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Interplay between Tectonics and Sedimentation in the Lower Pliocene Fill of the Crotone Basin, Southern Italy

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INTRODUCTION

The present work focuses on the Pliocene infill of the northern part of the Crotone Basin, characterized by spectacular interactions between tectonics and sedimentation. The succession was deposited in an area recently uplifted, crossed by a NW-trending shear zone related to the south-eastward migration of the Calabrian Arc. The studied area underwent a generalized extensional tectonics interrupted by phases of shortening probably related to the transpressional activation of strike-slip faults.

Excellent outcrops provided good three-dimensional control on the geometry of the sedimentary bodies. The reconstruction of sedimentary environment and the definition of the architecture helped to define the structural evolution of the basin and to highlight the role of tectonics and sea-level changes in the formation of sedimentary sequences.

GEOLOGIC AND STRATIGRAPHIC SETTING

The Crotone basin is located in the forearc region of the Calabrian Arc, in Southern Italy. It is bounded by two NW-trending left-lateral shear zones, the Rossano – San Nicola to the north and the Petilia – Sosti to the south (Meulenkamp et al., 1986; Van Dijk, 1990, 1991) (Fig. 1).

Sedimentation occurred from late Serravallian to middle Pleistocene time, and was controlled by extensional (Moretti, 1993) and strike-slip tectonics along the main NW-trending shear zones (Van Dijk, 1990, 1991). The studied succession is formed by the outer shelf deposits of the Cavalieri Marl, and by the shallow-marine deposits of the Zinga Molasse, that encompasses three informal lithostratigraphic units (Zecchin, 2002): Zinga sandstone (0 – 300 m thick), Montagnola clay (0 – 100 m thick) and Belvedere formation (0 – 450 m thick). The succession has been subdivided into three main sequences bounded by regional unconformities controlled by a complex interplay between tectonics and eustasy (Fig. 2).

SEQUENCE STRATIGRPHY

Zinga 1 sequence: Cavalieri Marl and Zinga sandstone

The base of the Zinga 1 sequence has been placed at the contact between the Messinian Carvane Conglomerate and the lower Pliocene Cavalieri Marl, interpreted to represent the Miocene-Pliocene boundary (Roda, 1964). There is no agreement on the nature of the contact. Roda (1964) refers to a rapid but continuous transition, whereas Moretti (1993) recognized a stratigraphic gap, marked by thick paleosols.

The lower part of the Zinga 1 sequence is formed by the Cavalieri Marl (up to 270 m thick), deposited in an outer shelf/ upper slope setting. Biostratigraphic data based on foraminifera suggest bathyal conditions near the base followed by a progressive shallowing trend approaching the base of the overlying Zinga sandstone. The Cavalieri Marl is inferred to represent the transgressive and highstand systems tracts of the Zinga 1 sequence, with the transgressive tract limited to the basal interval.

The upper part of the sequence is formed by the progradation of the shoreface and deltaic deposits of the Zinga sandstone (zero to 300 m thick) (Figs. 2, 3 and 4). The overall organization is that of a prograding clastic wedge (Fig. 3) of sharp-based, offlapping clinoforms that show a progressive basinward coarsening and a marked downward shift in facies, with superposition of upper shoreface and delta front deposits onto lower shoreface and offshore marls. These characteristics are representative of forced-regressive systems tracts (FRST, Hunt & Tucker, 1992), bounded at the base by a regressive surface of marine erosion (RSME), that grades distally to a non-erosional surface. The Zinga sandstone therefore, is interpreted to represent the forced regressive systems tract (FRST) of the Zinga 1 sequence (Fig. 3).

The age of the Zinga 1 sequence is uncertain. Biostratigraphic data on the Cavalieri Marl indicate an early Pliocene age, within the *Globorotalia margaritae* zone. The lack of marine deposits above the sequence prevents a time constraint of its upper boundary.

