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Chapter 3

EVIDENCE OF ACTIVE TECTONICS IN SOUTHERN ITALY: THE ROSSANO FAULT (CALABRIA)

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ABSTRACT

Unlike the Tyrrhenian side, the seismotectonics of the Ionian sector of the Calabrian peninsula is still not well defined, both in terms of active tectonics and seismic activity. This work focuses on a strong earthquake that occurred along the northern Ionian coast of Calabria in 1836 (Rossano area, Mw=6.2), by applying a multidisciplinary approach in order to find out its possible causative fault. Thanks to the reappraisal of the historical accounts of the earthquake - which also contain possible surface break descriptions - and to geological, geomorphological, structural and paleoseismological analyses carried out in the mesoseismic area, we propose that the poorly known, E-W striking, normal Rossano Fault might have been responsible for the 1836 event. This fault, which is characterized by an impressive ~100-m-high rectilinear scarp, downthrows the Palaeozoic rocks of the Sila Massif below the coastal alluvial plain of Rossano. Absolute dating of faulted talus-deposits, coupled with observations on the geometry and aspect of the fault free-face, allow to hypothesize repeated surface ruptures in the Late Holocene.

Keywords: Active fault, paleoseismology, Calabria, 1836 earthquake.

1. INTRODUCTION

The Calabrian peninsula is the arched narrow tip of the Italian “boot”, bridging the NW-SE Apennine chain and the roughly opposite ~E-W striking Siculo-Maghrebides chain. Its western side, from the Crati Basin to the Messina Straits, is characterized by one of the strongest seismicity in the Mediterranean, with earthquakes exceeding magnitude 7 (figure 1). Most of these earthquakes are caused by the extensional faults that downthrow the Palaeozoic massifs of Sila, Serre and Aspromonte (i.e., the crystalline backbone of the Calabrian Arc) toward the Tyrrhenian Sea (Ghisetti, 1981; Tortorici et al., 1995), as confirmed definitely by paleoseismic studies carried out across the Cittanova fault (9 in figure 1: ~372 AD earthquakes, and February 5, 1783 earthquake, Mw~7; Galli and Bosi, 2002), or the S-Serre fault (8 in figure 1: February 7, 1783 earthquake, Mw~6.7; Galli et al., 2007). However, apart from strong events reasonably related to similar structures (e.g., the one responsible for the catastrophic 1908 Messina earthquake, Mw=7.3; see insights in Argnani et al., 2008), or others related to oblique faulting in the inner Sila massif (e.g., Lakes Fault, 5 in figure 1: June 9, 1638 earthquake, Mw~6.8; Galli and Bosi, 2003; Galli et al., 2007), many others have not been still associated to a certain seismogenic source. This is particularly true for the few earthquakes known to have occurred on the Ionian side of Calabria, such as the 1832 (Mw~6.6) and the 1836 (Mw~6.2) events (figure 1; see insights and references in Galli et al., 2007).

In this work we focus on the area of the 1836 earthquake, where we investigated the poorly known normal Rossano Fault (RF from now). Firstly, we carried out a reappraisal of the effects of this earthquake on the basis of all the available coeval documents, some of which found in local archives. Then, through the interpretation of aerial photographs and field survey, we tried to piece together the overall Quaternary evolution of the area, finally identifying a site across the RF, which was prone to the excavation of an explorative paleoseismological trench. The comparison between historical data (e.g. informations on surficial breaks and the highest intensity datapoint distribution) and field results (geological, geomorphological, structural and paleoseismological data) allowed us to hypothesize repeated ruptures of this structure in the Late Holocene, the last one presumably related to the 1836 earthquake.

Figure 1. Earthquakes distribution in Calabria (mod. from Working Group CPTI, 2004. Mw>5.5) and primary seismogenetic faults (bold=certain, i.e. investigated by paleoseismological analyses). 1) Mt. Pollino Fault; 2) W-Crati Fault System; 3) Rossano Fault (this work); 4) Cecita Fault; 5) Lakes Fault; 6) Savuto Fault System (Piano Lago-Decollatura Fault); 7) Feroleto-Sant'Eufemia Fault; 8) Serre Fault System; 9) Cittanova Fault; 10) Reggio Calabria Fault System. Shaded earthquakes symbols derive from paleoseismic and/or archaeoseismic studies (see in Galli et al., 2008). The rectangle shows the investigated area, where the black circle evidences our preferred 1836 earthquake epicentre (i.e., with respect to Working Group CPTI, 2004).

2. Overview of the Local Seismicity

Calabria is struck by the strongest earthquakes of the whole Apennine chain (figure 1). Examples include the 1905 (Ms=7.5) and 1908 (Ms=7.3) earthquakes, and the catastrophic sequences of March-June 1638 (Mw~6.6÷6.8) and February-March 1783 (Mw~6.6÷7.0). Most of the Calabrian records of seismicity are clustered between the 17th century and the beginning of the 20th century, whereas we known only sparse earthquakes during the Middle Age (e.g., ~951 in the Rossano area; 1184 in the Crati Valley), and few others discovered through paleoseismological investigations (see Galli et al., 2008 and reference therein). As suggested by Scionti et al. (2006), this seismic pattern during the past millennium may be due to the seismogenic behaviour of the primary Calabrian active faults, which triggered each other starting from the early 17th cent., and not to the loss of archive data that, reasonably, involved only M<6.5 events information (e.g. in Stucchi and Albini, 2000).

Actually, few local earthquakes are on record in the Rossano area; the oldest known happened in ~951 AD and - according to *Bartholomaeus Rossanensis* (11th cent.) - it rocked the Rossano town, causing strong damage and landslides. In 1824, a moderate event caused light damage in Rossano and Corigliano, anticipating the strong earthquake of April 25, 1836 (Io=9 MCS, Mw=6.2, Working Group CPTI, 2004; from now CPTI). Recently (December 2, 1995), a small event (Ml=3.4) occurred close to Rossano; its focal mechanism suggests normal faulting on roughly E-W planes (Vannucci and Gasperini, 2004; figure 2).

2.1. The 1836 Rossano Earthquake

On the basis of all the contemporary sources - some of which are unpublished manuscripts that we read in the Rossano municipality archive - we re-evaluated the effects distribution of the 1836 earthquake (results are summarized in table 1 and in figure 2). The strongest effects occurred in the town of Rossano (9-10 MCS; Mercalli-Cancani-Sieberg scale), and in the small villages of Crosia (10 MCS) and Calopezzati (9 MCS), whereas the area of severe damage (i.e., 7 MCS) extends ~70 km in a WNW-ESE direction, enveloping about 20 villages.

Microtremor analyses that we carried out in all the localities of the mesoseismic area (following the Nakamura [1989] method; see some examples in figure 3) do not show HVSR peaks in the engineering range (2-5 Hz), suggesting that none of villages suffered particular geological site amplification.

Table 1. MCS intensity distribution re-evaluated for the 1836 earthquake

LOCALITY	LON	LAT	I (MCS)
Crosia	16,773	39,566	10
Rossano	16,635	39,574	9-10
Calopezzati	16,802	39,56	9
Caloveto	16,76	39,504	8-9
Corigliano calabro	16,518	39,596	8
Cropalati	16,726	39,516	8
Paludi	16,682	39,529	8
Schiavonea	16,541	39,652	8
Torre Cilento	16,538	39,6259	8
Scala Coeli	16,889	39,445	7-8
Bocchigliero	16,751	39,418	7-8
Campana	16,824	39,411	7-8
Cariati	16,949	39,497	7-8
Longobucco	16,611	39,449	7-8
Acri	16,386	39,49	7
Bisignano	16,285	39,513	7
San Demetrio Corone	16,362	39,568	7
San Giorgio Albanese	16,454	39,582	7
Castiglione Cosentino	16,288	39,351	7
Craco	16,439	40,377	7
Cosenza	16,251	39,303	6
Donnici sup.	16,301	39,251	6
Cirò	17,064	39,38	6
Rose	16,288	39,398	6
Motta	16,314	39,304	6
Rovito	16,321	39,308	6
San Pietro Guarano	16,311	39,342	6
Rovella	16,288	39,303	6
Zumpano	16,291	39,31	6
Ginosa	16,758	40,578	6
Castrovillari	16,202	39,814	5
Crotone	17,127	39,08	5
San Mauro	16,925	39,103	5
Santa Severina	16,913	39,146	5
Scandale	16,959	39,121	5
Strongoli	17,05	39,265	5
Catanzaro	16,586	38,914	5
Spezzano	16,3108	39,669	5
Nicastro	16,318	38,974	4-5

