Available online http://amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 29 (1), 2016, 91-105

ACTIVE TRANSPRESSIVE SURFACE FAULTING IN NORTH-EASTERN CALABRIA, SOUTHERN ITALY: EARLY RESULTS OF GEOMORPHOLOGICAL, STRATIGRAPHIC AND PALEOSEISMOLOGICAL ANALYSES

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ABSTRACT: We here first described field evidence of Holocene transpressive faulting in north-eastern Calabria, about 15 km east of Rossano, in the area of Mirto. There, we analysed a stratigraphic sequence exposed along a WNW-ESE trending, 4-km-long scarp, anomalous in the local geomorphic context. The sequence was made of marine deltaic sediments with embedded colluvial deposits, daylighted by an excavation for a building. The excavation occurred on top of a fluvial terrace at ~15 m a.s.l., that was embedded in a MIS 5a marine terrace.

Micropaleothological analysis and 14C radiometric dating defined an Early(-Middle) Pleistocene age for the marine sequence and a Holocene age for the overlain colluvial deposits. The whole sequence was back-tilted, warped and offset along shear planes showing an evident reverse sense of motion. The uphill sense of displacement, the local geomorphic setting and the available literature allowed to exclude any other cause (e.g. deep-seated or shallow landsliding, salt diapirism) than tectonics for the observed deformations. By considering the current knowledge about the structural and active tectonic framework of the northern Calabrian Arc, the observed reverse fault planes can be the surface expression of either local active compressional deformations (i.e. restraining bend) along the Rossano-Cirò Marina strike slip shear zone, being part of the regional, left-later strike-slip Pollino Line, or an inland splay of the active transpressional tectonic structures offshore of the Sibari Plain and the Rossano area. Even if at an early stage, our observations can represent a new piece in the active tectonics puzzle of the boundary region between the Calabrian Arc and the southern Apennines. They also provide new hints for seismotectonic evaluations, taking into thorough consideration that the ob-served tectonic features occur in the epicentral area of the 1836 (Mw 6.2) earthquake, the causative fault of which is still debated. Ultimately, the present study raises new questions about reverse surface faulting hazard assessment for this region.

Keywords: Holocene transpression; surface faulting; paleoseismology; north-eastern Calabrian Arc; Southern Italy

1. INTRODUCTION

The Calabrian Arc is a fragment of European continental crust that drifted towards the southeast since the Late Oligocene-Miocene (e.g. Gueguen et al., 1998) and interposed between the southern Apennines and the Maghrebian chains. It represents an accretionary wedge (Amodio Morelli et al., 1976; Dewey et al., 1989; Doglioni, 1991; Kastens et al., 1988; Malinverno & Ryan, 1986; Ogniben, 1973; Patacca & Scandone, 1989; Royden et al., 1987) formed by Alpine units consisting of a series of Mesozoic ophiolite-bearing tectonic units and overlain by crystalline-metamorphic basement nappes (Calabride complex; Ogniben, 1969). The Alpine nappes outcropping in the Coastal Chain and in the Sila massif, during Oligocene-Early Miocene, overthrusted on the Mesozoic carbonate terranes belonging to the Mesozoic Apennine domain. In the Middle Miocene- Middle Pleistocene time, the Calabrian Arc was affected by a regional NW-SE left-lateral transcurrent fault system which dissected the orogenic belt generating transverse and longitudinal structural highs and basins (Ghisetti & Vezzani, 1981; Dewey et al., 1989; Turco et al., 1990; Van Dijk et al., 2000; Tansi et al., 2007).

The lateral juxtaposition of these different tectonic blocks consists in two complex region-al shear zones, perpendicular to the axis of the Arc. These zones seem to reflect two lithospheric tear faults that permitted the south-eastward retreat of the Ionian slab subducting towards the NW (e.g. Rosenbaum et al., 2008), and onto which the Calabrian Arc “floats”. The tectonic boundary between the Calabrian Arc and the southern Apennine is commonly referred to as “Pollino Line” (hereafter PL) (Fig. 1). It consists in a NW-SE trending tectonic lineament at the transition between the Meso-Cenozoic carbonate sequences of the southern Apennines-Lucanian boundary and the metamorphic and igneous basement terrains of the Calabrian block. From a structural point of view, left-lateral strike slip sense of motion is commonly attributed to the PL (e.g. Tansi et al., 2007) (Fig. 1, inset), although its kinematic history, in the framework of the subduction system, is still a matter of discussion. From a seismological point of view, a change in the fast directions of the seismic anisotropy, that shifts from NNW-SSE trending, in the southern Apennines, to NNE-SSW trending, in northern Calabria (Baccheschi et al., 2008 and references therein) occurs across the PL. Moreover, seismic tomography analysis shows that the Line corresponds to a

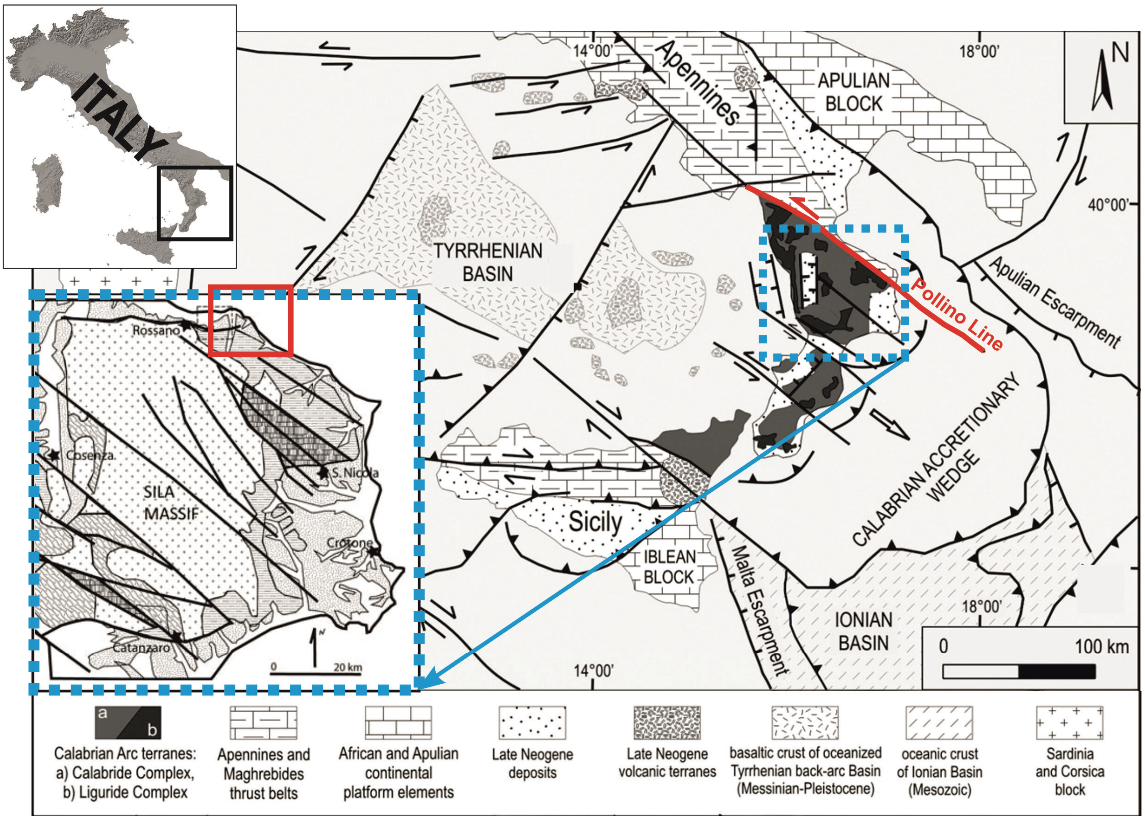

Fig. 1 - Tectonic-structural setting of the Calabrian Arc (modified from Tansi et al., 2007). A detail of the north-eastern portion of the Arc (after Tansi et al., 2007), inset. The area under investigation, red rectangle.

