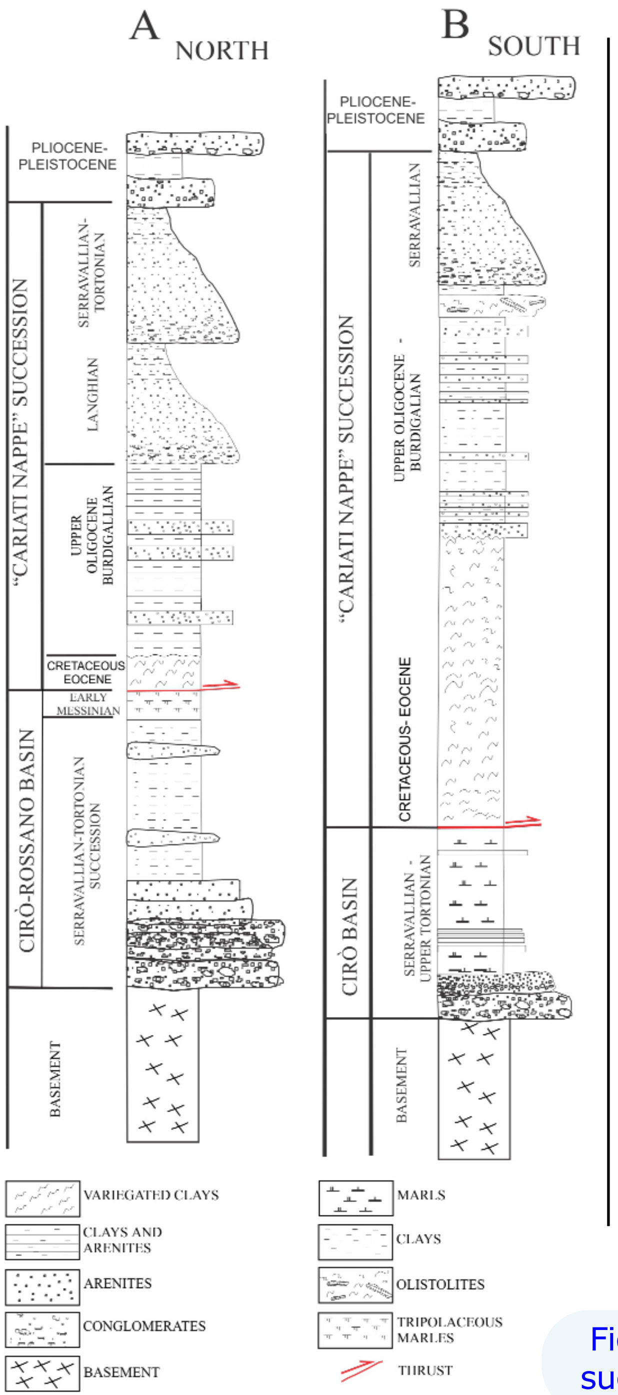


mainly consist of gypsum and halite, followed by a thin mudstone interval, and thin clastic and evaporite beds (Ogniben, 1955; Roda, 1964; Romeo, 1967; Di Nocera et al., 1974). The base of the late Messinian to Pliocene depositional sequence within the Crotone basin, is marked by an erosional unconformity overlying the evaporite sequence (Roveri et al., 1992). This depositional sequence consists of a basal conglomerate and sandstone strata with fining-upward trend (transgressive systems tract; Carvane conglomerate formation; Roda, 1964), overlain by basin-wide marine shales (highstand systems tract; marne argillose dei Cavalieri formation; Roda, 1964) (Roveri et al., 1992). The juxtaposition of basinal successions (Rossano and Crotone successions) and the Cariati nappe would suggest the detection, during the Serravallian-Tortonian, of the sedimentary basins developed in different contest; a basin on the inner set of the Calabrian Arc units which the western edge is well cropping out, and an outer external basin set on sicilidi units and Albidona formation. Therefore, the Cariati nappe would

Fig. 3 - Stratigraphic columnar sections of the Rossano and Crotone basin fill, after Barone et al., 2008.



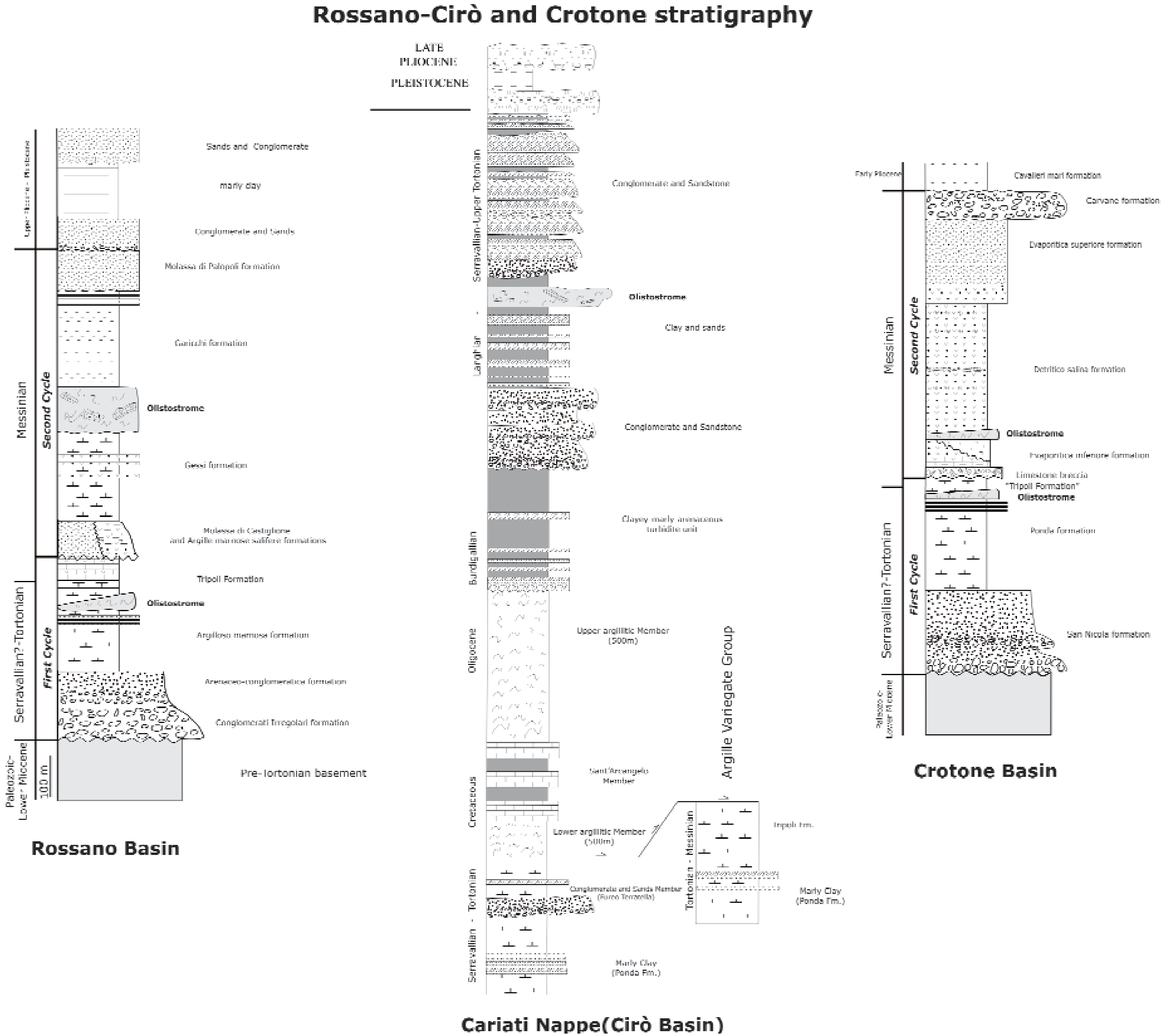


Fig. 4 - Stratigraphic columns of the “Cariati Nappe” and comparison of the three basin successions (from Muto et al., 2009; Muto et al., 2013).

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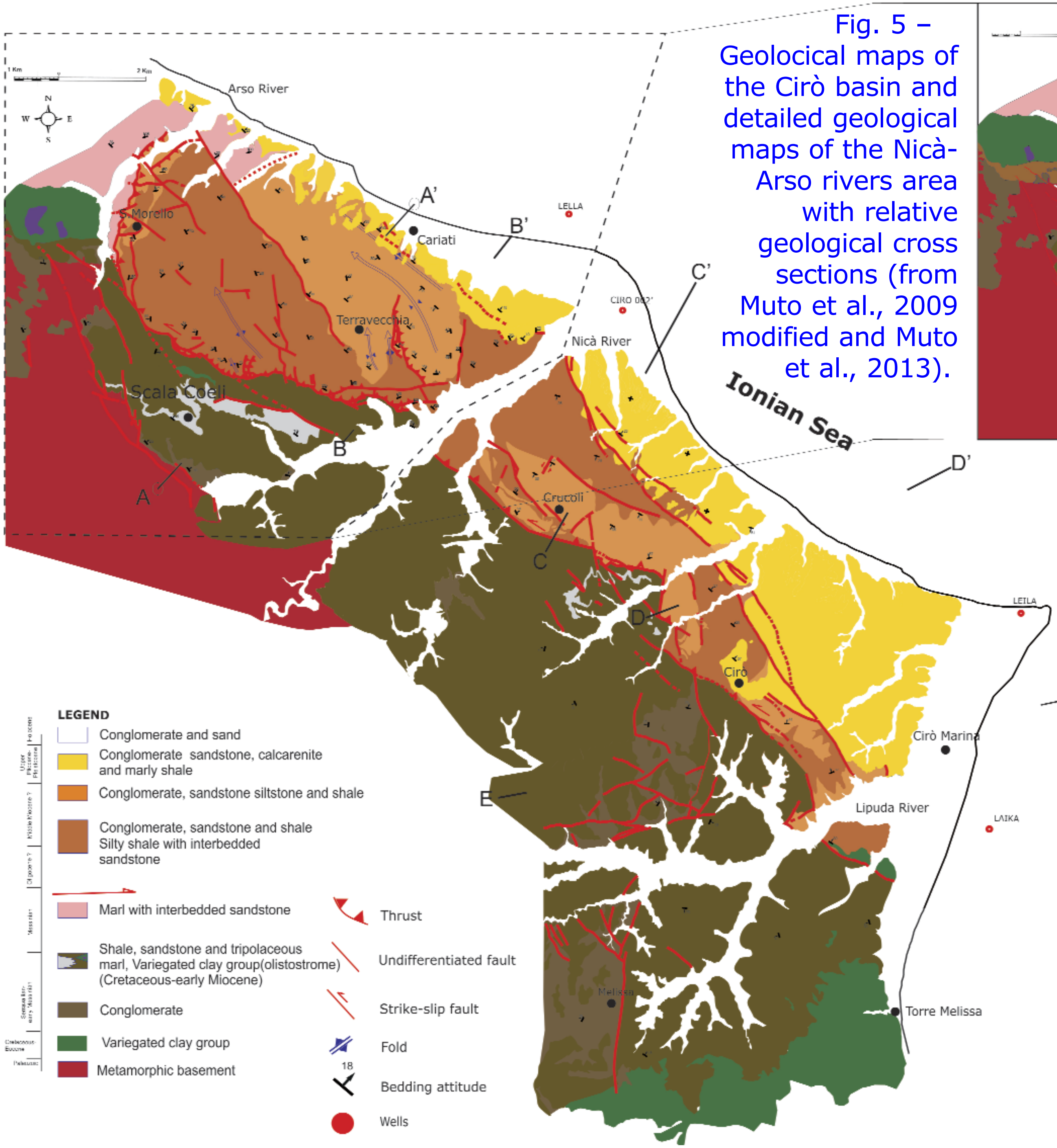
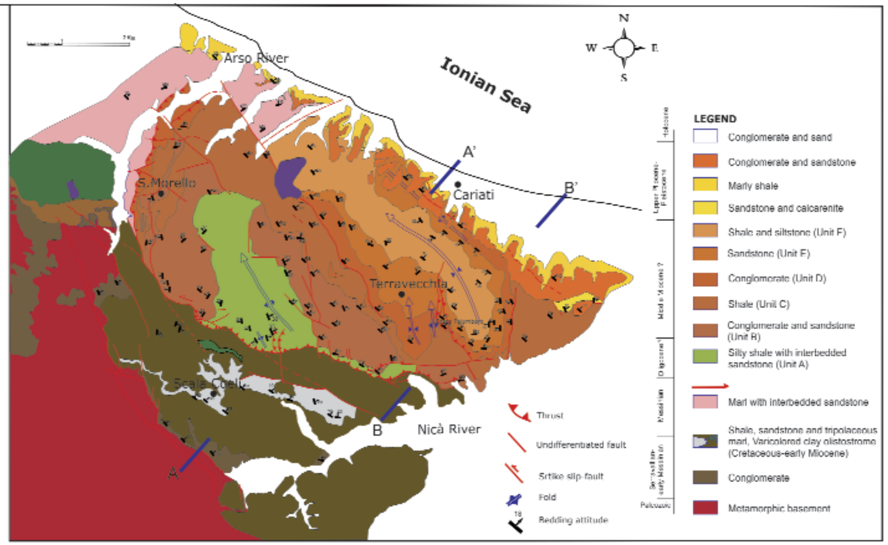
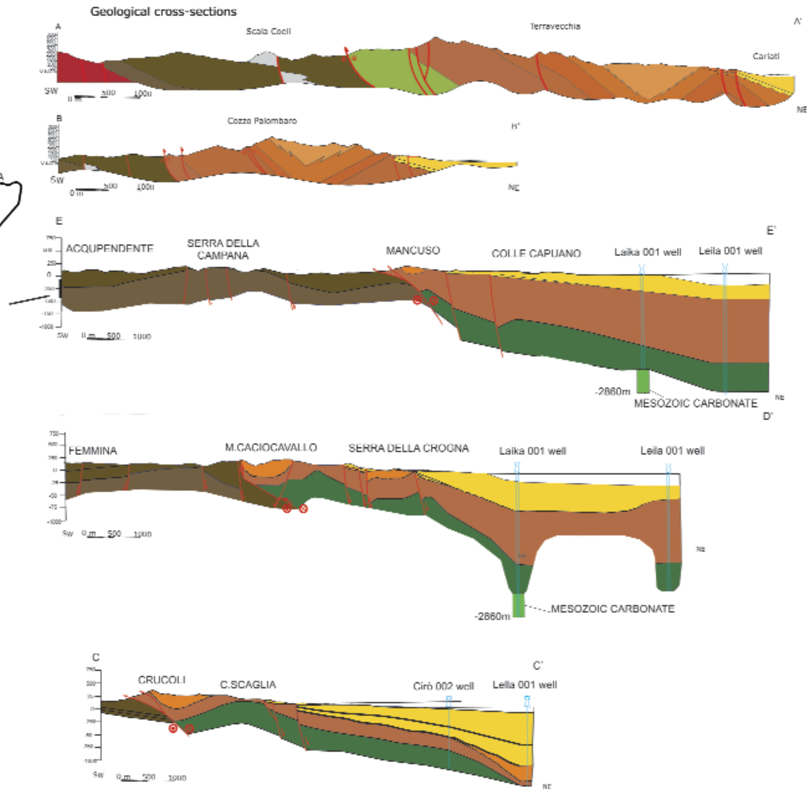


Fig. 5 – Geolocical maps of the Cirò basin and detailed geological maps of the Nicà-Arso rivers area with relative geological cross sections (from Muto et al., 2009 modified and Muto et al., 2013).





give the meaning of a backthrust of Tortonian age, related to the upper-middle Miocene accretionary phases that sharing the foreland basin system of the intersection of southern Apennines-Calabrian terrane. Because of its sedimentary succession, the Cariati nappe would include many tectonostratigraphic similarities with the sedimentary successions of the upper Ionian Calabria and Lucania, which identify the area of the Montegiordano-Nocara-Rocca Imperiale ridge (Zuppetta et alii, 1984; Mostardini & Merlini, 1986; Patacca & Scandone, 1987, 2001; Carbone & Lentini, 1990; Cinque et alii, 1993; Critelli, 1999; Critelli et al., 2011), where on the successions of the Albidona formation and the hight portion of the sicilidi units, rest conglomeratic and arenaceous turbiditic deposits belonging to Serravallian-Tortonian Oriolo formation and Nocara conglomerates formation.

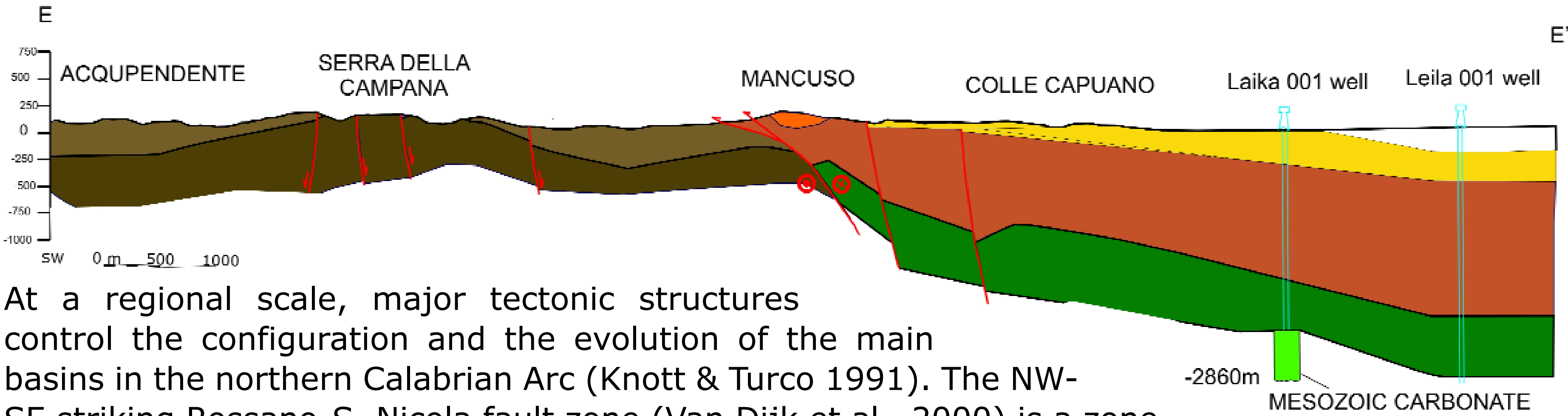


Fig. 6 – Geological section E-E' of the fig. 5, (from Tripodi et al., 2011 and Muto et al., 2013).

