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GIACOMO D'AMATO AVANZI (*) & ALBERTO PUCCINELLI (*)

DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS IN NORTH-WESTERN TUSCANY (ITALY): REMARKS ON TYPOLOGY, DISTRIBUTION AND TECTONIC CONNECTIONS

ABSTRACT: D'AMATO AVANZI G. & PUCCINELLI A., *Deep-seated gravitational slope deformations in north-western Tuscany (Italy): remarks on typology, distribution and tectonic connections.* (IT ISSN 0391-9838, 1996).

Some features make north-western Tuscany prone to Deep-seated Gravitational Slope Deformations (Dgsd), such as: high relief energy, high rainfall, intensely fractured and deformed rocks, active or recently active tectonics, strong seismicity. The territory investigated shows many examples of such phenomena, which differ owing to their geological and structural conditions, typology and activity.

The case history shows that both tectonics and lithostratigraphic structures have greatly influenced typologies and kinematic mechanisms, whilst neotectonic evolution and climatic conditions have had their influence on all phenomena studied. Among the cases where the tectonic structure is a prevailing factor, deep-seated gravitational slope deformations located on normal faults could be quoted, as those outlining the tectonic depressions of the Serchio and Magra valleys or other regional normal fault systems. These faults release and subdivide the bedrock into very large blocks, making them subject to gravitational adjustment. In addition, a preferential orientation of geomorphic features (scarps, trenches, reverse slopes, etc.) can be verified in accordance with the trends of tectonic displacements and brittle deformation systems. Some examples include the gravitational processes near Canossa, Bagnone and Chioso in Magra Valley, near San Romano in Garfagnana in the Serchio Valley and near the Abetone Pass. Block slide and rock flow are generally common types of movement, often structurally controlled by fault planes.

The lithostratigraphic structure may be frequently regarded as the main control feature in the development of deep-seated gravitational slope deformations; in particular, a structure of thick rigid rocks overlying ductile rock types is instrumental. In this case, block slides and lateral spreads are the most common kinds of movement. Some examples are found at Mt. Castri in the Serchio Valley (sandstone over shale) and in the Magra Valley near Bagnone and Chioso (marly limestone overlying shale). The underlying ductile rocks are remarkably deformed by tectonics and sometimes show deformations resulting from the load of overlying brittle rocks, such as bulges and reverse slopes.

Along the deep valleys which transversally cut the main tectonic structures, the topographic stress is sometimes considerable, owing to the Pleistocene - Holocene uplift; brittle/ductile deformations may then occur, due to gravitational slope tension rather than tectonic stress.

Finally, a considerable amount of the Dgsd here studied are believed to be dormant, because of debris filling up the trenches and no movement evidence in the past decades; in some cases, evidences of activity were recognised.

KEY WORDS: Deep-seated gravitational slope deformation, Geomorphology, Tectonics, Tuscany, Italy.

RIASSUNTO: D'AMATO AVANZI G. & PUCCINELLI A., *Le deformazioni gravitative profonde della Toscana nord-occidentale (Italia): considerazioni su tipologia, distribuzione e rapporti con la tettonica.* (IT ISSN 0391-9838, 1996).

La Toscana nord-occidentale presenta alcune caratteristiche favorevoli alla genesi delle deformazioni gravitative profonde di versante (Dgpv): elevata energia del rilievo, clima con alti valori di piovosità, rocce intensamente deformate e fratturate, tettonica attiva o recentemente attiva, alta sismicità; vi si riscontrano pertanto numerosi fenomeni di Dgpv, variabili per condizioni geologico-strutturali, tipologia e stato di attività.

I numerosi casi studiati hanno mostrato che soprattutto i lineamenti strutturali e l'assetto litostratigrafico condizionano le caratteristiche tipologiche e cinematiche delle Dgpv, mentre l'evoluzione neotettonica e le condizioni climatiche hanno sul territorio un effetto meno puntuale, influendo sostanzialmente in modo areale su tutte le Dgpv individuate.

