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BLOCK STRUCTURES (RESTRAINING BENDS) AND GREAT LANDSLIDES IN THE COASTAL AND IN POLLINO CHAINS (NORTHERN CALABRIA – SOUTHERN ITALY)

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EXTENDED ABSTRACT

Vengono individuate e descritte alcune strutture di blocco presenti lungo le faglie con deboli trascorrenze che attraversano la Catena Costiera (Calabria tirrenica settentrionale) da SW a NE (Fig. 1) utili soprattutto nel settore sismico. Qualcuna di esse è particolarmente interessante anche per possibili ricadute sismiche nei confronti della diga di Roggiano (Figg. 1, 10 e 13), una delle più importanti opera idrauliche in provincia di Cosenza. A dette strutture sono associate numerose DGPV e grandi antiche frane sia nelle metamorfiti delle Unità Alpine (Figg. 4, 8, 11 e 12), che nell'Appennino Calcareo (Figg. 14, 15, 16, 17, 18, 20 e 21) (Guerricchio & Melidoro, 1979; Guerricchio, 1982; 1985; 1986; 2014). Un accenno viene pure fatto alla struttura tettonica della Catena del M.te Pollino (Guerricchio, 1981, Guerricchio *et alii*, 1996) (Figg. 20 e 21). Nella Catena Costiera parecchie sono le faglie trascorrenti in prevalenza sinistre, che da sud-ovest a nord-est l'attraversano trasversalmente al suo asse diretto ca. N-S, (Figg. 1 e 7), frutto delle spinte da sud delle falde di ricoprimento, nonché, relativamente alla struttura dell'"Orsomarso", pure da NE a SW (Ogniben, 1973; Guerricchio & Ronconi, 1998) (Fig. 1). Esse rappresentano linee potenzialmente sismogenetiche, seppure la loro limitata lunghezza dovrebbe costituire un carattere di relativa tranquillità sotto quest'aspetto. Anche perché la loro geometria mostra andamenti curvilinei che creano incastri o "imbottigliamenti" (Figg. 2 e 3) non agevolanti gli scorrimenti a componente orizzontale e quindi la generazione di terremoti (Guerricchio, 1981; 1982).

Associate a tali strutture tettoniche si accompagnano spesso DGPV e grandi antiche frane, anche in terreni lapidei, la cui genesi è di difficile attribuzione facendo riferimento solamente alla forza di gravità (Guerricchio & Melidoro, 1996; Guerricchio & Ronconi, 1998; Guerricchio, 2014). Su tali corpi, talora di ciclopiche dimensioni e volumi, ricadono numerosissimi centri abitati, che, è intuitivo, saranno soggetti a subire gravissimi danni nei prossimi sismi, poggiando su strutture non radicate (quali appunto sono le DGPV e le grandi frane), che potranno entrare in risonanza ed accentuare quindi le energie delle scosse sismiche (Guerricchio & Melidoro, 1996; Guerricchio, 1982). Nel lavoro vengono esaminate le principali strutture trascorrenti, lungo cui si impostano e si sviluppano i bacini idrografici ai quali si farà riferimento (Fig. 3). In precedenti lavori sulla Catena Costiera, caratterizzata sotto l'aspetto geologico da formazioni carbonatiche di piattaforma giurassico-cretacee e da unità metamorfiche di alto grado (gneiss e scisti biotitici) (CGC, 1970; Ogniben, 1973; Guerricchio & Ronconi, 1997), questi ultimi poggianti su metamorfiti di basso grado (filladi) paleozoiche, di derivazione alpine, viene accennata talora una situazione strutturale di "incastro" dei labbri lungo le faglie trascorrenti. Tale condizione richiama la struttura indicata come "curva di imbottigliamento" (*restraining bend* – Crowell, 1984), cui segue la curva di rilascio (Fig. 2). Dal successivo movimento ed evoluzione di quest'ultima, poi, si forma un bacino di *pull-apart* (Crowell, 1984; Guerricchio, 1981). Dove la curvatura di una faglia trascorrente è pronunciata, la zona incurvata che separa i labbri delle faglie viene sottoposta a distensione (tensione) o a compressione (Figg. 2 e 7). Il riconoscimento delle strutture di imbottigliamento nella Catena Costiera è di notevole utilità in diversi settori di ricerca, da quello della meccanica delle rocce, della sismologia, delle misure degli spostamenti crostali, con ricadute pratiche anche nel settore della Protezione Civile (Guerricchio & Zimmaro, 2000; Fortunato *et alii*, 2001). E' pertanto utile, in un'area attiva sotto l'aspetto sismico, nella quale ricadono important centri abitati ed infrastrutture anche di rilevanza interregionale, pore l'attenzione sulle deformazioni meccaniche delle rocce, nonchè monitorare gli spostamenti connessi con fenomeni di compression e di distensione in atto anche mediante misure di Interferometria Spaziale da integrarsi con quelle GPS (Guerricchio & Zimmaro, 2000; Fortunato *et alii*, 2001; Guerricchio *et alii*, 2009 e 2014). Associate a tali ricerche vanno pure svolte misure sugli spostamenti per cause gravitative delle DGPV e delle grandi frane presenti su ambo i versanti della Catena Costiera, finalizzate anche agli studi sull'erosione costiera e ai maremoti così importanti in generale e in Calabria in particolare (Guerricchio, 1989; Guerricchio *et alii*, 2005). Dette deformazioni, infatti, per le loro dimensioni planimetriche e profondità delle superfici di scorrimento, sembrano strettamente connesse all'attività tettonica regionale. Un accenno viene pure fatto alla Catena del Pollino, ove, a seguito del suo innalzamento sono state "scaricate" verso sud e verso nord le unità Liguridi e Sicilidi (Ogniben, 1973) insieme ad altre unità flyschiodi, generalmente tutte in lento movimento tettonico-gravitativo verso la confinante Basilicata e la Calabria Jonica (Figg. 20 e 21).

ABSTRACT

Some block structures present along the faults with weak transcurrent components, crossing the Coastal Chain from SW to NE, due to pushes from south by thrust nappe, especially useful in the seismic field, are identified and described. Some of them are particularly interesting for possible seismic relapse towards the Roggiano Gravina dam, one of the most important hydraulic works in the province of Cosenza. Associated with these structures, there are numerous DSGSDs and large ancient landslides, both in the metamorphic of the Alpine units and in the limestones of the Apennines that distinguish the territory. A hint is also made to the tectonic structure of M.t Pollino Chain, with ancient movements of units with a plastic mechanical behaviour (Liguridi and Sicilidi Units) (Ogniben, 1973) towards N and S in consequence of its raising.

Keywords*: Northern Tyrrhenian Calabria, Coastal Chain, restraining bends, DSGSD and large landslides, Coastal erosion, Pollino raising*

REFERENCES TO BLOCK STRUCTURES

A large number of left transcurrent faults cross the axis of Coastal Chain (Northern Tyrrhenian Calabria) directed approximately N-S, from west to east. They represent potentially seismogenic lines, though their limited length should be a feature of relative tranquillity in this regard, also because their geometry shows curvilinear trends that create joints or "bottling" not facilitating the horizontal component of sliding and thus the generation of earthquakes (Figures 1 and 2).

These tectonic structures are often accompanied by DSGSDs and large ancient landslides, even in rocky terrains, whose genesis is difficult to attribute only to gravity. On such bodies, sometimes of cyclopian sizes and volumes, there are a lot of inhabited centers which, it is intuitable, will be subjected to severe damages in case of seismic crises. They are located on rootless structures (such as DSGSDs and large landslides), which may get into resonance and thus accentuate the energies of earthquake shocks. Here the description of the main transcurrent structures along which the river basins to which they will refer follows (Fig. 3). Some of the gravitational phenomena associated with them are also reported by Sorriso-Valvo (1988). Past works on the Coastal Chain, characterized for the geologic aspect by the carbonate formations of the Jurassic-Cretaceous platform and high - grade metamorphic units (gneiss and biotitic schists) resting on Paleozoic low - level metamorphic rocks (phyllades) of alpine derivation (Ogniben, 1973), sometimes report at a structural "joint" the situation of the edges along the transcurrent faults (Figures 1 and 2) (Guerricchio, 1975; Guerricchio *et alii*, 2012).

