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SCIENCE

Seismotectonics and landslides of the Crati Graben (Calabrian Arc, Southern Italy)

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ABSTRACT

The Crati Graben is a depression of Plio-Holocene age mainly controlled by extensional N–S striking faults and WNW–ESE transcurrent faults, in its northern and southern extremity. It is characterized by high landslide susceptibility due to the particular geo-structural pattern and seismotectonic characters. Landslides involve many villages, infrastructure and food crops, bringing serious economic and social damage. The seismotectonic and landslides Main Map of the Crati Graben, described in this paper, represents an update in detail of the framework of landslide risk areas and shows the main active and recent faults of the Crati Graben. The landslides and the faults, have been identified and classified, originally at detail scale (1:5000) and, then, represented at 1:50,000 scale. The geo-structural and geomorphological data were analysed in a geographic information system. The work has revealed a correlation between the trend of faults with respect to the distribution of landslides and of the historical and instrumental seismicity. The work presents an updated knowledge framework of risk conditions of the study zone, where risk areas related to slope instability are hierarchically classified according to the destructive potential of landslides. This document may be therefore a useful reference in planning and prioritising in the design of interventions for the safety of slopes and waterways.

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1. Introduction and geological setting

The Crati Graben (Lanzafame & Tortorici, 1981; Tansi et al., 2005a; Tortorici, 1981) is a Pliocene-Holocene tectonic depression, filled by Middle Pliocene to Holocene marine and continental clastic strata, and structured by N–S trending normal faults. On its western and eastern sides, the graben is bounded by Mesozoic and Palaeozoic crystalline-metamorphic rocks of the ‘Coastal Chain’ and the ‘Sila Massif’ horsts (Figure 1). Regional NW–SE normal left-lateral transcurrent faults bound the northern and southern end of the Crati Graben. This structure develops on the northern side of Calabrian Arc, an arc-shaped structure of the Mediterranean orogenic belt connecting the Maghrebian and Southern Apennine chains (trending E–W and NW–SE, respectively). It represents an accretionary wedge (Amodio-Morelli et al., 1976; Critelli, Muto, Tripodi, & Perri, 2011, 2013; Dewey, Helman, Turco, Hutton, & Knott, 1989; Doglioni, 1991; Kastens et al., 1988; Malinverno & Ryan, 1986; Ogniben, 1973; Patacca & Scandone, 1989; Royden, Patacca, & Scandone, 1987; Sartori, 1990; Tortorici, 1982) consisting of Alpine units made up of a series of ophiolite-bearing tectonic units (Liguride complex; Ogniben, 1969), and of overlying basement nappes (Calabride complex; Ogniben, 1969). The Alpine nappes, during Oligocene-Early Miocene, overthrusted on the Mesozoic carbonate terranes belonging to the Apennine Chain. 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 (Dewey et al., 1989; Ghisetti & Vezzani, 1981; Muto & Perri, 2002; Tansi, Muto, Critelli, & Iovine, 2007; Tripodi, Muto, & Critelli, 2013; Turco, Maresca, & Cappadona, 1990; Van Dijk et al., 2000). Since the Pliocene, strike-slip tectonics produced, at the tips of the fault segments, extensional structures: at the SE termination of a regional NW–SE fault (‘Falconara-Carpanzano Fault’ after Tansi et al., 2007), a regional transtensional area developed identifyng the Crati Graben (Figure 2). It is structured by N–S trending normal faults, showing seismogenic activity, as testified both by historical IX-X MCS events (Boschi et al., 1995; Boschi, Guidoboni, Ferrari, Valensise, & Gasperini, 1997; Postpischl, 1985) and by instrumental earthquakes (Moretti, Corea, & Guerra, 1990) (Figure 1). The Crati basin represents a longitudinal basin with respect to the Calabrian Arc, confined by the Pollino (Bousquet, 1971) and the Falconara-Carpanzano faults (Tansi et al., 2007; Van Dijk et al., 2000). Superimposition of extensional faults on strike-slip and contractional Neogene structures, in the Paola and Crati