Zinga 2 sequence: Montagnola clay and lower Belvedere formation
The second sequence encompasses the uppermost Lower Pliocene, and is formed by the middle part of the Zinga Molasse (Fig. 2). The sequence is up to 400 m thick and is marked at the base by few metre thick channelized trough to tabular cross-stratified conglomerates and coarse-grained sandstones cut into the upper shoreface deposits of the underlying Zinga sandstone. The erosional relief of the basal contact, the lack of bioturbation, the presence of imbrication and unidirectional currents suggest that the channelized units represent fluvial deposits. The unit is overlain by a thick (up to 100 m) grey to brown mudstone interval that form the bulk of the Montagnola clay (Figs. 2 and 3). The oligotypic faunal content represented by small cardid shells (*Cerastoderma edule*) indicate that the clays were deposited in a brackish-water, lagoonal setting.

The lagoonal deposits are sharply overlain by an up to 300 m thick succession of bioclastic and siliciclastic bioturbated to swaley cross-stratified shoreface deposits (Belvedere formation, Figs. 2, 3 and 4). The succession is organized into an aggradational stacking of high-frequency cycles (3-15 m thick), each characterized by a basal bioclastic/siliciclastic fining-upward interval, possibly marked at the base by a shell lag, in turn followed by a siliciclastic unit of bioturbated and swaley cross-stratified sandstones.

The sequence boundary of the Zinga 2 sequence is represented by the erosional surface at the base of the fluvial deposits, easily traceable throughout the study area at the top of the Zinga sandstone. The sequence is formed by lowstand fluvial deposits, a transgressive systems tract characterized by the lagoonal claystones and a highstand systems tract formed by the shoreface succession of the Belvedere formation.

Zinga 3 sequence: upper Belvedere formation
The deposits of the Zinga 3 sequence onlap an unconformity placed inside at the Belvedere formation (Fig. 2). In the central study area, the sequence is marked at the base by a shell lag formed by *Ostrea sp*. in a granule-grade matrix. The basal lag forms the base of a 45 m thick interval of large-scale cross-stratified sandstones, with sets up to 4 m thick. They are generally characterized by an unimodal palaeocurrent pattern. This interval has been interpreted to represent sand-waves migrating in the axial part of a narrow strait, bounded by listric normal faults. To the west, the lower part of the sequence is formed by a thin, up to 10 m thick, lagoonal mudstone interval. Sand-wave and lagoonal deposits are overlain by a shoreface interval up to 100 m thick, composed of small-scale cycles of bioclastic and siliciclastic, swaley cross-stratified sandstones, similar to those described in the upper part of the Zinga 2 sequence.

The Zinga 3 sequence represents a depositional sequence formed by a transgressive succession of sand-waves and lagoonal deposits and by a highstand systems tract of shoreface deposits. The basal surface represents the combination of a sequence boundary and a transgressive surface.

RELATIONSHIPS BETWEEN TECTONICS AND SEDIMENTATION
Tectonics and sedimentation during the deposition of the Zinga 1 sequence
The Zinga 1 sequence was strongly influenced by the growth of NE-trending non-cylindrical folds that produced strong thickness variations within the sedimentary succession (Fig. 3). The core of NE-trending non-cylindrical folds is formed by the halite deposits of the Messinian evaporites. Salt tectonics probably played a major role, possibly enhanced by motion along the NE-trending normal faults. The relatively shallow burial depth of the salt (some hundreds of metres) suggests salt tectonics linked to differential loading (i.e. Kehle 1988), probably enhanced by the variable thickness of deltaic and shoreface deposits of the Zinga 1 sequence.

Minor structures, as imbricate listric faults coeval with deposition of the Zinga sandstone and Montagnola clay, were also observed (Fig. 4).

Tectonics and sedimentation during deposition of Zinga 2 and Zinga 3 sequences
The deposition of Zinga 2 and Zinga 3 sequences was characterized by an accentuation of the extensional regime present already during the deposition of the underlying sequence. Growth folds and imbricate listric faults previously active during deposition of the Zinga 1 sequence, continued to be active during deposition of the lower part of the Zinga 2 sequence. Severe subsidence in the basin was linked to the activation of NE-trending listric growth faults that led to the formation of a series of horsts and half-graben sub-basins (Figs. 3 and 4). As a consequence of growth fault activity, thickness of the Zinga 2 and Zinga 3 sequences varies from few metres on the horsts up to 400 m and 150 m respectively in the half-grabens.