At a regional scale, major tectonic structures control the configuration and the evolution of the main basins in the northern Calabrian Arc (Knott & Turco 1991). The NW-SE striking Rossano-S. Nicola fault zone (Van Dijk et al., 2000) is a zone of deformation exposed along the Ionian side of the northern Calabria. This fault zone affects Neogene-Quaternary deposits belonging to the Calabrian foreland basin system and controlled, in a sector of fault releasing bend, the configuration of the Plio-Quaternary Crotone basin, to the south. Transpressional features formed as result of strain partitioning along left lateral strike-slip faults and offset the Miocene fault-propagation-folds. The main onland transpressional high is represented by the Cariati nappe.

A positive structure made up of allochthonous siliciclastic successions is represented by the Cariati nappe. It includes a Middle to Upper Miocene clastic succession unconformably covering an Oligocene to Burdigalian siliciclastic flysch. It shows two thinning and fining-upward units made of conglomerates and sandstones showing braided fluvial and deltaic facies associations, evolving to prodelta turbiditic bodies. The nappe

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overthrust Tortonian and Early Messinian sequences in the Cirò basin. The progressive growth of these compressive structures compartmentalised the formerly continuous basin, leading to the formation of distinct and asymmetric depocentres during Messinian and Pliocene. The Miocene and post Messinian emplacement of the "Cariati Nappe" in the central sector of the study area interrupts the lateral continuity and affects the sedimentary supply of a such configured foreland basin. The Cirò basin, located in an intermediate position between the Rossano and Crotone basins, is missing by the Messinian evaporites (Van Dijk & Scheppers, 1995). This suggests that a larger and previously continuous basin was wrenched in sub-basins recording a tectonic history (Barone et al., 2008). This succession was interpreted like an allochthonous series (Cotecchia, 1963) staying on post evaporitic (post Messinian) terrigenous sediments (Roda, 1967). Structural data show that the "Cariati Nappe" is a transpressive structure formed along restraining bends of the NW-SE striking, left-lateral, Rossano-S. Nicola fault zone (Stop 1.1). This structure represents the distal sediments of the Miocene basin infill, together with its back-thrust bedrock ("Sicilide Complex"). Along the outer front of the northern Calabria, strike-slip regional fault zones, produced regional wrenching of the Miocene basins and controlled the development of intrabasinal structural highs (like the "Cariati Nappe") related to backthrust and producing tectonic inversion in some sectors. The "Cariati Nappe" can be considered as exposed analogue of the off-shore structural highs, it is pointed out that at the scale of the whole basin, major compressional structures are time dependent, as they are Middle Miocene in age within the Crotone basin (see Luna Field), and they likely date latest Miocene within the Cirò basin (Muto et al., 2013). The tectono-sedimentary evolution of the inner portions of the late Miocene southern Italy foreland-basin system was affected by tectonic partitioning due to continuation of accretionary processes, rapid uplift of mid-crustal blocks, and the superposition of oblique tectonics (Muto et. al., 2014).

STOP 1.1: Mandatoriccio (CS). Thrust between the "Cariati Nappe" and the marginal Serravallian-Messinian successions.

This Stop is the first general outline of the relationships between two stratigraphic successions. The general view is introduced from the village of Mandatoriccio, from W to E. Are cropping out the, on the right of figure, gently est dipping Serravallian-Messinian strata, directy onlapping the Sila basement. These form a steep monoclinal flexure zone interrupted, to the est, by a thrust surface. The tectonic contact separates the hanging-wall (Oligocene-Middle Miocene Cariati Nappe succession, Fig. 4) from the Serravallian-Messinian succession of the

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Cirò basin (Fig. 4, 5). In this stop is possible to observe the progressive transition from an oblique thrust, left-lateral component of motion, on the right of figure 7, to the N-S trending frontal thrust ramp, on the left of Fig. 7. General assemblage of eastern basin infill and of the major backthrust in onland is outlined from the Stop 1.1.

Fig. 7 - General view, from the Mandatoriccio (CS) village, of the relations between the "Cariati Nappe" deposits and the Serravallian-Messinian successions (modified from Muto et al., 2009).

STOP 1.2: Scala Coeli (CS). The allochthonous Oligocene-Middle Miocene succession.

View of stratigraphic and tectonic relations between the Serravallian-Messinian Cirò basin succession and of the Cariati nappe. In this Stop the transpressive thrust contact is well exposed. In the area comprised between the villages of Terravecchia and Scala Coeli (Fig. 9A), the tectonic contact is made up of high angle faults (Fig. 9B) that displace and separate the successions of Rossano and Cirò basins (footwall block) from the Cariati nappe

Fig. 8 - Panoramic view, from Scala Coeli (CS) village.

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succession (hanging-wall block). The tectonic contact between the two succession consists in subvertical faults exhibiting prevalent left lateral strike-slip kinematics with a component of vertical displacement (Fig. 9B). Oligocene-Burdigalian flysch, correlated to the Albidona formation, is overlain with an evident angular unconformity by the Langhian Timpa dell'Avvoltoio conglomerates (Fig. 9A).

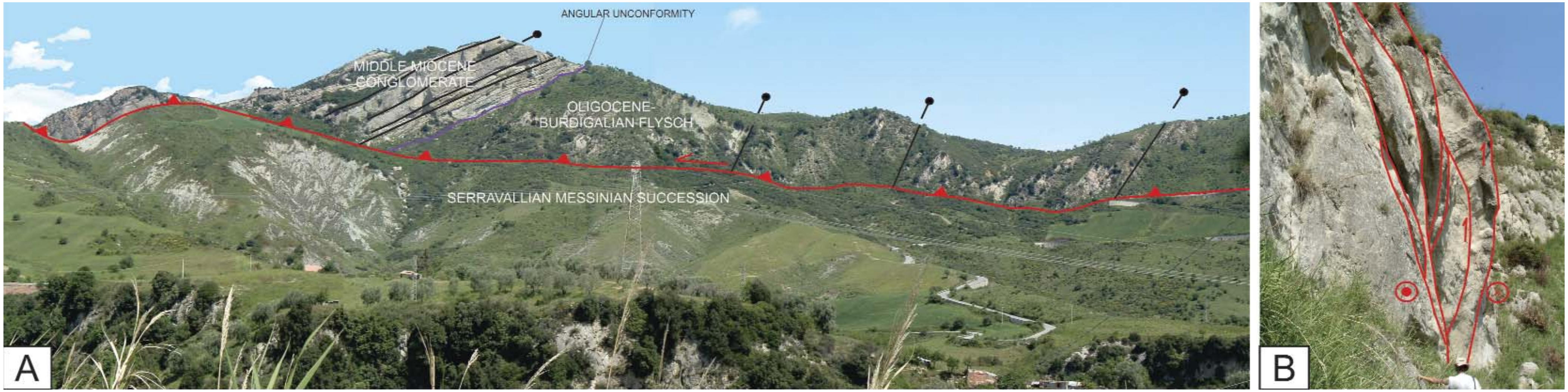

Fig. 9 - **A)** Line drawing showing stratigraphic and tectonic relations between the Cirò basin succession and the "Cariati Nappe" strata; in the hanging-wall, unconformity between Burdigalian flysch and Langhian conglomerates cropping out in the Timpa dell'Avvoltoio. **B)** Particular of the transpressive strike slip fault bordering the main contact (modified from Muto et al., 2014).

STOP 1.3: Geometry and kinematics of NW oriented transpressive fault

In this Stop is possible to understand the structural compatibility between the NW-SE transpressive faults (Figs 10B and C) and the NNW-SSE oblique thrust ramp of the "Cariati Nappe" (Fig. 10A). The fault is characterized by left-lateral movement with significant reverse component of slip.
In the hanging-wall, steepening of the Langhian-Serravallian conglomerates of the Cariati nappe strata along the major tectonic contact. Strata belong to the forelimb of a west verging anticline related to an E-dipping plane and are thrust on the Upper Tortonian clayes and the Tripoli Formation (Fig. 10A).

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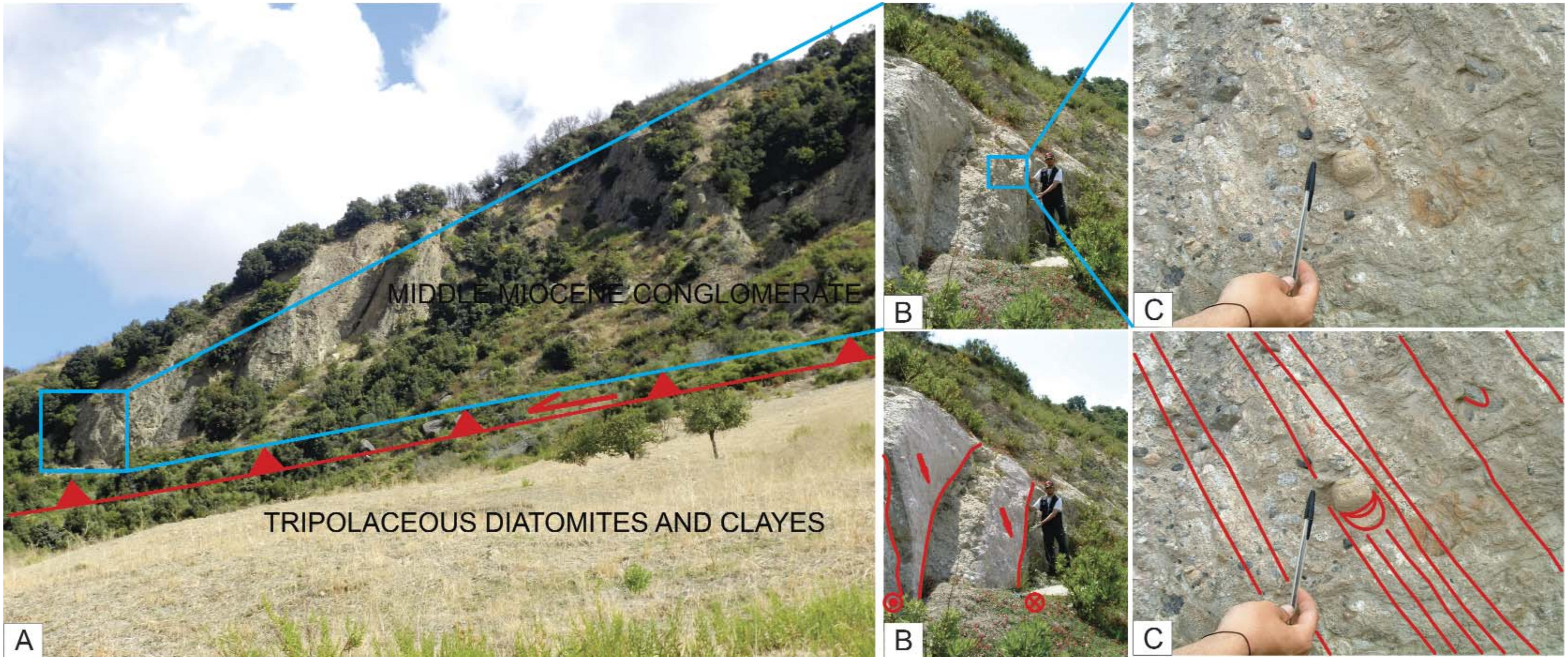

Fig. 10 - Particular of geometry and kinematics of the transpressive fault zone. **A)** Vertical Langhian conglomerates overthrust on the upper Tortonian clayes and Tripoli. **B)** Particular of the transpressive fault zone and **C)** kinematic indicators on the fault plane.

The Plio-Pleistocene succession of the Crotone basin (Stops 1.4, 1.5, 1.6)

Cavalieri marl and Cutro clay

These deep-marine units form an apparently continuous Plio-Pleistocene succession up to 1200 m thick in the central and southern part of the basin, whereas shallow-marine, coastal and locally continental deposits are commonly interposed between the two units toward the basin margin (Fig. 11). Despite this apparent continuity, seismic data show that the two formations are separated by an unconformity that is well

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recognizable at outcrop near the basin margin, where the thickness of both units does not exceed a few hundreds of meters.

The Cavalieri marl and the Cutro clay both consist of gray and light brown monotonous claystones and siltstones rich in foraminifera, calcareous nannofossils and mollusc shells, accumulated at distal shelf to slope depth (Roda, 1964; Zecchin et al., 2003, 2004a, 2012; Massari et al., 2010), which occasionally exhibit faint stratification. Well and outcrop data document that the formations contain sand layers interpreted as turbidites, which exhibit an erratic vertical distribution.

In the northern part of the basin, the Cavalieri marl crops out north of the Murgie mountain and between the Zinga and Belvedere di Spinello villages, and its base coincides with a sharp boundary at the top of the Messinian continental deposits. The formation is Zanclean in age (Roda, 1964; Van Dijk, 1990; Zecchin et al., 2003, 2004a, 2012) (Fig. 11). The Cavalieri marl interfingers with the Zinga sandstone and is overlain by the Belvedere formation and the Murgie sandstone (see below) (Fig. 11). Lateral facies relationships between the Belvedere and Murgie formations and the Cavalieri marl are not visible at outcrop.

The Cutro clay (Roda, 1964) is exposed discontinuously in the whole basin, and its age ranges between Piacenzian and Ionian (Zecchin et al., 2012) (Fig. 11). As mentioned above, at outcrop the contact with the underlying Cavalieri marl is undetectable in the distal

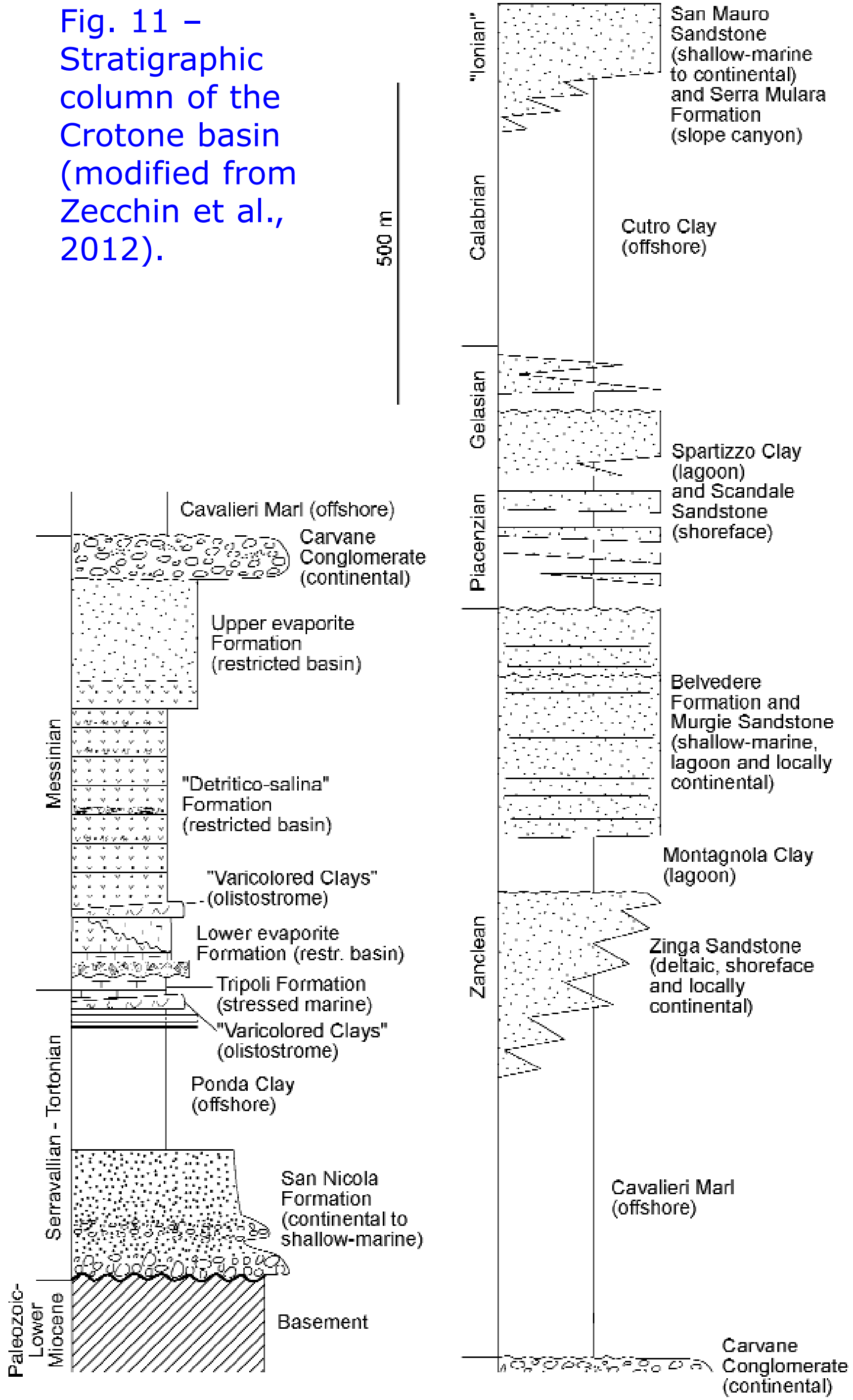

Fig. 11 – Stratigraphic column of the Crotone basin (modified from Zecchin et al., 2012).

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area, whereas it is marked by a coarse-grained lag and local fluvial sedimentation in the Strongoli area. The Cutro clay interfingers with the Scandale sandstone in the northern part of the basin. Higher in the succession, the unit passes abruptly into the Serra Mulara formation north of the Neto river, and into the San Mauro sandstone to the west (Fig. 11).

