Tectonic Evolution of the Salt-Bearing Crotone Basin (Southern Italy)*

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Abstract

New field data show the Late Miocene-Early Pliocene interplay between tectonics, salt tectonics and sedimentation in the north-eastern Ionian side of Calabria. In the northwestern part of the Neogene Crotone Basin (Italy) Messinian deepwater clastic evaporites represent the older evaporitic sediment, folded and thrust just after deposition. This fault-related fold represents the northwestern border of a younger, south-eastern basin progressively filled by a chaotic complex derived from the just folded clastic evaporites. Tectonics led to a restricted water circulation, which allowed the deposition of halite in the southeastern younger basin. The following latest Messinian succession, comprising pelites and gypsarenites of a younger evaporitic cycle, led to salt withdrawal by local overloading, presently marked by weld-rocks.

Our data on the Sr isotopic ratios also allowed reconstruction of a precise stratigraphy in the evaporitic suite. The Early Pliocene tectonic extension triggered salt diapirs piercing the latest Messinian sequence. Our data allow discrimination, in the sub-salt sequences, of the faults formed before from those formed after the salt deposition as well as to distinguish weld-rock from cap-rocks according to their different deformation pattern.

Geological Setting

This study describes the Messinian evolution resulting from the interplay between the coeval salinity crisis and tectonics in the northwestern part of the Crotone Basin in the Mediterranean area depozone of the foreland basin system developed on the Ionian side of Calabria (DeCelles and Giles, 1996; Cavazza and DeCelles, 1998; Figure 1). The northern Ionian Sea is composed of the NW forearc basin and subduction complex affected by NW-dipping, SE-verging thrusts (Cavazza et al., 1997; Rossi and Sartori, 1981), and by the SE Ionian abyssal plain. The study area presently represents the northwestern termination of the Crotone Basin where the sedimentary sequences (Serravallian – Pliocene) close against the basement complex highs, which border the study area to the north and west. The angles of pinch out of the various sequences allowed reconstruction of the tectonic and/or isostatic rise of the basement complex trough time. As a consequence the area presently forms a southeast-dipping homocline as a whole, where the older sequences outcrop only in the northwestern sector. They are folded and thrust representing the northern border of a south-eastern basin filled by younger sequences (Upper Messinian – Lower Pliocene; Figure 2).

The Crotone Basin is said to have been affected by major NW-SE trending, sinistral strike-slip faults active from the Middle Miocene onwards (Van Dijk et al., 2000 and references therein), which would have accompanied and allowed the shifting of the Calabrian Arc to the SE due to the opening of the Southern Tyrrhenian Basin, as well as the formation of the Ionian forearc basin and subduction complex (Cavazza et al., 1997; Rossi and Sartori, 1981). The area thus underwent a very complex tectonic evolution showing several alternated, short-lived tectonic regimes, although all the structures detected in the field seem to accommodate little deformation.

Stratigraphy

In sea-marginal settings affected by short-lived tectonics, like the one represented by the Crotone Basin, the evolution through time can be reconstructed in detail by unraveling the interplay between tectonics and sedimentation. The northern Crotone Basin fill have been subdivided into three large-scale composite depositional sequences (Roda, 1964; Zecchin et al., 2003; Costa et al., 2006) bounded by regional-scale unconformities marking the tectonic evolution (Figure 2). The lowermost sequence (Serravallian – Messinian) rests unconformably above the metamorphic basement complex and is topped by the intra-Messinian unconformity: it outcrops only in the northwestern area. The above Messinian-Lower Pliocene sequence, whose lower boundary is represented by the intra-Messinian unconformity, is mainly made up, in its lower portion, of resedimented, clastic evaporites derived from the complete dismantlement of *in situ* primary evaporites (Lower Evaporites, Decima and Wezel, 1973). This is also confirmed by the value of the 87Sr/86Sr isotopic ratio = 0.708917 (Flecker et al., 2002). The clastic evaporites are here interpreted as relatively deep-water gravity flow deposits *l.s.*. The clastic evaporites along with the sequence below form a SE-verging anticline plunging to the NE and encompassing the whole studied area (Figure 3). Folding occurred just after deposition of the gypsarenites, which slumped ahead forming a chaotic complex pinching out against the fold forelimb to the NW. This structural high borders to the north the southeastern sector of the basin, whose sedimentary fill, consisting of the younger stratigraphic terms of the Messinian-Lower Pliocene unit, onlaps the fold forelimb as well, lying above the chaotic complex. These observations suggest an intra-Messinian age to this compression tectonics affecting the lowermost sequences of the northwestern area.