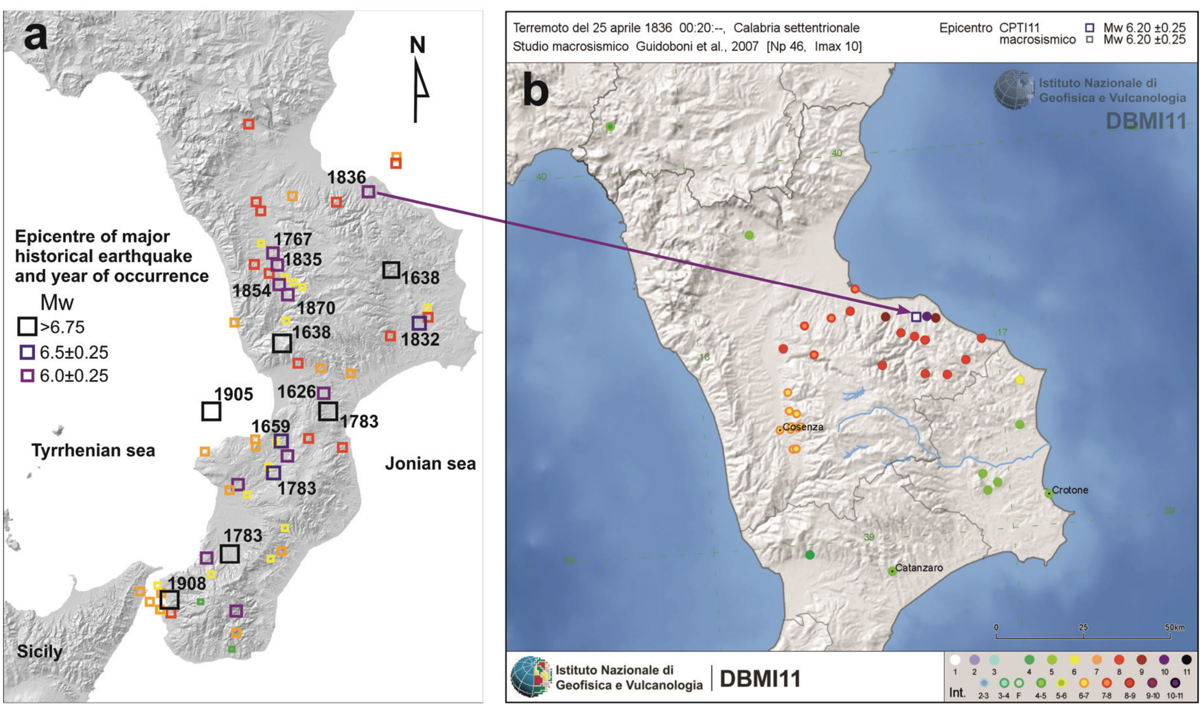

Fig. 2 - a) Digital terrain model onto which the epicentres of the major historical earthquakes that struck the Calabrian Arc (Rovida et al., 2011) are indicated (coloured rectangles); b) Intensities distribution (MCS scale) related to the 1836 Rossano earthquake.

lithospheric discontinuity (Totaro et al., 2014; Chiarabba et al., 2016). These seismological observations point out to structural-kinematic "separation" of the southern Apennines from the Calabrian Arc along such a crustal-scale discontinuity.

This boundary zone between the Calabrian and the Apennines blocks appears quite complex also in a Quaternary and active tectonics perspective. The southern tip of the Apennines was affected during the Quaternary by prevailing extensional deformation, presently active. This is witnessed by the NW-SE trending Pollino Range -Castrovillari active normal fault (Cinti et al., 2002), even if structural evidence of strike-slip movements has been detected along this structure (e.g. Monaco, 1993). Comparably, extension seems to affect the northern part of the Sila Massif, at the northern reach of the Calabrian block. Normal faulting has been indeed pro-posed along the WNW-ESE trending Rossano fault (Galli et al., 2009), that bounds the Sila Massif to the north-northeast. Nevertheless, evidence of WNW-ESE and NW-SE trending strike slip movements in the Early Quaternary has been found along the northern flank of the Sila Massif, with local transpressive component of motion (and, subordinately, transtensional deformations) (Folino Gallo, 2010). Furthermore, a complex zone of transpressive deformation, about NW-SE trending (Van Dijk et al., 2000; Muto et al., 2014) is seen in the coastal and off-shore sector of the Sibari Plain, and defined as active (Ferranti et al., 2009; 2014). In such a tangled region of structural-tectonic transition, the present study provides new field data collected in north-eastern Calabria, in the area of Rossano. The paper documents and interprets stratigraphic and structural data of a single exceptional outcrop of Quaternary deposits exposed during building construction near the coastal sector of the Mirto town. In particular, we examine the stratigraphic sequence through sedimentological and paleontological analyses. These data, together with radiometric age determinations (^{14}C method) and with the analysis of the local geomorphic framework, allow to obtain paleo-environmental and chronological information for the examined succession. The data obtained constitute the basis for a comprehensive interpretation of the deformations that the stratigraphic sequence underwent, as for the causative factors, kinematics and chronology.

After providing with a general overview of the geological characteristics of the northern Calabrian Arc and of the area under investigation, the results of our analyses are shown in detail. We took particular care in describing the deformations affecting the stratigraphic sequence. In the discussion, we examine the gathered data with the aim of interpreting them in the framework of the regional tectonic setting. Lastly, we unfold the implications that our study, although at an early stage, has in terms of active tectonics and related hazards assessment.

2. GEOLOGICAL AND SEISMOTECTONIC BACKGROUND

The Calabrian Arc constitutes an accretionary wedge growing up above a narrow and steeply dipping slab that subducts towards the northwest, resulting from the fragmentation of a wider slab related to the Western Mediterranean Subduction Zone (Faccenna et al., 2004). The related Wadati-Benioff zone is enlightened by tomographic studies (e.g. Piromallo & Morelli, 2003) and by the hypocentres of hundreds of earthquakes (Vannucci et al., 2004; Chiarabba et al., 2008). Since the Early Miocene, overthrusting of Palaeozoic basement nappes on Meso-Cenozoic basinal sequences occurred through compressive structures that progressively migrated east-and south-eastwards (e.g. Parotto & Praturlon, 2004), accompanying the progressive opening of the Tyrrhenian sea (e.g. Faccenna et al., 2001). Minelli & Faccena (2010) investigated the present structural setting of the Calabrian accretionary prism by means of geological investigations and interpreting a large number of industrial seismic reflection profiles. The authors defined that the growth of the belt took place through forward propagation stages of frontal accretion and out-of-sequence internal thrusting of Pliocene age (or later).

During the eastward and south-eastward migration of the compressive front, the inner portions of the Arc began to be affected by extensional deformation (e.g. Ghisetti, 1979; 1980; Tortorici et al., 1995; Monaco et al., 1996; Mattei et al., 2002; Muto & Perri, 2002; Rossetti et al., 2004; Cifelli et al. 2007; Critelli et al., 2013), which is currently active (e.g. D'Agostino et al., 2011). This process determined the formation of Arc-parallel, N -S and NE-SW trending normal-to-transtensive fault systems and extensional detachments, which dissected the structural edifice inherited by the compressive tectonic phase (Monaco et al., 1996). The activity of the extensional structures determined the formation of N-S and NE-SW elongated tectonic basins, such as the Crati and Mesima valleys and the Sant'Eufemia, Gioia Tauro and Messina Strait basins, that hosted marine and continental sedimentary sequences during the Pliocene-Quaternary.

Most of the N-S and NE-SW trending extensional faults are interrupted against others almost perpendicularly oriented, i.e. E-W and WNW-ESE, as the Rossano, Catanzaro Strait and Nicotera-Coccorino fault systems (e.g. Galadini et al., 2001; Tortorici et al. 2003; Guarnieri, 2006; Tansi et al., 2007; Tripodi et al., 2013; Brutto et al., 2016). These structures may have played - and may still play - the role of tear faults that absorb differential motions within the Calabrian accretionary prism, and/or of transfer faults that kinematically link different, *en-echelon* arranged normal fault systems.