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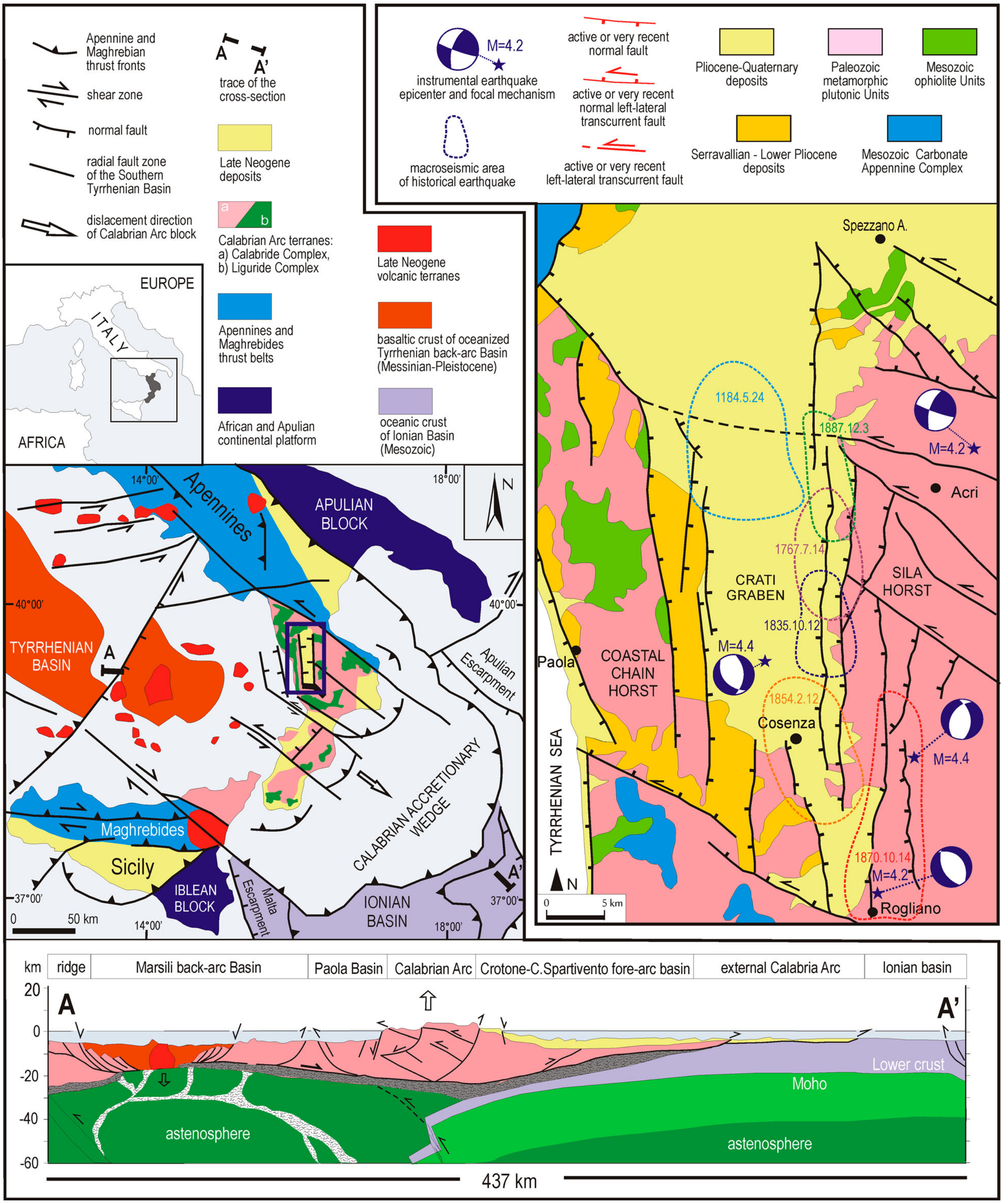

Figure 1. Geological sketch-map of the Central Mediterranean area and geological section on bottom (after Tansi et al., 2007, modified), with tectonic simplified sketch of study area. The continuous blue line marks the boundary of the study area. The trace of regional cross section A–A′ changes direction from W–E to NW–SE in correspondence of the Crati Graben.