Zinga sandstone
The Zinga sandstone, up to 300 m thick, is recognizable in the north-western corner of the basin, and is interpreted as a composite prograding wedge formed by shoreface to deltaic deposits, overlying and locally interfingering with the upper part of the Cavalieri marl (Zecchin et al., 2003, 2004a) (Fig. 11). The unit rapidly pinches-out basinwards and is composed of seven small-scale cycles (*sensu* Zecchin, 2007a). The boundary with the overlying Montagnola clay is very sharp and locally marked by thin fluvial and tidally-influenced fluvial deposits (Zecchin et al., 2004a). The accumulation of the Zinga sandstone is interpreted as the result of decreasing accommodation and forced regression due to local uplift aided by halokinesis, possibly coupled with eustasy and/or larger-scale tectonics (Zecchin et al., 2003, 2004a, 2012). The formation is inferred to be Zanclean in age (Zecchin et al., 2003, 2004a, 2012).

Montagnola clay
The inferred Zanclean Montagnola clay, up to 100 m thick, is a lagoonal unit that overlies the Zinga sandstone (Fig. 11), and consists of stratified, gray and brown claystones and siltstones containing an oligotypic fauna assemblage dominated by *Cerastoderma edule* (Zecchin et al., 2004a, 2012). The unit pinches-out to the SE and is erosionally truncated by the overlying Belvedere formation.

Belvedere formation
This unit of inferred Zanclean age crops out along the north-western corner of the basin, between the Casabona and Belvedere di Spinello villages, and in the western part, between Belvedere di Spinello and San Mauro. Its thickness varies between 50 and 450 m due to synsedimentary normal faulting (Zecchin et al., 2004a, 2006). The Belvedere formation is composed of well cemented, mixed bioclastic and siliciclastic shoreface deposits organized to form meter-scale cycles that are vertically stacked (Zecchin et al., 2004a; Zecchin, 2005) (Fig. 11). Such an aggradational component is a typical feature of the formation (Zecchin, 2007b). A prominent intra-formational angular unconformity is recognizable, and it is overlain either by an up

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to 100 m thick succession containing sand waves in its lower half or by lagoonal deposits up to 25 m thick. The upper boundary of the formation corresponds to one of the most important unconformities found in the Crotone basin fill (Zecchin et al., 2012).

Murgie sandstone

This unit, up to 300 m thick, is present in the northern part of the basin, near the Strongoli village, and is mostly composed of shoreface sandstones and conglomerates (Zecchin et al., 2006) (Fig. 11). An intra-formational angular unconformity found in the upper part of the unit is overlain by cemented shell beds. The upper boundary corresponds to a major unconformity. The unit exhibits a marked aggradational component due to the activity of a listric normal fault that controlled the deposition (Zecchin et al., 2006). Such a fault places the unit in lateral contact with the Cavalieri marl. The recognition of the intra-formational unconformity and of the top unconformity suggests that the Murgie Sandstone is at least in part lateral equivalent to the Belvedere formation (Fig. 11), whereas its lower part possibly correlates with the Montagnola and Zinga formations. Another unconformity, overlain by ca. 20 m thick fluvial, coastal and shallow-marine deposits, is present to the east in the uppermost part of the formation (Zecchin et al., 2006).

Spartizzo clay

The lagoonal Spartizzo clay (Ogniben, 1955; Roda, 1964; Mellere et al., 2005) is exposed between the Casabona and Belvedere di Spinello villages in the northern part of the basin, and its thickness varies from ca 10 to 150 m due to synsedimentary normal faulting. This unit is composed of dark gray and brown layered mudstone containing an oligotypic fauna assemblage dominated by *Cerastoderma edule*, very similar to that characterizing the Montagnola clay. The Spartizzo clay sharply overlies the Belvedere formation and interfingers laterally with the shallow-marine deposits of the Scandale sandstone, and it is inferred as Piacenzian in age (Mellere et al., 2005; Zecchin et al., 2012) (Fig. 11).

Scandale sandstone

The Scandale sandstone (Ogniben, 1955; Roda, 1964; Mellere et al., 2005; Zecchin et al., 2006) is found in the northern and western parts of the basin and shows a complex architecture that varies depending on the location. Overall, three members were recognized: Casabona, Strongoli and Rocca di Neto (Zecchin et al., 2012).

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Casabona member: the Casabona member represents the lower part of the Scandale sandstone, and consists of shoreface sandstones and conglomerates, forming decameter-scale prograding wedges that interfinger with the Spartizzo clay in the Rocca di Neto and Casabona areas (Roda, 1965; Mellere et al., 2005) (Fig. 11). The uppermost shoreface tongue is sharply overlain by a meter- to decameter-scale interval of shelf siltstones that represent the proximal part of the Cutro clay. The Spartizzo clay and the Casabona member of the Scandale sandstone, therefore, form together a package showing a thickness that varies between 30 and 180 m due to synsedimentary tectonics, which is composed of five transgressive-regressive cycles that testify to a deepening-upward trend during middle to late Piacenzian time (Mellere et al., 2005; Zecchin et al., 2006, 2012). Although thinner, the same deepening-upward package is found also north of the Zinga village (Mellere et al., 2005).

Strongoli member: the Strongoli member or tongue was formerly referred to as the Strongoli sandstone (Ogniben, 1955), consisting of a discontinuous shoreface to inner shelf belt (Capraro et al., 2006) oriented ENE-WSW and prograding to the SSE in the area of the Strongoli village. This unit, early Gelasian in age (Capraro et al., 2006; Zecchin et al., 2012) (Fig. 11), is up to 60 m thick and pinches-out distally within the Cutro clay.

Rocca di Neto member: The late Gelasian Rocca di Neto member is found at the homonymous locality only, and consists of meter- to decameter-scale shoreface tongues interfingering with distal shelf to slope mudstones and documenting a local alternation between the uppermost Scandale sandstone and the Cutro clay (Zecchin et al., 2012) (Fig. 11).

Serra Mulara formation

This unit consists of a conglomerate to sandy and mudstone body elongated for ca. 4 km to the south-east, lying west of the Neto river delta. The lower boundary is represented by a broad concave-up erosional surface cutting the Cutro clay. The upper boundary consists of an erosional surface overlain by fluvial deposits. The Serra Mulara formation is 178 m thick and exhibits an overall fining-upward trend, with a reversal to coarsening-upward in the upper 15 m. The unit represents a canyon fill (Fig. 11) composed of density-flow deposits and minor hemipelagites (Zecchin et al., 2011). These deposits record both high-amplitude glacio-eustatic changes and the onset of the uplift of this part of the Calabrian Arc (Zecchin et al., 2011, 2012).

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San Mauro sandstone

The San Mauro sandstone is found only in the western part of the basin, as documented by Roda (1964) and Massari et al. (2002, 2010). The unit, up to ca. 200 m thick, conformably overlies the Cutro clay (Fig. 11), and consists of shelf, shoreface, lagoonal and fluvial deposits organized in transgressive-regressive cycles recording both glacio-eustasy and synsedimentary transtensional tectonics (Massari et al., 2002, 2010).

STOP 1.4: The Pliocene south of Casabona.

Observation of the uppermost lower Pliocene and of the late Pliocene basin fill south of Casabona.

The cyclic succession of the Belvedere formation accumulated within the Montagna Piana half-graben can be observed from the Stop (Fig. 12). An angular unconformity is found within the unit. The Belvedere formation is characterized by an aggradational stacking pattern of minor cycles due to a long-term balance between the rate of accommodation creation and that of sediment supply. The formation is topped by a major unconformity of basinal scale that is the response of an important tectonic phase occurred between the late Zanclean and the early Piacenzian.

South of Casabona and Montagna Piana, NE-trending synsedimentary normal faults bound the South Casabona and Zoiaretto half-graben sub-basins during deposition of the lagoonal Spartizzo clay and of the shallow-marine Scandale sandstone (Fig. 12), which are

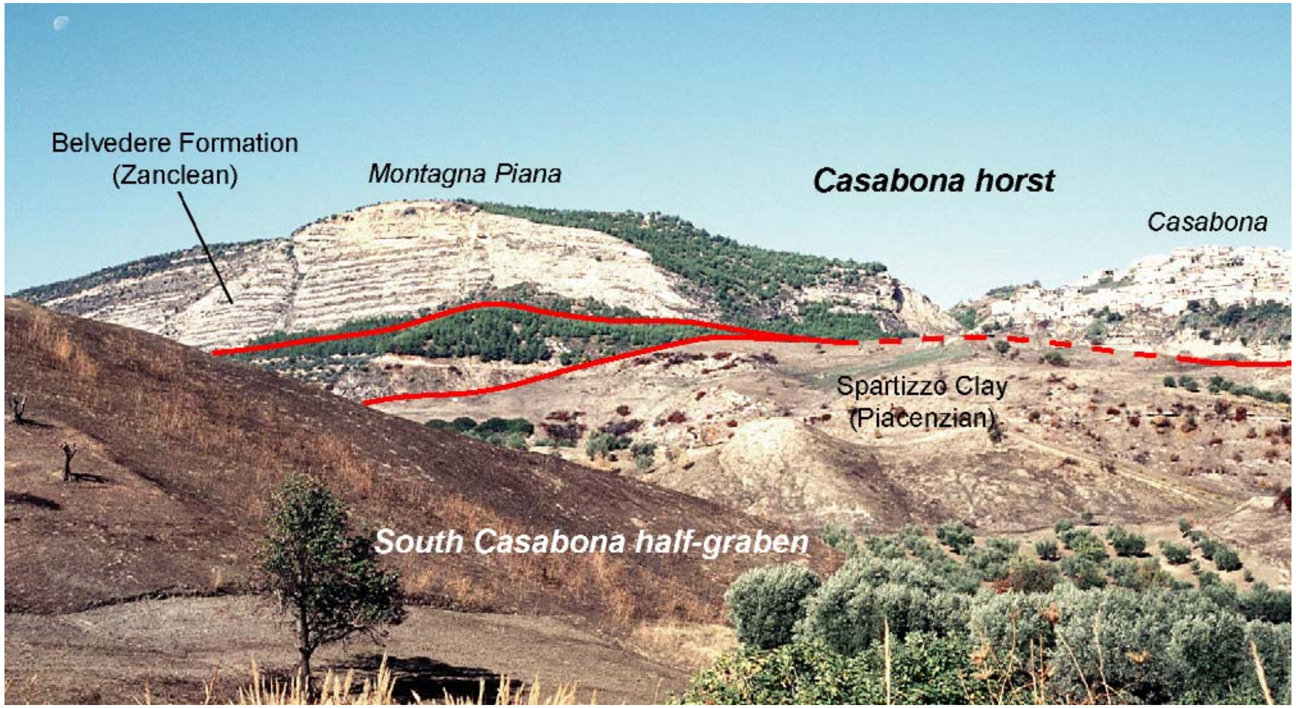

Fig. 12 - The Casabona horst and the South Casabona half-graben. The deposition of the Spartizzo clay (middle Pliocene) was controlled by the activity of the fault bounding the south Casabona half-graben, favouring the accumulation of a relatively thick succession.

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accumulated after renewed subsiding conditions that followed the middle Pliocene tectonic phase. The lower part of this succession consists of a backstepping wedge showing a high-frequency cyclicity and representing the transgressive interval of the Piacenzian (Fig. 13). The upper part of the Scandale sandstone represents a forced regressive deposit, transgressed by the deep-marine Cutro clay during Gelasian time (Fig. 13).
The Casabona horst, to the north, is developed in correspondence of part of the former Montagna Piana half-graben during the Piacenzian normal faulting (Fig. 12).

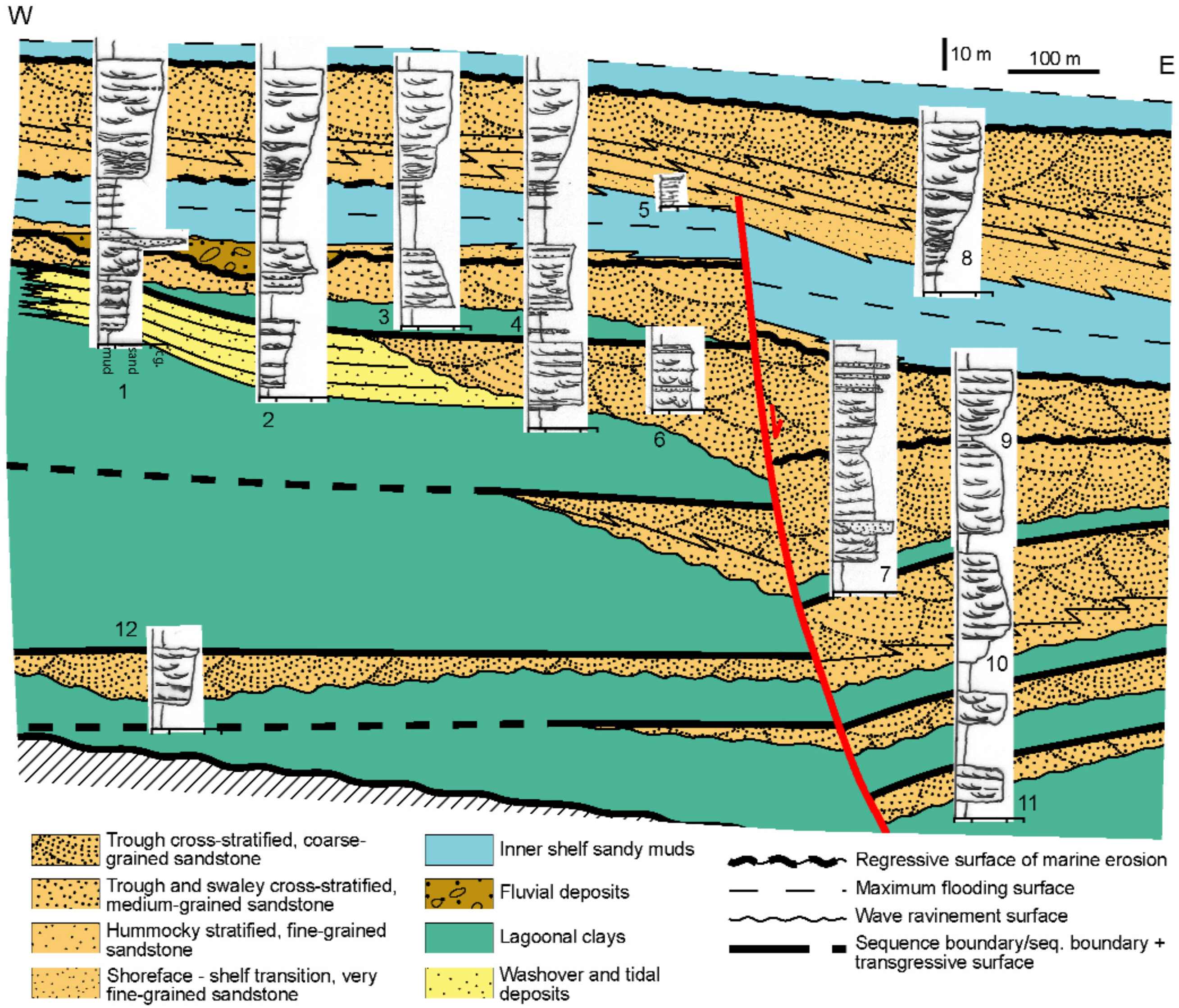

Fig. 13 - Correlation of sections measured on the middle Pliocene deposits located east of Casabona. The succession is composed of the Spartizzo clay, the Scandale sandstone, and the lower part of the Cutro clay. The succession deposited within the South Casabona and Zoiaretto half-graben sub-basins is subdivided into six high-frequency sequences. The fault that bound the Zoiaretto half-graben ceased the activity during the deposition of the last cycle (modified from Mellere et al., 2005).

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STOP 1.5: Zinga (KR). Timpa di Cassiano and the western side of the Vitrano Valley.

Crotone basin overview and panoramic observation of the Lower Pliocene succession of the western side of the Vitravo Valley.

This Stop offers a spectacular view of the Lower Pliocene succession (Fig. 14). The slope to shelf mudstones of the Cavalieri marl merge upward into the prograding shoreface sandy wedges of the Zinga sandstone, which is about 300 m thick (Fig. 14). The wedges pinch-out southward. The deposition of the prograding wedges was controlled by the growth of a NE-trending anticline (the Russomanno anticline), probably associated with salt tectonics (Fig. 14). The great thickness of the Cavalieri marl at the Russomanno anticline (about 250 m) suggests that the growth started later, during the deposition of the Zinga sandstone, and continued during the deposition of the lagoonal Montagnola clay.

Fig. 14 - The western side of the Vitravo Valley. Note (right) the prograding forced-regressive wedges of the Zinga sandstone. The geometry was controlled by the growth of a NE-trending non-cylindrical anticline (Russomanno anticline), that continued during deposition of the Montagnola clay. Deposition of the thick succession of the Belvedere formation within the Belvedere half-graben was linked to the activity of a NE-trending listric normal growth fault (modified from Zecchin et al., 2004).

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The top of the Zinga sandstone is a subaerial unconformity locally marked by thin fluvial and tidally-influenced fluvial deposits, passing upward into the Montagnola clay (about 100 m thick), which in turn is sharply overlained by the shallow-marine deposits of the Belvedere formation (Fig. 14). The latter shows a strong thickness in the southern part (roughly up to 450 m SW of the Timpa di Cassiano mountain), due to the activity of a NE-trending synsedimentary listric normal fault bounding the Belvedere half-graben (Fig. 14).
Timpa di Cassiano is bounded in the south by another NE-trending normal fault that was active during the deposition of younger units (Fig. 14).

STOP 1.6: The Serra Mulara formation.

Observation of a coarse-grained submarine canyon fill.