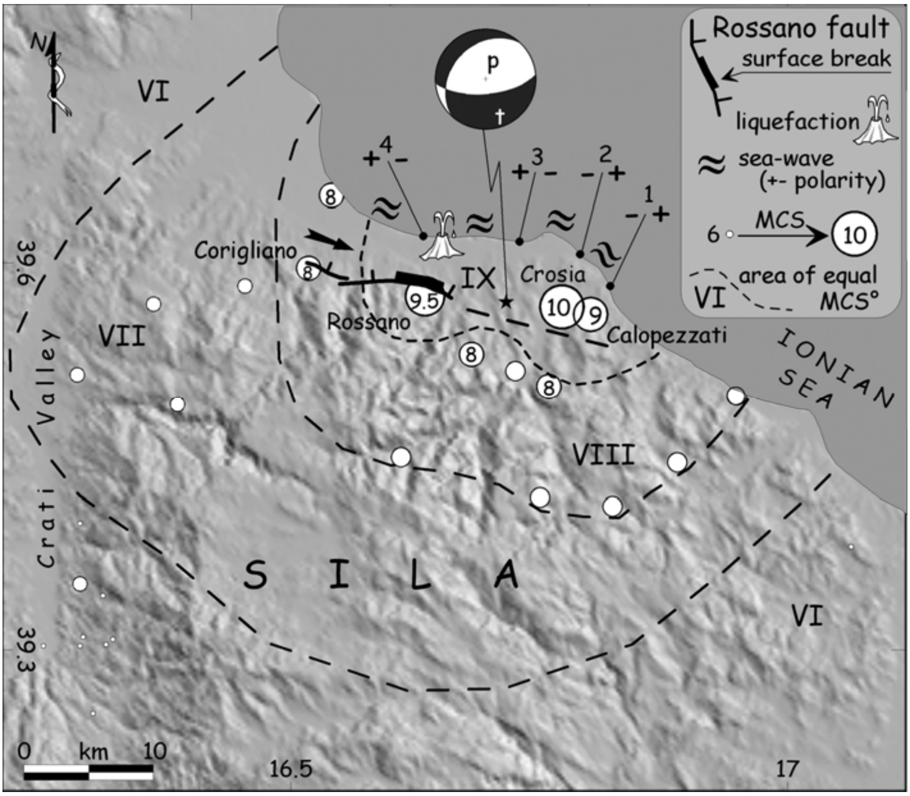

Figure 2. Intensity distribution of the 1836 earthquake. Note that the isoseismic lines are opened seward, and that the mesoseismic area roughly parallels the Rossano Fault; this fact suggests that this fault could be associated with the 1836 seismogenic structure. The *tsunamis* effects along the coast (site 1, Caloveto beach; 2, Centofontane; 3, Iapichello; 4, Sant'Angelo; from Rossi, 1836; De Rosis, 1838) imply the occurrence of a coseismic deformation of the area; polarity might indicate the lowering in the nearfield of the Rossano Fault hangingwall (positive, sea ingression), with sea retreat in the surrounding zones (negative). The black arrow indicates the possible fault rupture direction, accounting for strong effects in the small villages of Crosia and Calopezzati. The focal mechanism refers to the Ml=3.4 earthquake of December 02, 1995 (Vannucci and Gasperini, 2004; p, P-axis; t, T-axis).

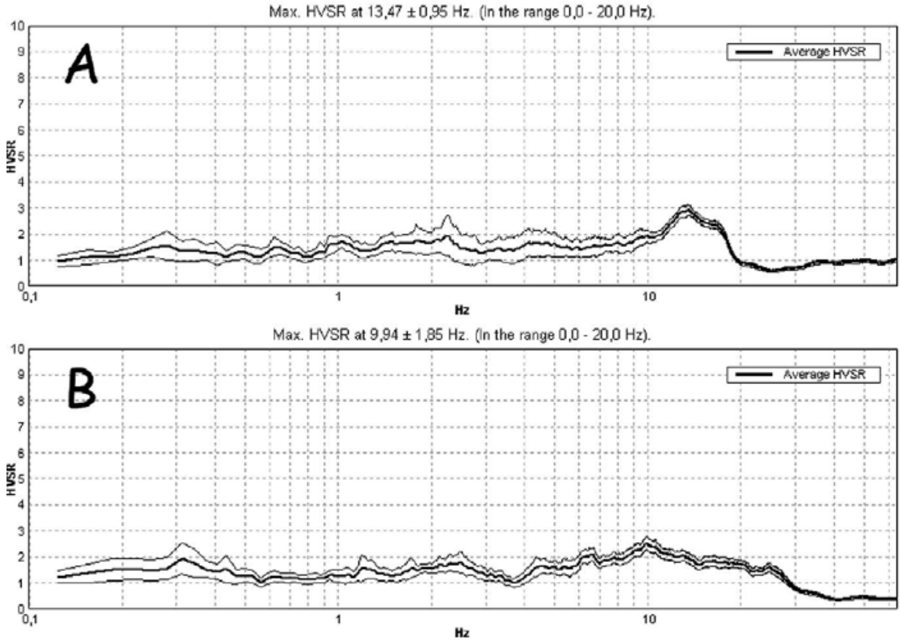

Figure 3. HVSR obtained in Rossano (A) and Crosia (B). Note the absence of amplification for any frequency. This fact has been observed in all the villages where we performed microtremor analyses.

On the other hand, as observable in figure 2, the 1836 highest intensity datapoint distribution (HIDD) is clearly "opened" seaward, its barycentre (i.e., its rough hypocenter) falling along the Rossano-Crosia coast. Here, along the shoreline, contemporary sources (i.e., Rossi, 1836; De Rosis, 1838) described an abrupt, coseismic sea-retreat, followed by a violent sea-wave (sites 1-2 in figure 2), and *viceversa* (sites 3-4). We hypothesize that the different polarity of the sea-wave might indicate the coseismic lowering of the RF hangingwall (i.e., positive = sea ingression), whereas surrounding zones recorded a first negative impulse (= sea retreat). Moreover, along the Rossano coast plain, liquefaction phenomena were also observed (figure 2; open vents with ejection of water and sand and sand-volcanoes; see in Galli, 2000 and references therein), whereas significant surface breaks were described along the hillside of Rossano (Romano, 1836; Rossi, 1836; De Rosis, 1838). In particular, some of these breaks were described as hundred-meters long, and as cutting through both sides of the valleys. These features fit with the RF trace (see location in figure 2), and thus we suggest that they could be ascribed to surface faulting phenomena.

3. GEOLOGICAL FRAMEWORK OF NORTHERN CALABRIA AND OF THE INVESTIGATED AREA

The Calabrian Arc is built of Palaeozoic crystalline-metamorphic rocks (Calabride Complex, *sensu* Amodio Morelli et al., 1976) belonging to the European-Iblean margin. Between 35 and 30 Ma the Neo-Tethyan slab-rollback induced the SE-translation of the orogenic front (Jolivet and Faccenna, 2000). As a result of that, since the Latest Oligocene, the Calabrian block thrusted onto ophiolite-bearing units and, since Middle Miocene, this thrust-nappe edifice over-thrusted the Mesozoic carbonates of the African domain (Amodio Morelli et al., 1976; Dewey et al., 1989; Messina et al., 1991; Rossetti et al., 2001).

According to Van Dijk et al., (2000), the main Neogene tectonic structures of the northern Calabrian Arc consist of NW-SE sinistral strike-slip crustal shear zones (e.g. Pollino and S. Nicola-Rossano Fault zones; PFZ and SNRFZ in figure 4), with associate thrusts in their restraining bends; these structures controlled both the architecture and the tectono-sedimentary evolution of the Neogene basins, such as the Rossano and Crotone Basins (figure 4; Van Dijk & Okkes, 1991). All the tectonic units deriving from the structuring of the orogen form the core of the Calabrian Arc (e.g. the Sila Massif), and are covered by thick sedimentary successions which fill complex basins (e.g., Crati, Rossano, Crotone basins; see figure 4).