Basins, have been documented (Argnani & Trincardi, 1990; Milia, Turco, Pierantoni, & Schettino, 2009; Muto et al., 2015; Pepe, Sulli, Bertotti, & Cella, 2010; Spina, Tondi, & Mazzoli, 2011; Van Dijk et al., 2000; Vespasiano et al., 2014) as results of relationships between slab retreat and accretionary processes in the eastern Calabrian margin and extensional processes in the western margin (Critelli et al., 2013; Critelli & Le Pera, 1995; Doglioni, 1991; Kastens et al., 1988; Muto, Spina, Tripodi, Critelli, & Roda, 2014; Zecchin et al., 2012; 2015). The early-mid Pleistocene extensional tectonic phase experienced the Crati Basin infill and the uplift of the Coastal Range to the west and the Sila Massif to the east. The sedimentary successions infilling the Paola and Crati Basins are characterized by progressive unconformities which record the migration of the Calabrian block towards the S–E. Well exposed unconformities are evident in the onshore and offshore

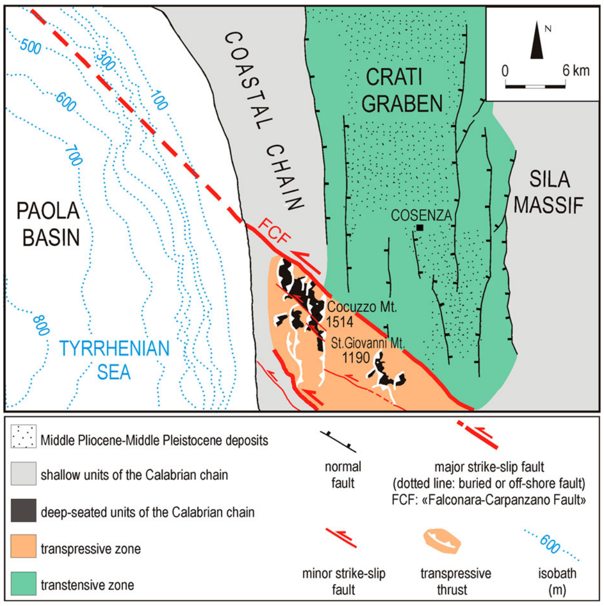

Figure 2. Kinematic scheme of the study area.

Plio-Pleistocene sedimentary strata (Fabbricatore, Robustelli, & Muto, 2014; Zecchin et al., 2015). The rainy seasons of the years 2008–2012 were marked by exceptional weather conditions causing landslide activation and reactivation. The event was particularly severe and destructive enough to cause the Presidency of the Council of Ministers to issue, for the study area, four ordinances for natural disasters. The disasters have damaged large areas of the territory, particularly affecting the road network and private construction, as well as economic activity in the study area and northern Calabria (Conforti, Muto, Rago, & Critelli, 2014). The study area is affected by many landslides, large-scale landslides and deep-seated gravitational and tectono-gravitational slope deformations (Iovine & Tansi, 1998), the distribution of which is often controlled by the lithology and geo-structural pattern. The aim of this study is the development of a multidisciplinary approach combining geological mapping, macro- and meso-structural lineaments, geomorphological analysis, and the study of the main historical and instrumental earthquakes, in order to define the seismotectonic and landsliding characteristics of an area of high geo-structural hazard, such as the Crati Valley. The results of this approach are summarized in the 1:50,000 scale map of the study area.

2. Methodology

On the map we depict recent and active faults obtained through geo-structural and geomorphological analysis, performed from the macro to the mesoscale. The macro-structural analysis has been carried out by aerial photographic interpretation which led to the identification of morpho-tectonic indicators such as fault scarps and triangular/trapezoidal facets. Other indicators are rectified waterways and morphological *steps* and *saddles* aligned along adjacent ridges. Along the faults recognized at the macroscale, we performed meso-structural studies (Hancock, 1985) collected at 52 stations located along the main fault zones. The most recent faults have been detailed, closely associated with the morphodynamics recognizable in the current landscape and with the seismotectonic setting of the area. The meso-structural data were collected at measuring stations uniformly distributed along the faults. For each striated fault plane we measured strike, dip and pitch, and so determined the direction of movement. The most representative elements of gravitational and tectono-gravitational origin have been recognized primarily using geomorphological criteria (detection of scarps and trenches along the ridges and on the slopes, the analysis of the shape of the latter and interference with the drainage network, etc.) and multi-temporal analysis of aerial photographs and satellite images followed by field surveys. We also report the outcropping lithologies. The synthesis of the above-mentioned studies led to the mapping (1:10,000). Quaternary faults have been recognized and mapped on the basis of Quaternary deposit displacements and on the morpho-tectonic evidences together with scarps related to cumulative and triangular facets and trapezoidal, as well as the relationships between faults and large landslides (LL) and deep-seated gravitational deformations.

