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SOME EXAMPLES OF DEEP-SEATED GRAVITATATIONAL SLOPE DEFORMATION AND LARGE-SCALE LANDSLIDES CAUSED BY TECTONIC UPLIFT IN TERRIGENOUS MATERIALS IN UMBRIA AND BOUNDERING AREAS

INDEX

ABSTRACT

Two examples of deep-seated gravitational slope deformations involving materials of complex behaviour (*sensu* Carrara *et al.*, 1987) are studied in this work. Rocks with complex behaviour are generally terrigenous rocks with sandy and marly alternation (generally flysch deposits). The evolution of these examples was caused fundamentally by movements of tectonic uplift which have occurred in the central areas of the Italian peninsular with a maximum in the lower Pleistocene.

The first zone is located in West Umbria and is represented by the alignment Poggio del Mandriano - M. Melonta where the sandy-marly sediments of the turbiditic formation of the Trasimeno Sandstone outcrop. Western slope presents certain morphological elements that indicate the presence of a D.G.S.D. The second zone is situated to the east of the town of San Sepolcro (northern Umbria) where the Unit of Monte Nero outcrops formed by an alternation of sand and marl in contact with the fluvial-lacustrine deposits of the Alta Valtiberina. Also in this case deep gravitational movements have been noticed accompanied by superficial deformation.

The aim of this work is not to present new cases of D.G.S.D., but to show up the morphological differences that such phenomena produce on lithotypes of complex behaviour with respect to lithic rocks. In fact although most of the D.G.S.D cases reported in the literature are found on this kind of rock, the undeniable existence of such phenomena on flysch type rocks, together with the widespread diffusion of these lithotypes makes their characterisation interesting with an end to their recognition on the territory. The presence of clay material may in fact increase the probability of the masses involved collapsing (sometimes breaking down into smaller portions) in shorter periods and under different conditions (such as depths of shear surfaces and less important relief energy) thus increasing the danger of the phenomena in these lithotypes.

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RIASSUNTO

Nel presente lavoro vengono esposti due esempi di dissesti gravitativi profondi che interessano materiali a comportamento complesso (sensu Carrara *et al.*, 1987) la cui evoluzione è stata pilotata essenzialmente dai movimenti di sollevamento tettonico che hanno interessato le aree centrali della penisola italiana con un massimo nel Pleistocene superiore. Con la dicitura "materiale a comportamento complesso" si intende un litotipo costituito da termini che mostrano risposte differenti alle sollecitazioni meccaniche (argilla e calcari o marne e arenarie).

La prima zona è situata nell'Umbria occidentale ed è rappresentata dall'allineamento Poggio del Mandriano – Monte di Melonta in sinistra del Fosso Migliari dove affiorano i sedimenti arenaceo – marnosi della formazione torbiditica delle Arenarie del Trasimeno. Il versante occidentale presenta alcuni elementi morfologici che testimoniano la presenza di una D.G.P.V. La seconda zona si colloca ad est del comune di Sansepolcro (Umbria settentrionale) dove affiora l'Unità di Monte Nero costituita da un'alternanza in rapporti differenti di arenarie e marne al contatto con la copertura fluvio-lacustre dell'Alta Valtiberina. Anche in questo caso sono stati riconosciuti dei movimenti gravitativi profondi accompagnati da dissesti superficiali.

Scopo del lavoro, oltre che presentare nuovi casi di D.G.P.V. è quello di evidenziare le differenze morfologiche che tali fenomeni assumono su litotipi a comportamento complesso rispetto ai litotipi a comportamento litoide. Nonostante infatti la maggior parte dei casi di D.G.P.V. riportati in letteratura si imposti su tali tipi di rocce, l'indubbia esistenza di tali fenomeni su rocce tipo flysch, unitamente all'alta diffusione di tali litotipi rende interessante una caratterizzazione al fine di un loro riconoscimento sul territorio. La presenza di materiale argilloso infatti può aumentare la probabilità che le masse coinvolte collassino (talvolta disaggregandosi in porzioni di dimensioni minori) in tempi più brevi e per condizioni differenti (tipo profondità della superficie di scorrimento ed energie di rilievo minori) aumentando così la pericolosità del fenomeno in tali litotipi.

KEY WORDS: Central Apennine, Deep-seated Gravitational Slope Deformation (D.G.S.D.), Landslide, Uplift, Terrigenous, Tectonic.

PAROLE CHIAVE: Appennino centrale, Deformazione Gravitativa Profonda di Versante (D.G.P.V.), Frana, Sollevamento, Terrigeno, Tettonica.