At the Early-Middle Pleistocene transition, the whole Calabrian Arc began to undergo uplift (e.g. Westaway, 1993; Bordoni & Valensise, 1998; Monaco et al., 1998). This is testified by the presence of flights of marine terraces along both the Tyrrhenian and the Ionian flanks of the Arc (e.g. Cosentino & Gliozzi, 1988; Dumas et al., 1988; Miyauchi et al., 1994; Carobene, 2003; Cucci, 2004; Cucci & Tertulliani, 2006; Robustelli et al., 2009). The uppermost terrace orders occur at more than 1000 m above the present sea level. Uplift rate of 0.6-1.3 mm/yr, increasing southward, has been defined (e.g. Molin et al., 2002; Dumas & Raffy, 2004).

From a seismotectonic viewpoint, the Calabria region has been the focus of some of the most destructive

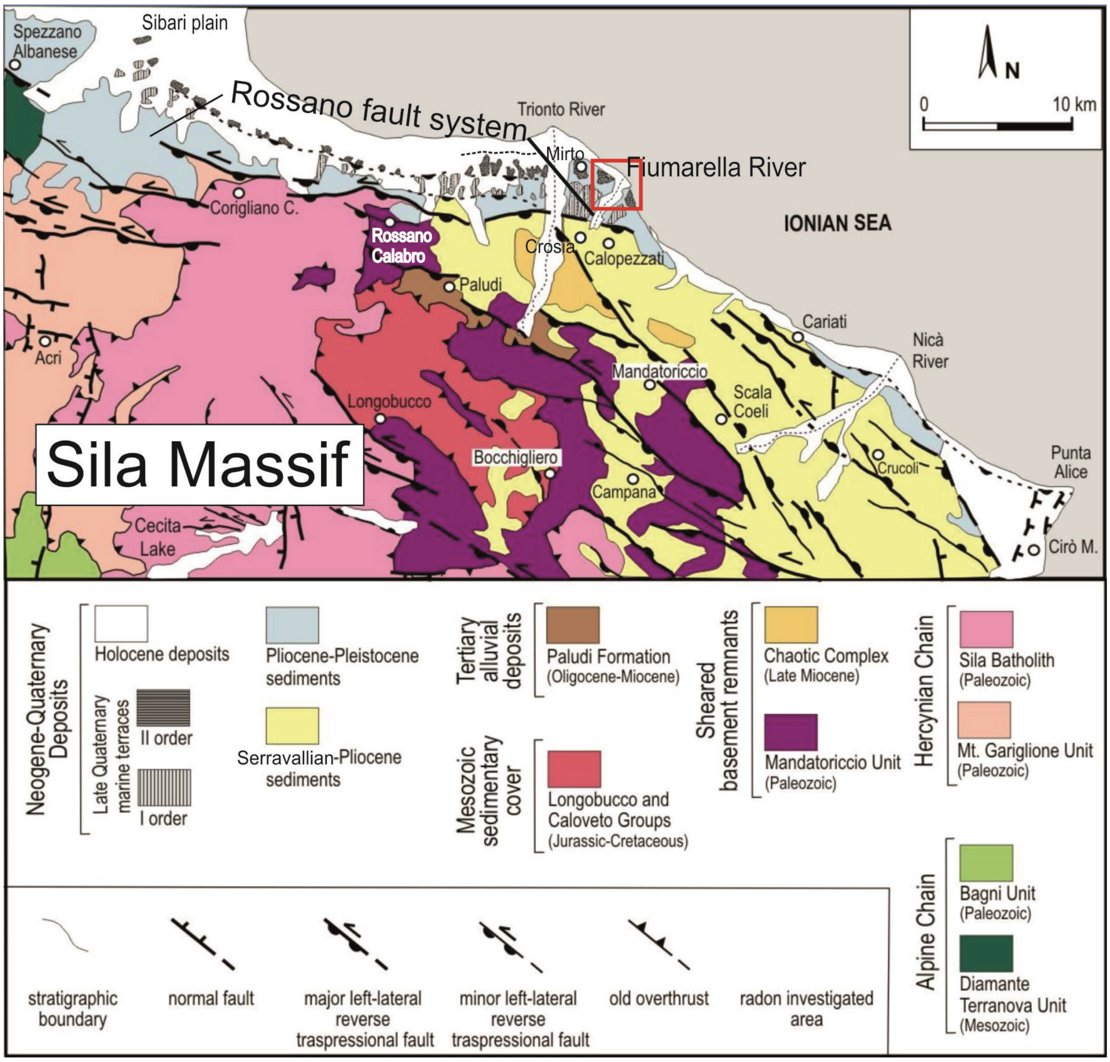

Fig. 3 - Geological and structural framework of the northern Sila Massif and of the Rossano area (modified from Folino Gallo, 2010). The area under investigation, red rectangle.

earthquakes that struck the Italian territory over the past millennium, characterised by magnitudes of up to about 7. These include the 1638 and 1783 seismic sequences - the two main shocks of the latter had Mw 7 and 6.9, respectively - and the 1832 (Mw=6.5), 1905 (Mw=6.7) and 1908 (Mw=7.1) earthquakes (Rovida et al., 2011) (Fig. 2a). More in general, at least 19 earthquakes with M>6 occurred since the 91 B.C. in this region. The sources of these events are commonly attributed to the activation of normal faults either west- or east dipping, affecting the innermost sectors of the Arc (Galli et al., 2009; DISS Working Group, 2015). However, the causative structures of some of these earthquakes are still a matter of debate. One of these is the Mw 6.2 event occurred in 1836, that is the strongest known earthquake of north-eastern Calabria (Fig. 2b). The earthquake determined severe damage to the villages of Rossano, Crosia, Calopezzati and Corigliano, which underwent 10, 9, 9 and 8 intensity degree (MCS scale), respectively. Different hypotheses - yet not conclusive - on the causative fault of this event are illustrated in the following paragraph.

3. THE ROSSANO SECTOR

The area under investigation locates at the north-eastern border of the Sila Massif, which is made of Hercynian crystalline basement and a Meso-Cenozoic sedimentary cover (Ogniben, 1973; Amodio Morelli et al., 1976) (Fig. 3), which is made up of Palaeozoic basement and its Mesozoic sedimentary cover (Critelli et al., 2013), unconformably overlain by alluvial to turbiditic deposits of Oligocene to Miocene age (Paludi fm). Up-section, Serravallian-Tortonian basal transgressive sequence consists of alluvial and fan-delta conglomerates, passing upward to cyclic alternations of shale, marls with interbedded arenite turbidites to the biosiliceous clay. Then, since Late Miocene two subsequent depositional cycles were unconformably deposited. These latter are unconformably overlain by two subsequent depositional cycles. The lowermost cycle, constituted by two sedimentary sub-cycles, is known as "Complesso postorogenico" (Ogniben, 1973). The lower sub-cycle is made up of a sandy -conglomeratic formation underlying evaporitic deposits related to the Messinian; clay and marly-clay units underlay calcareous and evaporitic limestones (Amodio Morelli et al., 1976, and references therein), that represent the closure of the sequence. The upper sub-cycle is represented by turbiditic clays and gypsum, that laterally pass to calcareous sands (Amodio Morelli et al.,1976, and references therein; Barone et al., 2008; Zecchin et al., 2013). The "Argille Varicolori" Formation unconformably overlays both the subcycles (Ogniben, 1962). The "Argille Varicolori" Formation has been involved in a backthrust with an Oligocene-Miocene succession starting from the Upper Tortonian in the northern Ionian basin (Roda, 1967; Muto et al., 2014; Muto et al., 2015) and during the Langhian in the southern Ionian basin (Cavazza & Barone, 2010; Tripodi et al., 2013).The second cycle is known as "Ciclo Suprapliocenico-Pleistocenico" (Vezzani, 1968) and it is made up of sandy, gravelly and clayey sediments (Vezzani, 1968; Ogniben, 1973; Critelli, 1990; Zecchin et al., 2012; 2015).