A middle Pleistocene coarse-grained canyon fill succession (the Serra Mulara formation) crops out in the northern sector of the Crotone basin (Figs 15 and 16). This succession provides the opportunity to study a field example of coarse-grained submarine canyon fill, which consists of a NW-SE elongated body (4.25 km long and up to 1.5 km wide) laterally confined by a deep-water clayey and silty succession and located behind the modern Neto delta (north of Crotone) (Figs 15 and 16). The thickness of the unit reaches 178 meters.
The lower part of the canyon fill is dominated by gravely to sandy density-flow deposits containing abundant bivalve and gastropod fragments, passing upwards into a succession composed of metre- to decimetre-scale density-flow deposits forming sandstone-mudstone couplets (Fig. 15). Sandstone deposits are mostly structureless and planar laminated, while the clayey layers record hemipelagic deposition during steady state phases. This succession is overlained by a succession composed of thicker, structureless sandstones alternating with layers of interlaminated mudstones and sandstones, which contain leaf remnants and freshwater ostracods and are directly linked to river floods. The canyon fill is overlain by gravely to sandy continental deposits (part of the Cutro terrace, Figs 15 and 16) recording a later stage of emergence.
Facies analysis, together with micropalaeontologic data from the hemipelagic units, suggest that the studied canyon fill records a progressive gravel material cut-off during deposition due to an overall relative sea-level rise, leading to progressive increasing entrapment of sediment in fluvial to shallow-marine systems, and successively a generalized relative sea-level lowering. This trend probably reflects high-magnitude glacio-eustatic changes combined with the regional uplift of the region, later determining the definitive emergence.

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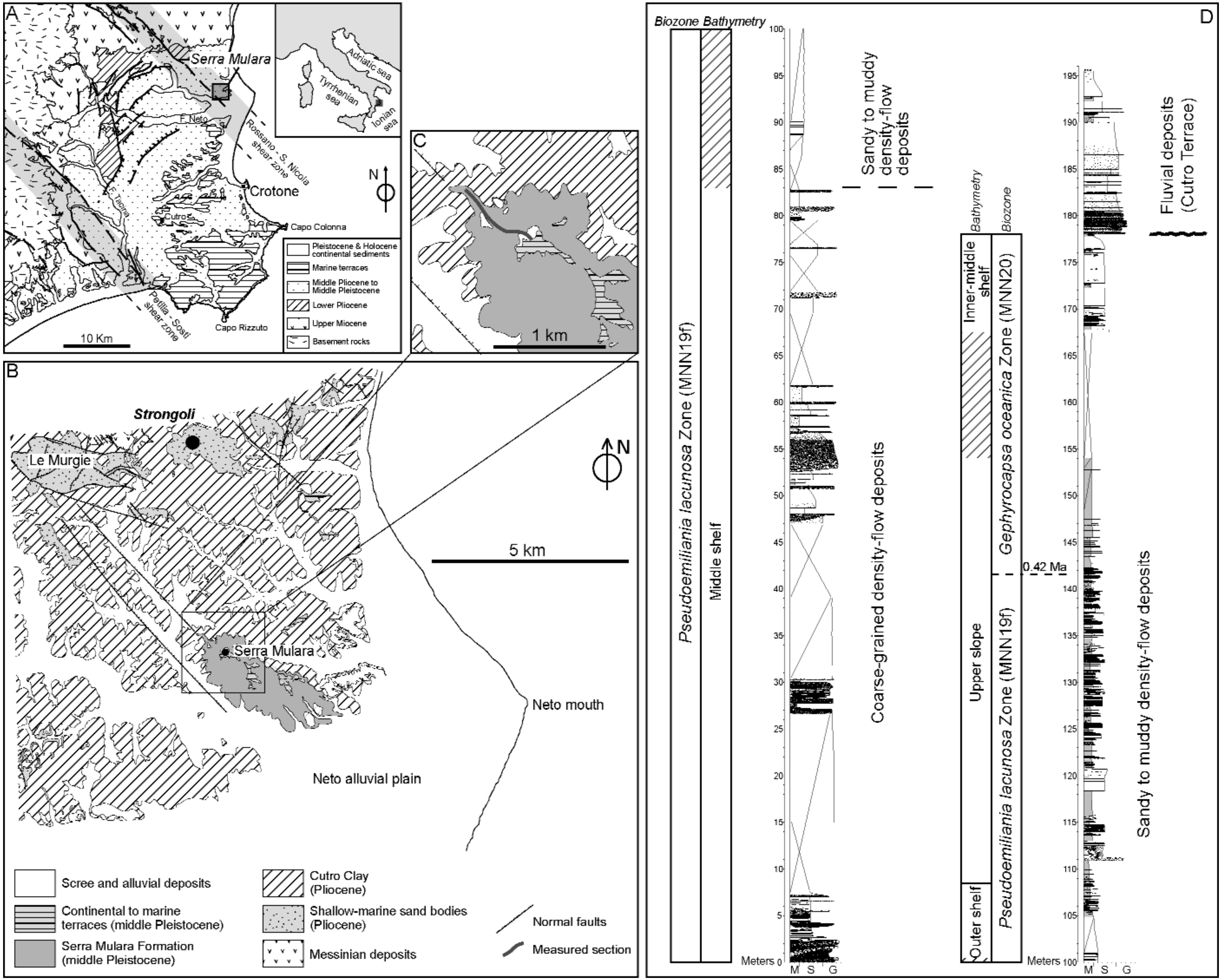

Fig. 15 - Geological map of the Serra Mulara area and sedimentological column of the Serra Mulara deposits (modified from Zecchin et al., 2011).

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Considering the whole Calabrian Arc, the onset of the uplift was diachronous, as it has been dated approximately near the end of early Pleistocene in some areas (Westaway, 1993; Westaway & Bridgland, 2007), and later in the Crotone area. In particular, Zecchin et al. (2011) estimated that the beginning of the uplift of the Crotone basin occurred between 0.4 Ma and 0.45 Ma, that is between Marine Isotope Stage (MIS) 12 and 11. This estimation, based on data collected in the Serra Mulara canyon fill, takes into account the time necessary to raise upper slope deposits at sea level assuming an uplift rate of 1 m/ka, which is close to the calculated long-term uplift rate since MIS 7 (Zecchin et al., 2004b).

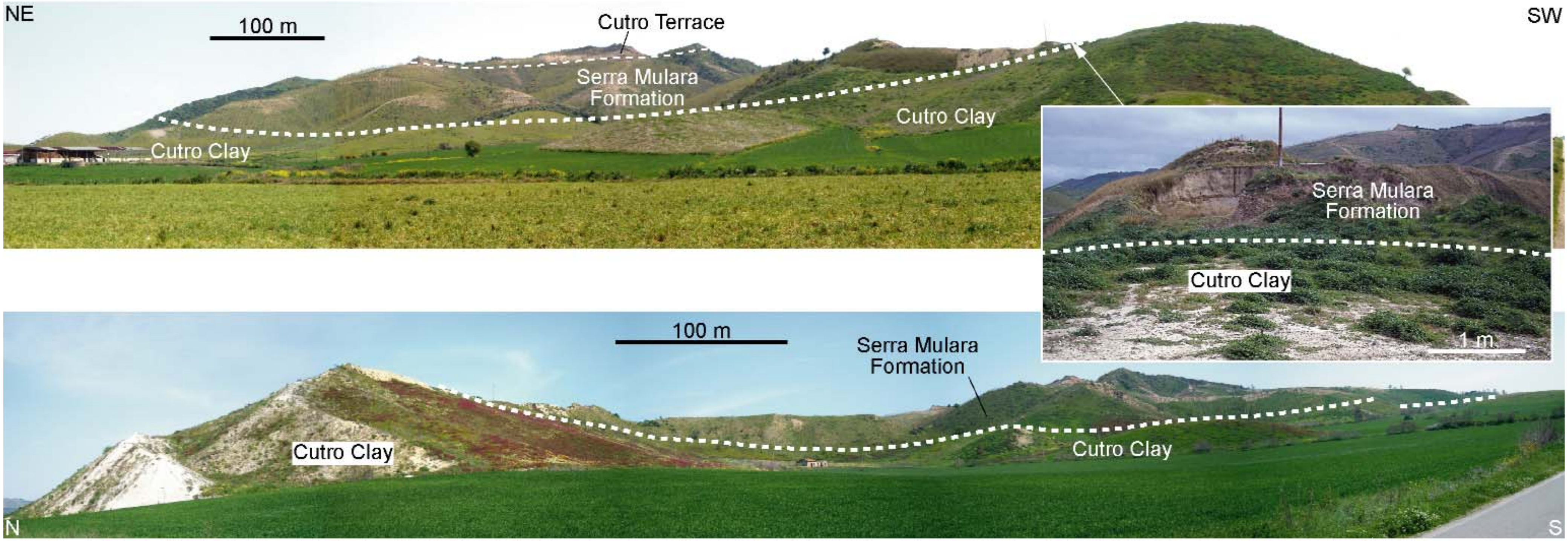

Fig. 16 - View of the Serra Mulara formation and the Cutro clay (modified from Zecchin et al., 2011).

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Day 2
The Crati basin

The Crati graben (Lanzafame & Tortorici, 1981; Tortorici, 1981; Tansi et al., 2005a, 2007) is characterized by N-S trending transtensional Quaternary faults, which separate Late Miocene-Quaternary deposits from the Calabrian terranes cropping out in the Coastal Chain and in the Sila Massif (Fig.17), on its western and eastern margins, respectively. Such deposits are represented, in the depocentral zone, by a Middle Pliocene-Middle Pleistocene conglomerate-sand-clay marine succession, closed at the top by Late Pleistocene-Holocene alluvial deposits. N-S normal faults show seismogenic activity, as testified both by historical IX-X MCS events (Postpischl, 1985; Boschi et al., 1995, 1997) and by instrumental earthquakes (Moretti et al., 1990). Morphologically, these faults are represented by sharp rectilinear escarpments, marked by active alluvial fans, bounding the uplifted footwalls. The mountain fronts reach elevations of about 700 m, and are characterized by 300–400 m high cumulative fault escarpments along which triangular/trapezoidal facets (70–100 m high) are found. An antecedent drainage network flows perpendicular to the fault segments; it is made of deeply entrenched canyons on the uplifted blocks, and of flat valleys on the down-thrown blocks (Tortorici et al., 1995; Tansi et al., 2005a). At the mesoscopic-scale, normal faults show fault planes striking from N-S to NNE-SSW, with subvertical to oblique slickensides, indicating a right-lateral component of motion related to an extensional direction (σ3) oriented N125E. They strongly control the evolution and the migration of the Calabrian Arc and were characterized by episodes of transtension (Van Dijk et al., 2000), responsible for the Crati basin development and the dissection of the interior of the Calabrian Arc (Lanzafame & Zuffa, 1976; Lanzafame & Tortorici, 1981; Tortorici, 1981; Turco & Knott, 1988; Turco et al., 1990; Cifelli et al., 2007b; Tansi et al., 2007; Spina et al., 2011).

The margins of the Crati basin are formed by the crystalline rocks of the Sila Massif at the east, by the crystalline and sedimentary rocks of the Coastal Range at the west and south, and by the sedimentary rocks of the Pollino unit at the north. It is L-shaped and can be divided into the N-S oriented Crati and the E-W oriented Sibari trough (Colella et al., 1987), as a result of strong tectonic control; the Sibari trough represents the main depocentral area, as suggested by the 1000 m thick Plio-Quaternary succession drilled for hydrocarbon exploration.
According to Lanzafame & Tortorici (1981), the stratigraphic succession of the Crati trough can be divided into three sedimentary units. The lowermost part of the succession, Pliocene in age, crops out extensively along

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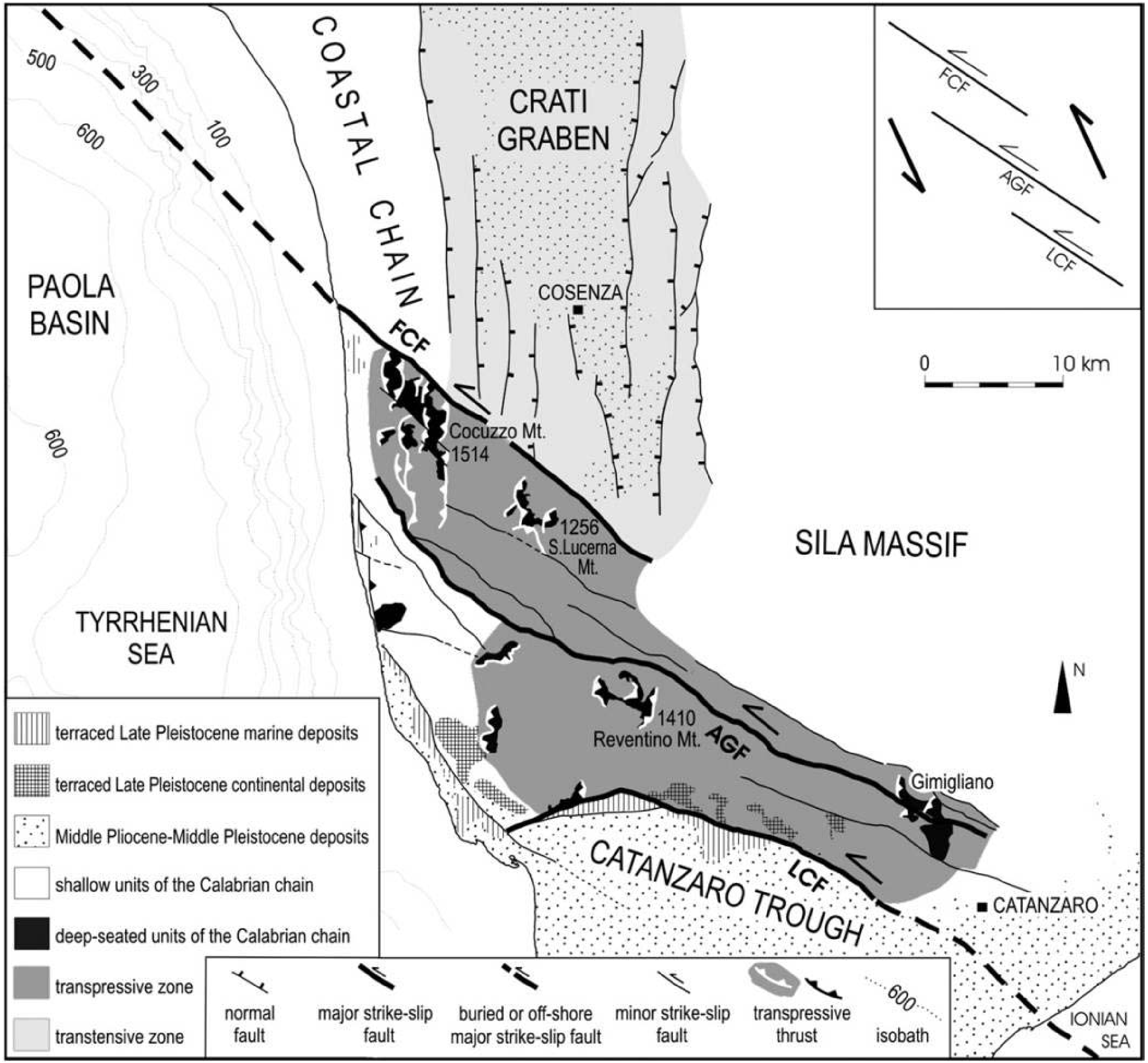

Fig. 17 - Structural scheme of the western Calabria in which are indicated the left-lateral shear zone and the transtensional Crati basin (after Tansi et al., 2007).

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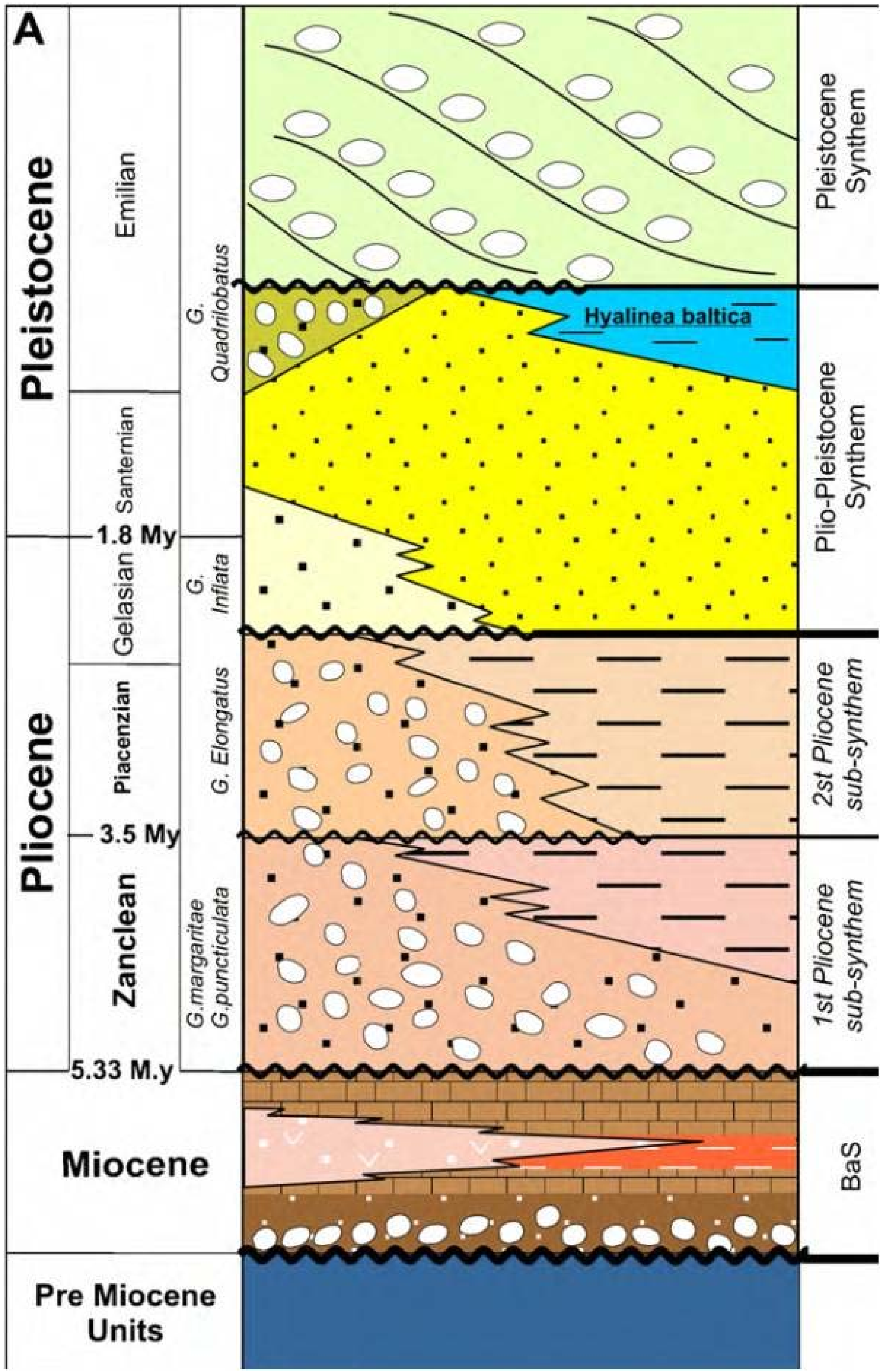

the western side of the basin and consists of a fining upward sequence overlaying the bedrock (fig. 18). A Plio-Pleistocene succession occur unconformably on Pliocene deposits and directly onto the bedrock, in response to basin subsidence that starts at the west and proceeded eastwards, causing an eastward diachronous transgression (Burton, 1971; Lanzafame & Zuffa, 1976; Lanzafame & Tortorici, 1980; Tortorici, 1981). The Plio-Pleistocene deposits consist of a complex sequence whose topmost part is constituted of clayey deposits grading into sandstones and conglomerates referred to Emilian and Sicilian, respectively (Lanzafame & Tortorici, 1981). The sandstones and conglomerates mostly match to the coarse-grained delta and shore deposits well documented by previous works (Colella et al., 1987; Colella, 1988, 1994; Carobene & Damiani, 1985), cropping out extensively along the margins of the basin.