In the investigated area, northward of the Sila Massif slopes (figures 4 and 5) the Rossano basin is filled by a late Miocene succession, composed of sands, calcarenites and conglomerates, alternating with clays. This succession evolves upward to clays with gypsum, ending with terrigenous deposits (Roda, 1964; thickness of ~1300 m in borehole Trionto-1, available at internet site: http://www.socgeol.info/pozzi/index.asp; location in figure 5). The Miocene sequence is unconformably covered by Plio-Quaternary sediments (figures 4 and 6), composed of basal fluvial-deltaic conglomerates, sands and marine gravels.

The Pleistocene units evolve both laterally and vertically to silty clays (Roda, 1964, Vezzani, 1968, Carobene, 2003) which, in turn, contain tephra levels dated ~450 ka by Bigazzi and Carobene (2004). During Middle Pleistocene (i.e., after ~450 ka) the area experienced strong regional uplift, as testified by the wide extension of outcropping deltaic and alluvial systems, and by the impressive staircase of alluvial and marine terraces.

The entire Neogene succession plunges northward (figures 6, 7 and 8), with strata steepening on nearing the Sila Massif bedrock, and it is cut by ~E-W normal faults. The most important - in terms of both offset and length - is the N-dipping RF (figure 9). As it will be discussed later, the RF has a ~12-km-long surficial expression, and it is mainly arranged in a series of overlapping and *en-échelon* fault segments, the longest of which are the Corigliano and Rossano segments (labelled with a and b in figure 5).

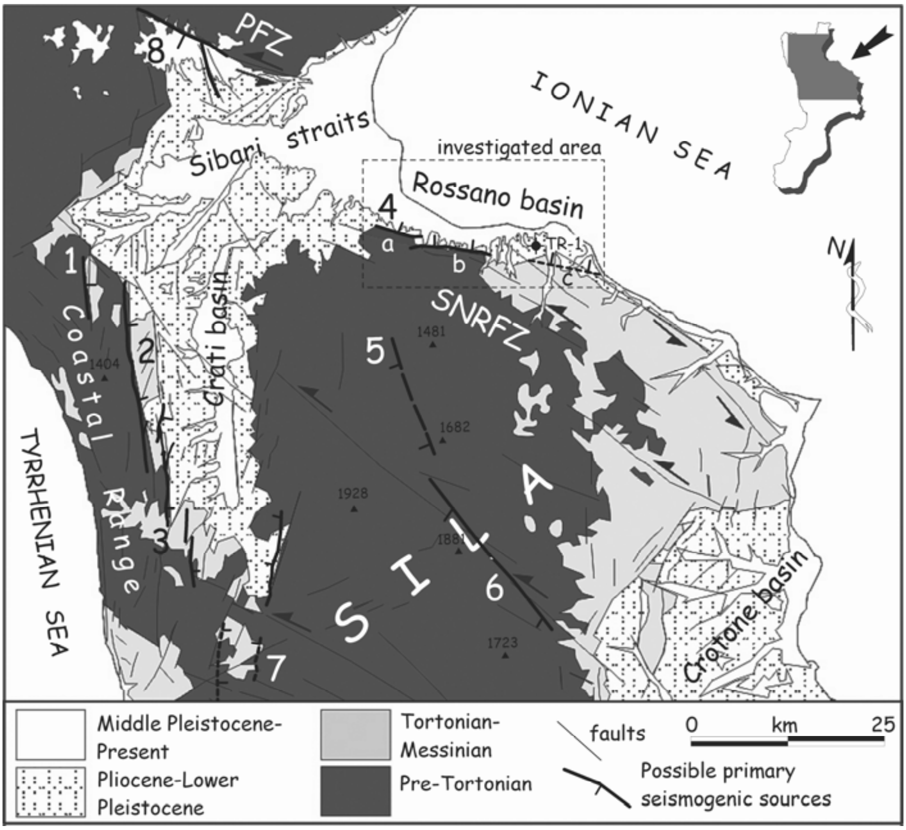

Figure 4. Structural sketch of northern Calabria and main possible seismogenetic faults: 1-3, W-Crati Fault System (1, Fagnano-Castello; 2, San Marco-San Fili; 3, Montaldo-Rende); 4, Rossano (segment a: Corigliano; b, Rossano; c, Crosia); 5, Cecita Lake; 6, Lakes; 7, Piano Lago-Decollatura; 8, Mt. Pollino. PFZ (Pollino Fault zone) and SNRFZ (S. Nicola-Rossano Fault zone) represent crustal shear zone. Only faults 4, 6, and 8 have been studied by means of paleoseismological analyses. TR-1, Trionto 1 borehole.

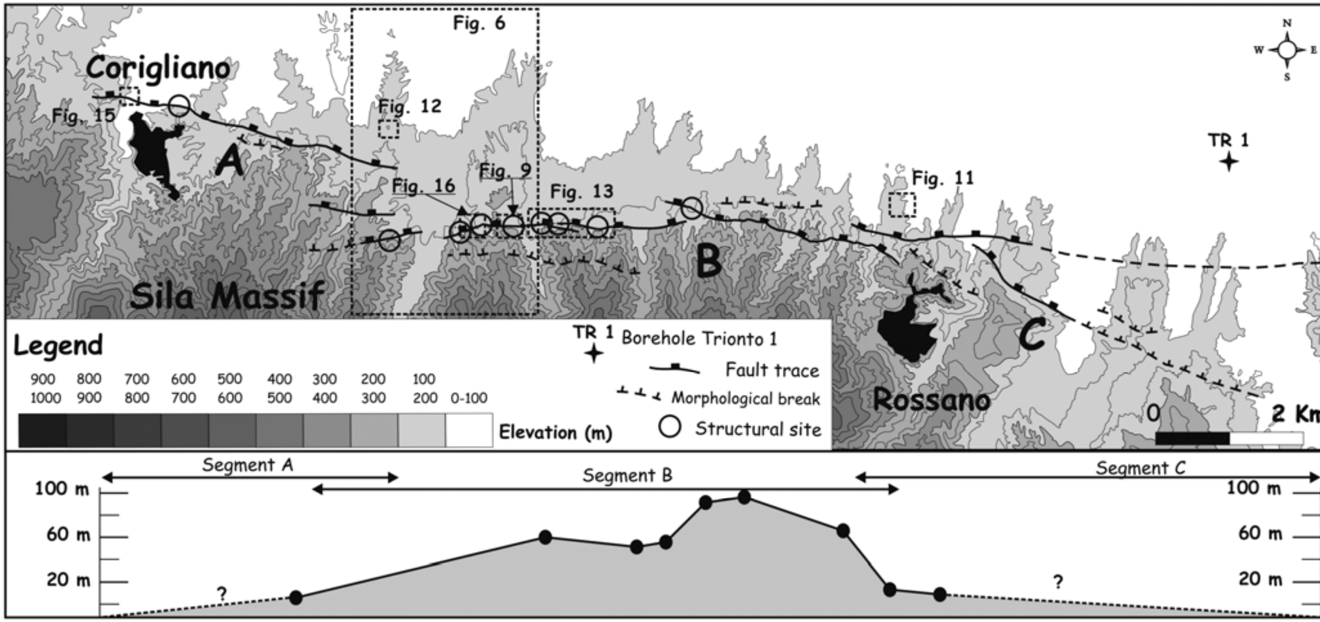

Figure 5. Rossano Fault segments (a=Corigliano segment, b=Rossano segment, c=Crosia segment) and locations of the structural sites and figures. TR-1 is the location of the deep borehole Trionto 1, reaching the crystalline basement at ~1600 m below s.l. In the figure is also shown the distribution along fault of the scarp height.