1. INTRODUCTION

Research for a direct relation between presence, typology of D.G.S.D., large-scale landslides and tectonic evolution of an area has been an object of study for a long time, even though it is still not quite clear (Crosta, 1996). If it is true that D.G.S.D. examples exist where the deformation surface is driven mainly by topography (Puma *et al.*,1989) in most of the cases the gravitational phenomena establish a relationship of consequentiality with the tectonic movement. Recognising the origin of these forms in the central Apennines may be very difficult (morphological convergence phenomena are frequent) for a similar orientation in the fields of gravitational and tectonic force. The stress following the extensional tectonic force, active in the central Apennines in the Pliocene as a result of the large-scale uplift, presents a maximum vertical compressive stress (σ_1) and a minimum horizontal stress (σ_3). Likewise in a slope (σ_1) is vertical while (σ_3) is directed towards the surface of free slope deformation (BARCHI *et al.*, 1993), without considering the previous stress history of the slope.

Taking into account the above, the tectonic uplift may be the predisposing or determining cause of the D.G.S.D. in three fundamental ways:

1) creating in the rock joints which, once begun, bring about the decline of the mechanical and physical characteristics of the rock independently of the stress field that gave it origin is still active or not;

2) causing deformations (folds and faults) as in the case of large scale uplifts, that cause zones of "weakness" where deformations can be triggered off;

3) indirectly involving the rock mass, like when the generalised uplift of a vast area causes a down cutting of the surface river drainage, with a consequent increase of relief energy (*sensu* CICCACCI *et al.*, 1988) and possible release of tectonic residued stress along the slopes (DRAMIS, 1984).

The aim of the following work is to characterise the D.G.S.D. phenomena and large-scale landslides on terrigenous lithotypes of complex behaviour (alternation of rocks different behaviour, *sensu* CARRARA *et al.*, 1987) in relation to the tectonic evolution of the area. In fact, in spite of the fact that these events occur mostly on lithoidal lithotypes (limestone and metamorphic rock) as shown in most of the reported cases in the literature, there are still, even though very rare, some examples in sandy and marly alternating terrigenous rock (CALABRESI *et al.*, 1995; COLTORTI, 1985; CRESCENTI *et al.*, 1994; D'AMATO AVANZI *et al.*, 1995; DRAMIS *et al.*, 1987; DRAMIS *et al.*, 1988; DRAMIS & SORRISO-VALVO, 1994; GENEVOIS & TECCA, 1984).

The less widespread diffusion in turbiditic rock can be accounted for two factors:

1) less favourable predisposing conditions, like lower acclivity of the slopes. In particular lithotypes of brittle behaviour can make, at the same conditions, higher slopes than those made by prevalently marly lithotypes;

2) a lesser marly lithotype conservativity. Forms indicating the phenomenon, like trenches, upward-facing scarps, double ridges, do not last for a long period, but modify rapidly assuming characteristics very different from those of the lithotypes with brittle behaviour (CAVALLIN *et al.*, 1987; DRAMIS & SORRISO-VALVO, 1994).

We choose the two following examples, as sample areas of the present situation in the central Apennines with regard to terrigenous lithotypes of complex behaviour, because they present the typical deep-seated gravitational deformation characteristics - intensely tectonic zones, medium-high values of relief energy, higher density of landslides - and because, despite the two areas are geographically independent, the deformations present the same characteristics, which has led to following considerations.

2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The first area is situated in western Umbria, west of M. Peglia (F. 130 map "Orvieto") and is represented by the southern alignment of Poggio del Mandriano (607 m. a.s.l.) – M. Melonta (623m.)

The second area is situated on the F.115 map "Città di Castello" where the mountains of the Alpe della Luna are boundering with the plain of the Alta Valtiberina to the west and includes the hydrographic basins of Rio Valdimonte and T. Vertola (fig.1).

2.1 **Melonta area**

Marine deposits outcrop from the Tuscan domain formed, from below upwards, of the *Insieme varicolori* and *Arenarie del Trasimeno* (DAMIANI, 1992). The second unit overlaps the other with low-angle inverse faults (DAMIANI *et al.*, 1993). The *Insieme varicolori* (Eocene- up Oligocene) is a clay-limestone sequence that, going upwards, includes a grey basal calcareous unit, an intermediate grey marly-calcareous one with reddish clay, and an upper unit, made prevalently with polychrome clay. In the study area it outcrops only on the eastern side of the ridge where clay portion predominates, reduced by fracturing into tiny thin elements. Above the *Arenarie del Trasimeno* (Up Oligocene. – Low Miocene) usually outcrops in stratigraphical continuity, except for the northern section (Settano area) where the contact is partly tectonic. These flyschioid sediments are formed by prevalent quartz-feldspathic sandstone in few decimetres layers and rare banks of 1-2 m, with thin marly-pelitic layers. The bedding has a monocline attitude with dip direction between 270-290° and variable dip between 15 and 60°. On the western slope, between 525-530 m. above a.s.l., dip increases up to 85° and then returns between 15° and 60°.