The above data were then digitized and analysed in a geographic information system. The data were geo-referenced in UTM (Universal Transverse Mercator) with WGS84 Datum.

3. Lithostratigraphy

In the study area, the following main tectono-stratigraphic and tectono-metamorphic units (Figure 3) crop out, on which Neogene-Quaternary strata lie unconformably.

The units are briefly described from bottom to top.

Tectonic units of the Chain

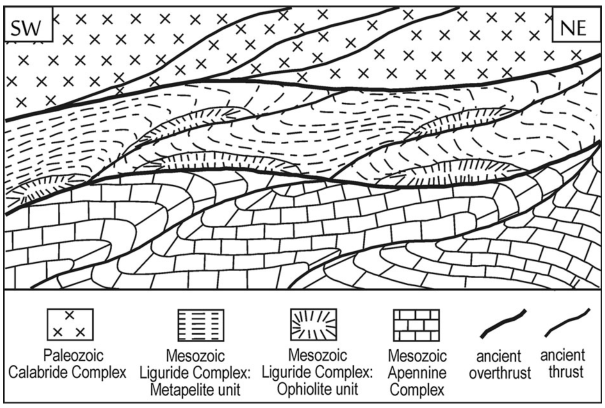

Figure 3. Tectonic scheme (not to scale) comprising the structural assemblage of the Calabrian belt.

Carbonate-Apennine Complex

Prevalent Triassic dolostone and metalimestone (*Monte Cocuzzo Unit*), outcropping in 'tectonic windows' along the southern edge of the Coastal Chain horst, and Mesozoic to Langhian succession constituted by phyllites, metalimestone, dolostone and calcarenites and marls, with turbiditic strata (*Lungro-Verbicaro Unit*) (Iannace et al., 2007), outcropping in the north-western extremity of the study area.

Ophiolite Units

Metabasalts and pillow breccia with a Calpionella limestone sequence cover (Malvito Unit) and massive and foliated metabasite and serpentinite, with metapelite and metalimestone cover (Diamante-Terranova Unit; Critelli, 1993). They crop out diffusely along the Coastal Chain (Filice et al., 2015) and in the NE extremity of the map.

Paleozoic metamorphic – plutonic units

A number of tectonic units belonging to the Calabrian Arc – diffusely outcropping along the Coastal Chain and Sila Massif – are constituted, from bottom to top, by:

- dominantly foliated slates, black metapelites and metasilts, interbedded with micaschists and porphyroids (*Bagni Unit*),
- milonitic gneiss, micaschists and marbles (*Castagna Unit*),
- high-grade metamorphic rocks (biotite-sillimanite-garnet gneiss), intruded by plutonic bodies (*Monte Gariglione-Polia Copanello Unit*), and
- Intrusive bodies of regional extension with variable composition from gabbro to tonalite, granodiorite and monzogranite intruded by felsic dykes, microgranite and aplite-pegmatite (*Sila Batholith*).