Since the Middle Pleistocene, the interaction between regional uplift, local tectonics, climate and glacioeustatic changes allowed the formation of flights of terraces. Four order of terraces have been recognized by Carobene (2003) and five by Robustelli et al. (2009) along the coastal portion of the Trionto River, while Cucci & Cinti (1998) distinguished seven order of terraces north of the Crati River. Ferranti et al. (2009) identified eleven orders of terraces in the area comprised between the northeastern border of the Sila Massif, the Crati Plain and the Coriglianeto River. Olivetti et al. (2012) pointed out uplift of the whole Sila Massif by means of morphometric analysis and incision rate estimation on fluvial systems crossing the Massif.

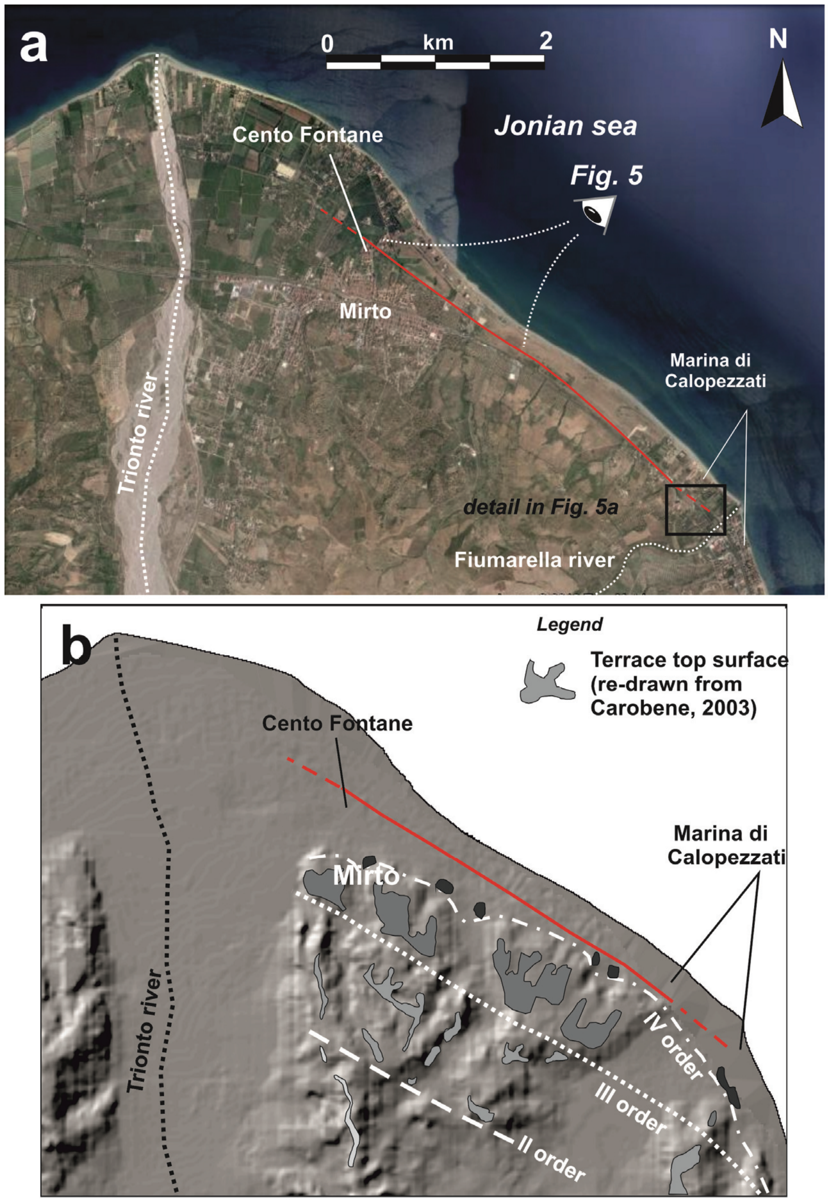

Fig. 4 - a) Google Earth image of the area comprised between the Trionto and the Fiumarella rivers. Trace of the scarp seen be-tween the Cento Fontane and Marina di Calopezzati localities, red line. b) Digital Terrain Model (shaded relief) onto which the three most recent marine terrace of Carobene (2003) are indicated

Different rates of uplift have been estimated: 0.46-0.69 mm/yr east of the Trionto River (Carobene, 2003), and 0.64-0.85 mm/yr north of the Crati River (Cucci & Cinti, 1998). Corbi et al. (2009) proposed that the uplift rate for Rossano-Corigliano sector increased through time, 0.52-0.57 mm/yr, based on the elevation of the "First Order" of terraces (i.e. the earliest one, related to the MIS 9 or 11), to 0.79-0.88 mm/yr, related to the "Fifth Order" of terraces (i.e. the latest order, related to the MIS 5a).

The structural setting of the area was the object of several studies in the past. The main tectonic feature of the area is referred to as the Rossano Fault, as segment of the "Cetraro-Rossano Line" in Moretti & Guerra, 1997, or "Rossano Fault" according Corbi et al., 2009 and Galli et al., 2009; Milia et al., 2009. The tectonic structure experienced a complex kinematic history, characterised by normal-to-normal oblique and strike slip kinematics (Moretti & Guerra, 1997; Corbi et al., 2009).

Van Dijk et al. (2000) identified the NW-SE oriented

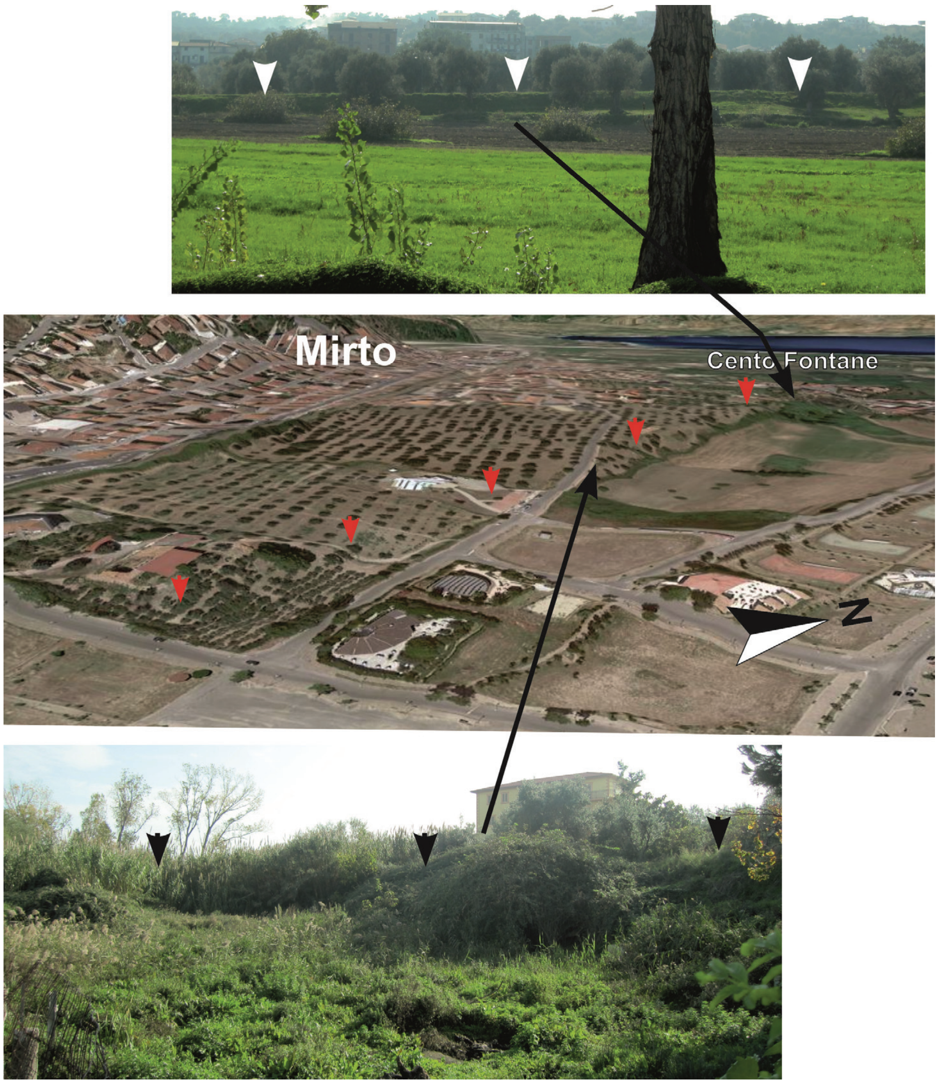

Fig. 5 - Google Earth image showing a frontal view of the scarp (indicated by red triangles); pictures of the scarp in insets, indicated by white and black triangles.

