Neogene Evolution of the Calabrian Wedge-Top Basins (Italy): Exposed Reservoir Analogues of the Offshore Gas Fields*

Vincenzo Tripodi[1], Salvatore Critelli[1], Francesco Muto[1], and Vincenzo Spina[1]

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[1]Department of Earth Sciences, University of Calabria (Italy) (vinstripodi@libero.it)

Introduction

Since the seventies, hydrocarbon exploration focused in the Ionian side of northern Calabria, resulting in some discoveries of gas fields of economic interest. Luna field, a Tortonian thrust-related anticline, produces from two different Miocene clastic sequences. The source rock in the area is not well defined, and the seal is given by middle-late Miocene deposits in different sectors of the field. Sediments, which reservoir gas offshore, are widely exposed along the Calabrian onshore and exhibit a complex deformation.

The southern Apennine thrust and fold belt and the northern Calabrian Arc, form an orogenic front, which is associated with basin infilling typical of the foreland basin systems (DeCelles and Giles, 1996). In particular, deformed Neogene longitudinal basins represent the wedge-top depozone and Plio-Quaternary basins (Taranto and Bradano troughs) represent the foredeep depozone (Figure 1) (Critelli, 1999; Barone et al., 2008; Critelli et al., 2011).

The Calabrian orogenic belt is composed by a thrust sheet of Palaeozoic basement units, - bearing units of the Neo-Tethys domain (Ogniben, 1973; Amodio Morelli et al., 1976; Dewey et al., 1989). As such, tectonic edifice tectonically covered Mesozoic carbonate rocks of the Apenninic Maghrebide chain, since the middle Miocene. 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 southeastwards migration of the Calabrian Arc of numerous Neogene foredeep and wedge-top depozones of the foreland basin system of the growing orogenic belt and flexed Adria passive margin (Critelli and Le Pera, 1998). 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 offshore (Roveri et al., 1992, Doglioni et al., 1999; Van Dijk et al., 2000). However, similar structures are not clearly described and structurally constrained onland. The onshore 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, a wedge-top depozone, located above thrust sheets of the Calabrian Arc and southern Apennines terranes, and B) the Paola Basin, on the Tyrrhenian side, a slope basin located on the eastern margin of the Tyrrhenian backarc Basin (Critelli, 1999).

Stratigraphy and Tectonics

The tectono-sedimentary evolution of the basin successions cropping out along the northeastern Calabrian margin was investigated, describing timing, style, and tectonic evolution. Middle Miocene deposits accumulated in a longitudinal wedge-top depozone of the Calabrian foreland-basin system, partitioned in three distinctive depocentres: the Rossano, Cirò, and Crotone basins. In the Ionian side of the Calabrian Arc, Neogene and Quaternary basin successions overlie Palaeozoic alpine units and their relative Mesozoic cover (Amodio Morelli et al., 1976).

The upper Oligocene-lower Miocene, about 400-m-thick Paludi Formation (Bonardi et al., 2005) unconformably overlies pre-Tertiary rocks and crops out discontinuously along the eastern sector of the northern Calabria. The 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 volcaniclastic intervals. On top of both crystalline rocks and Oligocene flysch, Serravallian to Pliocene terrigenous and carbonate sequences constitute the infilling of the thrust-controlled Calabrian foreland, which can be subdivided in three main depocentres: the Rossano, Cirò and the Crotone basins.