This situation refers to the structure indicated by Crowell (1984) as a "restraining bend", followed by the release curve (Fig. 2). From the subsequent movement and evolution of the latter, then, "pull-apart" basin shapes (Fig. 2), (Crowell, 1984, Guerricchio, 1986). Where the curvature of a transcurrent fault is pronounced, the bending zone separating faults edges is subjected to extension (tension) or to compression (Fig. 2).

Fig. 1 - The Coastal Chain (between the Crati Valley and the Tyrrhenian Sea) and Pollino Chain (arrow in the background) seen from the south. In the first there are some transverse breaks, constituting left transcurrent faults, that detach their axis with the direction of about N-S direction and that, particularly level with the Esaro and Cetraro watercourses (long arrows), tend to be shifted towards W. The horizontal small arrow in the upper part of Coastal Chain points out the "Orsomarso" Chain. Coordinates: 39°58'55.26"N15°20'26.56"E;40°09'55.59"N16°43'40.60"E; 38°59'02.39"N16°43'07.46"E;38°56'38.99"N-16°07'24.86"E

The compression forms a topographically elevated zone due to crustal shortening, marked by folds and inverse faults. The traction, as mentioned, results in a depression due to extension, known as a pull-apart basin. The pull-apart basins develop and expand in the same direction as the fault movement (Crowell, 1984; Guerricchio, 1982).

The structure of Cozzo Telegrafo (1.131 m a.s.l.), in the downward movement towards E following the push up of M. Cocuzzo, moves towards E and SE, almost as a domino effect, respectively the structures of the Scudiero (1.295 m) - Serratore (1.233 m) and Lucerne (1.256 m) mountains. Their displacement is also accompanied by an anti-clockwise rotation for the earlier (Scudiero and Serratore) and clockwise for the latter (Lucerne), converging both toward the Savuto River depression, which has a "recall effect towards the void" (appella au vide) (Figs 1 and 3).

The bending curves, due to the presence of mechanically weaker bands in the lithospheric masses and / or to the components of the inclined or orthogonal pushes with respect to the surfaces of the faults themselves or to the rotational movements of one of the two transcurrent blocks, create a succession of convergence alternating with others of divergence zones. In the rocky masses on the two sides of the faults themselves, therefore these surface evolutions cause mechanisms typical of convergent and divergent zones (Fig. 2). In the Coastal Chain the transcurrent faults are related to pushes which, starting from the south, have originated tectonic deformations directed from SW to NE, then from east to west, as well as for the structure of the "Orsomarso", also from NE to SW (Figures 1 and 2).

EXAMINATION OF SOME TRANSCURRENT FAULTS WITH EVIDENCES OF "BLOCK STRUCTURES"

In order to highlight the main transcurrent structures in the Calabrian Coastal Chain, it is useful to draw on the route of the river basins in the opposite sides, those to the east of the Chain, facing the basin of Crati River and those exposed toward the Tyrrhenian Sea, showing conforming alignments compared with the major tectonic pusher suffered by the Chain itself (Figs. 1 and 3). From the south to the north, this important structure at first increases gradually, then more and more evident its dislocation toward the Tyrrhenian Sea, losing, especially along the junction Bagni Torrent-Follone River, its previous NS axial alignment (Figs. 1 and 3a). However, by not examining all the configurations of transcurrent faults and block structures, later on we examine some shown by Fig. 3. Starting from the south, going beyond the Savuto River, a first fault with block structures (or curves of "bottling") is perceptible in the geologically complex structure between the basins of the Oliva and Busento rivers (Fig 3b).

Oliva Torrent-Busento Torrent

The valleys of the Oliva and Busento rivers, whose average axes are oriented SW - NE and NNE - SSW respectively, separate the structure of the Serratore M.t (1.238 m) - Lucerna M.t (1.257 m) from that of C. zo del Telegrafo (1.131m), at its turn detached from Cocuzzo M. from the valleys of Catocastro River at SW and from the left tributary of Busento River toward NNW (Figs. 1 and 3).

The movement of these structures could have produced the possible closure of the continuity zone between the Crati River valley and that of Savuto, the accentuation of the curvature of its main river course, pushed, as said, towards E and SE and the rise, for push from below ("leverage effect" in Guerricchio & Simeone, 2016), of Piano Lago, Piane Crati, etc. areas, up to the altitude of 643 m a.s.l., resulting in the compression of these structures towards the reliefs of Carpanzano, Marzi, Rogliano, Mangone, Aprigliano, Pedace (Fig. 4). In fact, it is noted that at the front of the reminded structures, the Iassa Torrent, left tributary of the Albicello Torrent, is setting into a very large slide gravitational

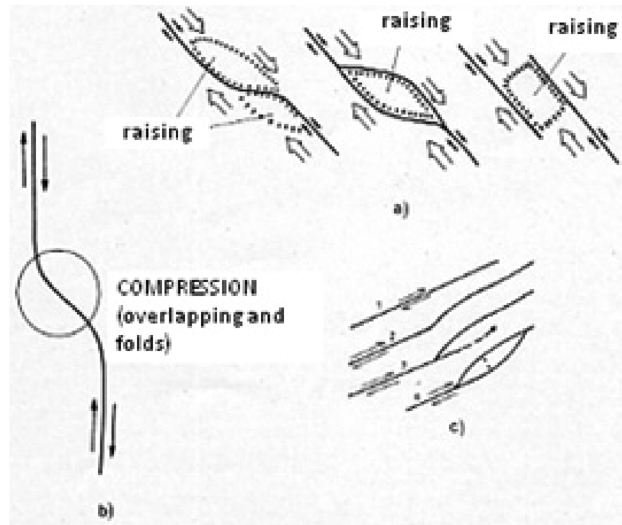

Fig. 2 - Structures that develop along the right transcurrent faults in correspondence of a double curve: a) elevations due to compression; b) overlappings and folds; (c) pull-out basin in the extension and deformation with raising in those areas of compression (after Crowell, 1974)

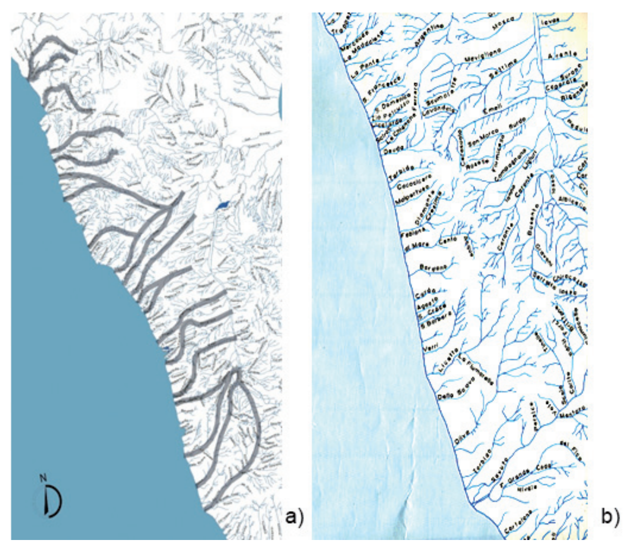

Fig. 3 - The hydrographic net of the Coastal Chain. In griseè, the water streams flowing on the opposite sides of the Coastal Chain are highlighted, in which there are "blocking structures" consisting of curved and counter curved stretches (a). In (b) the partial enlargement of the southern Coastal Chain river basins

rupture directed towards NS, detached from the eastern side of the Serratore M.t (1.233 m), with an average length of about 3 km and width of not less than 6 km (Figs 1 and 4).

