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Tectonics, Deep Seated Gravitational Slope Deformations (DSGSDs) and Large Landslides in the Calabrian Region (Southern Italy)

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ABSTRACT. Compressional tectonics in the allochtonous “crystalline” and sedimentary Units in the Calabria region has given rise to complex structural set-up, such as the overthrusts of competent rocky formations on ductile-plastic units. Such structural set-up, together with the high seismicity of this territory, are among the main reasons of the widespread presence of DSGSDs discovered in this area, that is one of the tectonically most active region in Italy. The identification of DSGSDs, such as slumps in south-eastern Aspromonte and in the northern slopes of Poro promontory, slides in the eastern Serre Chain and lateral spreads in the Casignana-Gerace areas has suggested new interpretations of the geological structures present there. In addition, highly accurate GPS topographic measurements have given evidence to DGSGDs along the coast, which, due to their slow movement towards the sea, play a considerable role in the increase of sea erosion phenomena in the coastal areas.

Key words: Calabrian region, Tectonics and gravitational tectonics, DSGSDs, Large landslides, GPS monitoring

Introduction

The large scale ductile deformation processes, pervasive in rocky masses, mostly evolving at a very slow rate, known as Deep Seated Gravitational Slope Deformations (DSGSDs), for which we cannot postulate a continuous shearing surface, are widespread not only in the Apennines, but also in the region of Calabria, whose surface is 300 km^2 (Melidoro & Guerricchio, 1969; Guerricchio & Melidoro, 1973, 1979, 1981, 1982, 1996, 1998; Guerricchio 1982, 1985, 1989, 1992, 1994, 2000, 2001; Guerricchio et al. 1994, 2000; Guerricchio & Ronconi, 1997; Guerricchio & Zimmaro, 2000; Sorriso Valvo M., 1984; Sorriso Valvo M. & Tansi, 1996).

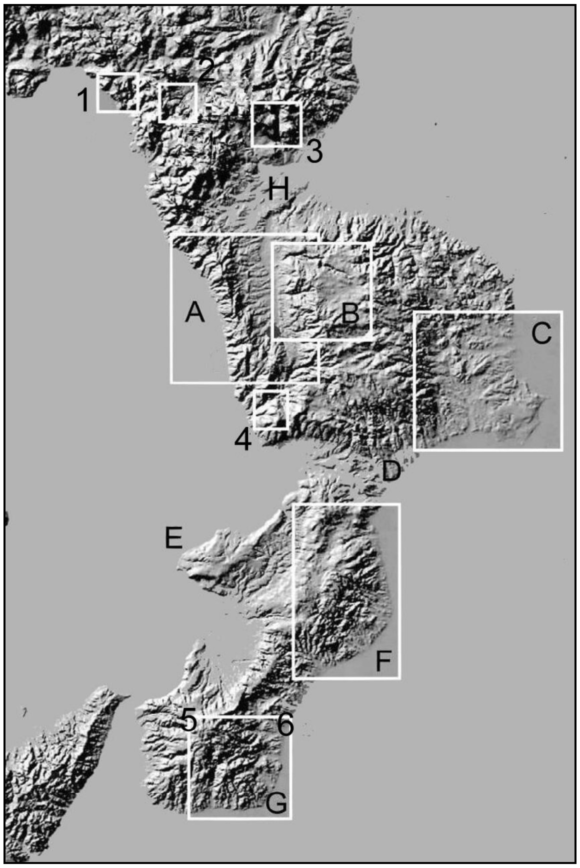

Fig. 1. DTM of the Calabrian region and location of the study areas. The square A shows the half graben of the Crati river basin, evolving by a rollover mechanism toward the Tyrrhenian sea-bed. Fault systems with an approx. main NW-SE and N-S direction affect the Sila block, from which the southern part of the region has become detached and, rotating in an anticlockwise direction of about 25°, forms the Catanzaro graben. This movement has facilitated the opening of the Mesima river basin and the consequent detachment of the Poro promontory (E).

Square A. Crati graben and Coastal Chain; B. a part of Sila; C. Crotone basin; D. Catanzaro graben; E. Poro promontory and Mesima graben; F. Serre Chain; G. Aspromonte; H Sibari plain. 1. Maratea area; 2. Lao River; 3. Mount; Moschereto-Pollino; 4. Savuto area; 5. Colella landslide; 6. Casignana and Gerace lateral spreadings.

With time DSGSDs can undergo sharp accelerations of their movements, leading to phases of collapse of entire and even extensive slopes, with bands of breakage affecting not only the ridge-valley bottom system but also considerable portions of the slope opposite the more obviously unstable one (Guerricchio & Melidoro, 1979; Nemcok, 1972; Hutchinson 1988; Varnes, 1978).

Decisive situations triggering DSGSDs are the tectonic-structural conditions, in which competent rocks are laid over formations with ductile or plastic mechanical behavior, with strength close to residual state, or pushes from below, e.g. as in the flowers structures. The DSGSDs are almost a "continuum" with gravitational tectonics (Guerricchio & Melidoro, 1981).

Schematic Tectonic Features of the Calabrian Region

The evolution of the central-western part of the Mediterranean has seen the migration towards the south-east, especially of crystalline rock complexes making up the Calabrian Arc in the post-Eocene period, covering the northern edge of the African Plate and its promontories (Caire, 1962; Boccaletti et al., 1984), (Fig. 1).

This foreland includes the Apulian Block to the north, which is a part of the Adria Plate, and the Hyblean Block to the south, which is a promontory of the African Plate. Between these two structural elements lies the Ionian Basin, formed after oceanization or rifting, probably in the Jurassic and subsequently subducted below the Arc. The retro-arc areas are the Western Mediterranean Basin, formed in the Oligocene - infra-Miocene, and the Tyrrhenian Basin, that developed from Middle Miocene to Pleistocene, when progressing manifested various episodes of rifting and of subsidence were active (Sartori, 1990; Van Dijk et al., 2000). Characteristic elements of the actual retro-arc area are the presence of profound earthquakes, of an active volcanic arc (Aeolian Islands) and of a high thermic flow, together indicative of active subduction. The Calabrian Basement is constituted by a group of deformed units, including crystalline and metamorphic units, carbonate platform units and terrigenous, metamorphosed or not, on which Neogenic transgressive sequences from Middle Miocene to Holocene are deposited. Locally, the Calabrian territory is very rough, with a relief which ranges from sea-level to 2000 meters, including some massifs and intra-arc basins which, from the Tyrrhenian and proceeding eastwards and southwards, are: the Sibari plain, the southern sector of the Coastal Chain and the Crati Basin, the Catanzaro Basin, the Sila Massif, the Crotonese fore-arc and Rossano-Cirò basins, the Poro and Serre Massifs, the Mesima intra-arc basin and the fore-arcs of Locride and Reggio Calabria (Fig. 1).

Limited to the central Calabrian area (Van Dijk et al., 2000), a large part of the outcropping basement is composed of Hercinian and Alpine crystalline and metamorphic allochthonous complexes, with a flat base, of European provenance, overlapped on previously structured units, successively incorporated in the evolution of the thrust area, with associated Eocene and Lower Neogene sedimentary covers. Along the internal side of the Arc, carbonate rock platforms, similar to Apennine allochthonous units, crop out in windows below this basement.

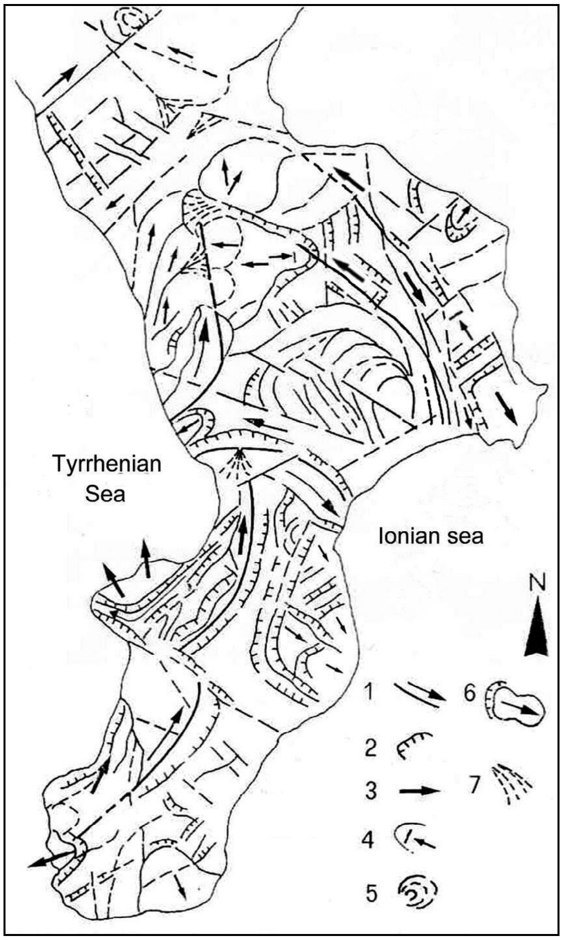

Fig. 2. Schematic map of the main lineations and DSGSD in Calabria, inferred from satellite images. 1. Transcurrent fault. 2. Scarps of main faults or DSGSD and huge landslides. 3. Direction of movements. 4. Areas affected by tilting (the minus sign points out the lowered zone). 5. Circular structures. 6. Large landslide. 7. Main alluvial fan deltas.