3.1. Neogene-Quaternary deposits

Neogene transgressive deposits – outcrop along the western and eastern borders of the Coastal Chain – made up of Serravallian conglomerate-arenite, Tortonian mixed arenites (Calcare di Mendicino Formation) passing upwards to clay with shelf turbidites and thin bedded diatomites and marls (Lanzafame & Zuffa, 1976; Mastandrea et al., 2002; Mattei et al., 2002). Messinian deposits consist of evaporite and terrigenous strata and mainly outcrop to the NE margin of the map, in the area comprised between the Rosa River and the Grondo River (Figure 1). They consist of calcarenite and clayey and arenaceous strata passing to thin laminated limestones alternated with vacuolar limestones. The succession grades upwards into clay with thin laminated gypsum strata, in which are intercalated thick levels of halite. The Messinian succession of the Crati Basin is partially correlated to the evaporite deposits of the Crotone Basin (Zecchin et al., 2013a, 2013b and references therein) and to the Messinian infill of the Amantea Basin (Longhitano & Nemec, 2005; Mattei et al., 2002; Muto & Perri, 2002). Conglomerate–sand–clay succession, unconformably overlies the above-mentioned Miocene units. Middle Pliocene to Middle Pleistocene deposits, made of thick conglomerate–sand–sandstone–lay marine succession (Figure 1), represent the basin-fill deposits of the Crati Graben (Fabbricatore et al., 2014; Lanzafame & Tortorici, 1981). The stratigraphic succession of the Crati Basin is generally divided into two sequences. The first unit consists of Lower Pliocene deposits unconformably overlying the bedrock and the Messinian formations, cropping out exclusively in the western margin of the basin. In this zone the Neogene-Quaternary deposits are displaced by N–S trending normal faults with respect to the metamorphic units of the Coastal Chain. The lower sequence consists of conglomerates and sandstones passing upward into silty clays and clays (Burton, 1971; Lanzafame & Tortorici, 1981; Lanzafame & Zuffa, 1976; Spina et al., 2011; Tortorici, 1981). The second unit unconformably lies either on the first unit or directly onto the bedrock in the eastern margin of the basin (Fabbricatore et al., 2014). The Pleistocene sequence represents the sedimentary response to the basin subsidence and the uplift of the margins. In this time the Crati Basin shows the tectono-sedimentary architecture of a fault bounded intra-arc depozone cut to the north and south by transversal major faults while, to the east and west, by longitudinal major normal faults. Further, sedimentation proceeds eastwards, causing a diachronous transgression, propagating the progressive onlap on the western Sila Massif slope. The deposits are constituted of conglomerates, sandstones and mixed arenites mostly belonging to deltaic and coastal deposits (Carobene & Damiani, 1985; Colella, 1988; Colella, De Boer, & Nio, 1987; Fabbricatore et al., 2014) and compare to the same coeval successions of other basins bordering the eastern and southern margins of the Sila Massif (Corbi et al., 2009; Longhitano, Chiarella, & Muto, 2014; Muto et al., 2015; Zecchin et al., 2012, 2013a, 2013b, 2015). Starting from Middle Pleistocene, northern Calabria experienced a marked uplift (Tortorici, 1981; Westaway, 1993) that caused the deformation of the Lower Pleistocene deposits and the accumulation of a 40 m thick succession of fluvial conglomerate well exposed in the western margin of the Crati Basin; a comparable stratigraphic succession is found on the eastern side of the Sila Massif (Corbi et al., 2009; Robustelli et al., 2009). A series of piedmont alluvial fans and marine terraces, are formed in response to the late Pleistocene uplift of the entire Coastal Range-Sila Massif and Crati Valley system. These deposits are carved into the substrate of the older successions of the Crati Basin infill, of the Tyrrhenian margin of the Coastal Range (Muto, Robustelli, Scarciglia, Spina, & Critelli, 2003; Robustelli, Muto, Scarciglia, Spina, & Critelli, 2005) and of the eastern Sila margin (Carobene, 2003; Ferranti, Santoro, Mazzella, Monaco, & Morelli, 2009; Molin, Dramis, Lupia, & Palmieri, 2002; Robustelli et al., 2009). Holocene alluvial fan deposits crop out in the Crati River valley and along the subsidiary transverse valleys.

4. Tectonic structures

The Crati Graben is a Pliocene-Holocene tectonic depression, mainly structured by N–S trending normal faults and filled by marine and continental clastic deposits (Figure 1). On its western and eastern sides, the graben is bounded by Palaeozoic crystalline-metamorphic rocks of the Coastal Chain and the Sila Massif horsts, respectively. Regional NW–SE normal left-lateral faults border the Crati Graben in the southern and northern margins (Tansi et al., 2007; Van Dijk et al., 2000). From a morphological perspective the faults are characterized by a remarkable 'freshness', by displacements of Quaternary deposits and are represented on the Main Map, together with structural data at the mesoscale.

4.1. N–S normal fault system

Morphologically, these faults are represented by sharp rectilinear escarpments, marked by active alluvial fans, bounding the uplifted footwalls. The mountain fronts reach elevations of about 700 m, and are characterized by 300–400 m high cumulative fault escarpments along which triangular/trapezoidal facets (70–100 m high) are found. An antecedent drainage network flows perpendicular to the fault segments; it is made of deeply entrenched canyons on the uplifted blocks, and of flat valleys on the down-thrown blocks (Tansi et al., 2005a; Tortorici, Monaco, Tansi, & Cocina, 1995). Along some fault scarps, broken ridges documenting also a transcurrent right-handed component of motion are recognizable.