In some traits they show curvilinear developments similar to "bottling" curves, concave to NW in the first and towards E and S in the second. In the Oliva Torrent basin dominate the medium - upper Miocene terrains, consisting of sandstones, conglomerates and sands (Geological Map of Calabria, 1969),

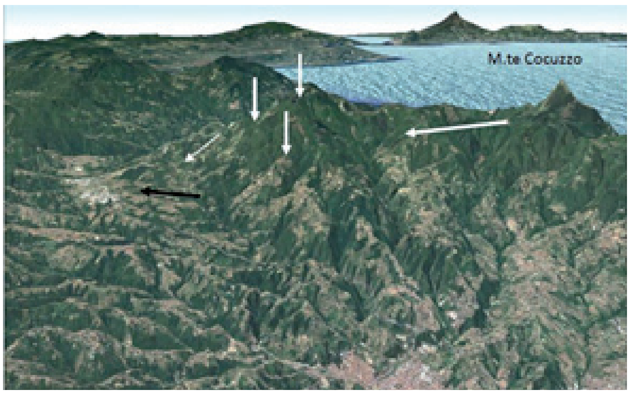

Fig. 4 - *Possible closure of the continuity zone between the Crati and Savuto river valleys, resulting from compression of Cocuzzo's M.t push up (long arrow), with "discharge" and landslides (small arrows) towards E (i.e. reliefs of Marzi, Rogliano, Mangone, etc.) and rise from the bottom of the conglomerates with sand, even continental, Calabrian (?) in the area of Piano del Lago, Piane Crati (dark arrow) etc., up to the altitude of 643 m. In the foreground, beyond the town of Cosenza, the deep grooves, with a NNE-SSW and N-S orientation, still attributable to the Cocuzzo push up, later elaborated by the late Quaternary erosion processes. Carpanzano, Marzi, Rogliano, Mangone, Aprigliano, Pedace towns are situated on the left side of the picture. The image is deformed 3 times in heights. Coordinates: 39°16'00.53"N-16°08'46.20"E;39°18'45.90"N-16°12'37.34"E;39°17'32.79"N-16°19'34.34"E;38°36'05.67"N-16°28'17.34"E*

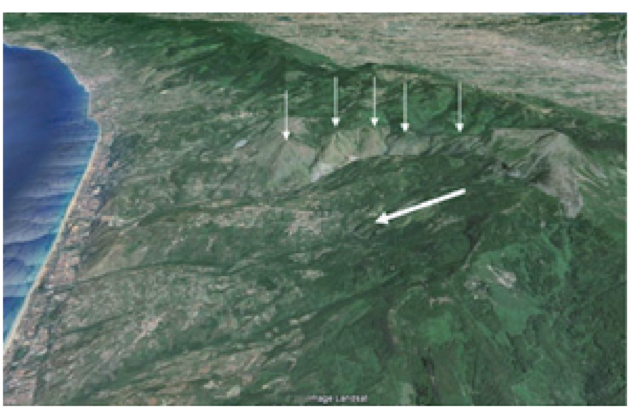

Fig. 5 - *Cocuzzo M.t from south; The DSGSDs (evolving very slowly) in Alpine units, as well as the gravitational sliding of the dolomitic right flank (small arrows), originated from the push up of the Apennine carbonate can be recognize. To note, in the lower middle part, the "plastic" phyllite masses, with bulgings by macro - "slumping-sliding" mechanism, involved in slow progression towards the narrow coastal strip, on which Longobardi, S. Barbara and Belmonte Calabro towns rest. Coordinates: 39°30'29.56"N-15°57'43.60"E;39°29'42.22"N-16°20'12.51"E;39°11'25.51"N-16°08'49.0"E;39°12'03.95"N-16°03'46.55"E*

resting on a relative base of alpine units of low and very low metamorphic degrees. These latest lithologies continue in part in the neighboring river basin of Busento Torrent, where the high Miocene lithologies and the middle high degree metamorphites

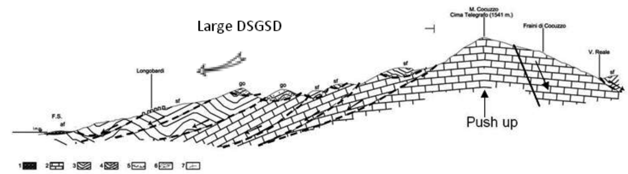

Fig. 6 - *Geological section between the peak of Cocuzzo M.t and the town of Longobardi, with the highlight of the impressive DSGSDs that characterize its western side; the eastern one is as well seat of large gravitational deformations, with compressions of "plastic" phyllite units and unblocking (faults) in those of medium to high metamorphic degree (see Fig. 4). 1. Littoral deposits; 2. Dolomites and limestones; 3. Phyllites; 4. Gneiss; 5. Biotite schists; 6. Slip surface; 7. DSGSD direction*

along with acid intrusive rocks outcrop.

Between the two valleys, however, it seems to be no "block structures" that must have been erased, where ever they could exist, by the great gravitational deformation of Serratore M.t, in turn modified and moved toward E from the Cocuzzo push up.

It is also obvious that the date of the great instability phenomenon dates back to Piano Lago pre-lake deposits, i.e. to late Pleistocene and post conglomerate deposits attributed to Calabrian age (Geological Map of Calabria, 1969). On the Tyrrhenian Seaside, the push up of Cocuzzo M.t determines the wide and deep DSGSD with very slow evolution, in which there are the built-up areas of Longobardi, S. Barbara and Belmonte Calabro, as well as other smaller urban conglomerations (Fig. 4). The units involved in gravitational deformation belong to the Castagna and Diamante Terranova Units (Bonardi *et alii*, 1976), with the usual tectonic overlay of the most resistant and heavy lithologies (the gneiss) on the weaker ones (the phyllades and the calcischists), all resting in the depth on the dolomites and the limestones of the relative basement of Cocuzzo M.t (Figs 5 and 6).

T. Licetto -T. Charon

Both basins show a predominant SW - NE orientation with hints on curvilinear structures with curves and counter curves, whose concavity is south and north for Licetto and towards east and south for Caronte torrents. Licetto, which has a significant part of its basin at Cocuzzo's feet, has its estuary at Amantea. It develops (always considering its going uphill) with a wide arch path in low-grade metamorphites, with concavity to the north. At the end of this stretch of a wide arch path, between C.zo Burrara (921 m) and C.zo Pescato (974 m), there are large, active slidings, although they are also missing in the rest of the valley, always going uphill, as in the case of the great sliding-flow originating in the southern slope of C.zo Serralto (1.129 m), always in phyllites. Further on La Serra dei Moli (1.047 m), the Licetto valley joins the upper part of Caronte Torrent, still in phyllites, defining a slightly straightened structure, with SW-NE orientation, with which the low middle section of Caronte River reaches Cosenza, where it forms a concave bow to the south, almost certainly a "bottling curve", producing compression and extension structures respectively at south and north of it.

Cento Acque Torrent - Caronte Torrent

The first valley, starting from Fiumefreddo Bruzio village in the direction W-E, crosses the first masses of low-medium degree metamorphites and then it develops along the limestones of Cocuzzo M.t, lowered by gravity (to the right Cento Acque River), where a first double bottling curve (predominantly with bend to the south - dello Sperone M.t) outlines, to proceed still in metamorphites to the ridge (Fig. 7). From here the valley of Cento Acque T. "joins", through a curvilinear structure more marked with convexity to the north, in Caronte T., which in its middle part flows from S-W to N-E, and only in the Cosenza area, after crossing coherent sediments and low-medium degree metamorphites, still involves the coherent soils in the Cosenza Castle hill with a large concave arch to the south, which can still be interpreted as a block curve (Figs 3a, 7b), with compressive structures in that sector.

FabianoTorrent - Emoli Torrent

Starting from the coast, the two valleys develop along a first important left-handed fault that begins in the Falconara Albanese territory in low-grade metamorphites involved by Cocuzzo's pushes, and then affect higher degree metamorphites and sediments of Crati River, touching Arcavacata village and ending in the Quattromiglia area (Fig. 7). The bottling curve is included in the high parts of Fabiano and Emoli valleys in the area of Londro C.zo (1.157 m), where the presence of particularly cataclastic rocks document the wide friction band of the transcurrent movement (Fig. 7).

On the side of the Coastal Chain facing the Crati Valley, behaviors can be differentiated in gravitational movements: the first concerning the blockage at east of the reliefs of Martinella M.t (1.100 m a.s.l.) and its southern tops, from which the great landslides of the S. Angelo graben, between this structure and that of Cozzo Tunno, Timpa di Taccio, Cozzo Coscarello (respectively 1.007, 1.015, 1.044 m a.s.l.) (Fig. 7). It is set along the NNE-SSW oriented left-hand side, which runs along the "Mandrone" waterways in the southern section and Manganaro and Emoli in the north. In the aforementioned graben there are some enchelon structures, such as, for example, that of "la Serra delle Fraine" locality (997 m s.l.m.) and numerous large landslides involving Miocene plastic soils, as well as the metamorphites of its base. All the remaining metamorphic bodies are involved by deformations attributable to gravitational scissor tectonics, with partial rotations of the masses in a clockwise direction.