Contact between the basement units is overlapping at a low angle, obliterated by successive high angled faults. Terrigenous Eo-Oligo Miocene sequences are present in the form of remains along the over-running contacts between these basement units and as tectonic wedges along the fault zone at a higher angle. All these rocks are crossed by a complex group of high angled faults which can be organized and put into a hierarchy based on the number of patterns, partly correlated to past faults. Due to the activity of such fault systems, overthrust between sedimentary rocks from Late Neogene and basement rocks, long flower structures, and low angled over-running are local products. Externally along the arc, low angled regional overthrust can be observed in the Neogene sedimentary sequences. In conclusion, one can say that the geological structure is characterized by a group of subtle low angled thrusts, dried by high angled faults, with oblique movement components (Figs. 1 and 2).

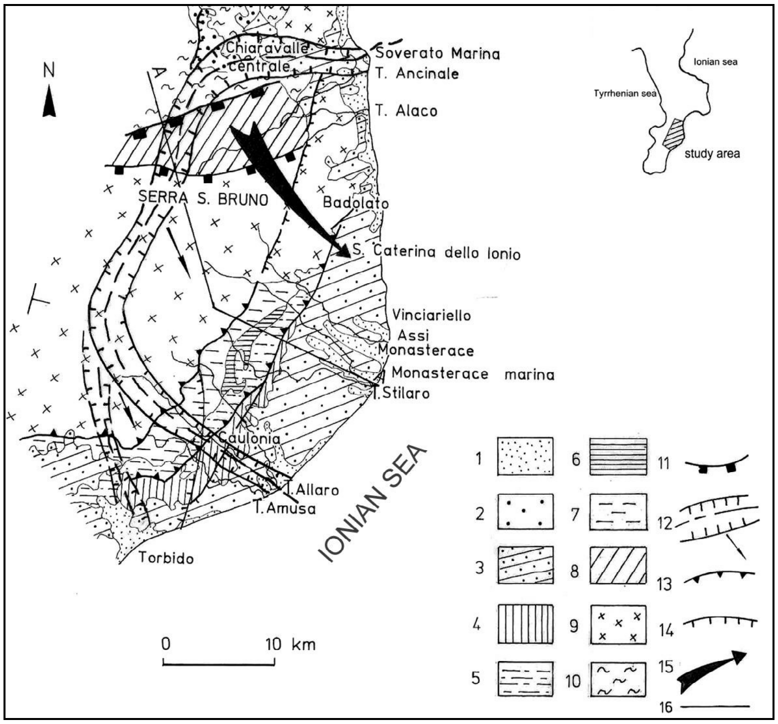

Fig. 3. Schematic geological map of the huge DSGSD in the Ionian Serre Chain. 1. Fluvial and littoral deposits. Upper Pleistocene-Holocene. 2. Conglomerates, sands and clays of fluvio-lacustrine environment. Middle Pleistocene-Middle Pliocene (?). 3. Gypseous sulphide formation. Middle Pliocene-Tortonian. 4. Scaly Variegated Clays – Cretaceous; Numidian quartzarenites – Langhian-Burdigalian. 5. Stilo-Capo d'Orlando Formation. Lower Langhian-Upper Burdigalian. 6. Stilo Unit-sedimentary cover. Upper Cretaceous-Upper Trias. 7. Stilo Unit-Stilo "Batolite". Magmatites. Upper Paleozoic. 8. Stilo Unit-Metamorphic Complex. Paleozoic. 9. Stilo batholite. Upper Paleozoic. 10. Polìa-Copanello-Gariglione Unit. Metamorphic Complex. Paleozoic. 11. Tectonic superpositions. 12. DSGSD trenches and direction of movements. 13. Thrusting involving sedimentary or metasedimentary units. 14. Normal faults. 15. Principal movement of the DSGSD slipping. 16. Geological section line.

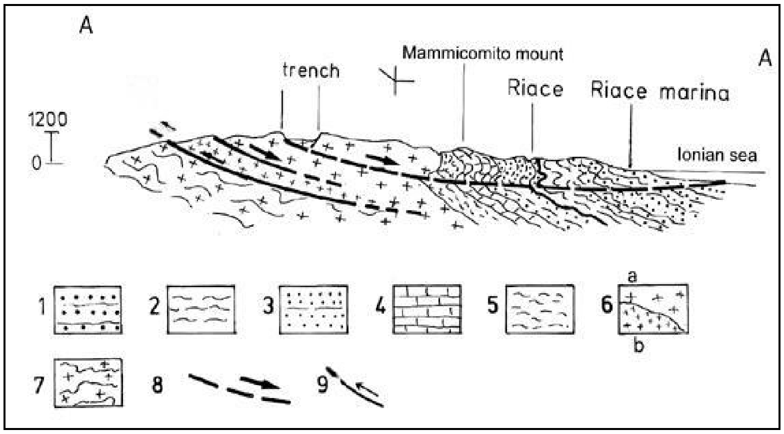

Fig. 4. Schematic geological section of the DSGSD in the Serre Chain. 1. Fluvial-littoral deposits; fluvial-lacustrine conglomerates, sands and clays. Holocene-Middle (?) Pliocene. Conglomerates, clays, evaporitic deposits. Middle Pliocene-Tortonian; 2. SVC with Numidian quartzarenites. Upper Messinian-Upper Tortonian; 3. Deposits of the Stilo-Capo d'Orlando Formation. Lower Langhian-Upper Burdigalian; 4. Stilo Unit-sedimentary cover. Upper Cretaceous-Upper Trias; 5. Stilo Unit-Metamorphic Complex. Paleozoic; 6. Stilo Unit-Stilo "Batolite" (a). Magmatites (b). Upper Paleozoic; 7. P.C.G.U.. Metamorphites. Paleozoic; 8. Gravitational slips and versus of movement. 9.Tectonic superposition.

DSGSDs Limiting to Gravitative Tectonics in the Mid-Southern Calabrian Area

Widespread DSGSD limited to tectonics, is represented by the eastern body of the Stilo batholite (Messina et al., 1993) or Serre Plutonic Complex, constituting a part of the Serre Chain in the Ionian slope, perimetrically bounded by the hydrographic basins of the Ancinale, Allaro and Torbido torrents, and by the coastal sector from Roccella Jonica (Reggio Calabria province) to Soverato Marina (Catanzaro province), (Figs 1 and 2).

The involved Palaeozoic magmatites overthrust a Cambrian-Devonian micaschists and paragneiss complex (Polìa-Copanello-Gariglione Units), (Figs. 3 and 4); this is also confirmed by the presence of DSGSDs. The whole DSGSD, culminating in Mount Pecoraro (1423 m a.s.l.), more than 25 km in total length (from WNW to ESE) and 30 km in width (from NNE to SSW), has undergone a slip with a doubling of crests and a consequent, widespread curved trench, with an average width of about 5 km, (Guerricchio, 2001), (Figs 1, 2, 3 and 4).

The ample slipping, facilitated by the "lubricating" metamorphic units cropping out in its northern parts, in the Ancinale valley (Fig. 4), also produces a semicircular shape, with ESE-ward convexity, of the coastal profile (Fig. 1). In the northern part of the trench, a Middle Pleistocene lacustrine deposit is present, consequent to the damming of the Ancinale caused by a large landslide as a repercussion of the more ample and principal movement (Fig. 1). The DSGSDs participate, in a not evident manner at a first examination, in coastal erosion (Guerricchio, 1989; 2000). It is almost certain that an important rate of the actual seismicity of the area is attributable to the release remobilization of slipping movements (Irikura & Kawanaka, 1980) of the enormous DSGSD towards the Ionian Sea (Guerricchio, 2000).

