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GRAVITATIONAL SLOPE DEFORMATIONS NEAR THE ABETONE PASS (TUSCAN-EMILIAN APENNINES)

ABSTRACT: CAREDIO F., CASTALDINI D. & PUCCINELLI A., *Gravitational Slope Deformations near the Abetone Pass (Tuscan-Emilian Apennines)*. (IT ISSN 0391-9838, 1996).

In this paper some Deep-seated Gravitational Slope Deformations (Dgsd), identified in the Rio delle Pozze valley near the Abetone Pass, are for the first time described. These deformations are developed in competent rock types (sandstone layers with argillite intercalations belonging to the Macigno Formation) and are characterised by a dominant structural control (NW-SE and SW-NE oriented faults). From the geomorphological viewpoint they show double ridges, trenches, concavities and reverse slopes. The Dgsd typologies correspond to rock flows (*Sackungen*).

On the eastern slope of Monte Gomito (located in the adjacent Torrente Motte valley) the same geomorphological features shown by the Rio delle Pozze valley Dgsd have been surveyed. These landforms, which were analysed with respect to the structural characteristics of the zone, are here considered as the surface expression of an incipient rock slide. It is therefore an example of «geomorphological convergence» within the framework of slope gravitational processes.

KEY WORDS: Deep-seated Gravitational Slope Deformations, Rock slide, Abetone Pass, Tuscan-Emilian Apennines.

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In questo lavoro vengono segnalate per la prima volta alcune Deformazioni Gravitative Profonde di Versante (Dgpv) individuate nella valle del Rio delle Pozze in prossimità del Passo dell'Abetone. Esse si sviluppano in litologie competenti (banchi di arenarie con interstrati argillitici, appartenenti alla formazione del Macigno) e sono interessate da un predominante controllo strutturale (faglie orientate NW-SE e SW-NE). Da un punto di vista geomorfologico sono tutte caratterizzate da sdoppiamenti di cresta, *trenches*, concavità e contropendenze. La loro tipologia è da ricondursi alle colate di roccia (*rock flows, sackungen*). Nel versante Est di Monte Gomito (ricadente nell'attigua valle del Torrente Motte) sono stati rilevati gli stessi caratteri geomorfologici che accompagnano le Dgpv della valle del Rio delle Pozze. Tali morfologie, dopo lo studio delle caratteristiche strutturali della zona, sono state qui ritenute come l'espressione superficiale di uno scivolamento traslativo di roccia ad uno stadio incipiente. Si tratta quindi di un esempio di «convergenza geomorfologica» nell'ambito dei processi gravitativi di versante.

TERMINI CHIAVE: Deformazioni Gravitative Profonde di Versante, Scivolamento traslativo di roccia, Passo dell'Abetone, Appennino Tosco-Emiliano.

FOREWORD

The area investigated is located on the Po Valley side of the Tuscan-Emilian Apennines, within the catchment basin of the River Panaro, SW of the Abetone Pass (Province of Pistoia), next to the main watershed (fig. 1). More in detail, in three areas of the Rio delle Pozze valley double ridges, concavities and reverse slopes which were analysed with respect to structural characteristics, have been interpreted as the surface expression of Deep-seated Gravitational Slope Deformations (Dgsd). In the upper part of the eastern slope of Monte Gomito (located in the Torrent Motte valley, immediately to the east of the Rio delle Pozze valley), the same geomorphological features were identified. Nevertheless, the different structural characteristics of the zone suggested that these features have resulted from a rock slide at an incipient stage. It is therefore an example of «geomorphological convergence» within the framework of gravitational slope processes.

The particular geomorphological features had already been noticed by DESIO (1927) who wrote: «...there are some peculiar and interesting doline-shaped cavities which are usually found on ridges; ... they correspond to rather elongated concavities or funnel-like depressions». He also added: «... they are always found above the areas which had been covered by glaciers; therefore their origin cannot be attributed to the ice erosive action». This Author considered the existence of these depressions as derived from