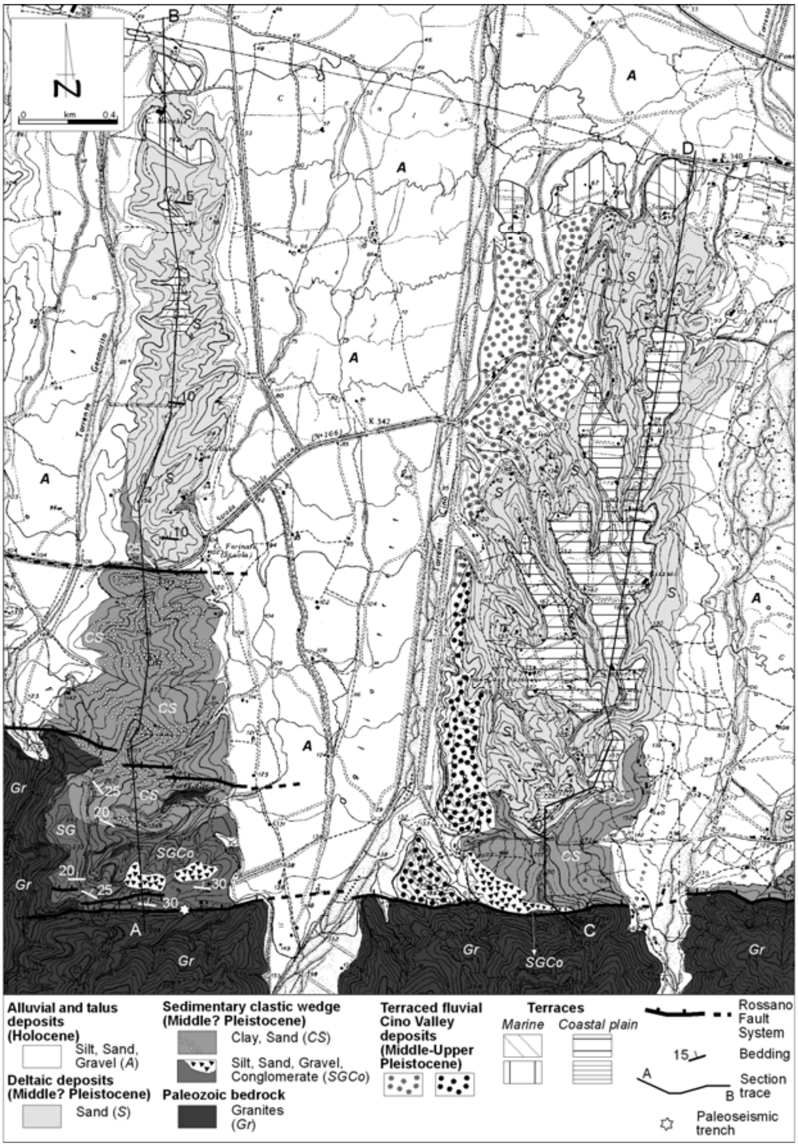

Figure 6. Geological sketch of the relay zone between the Corigliano and Rossano segments (location in figure 5), where the Quaternary marine and fluvial terraces are extensively exposed. The trace of sections of figures 7-8 are also shown.

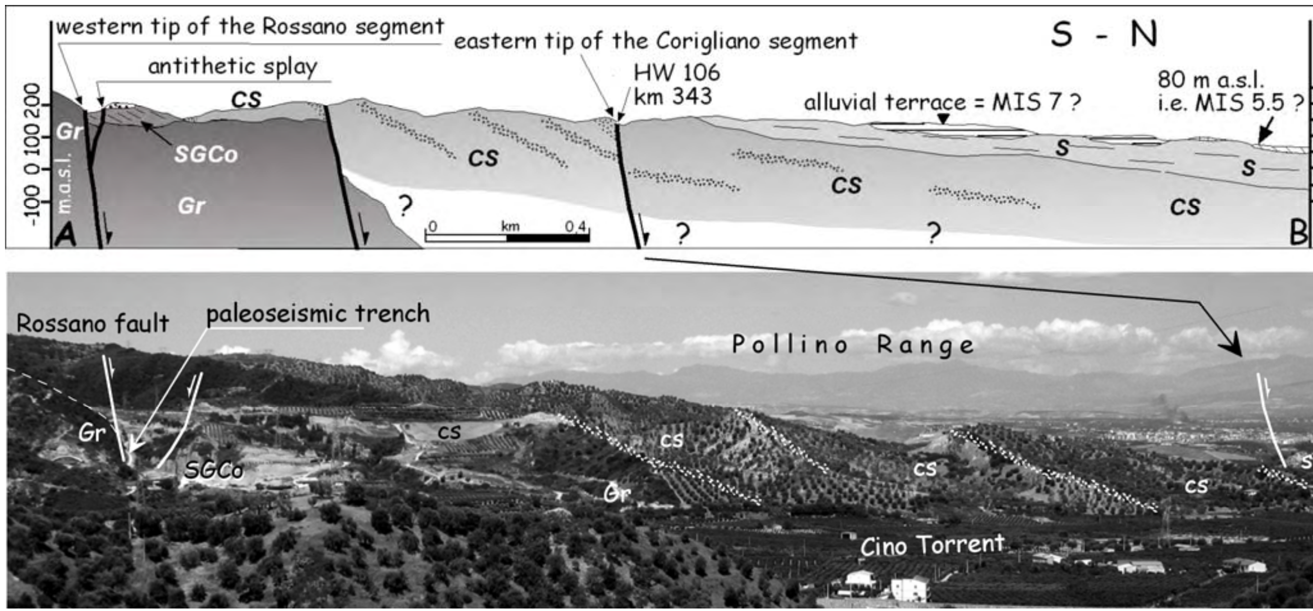

Figure 7. Simplified geological cross section across the Rossano Fault (A-B in figure 6; legend same as figure 6). The section shows the overlap zone between the Corigliano and Rossano segments. Note the Middle(?)-Pleistocene marine succession, dipping seaward, faulted against the crystalline Sila basement. The possible inner-edge of the marine terrace MIS 5.5 is showed. The lower panel is a picture of the left sector of the geological sketch.

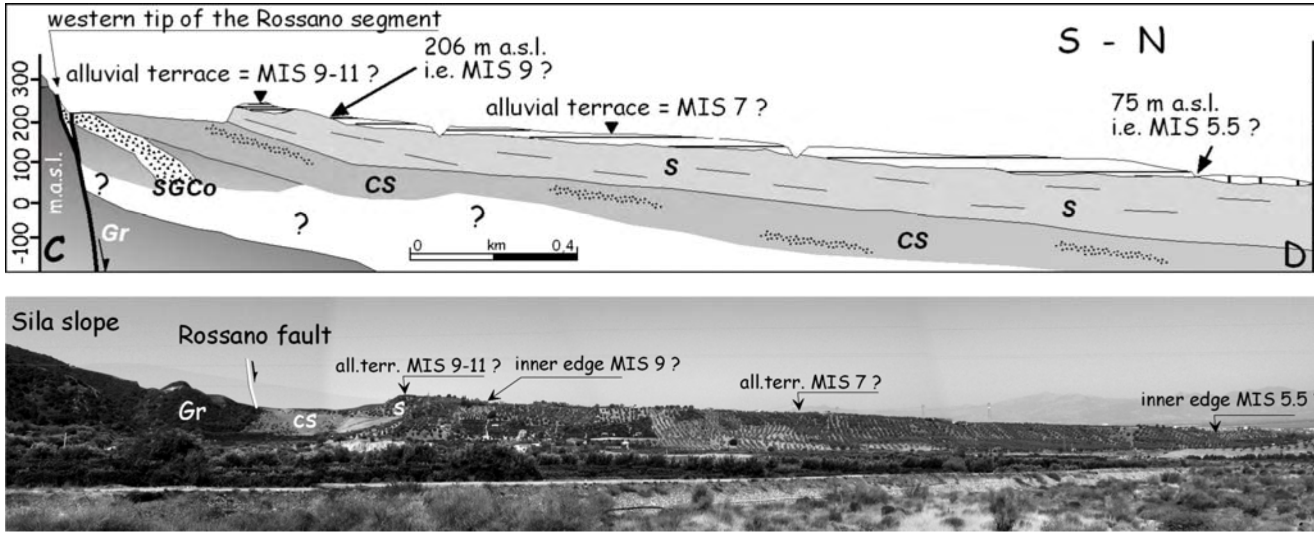

Figure 8. Simplified geological cross section across the Rossano Fault (C-D in figure 6). Note in this section the flat paleosurface topping the Pleistocene sands (S), tentatively interpreted as an alluvial coastal plain terrace, developed over a previous marine erosional terrace. The possible inner-edge of this marine terrace (MIS 9) is showed, together with the one of MIS 5.5. Lower panel is a picture of the geological sketch.