Tra i casi in cui l'assetto tettonico può essere considerato un fattore preponderante, si citano i fenomeni di Dgpv che si impostano in corrispondenza delle faglie dirette che individuano le depressioni tettoniche della Val di Serchio e della Val di Magra o di altre faglie di importanza regionale; esse esercitano sugli ammassi rocciosi un'azione di svincolo e di frammentazione in megablocchi, permettendone l'adattamento gravitativo; si nota inoltre l'isorientazione dei caratteri morfologici fondamentali (scarpate, trincee, contropendenze, ecc.) sia con le dislocazioni tettoniche, sia con i sistemi di deformazione fragile. Questi casi comprendono: le Dgpv presso Villafranca in Lunigiana, Bagnone e Chioso in Val di Magra; i casi di S. Romano in Garfagnana e della zona del Passo dell'Abetone in Val di Serchio; i movimenti generalmente si impostano in corrispondenza dei piani di faglia e consistono in scorrimenti in blocco o in colamenti di roccia.

In altri casi è l'assetto litostratigrafico che può essere considerato il carattere guida principale; in particolare, la configurazione più favorevole

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(*) *Dipartimento di Scienze della Terra, Università di Pisa - Via Santa Maria, 53 - 56126 Pisa (Italy).*

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allo sviluppo di movimenti gravitativi profondi è rappresentata dalla sovrapposizione di rocce rigide su rocce duttili; in questi casi i tipi di movimento più comuni sono lo scorrimento in blocco e l'espansione laterale. Come esempi, in Val di Serchio si ricordano i fenomeni riscontrati sul M. Castri (arenarie su argilliti), in Val di Magra le Dgpv a nord-ovest di Bagnone e presso Chioso (calcari marnosi su complesso argillitico). Le rocce duttili sottostanti, intensamente deformate dalla tettonica, presentano talvolta anche deformazioni derivanti dal carico delle rocce rigide soprastanti, con rigonfiamenti e contropendenze. In alcuni casi, localizzati lungo le profonde incisioni vallive trasversali agli assi tettonici principali, lo *stress* topografico generato dai sollevamenti del Pleistocene - Olocene assume grande rilevanza; può esserci allora la comparsa di deformazioni di tipo duttile/fragile, non derivate dalle vicissitudini tettoniche, ma dalle tensioni gravitative agenti sul versante.

Infine, lo stato di attività delle Dgpv di questi territori è di valutazione difficoltosa, anche per il carattere di movimento intermittente che non di rado le caratterizza, con periodi di stasi o di movimenti impercettibili, alternati a fasi parossistiche legate a eventi sismici o a crisi climatiche. La maggior parte dei fenomeni osservati può ritenersi nel suo complesso quiescente, sulla base dei riempimenti detritici delle trincee e dell'assenza di testimonianze di movimento negli ultimi decenni; in alcuni casi sono stati riscontrati indizi di attività, prevalentemente legati alla particolare dinamica geomorfologica locale.

TERMINI CHIAVE: Deformazione gravitativa profonda di versante, Geomorfologia, Tettonica, Toscana, Italia.

INTRODUCTION

In the morphogenesis of mountain areas particular importance have large mass movements, among which Deep-seated Gravitational Slope Deformations (Dgsd) play a significant role.

Investigations carried out in the past few decades have led to a remarkable progress of knowledge on the geological and geomorphological aspects and on the mechanical, kinematic and classification aspects (PASUTO & SOLDATI, 1990, review). For further information on the Italian situation reference is made on the Proceedings of the Symposia organized by the Cnr National Group «Deep-seated Gravitational Slope Deformations» (SORRISO-VALVO, 1984, 1987, 1989; CRESCENTI & SORRISO-VALVO, 1995).