Throughout the study area, the Zinga 3 sequence is marked at the top by a major angular unconformity related to the activation of a tectonic phase with compressional component that led to a NE-SW shortening. The tectonic phase was probably linked to the transpressional activation of the NW-trending left-lateral shear systems that bound the Crotone basin, dated latest Early Pliocene – earliest Middle Pliocene (Roda, 1964; Van Dijk, 1990, 1991).

The NE-SW shortening linked to the new tectonic phase interrupted the movements along the NE-trending normal faults bounding the half-graben sub-basins, and enhanced the growth of N- to NW-trending folds.

CONCLUSIONS

The Lower Pliocene succession of the Crotone Basin was deposited in a strongly active tectonic setting which generated spectacular responses in the sedimentary architecture. The studied succession were first controlled by the growth of NE-trending salt-cored anticlines, and then by listric normal growth faults. Both tectonic settings highlight an extensional regime, whereas the end of deposition coincides with an important tectonic phase with compressional component at the end of early Pliocene, probably related to strike-slip tectonics. The studied succession can thus be regarded as the expression of the interplay between extensional faulting, typical of an active forearc setting, and transpressional tectonics due to the activation of NW-trending shear zones. Despite the intense local tectonics, the basal unconformities of the sequences are inferred to result from sea-level changes as local tectonics continued uninterrupted across the sequence boundaries.

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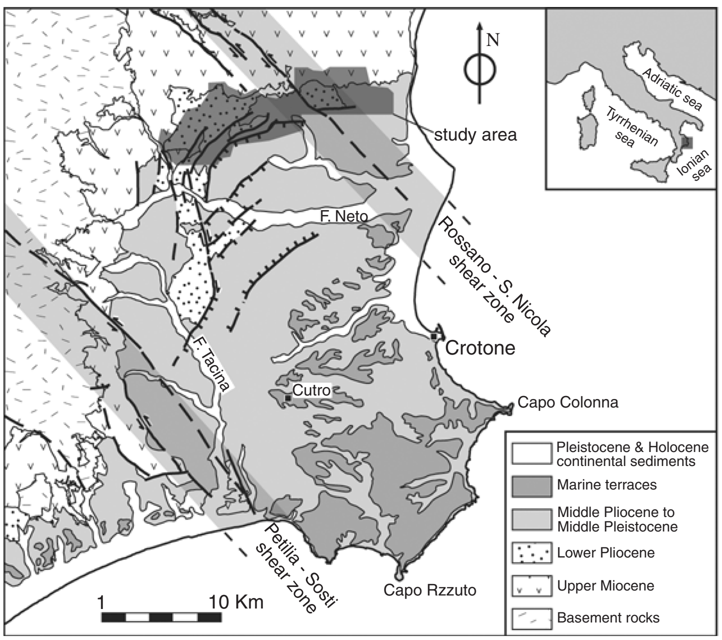

Fig. 1. Geological sketch-map of the Crotone Basin, with location of the study area (modified from Massari et al., 2002).

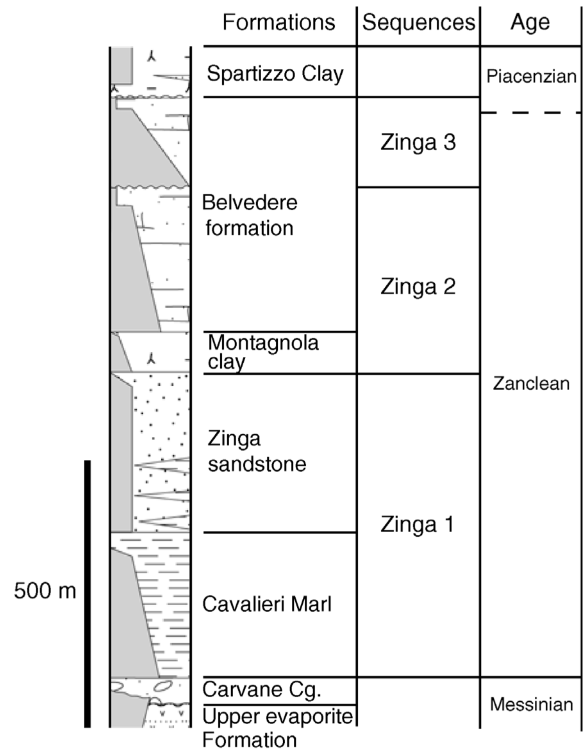

Fig. 2. Lithostratigraphic units and sequences object of the present work.