Rossano-San Nicola Fault Zone, extended from the Rossano site, to the north west, and San Nicola dell'Alto to the southeast. The structure is characterized by a sinistral transpressive kinematics along which basement and cover of the Sila Unit and Miocene deposits have been extruded and sheared. According the Authors the E-W oriented Rossano Fault is depicted as a normal fault that interrupts toward the north the NW transpressive Fault Zone. Moreover, this fault is interrupted to the west by the N-S fault system of the eastern Crati basin (Spina et al., 2011; Tansi et al., 2007).

As for the activity of this fault system, several minor normal-to-strike slip shear planes affected Quaternary marine and continental sequences in the area of Rossano (Corbi et al., 2009). Moretti (2000) hypothesised the Late Pleistocene-Holocene activity of this tectonic structure, even if the author did not provide clear geological evidence supporting this statement. More recently, Galli et al. (2009) described evidence of extensional displacement of Holocene slope deposits along the 12 km long Rossano Fault. Conversely, evidence of early Quaternary displacement along WNW-ESE and NW-SE strike slip tectonic structures has been identified, with mainly transpressive components of motion (Folino Gallo, 2010) (Fig. 3).

The "Corigliano-Rossano Line" was hypothesised by Moretti (2000) to be the causative fault of the 1836 earthquake. The same hypothesis has been proposed by Galli et al. (2009) for the Rossano normal fault. The authors also suggested the structure as the source of a Middle Age event, that heavily affected Rossano in ~951 AD. However, no conclusive data have been provided thus far. Moreover, recent investigation made by Ferranti et al. (2014) add information about the recent growth of the Amendolara Ridge, an anticline located offshore of the Sibari coastal plain (Fig. 3). The formation of the anticline is related to a transpressive tectonic structure defined as a potential source of M ~6 seismic events. Nevertheless, the authors did not explicitly make hypotheses about the involvement of the Amendolara Ridge structure in the 1836 earthquake, whose focus remains currently located inland.

4. FIELD DATA

Geomorphic field investigations in the coastal area just SE of the Trionto River mouth allowed the identification of a 6 meters-high scarp, trending about NW-SE (Figs. 4a, b). Although seldom reshaped by anthropic activities, the scarp is roughly detectable from the Cento Fontane to the Marina di Calopezzati localities, for a total length of about 4 km (Fig. 5), and it tapers down to about 3 m-high moving eastward. Noteworthy, in the area of Cento Fontane, water emission occurred along the scarp (De Rosis, 1838).

Some hundreds of metres northwest of Marina di Calopezzati, the scarp merges with the toe of a terrace occurring at ~30 m a.s.l., that we can refer to terrace T4 of Carobene (2003), attributed by the author to MIS 5c-5a. This attribution is supported by the presence of a further terrace west of the Trionto River, attributed to MIS 5a by Robustelli et al. (2009), and that occurs at comparable elevation.

The terrace is incised towards the southeast by the Fiumarella River valley. A narrow almost flat surface is seen along the left flank of this valley (Fig. 6a). This landform gently dips towards the north - i.e. seawards - and occurs at about 15 m over the present coastline. The land surface displays a slightly convex upward longitudinal profile. On top of the terrace, we found an excavation for a building whose walls were up to 2.5 m high and oriented NE-SW, that is roughly parallel to the landsurface elongation (Fig. 6b). The excavation exposed a prevailing sandy-clayey sedimentary sequence, that we describe in detail in the following.

4.1. MORPHO-STRATIGRAPHIC ANALYSES

The succession exposed by the excavation was made of layered yellow-orange fine-to-coarse sands, clayey sands and clay, with rare gravel levels interbedded (Fig. 6a). The layers generally displayed a fining upward grading. The gravels were made of rounded and flattened pebbles (whose long axis paralleled the bedding) of limestone, granite and metamorphic rocks, pertaining to the pre-Quaternary bedrock sequences that crop out along the inner sectors of the Fiumarella catchment.

We sampled the clay and clayey-sandy portions of the sequence for micropaleontological analyses (Fig. 6b). They provided marine foraminifera of both planktonic and benthic species.

The planktonic foraminifera were: *Globorotalia inflata, Neogloboquadrina acostaensis sx, Globorotalia crassaformis, Globorotalia scitula, Globigerinoides obliquus, Globigerina bulloides, Orbulina universa.*

The benthic foraminifera were: *Ammonia tepida, Ammonia parkinsoniana, Elphidium crispum, Elphidium advena, Cassidulina carinata, Cassidulina crassa, Bulimina basispinosa, Bulimina elegans marginata, Bulimina elongata, Cibicidoides kullenbergi, Hyalinea baltica, Melonis barleeanum, Valvulineria bradyana*.

In terms of chronology, *Globorotalia inflata* appeared at the base of MPL6 biozone, i.e. between the Gelasian and Calabrian stages. *Hyalinea baltica* appeared at the early Emilian substage, i.e. in the middle Early Pleistocene. *Bulimina basispinosa* disappeared at the end of the Emilian substage. Such a faunal association and the described sedimentological characteristics indicate that the sequence was deposited during or after the Early Pleistocene, in a marine environment - likely a paleodelta - relative to infra- to circa-littoral zone. This chronological attribution is corroborated by the fact that towards the southwest, the analysed sequence laterally passed to a clay succession (about 3 m exposed thickness). The geomorphic and stratigraphic framework of the area permits to relate the clay to the marine sequence of the "Ciclo Suprapliocenico-Pleistocenico" of Vezzani (1968), described in this area by Bigazzi & Carobene (2004). The mentioned authors attributed the deposits to the Middle Pleistocene, based on the presence of an interbedded tephra layer related to this period.

The excavation walls also showed colluvial deposit (about 2 m exposed thickness) embedded within and partly overlying the marine sequence through an evident surface of linear erosional (Figs. 7a, b) - i.e. a channel - trending WNW-ESE, i.e. roughly perpendicular to the excavation walls. The colluvial sediments were made of sparse rounded pebbles (mainly sandstone, limestone, granite and gneiss) in a brownish-reddish silty-clayey matrix. They were probably fed by a small stream incision, still partly visible along the flank of the Fiumarella valley (Fig. 6a). The incision sourced from the top of the above mentioned marine terrace at 30 m a.s.l., cutting through the described marine sequence. A sample of organic rich matter collected from the uppermost portion of the colluvial sediment (Fig. 7b) gave an age of 8397±47 ka B.P. (radiocarbon age)/7553-7351 B.C. (calibrated, 2σ, with code CALIB5) (radiocarbon dating performed by CIRCE Laboratory, Dept. of Environmental Sciences, Caserta, Italy; sample DSH612). As the radiocarbon date refers to organic matter contained within the colluvial body, it implies that the obtained age relates to the parent material, the colluvial deposition being inherently subsequent.

4.2. EVIDENCE OF DEFORMATION

The whole sedimentary sequence displayed evidence of deformation, which can be distinguished into two different types. First, on a broad scale, the paleodeltaic sequence displayed a 20° to 40° counterslope dipping attitude (i.e. west- and south-westward). Such geometrical feature is inconsistent with the depositional and paleo-environmental features of the deposits (north to north-eastward), that is, a paleo-delta, which is supposed to have had a NE-ward progradation. Such a high angle dipping attitude is geometrically inconsistent even considering the possibility that the observed section affected a lateral portion of the delta, where the layers may have an apparent counterslope dipping but with a much lower degree with respect to that here observed.