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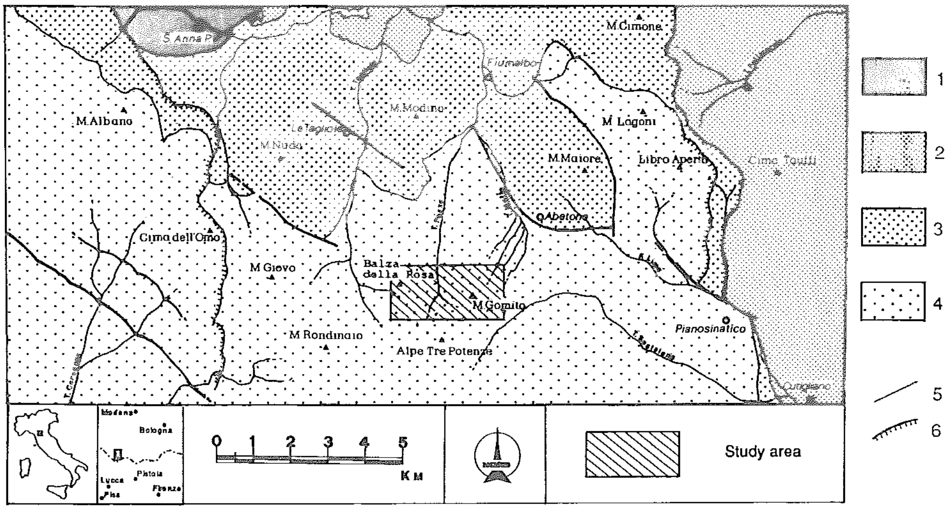


FIG. 1 - Tectonic schetch and location of the study area. Legend: 1) Ligurian Units; 2) Mt. Modino Unit; 3) Mt. Cervarola Unit; 4) Tuscan Sequence; 5) fault; 6) overthrust.

two different processes: 1) selective erosional processes in arenaceous rock types with argillaceous intercalations which may act differently on the two rock types; 2) karst processes, locally developed owing to the presence of calcareous cement in these arenaceous formations (calcareous sandstones).

In this paper the above mentioned gravitational deformations are described in detail and their structural characteristics, geomorphological features, typology and causative factors discussed.

GEOLOGICAL SETTING

Among the various Authors which most significantly investigated the geology of this sector of the Northern Apennines, the following should be quoted: GÜNTHER & RENTZ (1968), SERVIZIO GEOLOGICO D'ITALIA (1968), AUTORI VARI (1980), NARDI & *alii* (1981), ABBATE & BRUNI (1987) and GELMINI (1992). For a more detailed pictures on the regional geology of the Gelmini area, these Authors should be consulted.

Here after the essential stratigraphical and structural characteristics of the study area are illustrated: they make up the primary factors of the slope phenomena due to gravity described in this article.

In the area investigated the Macigno Formation, belonging to the Tuscan Sequence, crops out (= «Falda Toscana» Auctt., cf. fig. 1). It is made up of turbiditic, graded quartz-feldspar sandstones showing a NNE dipping monocline attitude, with angle around 20°; at the top of the turbiditic interval argillaceous, siltitic and marly-siltitic levels are often found, with a sandstone/pelite ratio approaching 1. The sandstones, considered as litho-arenites, are characterised by a great abundance of quartz and, secondarily, of feldspars; rather frequent are biotite, granates, zircon and tormaline; among lithic components, metamorphic and sedimentary rocks are found, as well as vulcanites. The formation thickness, of which only the upper portion crops out, is about 2,000 metres. Its age is Middle-Upper Chattian to Upper Chattian (DALLAN & *alii*, 1981). According to CATANZARITI & *alii* (1991), its top reaches the Aquitanian.

GEOMORPHOLOGICAL SETTING

On the whole, the Northern Apennines are a NW-SE oriented mountain chain; in the study area, though, the main ridge does not follow a linear trend but is characterised by the peculiarity of being in many places segmented and shifted to the east, along a series of vicarious reliefs always aligned in the same direction. The transversal profile of the Apennine range is asymmetrical, with a rather steep and rugged Tyrrhenian side, since it was modelled on dip-upstream strata, whereas the Adriatic one is much smoother and regular since it was prevalently shaped on dip-downstream strata.

The influence of the structural characteristics on the slope morphology is particularly relevant in the upper part of the Rio delle Pozze valley and on the NE face of Monte Gomito (located in the adjacent Torrente Motte valley), where the slope inclination coincides with that of the strata, thus corresponding to structural surfaces. Moreover, the higher erodibility of the clayey and silty intercalations determined the modelling of steps and reverse slopes upstream of which water stagnations and ponds were formed, afterwards filled by palustrine deposits. In this sector of the upper Apennines the evidence of glacial traces is quite common and is represented by both erosion (glacial cirques and *roches moutonnées*) and deposition (moraines, moraine ridges) forms. Also landforms derived from successive periglacial processes are widespread, although in some cases they are coeval with the last glaciation; they are: avalanche cones and tracks, block streams, protalus ramparts, block fields, nivation hollows and gelifluction deposits.

The most typical slope landforms, derived from the weathering of arenaceous rocks due to ice shattering, are scree slopes and talus cones, usually located at the foot of the numerous structure-controlled scarps.