From Middle Pleistocene onwards, this sector experienced a marked uplift (Tortorici, 1981) that promoted the partial dissection of the Plio-Pleistocene deposits and successively its covering by a thick succession of fluvial conglomerate (Fabbricatore, 2011), well exposed in the southernmost part of the Crati trough, along the Crati Valley right side; a similar stratigraphic framework is to be found on the eastern side of the Sila Massif (Robustelli et al., 2009).

Fig. 18 – Stratigraphic column showing the distribution of the different stratigraphic formations and their relationships as observed in the southern-central Crati basin (after Spina et al., 2011).

According to Lanzafame & Tortorici (1981), the topmost part of Pleistocene deposits consists of clayey sediments grading into sandstones and conglomerates that are Emilian and Sicilian in age, respectively. In particular, sandstones and conglomerates correspond to the coarse-grained delta and shore deposits cropping out extensively along the margins of the basin ad already described by previous works, (Colella et al., 1987; Colella, 1988, 1994; Carobene & Damiani, 1985).
In particular, coarse-grained Gilbert-type deltas represent a volumetrically significant component of the Crati trough sedimentary infill; such a depositional system dominates along the western side of the Crati trough, where the depositional architecture of deltaic deposits is represented by a series of forward-stepping delta sequences producing an eastward migration of basin depocentre in response to coastal uplift.

At small scale, tectonic control is also highlighted by two or more stacked groups of foreset beds (Fig. 19); in this case, basal unconformity is well noticeable. The overlying major bounding surfaces and stratal geometries indicate alternating episodes of aggradation and progradation, so that the clinoform wedge is composed of a stack of unconformity-bounded units characterised by oblique to sigmoidal geometry. This particular arrangement represents the sedimentary response to high (unconformity) and slow (complex sigmoid-oblique geometry) vertical displacement along the back-edge delta system fault.

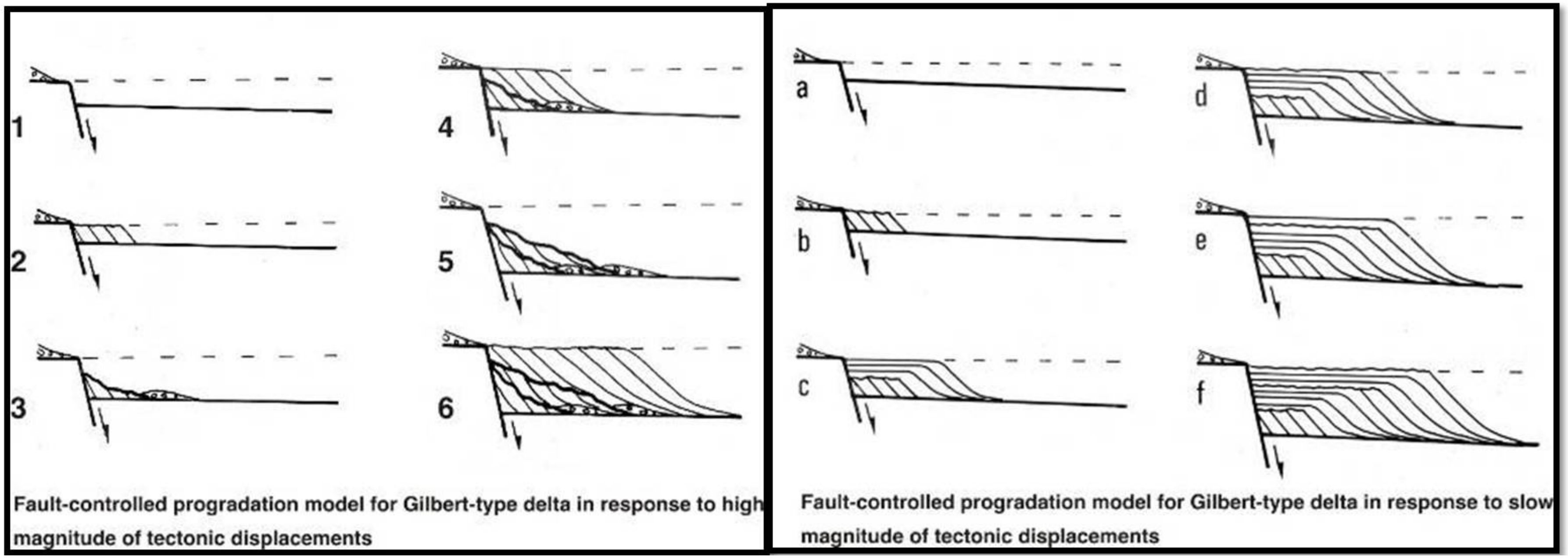

Fig. 19 – Schematic development of Gilbert-type delta.

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Detailed sedimentological studies of the Gilbert-type fan deltas of the eastern margin of the Crati trough have been previously published (Colella et al., 1987) but facies analysis and stratigraphic architecture of shoal water deltas have been mostly neglected. Such a depositional system crops out along the southeastern margin of the Crati trough.

Fig. 20 – Gilbert-type delta in the Crati basin.

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STOP 2.1: Arente River (Crati Valley, CS). The eastern Lower Pleistocene Crati basin infill.

The vertical and lateral relationships among the facies have been used to group them in facies associations, related to their spatial distribution and genesis,showing the main depositional setting. These assemblages correspond to seven facies associations: proximal mouth bar conglomerates (FA1) and sandstones (FA3), distal mouth bar conglomerates and sandstone (FA3), proximal delta front sandy conglomerates (FA4), distal delta front sandstone (FA5), wave-influenced delta front sandstone (FA6) and prodelta muddy sandstones (FA7).

Fig. 21 - Shoal water delta deposits are very widespread along the southeastern side of Crati basin (the picture is taken on the right side of the Arente River); Lower Pleistocene deltaic sediments rest directly on crystalline bedrock of the Sila Massif (blue lines). In red, Lower Pleistocene synsedimentary fault belonging to the eastern Crati Valley normal fault system.

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Facies association FA1 is characterised by clast-supported, granule- to cobble-size conglomerates organised into lenticular and sheet-like units. Planar cross-stratified gravel, having symmetrical or asymmetrical concave-up base also occur. This facies association rests erosively on stratified sandstones of facies association FA3 and grades basinward into facies association FA2.

Facies association FA2 is characterised by planar-parallel stratified sandstone and conglomerate beds. They show a sheet-like to broadly lenticular geometry and distinct to diffuse boundaries. Typical dimensions for individual units range from centimetres to 0.5 m in thickness and generally to tens of metres in lateral extent. This facies association shows an overall fining upward and thinning upward trend and grades upward and laterally into facies association FA4.

Facies association FA3 is mainly composed of sand. This facies association represents a wedge-shaped unit, enclosed between facies associations FA1 and FA2. It is mainly constituted by large-scale cross-bedded sandstones interpreted as sand-dominated mouth-bar wedges of a shoal-water delta. In particular, sandstones are representative of low-relief mouth-bars deposited by fluvial processes at the mouth of a secondary distributary channels within a protected area.

Facies association FA4 overlaps and passes laterally (northwestwards) and downdip to distal delta front deposits (FA5). This facies association primarily consists of planar-parallel and trough cross stratified sand and pebbly sand, with rare gravel sheets and lenses and lesser amounts of ripple cross-laminated sandstone and sandy mudstone. The main architectural feature consists in the vertical stacking of fining-upward packages, i.e. bedsets, frequently displaying planar-parallel and cross bedding and locally characterised by a wedge-shaped form.

Facies association FA5 is constituted the main sandstone outcrops, passes laterally northwards and downdip into prodelta fines and is seen as direct basinward extension of FA4 facies association. The FA5 is quite bioturbated with trace fossils such as Thalassinoides, Ophiomorpha and Skolithos. A westward fining within the deposits of the FA5 is clearly recognizable, as more conglomerates are present towards the east. FA5 is composed of medium- to thick-bedded, moderately to poorly sorted fine- to medium-grained sandstones, which alternate and interfinger along dip with granule to pebble conglomerates.

Facies association FA6 is typically alternated with prodelta deposits which become dominant basinwards. It is characterized by amalgamated sandy beds, consisting of medium- to thick-bedded sandstones; they are alternated and interfingered with hummocky cross-stratified sandstone and fine-grained, ungraded conglomerate beds and lenses. Bioturbation is well developed giving a mottled structure to some beds. Trace fossils in this facies are represented by Thalassinoides, Planolites, Teichichnus, Ophiomorpha, Skolithos, Scolicia and Cruziana.

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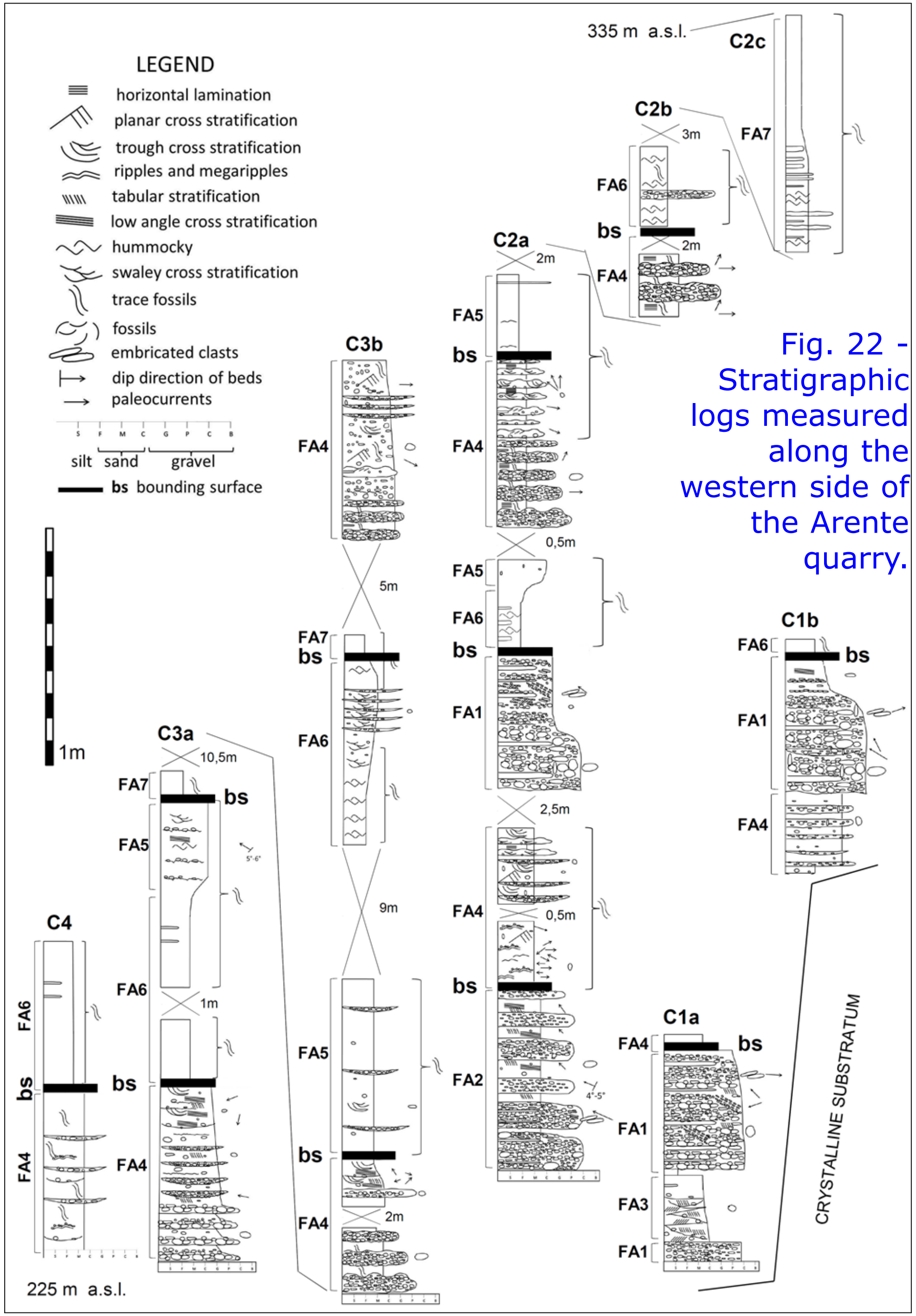

Fig. 22 - Stratigraphic logs measured along the western side of the Arente quarry.

Facies association FA7, interpreted as prodelta sediments, is generally well exposed along the right side of the Crati River and consists of interbedded mudstone, siltstone and thin sandstone. Updip it is alternated with sandstones of distal delta front facies association and wedged out.

The main control on the variation in deltaic architecture – from Gilbert-type, to the North, to shoal water deltas, to the South - is related to tectonically-influenced differences in accommodation, being sediment supply comparable along the margin. In particular, low rates of subsidence coupled with high sediment supply derived from large fault tip drainage catchments, should result in strongly progradational deltas. Nevertheless, the foremost noticeable feature of the succession is its retrogradational stacking pattern, with successive deltaic units stepping landwards through time, onlapping fault stepped, retreating bedrock.

It is also worth emphasizing that the retrogradational character of the succession is punctuated by regressive episodes; this make possible to divide internally the delta complex into transgressive-regressive sequences. The stacked landward-stepping architecture of the succession here represents more phases of E-directed retrogradation, capped by hardground horizons or erosive surfaces formed during the subsequent flooding phases.

Therefore, tectonics is to be considered as a causative factor in the Early Pleistocene sea-level rise, onto which climate-driven, short-lived sea-level changes are superimposed.

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Fig. 23 – NW-trending left lateral strike-slip fault in the metamorphic substrate of the Arente River area (Crati Valley).

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STOP 2.2: Noggiano (Rende). Pleistocene-recent normal fault in the western margin of the crati basin.

The western Lower Pleistocene Crati basin infill outcrops along the hanging-wall of the N-S trending major fault of the Crati Valley. In this stop is possible to view the transition from the Pliocene clay to mixed arenites formed by siliciclastic and intrabasinal carbonates. This unit is correlated to the lower Pleistocene deposits of Stop 2.1 and represents the first sedimentary input, in the basin, of the Coastal Chain structural high. Post infilling fault is well exposed in the same stop.

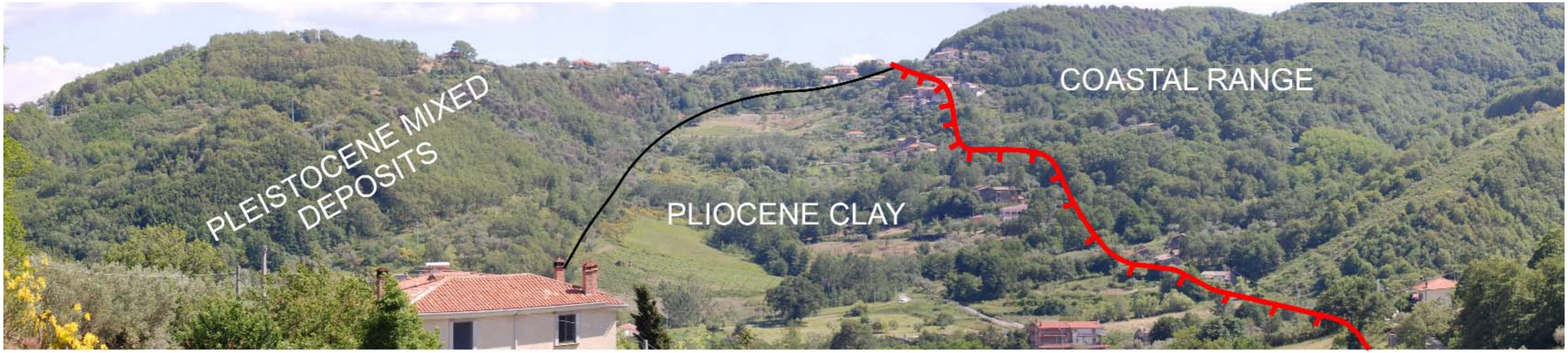

Fig. 24 - View from the north of the western border of the Crati basin; fault separates the Miocene-Quaternary deposits from the Coastal Range rocks.