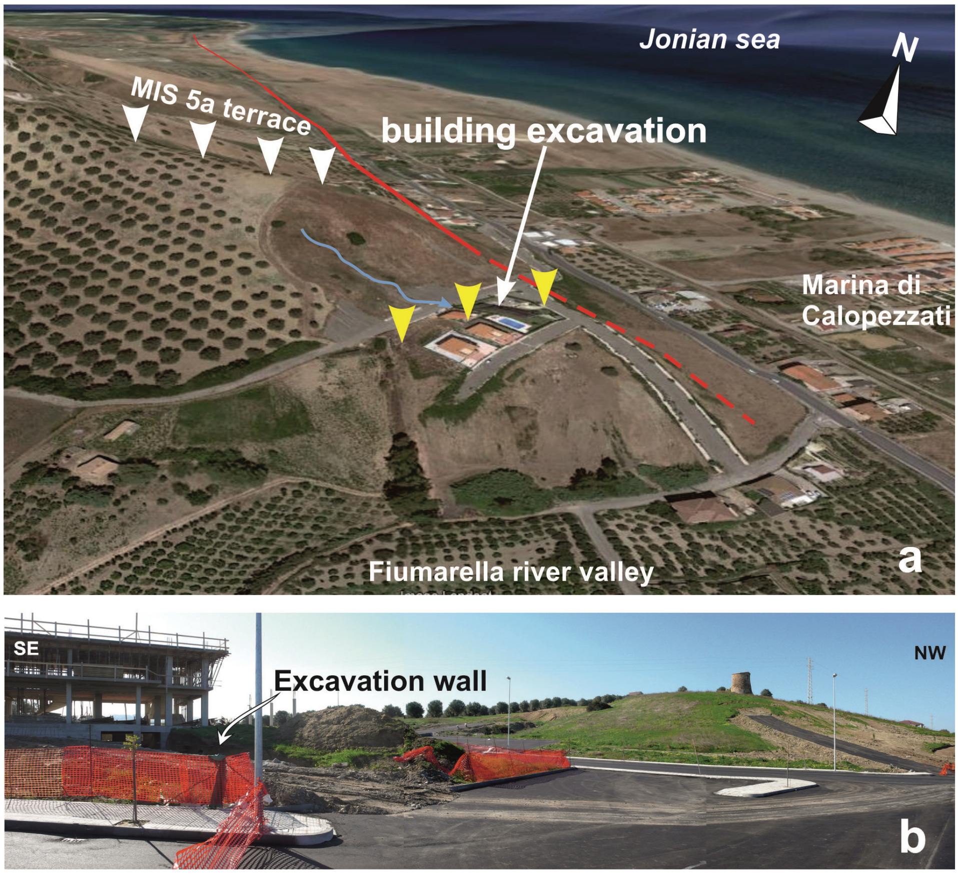

Fig. 6 - a) Google Earth image on which the main geomorphic features of the area under investigation are indicated; MIS 5a marine terrace, white triangles; terrace affected by the excavation, yellow triangles; trace of the described scarp (see text), red line; stream incision that fed the colluvial deposits (see text), light-blue arrow. b) picture of the building under construction.

Second, evidence of localised deformation was represented by a series of shear planes, trending (i.e. about N130° to N150°) and dipping towards the northeast (Fig. 8a). These faults splay showed a top-to-SW (then landward/uphill) reverse sense of motion, and local curviplanar geometry, determining also folding of the strata. In the core of the observed fold, the deformation was mainly accommodated by the shear planes and bending became less evident. The bent geometry of the lowermost marine layers, marked by the pebbles attitude, also suggested the presence of a deeper reverse shear plane not reached by the excavation (Fig. 7b). The colluvial sediment, moreover, was displaced by some minor nearly vertical, about NW- SE striking (~N130°-150°) conjugate fault planes that showed faint horizontal slickenlines (Figs. 7b and 8b), and which seemed to join the uppermost portions of the above described inverse faults. Coupled with the reverse shear planes, these structural features suggest that, overall, the observed deformation is to be referred to a transpressive shear zone. This might be also responsible for the gentle upward convex attitude of the terrace.

The paleontological determinations and the ^{14}C age obtained by dating the colluvial deposits yields that the fault planes were active over the Quaternary, even during the Holocene.

5. DISCUSSION

The sedimentological characteristics, the micropaleontological content and the morphostratigraphic framework (Fig. 9) of the analysed marine sequence define a deposition in an infra- to circa-littoral paleodeltaic environment, that is a hundred metres below the sea level (or even more) (Carobene, 2003). Because the investigated Early-Middle Pleistocene deltaic succession has strata steeply dipping to S-SW, i.e. opposite to the expected progradation of the sedimentary body, and is presently located at about 15 m a.s.l., it must have undergone a significant tilting and uplift after the deposition. From the tectonic point of view, tilting and uplift likely stem from superimposition of a major regional component (due to deep-seated thrusts and/or crustal-scale folding), that involves large part of this sector of the Calabrian Arc, and local components likely related to the transpressive observed faults.

After landward tilting, the sequence has been cut by inverse fault planes. As for the origin of the observed displacements, the counterslope tilting of the sedimentary sequence and the upslope/top-to-SW sense of motion of the shear planes allow to exclude any possible gravitational cause (i.e. landsliding) of the deformation. Salt tectonics can be ruled out as well. Indeed, while

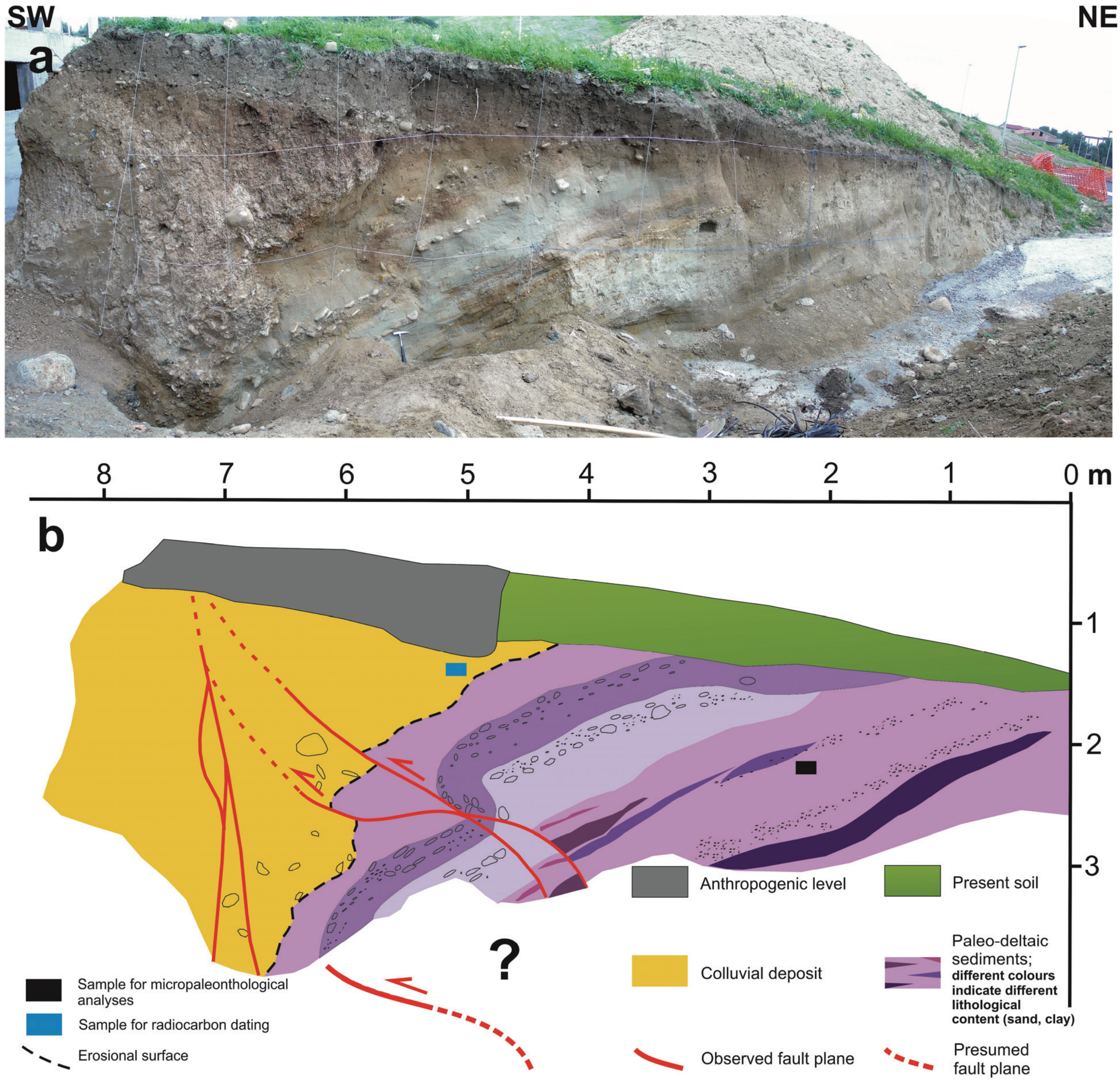

Fig. 7 - a) Picture of the excavation wall. b) Stratigraphic scheme of the excavation wall.