The succession starts with breccias and conglomerates and arkosic sands, passing upwards to sands and sandstones with interbedded clays (S.Nicola dell'Alto, Umbriatico and Arenaceo Conglomeratica formations, (Ogniben, 1955)). The latter sediments evolve towards a succession composed of clays, marls, and thin turbiditic sandstones of Tortonian age (Ponda Group). The succession includes alluvial fan, near shore, and shallow-water sediments. The Ponda units include siltstone, mudstone, and marl in the lower portions, having sedimentary cyclicity characterized by an alternation of decimetric indurated dark clay and light grayish or light blue marl in the upper part. The middle portion of the units, about 25 m in thickness, consists dominantly of sandstone strata locally having interbedded slumps and scour-and- fill structures (Barone et al., 2008). The group sediments evolve towards a succession composed of grey marls and white diatomites alternating with carbonates and cherty beds (Tripoli Formation, Ogniben, 1962), of deep-water environment. On top of these deposits, the Rossano and Crotone basins show evaporitic sedimentation whereas there was a lack of sedimentation lack central Cirò depozone. In the Crotone Basin the Tripoli Formation is overlain by a clastic succession consisting of limestone breccias grading to gypsrudites–arenites and gypsum-bearing sandstones. These successions are overlain by deposits consisting of meter-scale blocks of limestone, gypsarenite breccias, and gypsarenite slumps and halite (Roda 1964a; Barone et al., 2008). An upper Messinian succession consisting of shale, sandstone, and minor gypsarenite levels with a Lago-Mare fauna at the top onlaps the unit below. An erosional surface separates these uppermost Messinian deposits from the overlying deltaic sand lobes and fluvial conglomerates of the Carvane Conglomerate unit.

The Messinian succession continues with terrigenous sedimentation and closes with conglomerate of fluvial and deltaic environment (Carvane Formation) mainly cropping out in the southern sector (i.e., Crotone Basin).

Pliocene to Pleistocene sediments seal the former deposits; the succession is composed of marls (Cavalieri Formation, Roda,1964a) evolving to clastic sediments (Zinga, Spartizzo, Scandale, Cutro and Strongoli formations; Zecchin, 2002) and shales.

Lower to middle Pliocene is absent in the central part of the study area, where bioclastic calcarenites and marls of late Pliocene unconformably cover the Miocene succession. A series of Pleistocene marine terraces crop out along the Ionian coast, testifying to the strong Quaternary uplift this sector of the Calabrian Arc underwent. Tectonic structures strongly controlled the geometry of the Neogene basin as a consequence of the progressive south-eastwards shifting of the Calabrian belt.

A complex network of strike-slip faults and associated thrust characterized the entire Ionian side of the northern Calabria. The neotectonic transcurrent activity of the transversal fault zone offsets the accrectionary front of the chain and provides the structural high that separates pull-apart depressions in onshore and in offshore zone (Amendolara, Rossano, Cariati, Cirò ridge) (e.g., Pescatore and Senatore, 1986; Romagnoli and Gabbianelli, 1990).

During late Tortonian-early Messinian, huge volumes of Sicilide-derived rocks composed of variegated clay matrix and large blocks of limestone and sandstones were emplaced. The latter bodies can be related to the accommodation due to out-of-sequence thrusts, or with hinterland thrust propagation of the Sicilide complex. Along the entire Ionian side of the northern Calabria, bodies of varicolored clays (called “Anti-Sicilide complex” by Ogniben, 1969) have been observed within upper Miocene deposits. Varicolored 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).

At a regional scale, major tectonic structures control the configuration and the evolution of the main basins in the northern Calabrian Arc (Knott and 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 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 a result of strain partitioning along left lateral strike-slip faults and offset the Miocene folds propagation fault. The main onland transpressional high is represented by the Cariati Nappe (Figure 2).

A positive structure made up 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 contains 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 ovethrusted Tortonian and lower 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.

Results and Discussion

The Miocene and post Messinian emplacement of the so-called "Cariati Nappe" (CN) in the central sector of the study area interrupts the lateral continuity and affects the sedimentary supply of such a configured foreland basin. The Cirò Basin, located in an intermediate position between the Rossano and Crotone basins, is missing the Messinian evaporites (Van Dijk and Scheppers, 1995). This suggests that a larger and previously continuous basin was wrenched into sub-basins recording a separate tectonic history (Figure 3) (Barone et al., 2008). This succession, of uncertain age, was interpreted like an allochthonous series (Cotecchia, 1963) on post-evaporitic (post-Messinian) terrigenous sediments (Roda, 1967).