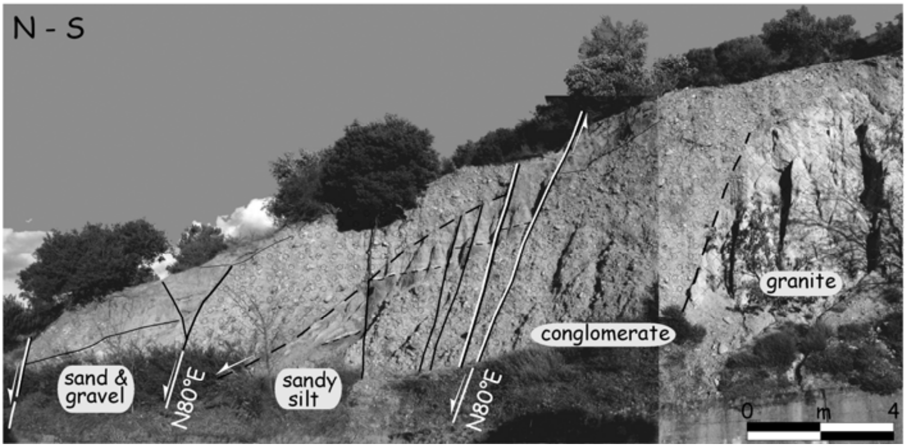

Figure 9. View looking east of the western tip of the Rossano Fault zone (location in figure 5). The Middle Pleistocene fan-delta succession (conglomerates and sandy silts and gravels, partly laying over the granite basement; right side) is displaced by several ~E-W normal faults. These faults downthrow definitely the Sila Massif below the coastal plain (left side), where the crystalline bedrock has been reached in borehole at 1600 m below s.l.

3.1. The Terrace Sequences of the Rossano Coast (Marine *vs* Alluvial?)

An impressive flight of marine and alluvial terraces characterizes the coastal sector of the investigated area. Terraces formed and were preserved because of the strong regional uplift affecting this sector of Calabria since the Middle Pleistocene, and particularly after 0.4 Ma (Carobene, 2003). Their correct identification and dating would represent a key point for the evaluation of differential crustal vertical movements (i.e. in the hangingwall of the RF).

Actually, these paleosurfaces are quite complex, and no agreement exists amongst authors about their age and nature. According to Vezzani (1968; who identifies seven orders of surfaces), and Cucci (2004; four orders), the terraces paralleling the coastline between Corigliano and Rossano are marine, as are those investigated and described in detail by Carobene (2003) farther east (four order sequence along the right side of the Trionto River). Both Cucci (2004) and Carobene (2003), by correlating the age of the interglacial peaks with the variation of the paleo-climate curves, inferred the age of each single marine terraces. However, in the overlap area of these studies, elevation (or age) of the inner edges does not fit each other. For instance, the elevation of the presumed

MIS 5.5 highstand (~125 ka) is ~70 m a.s.l. in Carobene (2003), but is ~130 m a.s.l. in Cucci (2004). Conversely, following Molin et al., (2002), Corbi et al., (2008), and Robustelli et al., (2009), on the basis of the nature of deposits in which they are carved, these paleosurfaces are mainly alluvial terraces. These authors also provide ages and elevation of fluvial terraces that are roughly consistent with the corresponding marine highstands evaluated by Carobene (2003). Considering the complex and controversial state of the art, we performed an independent aerial photo study of the terraced surfaces, followed by field survey, strictly focused toward the understanding of the possible interactions between the RF and the existing flight of terraces. Our data are summarized in figure 10, where seventeen topographical sections show the existence of several "scarps" parallelling the present shoreline in the Rossano area, all interrupting the flat profile of the paleosurfaces. The elevation reported on the map (meters a.s.l.) refers to the bottom of these scarps (arrows) or to the top of the uphill truncated surface (+ symbol; i.e., in case of missing uphill scarp). Terraces and scarps are mainly carved in the remnant divides of the streams, that is in the Middle Pleistocene (?) gravel-clay-sand succession (upper part of the Ciclo Suprapliocenico-Pleistocenico in Vezzani, 1968; part of the clayey formation in Carobene, 2003; "sedimentary clastic wedge" in Robustelli et al., 2009), and end uphill against the Rossano fault scarp (actually, they end before reaching the granite hillside, because of the selective and accelerated erosion between the crystalline bedrock of the footwall and the Quaternary succession in the hangingwall). The bottom of some of these scarps occurs at comparable elevations in different transects, whereas others scarps appear only in some profiles (figure 10). We checked some of these cases in the field, finding two types of situation: 1) some of these scarps fit with secondary faults affecting both the marine substratum and the alluvial-marine terraced deposits (e.g., north of Rossano, or right bank of both Colognati and Coserie torrents; figure 11); 2) others scarps have their bottom that matches with buried upward-coarsening and tapering, reddish gravel deposits (with imbricated, flattened boulders, with lithodomes holes in the carbonate clast), sealed by finer colluvial wedge, which we though to represent – in the whole - paleoshore *facies* (e.g. in figure 12). Therefore, we interpret the former as retreated fault-scarps, while the latter could be inner-edges of ancient marine terraces. As far as the nature of terraces is concerned, in our opinion, most of the marine abrasive surfaces are now obliterated by fluvial morphologies and deposits. Therefore, part of the terraces of the investigated area are remnants of alluvial coastal-plain surfaces, with fluvial gravel and sand deposits (up to several meters thick) overlying and burying older, raised marine terraces (see also Molin et al., 2002).

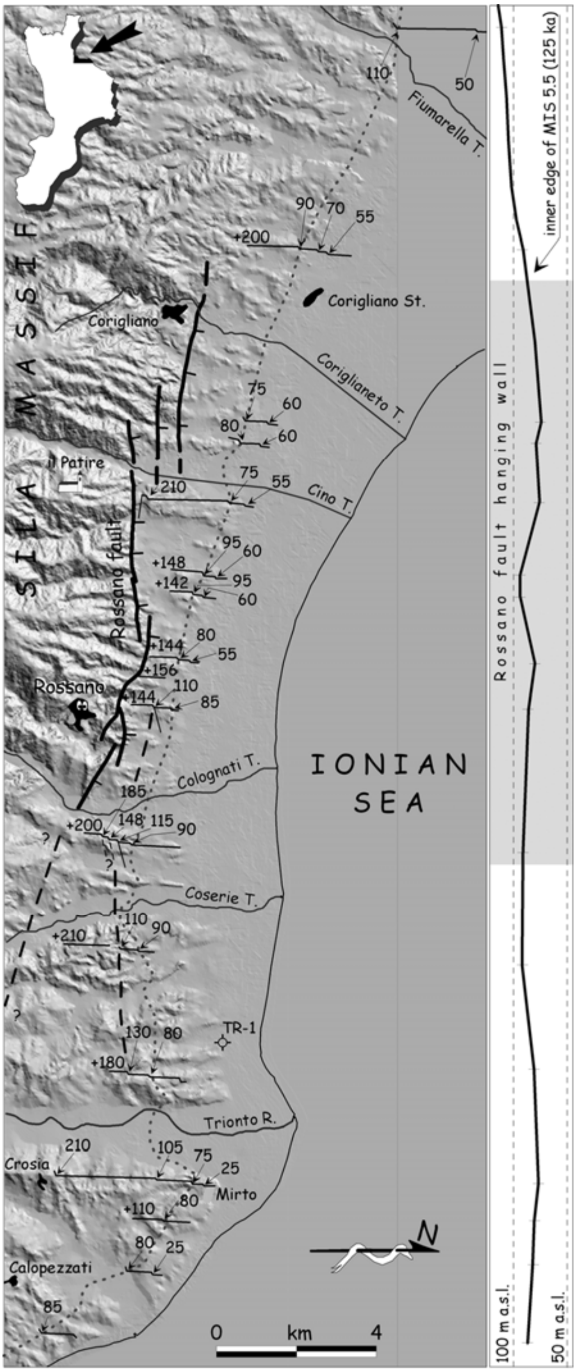

Figure 10. Shaded relief image of the Rossano coast. The main segments of the Rossano Fault are shown, together with seventeen topographical sketches drawn across the flight of marine/alluvional terraces of the area. Elevations in meters a.s.l. refer to the bottom of each identified scarp (arrows) that – in case of marine terrace – should indicate the inner edge of the relative MIS. Certain fault-scarps are evidenced on the sections by a line dipping seaward (dashed where inferred). Elevations marked by the symbol + indicate that the surface has not a scarp uphill. The right panel shows the projected profile of the presumed MIS 5.5 coastline, which appear lowered by the Rossano Fault with respect to the western (top) area.