STOP 2.3: Villa Miceli-San Fili (CS). Transpressive N-S trending fault at the western margin of the Crati basin.

In the western margin of the Crati basin, reverse faults border the contact between the metamorphic units of Coastal Chain and the Miocene deposits (Fig. 25, Stop 2.3). In particular, N-S right lateral transpressive faults are exposed along the major N-S fault bordering the eastern Coastal Range. High angle transpressive fault are present in the Lower Pleistocene marginal deposits in the same area, and are responsible for their deformation (Fig. 26).

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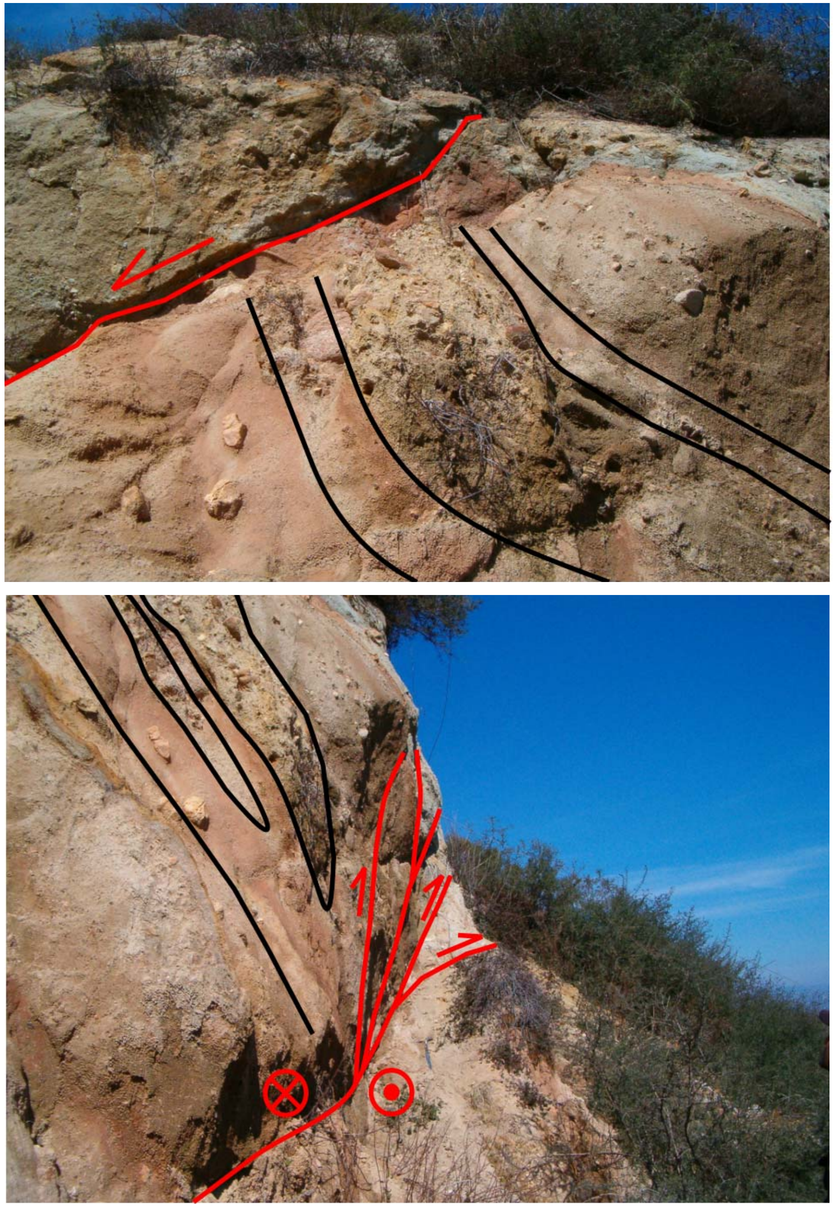
Fig. 25 - Miocene conglomerates dipping to the east along the western Crati basin fault system. Above, rotated normal fault; below, transpressive N-S trending fault.



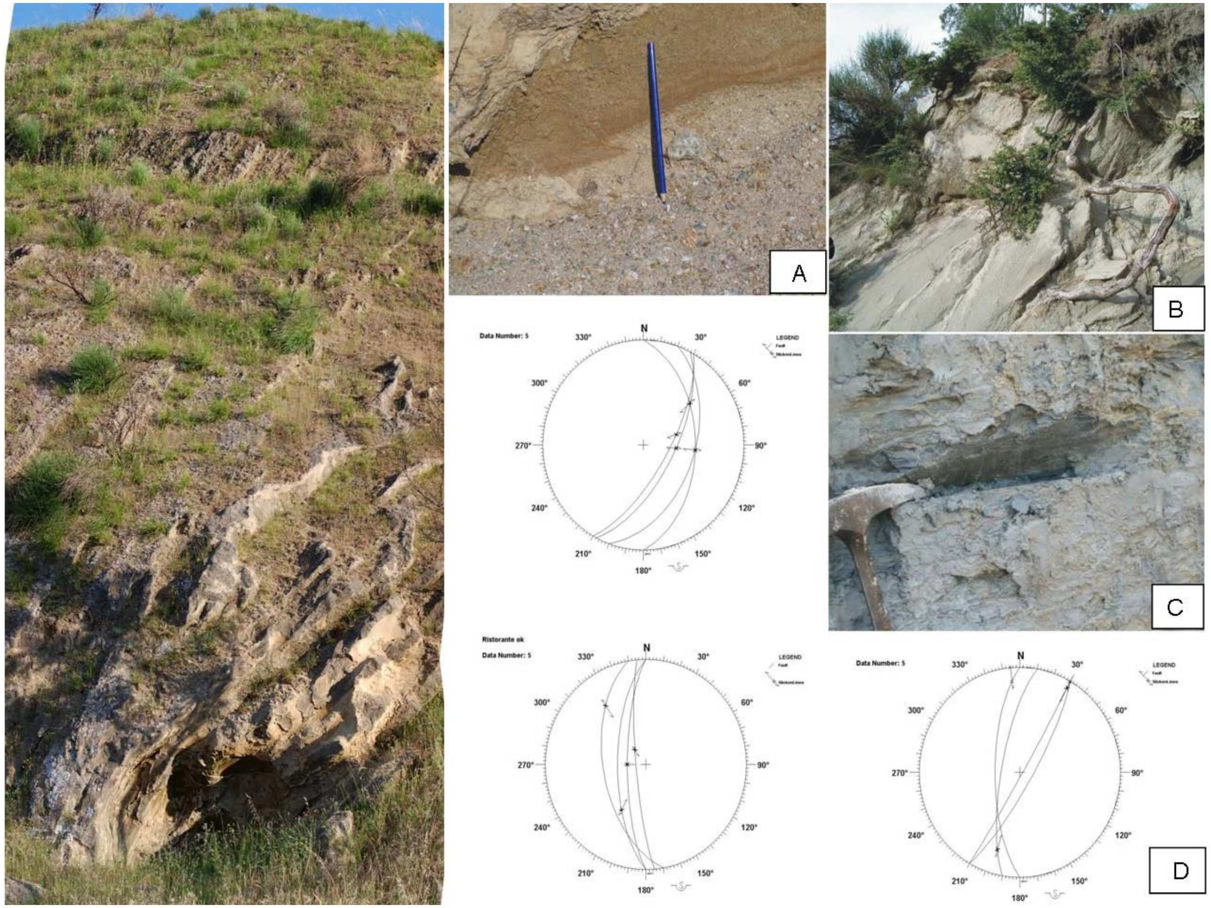


Fig. 26 - East dipping Lower Pleistocene mixed deposits along the major N-S trending fault, on the left. Mesoscale east dipping reverse faults in the Plio-Quaternary Crati basin deposits (**A**, **B**, **C**). Stereographic projection of reverse N-S trending faults (**D**).

Tectono-stratigraphic architecture of the perityrrhenian Amantea basin (Stops 2.4, 2.5, 2.6, 2.7).

The Amantea basin (Di Nocera et al., 1974; Ortolani et al., 1979; Colella, 1995) is one of many Neogene basins along the Tyrrhenian margin of Calabria. The onset of the basin occurred

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in response to tectonic subsidence induced by extensional faulting during the Serravallian-early Tortonian (Mattei et al., 2002). The sedimentary infill has been subdivided into five main depositional units, bounded by stratigraphic discontinuities by Muto & Perri (2002) and in three depositional sequences by Mattei et al. (2002) and Longhitano & Nemec (2005). The first unit, Serravallian in age, is strongly influenced by a combination of tectonic activity and eustatic rise in sea level; the structural architecture and sedimentary evolution of the basin is time-transgressive from alluvial fan to submarine fan deltas. The second unit, Tortonian in age, overlies the first with an angular unconformity and hiatus (Mattei et al., 2002), due to the fall of sea level and synsedimentary activity of normal faults. This unit is constituted by alluvial fan deposits overlain by a carbonate shelf depositional system. During the deposition of second unit in the middle and late Tortonian, the basin was affected by local contractional deformation (Colella & Longhitano, 1998) with the development of synchronous normal faulting. The sedimentation and the architecture of the basin were abruptly influenced by tectonic activity. As a consequence, in the sedimentary sequences developed numerous unconformities, related with the growth of local and fault related folds (transpressive component of motion along NW-SE trending major fault, and roll-over anticline in listric N-S trending normal faults). At the same time, a new sea level rise caused the drowning of the basinal area as well as the subsequent transgression over adjacent continental zones (Figs 27, 28). Local emergence of basin-fill, caused by growth of anticlinal structures, produced intrabasinal sediments, and the deposition of a coarse-grained fan at the base of the third depositional unit (Muto & Perri, 2002). The fourth depositional unit is represented by a thin evaporitic succession which lies with an angular unconformity on the underlying sediments and bedrock. These facies associations can be explained by the drop in sea level accompanied by structural highs related to growth of the folds (Butler & Grasso, 1993) or to extensional uplifted blocks. Thrust activity is recorded in onland Miocene deposits and have been recognized in the Paola basin (Tansi et al., 2007; Pepe et al., 2010; Spina et al., 2011) probably testifying the last contractional event of the Calabrian Arc thrust sheet, when the deformation began to be characterized by the development of NW-SE trending shear zones. The uplift of the Amantea basin probably occurs in the Pleistocene. This event is testified by marine sediments, described as the fifth depositional unit (Muto & Perri, 2002), lying at various topographic levels (Sorriso Valvo & Sylvester, 1993). The last deformation phase, characterized by extensional fault systems dipping towards Tyrrhenian Sea, realised the basin emergence and represents the propagation of the Tyrrhenian back arc rift system on the western Calabrian margin (Mattei et al., 2002; Muto & Perri, 2002).

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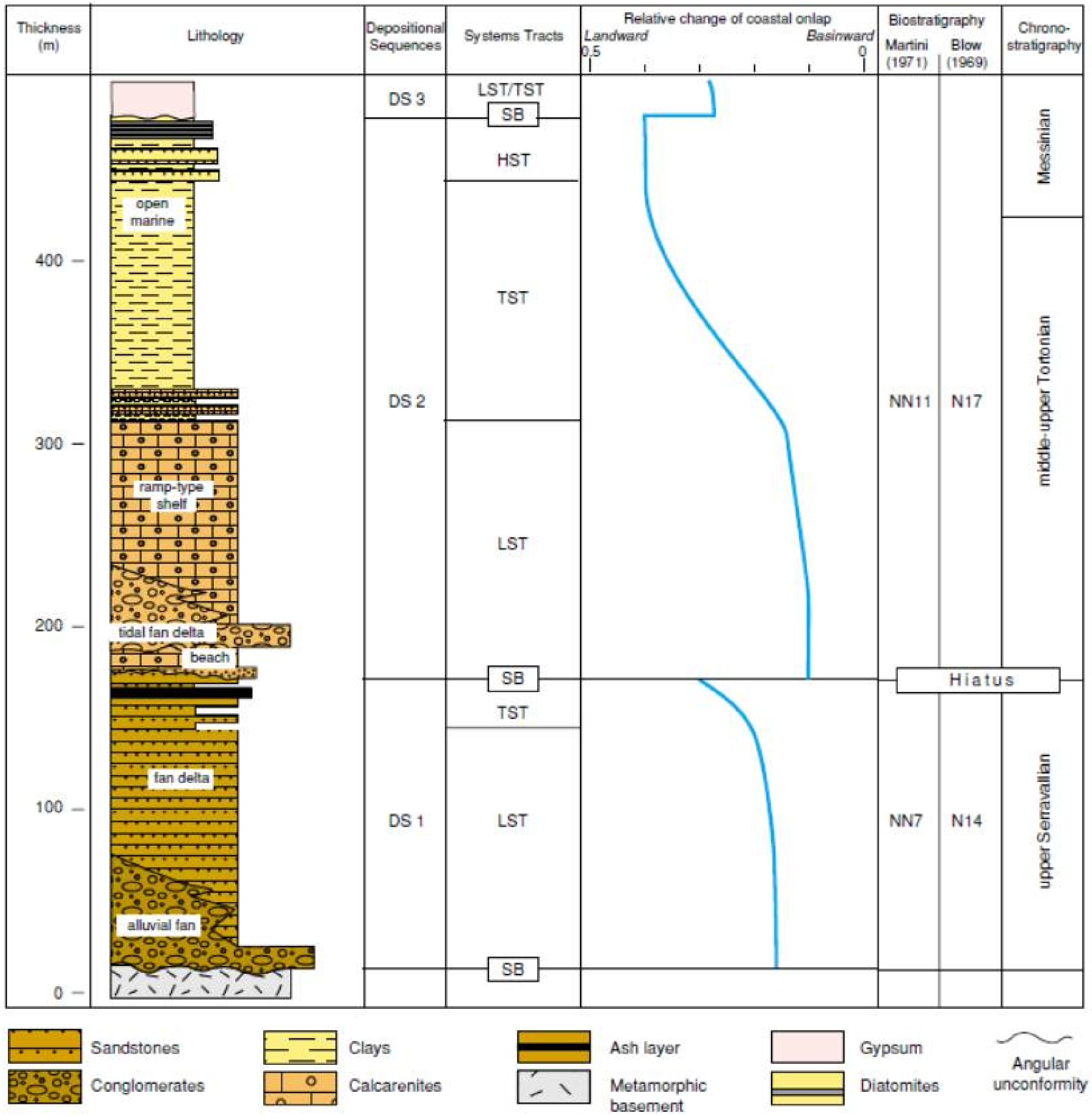

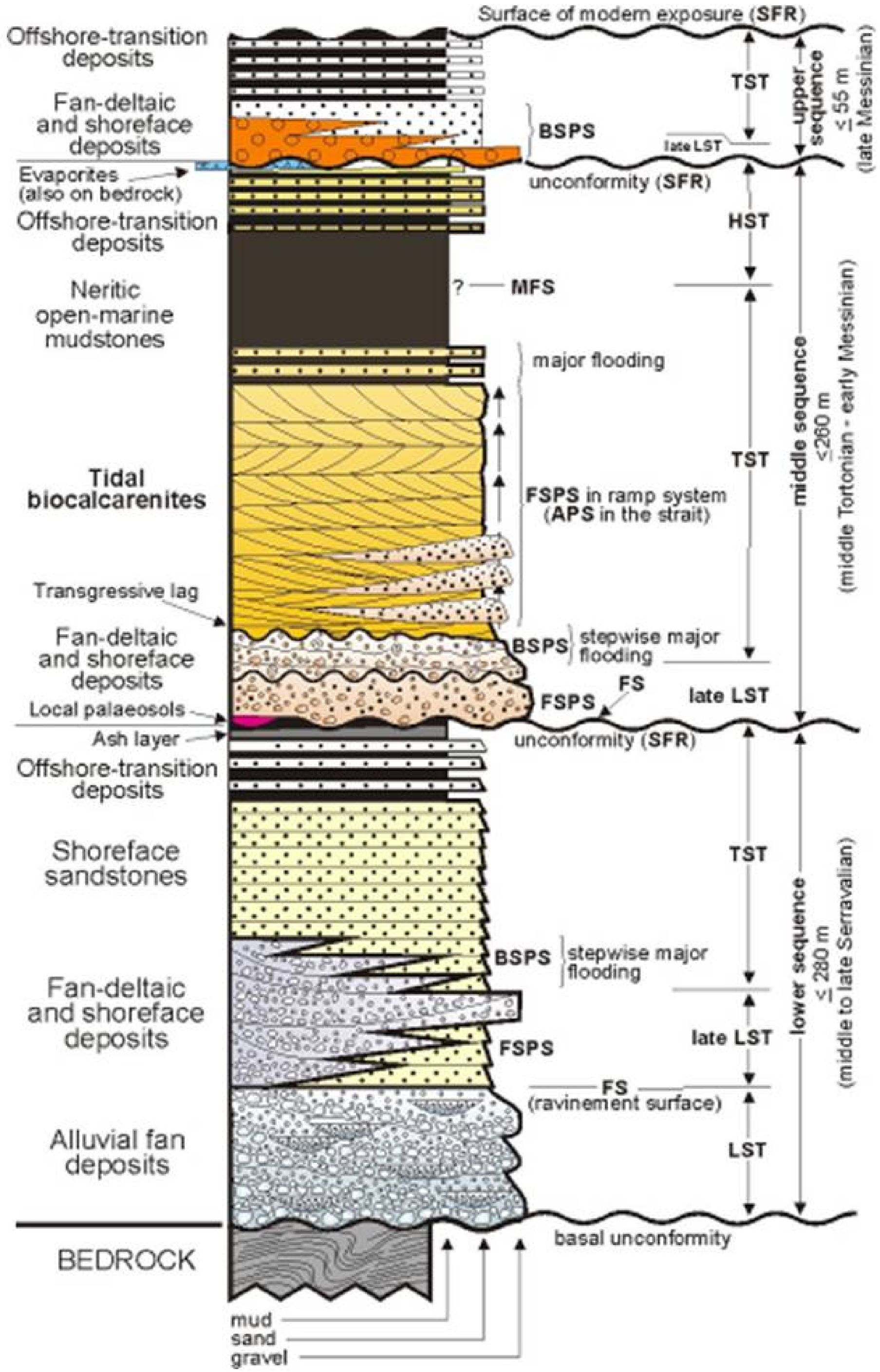

Fig. 27 – Stratigraphic columns of the Amantea basin after Mattei et al., 2002 (on the left) and Longhitano & Nemec, 2005 (on the right).