The watershed areas are locally characterised by double ridges, trenches, concavities and reverse slopes. After analysing their structural characteristics, these morphological features have been interpreted in some cases as the surface expression of «Deep-seated Gravitational Slope Deformations» (Dgsd) and, in another case, as the evidence of a rock slide at an incipient stage. In correspondence with depressions determined by concavities, reverse slopes and trenches, water stagnation zones partially filled with palustrine deposits are found in places.

The action of surface running water is mainly represented by slopes affected by rill wash, gullies, colluvial fans, debris flow lobes, small V-shaped and flat-bottom valleys, and by alluvial deposits and torrential scarps on the valley floors.

Also anthropogenetic landforms mainly linked to winter tourism, which has been particularly accentuated in the past decades, are widespread. Its expansion has in fact determined several cases of excavation and landfill areas which in some places have altered the original morphology. Moreover, the construction of ski tracks has produced the deforestation thus exposing some areas to rillwash erosion. For more detailed information on the geomorphological characteristics of the Abetone Pass area, see CASTALDINI & *alii* (in press).

DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS

Three cases of Deep-seated Gravitational Slope Deformations surveyed on the upper portion of the slopes in the Rio delle Pozze valley are here described. Two of them are located on the left-hand side of the valley (one near Balza della Rosa and the other about 1 km to the south of the former) whereas the other is found on the right-hand side of the valley (SW slope of Monte Gomito). The geomorphological characteristics of the study area are shown on the geomorphological maps of figs. 2 and 7, elaborated

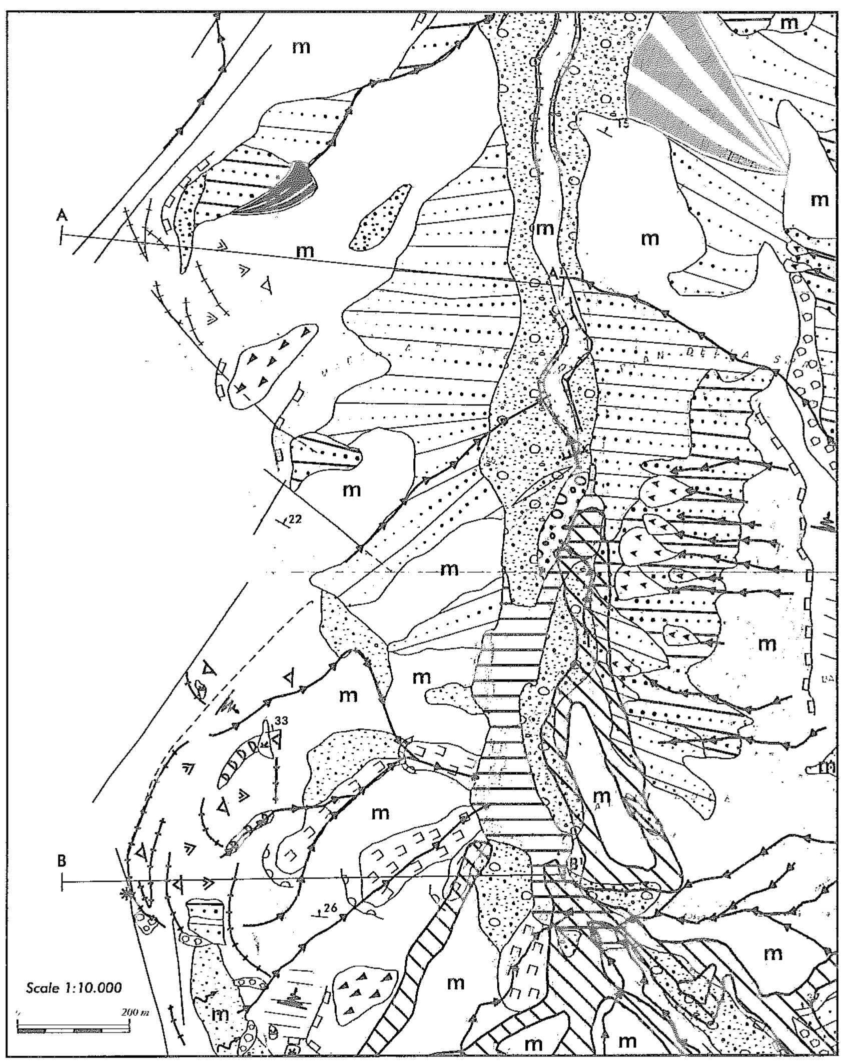


FIG. 2 - Geomorphological map of the western sector of the study area (cf. Legend in fig. 3).

on the basis of the legend set up by GRUPPO NAZIONALE GEOGRAFIA FISICA E GEOMORFOLOGIA (1993) (cf. fig. 3).

The left-hand slope of the Rio delle Pozze valley

These two cases of deep-seated gravitational slope deformations are grouped and described together since not only they show the same geomorphological features but they are also conditioned by the same normal fault systems.