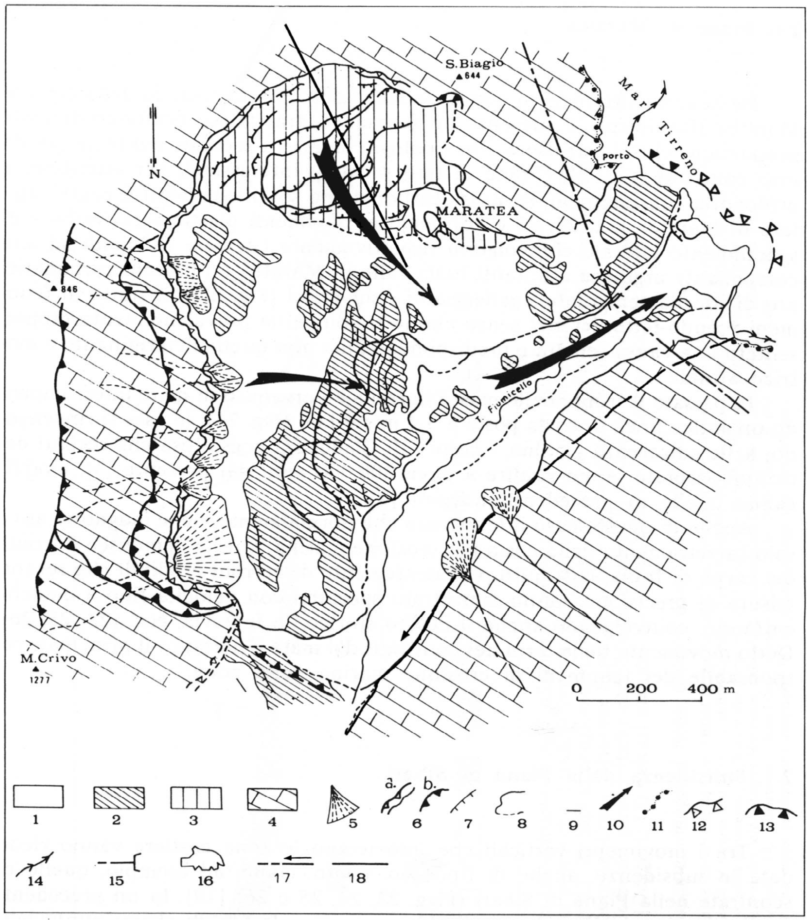

Fig. 5. Geomorphologic schematic map of DSGSD (sagging) in Maratea mountains (Basilicata region). 11. Detritus (Holocene); 2. Large units of slided limestones and breccias (Pleistocene); 3. Limestone unit brocken by the sackung (Pleistocene); 4. Carbonatic units (Mesozoic); 5. Alluvial fan; 6. a) Reactivated fault scarp enveloping gravitational slide movements; b) Ancient scarp slide; 7. Scarps of the "sackung" area; 8. Landslide body limit; 9. Landslide depression; 10. Main direction of the slide; 11. Old coast line dated 300.000 years b.p.; 12. Severe marine erosion in sea coast made by soil; 13. Severe marine erosion in rocky sea coast; 14. Submerged lateral landslide rupture coinciding with canyon; 15. Railway; 16. Maratea town; 17. Left strike-slip fault; 18. Geological section line.

Some Significant Cases of DSGSDs in Calabria

DSGSDs of smaller dimensions than the case of the aforesaid Ionian Serre are spread over the Calabrian region. The first significant case of a reconstructed DSGSD model was that of Maratea (Guerricchio & Melidoro, 1979), which, even if not in Calabria, is geologically correlated with northern carbonatic structures of this region (Fig. 1).

DSGSDs and Large Landslides in the territory of Maratea (Basilicata-Potenza province)

The Maratea Valley is a tectonic rift (Fig. 1, square 1), bounded by Mesozoic limestone massifs (Apennine Limestones, Ogniben, 1969) and with the Black Flysch (Cretaceous) in its bottom and at the base of the same limestones (Guerricchio & Melidoro, 1979), in which multiple sliding of large rocky masses and DSGSDs of the "sagging" type, are evident (Figs. 5, 6 and 7).

Fig. 6. General view from the west of the Valley of Maratea (Basilicata region). The small arrows in the background point out the active tectonic rupture from which DSGSD and large landslides (large arrows) originate.

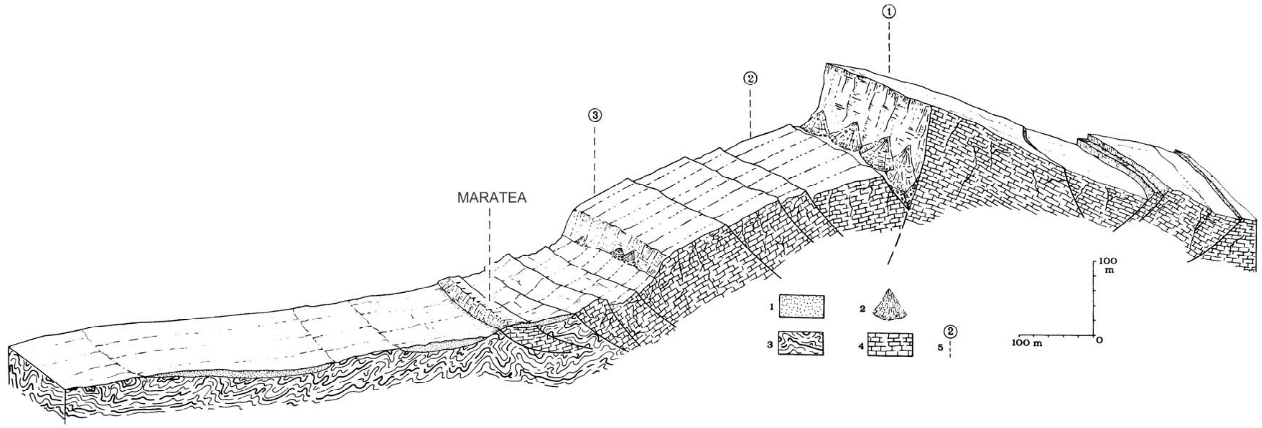

Fig. 7. Block diagram of the sagging. 1. Talus; 2. Talus fan; 3. Black Flysch; 4. Limestone formation; 5. Dislocated units

River Lao gorge

The River Lao gorge (Fig. 1), heading from NE to SW, is constituted by the Verbicaro Unit (Triassic Upper-Cretaceous, Upper-Burdigalian-Langhian), on which the terrigenous Liguride Complex (Frido Unit, Cretaceous-Eocene?) is overthrown (Ogniben, 1969). Such complexes have been involved in the Quaternary of direct faults, of which, the Colle Trodo fault, with regional character, running from SW to NE, controlled numerous DSGSDs in Middle-Upper Pleistocene (Fig. 8).

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Following such a mechanism, the easternmost block (Timpone Arenazzo) is subject to a clockwise rotation with an initial expulsion towards the east (Fig. 8), like some conspicuous adjacent dolomite masses, which were subject to compass openings. The maximum thickness of the DSGSD appears to be not less than 500 m, while its total length is 4 km. The horizontal displacement undergone by the carbonatic formations must have been not less than one kilometer, while their height in the foot zone (today a deep gorge) is about 120 meters.

S *Mount Moschereto-Civita-Raganello Torrent*

In the southern part of the Pollino Chain (Fig. 1), following the tectonic elevation of Mount Moschereto (1318 m a.s.l.) (Fig. 10), a complex DSGSD was produced.

All the area, in fact, has been elevated by the extensive and deep rupture of the Cretaceous limestones of Mount Sellaro (1439 m a.s.l., off the map), belonging to the V.U., following the listric fault with a N-S direction, conjugate to the NW-SE Pollino left strike-slip. In their movement westwards they involved the most ancient rocky terrains (Triassic) thus forming the right side of the Raganello Torrent paleo-topographic depression. Such an uplifting, a real "jack" mechanism, which involved Mount Moschereto itself for over 1 km toward NW, produced simultaneous

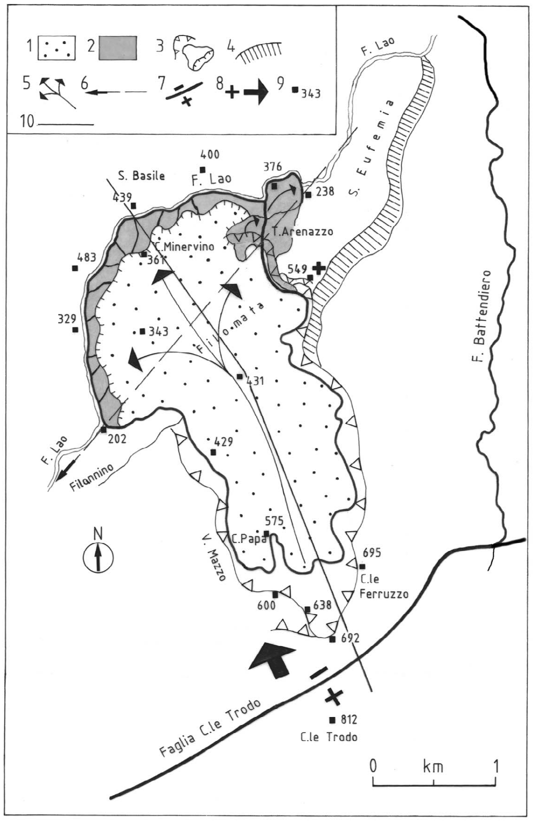

Fig. 8. Schematic geological and geomorphological map of the River Lao gorge, in Timpone Arenazzo locality. 1. Frido Unit: Slates, argillites, quartzites, metalimestones and metarenites. Cretaceous. 2. Verbicaro Unit: Carbonatic breccias, calcarenites, hemipelagic clays and marls, and quartzarenite turbiditic strata. Burdigalian-Langhian; Limestones, dolomitic limestones and calcareous breccias. Lower Lias; Cherty limestones, carbonatic breccias, calcarenites and rudist limestones. Dogger-Upper Cretaceous. 3. Main scarp and DSGSD body. 4. Secondary landslide scarp in Pleistocene lacustrine deposits. 5. Directions of movement. 6. Ancient river course. 7. Colle Trodo fault (minus sign indicates the lowered part). 8. Bulging (plus sign); General displacement of the left side of the Lao River (big arrow). 9. Altitude (m a.s.l.). 10 Section line.