evidence of this phenomenon was identified in other sectors of the outer margin of the Calabrian Arc (e.g. Del Ben et al., 2008; Minelli & Faccenna, 2010), no signature of salt diapirism has been found in this area on the many seismic lines that cross the Corigliano-Rossano onshore and offshore sectors (e.g. Van Dijk et al., 2000; Del Ben et al., 2008; Ferranti et al., 2014). Therefore, a tectonic cause has to be invoked.

The radiometric age constraint indicates activation of the reverse fault planes over the past few millennia, resulting in surface faulting. The activation in recent times of the structural features is also corroborated by the morpho-stratigraphic setting of the area: the displaced Holocene colluvial deposits are embedded within a terrace that, in turn, is embedded within the MIS 5a marine terrace. This fact suggests that the landsurface may be associated to a later isotopic stage, likely MIS 3, aged at 60-30 ka. In this perspective, Molin et al. (2002) formerly recognised just east of the Trionto River a terrace order (name as T5) embedded within MIS 5a terraces, at 15-8 m a.s.l., i.e. at the same elevation of the terrace that we are dealing with. Moreover, MIS 3 terraces (specifically MIS 3.3) have been identified by other authors in the area of Capo Vaticano (Tortorici et al., 2003), along the central portion of the western Calabrian Arc. Therefore, a MIS 3-related age of the considered terrace is likely. As a result, the incision filled

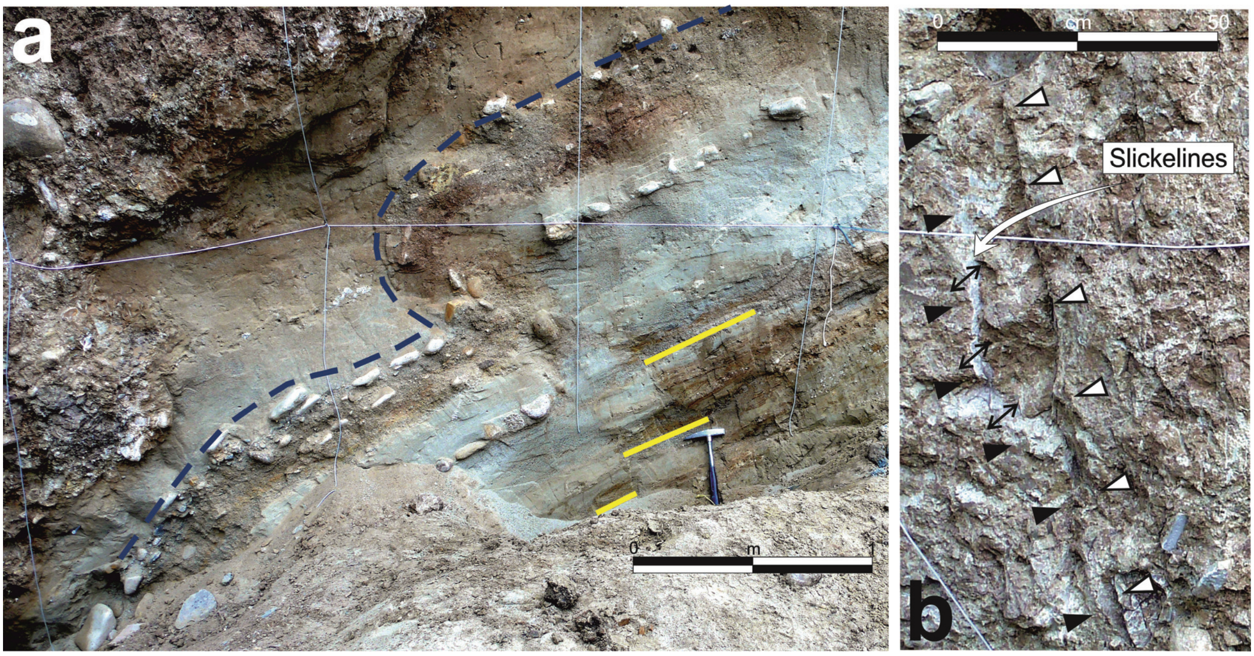

Fig. 8 - a) Detail of the deformation (bending, marked by the dashed blue line; offset, marked by the dashed yellow lines) that affect-ed the sedimentary sequence. b) Detail of the sub-vertical shear planes (indicated by black and white triangles) that affected the collu-vial deposit (sub-horizontal slickenlines are indicated).

by the colluvial deposits can be related to the fall of the sea level occurred during the Last Glacial Maximum (MIS 2), that is 25-15 ka; and this is concordant with the radiometric age obtained for the uppermost portion of the colluvial body, that postdates the end of MIS 2.

In terms of active tectonics, the present knowledge about the northern Calabrian Arc, earlier illustrated, allows making hypotheses on the plausible major structure associated to the observed reverse fault planes, illustrated in the following:

1. On the one hand, they may be the surface expression of the major transpressional shear zone, roughly WNW-ESE trending, located in the offshore sector of the Rossano area and of the Sibari Plain, identified by Van Dijk et al. (2000) and Del Ben et al. (2008) through the interpretation of reflection seismic lines. The evidence of Middle-Late Pleistocene activity of the transpressional deformation responsible for the growth of the Amendolara ridge, shown by Ferranti et al. (2014), are indeed consistent with the observed reverse faults, that may represents landward splays of this transpressive shear zone.
2. On the other hand, the identified deformation is also consistent with the occurrence of Quaternary strike slip movements, with local transtensional and transpressive kinematics, in the area comprised between Rossano (east of the town) and Cirò Marina (Corbi et al., 2009; Folino Gallo, 2010), referred to as Rossano-San Nicola Fault Zone by Tansi et al., 2007, Muto et al., 2014. The investigated structures are compatible with the offshore NW-SE oriented major shear zone provided by Ferranti et al. (2009, 2014) and can represent the onshore expression of transpressive left-lateral high angle faults. The presence of a major tectonic feature with prevailing strike slip sense of motion is also supported by low-to-moderate magnitude seismicity (M of up to 4.5-5), consistent with strike slip ruptures, clustered along the “NE-Sila seismic zone” (Presti et al., 2013). Hence, the compressive deformation analysed in the present work may represent local reverse planes associated to a restraining bend.
3. The sole different view of the active tectonics of the area is that proposed by Galli et al. (2009), who proposed the Rossano fault as an extensional tectonic structure active during the Holocene.

As a result, a twofold reason makes us lean for the second hypothesis: firstly, the fact that the observed fault planes are aligned with the inland Rossano-San Nicola Fault Zone fault zone and, secondly, the distance between the investigated site and the transpressive structure in the near offshore sector of the Sibari Plain. Within this light, the extensional faulting recognised by Galli et al. (2009) along the Rossano fault can be a local kinematic complexity or an extensional fault associated to the mainly NW-SE strike slip regional shear zone.