The faults, identified in the upper slope portion (fig. 2 and A-A', B-B' in fig. 4), show two main trends: Apennine and anti-Apennine which, by intersecting each other, form an angle of about 90° to 100°. The Apennine trend, between N140° and N170°, is the most important and is widespread all over the Northern Apennines. In the areas north of the River Arno it is ascribable to the Lower Pliocene (age of the lacustrine basins of Lunigiana and Garfagnana). The anti-Apennine trend, between N30° and N60°, is less common. The latter could be coeval with the former and originated along the transcurrent fault planes formed during the compressive tectonic phases which occurred before the Upper Miocene. The fault planes, as can be observed near Balza della Rosa, are nearly vertical. From the analysis of the striae found on their surfaces, an extension-type movement, with a prevailing vertical component, was deduced.

The geomorphological features, observed in the upper parts of the slope in both cases of Dgsd, are trenches, concavities, double ridges and reverse slopes (figs. 2, 5 and 6), which are aligned parallel to the above described tectonic systems which have NW-SE and NE-SW trends. Also the zig-zagging ridge direction is influenced by this tectonic restraint.

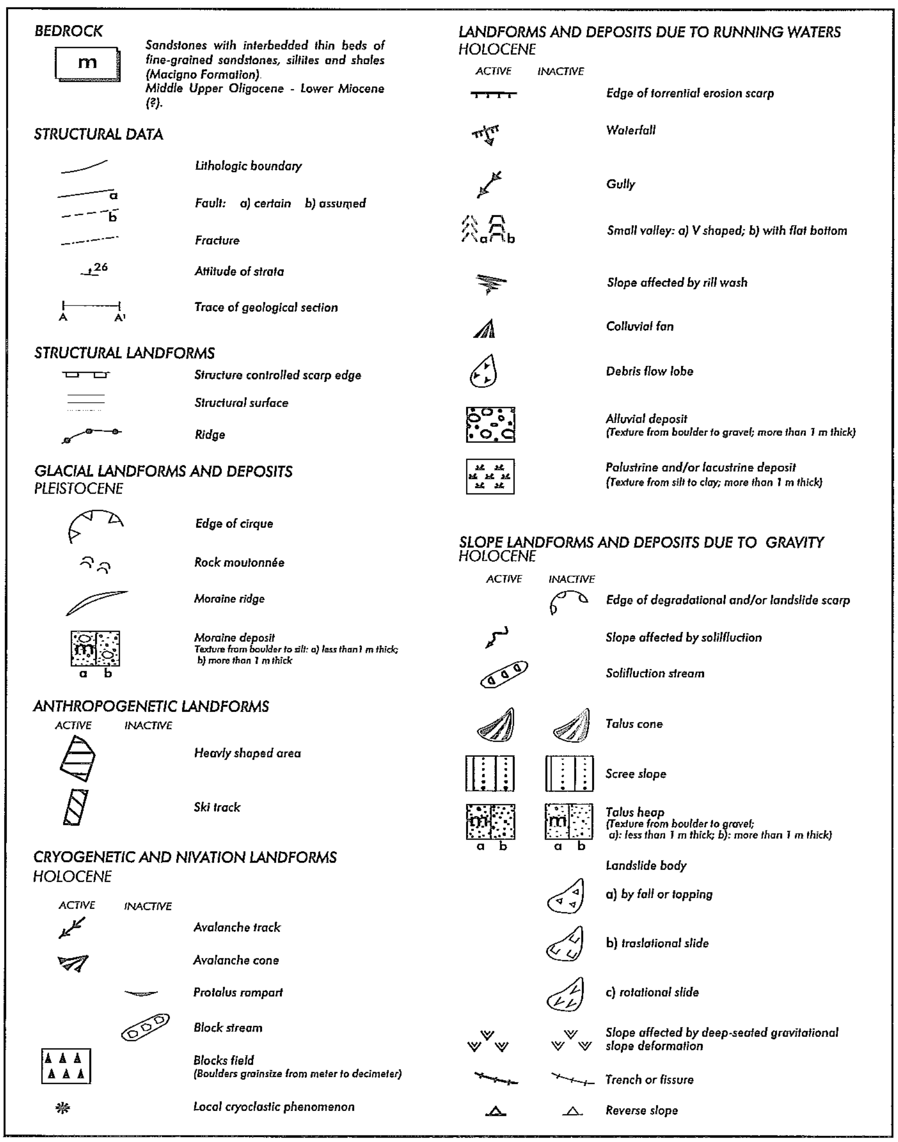
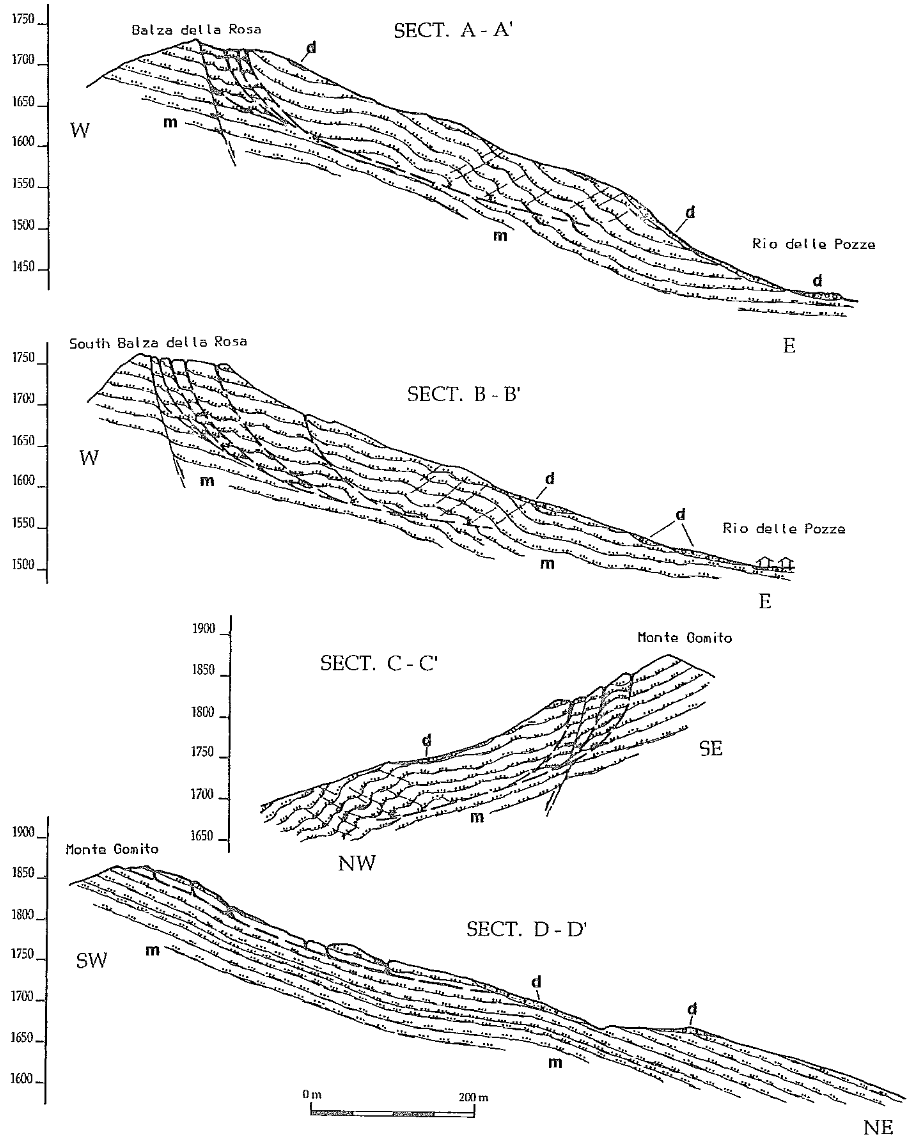