The halite, commonly forming diapirs piercing the overlying latest Messinian to early Pliocene units, sometimes reaching the surface (Figure 4), crops out in the southwestern area in its original stratigraphic position, sandwiched between the resedimented evaporite unit, below, and a mainly terrigenous unit, made up of arenites and clay alternations, containing subordinately fine-grained gypsarenites, locally named “detritico-salina fm” (Figure 2; Roda, 1964). Seismic and well data from salt mining areas (courtesy of Syndial, Belvedere di Spinello) show that halite is interposed between organic-rich laminites similar to the Tripoli Fm (Lower Messinian) below and uppermost Messinian gypsarenites, arenites and pelites above. Based on the lower Sr isotopic ratio of these fine-grained gypsarenite (87Sr/86Sr = 0.708833; Flecker et al., 2002), the unit capping the salt is derived from the dismantlement of the primary evaporites of the younger Upper Evaporites (Decima and Wezel, 1973), now outcropping south of the study area.

The upper portion of the Messinian-Lower Pliocene sequence is made up of coarse-grained fluviodeltaic systems (Carvane conglomerates) topped by a thin finer-grained horizon containing Lago Mare fauna (Gennari and Iaccarino, 2004). The above Early Pliocene offshore Cavalieri Marls grade upward into the shallow-marine sandstones and the biocalcarenites of the Zinga Fm. (Roda, 1964). The latter has been recently subdivided into three unconformity bounded sequences (Zinga 1, 2, 3 of Zecchin et al., 2003): only the two lower sequences outcrop in the study area.

Tectonics

The first and main stress field had a max compression direction NW-SE that was responsible for the formation and sinistral movement of crustal scale NNW-SSE faults bordering the study area. This stress field switched from transcurrent to compressive, causing first, strike-slip structures in the lowermost sequence (Serravallian – Messinian), and then compressive structures like the fault-related fold and thrusts detected in the lower portion of the Messinian-Lower Pliocene sequence (Figure 3), the switching being probably caused by the inversion of previous faults affecting the basement.

The intra-Messinian shortening previously described was followed by Early Pliocene extension, which caused the tilting of the overlying Lower Pliocene succession and triggered salt diapirism by normal faults (Figure 5); these movements have been enhanced by the presence of halite below.

The sub-salt sequences have also been affected by extension. The early Pliocene age of extension is also fully constrained by seismic data (courtesy of Eni S.p.A) that show normal faults also cutting the intra-Messinian unconformity as well as the lowermost sequence. These data demonstrate that extension is not related only to salt flow but, on the contrary, is crustal-scale, although of little amount in the study area.

Deformation Pattern and Fault Distribution

The tectonic evolution of the area caused deformation and faulting of both the sub- and supra-salt rocks, with different patterns depending on lithology and the reciprocal relationship and timing between rocks and deformations. The intra-Messinian transpression and compression, described in the previous section, caused faulting in the rocks located below the salt horizon. The Lower Pliocene extension, to the contrary, affected both the sub-salt organic-rich laminites (reported as “Tripoli” in Figure 2; Figure 6) and the supra-salt rocks.

Thick salt should have been located just ahead the fold forelimb in the northeastern area. This salt stock lately flowed into the adjoining diapirs causing rollover anticlines in the Early Pliocene successions and leaving weld-rocks (as defined by Jackson and Cramez, 1989 in seismic sections of the Gulf of Mexico) dominated by the insoluble deposits, originally interlayered within the salt. This weld horizon shows layers collapsed by salt withdrawal, unconformably juxtaposed and superposed (Figure 7). Cap-rocks underwent a completely different deformation, showing gypsum filling the faults and cracks formed by shear between the rising diapir and the pierced cover (Figure 8); these different deformation patterns allow distinguishing in the field the two different types of residual rocks after halite (Lugli et al., 2007b).