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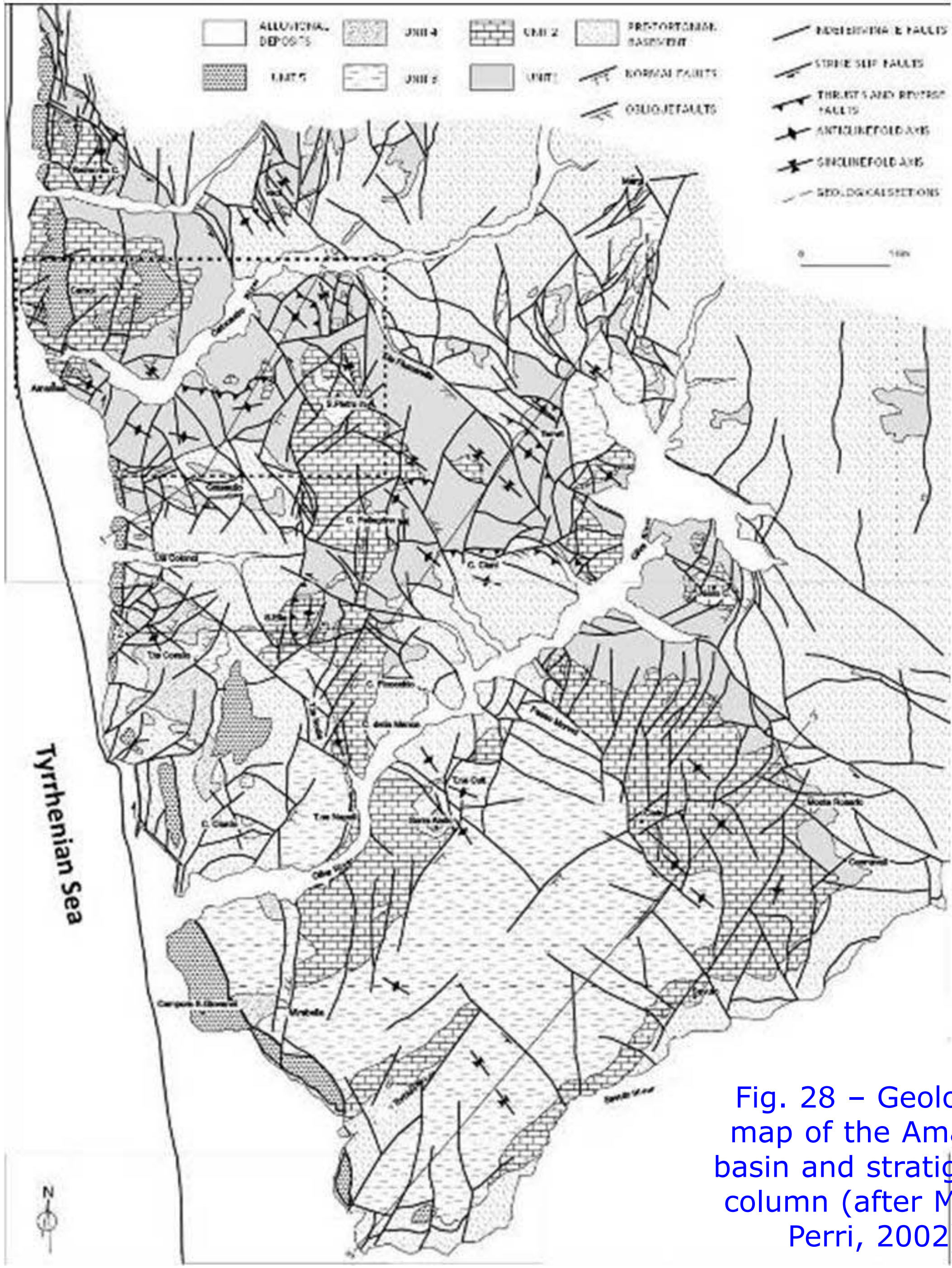

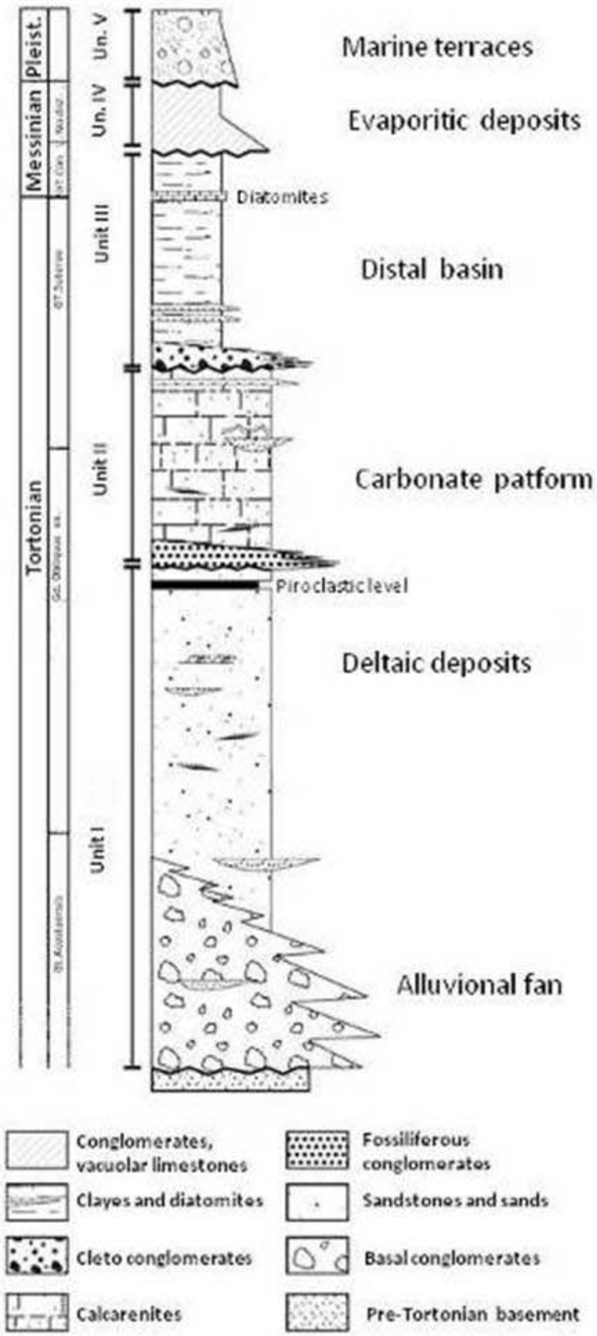

Fig. 28 – Geological map of the Amantea basin and stratigraphic column (after Muto & Perri, 2002).

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STOP 2.4: Belmonte Calabro (CS). Tectono-stratigraphic architecture of the Serravallian-Tortonian Amantea basin infill (Cozzo Varallo section) and post infill tectonics.

The panoramic stop is located at the Belmonte Calabro village towards the nord (Fig. 29), in which the two older sequences of Amantea basin succession are exposed. The sequences are separated by an angular unconformity recognized in all coeval basins (Colella, 1995; Morrone, 1991; Longhitano et al., 2012). The Cozzo Varallo section

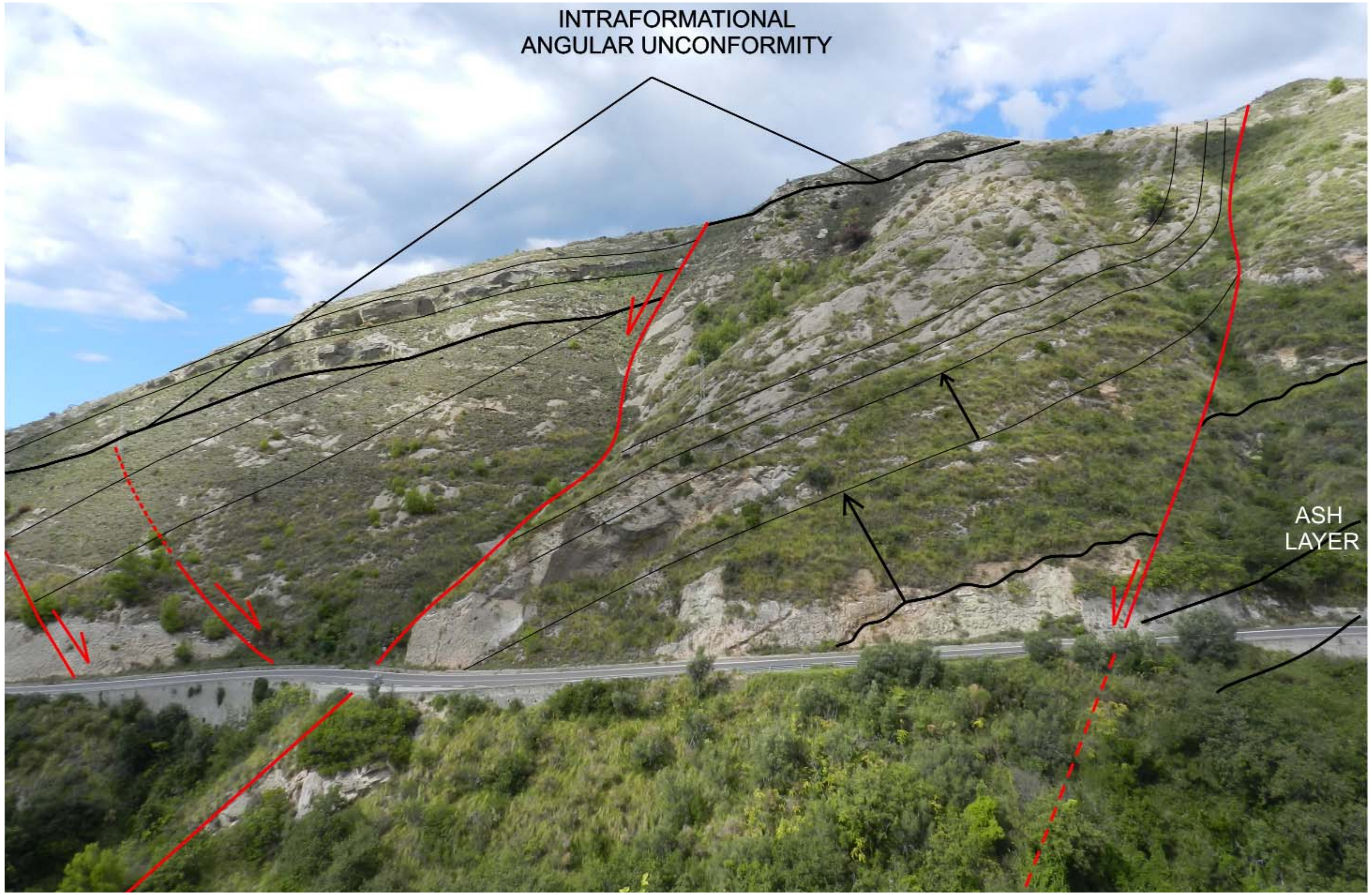

Fig. 29 - Panoramic view from Belmonte Calabro of the Cozzo Varallo section. Stratigraphic contact between the first and the second sequences.

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Fig. 30 - Particular of the unconformity between the two Serravallian and Tortonian sequences.

shows the vertical and lateral transition between the lower first sequence made up of proximal, conglomerates and deltaic sands, with ash layer on the top, and the upper second sequence made up basal fossil-bearing breccia, evolving upward to massive, normal-graded sandstones and cross-stratified mixed, bioclastic-siliciclastic sandstones (Longhitano et al., 2012) (Figs 29, 31). The two sequences are separated by a strong erosional discontinuity and angular unconformity (Figs 29, 30). This section records two tectonic phases: the first involves the Serravallian sequence in a compressional complex pattern, inducing folds and thrust coassial with major strike-slip NW-SE trending fault zone (Tansi et al., 2007), the second Tortonian sequence is affected by N-S high and low-angle east dipping normal faults. Synsedimentary activity of the fault system is testified extensively in the second sequences and in the entire basin. Domino-like arrangement (Mattei et al., 2002; Longhitano et al., 2012) is the result of block rotations of the basal primary normal faults involving the lower

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part of the second sequence. Faults detached the over-thrusted alpine units respect the Mesozoic dolostone unit, identifing two different margins and provenance, composition of sediments during Tortonian and Messinian. The Tortonian structures are displaced by high angle Quaternary normal faults particularly cropping out in the Belmonte Calabro area (Fig. 32).

Fig. 31 - Sedimentary features of the second sequence (Tortonian). Tidal dominated mixed deposits.

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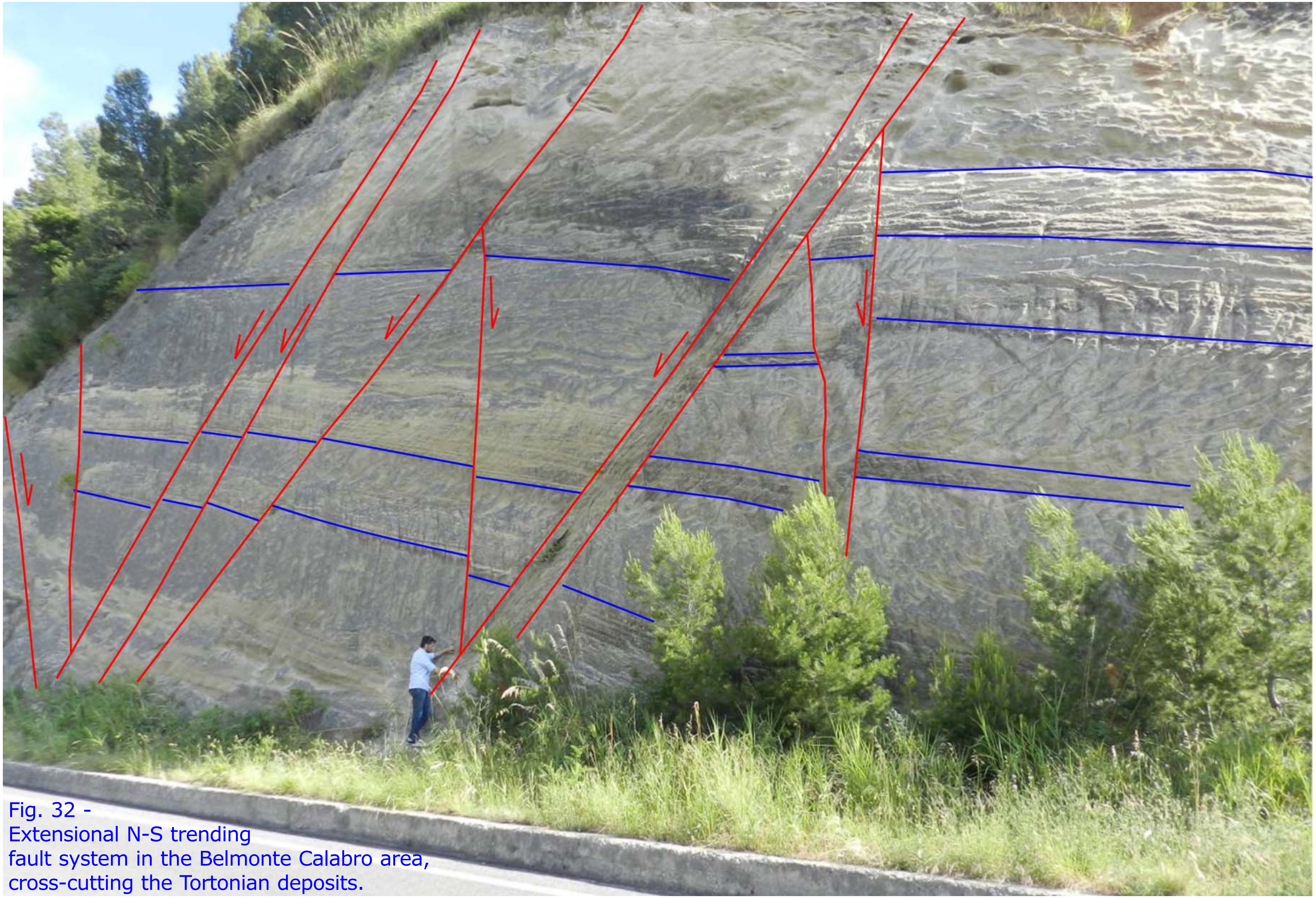

Fig. 32 -
Extensional N-S trending
fault system in the Belmonte Calabro area,
cross-cutting the Tortonian deposits.

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STOP 2.5: Regastili (CS). Transpressive fault zone at the northern margin of the Amantea basin.

Post sedimentary infill contractional structures, faults and folds, have been survived by Muto & Perri (2002) in the Amantea basin and related, probably during the Pliocene-lower Pleistocene, to a prevailing wrench tectonic deformation. The Neogene-Quaternary activity of major NW-SE strike-slip fault zone has been argued by Van Dijk et al. (2000) and by Tansi et al. (2007). On the northern margin of the Amantea basin transpressive faults inverted the relationships between the metamorphic substrate and the Serravallian conglomerates (Figs 33, 34). Moreover, N-S trending thrust faults with related west verging folds, offset the Neogene deposits along the western area of the basin (Fig. 35).