FIG. 3 - Legend of the geomorphological maps of figs. 2 and 7.

FIG. 4 - Geological sections (section traces are shown in figs. 2 and 7). Legend: m = Macigno Formation; d = Quaternary deposits.



Along these tectonic discontinuities portions of the slope were released; their geomorphological features are observable between about 1,730 m a.s.l. and 1,650 m (near Balza della Rosa) and between about 1,770 m and 1,660 m (in correspondence with the Dgsd located 1 km to the south). On the basis of the areal distribution of the geomorphological features, the latter seems to affect a larger slope portion compared with the one found near Balza della Rosa. Furthermore, the first case examined does not seem to show any sign of activity, since all trenches are filled by gravity and rillwash deposits, whereas the presence of gaping trenches in the second case points to a still active deformation.

The two phenomena investigated have been defined as «rock flows» on the basis of the description provided by DRAMIS & SORRISO-VALVO (1994) and BISCI & *alii* (1996). The definition was reached after considering the following list of characteristics: 1) the size and thickness of the rock masses; 2) the lack of a net boundary surface between rocks both affected and unaffected by the movement; 3) the modest dimensions of the displacements with respect to the size of the rock masses involved; 4) the presence of trenches, double ridges, concavities and reverse slopes in the upper portion of the slope; 5) the particular geological structure.