Conclusions

The deformation structures detected in the various sequences outcropping in the study area allowed reconstructing the tectonics versus sedimentation history of the northwestern part of the Crotone Basin. The Sr isotopic ratios found in the various evaporite rocks outcropping in the Crotone Basin allowed us to assign them to either the earlier or the later evaporitic cycle, defining precisely their stratigraphic position within the evaporitic suite. It was also possible to discriminate between the various types of faults that affected the sub-salt sequences, according to their time of nucleation: either before or after the salt deposition, as well as to distinguish weld-rocks from cap-rocks according to their different deformation style.

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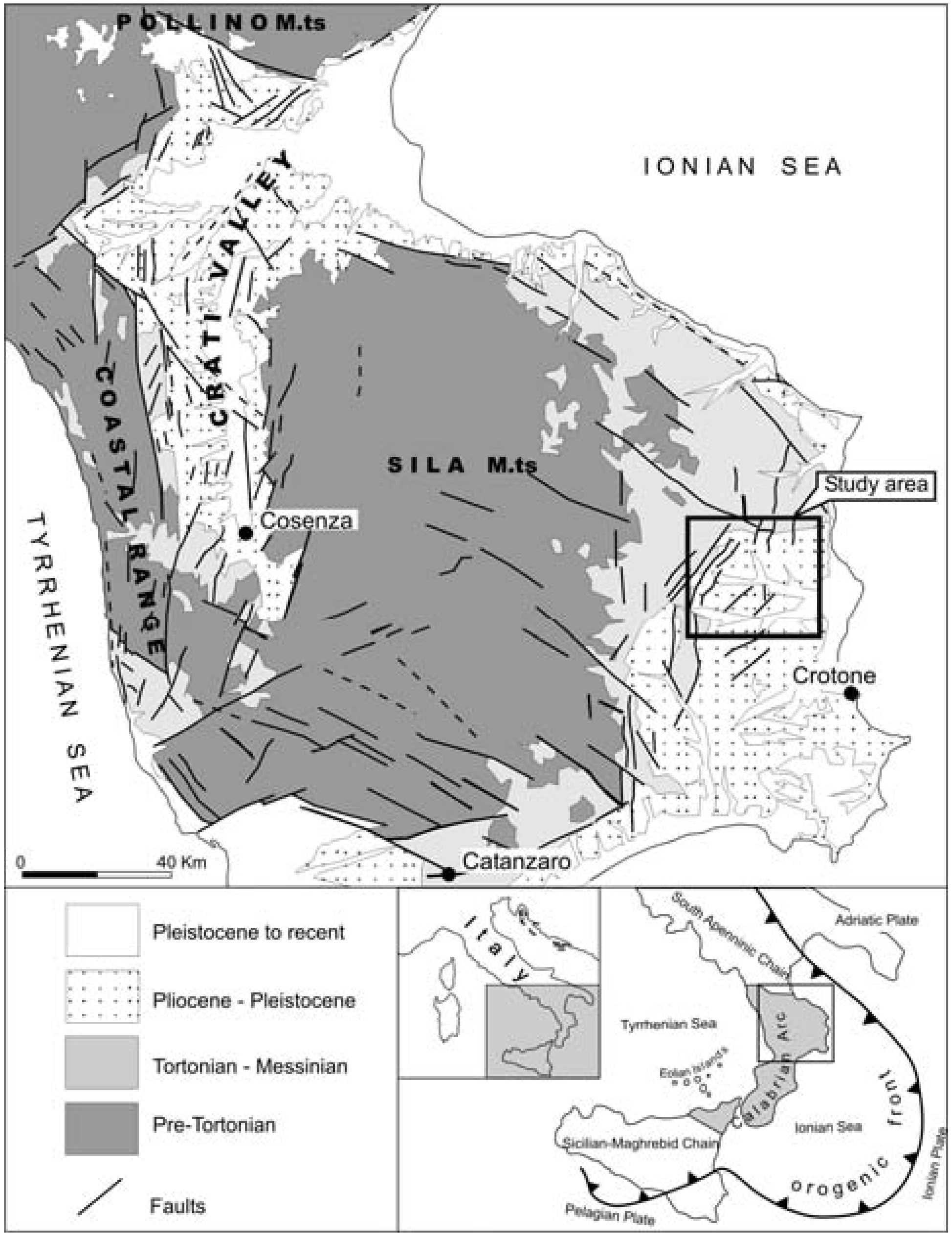