The north-eastern border of the area is marked by a tectonic dislocation oriented to a NW-SE direction (fig. 2). This dislocation, where the Migliari trench, principal collector of the area, undergoes a strong deviation, is responsible for the uplift of the southern part of the territory (CATTUTO *et al.*, 1988).

The western slope of the relief is characterised by the presence of "blocks" of large dimensions, separated from the crest by aligned saddles. Rivers with frequent sharp curves, contribute to delimitate these blocks. The blocks present characteristics similar to those further south (Pod.

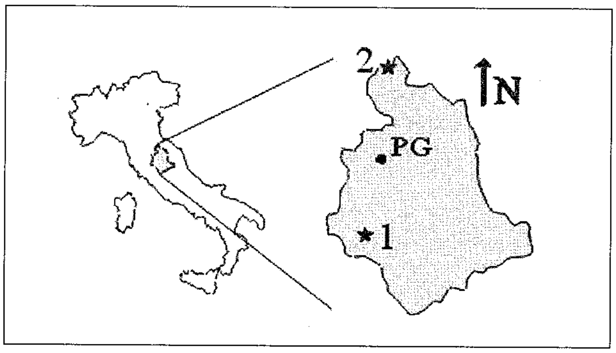

Fig.1 – Location map.

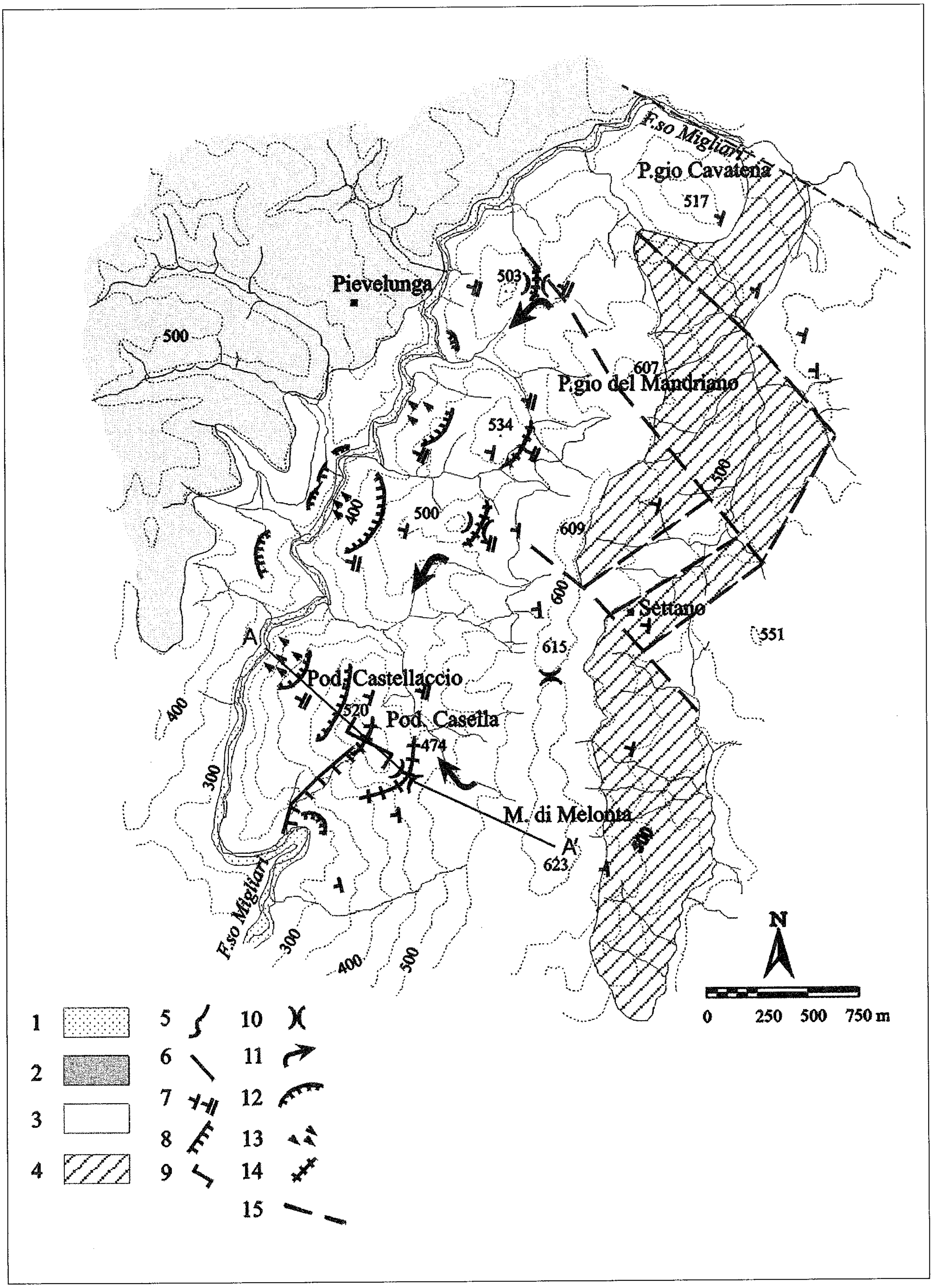