In both cases, in the lower portion of the slope the thick vegetation and debris cover do not allow any particular feature to be identified, such as the presence of sub-horizontal shear surfaces at the base of folds with an axis parallel to the valley direction. In other areas some authors attributed these features to slopes affected by compressive deformation (D'AMATO & *alii,* 1995). For this reason, the lower boundary of the Deep-seated Gravitational Slope Deformations is not shown on the geomorphological map (fig. 2), whereas in the geological sections it is hypothetically traced (A-A' and B-B' in fig. 4).

The right-hand slope of the Rio delle Pozze valley (SW slope of Monte Gomito)

The presence in the slope's upper part of trenches, double ridges, concavities (figs. 7 and 8), accompanied by favourable structural factors, was also in this case ascribed to gravitational movements such as Dgsd. In particular, the slope deformation observed is affected in its upper part by a normal fault, SW-NE oriented, and seems to be confined to the NW by another NW-SE normal fault. Therefore, the above mentioned displacements could have allowed the release of the upper portion of the Monte Gomito SW slope (fig. 4, C-C' section). Also the cleavage, SW-NE oriented, has certainly been a favourable factor.

The geomorphological features of this deformation are generally observable between the altitude of 1,870 m and 1,800 m and owing to the presence of gaping trenches, the movement seems to be still in progress. On the slope's lower portion it was not possible to carry out any observation owing to the presence of surface deposits (made up of landslide deposits and slope debris) and to the lack of significant outcroppings. Structural data and geomorphological elements suggest that, like those previously described on the left-hand side of the Rio delle Pozze valley, also this gravitational deformation could be defined as a «rock flow», according to DRAMIS & SORRISO-VALVO (1994) and BISCI & *alii* (1996).

THE INCIPIENT LANDSLIDE ON THE EASTERN SLOPE OF MONTE GOMITO

In the upper portion of Monte Gomito eastern slope the same geomorphological characters accompanying the Dgsd of Rio delle Pozze valley were surveyed (cf. fig. 7). Here, in fact, where the ridge assumes an arc-shaped form, whose subtended chord is parallel to the bedding direction, double ridges, trenches, concavities and reverse slopes were found. Although some of the trenches have recently been filled with backfill material for the construction of ski tracks, their presence remains quite evident; another remarkable geomorphological feature is given by the presence of several reverse slopes. On the whole, geomorphological evidence is observable from the mountain crest (about 1,870 m a.s.l.) to the altitude of 1,750 m (fig. 9). The direction of trenches and reverse slopes is parallel to the bedding direction of the Macigno Formation (N100° to N110°). In this area the Macigno strata are dip-downstream coinciding with the slope's inclination; therefore the slopes correspond to structural surfaces and, in particular, to layers' joints (cf. fig. 4, D-D' section).

On the basis of the structural characteristics related to geomorphological features, this slope seems to be affected by a movement to NNE, along the slope's maximum inclination. The movement originates along lithological discontinuities of the Macigno Formation, in correspondence with pelitic levels which form preferential sliding surfaces for the overlying rocks.

On the slope's lower portion detailed observations were hindered by the woodland, the Quaternary cover, made up of moraine deposits and talus heap, and its resulting thick soil.

The Macigno Formation should, nevertheless, change its attitude in the slope's lower part (fig. 4, D-D' section), otherwise around the height of 1,670 m it would show a dip-downstream with high angle, thus preventing the release of the rock mass. It is therefore congruent to assume that around that height the Macigno strata are dip-downstream with low angle. In this way, the structural conditions necessary for rock detachment are achieved. Indirect

FIG. 5 - Geomorphological features of deep-seated gravitational slope deformation near Balza della Rosa.

FIG. 6 - Double ridge on the watershed between the Rio delle Pozze valley (on the left hand-side) and the Rio delle Tagliole valley (on the right): geomorphological feature of the deep-seated gravitational slope deformation located 1 km to the south of Balza della Rosa.

confirmation regarding the attitude of this portion of slope is obtained by projecting the bedding inclination observable at a short distance from the movement studied, which is dip-downstream with low angle. Owing to the structural characteristics illustrated, this phenomenon can be defined as rock slide (cf. SORRISO-VALVO & GULLÀ, 1996) rather than Dgsd (cf. DRAMIS & SORRISO-VALVO, 1994 and SORRISO-VALVO, 1995).

Nevertheless, since the surface of rupture is not evident and the rock masses appear only partially released, the phenomenon is likely to be a landslide at an incipient stage (cf. SORRISO-VALVO, 1995). Moreover, it may be observed that translational rock slides are rather common processes in the study area (cfr. fig. 2 e 7) and, more generally, in the Abetone Pass area (CASTALDINI & *alii,* in press).

Since this incipient rock slide shows the same geomorphological evidence as the Rio delle Pozze valley Dgsd, it may be defined as an example of «geomorphological convergence». Usually the examples of geomorphological convergence deal with landforms which have the same appearance but a different genesis (PANIZZA & PIACENTE, 1976; PANIZZA, 1988; CASTIGLIONI, 1991). In this specific case of slope processes due to gravity, they are similar forms originated by different types of phenomena.