It is worth emphasizing some features that are commonly considered more typical of Dgsd (RADBRUCH-HALL & *alii,* 1976; MAHR & NEMCOK, 1977; RADBRUCH-HALL, 1978; DRAMIS, 1984; DRAMIS & SORRISO-VALVO, 1994; DRAMIS & *alii*, 1987, 1995; BISCI & *alii,* 1996), namely:

1. large extent (some square kilometres) and thickness of the rock masses involved of tens, sometimes hundreds, of metres;
2. moderate displacement with respect to the dimensions of the rock masses involved;
3. absence of a net failure surface delimiting the rock mass subject to movement;
4. very slow evolution, with long inactivity or extremely reduced activity periods, during which a sudden reactivation may take place in concomitance with earthquakes or extreme meteoric events;
5. failure mechanism due to creep;
6. kinematics often influenced by active tectonics and by the presence of residual tectonic stresses and high confinement pressure;
7. movement controlled by geological-structural attitudes rather than by local morphological configurations.

Among the morphological elements which permit to recognise the above phenomena, slope relaxation forms are common; they are localised near the summit and the foot of the slope, where the confining pressure is lower. The following surface effects are often observed:

1. the highermost portion of the deformed slope is affected by extensional stresses which produce high-angle shear planes, with which counterslope steps, graben-like trenches and double ridges are associated;
2. the lowermost portion of the slope is affected by compressional stress determining bulging and, sometimes, low-angle shear planes at the toe; shear planes may not be easily identifiable, when proper outcrops are lacking or the toe is buried by superficial deposits, such as landslide bodies, alluvial sediments or other.

The areas affected by Dgsd frequently show the following features:

1. high relief energy, with high gradient, well developed slopes, modelled in competent rock types;
2. morpho-climatic conditions favourable to a particularly active channelised erosion, with high rainfall values;
3. strong seismicity;
4. active or recently active tectonics.

North-western Tuscany is characterised by large mountain areas of the Northern Apennines, where deep-seated gravitational slope deformations are favoured by all factors listed above. Indeed, several cases of Dgsd were identified and their geological-structural and geomorphological aspects were further investigated (D'AMATO AVANZI & PUCCINELLI, 1989; DALLAN & *alii,* 1991; BUTI & *alii,* 1995; CAREDIO & *alii,* 1996; D'AMATO AVANZI & *alii,* 1995a, 1995b). These studies showed that, under the same meteoclimatic conditions, these processes are subject to a marked lithological and structural control and occur in areas affected by active tectonics, where a high relief energy is produced and residual stresses set free along deep valley cuts.

The following remarks are based on the knowledge so far acquired in the Serchio and Magra Valleys, where hundreds of large mass movements with surface of some square kilometres and thickness of several tens of metres occur. In this paper, the movements recognised as Dgsd are dealt with, disregarding large landslides.

The distinction between landslide and Dgsd, fundamentally in agreement with SORRISO-VALVO (1995), is based on the presence or not of a surface or zone of failure: in an ordinary landslide this feature is always identified or reconstructable with some continuity whereas the movements derived from a Dgsd can be explained also in absence of well-defined failure surfaces or zones. This is in agreement with HUTCHINSON (1988), who regards as «sagging of mountain slopes» those processes which «in their present state of development, do not justify classification as landslides». This discriminating principle better applies to rock flows and some types of lateral spreading, whilst most lateral spreads and block slides should better be included among landslides, which are frequently characteri-

sed by displacements along more or less continuous and easily recognisable surfaces (DRAMIS & *alii,* 1995). However, the amount of deformation is usually small with respect to the rock masses involved and the evolution is extremely slow and accompanied by creep. For this reason, according to DRAMIS & *alii* (1995), also these gravitational processes are ascribed to Dgsd, thus distinguishing them from landslides in the strict sense. From a ranking viewpoint, Dgsd are commonly subdivided into the following types (JAHN, 1964; ZISCHINSKY, 1969; VARNES, 1978; CARRARA & *alii,* 1987; DRAMIS & *alii,* 1987; DRAMIS & SORRISO-VALVO, 1994; CRUDEN & VARNES, 1996):
1. rock flow (Sackung);
2. lateral spreading;
3. block slide.

The category of Dgsd is not expressively considered in the landslide classifications of VARNES (1978), CARRARA & *alii* (1987) and CRUDEN & VARNES (1996), where the Dgsd are mainly comprised within rock flow, rock spread and complex types.