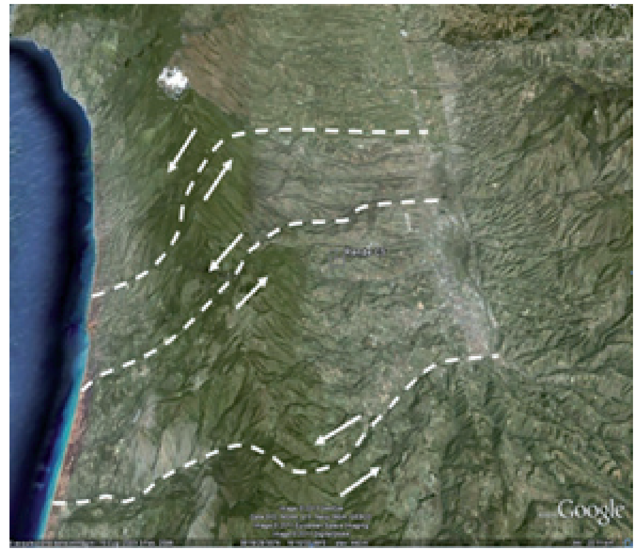

Fig. 7 - The image highlights three important transcurrent faults, the first with a direction WE-NW-SE, the second and the third NNE-SSW, interrupting the continuity of the Coastal Chain axis (N-S); the first one originates in Fiumefreddo Bruzio town and along the Caronte Torrent goes to Cosenza (below the Castle); the second begins in the territory of Falconara Albanese and goes to S. Fili and S. Vincenzo la Costa-Montalto Uffugo towns; the third goes from the territory of Paola and leads to San Benedetto Ullano village. All show "restraining structures". Coordinates: 39°13'59.45"N-16°03'31.09"E-39° 32'48.98"N-15°52'39.73"E;39° 31' 13.55"N-16°23'29.66"E; 39°11'38.16"N-16°18' 59.59"E

The aforementioned movements should be attributed to the remarkable lateral expansion towards the Crati Valley of the metamorphic masses of the Coastal Chain (Fig. 7). In fact, at least three structural elements, at the same time parallel to each other, with N-NE-S-SW oriented axes are observed, in which the high parts of the Emoli and Cerasuolo streams are set. The fulcrums of these scissor breaks can be found just north of Mezzotumolo Cozzo (1.155 m a.s.l.) and at Crocicchio Cozzo (1.002 m a.s. l.). The eastward movements of the relative basement were then transmitted to the tertiary deposits filling the depression of the Crati Valley, which are in tectonic contact with this latter, already crossed by a paleo hydrographic pattern of consequent type. In this extended body of sediments, therefore, gravitational slides, partial rotations, trenches and possible lifting in its foot band have been produced, resulting in a consequent slow transfer of Crati's axis more and more to the east, i.e. at the base of the western slope of the Sila block, where erosion and instability phenomena have been increased in general (Fig. 7). To favor these slow gravitational movements the presence at the base of plio-quaternary soils of the upper Miocene (Messinian) silty, marly and silts formation, with interlaces of marls and violet silts, sometimes laminated, by poor mechanical strengths has contributed a lot. An example of this phenomenon, albeit at a

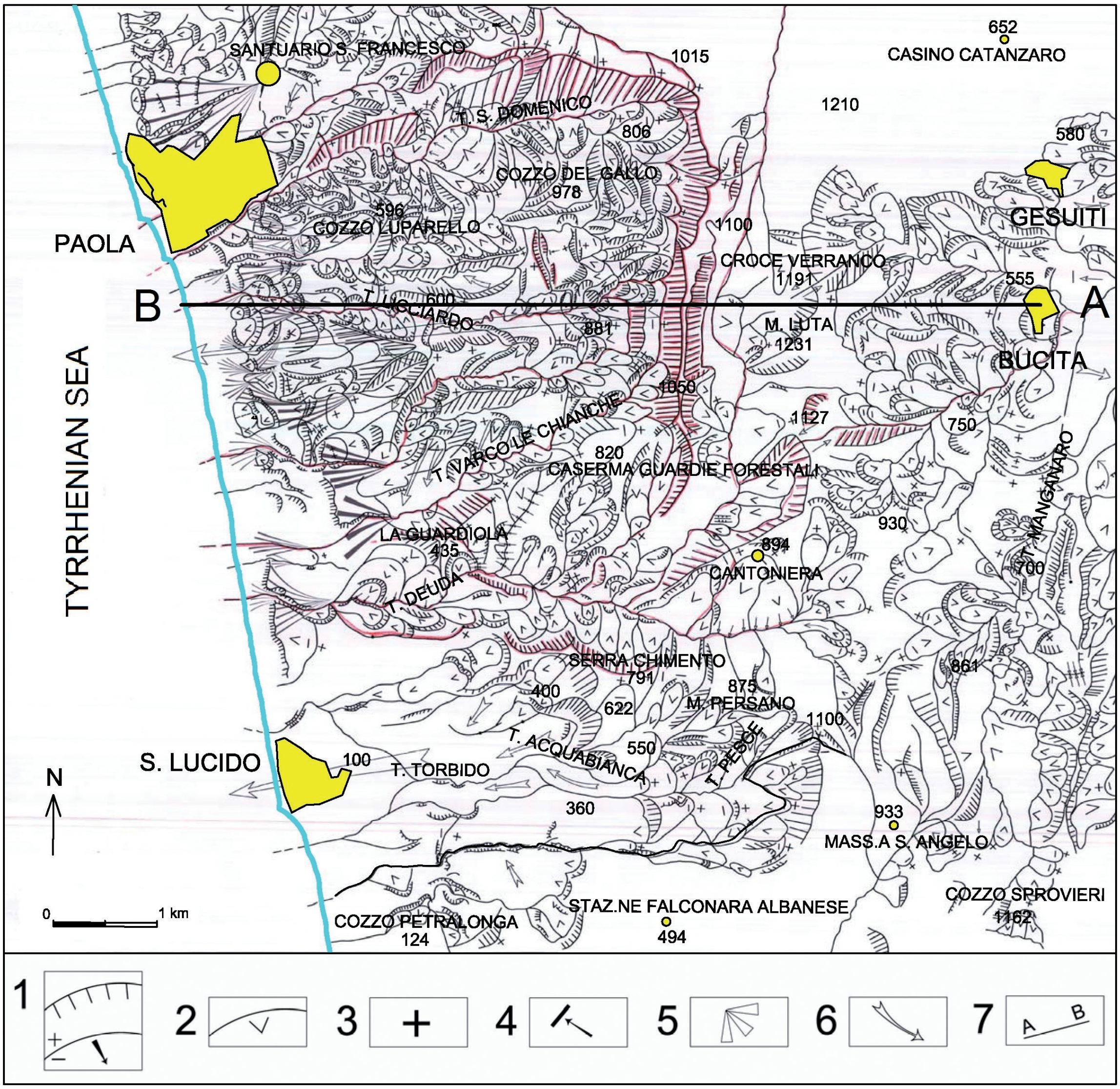

Fig. 8 - Geomorphological map of the Coastal Chain between Bucita village (at east) and the coast of San Lucido and Paola (to the west), directed to deep gravitational phenomena. 1. Scarp, DSGSD rupture and rototraslation sliding direction (the sign – points out the lowered part); 2. More "superficial" sliding; 3. Bulgings due to upstream pushes; 4. Tiltings; 5. Alluvial fans; 6. Main directions of gravitational displacement in the opposite slopes. 7. Section line. Coordinates:39°22'43.35"N16°01'24.30"E;39°22'27.16"N-16°07'55.58"E;39°14'49.24"N-16°08'37.18"E; 39°17'30.83"N-16°03'09.39"E

very small scale, is the active one in the extensive hill of Marano Marchesato (Cosenza province) (550 m a.s.l.) (Fig. 7), which in its predominantly NNE movement deviated the upper part of SurdoTorrent at least of 400 metres during the Holocene, causing foot-footing and strong erosion in the southern slope of the Rende hill (CS), which is undergoing to a slow but continuous uphill backing, i.e. towards the inhabited area.