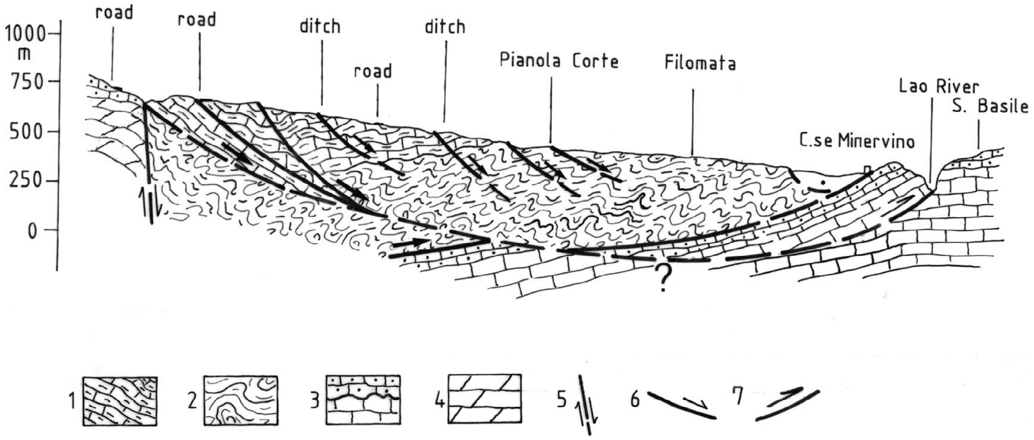

Fig. 9. Geological section of the River Lao gorge. Frido Unit (Cretaceous): 1. Metarenites and metalimestones; 2. Argilloschists and scaled argillites. 3. Verbicaro Unit: a) Calcarenites. Upper Cretaceous; b) Dolomitic limestones and calcareous breccias, sometimes with basic volcanoclastic intercalations. Upper Cretaceous-Paleocene; 4. Dolomites and dolomitic limestones. Trias. 5. Normal fault. 6. Overthrust surface. 7. Slipping surfaces and versus of movement (arrow).

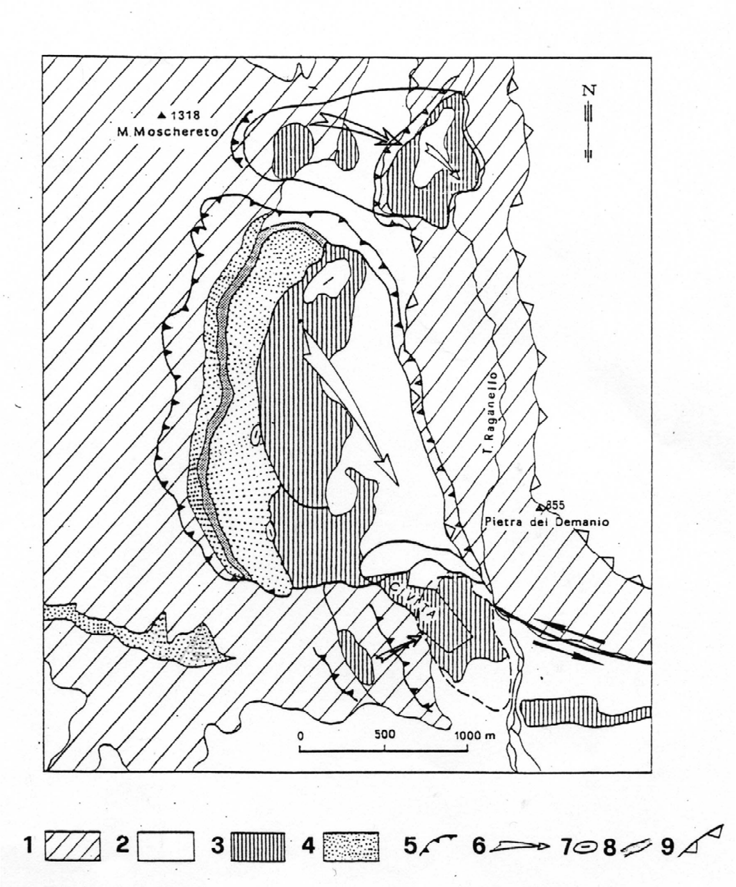

Fig. 10. Schematic geological map of the DSGSD in Mount Moschereto. 1. Apennine limestones. Trias-Cretaceous; 2. Black Flysch (Liguride Complex). Cretaceous; 3. Limestones displaced by ancient landslides; 4. Talus, also in fan shape; 5. Main scarp of DSGSD; 6. Main versus of DSGSD and large landslide movements; 7. Landslide depressions; 8. Active landslide rupture with the renewed band; 9. Tectonic superposition; 10. Strike-slip fault.

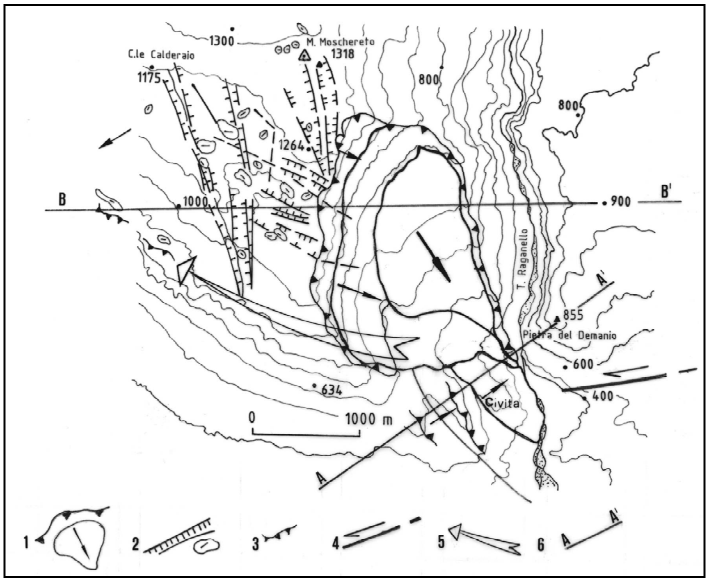

Fig. 11. Geomorphologic map of the Mount Moschereto DGSGD. 1. Landslide main scarp and body with versus of movement; 2. Main scarp of the trenches in the Mount Moschereto DGSGD with pseudokarst depressions; 3. Pollino strike-slip scarp; 4. Strike-slip fault; 5. Versus of the horizontal displacement and uplifting of Mount Moschereto as a result of the push of the Pietra del Demanio limestones; 6. Geological section.

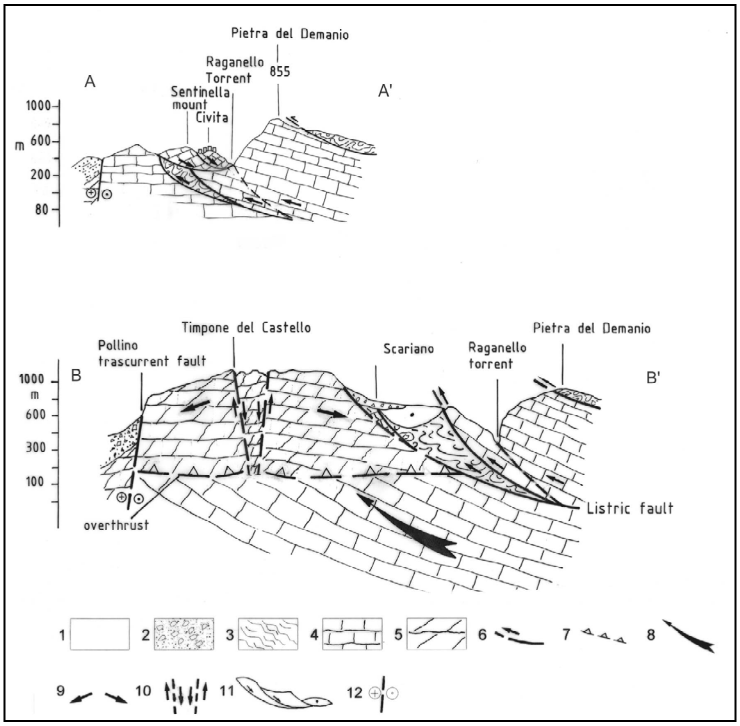

Fig. 12. Geological sections of M. Moschereto and the Civita-Raganello Torrent. 1. Landslide detritus. Present; 2. Talus. Present-Holocene; 3. Black Flysch (Liguride Complex). Cretaceous; 4. Limestones (V.U.). Cretaceous; 5. Dolomites and dolomitic limestones (Pollino Unit). Triassic-Jurassic; 6. Tectonic superposition; 7. Overthrust. 8. Push from below by the Pietra del Demanio Cretaceous limestones. 9. Lateral spreading triggered by the uplifting. 10. Sagging. 11. Slump and sliding with the versus of movement (arrow); the point indicates a movement normal to the section; 12. Pollino left strike-slip fault.

DSGSD-type release, with eastwards backsliding of a part of the right slope of the Raganello Torrent, thus filling its depression (Figs 10, 11 and 12 A).

The raising of Moschereto also brought about a 60° clockwise rotation of its most southern part, with a vague trapezoidal form about 2500 m in width (Fig. 11). This rocky mass, isolated on the east by the deep slope of the gravitative deformation of Civita, and on the west by that of the Pollino strike-slip fault, was subject to, both during the elevation and subsequently due to decompression phenomenon of the slopes (and therefore for the start of lateral spreading), a sagging in the medial part with a "graben" formation, about 200 m in length and 400 m in width (Guerricchio, 1982), (Figs. 11 and 12 B). Furthermore from the opening in the hinge zone following rotation, other impressive DSGSDs originated upstream of Civita (Figs 10 and 11).