CAUSATIVE FACTORS OF THE PHENOMENA STUDIED

Certainly Dgsd are complex phenomena since they are controlled both by geodynamic factors related to the endogenetic and exogenetic activity and by structural factors related to the nature and attitude of the rock masses involved (cf. SORRISO-VALVO, 1984; 1987; 1989; 1995; DRAMIS & *alii,* 1987; D'AMATO & PUCCINELLI 1989; MENOTTI & *alii,* 1990; articles quoted in PASUTO & SOLDATI, 1990; SOLDATI & PASUTO, 1991; DRAMIS & SORRISO-VALVO, 1994; CRESCENTI & SORRISO-VALVO, 1995; BISCI & *alii,* 1996; PASUTO & SOLDATI, 1996).

In the study area favourable factors for the development of these phenomena were identified.

Structural characteristics: in the cases observed deformations are strongly controlled by structures. On the left-hand slope of the Rio delle Pozze valley the movements are localised on the slope higher altitudes, where the rock masses involved are released, and take place along the planes of two normal fault systems, which form an angle of 90° to 100° by intersecting each other. The sense of movement is along a direction corresponding to the bisector of this angle, that is according to the slope's maximum dip. On the right-hand side of the Rio delle Pozze valley (SW slope of Monte Gomito) the movement is controlled by two normal faults, orthogonal to each other, and by cleavage parallel to the slope.

Remarkable thicknesses of competent rock types: in the study area the only rocks cropping out are sandstones belonging to the Macigno Formation which in this sector of the Northern Apennines reaches a thickness of about 2,000 m. It is made up of pelitic levels and thick arenaceous alternances. Considering that the study area, between Monte Gomito and Balza della Rosa, is nearly at the top of the formation, it is plausible that in this area the Macigno Formation attains a thickness of at least 1,600 m.

High relief energy: the present considerable differences of level are the result of uplifts started in the Middle-Upper(?) Pleistocene (CARTON & *alii*, 1978; BARTOLINI & *alii*, 1982; AMBROSETTI & *alii,* 1983) and still in progress, as witnessed by the intense river erosion which led to a marked deepening of the hydrographic network.