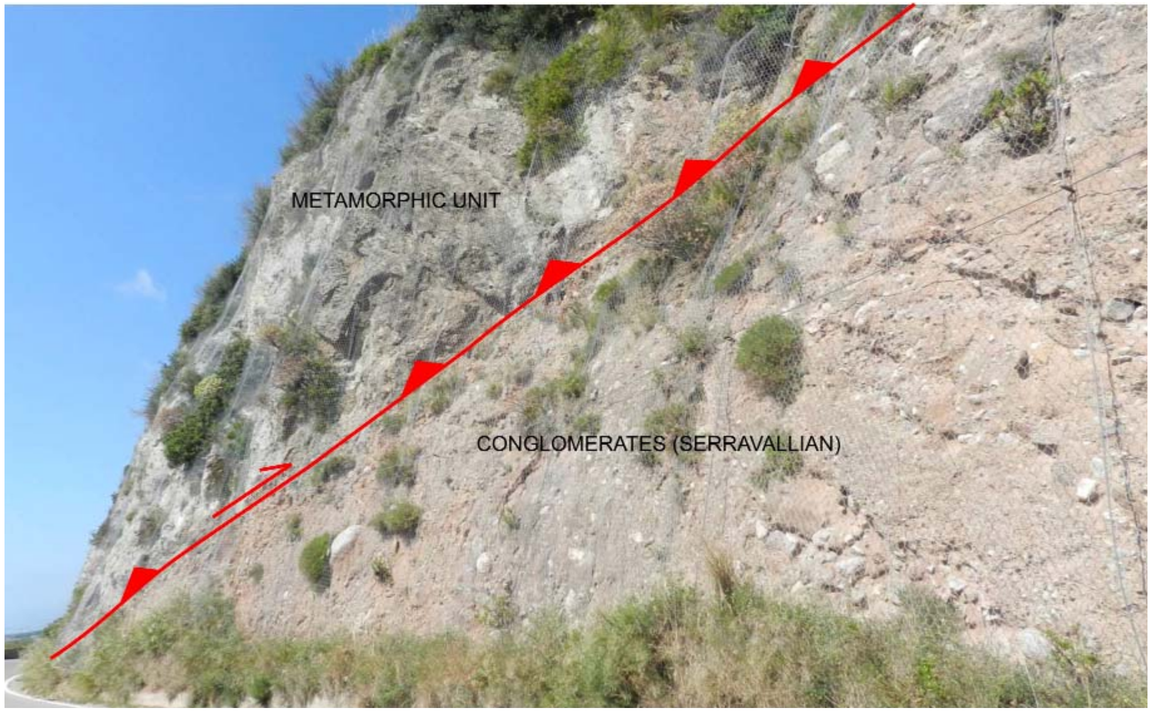

Fig. 33 – Tectonic contact between the basal conglomerates of the first stratigraphic sequence (Serravallian) and the metamorphic substrate (Paleozoic).

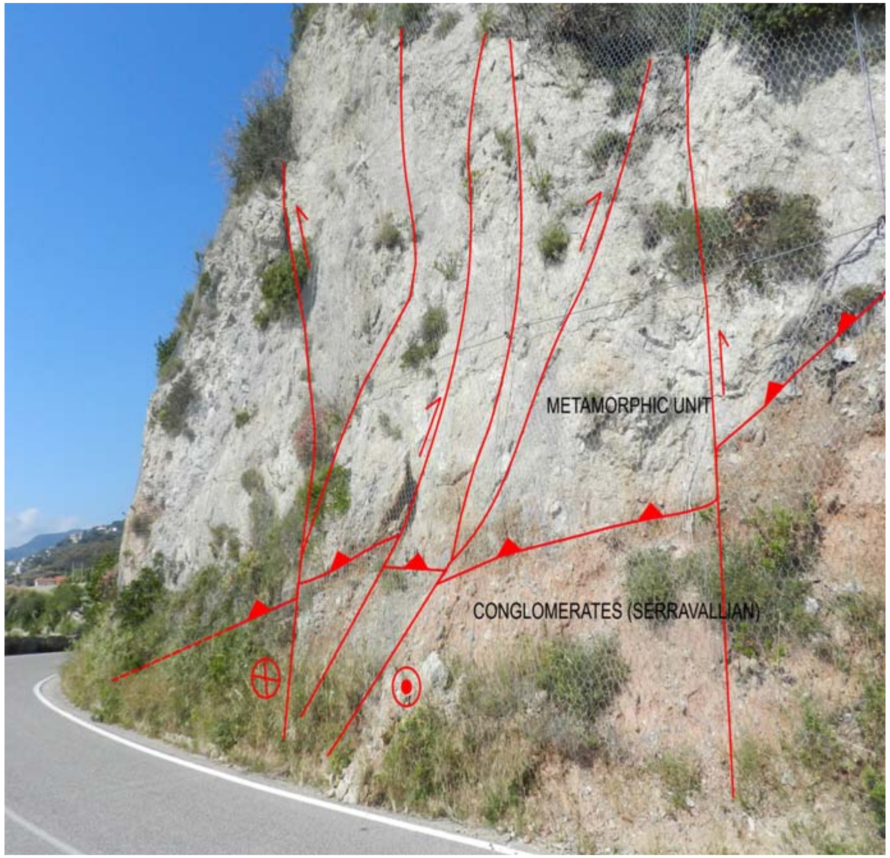

Fig. 34 – Particular of the northern margin of the Amantea basin and the transpressive tectonic contact.

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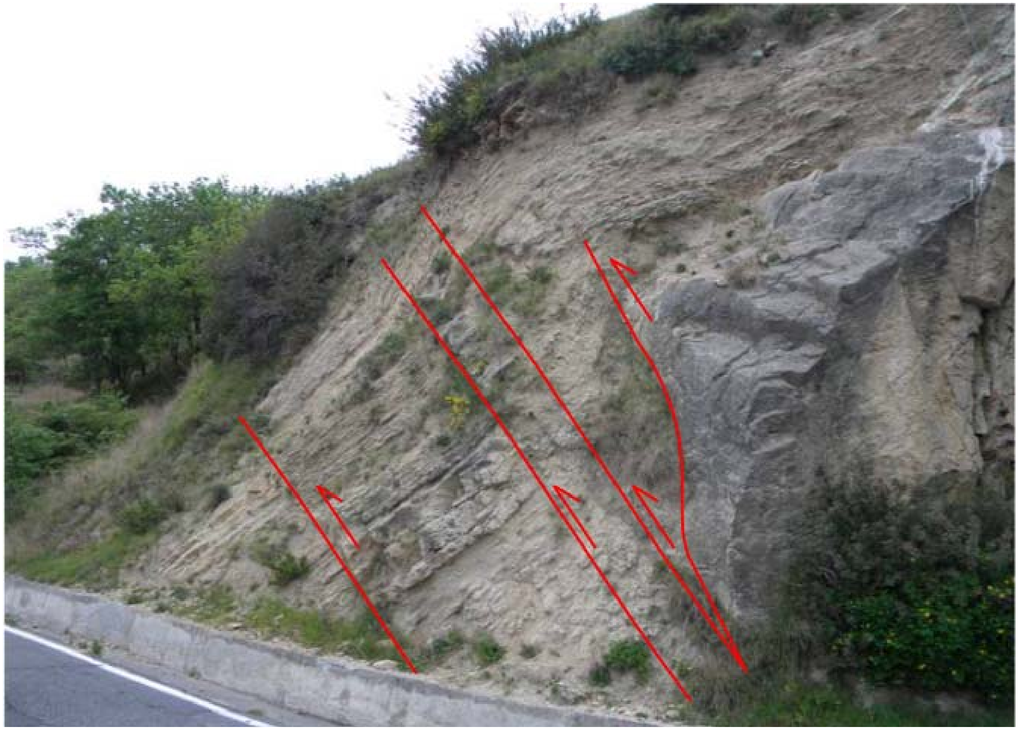


Fig. 35 – N-S, E-dipping reverse faults and W-verging related folds along the western margin of the Coastal Range. Tortonian deposits on the left, Serravallian on the right.

STOP 2.6: Serra d'Aiello (CS). Tortonian extensional tectonics in the Amantea basin infill.

Tectonic history of the Amantea basin is characterised by pulsating compressional and extensional phases (Fig. 36). The stop give a general and excellent view of the Tortonian tectonic activity. In the figure 37, outcrop, on west a structural high formed by the lowermost metamorphic unit of the chain, while, to the est, are cropping out the Tortonian strata belonging to the second sequence of the Amantea basin infill (Figs 27, 28). The Torrente Scala fault is a synsedimentary extensional fault, dipping to the Est, to which is related the synsedimentay folding and the development of progressive unconformities.
The same fault system, is reactived, after the Tortonian time, as reverse faults, causing direct (Fig. 37) or indirect inversion tectonics in the Amantea basin that improve the tectonostratigraphic architecture of the Pliocene-Pleistocene Paola slope basin.

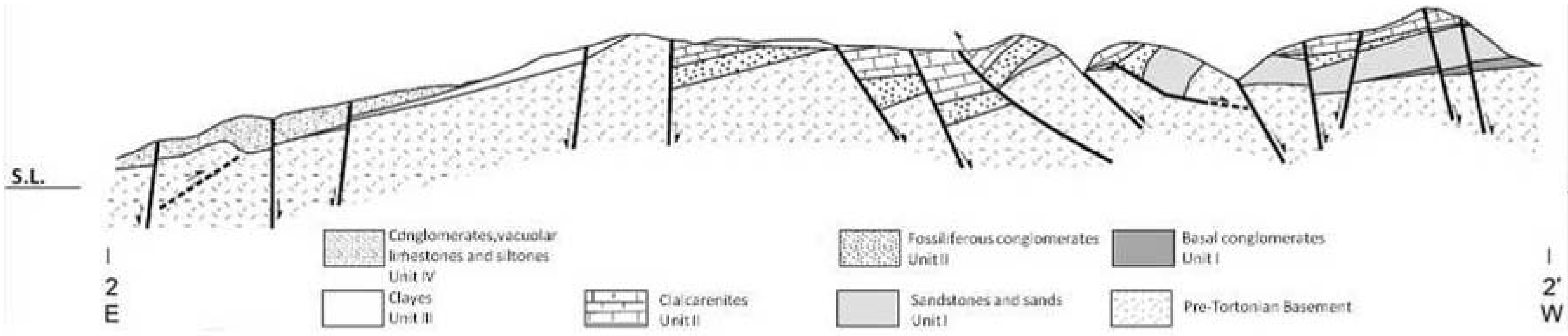

Fig. 36 – E-W geological section of the Amantea basin (for orientation of section see Fig. 28, after Muto & Perri, 2002).

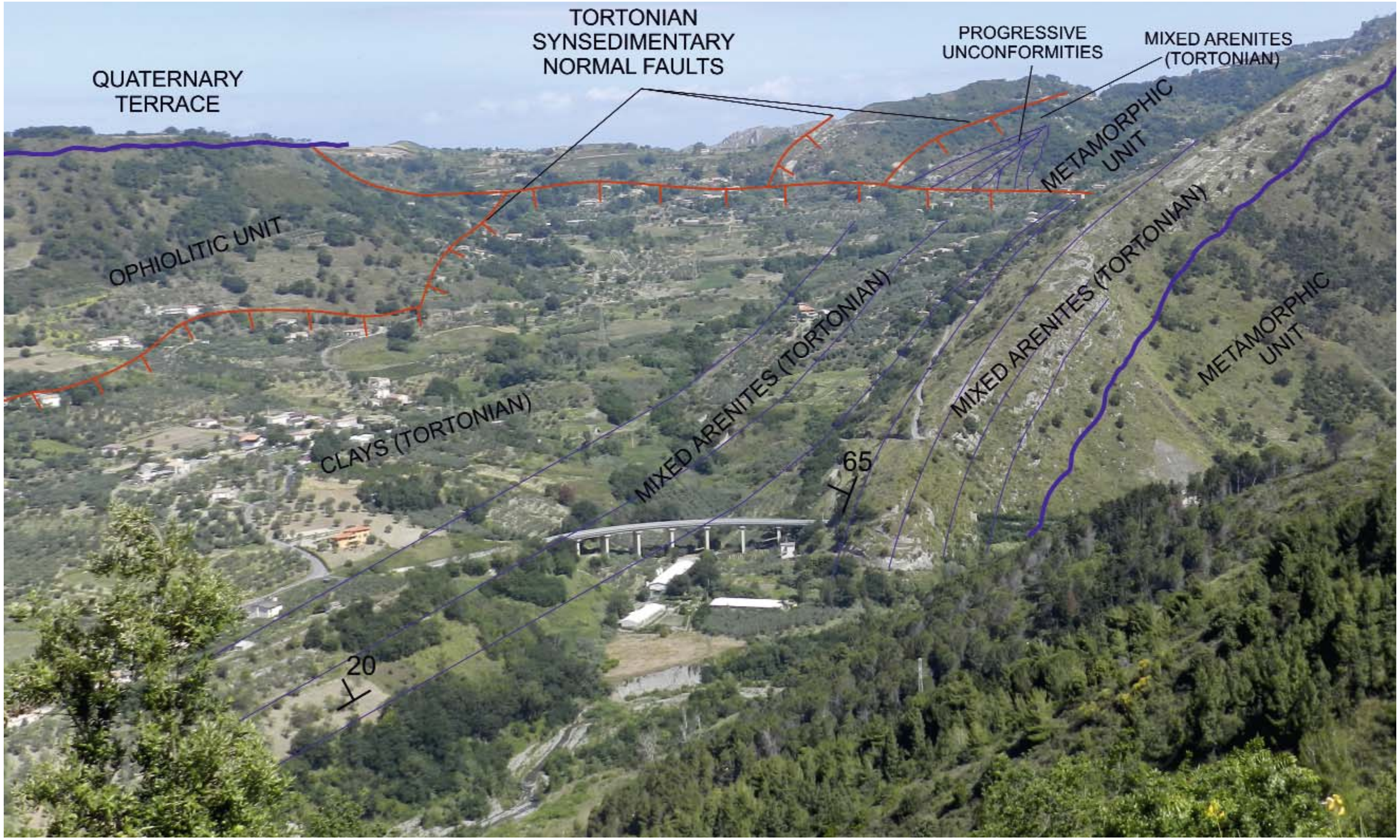

Fig. 37 – General view of the Torrente Scala cachment with synsedimentary low angle Tortonian faults. Footwall of fault system is made up of ophiolitic unit, hanging-wall is made up of the second Tortonian sequence covering the Stilo unit.

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STOP 2.7: Torrente Scala (CS). Rotated extensional faults and rollover anticline.

In the Tortonian sequence of the Amantea basin infill, extentional faults are followed by growing sedimentary wedge testifying the presence of a western paleomargin. Roll-over folds accompained sedimentation in forming growing sedimentary wedges and progressive unconformities in the hanging-wall of the synsedimentary faults (Fig. 38).

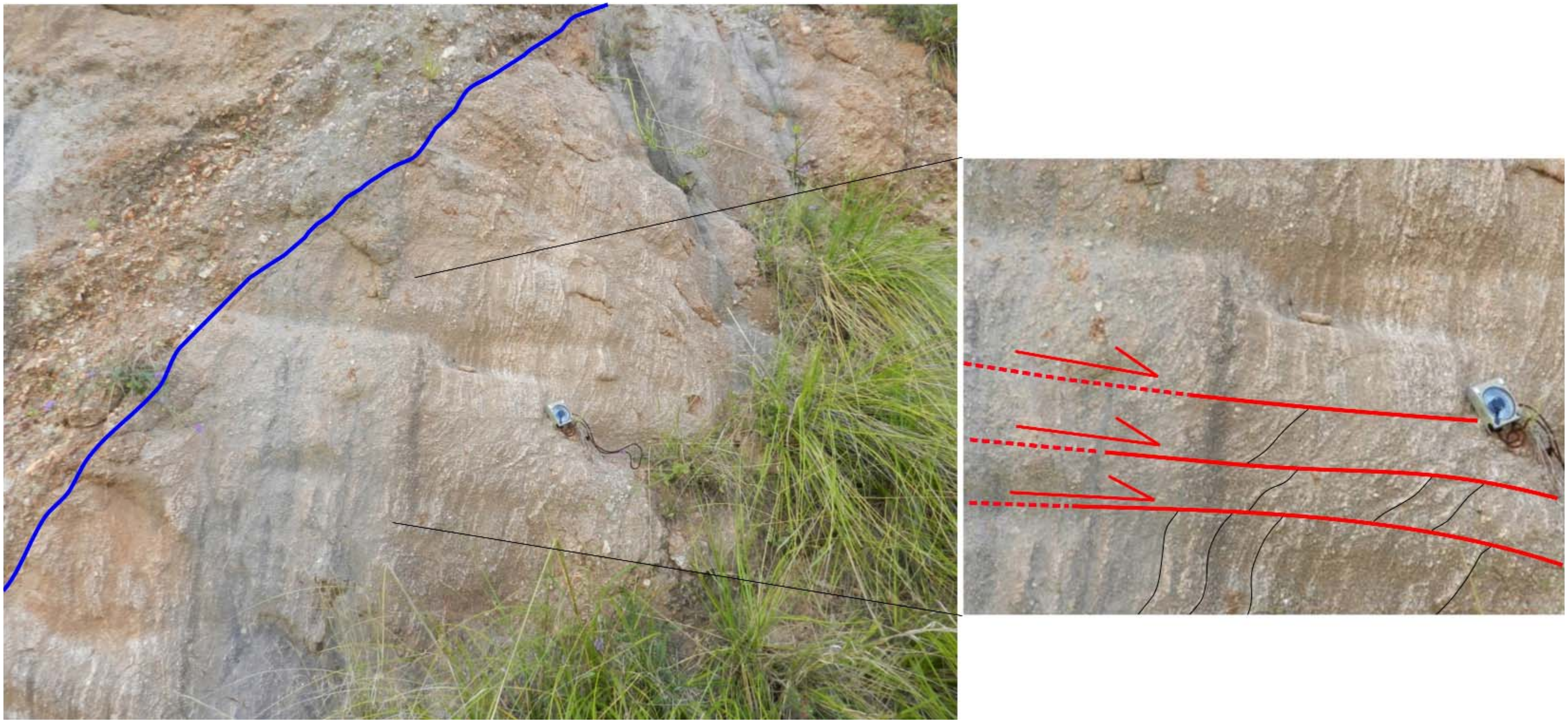

Fig. 38 – Particular of rotated synsedimentary Tortonian normal faults and intra-formational progressive unconformities.

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