Savuto River Valley (Northern Tyrrhenian Coast, Calabria)

In the Savuto river valley, at Mount Mancuso (1329 m a.s.l.), (Figs 1 and 13), a large DSGSD, in the Ofiolitic Unit (Amodio Morelli et al., 1976), including the Frido Unit (Cretaceous-Eocene?, alternating slate and shale, quartzite and metarenites), the Gimigliano and Diamante-Terranova Unit (metabasites, serpentinites, limestone schists, phyllites,

Fig. 13. Landsat image of the Savuto valley. In the middle the DSGSD is evincible in the Piano del Corvo relief, which slipped with an initial anticlockwise rotatio

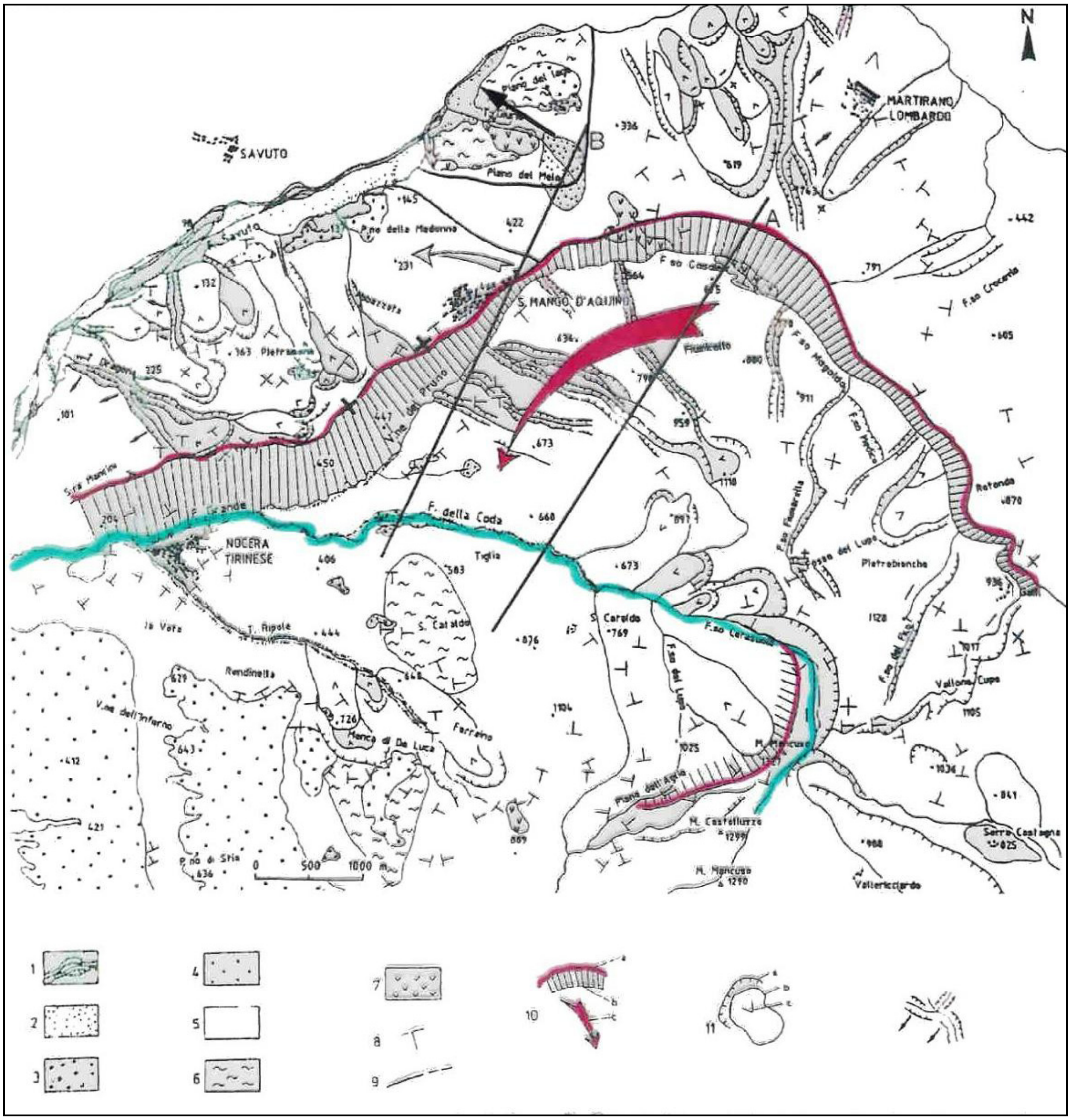

Fig. 14. Schematic geomorphologic map of the large DSGSD in Piano del Corvo-Savuto river basin; it is rotated 90° in a clockwise sense compared to the landsat image of the previous figure. 1. Alluvial deposits. Present-Holocene; 2. Landslide detritus. Recent-Holocene; 3. Eluvial-colluvial deposits. Holocene; 4. Brown-reddish conglomerates and sands resting on ancient terraced surfaces. Pleistocene; 5. Chlorite-sericite-quartz phyllite schists - Frido Unit. Cretaceous; Gimigliano and Diamante Terranova Unit. Jurassic-Lower Cretaceous: 6. Chlorite-quartz green schists with epidote. 7. Green serpentinites, locally passing to gabbros and diorites. 8. Attitude of schistosity. 9. Fault; 10. Scarp (a), rupture (b) and versus of movement (c) of the Piano del Corvo (1118 m a.s.l.) DSGSD; 11. Landslide nomenclature: a) main scarp; b) limit of landslide body; c) principal versus of movement; 12. Main trenches and versus of spreading.

meta-limestones, from Lower Cretaceous-Jurassic), involves all the medium-high Piano del Corvo relief (1128 m a.s.l.).

The DSGSD possibly connected to the right strike-slip fault with WNW-ESE direction, not far from that zone (Figs. 1 and 2), probably occurred in the Holocene (Guerricchio, 2000). In the deep ruptures that delineates it, some ditches have formed, which therefore have no origin in subaerial erosion phenomena. The DSGSD, associated with an initial anticlockwise rotation, produced the visible lateral displacement of the adjacent Coda and Cerasuolo IV order hydrographic basin (Figs. 14 and 15). At the same time the rebalancing of the tensional states inside the rocky masses deformed in this way must have determined the "extrusion" of the actual Piano del Lago block (B in Fig. 13) in green schists (G and D-TU), which hosted some Holocene small lakes (Figs. 13 and 14).

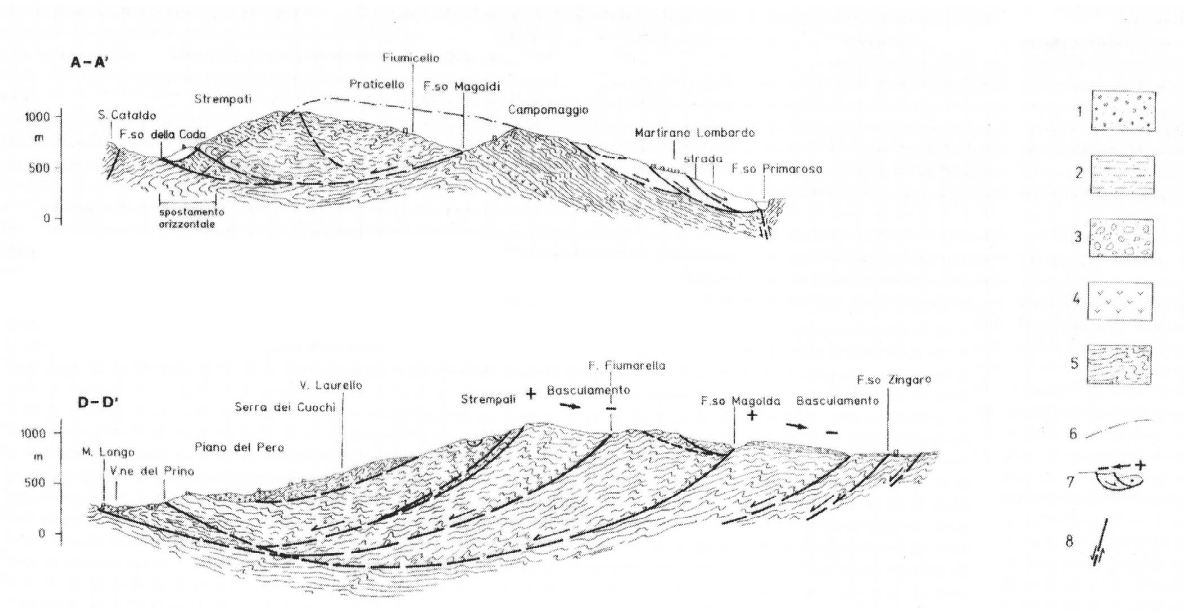

Fig. 15. Geological section of the Piano del Corvo DSGSD. 1. Alluvial; 2. Eluvial-colluvial deposit; 3. Continental sandy conglomerate; 4. Green serpentinite; 5. Phyllite schist; 6. Topographic profile previous to the DSGSD; 7. Scheme of the deformation: plus sign indicates compressional zone, minus the lowered zone due to tilting (arrow). 8. Fault.