Fig. 2 – Geological scheme with geomorphologic elements of Melonta area. (1) Ancient and recent lacustrine and alluvial deposits (Pleistocene - Holocene); (2) marine deposits (Pliocene); (3) Arenarie del Trasimeno Formation (Oligocene-Miocene); (4) Insieme varicolori Formation (Eocene-Oligocene); (5) stratigraphical boundary; (6) uncertain main discontinuities (fault or joints) inferred from morphological elements; (7) strike and dip of bedding; (8) scarp; (9) planoaltimetric discontinuity; (10) saddle; (11) stream deviation; (12) landslide zone of depletion; (13) landslide main body; (14) trench; (15) cross section location.

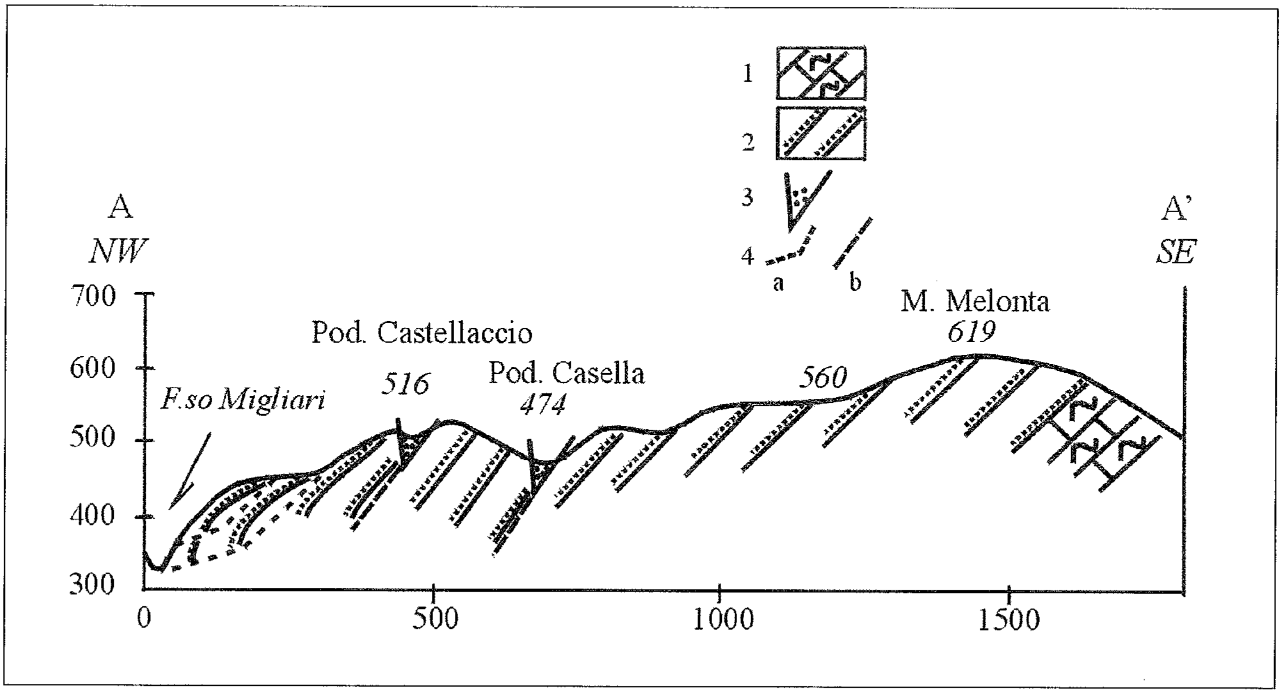

Fig. 3 – Geological cross section of the Col di Raso slope. (1) Arenarie del Trasimeno Formation; (2) Insieme varicolori Formation; (3) trench; (4a) presumed superficial failure surface; (4b) presumed deep failure surface.