Deuda Torrent-Mavigliano Torrent

Among the basins of Deuda and Mavigliano streams, the transcurrents, almost certainly in close correlation with the Cocuzzo's push up, create remarkable restraining bands structures both in the upper part of the first, e.g. in Leuta's M.t Vallone, and in the second, in the Argentine V.ne, high part of the Mavigliano stream (Figures 3 and 7). In the latter, in the concavity zone south of Vaccarizzo village, compressive structures in medium-low Pliocene conglomerate-sandy and clayey are generated, with small inverse faults. In San Lucido territory, the left transcurrent faults, with their movement towards ENE (i.e. to the Crati Valley), determined the detachment of the masses on the back of the so moved Coastal Chain portion, displacement of about 8 km in the WE and 3 km in SN components for the one that runs along the

Busento River and 3 and 1.5 kilometres for that flowing in the Malpertuso of the Martinella M.t (1.100 m a.s.l.), Persano M.t, etc. block (Fig. 7). The further loss of contact of San Lucido block, detached from the middle-low side of the Persano - Martinella mountains slope, is due to the displacement of the Coastal Chain portion in Fig. 7. Also on this side of San Lucido the ancient deep gravitational breaks, strictly related to the abovementioned transcurrent tectonic, are highlighted by numerous trenches, at the bottom of which Miocene deposits are covered by Holocene-Pleistocene continental sediments of lacustrine and colluvial origin. The so-disarticulated crystalline masses are currently involved in gravitational movements of lateral and sloping spreads, which are also observed in transgressive, conglomerate, arenaceous and calcareous Miocene formation, while numerous are the multiple rotational landslides in the Pleistocene conglomerate formations in the medium-low slope, including Miocene limestone blocks (Guerricchio *et alii*, 2012). Also to these last gravitational movements the remarkable extension of Pleistocene continental conglomerate outcrops is due, which, having been displaced in the kilometric order, are therefore largely not in place.

The movement towards NNE, with a slight left-hand transcurrence of the block east of S. Lucido (Fig. 7), has resulted in the removal of the same in the Tyrrhenian coast, which must have followed a "release" of rock masses, among which Martinella M.t. From the western portions of this latter, the extended releasing of the rocky limestone body must have been the last act of such releasing, on which the San Lucido town will be built (Fig. 7).

The crowning and the main scarp of the great ancient landslide, within the most general gravitational deformation, affect the western slopes of Martinella M.t (1.100 m a.s.l.), starting from the 1.800 metres a.s.l. (Fig. 7).

Even in this "come down" it is noted that the breaks of its lateral sides, real "tracks" along which it moves towards the coast, were subsequently occupied by some streams such as Malpertuso, Torbido and Deuda torrents, with an about EW trend, far away from each other, in the area near the coast, 4 km approximately. The latter value, therefore, represents the mean transverse dimension of the body of the slope deep gravitational deformation, within which, as mentioned, the large ancient landslide, with a mean width ranging from 2 to 3 km, develops (Fig. 7). The continuation of the gravitational movements of the slope towards the sea is producing a progressive thinning of the coastal strip until its substantial disappearance (Fig. 7), generating in many points stability and integrity problems to the infrastructures of the area, such as the Lower Tirrena Road. N. 18 and the Railway Reggio Calabria-Naples (Fig. 7), as well as to densely urbanized areas close to the coast but also developed throughout the gravitational deformation body. In a recent past, the Paola-Cosenza old railway line had to be abandoned due to the strong deformations in the Falconara Albanese Station tunnel and the ever-evolving series of ruptures on the northern shoulders in the long 12 - spans bridge, involved by NNE tangential thrusts (Guerricchio & Ronconi, 1997).

The San Lucido area is a clear example of a "continuum" between neotectonic breaks, DSGSDs, large landslides and in the true sense landslides, whose mobility degree is increasing from the first to the last; the opposite is true for the maximum depths of the discontinuity surfaces.

The same macro slidings phenomena on both sides of the Coastal Chain, just north of S. Lucido, refer to the phenomena mapped in the geomorphological map (Fig. 8) and the relative geomorphologic section (Fig. 9).

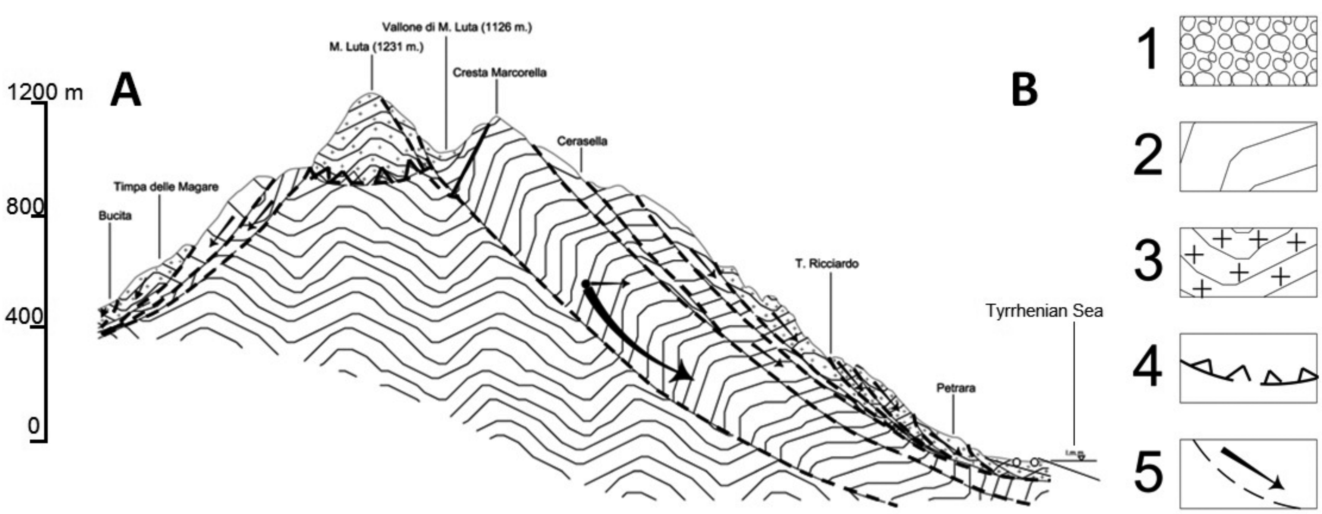

Fig. 9 - Schematic geological section of DSGSD of the Coastal Chain between Bucita village and the coast. 1. Conglomerates and sands - Late Pleistocene; 2. Muscovite schists - Paleozoic; 3. Gneiss and biotite schists - Paleozoic; 4. Tectonic superposition; 5. Gravitative ruptures due to DSGSD and movement direction

Fig. 10 - The clear left-handed transcurrent fault (arrows), where Triolo Torrent to SW and Esaro River to NE are setting out, producing the great opening of Fagnano Castello eastern territory, undergoing the Pizzo M.t -724 m anticlockwise movements and clockwise to the west the S. Marco Argentano reliefs (Bucita M.t - 684 m and Chiaraia M.t - 678 m). The fault goes to the Roggiano Gravina dam. Coordinates: 39°21'21.01"N-16°01' 49.07" E; 39°28' 06.60 "N-15°58'18.19"E;39°38'22.74"N-15°56'19.52"E;39° 41 '19.96"N-16°29'12.71"E; 39°19'24.62"N-16°24'27.91"E

Fig. 11 - View of Caloria M.t (arrow); in the northern slope there are numerous dolina shaped depressions, concentrated due to piping phenomena (thin arrows), at the rotational and lateral spreads and sliding bands. Coordinates: 39°31'21.04N15°55'38.41"E; 39°42'10.85"N16°10'12.90"E;39°30'18.52"N16°17'16.12"E; 39°27'12.48"N15°59'05.48"E

Bagni Torrent-Follone Torrent

Moving far north, between the Bagni Torrent in SW and Follone Torrent at NE the first significant left-transcurrent feature (Fig. 3a) pass, which significantly realeases the Coastal Chain axis by shifting it over 6 km to west, as can also be deduced from the coastal profile (Fig. 1). The latter, already between Fuscaldo and Guardia Terme, gave a first indication of a weak deformation always moving westward. The transcurrent fault involves the metamorphic alpine soils from the very low to medium degree (claystone, slates and phyllites), down from the low to the high metamorphic degree and, in the Fagnano Castello area, sedimentary soils (sand, clay and gravel) (Figs 1 and 10). The block structure is located in the crest area between Bagni and Follone, between M.te Pistudo (965 m) - Pietrabianca and Serra Cavallo (879 m), the first in cretaceous limestones "immersed" in the flax (almost like extruded by compression), the second in granulites and garnet gneiss.