DSGSDs and large landslides in Aspromonte

Aspromonte (Fig. 1) is one of the most tectonically active regions in the Mediterranean, constituted by three Paleozoic metamorphic tectonic units that overlapped before the Lower Miocene: of low and medium grade the lowest one, of medium-high with a variety of Hercinian granite for the intermediate one (Melidoro & Guerricchio, 1969), and low – medium grade with Jurassic limestone sedimentary cover on the highest one (Bonardi et al., 1979). These units are constituted by phyllades, paragneiss, micaschists, augengneiss from Cambrian-Carboniferous and plutonites. During the uplifting, Aspromonte was divided into blocks by a N50°E strike-slip fault and normal faults in the western slope and by prevalently DSGSDs in the eastern one (Figs. 1, 2, 16 and 17).

Along the last of these, contact between the crystalline nucleus and sedimentary deposits is of tectonic compression, with NNE-SSW folds and thrusts, verging towards NW, so that the Cretaceous Scaly Variegated Clays also overlap the crystalline units. From the normal faults in the western slope, where the "tower" of the future Strait of Messina Bridge will lie, some DSGSDs originated (Guerricchio, 2000 and 2001), (Figs. 1, 2 and 16). In the Pleistocene-Holocene, Aspromonte was elevated notably with variable tectonic phases, from local to regional (Ghisetti, 1992; Locardi and Nicolich, 1988; Miyauchi et al., 1994; Guerricchio & Melidoro, 1998). Also to be noted is the N-S rupture (Figs. 1 and 16) which, from the Amendolea Torrent (southern Aspromonte), heads, passing Montalto, towards the Petrace river valley (northern Aspromonte), probably triggered, with others, following the 1783 earthquake (Baratta, 1897; Cotecchia et al., 1986; Guerricchio, 2000). At the great uplifting of the central nucleus of Aspromonte, gravitative descents of the slopes, interpreted as "gravitative faults", among which the one (described) between the Amendolea and the Petrace torrents represents the effect, in the form of a "tear", of the push from below (Figs. 1, 16 and 18), (Guerricchio & Melidoro, 1998).

Furthermore, on the Tyrrhenian slopes, at least 12 orders of Pleistocene marine terraces exist: the highest coastal terrace line is found at 1350 m (a.s.l.), (Miyauchi et al., 1994). On the southwestern slopes of Aspromonte, gravitative lowerings due to DSGSDs have overlapped onto normal faults, simultaneously with rapid dome elevation with a maximum speed of 3.8 m/ka, (Fig. 16).

From late Middle Pleistocene (about 500 ka), general regional uplifting prevailed with an average speed of 0.9-1.1 m/ka in the Calabrian Arc and 1.1-1.4 in Aspromonte. In the southeastern slopes of Aspromonte, the DSGSDs evolved with prevalent roto-translative large slump and lateral spread mechanisms (Guerricchio, 1989).

These are laterally defined by the important Amendolea and La Verde torrents ("fiumare") and by the large trench at Montalto (1955 m a.s.l.), describing an enveloped arched line (Fig. 1), which, according to a conjecturable hierarchical order, could be thought a DSGSD of maximum order (Figs 16 and 18). The aforementioned SE-ward spread mechanism created the deep "tear" recognizable in mounts Cuvalo (1436 m a.s.l.) and Punta d'Atò (1378 m a.s.l.) (Melidoro & Guerricchio, 1969), where lower order DSGSDs are active within the gneiss formation overlapping the partly clayey phyllites (Figs. 19 and 20).

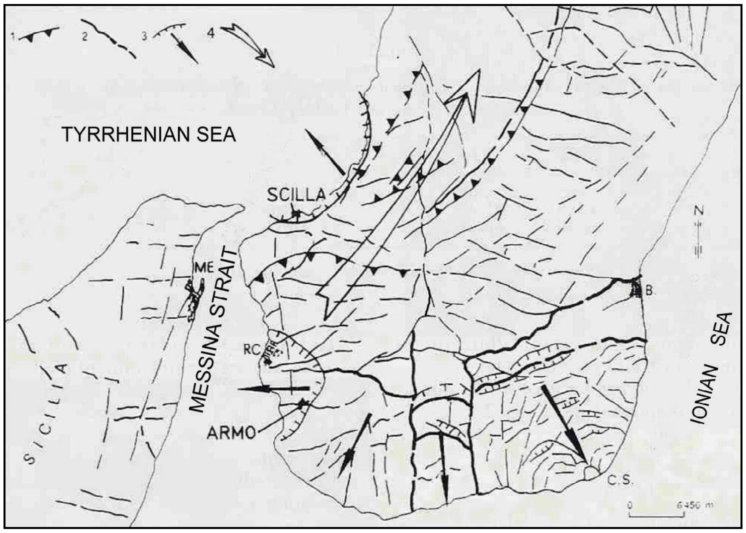

Fig.16. Main lineations of tectonics, DSGSD and large landslide origin in the Aspromonte region, observable by satellite images. 1. Normal fault; 2. Lineation of DSGSD; 3. Crown scarp and versus of movement of large landslides; 4. Direction of the displacement of the western side of Aspromonte due to strike-slip fault.

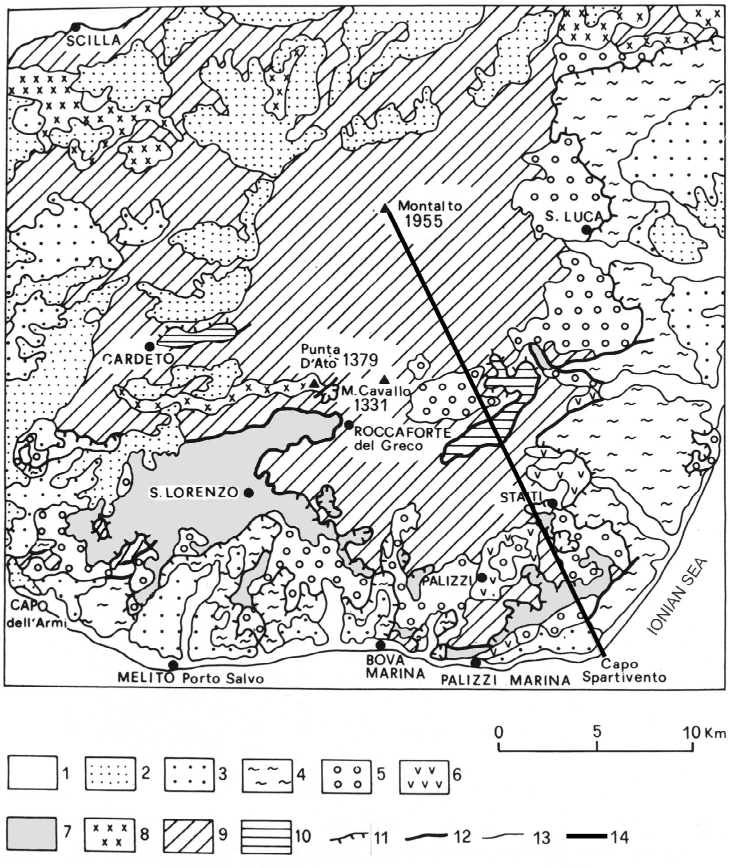

Fig. 17. Schematic geological map of the southeastern part of the Aspromonte massif: 1. Present and recent deposits; 2. Post-orogenic deposits – Plio-Pleistocene; 3. Deposits of Infra-Pliocene-Tortonian cycle; 4. Scaly Variegated Clays and sandstones. Stilo-Capo d'Orlando Formation – Upper Oligocene-Lower Miocene; 5. Fine and coarse calacarenites and turbidites - Miocene; 6. Metamorphites - Cambrian – Carboniferous; 7. Aspromonte Units - Paleozoic: 8. Plutonites; 9. Paragneiss, micaschist and augen gneiss; 10. Phyllites, quartzites and metalimestones - Cardeto Unit; 11. Overthrust; 12. Various tectonic contacts; 13. Geological limits; 14. Geological section line.