Structural data show that the CN is a transpressive structure formed along restraining bends of the NW-SE-striking, left-lateral, Rossano-S.Nicola Fault Zone. This structure contains the distal sediments of the Miocene basin infill, together with its back-thrusted bedrock (Sicilide Complex). Along the outer front of the northern Calabria, strike-slip regional fault zones produced regional wrenching of the Miocene basins, controlled the development of intrabasinal structural highs (like the CN) related to back thrust, and produced tectonic inversion in some sectors. Since the CN can be considered as an exposed analogue of the offshore structural highs, it is noteworthy 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. 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 (Figure 3), rapid uplift of mid-crustal blocks, and the superposition of wrench tectonics.

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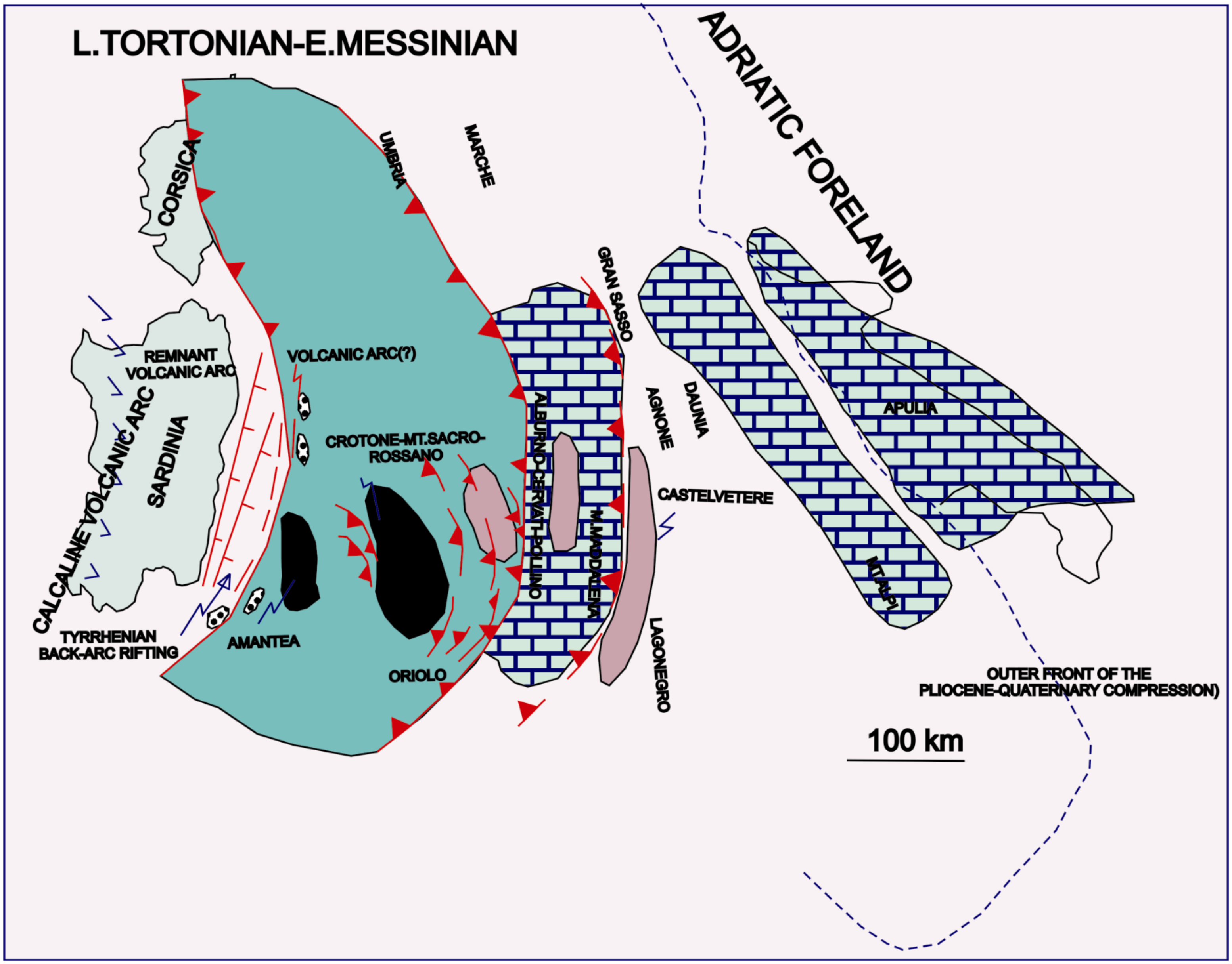