In seismotectonic perspective, our observations provide with insight on the geometry and kinematics of potential seismogenic structures of the area, comprising the causative fault of the 1836 seismic event. The intensity distribution of this large magnitude seismic event appears as rather incomplete, owing to the lack of any intensity datapoint in the Ionian sea, evidently (Fig. 10). Despite such incompleteness, the maps of the highest intensity datapoints (Galli et al., 2009; Locati et al., 2011) suggest a local origin of the earthquake. In par-

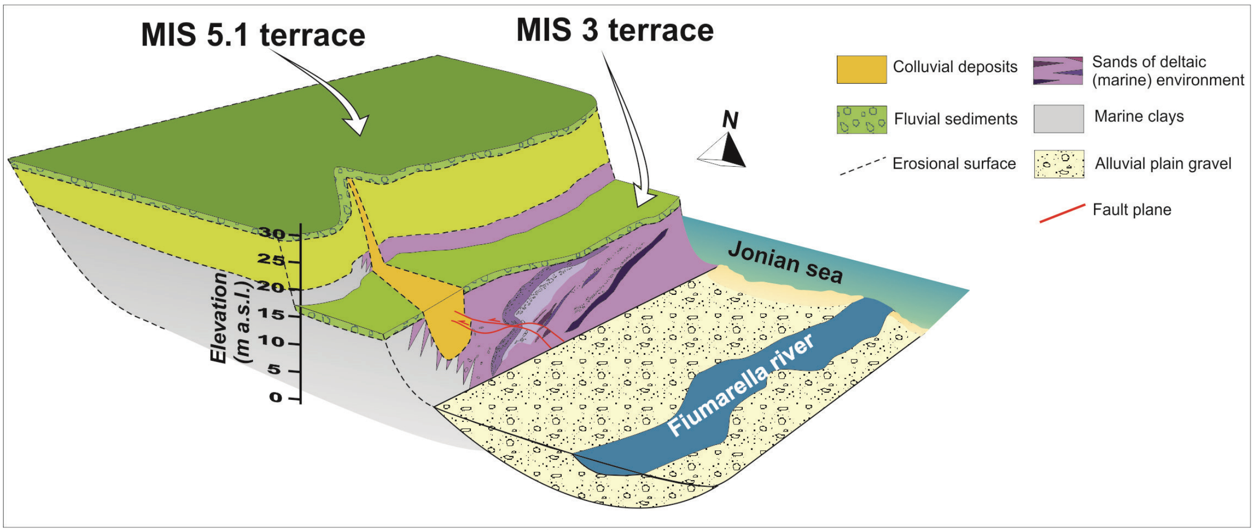

Fig. 9 - Schematic reconstruction of the morpho-stratigraphic and structural setting of the examined area.

ticular, it would have been sourced from a roughly NW-SE to WNW-ESE trending structure which, as mentioned above, Galli et al. (2009) associated to an activation episode of the Rossano normal fault (Fig. 10 and inset). Nonetheless, the transpressive faulting evidence we collected is compatible both in terms of orientation and of location with a main seismogenic fault located right in the epicentral area of the 1836 earthquake (Fig. 10, inset). This is particularly evident in the cases of Crosia and Calopezzati. These villages are in fact the closest to the identified structures, and they did "suffer" the highest level of damage (10 and 9 intensity degree, MCS scale, respectively). Such high degrees of damage were hypothesised by Galli et al. (2009) to be caused by a possible eastward directivity of the coseismic rupture, located several kilometres to the west of these villages. Instead, it may be more likely due to the activation of a closer fault, in this portion of the Ionian coastal area.

6. CONCLUSIONS

We investigated a stratigraphic section exposed about 15 km east of Rossano, in north eastern Calabria (southern Italy), on top of a terrace located at the south-eastern tip of an anomalous scarp, a few km long, trending about WNW-ESE and dipping NNW-wards. The section revealed that a marine paleo deltaic sequence, aged at the Early(-Middle) Pleistocene by means of

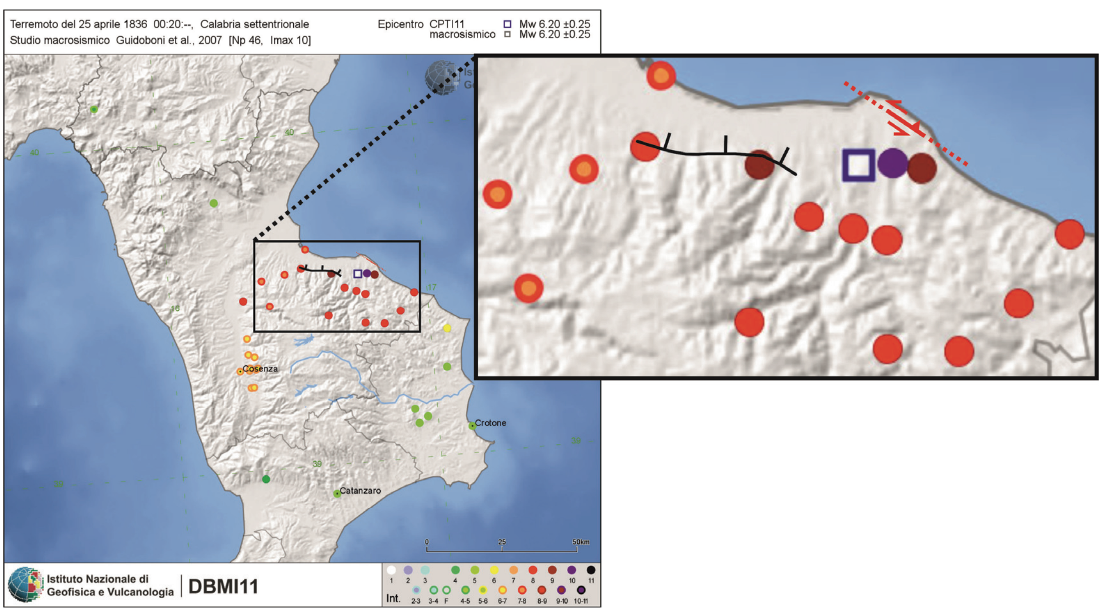

Fig. 10 - Intensities distribution of the 1836 Rossano earthquake (Rovida et al., 2011); trace of the Rossano extensional fault according to Galli et al. (2009), black line; probable trace of the tectonic features investigated in the present work, red lines. A detail in inset.

micropaleontological analyses, and overlaying colluvial deposits, radiocarbon data at the Holocene, were tilted landwards, folded and offset by NE dipping, SW-verging reverse fault planes. The WSW-ward, uphill sense of motion of these structural features and the local geomorphic characteristics allowed ruling out other causes than tectonics (e.g. landsliding or salt tectonics) as cause of the observed deformations. The offset of the Holocene colluvial body testified to the activity of the fault planes in very recent times.

The tectonic framework of the region allowed us to hypothesise that the observed shear planes are associated to the activity of a mainly left-lateral strike slip regional shear zone that affects the area, whose evidence have been observed by previous works both onshore (Muto et al., 2014; 2015) and offshore (Ferranti et al., 2009; 2014).

The results of the present study, although preliminary, add new information for understanding the active tectonic and seismotectonic setting of the northeastern Calabrian Arc. Indeed, active surface faulting in the inland sector comprised between northeastern Calabria and south-western Basilicata regions was related only to extensional structures thus far. Instead, this study indicates that active transpressive surface faulting is here likely and has to be considered both for deciphering the present structural relationship between Apennines and the Calabrian blocks and for planning and managing the land use of the region. Ultimately, the identified structures can be the surface expression of a major tectonic structure that could be a candidate as causative fault of the 1836 Rossano earthquake, of the ~951 AD seismic event and of future moderate to large magnitude earth quakes in the area.

Although at an initial stage, the promising results of our work show that future efforts in investigating this area are desirable, to gain a more accurate picture of the seismotectonic characteristics of such a tectonically complex region.

ACKNOWLEDGEMENT

We warmly thank Fabrizio Galadini for his useful discussion on the interpretation of the tectonic deformations. Micropaleontological determinations have been made by Elsa Gliozzi at Università degli Studi Roma Tre. We thank her very much. The useful and accurate revisions and comments made by the two Referees, Eliana Poli and Pietro Mosca, allowed a significant improvement of the paper. We thank Bebbè for hosting us in her cosy agritourism many times at Contrada Amica.

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Ms. received: June 20, 2016
Final text received: October 10, 2016