Cetraro Fiumara - Esaro Fiumara

The transcurrent fault that can be identified along the Esaro Fiumara to the east and the Cetraro and Triolo streams to the west (Fig. 10) deforms besides the coastline also the width of the same Coastal Chain almost doubling it, widening to NE of approximately 5 kilometers. Such an important tectonic event is associated with impressive DSGSD, of macro slump type, especially on the western side of Caloria M.t in Fagnano Castello territory (Guerricchio, 1985; Sorrriso-Valvo, 1988), (Figs. 1, 10, 11). The most extensive and deep of them seems to be in the initial state, as shown by the modest height of the main scarp, at whose base, arranged as horseshoe, there are some depressions or hollows occupied by ponds (Figs, 11 and 12). The terrains involved in gravitational deformation are gneiss and garnet fels, with marble intercalations and basic rocks belonging to the Polya-Copanello Unit of Cretaceous-Paleogenic Alpine Chain (Bonardi *et alii*, 1970-76). The gravitational deformations of the gneissy unit of that territory are associated to the transcurrent fault identifiable along the Esaro River to the east and the Cetraro Fiumara to the west, favored by their support on the less resistant and more "plastic" Diamante Terranova Unit, to calcschists and phyllites, of the same age (Fig. 12).

San Gineto-Capo Bonifati

Along the important Sangineto Line, which from Capo Bonifati reaches beyond Castrovillari, where the limestone Apennine structure ends and the Alpine one of the true Coastal Chain begins (Fig. 13), the outcropping terrains, in addition to those still carbonatic in the Limestone Apennines, belong to Diamante Terranova and Malvito Units (Bonardi *et alii*, 1970-76), on which the Lower Pliocene-Middle upper Miocene (Tortonian)clays, marls and arenites, in transgression, rest.

It is in the limestone unit which can be identified a restraining bend structure to which DSGSD and/or ancient, large landslides

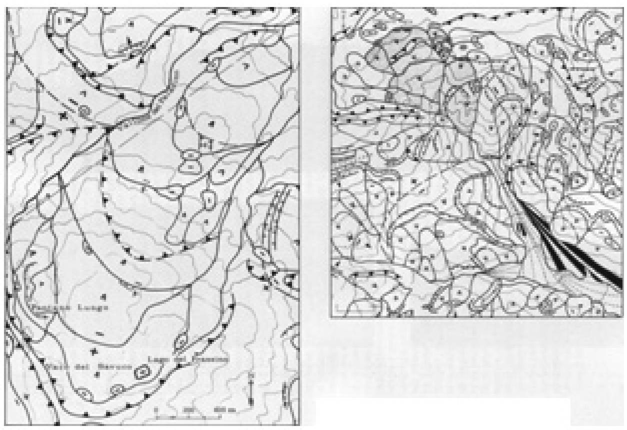

Fig. 12 - Examples of mass movements; (left) - at the breaks of the deep macro slumps and lateral spreadings in the Caloria M.t northern slope, numerous dolina shaped depressions are concentrated due to piping phenomena. Moreover, the landslide bodies caused a significant lateral displacement in Palladino's Waloon riverbed. (Right) - Lateral spreads, very deep mass movements, sliding on the Caloria M.t western side. The upstream erosion in Giovaniello Ditch, responsible for the old fan (or lacustrine deposit?) erosion perhaps in the Riss-Wurm Interglacial or more recent, is now attacking the "grise" coloured masses that will be the first to remobilize (after Guerricchio, 1985)

Fig. 13 - Northern Coastal Chain territory, where the true Limestone Apennine ends, dominated by the Montea structure and the Alpine one begins. On the extreme right, in the Cetraro river (arrow), you can see a part of the left transcurrent fault, which continues towards the Esaro dam (vertical arrow). The image is deformed 3 times in height. Coordinates: 39°45'32.88"N-15°47'41.80"E; 40°04'25.54"N-16°10'31.38"E; 39°40'53.49"N -16°31'22.49"E; 39°27' 42.15" N -15°58'16.76"E

can be associated. Reconnecting to the Sangineto Line, another major DSGSD, of a slow traslational sliding type, of 12.5 width and 5.5 kilometers long, runs over the La Caccia (1.744 m) whole west side in the territory of Belvedere M.mo and Diamante (Guerricchio, 2016). This is the most advanced front of Montea (1.785 m) largest and deep DSGSD, produced by multiple slidings towards the coast (Figs 13, 14 and 15), which have left and right "tracks" coinciding respectively with Corvino-delle Cene Valley and Soleo streams to a limited extent to the little part downhill of Trifari's village amphitheater (Figs 13, 14 and 15).

It determines the remarkable advance to the west of the coastal profile considered between the two mouths of the aforesaid streams, of which the first is also the right "track"of the Montea gravitational rupture, while the second, the left one, is given by the Sangineto Torrent from Passo dello Scalone (Figs 13 and 14). In substance, it is from the Montea western side that the Calabrian coast accentuates its westward displacement, already begun, as mentioned, at the level of Guardia Piemontese town. To the north, a further significant shift towards the west of the Coastal Chain profile is taken into account, determined by the umpteenth immense DSGSD involving the Carpinoso M.t (988 m) and the whole territory between Maierà, Visciglioso (upstream) and Diamante (pro part) and Cirella along the coast (Figs 13 and 15).

Also in this case the breaks that perimeter gravitational deformation are the site of the main streams of that territory: Corvino Torrent to the south, which almost joins east, at the level

Fig. 14 - The multiple roto-translational deformations that originate from the Montea western side and then by La Caccia M.t, having as movement "tracks" the S. Gineto to the south and Corvino and Vaccuta watercourses to the north (arrows), for a width of more than 10 kilometers. These shifts towards the coast are the first reason for the marine erosion of that area, where the beach is visually very small and eroded. Coordinates: 39°41'14.70"N-15°48'45.92"E ;39°44'51.65" N-16°00'09.38"E;39°33'37.20''N-16°11'51.61" E; 39°34' 35.07" N -15°51'56.07" E

Fig. 15 - Another view of Montea and La Caccia M.t deformation. From this latter structure we can observe the landslide high scarp (arrow), the morphological depression at its foot and the bulging at the coast, protected at the time with"T shaped" structures to contrast marine erosion which, however, little will be able to solve in medium time. The image wants to give the perception of the slow shift towards the coastline of the entire slope. Coordinates:40°03'45.52"N-15°34'23.72"E ;40°05'30.57"N15°33'47.70"E;39°42'16.84"N15°52'30.73"E;39°36'36.94"N15°52'32.83"E;39°37'18.41"N15°50'51.11"E

Fig. 16 - View of the Praia predominantly calcareous dolomite land, where the great, ancient gravitational deformations can be observed today, in a very slow evolution, which can be partly remobilized by significant seismicity. Coordinates: 39°55'46.01"N-15°47'55.84"E ;39°53' 42.65" N-15°46'44.92"E;39°34'51.93"N-15°52'13.41"E;39° 47' 12.20"N-16°01'26.71"E;39°56'15.69"N-15°52' 33.93" E

of Serra Milarra at the height of 691 m a.s.l., with the Vaccuta Torrent terminal part.

It should be noted that the rocky body on which Maierà's village rises appears to be westward about 800 m from its previous position, which saw it at the same planimetric height as Grisolia village (Fig. 13).