We regard the cases described in this paper rather representative of the most significant situations of deep-seated gravitational slope deformations in the north-western sector of the Northern Apennines (Serchio Valley, Magra Valley, Tuscan-Emilian Apennines). In this area, over 50 examples of Dgsd have been so far identified by us, whereas for the Apuan Alps the investigations have just started.

GEOLOGICAL-STRUCTURAL BACKGROUND OF NORTH-WESTERN TUSCANY

The Northern Apennines are a fold-and-thrust belt derived from a complex, multiple-staged evolutive story (ELTER, 1960, 1973; DALLAN & NARDI, 1974, 1979; BOCCALETTI & *alii,* 1981, 1987) which schematically can be ascribed to two main periods:
– from the Middle Cretaceous to the Upper Miocene a compressive style prevailed, which was responsible for the piling up and emplacement of tectonic units coming from different paleogeographic domains (from west to east: Liguride Domain, Sub-Liguride Domain, Tuscan Domain, respectively);
– from the Upper Miocene to the Lower Pliocene extensional tectonics took place which originated the formation of tectonic depressions (Serchio Valley, Magra Valley), where thick lacustrine and fluvial sequences were deposited (FEDERICI, 1980; FEDERICI & RAU, 1980; BARTOLINI & *alii,* 1983).

Excluding the Apuan Alps region, which is not considered in this study, the most significant tectonic units are the Tuscan Sequence and the Liguride Units *s.l.* They are listed starting from the geometrically lowest unit:
1. the Tuscan Sequence is made up of a prevalently calcareous lower and middle portion and an upper portion including shale and calcareous shale (Scaglia rossa Formation), on which sandstone (Macigno Formation) lies. Locally, Pontecchio Marl superimposes on Macigno Fm.;
2. the Canetolo Unit (Sub-Liguride Domain) is essentially made up of a shale with interbedded limestone (Argille e calcari Formation), overlain by a calcareous-marly flysch (Groppo del Vescovo Limestone);
3. the Ottone/St. Stefano Unit (External Liguride Domain) is mainly characterised by a prevalently argillitic complex (base complex), overlain by the Helminthoid Flysch (calcareous-marly flysch);
4. the Mt. Gottero Unit (Internal Liguride Domain) is prevalently made up of a shale with interbedded limestone (Palombini shale), overlain by the Mt. Gottero sandstone.

These units have undergone various deformation stages, both compressive and extensional; the former caused intensely deformed and tectonised rock bodies, with pervasive folds and cleavage, whereas the latter mainly favoured prevalently vertical movements which led to increased relief energy.

As previously stated, starting from the Lower Pliocene, in the Serchio and Magra Valleys, tectonic depressions were formed at the back of the areas subjected to compression. These depressions are bound by Apennine-directed and SW-dipping main faults along their north-eastern margin (fig. 1), and by secondary (antithetic) NE-dipping faults along their south-western margin. This stage is followed by another stage characterised by differential uplift and tilting, correlated with the tectonic uplift which affected the whole Northern Apennines since the Middle Pleistocene. These movements seem to be still active in the considered regions, as witnessed by some geomorphological features (eroding streams, fluvial terraces, uplift of recent fluvial deposits) and by the intense seismic activity.

In the Serchio and Magra Valleys depressions, as well as in some adjacent areas, such as the Abetone Pass, two situations may be distinguished:
1. deepening areas, corresponding to the lowered flanks of faults bounding the tectonic depressions and including mainly lacustrine Villafranchian deposits and shales of the Liguride (base complex of the Helminthoid Flysch) and Sub-Liguride (Argille e calcari Fm.) Units;
2. uplifting areas, corresponding to the lifted flanks of the above mentioned faults, which correspond to mainly arenaceous rocks of the Tuscan Sequence (Macigno Fm.).