Figure 1. Palinspastic restoration of the Apenninic domains during the late Tortonian to early Messinian (time interval 8-6 my.). Initial back-arc rifting of the Tyrrhenian Sea and diverse wedge-top and foredeep depozones in the southern Apennine foreland region (from Critelli, 1999; Critelli et al., 2011).

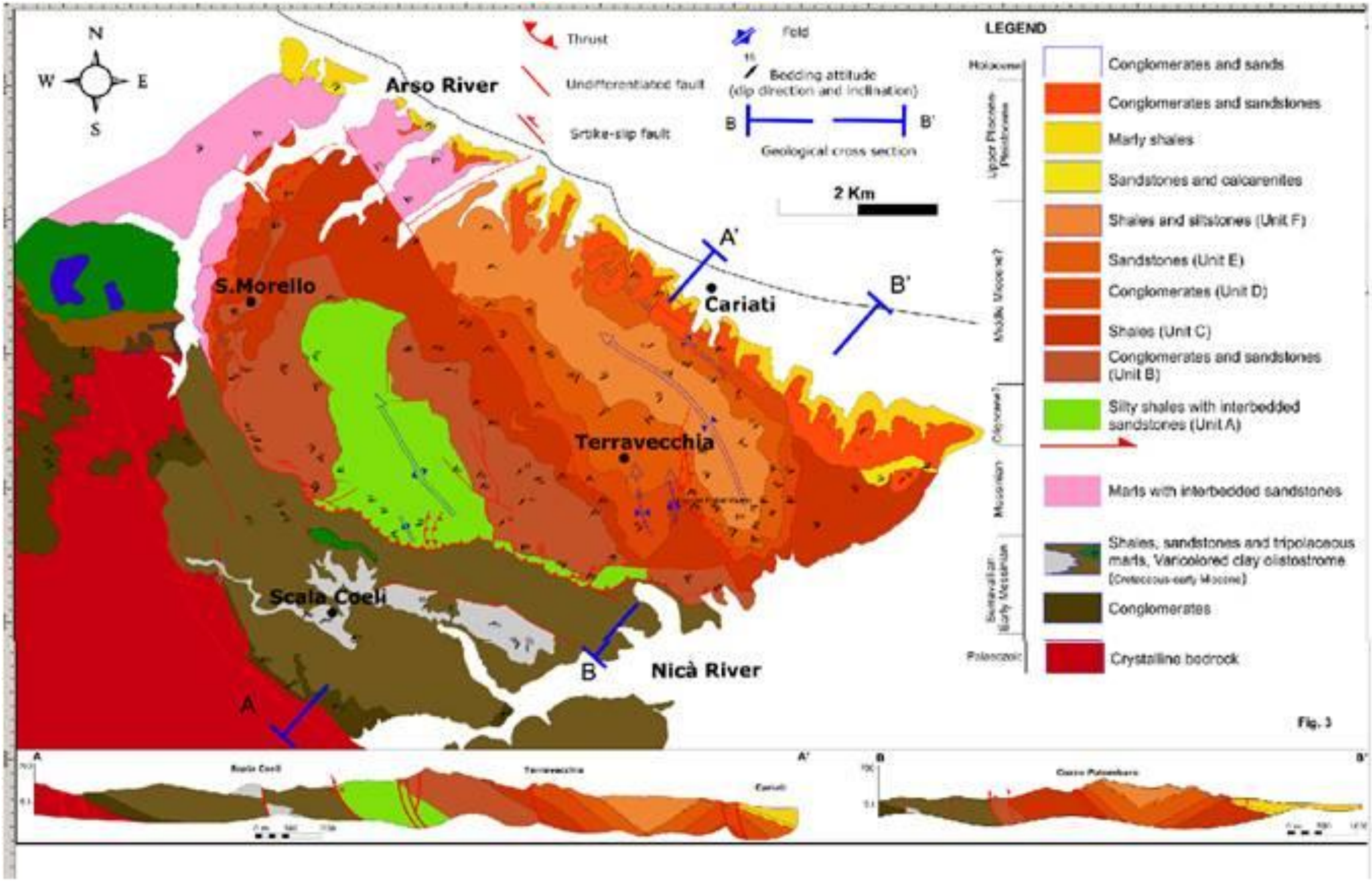