At the mesoscopic-scale, fault planes strike from N160E to N25E, and dip 60°–80° mostly towards the west. The planes of this fault system are characterized by sub-vertical inclination and dip-slip to oblique slickensides: pitches indicate a lateral component of displacement, progressively evolving from strongly left to moderately right (see the Main Map). The meso-structural data indicate overall a direction of late extension oriented on average WNW–ESE.

4.2. NW–SE transcurrent and normal-transcurrent left-lateral fault system

The faults of the NW–SE-oriented system are characterized by transcurrent and oblique left-lateral kinematics, mainly dip towards NE, and present *mean* directions N120E (field variability N100E–N140E) and sub-vertical planes (average inclination 70°–80°). Furthermore, vertical displacements of these faults are significantly lower than those of the N–S and extremely variable, as evidenced by triangular facets and/or trapezoidal and by the cumulative fault scarps (height between 0 and 300 m). At the mesoscale, fault planes strike from N120E to N145E, and show sub-vertical dip mostly towards NE in the southern side (Carpanzano-Falconara, in Van Dijk et al., 2000) and dip towards SW to the northern Pollino fault. Planes are characterized by sub-horizontal slickensides documenting left-lateral transcurrent motions, supporting a direction of late compression oriented on average E–W.

4.3. Transpressive thrusts

The Mt. Cocuzzo and Mt. San Giovanni carbonate outcrops are two transpressional push-ups bordered by left-lateral trascurrent faults, penetrating the overlying Calabrian Terranes (e.g. Tansi et al., 2007).

The thrust ramps building the Mt. Cocuzzo push-up depict, as a whole, well-developed flower structures some of which portray positive flower structures (Figure 4).

At the mesoscopic-scale, transpressive thrust planes strike roughly NNE–SSW, and dip from 45° to 80° towards either E or W. Thrust planes show dip-slip to oblique slickensides, documenting reverse movements and a sub-horizontal σ1-oriented WNW–ESE (Tansi et al., 2007).

4.4. Ancient thrusts

In both the Mt. Cocuzzo and the Mt. San Giovanni push-ups, ancient thrusts – characterized by sub-horizontal planes striking E–W to WNW–ESE – were also recognized. These thrusts do not show any morphological evidence, and are documented only at the mesoscale (where they are commonly dislocated by the N–S oriented thrusts which build the push-ups). These planes display reverse dip-slip slickensides, documenting – if tilting is ignored – a N–S oriented sub-horizontal σ1: they can be related to the overthrusts responsible for the Oligocene-Early Miocene building of the chain.

5. Seismotectonics

The Crati Graben corresponds to the epicentral zone of significant instrumental ($3 > M > 5$, years 1983–2014 – after INGV) and historical earthquakes (Imax up to X MCS; after Boschi et al., 1995). As regards historical seismicity, the area was affected by six earthquakes with Imax = VIII–X MCS: five of them (occurring in 1184, 1767, 1835, 1854, 1870, and 1887) show

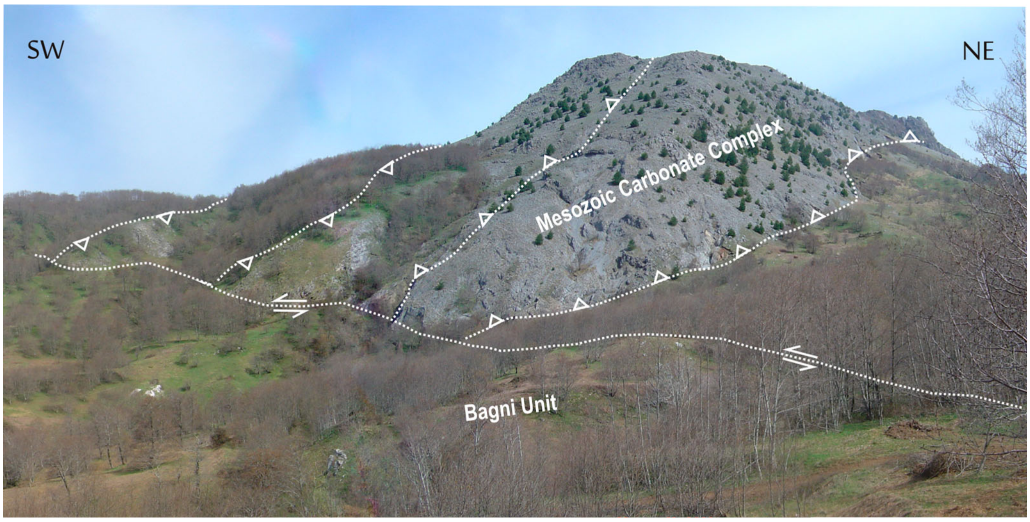

Figure 4. Panoramic view, from the south, of the Cocuzzo Mt. push-up (modified after Tansi et al., 2007).

epicentral areas located along the eastern border of the Crati Graben, and one earthquake (occurring in 1184, characterized by a more uncertain location) along its western border (Figure 1).