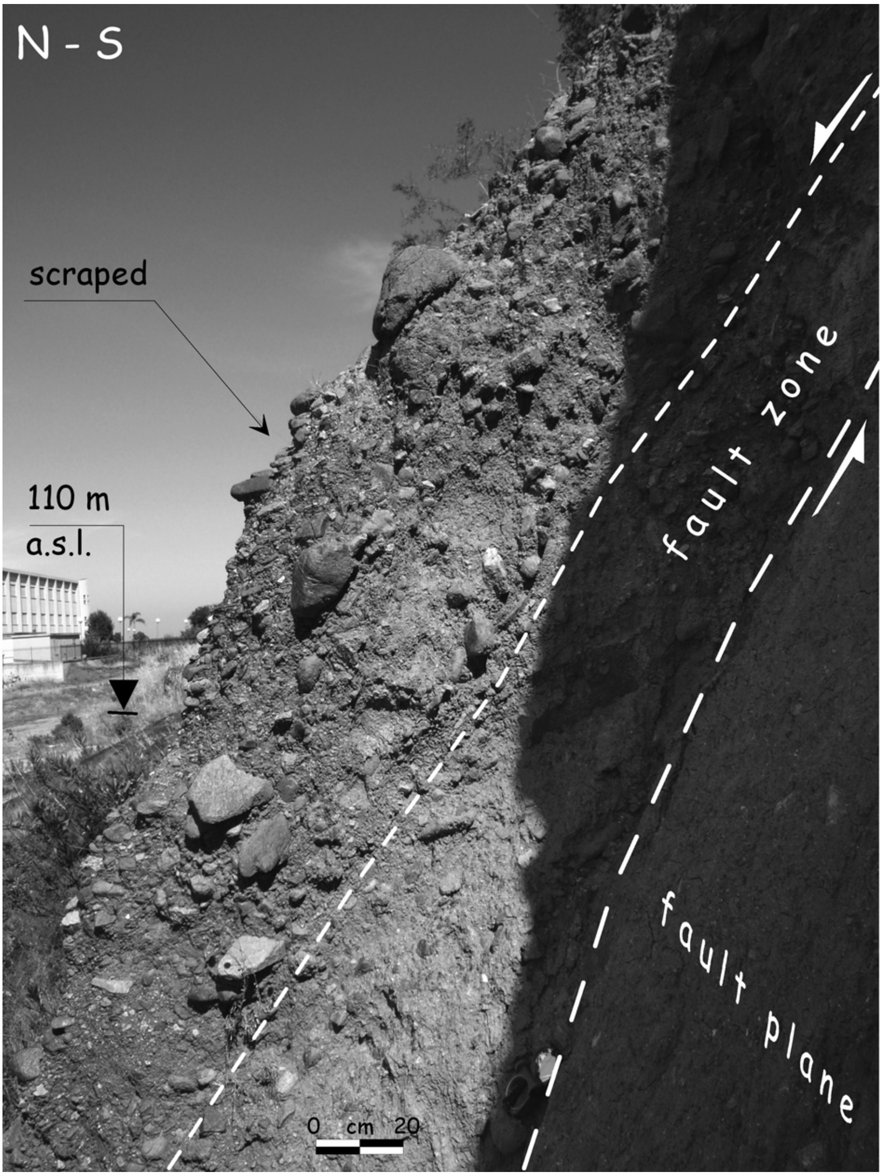

Figure 11. View looking west of one of the faults affecting the flight of marine/alluvial terrace close to the Rossano town (location in figure 5). Note the clasts of the terrace deposits dragged along the fault zone.

Figure 12. View looking west of a fresh outcrop (location in figure 5) at the top of the terrace reasonably belonging to MIS 5.5 (see Carobene, 2003), at elevation ~80 m a.s.l. Note the gravel body pinching out uphill, marking the possible inner edge of the marine highstand. Boulders and cobbles are interested by lithodomes holes.

Thus, the inner edge of the marine terraces that are coeval to these alluvial terraces should stay below the outer edge of the alluvial surfaces (i.e., at the bottom of the scarps shown in figure 10). However, fluvial erosion and deposition have erased and/or buried most of the inner edge traces. This could explain why we did not recognise the traces of the MIS 7 paleoshoreline (quoted by Carobene, 2003 at 105-120 m), which is probably obliterated by the long and flat alluvial terraces extending up to ~200 m a.s.l. in the studied area (it is worth noting that some surfaces have an uphill termination - i.e., the bottom of the above scarp - at 110-115 m a.s.l., but these cases always fit with the presence of faults displacing the terrace deposits; see figures 10 and 11).

On the other hand, we found the buried traces of the inner edge of a marine terraces, quoted MIS 5.5 by Carobene (2003), at elevation ~80 m a.s.l. (Cino Torrent area). We correlated this outcrop to an inner edge surveyed between 95-75 m a.s.l. in the rest of the area (figure 10; note that the absolute elevation is affected by errors due to the presence of talus colluvial wedge at the base of the scarp) and to the edge reported by Cucci (2004) westward of Fiumarella Torrent at 110 m a.s.l. A lower edge, observed at 55-60 m a.s.l. between the Corigliancto and Colognati torrents, could be ascribed to a later marine highstand (i.e., MIS 5.3). Finally, in two cases, we found faint traces of an older and higher marine inner edge (marked by upward-tapering gravels, with lithodomes holes), at elevation of ~205 m a.s.l. (right bank of Cino and Colognati torrents), which could fit the MIS 9 terrace of Carobene (2003; Bigazzi and Carobene, 2004; 210 m a.s.l.). It is worth noting that other sparse flights of remnant surfaces are visible on the northern granite slopes of the Sila Massif (see also Molin et al., 2002); some of these are covered by continental gravels (sometime with boulders >1 m) and sands, and they are clearly hanging on the footwall of the RF. They could be considered relics of the apical portion of the deltaic complexes associated with the alluvial terraces of the plain, offset by the RF, and isolated by the strong erosion of the uplifted block.

4. Indications of Recent Activity of the Rossano Fault

As a result of the previous surveys, we felt more confident as far as the Late Quaternary geological evolution of the area, and then we focused our efforts along the RF. In facts, the RF has not been studied before, nor does it appear in the official geological map of the area (Burton, 1971). Only Vezzani (1968) traced a short segment fitting with the scarp showed in figure 13, whereas Molin et al. (2002) report other different strands.

We followed the surficial expression of the RF along ~12 km between the villages of Corigliano and Rossano, where the fault downthrows abruptly the northern side of the Sila massif, faulting the crystalline bedrock against the northward dipping Pleistocene marine succession (figures 2 and 8). The fault is arranged into several ~E-W segments, which slightly overlap with *en-échelon* geometry.

As mentioned before, flights of remnant paleosurfaces, together with continental and marine deposits, have been raised by the fault, and now lie hanging over the footwall (figure 13).

Although the slopes of Sila are entirely lushly forested and/or masked by agricultural works (e.g., agricultural terracing), we recognised indication of recent fault activity (e.g rock fault scarp and displaced deposits), following also the evidence gathered through the interpretation of 1954-1992's air photos. Moreover, structural data collected along the fault plane (figure 5) show two main trends, oriented N55°E and N83°E, respectively, mirroring the presence of short fault jogs (see rose diagram in figure 14), whereas *striae* orientation indicate that RF has an almost pure normal dip slip kinematics, with a direction of extension (direction of the minimum stress axis σ3) sub-horizontal and oriented N191° (figure 14).

Figure 13. View looking ESE of the Rossano Fault scarp (big arrows; location in figure 5). Rossano is the village (left-background) where historical sources described surface breaks during the 1836 earthquake. Note the prominent triangular facets which characterize this sector of the northern Sila hillside; they are probably due to combined erosive exhumation (regional uplift) and cumulated surface faulting processes. Little arrows indicate a gently dipping paleosurface carved in the granite of the RF footwall, which hangs now hundred meters over the plain.