Figure 1. Location and geologic map of Crotone Basin area

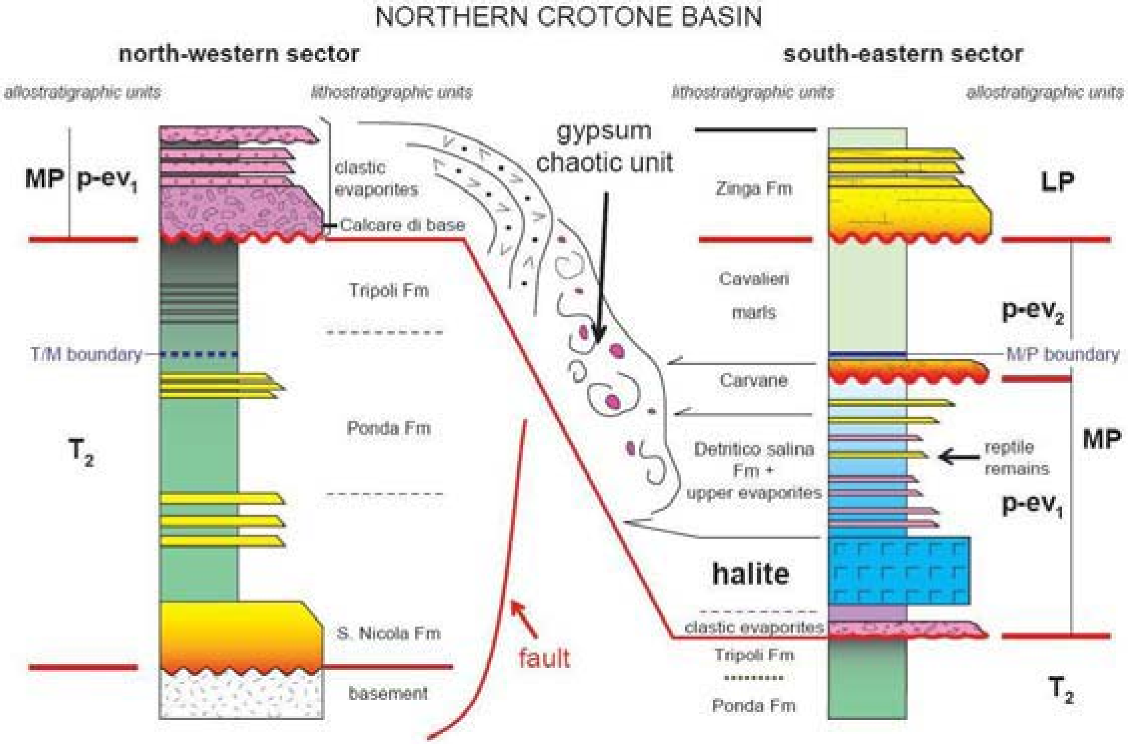

Figure 2. Northern Crotone Basin stratigraphic framework.

Figure 3. Outcrop of the clastic evaporites along with the sequence below form a SE-verging anticline plunging to the NE.

Figure 4. Halite commonly forms diapirs piercing the overlying upper Messinian to lower Pliocene units.

Figure 5. Halite diapir triggered by normal faults.

Figure 6. The Lower Pliocene extensional fault affected the sub-salt organic-rich laminites.

Figure 7. This weld horizon shows layers collapsed by salt withdrawal, unconformably juxtaposed and superposed.

Figure 8. Cap-rocks underwent a completely different deformation, showing gypsum filling the faults and cracks formed by shear between the rising diapir and the pierced cover.