In particular, as regards the epicentres of the main shocks (cf. events of 1835, 1854, and 1870, Imax = X MCS, which were responsible for ∼800 deaths), these are located in the southernmost sector of the map, with a progressive migration towards the south. The axis of elongation of the macroseismic zones related to the above-mentioned earthquakes coincide with the principal (and most recent) N-S faults. As regards the earthquake of 1184, informations on the number of deaths and the epicentral area are very poor, although the fragmentary historical informations refer to a thousand victims (see Table 1).

Moreover, the focal mechanisms of 18 October 2001 ($M = 4.2$), 20 February 1980 and 28 December 2014 earthquakes (both $M = 4.4$) confirm, on the basis of fault planes solutions, the activity of N–S faults, while the focal mechanism of the 24 April 1996 ($M = 4.2$) earthquake points to activity of the NW–SE faults.

6. Gravitational and tectono-gravitational phenomena

The study area is characterized by the widespread instability of slopes. These phenomena, of various types and sizes (Cruden & Varnes, 1996), are determined by the particular geodynamic context that displays gravitational energy (produced by tectonic uplift occurring in the Calabrian Arc), the degree of fracturing of the rock types involved in the tectonic deformations and the particular structural styles predisposing the slopes to instability.

Table 1. Main historical earthquakes occurred in the study area.

Date of the earthquake	Epicentral zone	I_{max} MCS	Deaths
1184.05.24	Cosenza-Luzzi-Bisignano	IX	Thousand (?)
1767.07.14	Rose-Luzzi	VIII-IX	Hundred
1835.10.12	Castiglione Cosentino	X	115
1854.02.12	Donnici-S.Ippolito	X	500
1870.10.04	Mangone	X	117
1887.12.03	Bisignano	IX	20

As a result, the Province of Cosenza, in 2012, signed with the Research Institute for Hydrogeological Protection of the Italian National Research Council (CNR-IRPI) a Convention for mapping the geo-hydrology of risk areas. This study is part of the results of the Convention. The Main Map summarizes the efforts to integrate available databases with original surveying, trying to respect the original classifications. In particular, on the map were distinguished the following groups of gravitational and tectono-gravitational phenomena. *Slide*, *flow*, *fall*, *complex*, *deep-seated gravitational slope deformation*, *shallow landslide area*, *deep landslide area*, and, in addition, *area of erosion*.

In addition, landforms were distinguished based on the period of activation as follows:

- *Landslides activated in the period 2008–2012* that affected residential areas (with more than 200 inhabitants) and roads.
- *Landslides before 2000* affecting residential areas and roads collected by Basin Authority (BA) of Region of Calabria (Hydrogeological Plan For Soil Protection – PAI – of the Region of Calabria, Italy. Autorità di Bacino della Calabria, 2001). They are differentiated as *dormant* or *active*, and distinguished in the same typologies of the above class in addition to *Falls* and *Deep-seated gravitational slope deformations* (*DGSD*).
- *LL, gravitational and tectono-gravitational slope deformations* (after Autorità di Bacino della Calabria, 2001; Sorriso-Valvo & Tansi, 1996; Tansi, Iovine, & Folino Gallo, 2005b). They are

distinguished as *Slide*, *flow*, *complex*, *LL*, *Sackung* (SK), and *lateral spreading* (LS).

- *Deep-seated gravitational and tectono-gravitational accommodation wedge* (Gravity-accommodated structural wedges, GASW, Iovine & Tansi, 1998)
- *Tectono-gravitational trench* (Iovine & Tansi, 1998; Sorriso-Valvo & Tansi, 1996).