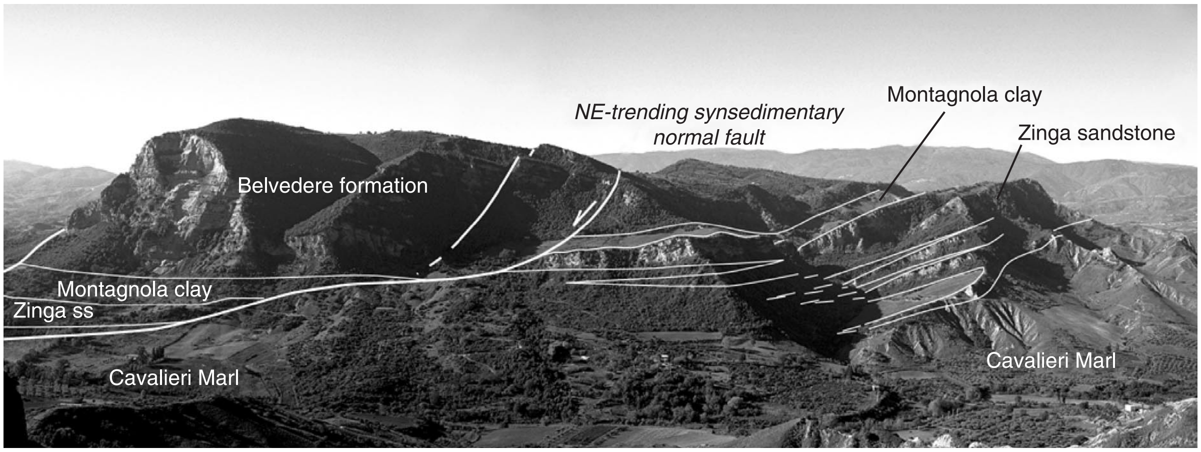

Fig. 3. The lower Pliocene succession located in the western study area. Note (right) the prograding forced-regressive wedges of the Zinga sandstone (upper Zinga 1 sequence), related to the growth of a NE-trending non-cylindrical anticline. Deposition of the thick succession of the Belvedere formation (Zinga 2 and Zinga 3 sequences) was linked to the activity of a NE-trending listric normal growth fault.

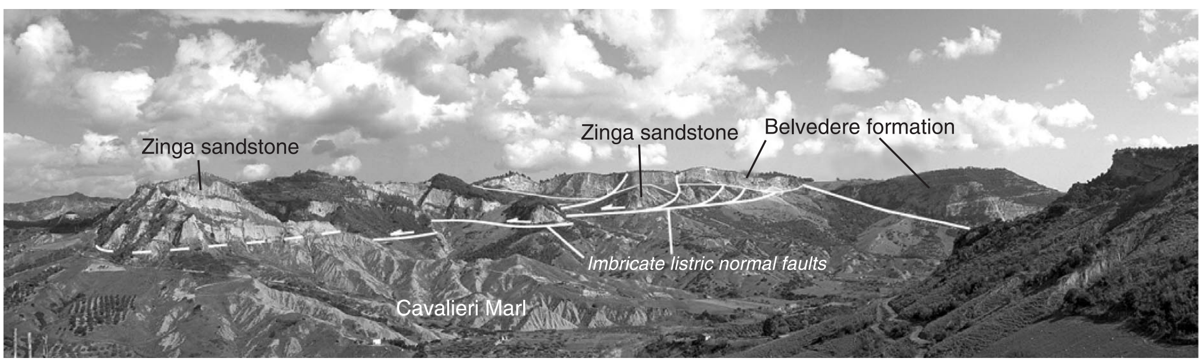

Fig. 4. The lower Pliocene succession located in the central study area. Note the imbricate listric normal faults, active during deposition of the Zinga sandstone (upper Zinga 1 sequence) and Montagnola clay (lower Zinga 2 sequence). The strong thickness increase of the Belvedere formation (right) was linked to the activity of a NE-trending listric normal growth fault.