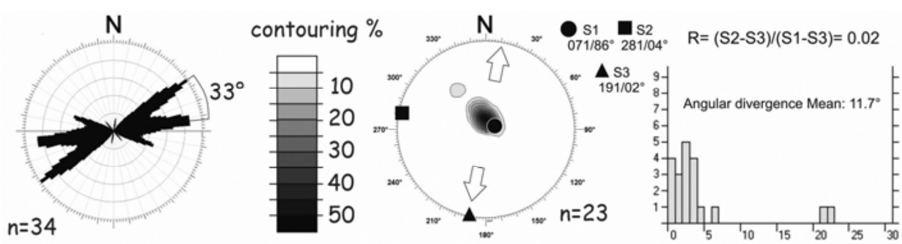

Figure 14. Synthesis of the structural analyses carried out along the Rossano Fault (see Fig. 5 for location of surveying). Dispersion of plane strike is 33° (left panel), whereas the *striae* indicate a horizontal, 191° trending σ3 axis (central panel), with a mean angular divergence of 17° (right panel).

From the morphological point of view, the fault generates an impressive rectilinear hillside, associated with prominent triangular facets carved in the crystalline bedrock (figure 13). The scarp varies between 10 m, in the tip zones of the fault, and almost 100 m, in the central part, (figure 5) with a pattern similar to the distribution of displacement along large basin bounding normal faults (Roberts, 2007). However, the genesis and height of the triangular facets must be interpreted as due to the combined action of granite-bedrock exhumation (i.e., due to the strong regional uplift) and to the cumulated coseismic surface rupture events.

A robust indication of recent activity is the presence of a basal fault scarp (*sensu* Gilbert,1884), which is equally carved in sandy-clayey Middle Pleistocene deposits (e.g., Corigliano area; see figure 15), in highly degraded granites (see figure 16), and in coarse slope deposits (see figure 17).

This scarp is usually ~2-m-high, being somewhere characterized by at least three 0.5/0.6m-high horizontal bands, each one with both different dips (from ~85° at the bottom, to ~55° at the top) and degradational aspect. Figure 16 summarizes the observations carried out along twelve sections at the base of the central portion portrayed in figure 13, and provides the average height and dip ranges of the three bands that characterize the fault free-face. A possible explanation for these features is that each band might be partly associated with a single faulting episode, so that the higher, less steep and more degraded the band, the older is the event which it is associated to (see Giaccio et al., 2002).

Figure 15. Morphological evidence of the recent fault re-activitation (location in Fig. 5). A) view looking south of the fault scarp affecting the Middle Pleistocene sandy-clayey succession near Corigliano. Considering the high erodibility of these terrains, the freshness of the scarp suggests a recent activity of the fault. B) fault-plane (arrows) along the same scarp, between the marine sands (footwall) and talus and marine clays in the hangingwall.

According to this interpretation, the free-face records at least three surface faulting events, each one with offset of ~0.5÷0.6 m. However, we can not exclude that part of this value was caused by climatogenic processes, as exhumation due to soil instability along the slope. Therefore, the measured bands represent a maximum amount of offset per event.

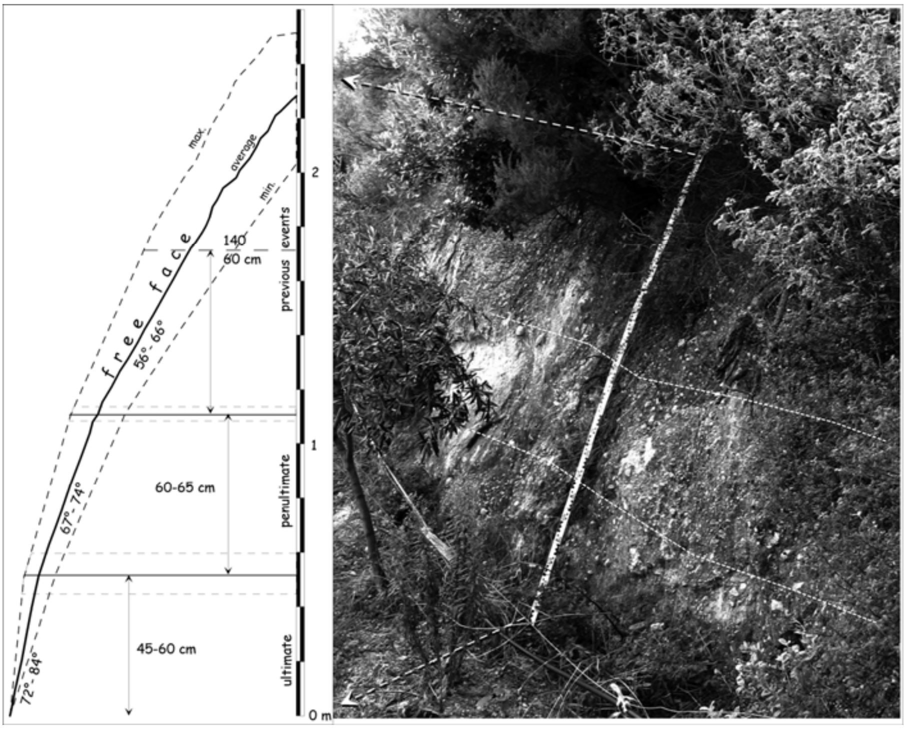

Figure 16. Free-face cropping out at the base of the Rossano Fault scarp (location in Fig. 5), and, on the left, sketch summarizing the geometrical properties of the plane (dips and heights have been averaged on twelve spaced sections). We recognized at least three ~0.6-m-high bands with different dip and degradational aspect, each one partly associable to single coseismic rupture. The upper (and oldest) one is deeply degradated, and it presents the lowest dip; thus, it might record several past surface ruptures, beside long-term erosive exhumation.

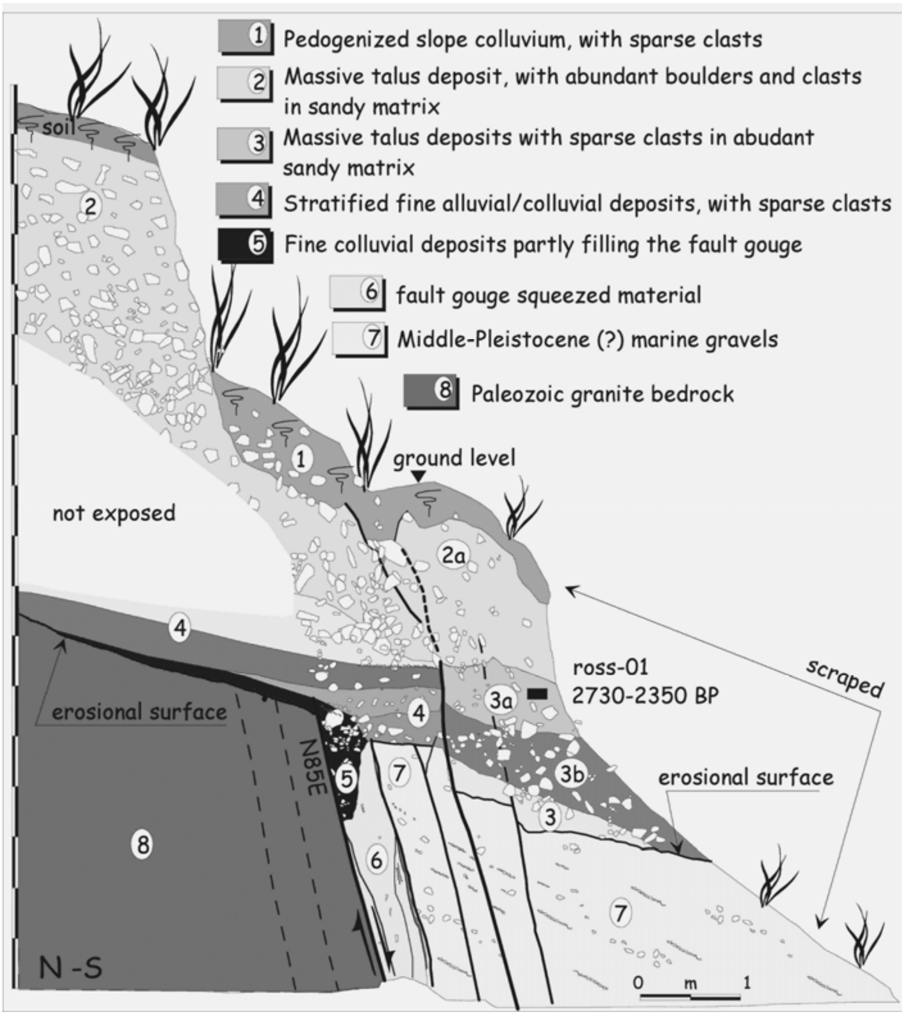

Figure 17. Sketch of the paleoseismic trench excavated across the Rossano Fault (location in Fig. 6). Even if no certain event-horizons can be recognized within the talus succession, the absolute age of a charcoal sampled in unit 3 provides the *terminus post-quem* for the latest fault ruptures.