Praia a Mare territory

In the north, in Praia a Mare town (CS) and its immediate hinterland, the C.zo Petrara DSGSD (Fig. 16), with a height of 1.158 m a.s.l., is the dominant geomorphologic element. Under the geological aspect it deals with dolomite and limestone structures consisting, from down to up, of grey-dark dolomites, dolomite limestones and algal limestones, generally well stratified (4 and 5 in the section of Fig. 18), of Triassic age (Calabria Geological Map) (Fig. 18). Locally, however, the intensive tectonization and the mechanical action of the great landslides have erased any trace of stratification in this unit and not only in it. Towards the top light, well-stratified limestones of the Upper-Trias-Lias (4 in the section of fig 18) follow and later well-stratified gray-dark limestones, locally with reddish-browned clayeyes intercalations, perhaps Triassic (4? In Fig. 18), outcropping at the summit starting from 925-950 metres a.s.l. (Figs 16 and 18). In the coastal area, to the dolomites with direction of dip variable from west to south, starting from altitude 325 m a.s.l. (in the south) and 475 m (in the north), we pass to the unit 4 (Fig. 18) through a partially stratigraphic contact and partly from a large landslide rupture (Fig. 18). Indeed, starting from the southern sector along the Fiuzzi stream, the dolomite (4 in fig. 18) is lowered by a large horseshoe breaking of the ancient DGPV, which develops for approx. 1100 m, approximately from S to N in the Zaparia (450 m) shelf-depression, now filled with Holocene-colluvial deposits (maybe lacusters?), rupture which then connects to the V.ne Cancer (NE-SW) disappearing on the surface in Fiumarulo, on the north coast of Praia a Mare (Figures 16 and 18). Larger is the general breakdown of DGPV by Cozzo Petraro which, on the western side (towards the coast), is set along the Canal Valley-T. Saracena (Piano del Pero resort) ending in the pocket beach at the Grotto of Arcomagno with the southern part (left binary), while with the northern (right binary) it develops in V.ne Campiello and then in the V.ne del Cancero (Fig. 16).

In the southwest the glossy, shiny, gray-dark, clayey schists Unit outcrops, with phyllite facies, with quartzite, crystalline limestones intercalations (Frido Formation - Ogniben, 1973), in tectonic contact with limestones and calcarenites unit of Lower Miocene in layers of 10-15 cm, with thin intercalations of marls and scaly clays. In the eastern portion (Papasidero Ditch), the lower part of Petrara Cozzo is made up by the lithologies 4 and 5 as in Figure 18. Acqua Spasa-Cavolo Mangiato Valley are the places crossed by the sliding rupture of the whole structure and that surrounds it connecting to the north with Campicello and to the south with della Canna Walloon. It is very clear that the dolomite (4 in fig. 18) on the left bank of the valley represents a part of the sliding scarp that more and more in the South involves the 4 and 5 units in fig.18. To the north the break in 5 unit (Fig. 18) follows the ditch trend in the Picello, Acqua Scosa and Venarite localities. To the north the whole territory, starting from 885 metres a.s.l. (Capisto, Zoppicello, Vernarite and Acqua Scosa *p.p.* localities) is deeply mechanical divided and karstic, with extensive eluvial – colluvial covers to fill the many depressions. The Pleistocene sands and conglomerates close the soil succession (Figs. 16 and 18).

Similar gravitational phenomena may also be associated with the great deformations of Capo Scalea territory (Fig. 19) at the mouth of Lao River. In the ancient slidings of the Apennine stone structures of the Capo Scalea, two limestone tongues represent the foot of an ancient Pleistocene sliding of Serra La Limpida (1.119 m a.s.l.) western slope (arrow).

Pollino

Although this relief is not part of the Coastal Chain, it is still useful to give some geomorphologic-structural note of it, because by its evolution is due that of the vast territory bordering with. It is the carbonate structure of the Southern Apennine that, along with that of the "Orsomarso" closes Calabria to the north (Fig. 1); one

Fig. 17 - Traces of the geological sections of Fig. 18. Coordinates:39°49'46.74"N-15°46'13.58"E;39°49'38.51" N-15°54'09.40" E;39°55'06.44" N-15°54'33.56" E;39°56' 13.89"N-15°42'22.32"E

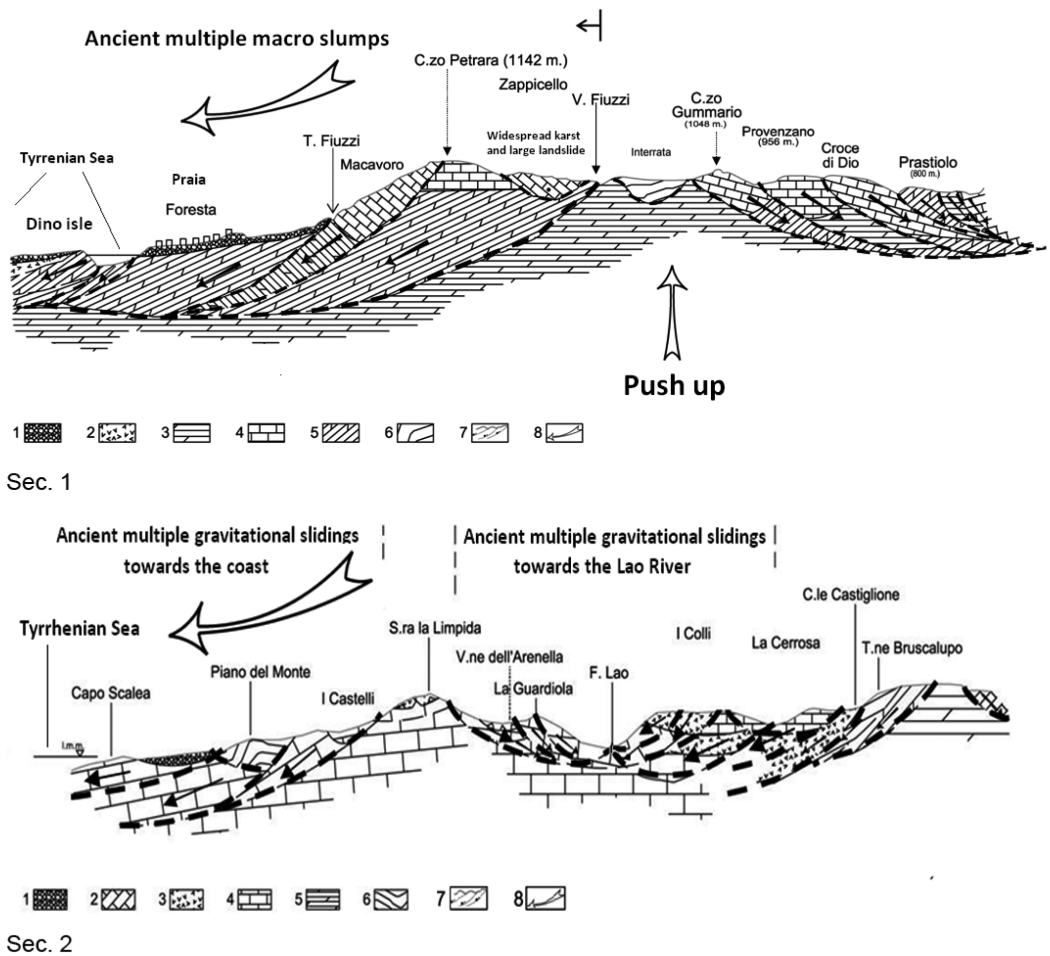

Fig. 18 - In the center of Section 1 the relief of CozzoPetrara (1,158 m a. s. l.), involved in the coastal side by an impressive ancient sliding in a very slow evolution (hatching sliding surfaces), which influences the contour of the coast, which is itself the element of a very large macro sliding, still toward the coast (arrows). 1. Conglomerates and sands - Pleistocene; 2. Limestones - Trias - Paleocene; 3. Calcareous Breccias - Eocene; 4. Limestones and Dolomites – Upper Trias; 5. Dolomites - Trias; 6. Clayey Schists – Cretaceous?; 7. Sliding and moving surfaces; 8. Ancient large gravitational slidings