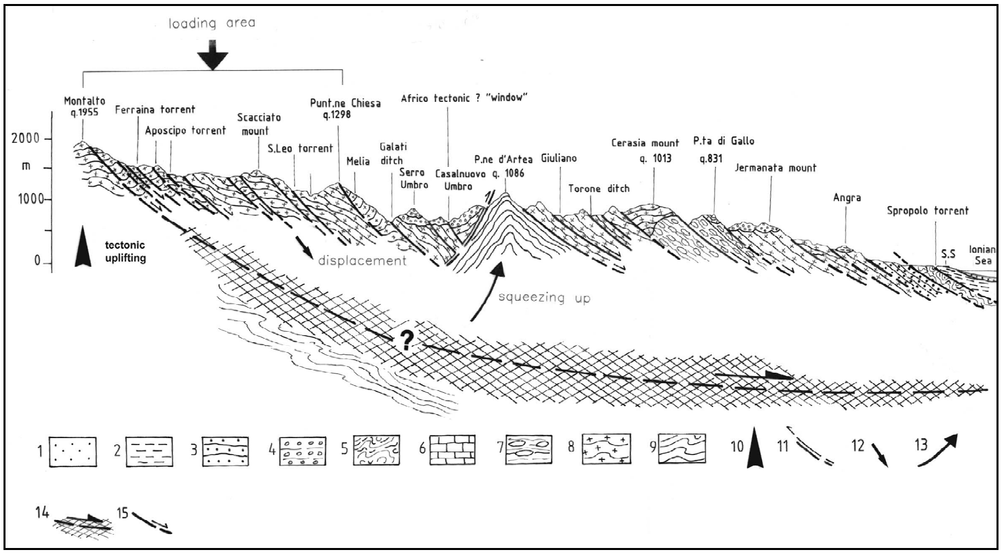

Fig. 18. Schematic geological section of the southeastern slope of Aspromonte. 1. Gravel, sand, silt. Holocene-Upper Pleistocene; 2. Sands and clays. Middle Pleistocene-Middle Pliocene; 3. Arenites, silts and marls. Middle Pliocene-Upper Tortonian; 4. Stilo-Capo d'Orlando Formation. Conglomerates, sandstones, biocalcarenites, marly strata and pelitic-arenite turbidite strata. Upper Burdigalian-Lower Langhian; 5. Scaly Variegated Clays (olistostroma), with olistoliths of Jurassic to Eocene limestones and marls, Cretaceous siliciferous argillites, Numidian quartzarenites (Burdigalian to Langhian). Cretaceous; Stilo Unit: 6. Metamorphic complex: metalimestones, metabasites. Cambrian-Carboniferous; Aspromonte Unit: 7. Augen gneiss. Upper Carboniferous-Lower Permian; 8. Metamorphic complex: paragneiss, micaschists, amphibolic gneiss, metabasites and marbles. Cambrian-Carboniferous; Africo Unit: 9. Phyllites, metarenites, quartzites and micaschists. Cambrian-Devonian; 10. Tectonic uplifting; 11. Tectonic superposition; 12. Versus of the DSGSDs displacements; 13. Squeezing up of phyllades; 14. Zone of plasticization; 15. Rupture surface of the DSGSD.

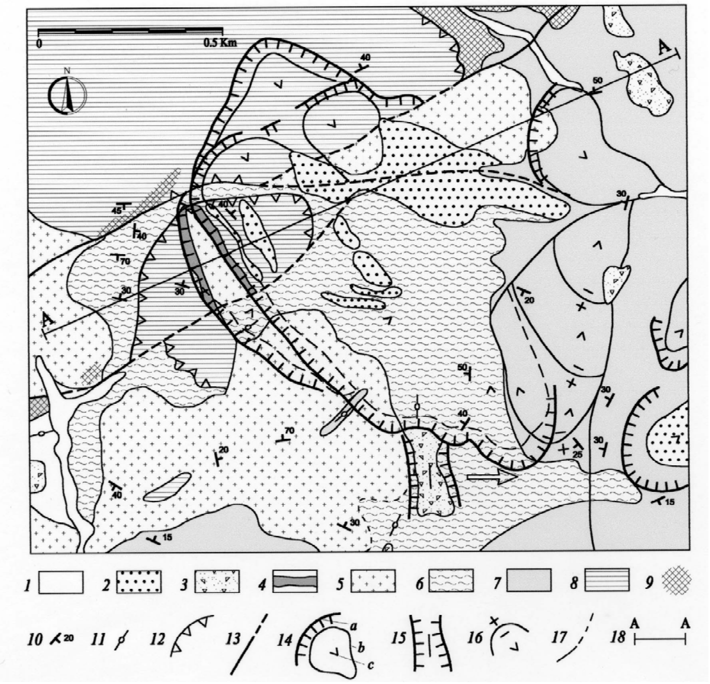

Fig.19. Geological map of the Colella ditch (Amendolea basin, southern Aspromonte). 1. Alluvium. Present; 2. Landslide debris. Present-Recent; 3. Eluvium. Holocene; 4. Hydrothermal sulphide-bearing quartz dyke. Paleozoic; 5. Granites and granodiorites. Paleozoic; 6. Phyllites, highly kaolinized, sometimes with quartz levels; 7. Biotite schists with granite dykes and amphibolite lenses. Paleozoic. 8. Biotite augen gneiss with granite and pegmatite dykes. Paleozoic. 9. Cataclasites. 10. Attitude of schistosity: Inclined; 11. Vertical; 12. Tectonic contact; 13. Faults; 14. a) Landslide crown and scarp; b) landslide body limit; c) slump and slip; 15. Main trench and versus of spreading (arrow); 16. DSGSD (minus sign indicates the lowered part); 17. Formation boundary; 18. Line of section.

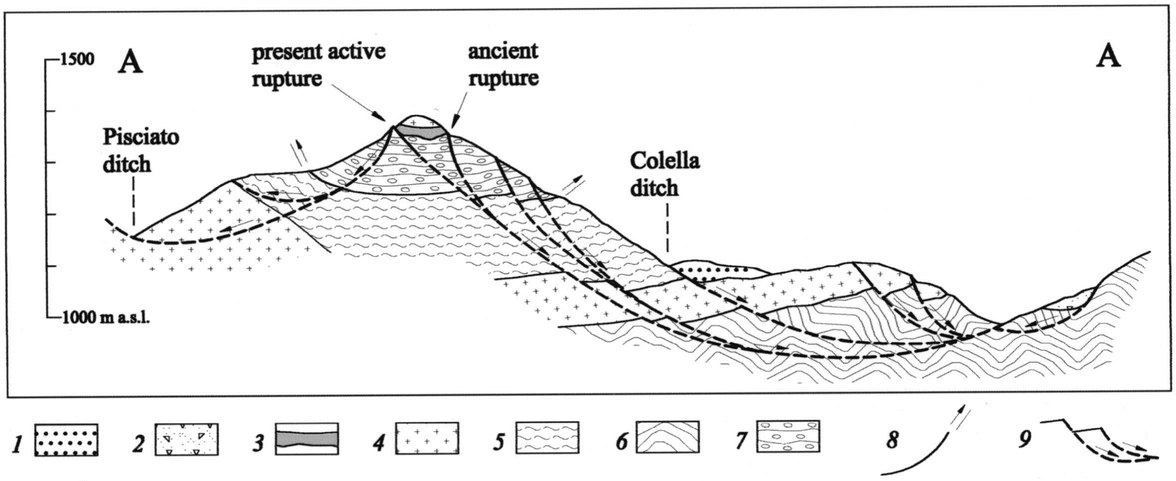

Fig. 20. Geological section of the Colella large landslide. 1. Landslide debris; 2. Eluvial deposit; 3. Sulphide bearing quartz dyke; 4. Granite; 5. Phyllite; 6. Biotite schist; 7. Augen gneiss; 8. Superposition tectonic contact; 9. Landslide body and versus of movement.

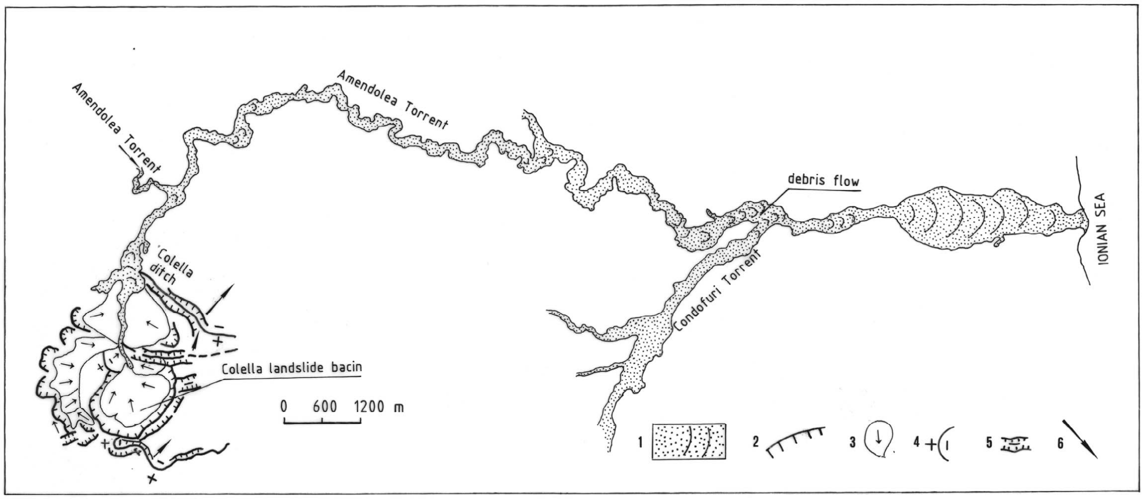

Fig. 21. Schematic planimetry of the Colella landslide basin, which feeds the long debris flow of the medium-low bed of the Amendolea torrent, as other landslide basins feed that of the Condofuri torrent. 1. Debris flow deposits; 2. Main landslide scarps; 3. Landslide body limit; 4. DSGSD rupture; minus sign points out lowered portion; 5. Main trench; 6. Main direction of stretch.

Almost in a sort of “continuum”, from the aforementioned DSGSDs, the large multiple slip, which originated at the head of the Colella ditch, evolved into a sort of long debris-flow filling the Amendolea river-bed, starting from the confluence with the Colella ditch (Fig. 21), (Guerricchio et al., 1996).

The deep underwater tectonic trench in the Ionian Sea, which borders the southern Calabrian coast, participates in the expansion phenomena of the Aspromonte slopes. Extensive and recent lateral spreads (lower order DSGSD) in Numidic Flysch quarzarenites (Lower Miocene), tectonically overlapping the SVC (Cretaceous), are framed, on which the built-up areas of Casignana, S. Agata del Bianco and Caraffa del Bianco rest (Guerricchio, 1986), (Figs 22 and 23).