The following tables summarize the results of statistical analysis on the different types of the analysed mass movements. In particular, Table 2 shows the statistical data on the landslides activated in the period 2008–2012, with 2440 landslides in total (area: 27.5 km^2), of which the most frequent typology is 'slide' (1433), while the more extensive are the 'landslide areas', involving both 'shallow landslide areas' and 'medium-deep landslide areas' (Autorità di Bacino della Calabria, 2001). Of this total, 91.3% of landslides (2228 over 23.88 km^2) affects the Crati Graben; these landslides are, on the whole, rather widespread along its two margins, in correspondence with the main faults responsible for the tectonic contact between the Palaeozoic-Mesozoic rocks of Coastal Chain and Sila Massif horsts and the Plio-cene-Pleistocene sedimentary deposits filling the Crati Graben. It also evidences the control of faults on the distribution of landslides: 51% (1243) of the landslides originate in the cataclastic bands associated with the main faults, that were localized on their footwall and estimated to be 300 m thick. The landslides occurring along the western edge of the Crati Graben occupy an area about three times greater than the eastern edge (16.88 km^2 versus 7.0 km^2), although the total number of phenomena are similar (1135 versus1093 landslides).

A comparison of the data collected by the BA of the Region of Calabria – relating to information prior to 2001, shows a large number of landslides activated in the period 2008–2012 (1513 for a total area of 15.12 km^2) affecting areas classified by BA as dormant landslides. In other cases, some landslides indicated by BA as having significantly increased their surface area (927, 38 %) with recent landslides occurring in areas not surveyed by BA.

Table 2. Statistical data on the landslides activated in the period 2008–2012 (total area of the map: 2039.7 km^2).

Type of movement	n. Landslides	% Landslides	Area (km^2)	% Area
Slide	1433	58.65	9.06	32.85
Flow	220	9.00	1.60	5.80
Complex	172	7.10	3.20	11.60
Shallow landslide area	557	22.80	8.70	31.65
Deep landslide area	21	0.85	4.40	16.10
Area of intense erosion	37	1.60	0.54	2.00
Total	2440	100.00	27.50	100.00

Table 3. Statistical data on the LL and gravitational and tectono-gravitational slope deformations (total area of the map: 2039.7 km^2).

Typology	n. Phenomena	% Phenomena	Area (km^2)	% Area
LL	30	34.00	56.65	28.30
GASW	35	39.80	84.35	42.00
SK	21	23.90	36.50	18.20
LS	2	2.30	23.15	11.50
Total	88	100.00	200.65	100.00

Table 3 shows the statistical data on the LL and gravitational and tectono-gravitational slope deformations: LL, GASW, SK and LS.

These phenomena are found along both the western and eastern borders of the Crati Graben, where high relief energy and steep slopes are commonly associated with severe tectonic fracturing, such as deep weathering profiles of crystalline rocks (e.g. Borrelli, Perri, Critelli, & Gullà, 2012, 2014; Borrelli, Critelli, Gulla, & Muto, 2015a; Borrelli, Coniglio, Critelli, La Barbera, & Gullà, 2015b). A total sample of 88 phenomena (LL, GASW, SK, and LS) were recognized and depicted on the map involving 200.65 km^2 corresponding to 9.85% of the surveyed area. These tipologies of phenomena are generally developed within the pre-Miocene bedrock outcropping in the footwall of the major faults (i.e. Coastal Range) and are bounded by N–S or NW–SE normal faults or transpressive thrust ramps.

7. Conclusions

The Crati Graben is mainly controlled by extensional N–S striking faults and WNW–ESE transcurrent faults at its northern and southern end. The comparison of the data testifies to a correlation between tectonic structures and areas affected by landslides. The recent and active faults were compared with historical and instrumental seismicity, in order to identify the main seismogenic structures. In historical time, numerous severe crustal earthquakes (VIII–X MCS) occurred in the Crati Graben; present seismicity confirms its seismogenic character related to fault activity dominantly into the eastern margin of the basin. The seismological, geo-structural and geomorphological analysis was performed in a geographic information system. In conclusion, we produced an updated knowledge framework of risk conditions of the whole province, where the risk areas are hierarchically classified according to the destructive potential of landslides. The large-scale seismotectonic and landslides map may represent a useful tool for territorial engineering-geological planning and Civil Protection.

Software

The topographic basemap, the landslide inventory map and related layout were drafted using the software open source QGIS. Data collected, using previous geological and geomorphological information, air photo interpretation, topographic maps and field survey, were georeferenced and digitized and a database containing attributes of the main features observed was created for each mapped landform. Adobe Illustrator CS3/CS4 was used to produce the final layout of the map.

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