GEOMORPHOLOGICAL SETTING

The Serchio and Magra Valleys show a geomorphological setting remarkably conditioned by structural elements and by the selective erosion on rocks with different physic-mechanical properties:
1. the flanks of the two valleys show in many stretches a step-like profile formed by normal faults;
2. the hydrographic network has been conditioned by important tectonic structures: the Serchio and Magra rivers run mostly in the Apennine direction (NW-SE), along the axes of the tectonic depressions; by contrast, in other stretches they follow an anti-Apennine direction, owing to the presence of NE-SW oriented transverse faults;

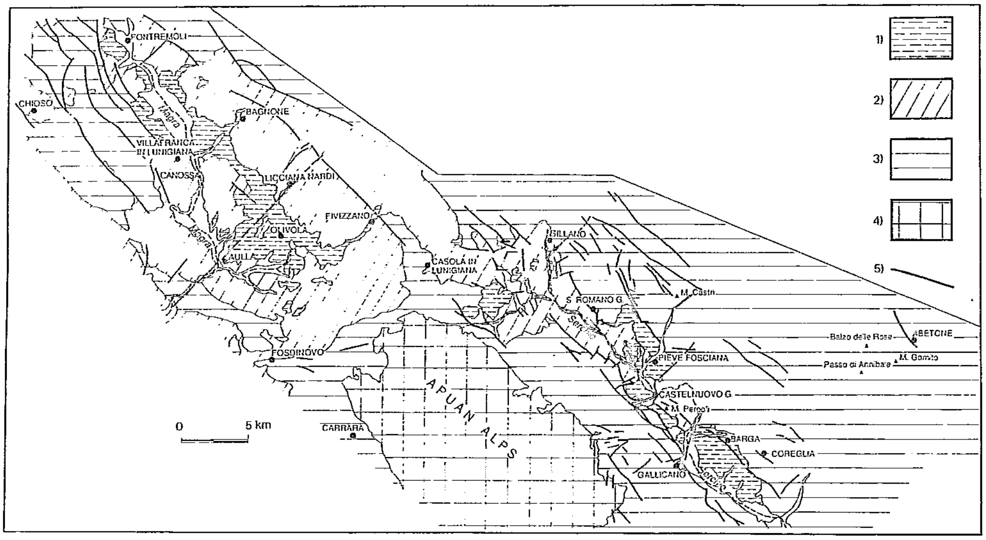


FIG. 1 - Tectonic scheme of north-western Tuscany - 1) Fluvial and lacustrine sequences. 2) Liguride and Sub-Liguride Units. 3) Tuscan Sequence. 4) Apuan Alps Metamorphic Complex. 5) Fault.

3. lithology conditioned the morphological setting of the slopes: rugged landforms and steep slopes, locally subvertical or overhanging, are prevalent, especially in correspondence with carbonatic rocks. Conversely, more rounded forms and more open valleys are more frequent along the Apennine ridge, owing to the presence of arenaceous rock types; even milder forms and low-gradient slopes, locally steeper owing to the presence of ophiolite rock bodies enhanced by selective erosion, are prevalently found in the shales of the Liguride and Sub-Liguride Units (base complex of the Helminthoid Flysch, Argille e calcari Fm.) and in the Villafranchian clayey lacustrine sediments outcropping at the centre of the two depressions;
4. the tectonic culminations bounding the above described depressions prevalently control the watershed trends of the corresponding catchment basins.

CLIMATE OUTLINE

The geographical position with respect to the humid sea winds, the altitude variations and the morphological setting deeply influence the precipitation regime and distribution; meteoric input, mainly represented by rainfall, reaches values of 1,500-2,000 mm/year in the mid-portions of the Serchio and Magra Valleys (Cnr, 1964) and in the highest areas of the basins maximum values exceeding 2,900 mm/year (Tuscan-Emilian Apennines) and 3,200 mm/year (Apuan Alps) are attained. The precipitations are prevalently concentrated in the October to February period, whereas intense rainfall is frequent during summer (BALDACCI & *alii,* 1993).

SEISMICITY

The Serchio and Magra Valleys fall within the seismically most active areas of the Northern Apennines. This is witnessed by several earthquakes (fig. 2), some of which are characterised by a very high intensity, with epicentres often aligned with the normal fault systems which delimitate the tectonic depressions.