Castellaccio – 529 m). These are separated from the upside-area of M. Melonta by a depression (Pod. Casella – 474 m), under a scarp that goes down to the river-bed of the Migliari River. The ridge of Pod. Castellaccio presents a planoaltimetric discontinuity which separate two long depressions full of debris material which extend on the slopes of both sides. There are no kinematics evidences or lithological discontinuity to explain planoaltimetric discontinuity as faults or lithoselection example. The declivity towards the west presents a longitudinal concave profile in the summit part and convex in the lower part. The relief of Pod. Castellaccio therefore seems to collapse towards the valley and this can be due to large-scale gravitational deformation (fig.3).

The principal break area is aligned with the saddles, where the dipping of bedding is accentuated. This can be interpreted as trenches. The fragmentation of bedrock in blocks by the faults and/or joints (without kinematic evidences of a significant fault along alignment depressions), the presence of more plastic pelitic levels, the dipslope bedding contribute to the local phenomena of the differential slipping of the blocks downwards and the formation of steep slopes and trenches. Finally, the plastic deformation of the rock mass can be attributed to stratification curving and bulging at the foot of the slope. The west side of the relief is marked by extensive superficial gravitational deformation.

2.2. **Sansepolcro area - Alpe della Luna**

In this area parts of the *Unit of Monte Nero* (Umbria-Marches domain, Aruta *et al.*, 1998) outcrops in NE verging synclinals formed by an alternation of sandy and marly elements in different reciprocal ratio. *The Unit of Monte Nero* (lower Miocene – middle Miocene) is represented from the bottom upwards by calcareous marly base sequences (*Bisciaro, Schlier Formations*) followed by more than 1.000 m thick Langhiano – lower Serravalliano unit. This marly-sandstone unit is subdivided into three members (fig.4).

The first (member A, age between upper Burdigaliano and lower Langhiano) formed from mixed turbidites coming from NW, has a sand/marl ratio less than 1. The second (Member B age Langhiano) has a sand/marl ratio greater than 1. Rock is arkose turbidites and the thickness is 185 m. The feeding was coming from SE into a narrow and long depression, identified along the western border of the basin of the formation of the marly – sandstone. In the third, Member C (age Langhiano – Serravalliano), the sand/marl ratio goes back to less than one. The sand/marl ratio is reported in order to understand the importance of clay for the probability of the presence of these phenomena. The bedrock towards south-west is in contact with fluvial-lacustrine deposits of the Alta Valtiberina deposited after the tectonic uplift in the Pleistocene (Ambrosetti *et al.*, 1982). As a result rivers like T. Vertola or R. Valdimonte had to cut into their beds to reach a new equilibrium to compensate gravitational disequilibrium along the slopes. The tectonic uplift and evolution of the area is still active as is shown in recent neo-tectonic studies as well by present seismic activity in the area (Boncio *et al.,* 1998).

The most important gravitational deformations have been noticed in Member A where relief energy is usually high, (more than half of the territory is between 200 and 300) and the tectonic activity has significantly conditioned the mechanical behaviour of the rocks. Plastic deformations are present, like the two anticlines along the left slope of Rio di Valdimonte, and the whole rock mass is interested by two joint systems (S_1, direction NNW-SSE and inclination about 80° and S_2 NE – SW, with same inclination). The superficial slide-tendency is medium-high (density of superficial frequency 3%), the deformations are mostly