Figure 2. Detailed geological map with cross-sections of the Cariati area, showing the structure of the Cariati Nappe.

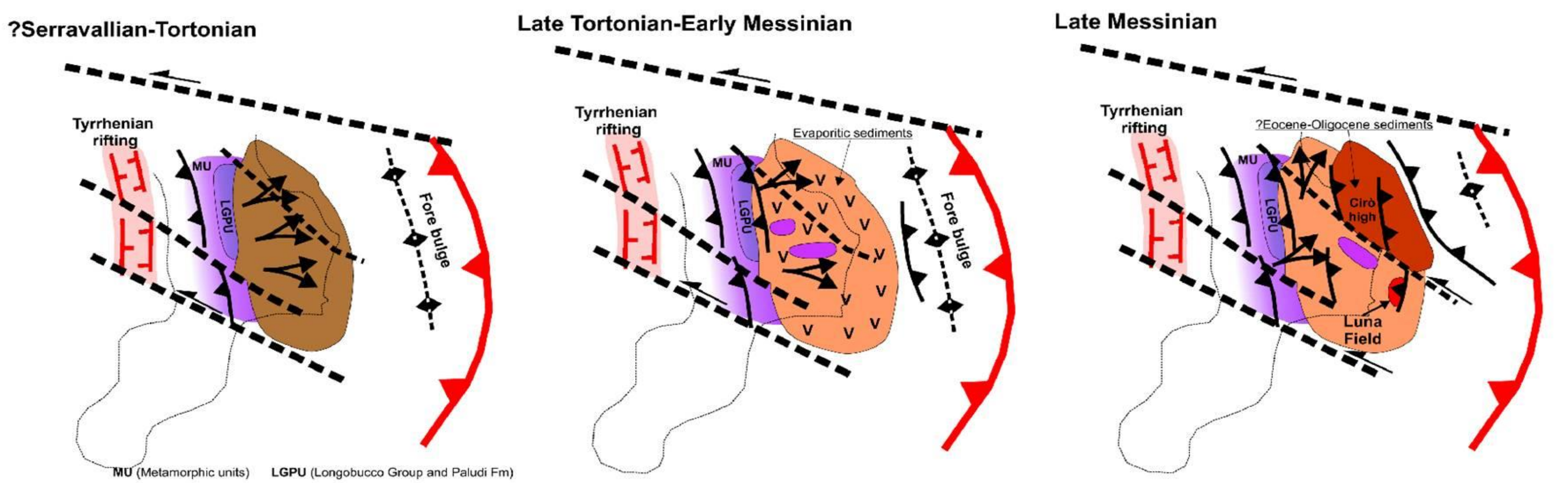

Figure 3. Schematic tectonic evolution of the outer front of the Neogene Calabrian belt. The figure shows that thrusts can be associated with NW-SE striking strike-slip regional fault zones(modified from Barone et al., 2008).