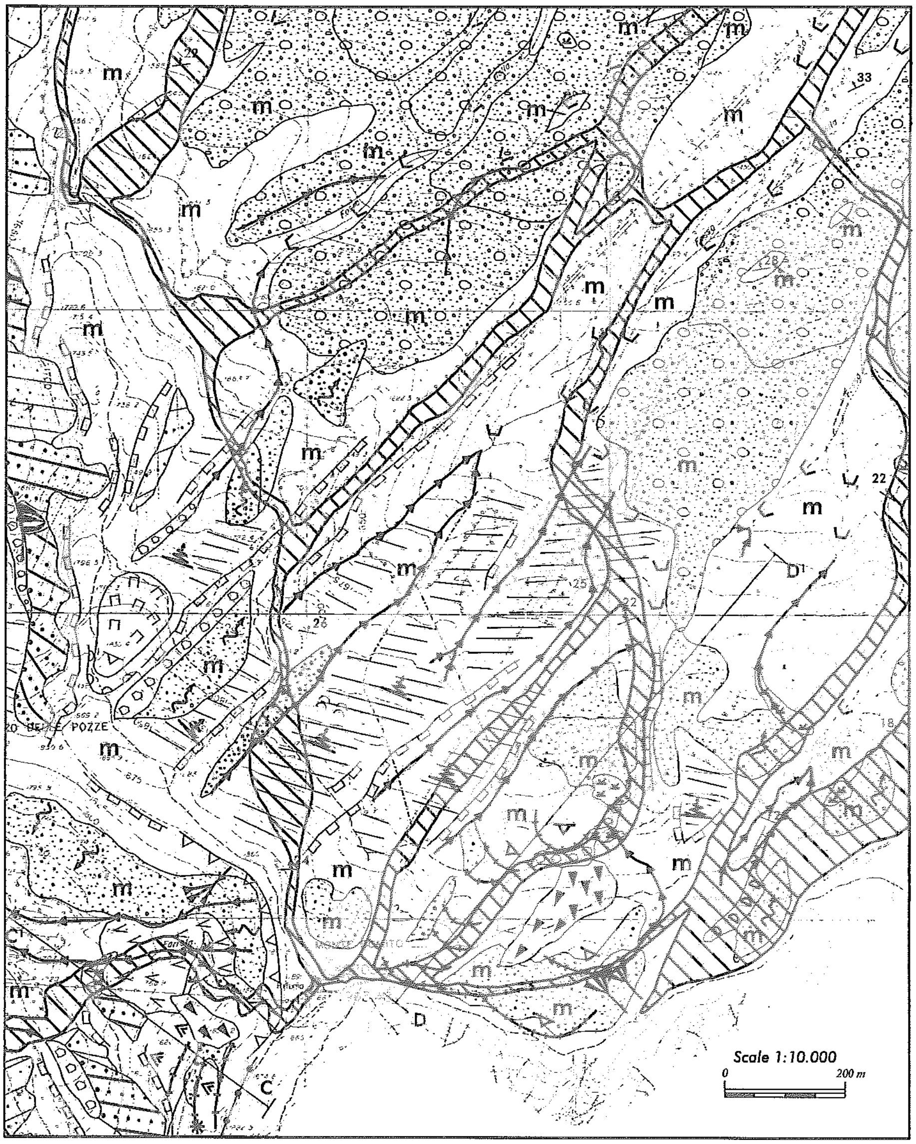


FIG. 7 - Geomorphological map of the eastern sector of the study area (Monte Gomito area; cf. Legend in fig. 3).

High seismic intensity: it is documented by several earthquakes occurred in historical times (POSTPISCHL, 1985). Also recently, on 24th August 1995, a quake with epicentre in the Abetone Pass area took place (5.5 MCS intensity and 4.1 magnitude; cf. STUCCHI & *alii*, 1996). Moreover, the area investigated is next to Garfagnana, one of the most seismic areas of the whole Northern Apennines; in this context, the X degree M.C.S. scale earthquake which struck Garfagnana and Lunigiana on 7th September 1920 and the other ones exceeding the VII-VIII degree (1481, 1767, 1837, 1939) should be mentioned. Seismic shocks around the VI degree were recorded also on 7th June 1980, 23rd January 1985 and 10th February 1987.

Deglaciation: the withdrawal and final disappearence of the glaciers, after the ice period corresponding to the Alpine Würm glaciation, determined a relaxation of the slopes which reacted in order to re-establish their pristine equilibrium condition.

Among the above mentioned causative factors which could have contributed in various ways to the triggering and evolution of Dgsd, both singly and jointly, it seems that a major role was played by the area's structural factors and in particular by extension-type fault systems. In the case of the incipient rock slide identified on the eastern slope of Monte Gomito, the movement takes place along the layers' joints, which correspond to lithological discontinuities (alternances of sandstones and pelites), along the slope's steepest direction which coincides with the inclination of the Macigno Formation strata.

Besides the dip-downstream attitude, in this situation an important role is also played by the meteo-climatic conditions. In particular, rainfall and water from snowmelt may lubricate the Macigno's pelitic layers. In particular, the bibliographical data (PIACENTE, 1992; SERVIZIO METEOROLOGICO REGIONE EMILIA-ROMAGNA, 1995) show that in the watershed area rainfall exceeds 2,000 mm/year.

FIG. 8 - Double ridge and trenches on the right-hand slope of the Rio delle Pozze valley: geomorphological features of the deep-seated gravitational slope deformation SW of Monte Gomito.

FIG. 9 - Reverse slopes characterising the incipient rock slide on the east face of Monte Gomito.

The annual mean values for the most rainy days range from 80 mm up to 125 mm and the ground is covered by snow for about 100 days a year.

CONCLUSIONS

Investigations showed that the deep-seated gravitational slope deformations surveyed in the Rio delle Pozze valley are characterised by a prevailing structural control of NW-SE and SW-NE oriented faults, besides the various causative factors previously considered.

From the geomorphological standpoint, the three cases of Dgsd surveyed show the same features: double ridges, trenches, concavities and reverse slopes, which are all aligned parallel to the controlling tectonic systems. These phenomena are defined as rock flows (*Sackungen*).

On the upper portion of the eastern slope of Monte Gomito the same geomorphological characteristics which accompany the Dgsd previously described were recognised. In this area the Macigno layers dip downstream with the same inclination as the slope's. Therefore, on the basis of the structural characteristics observed, the double ridges, trenches (in many cases gaping), concavities and reverse slopes are considered as the morphological expression of a rock slide and not a Dgsd. Nevertheless, since the surface of rupture is not evident and the rock masses seem to be still partially bound, this movement was classified as an incipient rock slide.

Since the phenomenon described on the eastern slope of Monte Gomito shows the same geomorphological evidence as the Dgsd of the Rio delle Pozze valley, it is considered an example of «geomorphological convergence». Within the framework of slope gravitational processes, this specific case is therefore characterised by similar landforms resulting from different types of phenomena. This case emphasizes the concept that in interpreting the genesis and/or the type of geological phenomena it is not sufficient to consider only the landforms.

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