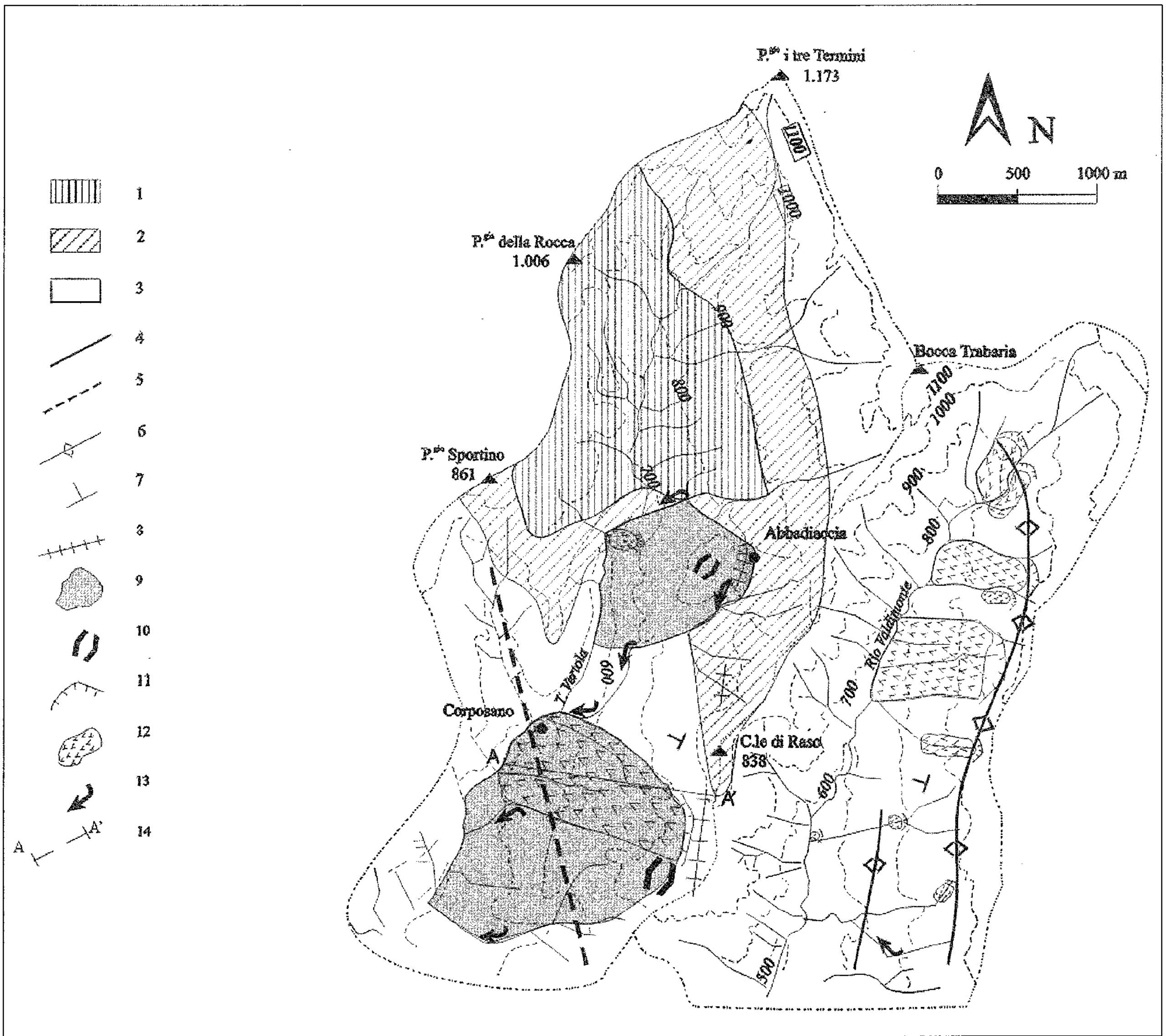

Fig. 4 - Geological scheme with geomorphological elements of Sansepolcro - Alpe della Luna area. (1) Unità di Monte Nero Formation - Membro C (Langhiano p.p. - Serravalliano); (2) Unità di Monte Nero Formation - Membro B (Langhiano p.p.); (3) Unità di Monte Nero Formation - Membro A (Burdigaliano - Langhiano inf.); (4) stratigraphical boundary; (5) uncertain main discontinuities (fault or joints) inferred from morphological elements; (6) anticline axial trace; (7) strike and dip of bedding; (8) trench; (9) large-scale landslide or D.G.S.D. main body; (10) area in extension; (11) landslide zone of depletion; (12) superficial landslide main body; (13) stream deviation; (14) cross section location.

found on the slopes with dip slope attitude. The left slope of the Rio Valdimonte is significant because its inactive or quieting movements are superficial, and cover the whole surface of the area from the top to the connection with the southern plain. To the left of the T. Vertola an example of a probable deep-seated deformation has been found in the area of Colle di Raso with dip slope layer arrangement. In correspondence with the top area of both the phenomena there are long depressions parallel with the slope filled with detritus alteration material interpreted as trenches. The Colle di Raso case covers an area of about 3 km^2. The height of the slope is 380 m.

Morphologically there are strong variations in declivity, particularly in the top part (fig. 5). It can be considered as a very complex large landslide (ca. 1.230 m maximum length by a maximum width of 510 m) now quieting. In the medium-low part of the slope sandy blocks outcrop frequently, detached from the bedrock, and superficial and recent landslides are present in the lower part of the slope involving material from the larger landslide. The landslide comes into the category of deep-seated gravitational deformations with a deformation surface calculated at about 50 m deep.