An analogous situation applies for the town of Gerace, not far from these built-up areas (Fig. 24). Also in this case the SVC make up the unstable basement for the semirigid Plio-Pleistocene plate, on which the town rests. Confirmation that Ionian DSGSDs are from more recent epochs is given by the absence of Eutyrrhenian sea-level (120,000 years ago) with Strombus Bubonius, present, on the contrary, in the Tyrrhenian slope at Bovetto near Reggio Calabria, where it is displaced at more than 150 m a.s.l.. The activity of the mentioned gravitative movements, besides producing superficial local earthquakes, also increases coastal erosion phenomena, despite the notable solid transport of the previously mentioned torrents due to the slow and inexorable submersion of the coast (Guerricchio, 1989).

Fig. 22. Geomorphologic map of the lateral spreadings of Casignana, Sant'Agata del Bianco and Caraffa del Bianco (Aspromonte - Reggio Calabria province). 1. Trench; 2. Crown and scarp of landslide; 3. Landslide body limit and direction of movement; 4. Tilting; 5. Slump and slide; 6. Flow; 7. DSGSD rupture; 8. Line of geological section.

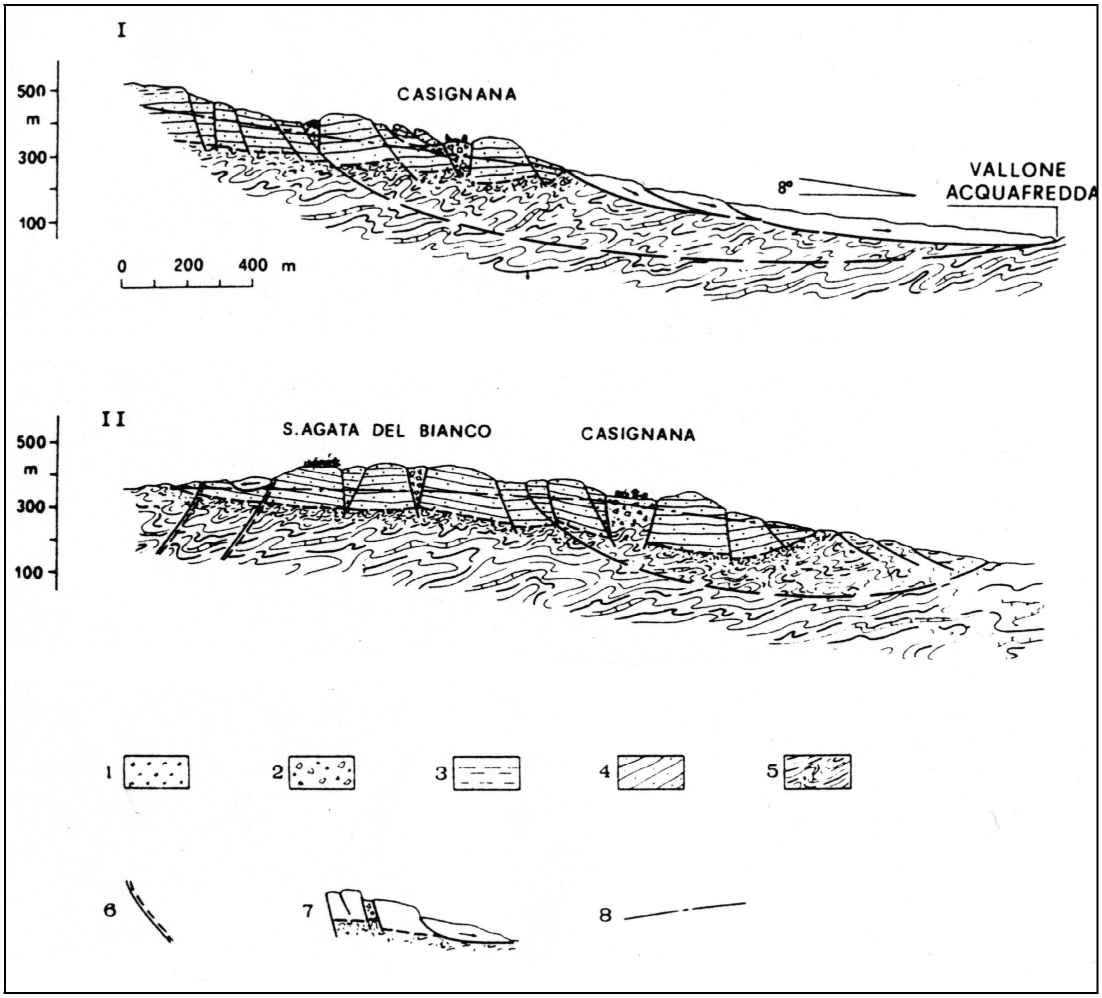

Fig. 23. Geological sections of Casignana (Aspromonte). 1. Eluvial-colluvial deposits. Recent; 2. Detritus filling trench. Recent-Holocene; 3. Grey silt, with thin arenitic intercalation. Lower Miocene; 4. Quartzarenite - Numidian Flysch. Lower Miocene; 5. Scaly Variegated Clays. Cretaceous; 6. DSGSD rupture; 7. Lateral spread, landslide body and direction of movement; 8. Piezometric surface.

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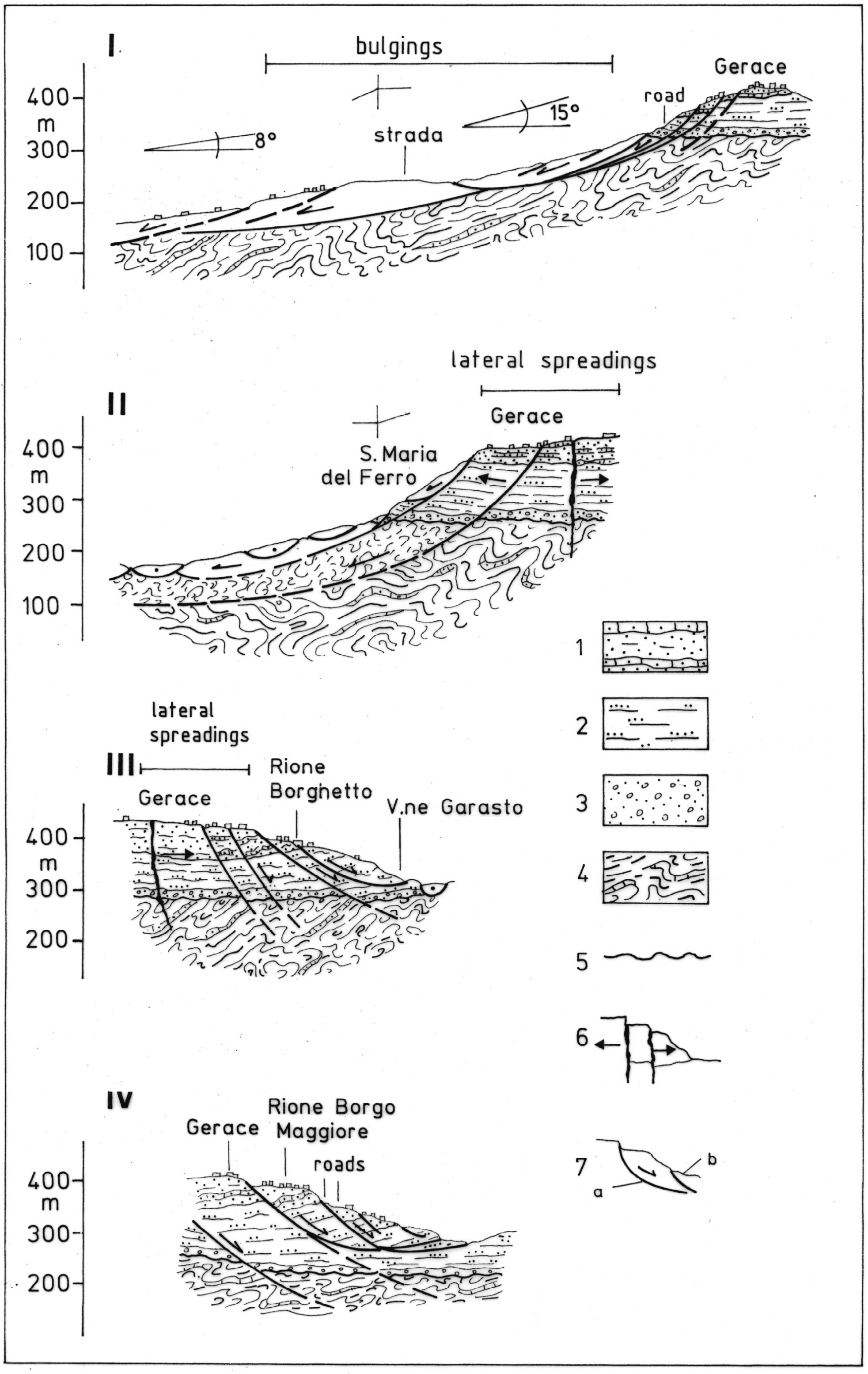

Fig. 24. Geological section of the DSGSD in Gerace hill. 1. Sand and sandstone with rare marly and conglomeratic intercalation. Calabrian; 2. Marly clay and marl. Middle-Lower Pliocene; 3. Polygenetic conglomerate with sandy intercalation. Lower Pliocene; 4. Scaly Variegated Clays, in a chaotic attitude. Cretaceous; 5. Unconformity. 6. DSGSD (lateral spreading) rupture; 7. Landslide body, versus of movement and rupture surface (a)

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