Fig. 19 - Scalea and mouth of Lao River. The ancient slidings evolve in both the Apennine and the Metamorphic structures of medium high degree. The one with a vertical arrow produces a considerable displacement towards the left bank of the Lao course (oblique arrow), while the Capo Scalea two carbonate tongues (arrow at the coast) represent the foot of an ancient Pleistocene sliding in the Serra La Limpida (1.119 m a.s.l.) western slope (horizontal arrow). Coordinates: 39°44'44.79"N-15°46'22.69"E; 39°43'48.17"N-15°51'40.67"E; 39°50'20.28" N- 15°55'32.80"E; 40°00'09.69"N-15°39'29.30"E

of the most visible peaks from Calabria and Lucania, Moschereto, Serra Dolcedorme, Pollino M.t (2.248 m a.s.l.) and S.ra Del Prete (2.181 m a.s.l.) with direction axis NW-SE, the other, with a similar orientation, of Sellaro M.t (1.439 m a.s.l.), Porace Timpa (1.423 m a.s.l.), San Lorenzo Timpa (1.652 m a.s.l.) and Falconara (1.656 m a.s.l.), separated by an average distance of about 5 kilometres. The two limestone structures, originally united (though those of the present Pollino Chain are of Jurassic age and perhaps Triassic, the other of the Cretaceous age), are separated from the vast flyschoid territory of the high basin of Raganello Torrent, culminating with the Toscano Casino (1.600 m a.s.l.). The tectonic thrust of the structure has led to the division of the original unit into the two above elements, with the displacement and divide of the second with weak rotation in a clockwise direction and consequent collapse in the central sector, today occupied by the Raganello Basin. Therefore, the deposits of Sicilide Unit, which cover the entire limestone unit through the phenomena of lowering and raising the limestone structure, have been discharged from both sides of the southern and northern slopes or sunk into the "graben" areas (Figures 20 and 21). Similarly to the structure of Coppola di Paola and Cerviero M.t (1.441 m a.s.l.), which starts from Serra del Prete, however, it is directed towards about EW, from which the north-west is the large structure today the seat of the high basin of the Mercure River. This movement towards Caramola M.t (1.524 m a.s.l.), for the "domino effect" arcs deformed the separation structure with the upper part of the confined Frido Valley, in ligurides rocks, compressing it and raising it (Guerricchio, 2005). It is no surprising, therefore, that today, through Interferometric measurements, we observe a movement of a structure still in

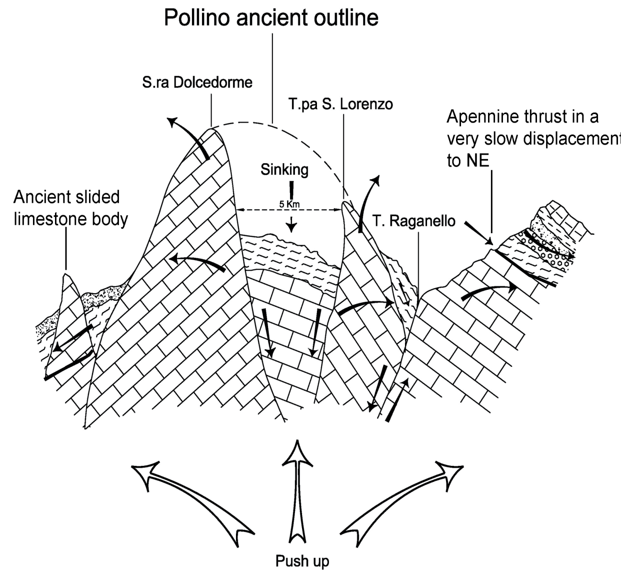

Fig. 20 - Tectonic sketch of the Pollino Chain showing the ancient sunken (graben) between Dolcedorme Serra (of Trias age (?) - Jurassic) and San Lorenzo Timpa (Middle-upper Cretaceous), among them detached from no less than 5 kilometres

Fig. 21 - The Pollino Chain seen from SE. The widespread collapse of the ancient structure (between Dolcedorme Serra (1), etc. and Timpa di San Lorenzo (2) etc.) is observed, the present seat of the Raganello Torrent (arrow) basin. It is opening in a clockwise direction from Raganello Torrent (arrow), involving the territory to E and NE. In the foreground (in the bottom left part) the long and deep ancient Civita (small arrows) landslide, which in the late Pleistocene dammed the Raganello, creating a lake with some residual deposits (oblique arrow). Sicilid plastic covers, which are supported on the calcareous "basement", slid slowly into the Raganello or its tributaries, as the surfaces with almost no vegetation in the bases of the limestone reliefs (2) show (after Guerricchio, 1994). The image is deformed at 3 times. Coordinates: 39° 46'44.71"N-16°18'17.33"E;39°54'21.72"N-16°22' 06.21" E; 40°05'14.92"N-16°08'22.15"E; 39°49'05.13"N-16° 04'54.73"E

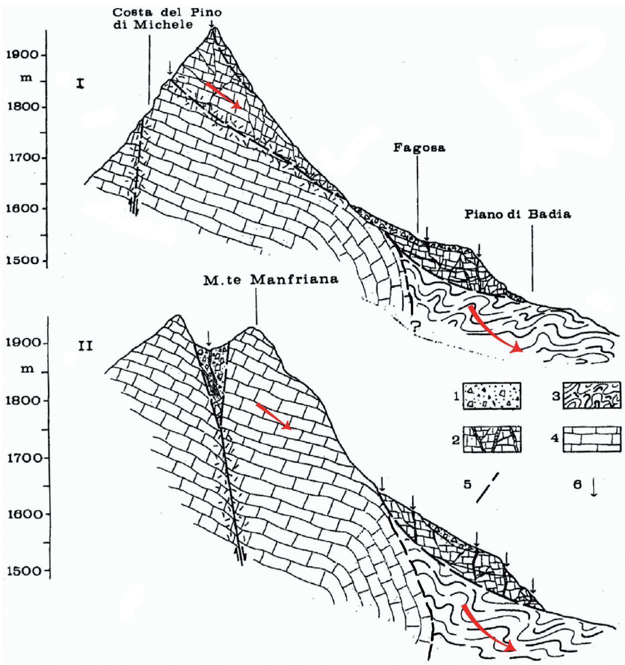

Fig. 22 - Schematic DSGSD in the Pollino Chain: I) Costa del Piano di Michele; II) M. Manfriana still in slow gravitattive evolution (red arrows), with sliding surfaces sometimes present above the ridge (I). 1. Holocene debris; 2. Ancient landslide bodies; 3. Liguride Unit in tectonic superposition on the Apennine Limestones (4); 5. Faults; 6. Concentrated karst zones (after Guerricchio et alii, 1996)

tectonic motion, which involves extensive territories, to be taken into account for important engineering works.

CONCLUSIONS

The recognition of the restraining bends in the Coastal Chain is very useful in various research fields, from that of Rock Mechanics, Seismology, measurements of crustal movements, with practical repercussions also in the field of Civil Protection. It is therefore useful, in an area seismically active (Grandori *et alii*, 1988; Guerra, 1997; Petrini, 1991), in which important cities and infrastructures also of interregional importance exist, to take care to rocks mechanical deformations, as well as monitoring the movements associated with the compression phenomena in place also by means of Space Interferometry measures to be integrated with those GPS (Guerricchio & Zimmaro, 2000; Guerricchio *et alii,* 2000; Guerricchio *et alii*, 2001). Associated with this research measures are also carried out of causes that shift gravitational the DGPV and large landslides on both sides of the Coast Range, designed also to study coastal erosion so important in general and in Calabria in particular (Guerricchio, 1989; Guerricchio & Ronconi, 1997; Guerricchio & Zimmaro, 2000; Guerricchio *et alii*, 2000). These deformations, in fact, for their planimetric dimensions and depth of the sliding surfaces, seem to be closely related to regional tectonic activity. In fact, from south to north are identified gravitational deformations mainly associated with transcurrent faults crossing the Chain.

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Fig. 23 - The San Lorenzo Timpa (1,652 m a.s.l.) and higher the Falconara (1,656 m a.s.l.). Sicilid plastic covers, with tectonic support on the calcareous "basement", slide slowly into the Raganello or its tributaries (oblique arrows), as almost no vegetation in the base of the limestone pads (small vertical arrows) shows, documenting the extensive tectonic-gravitational deformations still active (after Guerricchio, 1994). Coordinates: 39°53'11.35" N-16°19'16.84" E;39° 53'17.60"N-16°19'40.61"E;39°55'56.09" N-16°18' 16.31" E;39°54'32.90"N-16°17'28.73"E

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