The phenomenon in the area of Abbadiaccia instead is situated on Limb B of the Unit of Monte Nero. It is characterised by a higher relief energy (about 70% of the zone has values between 200 and 300) and by a higher percentage of sandy elements. This means a lesser tendency to slide whilst the only recognised gravitational phenomenon presents characteristics more similar to those typical of cases on lithotypes of lithoidal behaviour. The area extends to about 0.7 km^2, with a difference in level of about 300 m. The slope in this example has zones of different acclivity, upward-facing scarps and significant anomalies of the river

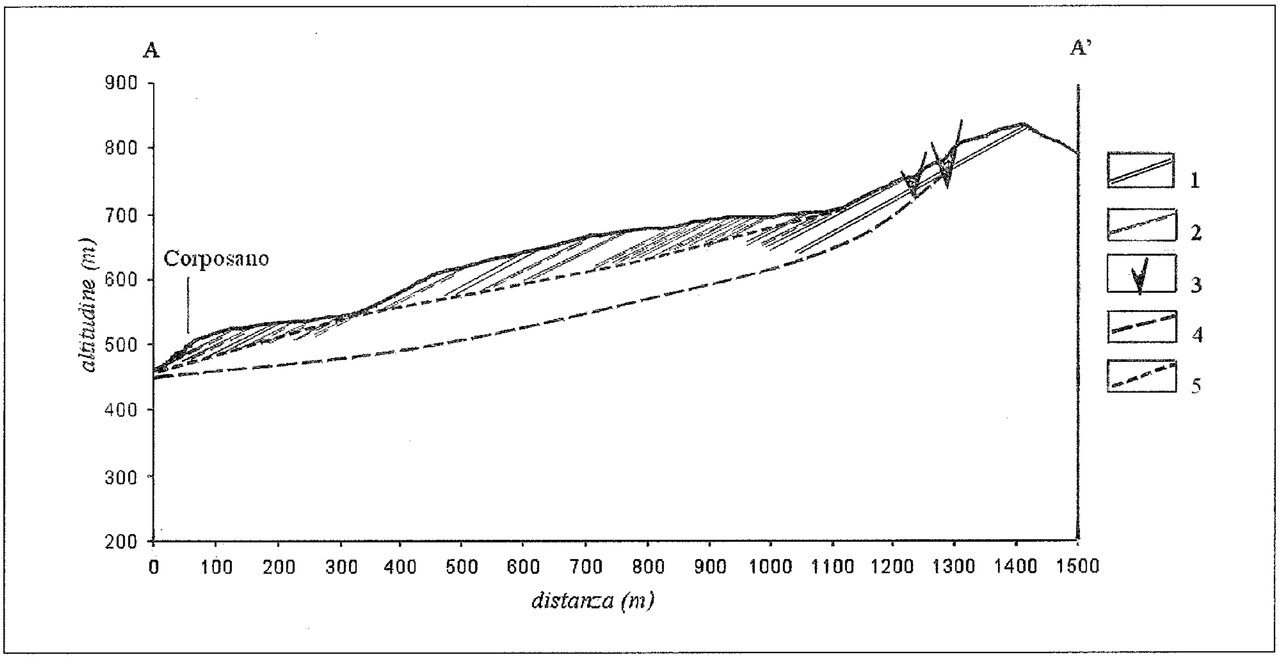

Fig. 5 - Geological cross section of the Col di Raso slope. (1) Prevalent sandstone layer ; (2) prevalent marly layer; (3) trench; (4) presumed superficial failure surface; (5) presumed deep failure surface.

track with the poles of the trenches along the slope parallel to it instead of being deposited along the line of greatest incline. Furthermore the example presents a superficial landslide at the bottom of the slope.

3. DISCUSSION

On the basis of what has been observed in the two areas and from an analysis of the examples reported in the literature (MELELLI, 1998) an attempt can be made to show up the differences and analogies from a morphological point of view that the D.G.S.D. present in terrigenous materials with respect to materials of lithoidal behaviour, as follows:

1) the mostly dipslope layer arrangement is to be found in both lithotypes;

2) shallower surface depths of deformation are statistically (CRESCENTI *et al.*, 1994) more frequent for lithotypes of complex behaviour as the marly levels facilitate the deformation of the masses above even at lower depths (and therefore lithostatic pressure);

3) lower relief energy in the case of materials of complex behaviour;

4) a more diffused superficial landslide tendency in rocks of complex behaviour;

5) a greater presence of anomalies of the river drainage in the rocks of complex behaviour caused by the presence of marly-clay materials. In fact, the drainage density is higher with a consequent increase in the probability of finding anomalies in the hydrographic track;

6) a different aspect of characteristic morphotypes. While in the lithoidal rocks there are more morphotypes that lead to suppose a greater conservativity of the lithotype like steep slopes, gulls and tension cracks, in the rocks with a high clay content bulging, upward-facing scarps and trenches are more frequent (MELELLI, 1998). The latter, unlike lithotypes of lithoidal behaviour, do not come about by means of narrow depressions and steep sides filled with detritus, but in particularly ample flat areas parallel to the slope. The profile of the slope is therefore articulated, from mountain to valley with short and steep slopes followed by a vast flat area, while the lower part is often subject to swelling and can be divided into a series of smaller zones sometimes with landslides *s.s.*