4.1. Paleoseismic Trench

In order to ascertain the recent activity of the RF, we dug an explorative trench, exploiting the erosive bank of a natural gully at the toe of the fault-scarp

(Galli et al., 2006), finding both marine and slope deposits faulted against the crystalline rocks (figure 17).

The marine succession which we have found in the hangingwall (unit 7 in figure 17) is deeply affected by regularly spaced shear-planes; pure dip-slip *striae* are visible on the fault planes, providing reliable evidence to constraint the fault kinematics. A ~20 cm thick, argillitic cataclastic zone (unit 6) is packed between the Quaternary conglomerates and the crystalline rocks (unit 8). The top of the marine succession is truncated by an erosional surface, that in turn is overlain by both organized (unit 4) and massive (unit 3) slope-deposits, with occasional granite cobbles and boulders in a coarse, slightly cemented sandy matrix. Also these units are faulted, dragged, and partly trapped between the fault and the marine deposits. Finally, unit 2 is a faintly pedogenized rudite, currently forming along the slope, and probably involved in the last deformation. An absolute date of a small charcoal fragment picked in unit 3a provides a ^{14}C age of 2730-2350 BP (ross-01, 2σ cal. age). Unfortunately due to the texture and coarse lithology of the slope deposits - which hamper the identification of eventual offsets (e.g., between subunits 2-2a) - and due to the repeated erosive/depositional events occurred within the gully *thalweg*, we were not able to identify individual faulting events. However, taking into account the dating of the collected sample (which gives the minimum age of unit 3), the last rupturing paleoearthquakes occurred in the past 2-3 ka, being possibly associated with part of the free-face running along the base of the fault scarp.

5. Discussion and Conclusions

According to the observations and data herein presented, it emerges that the activity of the RF conditioned the sedimentary and morphological evolution of this sector of the northern Calabria during the Middle-Upper Pleistocene, i.e., after the inception of the strong ~1mm/yr regional uplift (Bigazzi and Carobene, 2004). In fact, with the exception of the Rossano area – where Tortonian deposits outcrop in the Rossano Fault footwall - the Pleistocene marine-deltaic succession is faulted directly against the crystalline basement, which – in turn - is lowered 1600 m below s.l. in the hangingwall (data from onshore borehole Trionto 1). In one of the main fault step zones, west of Cino Torrent (i.e. in the hangingwall of Rossano segment), the Middle Pleistocene sandy clays deposited directly on a paleosurface carved in the granite rocks (figure 7); here, the entire sedimentary succession hangs in the footwall of the Corigliano segment, so that the uppermost terraces (i.e., older than MIS 5.5) have been dissected by accelerated erosive processes. The lower terraces, instead, appear again in the hangingwall of the Corigliano segment, with elevations comparable to those observable eastward (figure 10). As far as the marine/alluvial terraces are concerned, in the entire hangingwall of the RF, the presumed (~buried) inner edge of MIS 5.5 is at 75-95 m a.s.l. (it is ~80 m a.s.l. in the certain outcrop of 10), whereas it is 110 m a.s.l west of Fiumarella Torrent (figure 10).

Moreover, according to Cucci (2004), farther west, in the Sibari Straits the inner edge of MIS 5.5 highstand crops out at 130-140 m a.s.l., that is ~50-60 m higher than in the Rossano area. Considering the short distance of the MIS 5.5 paleoshoreline from the RF, if this elevation difference could be tentatively ascribed to the hangingwall downthrown, the rough slip-rate during Late Pleistocene would be ~0.5 mm/yr. On the other hand, considering that the elevations of the presumed MIS 5.5 remain the same proceeding toward Mirto (Carobene, 2003), it is possible to hypothesize that an eastern “hidden” step of the RF might exist south of Calopezzati and Crosia villages (c in figure 5; dashed line in figure 10), where only faint scarps were recognised. In this area, the surficial expression of this structure could be masked by erosion and landsliding processes in the sandy-clayey succession (conversely, it is magnified by the abrupt contact between hard crystalline and soft Pleistocene deposits along the RF). However, no certain field indications exist concerning this issue, which will need future investigation.

As far the present activity of the RF is concerned, morphological (i.e., rectilinear fault-scarp, triangular facets, fault free-face), and geological data (late Pleistocene faulted deposits) suggest recent surface ruptures, at least between the villages of Corigliano and Rossano (for a length of ~12 km). Actually, the explorative paleoseismic trench that we dug across the western sector of the fault confirmed the rupture during late Holocene time, at least after ~3 ka BP. In particular, systematic observations along the rock fault scarp showed steady dip-variations from the bottom to the top of the free-face, each one associated with different degradational aspect of the plane; we tentatively associate part of these features with as many consecutive surface rupture.

At the same time, documents research in archives and libraries, coupled with the reinterpretation of all the available primary historical sources, allowed the reappraisal of the effects of the strongest known earthquake of the area (April 24, 1836). The 1836 HIDD matches well with the RF trend, suggesting this normal fault to be the causative source for the earthquake. Moreover, coeval accounts on sea-waves, liquefactions and surficial breaks have been compared with the RF location and kinematics, providing further indication concerning the coseismic rupture of this structure in the 1836 event. Fault length and average co-seismic offset allow us to calculate a rough value of magnitude associated to this structure. According to the empirical relationships of Wells and Coppersmith (1994), we obtain Mw=6.28, which is close to the value expected using the regression law calculated by Galli et al (2008) for "Apennine faults" (Mw=6.13). Both values are consistent with the macroseismic equivalent magnitude evaluated by using the Boxer algorithm (Gasperini, 2002), applied to our HIDD (Mw=6.24). Based on our seismotectonic interpretation, the epicentre of the 1836 earthquake (currently located near the village of Crosia) would fall farther west, in the hangingwall of the RF (namely at average coordinates 16.58°E 39.62°N); the strong effects in the small villages of Crosia and Calopezzati might be explained with directivity effects, i.e., with an eastward rupture (from Corigliano – that suffered a relatively low intensity - to Rossano; see arrow in figure 2). The current activity of the RF is strengthened also by the existence of the 1995 event at the eastern tip of the fault, the focal mechanism of which suggests the rupture of an E-W oriented fault plane with extensional kinematics (i.e., like the RF; see figure 2).

Finally, considering the number of bands observed along the ~2-m-high free-face, the reasonably recent age of the fresh rock fault scarp (which is conserved both in clayey and coarse deposits, and in granite rocks), and the occurrence of historical earthquakes in the area, it is possible to hypothesize that at least three events occurred in the past ~3 ka, the last ones being the ~951 and 1836 earthquakes, respectively. This gives a return time of ~0.9 ka for Mw=6.2 events on the RF, which, in turn, would be characterized by ~0.6 mm/yr of slip-rate.

As a concluding remark, basing on both kinematics of the RF and fault slip data coming from other active faults (i.e. Lakes Fault in figures 1 and 4), and considering also the contribution of the WNW-ESE Pollino normal fault (figure 1), we observe that the central and eastern sector of northern Calabria is currently experiencing ~N-S extension, in agreement with the different GPS velocities calculated by D'Agostino and Selvaggi (2004) for central-southern Calabria (3.2-3.3 mm/yr in a NNW direction) and Apulia (4.6-4.8 mm/yr in a NNW direction).

As widely demonstrated in several others published works concerning earthquake geology, we think that a multidisciplinary approach - such that consisting of archive research (historical seismology), structural and geomorphological analyses, and paleoseismology - is a robust tool to identify, and to characterize seismogenic sources, providing also useful data for seismic hazard assessment. However, it is our opinion that additional paleoseismological investigation across the RF are needed to better constrain fault parameters (i.e. recurrence time, fault slip rate) and to reduce the uncertainty in terms of the recent seismogenic behaviour of this structure.

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