Selective erosion is excluded as a cause of the forms in the examples because there is no correspondence between attitude, power of the beds and mechanical characteristics of the rocks and the forms found. On the contrary, gravity is considered the principal cause of the morphogenesis because: the scarps of the detaching area are concave towards the bottom and are present only in the area subject to deformation; the rock appears broken; the surface hydrography presents frequent track anomalies and the morphology of the whole slope is similar to that of a landslide *s.s* (but different in dimension and lacking of a sliding surface visible on the surface or directly deducible from the evidence, SORRISO – VALVO, 1995) if we interpret the steep slopes and flat areas as areas in extension and those subject to bulging at the base in compression. The tectonic activity can be invoked directly or indirectly at the beginning and in the continuation of the phenomenon.

4. CONCLUSION

Central Italy presents numerous elements which favour the triggering off and the persistence of D.G.S.D and large-scale landslides. First of all tectonic activity is considered both a predisposing and determining cause. In particular tectonics, active or inactive, may influence the mechanical behaviour of the rocks increasing the degree of fracturing and so diminishing cohesion or causing deformation in the rock mass at the moment in which it acts (folds, faults) forming zones of weakness where deep-seated gravitational phenomena will be easily set off. Finally tectonics can indirectly create predisposing conditions for gravitational collapse. This append when large-scale uplift induces the down-cutting of the drainage network, increasing relief energy on the slopes (DRAMIS, 1984).

In this study we have described two areas with D.G.S.D. and large-scale landslides brought on by plio-pleistocenic tectonic uplift. The two areas were chosen on flysch lithotype terrain (sand and marl alternation) to show up the differences, from a geomorphologic point of view, between lithotypes with lithoidal behaviour and lithotypes with complex behaviour. Most of literature example are on brittle and fractured rocks (29,3%) or on brittle rocks over plastic terrain (36,6%). Examples in rocks with complex behaviour are only 14,6% (CAVALLIN *et al.,* 1987) because of less favourable predisposing conditions and a lesser conservativity of the marly lithotype.

The following conclusions have been drawn from the reported examples and from literature (CROSTA & TUCCI, 1995):

1) the phenomena are found on slopes with dipslope arrangement of layers with an inclination of the layers that sometimes increases towards the valley;

2) under the ridge inclination variations can be observed represented by cliffs and small flat areas, parallel to the slope and slightly concave towards the valley (plain) followed immediately by a flat area of larger dimensions. Debris material produced by bedrock decay emerges in all the flat areas;

3) slope profile at the bottom can be convex and is often involved by surface landslide phenomena.

The genesis of the forms is therefore gravity because:

a) kinematic elements like fault are not present. Tectonic influence is evident only by joints that bring about the decline of the mechanical and physical characteristics of the rock;

b) selective erosion determines these forms only on slope with horizontal attitude of layers or in flat inclinations. Furthermore the height of the layers is not corresponding with the width of flat area or cliffs;

c) in some examples (MELELLI, 1998) the landscape evolution trend follow the slide surface trend, so the flat areas are not in conformity with superficial layers attitude (direction);

d) in literature gravity is the major cause of similar forms (D'AMATO AVANZI & PUCCINELLI, 1996);

e) cliffs and flat areas are concave toward the bottom of the slope;

f) cliffs and flat areas are present only in the area recognized like D.G.S.D. These forms are not present along other part of the slope with the same lithological characteristics;

g) river at the bottom of the slope turns always near D.G.S.D.;

h) drainage network along slope with D.G.S.D presents minor rivers parallel instead of orthogonal to slope;

i) superficial landslides are always present like in other D.G.S.D. literature examples (PUMA *et al.*, 1989; SOLDATI & PASUTO, 1991).

Moreover, movement or deformation desegregates more easily from a lithoidal mass, favouring surface landsliding especially at the bottom of the slope where the undermining action of the water courses has more effect.

Taking in account this, the flat areas on the high part of the slopes can be considered trenches, which unlike lithoidal lithotypes, are not narrow depressions filled with more or less recent debris.

All other conditions being equal, the conclusions point out a greater danger of large-scale gravitational deformation in materials of complex behaviour. The presence of clay can in fact accelerates the evolution of the slope in deformation towards the final collapse and render more probable, if combined with a high degree of fracturing, the desegregation of the mass involved in smaller dimensions and higher degrees of instability. Moreover the low conservativity of lithotypes with a high clay-marl percentage makes it more difficult to recognise a gravitational genesis.

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