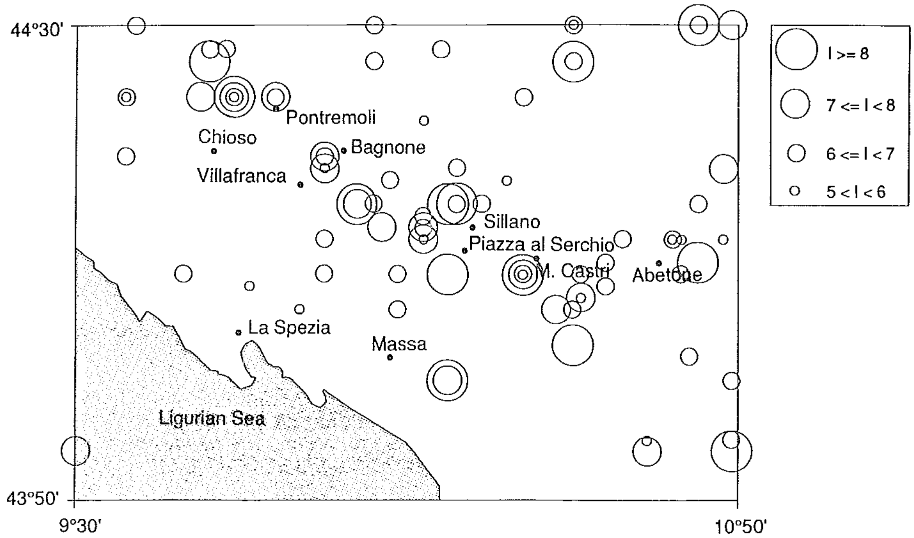
Among the most violent quakes affecting the region, the quake on September 7, 1920 struck the Serchio and Magra Valleys with an intensity of the 10th degree of the M.C.S. scale, should be particularly quoted. Many other strong earthquakes were registered, e.g. in 1481, 1545, 1641, 1740, 1746, 1834, 1921, 1939, with an intensity greater than the 7th-8th degree of the M.C.S. scale (POSTPISCHL, 1985; BOSCHI & *alii,* 1995).

EXAMPLES OF DGSD IN RELATION TO THE GEOLOGICAL-STRUCTURAL BACKGROUND

In most cases the mechanical behaviour of rock masses involved in gravitational processes is strongly conditioned by the geological-structural characteristics. In order to illustrate some typical situations of the areas, some cases of deep-seated gravitational slope deformations are described. They are located in areas characterised by high energy relief due to recent uplift and to the existence of stress fields derived from compressive tectonic phases which led to the emplacement of the tectonic units. These areas were also affected by normal faults which segmented the resulting tectonic arrangement. The fundamental clues which allowed Dgsd to be identified are represented by trenches and double ridges in the slope upper parts; less frequently bulges and ductile/brittle deformations were recognised in the slope mid-lower portions and at the toe of the slopes respectively.

For clarity sake, Magra Valley and Serchio Valley are described separately since, despite many geological and structural similarities, they belong to different geographical domains.

FIG. 2 - Scheme of the earthquake epicentres with Intensity I > 5[th] degree of M.C.S. scale (1000 to 1995 years) (after CASTALDINI & *alii,* 1995, redrawn and partially modified).



MAGRA VALLEY

Area between Canossa and the Magra River - This area is situated west of Villafranca in Lunigiana, in the mid-part of the Magra Valley. A Dgsd involves a slope downhill of one of the main faults which border the tectonic depression of the Magra Valley to the SW (D'AMATO AVANZI & PUCCINELLI, 1989).

The slope involved in the movement is mainly modelled in shale (Argille e calcari Fm.), which superimpose on sandstone (Macigno Fm.). Marlstone and marly-limestone (Helminthoid Flysch) superimpose on Argille e calcari Fm. (fig. 3). The slope, facing the Magra River, is marked by flat or reverse-sloping surfaces and by depressions and trenches, placed at various altitudes and substantially aligned in the Apennine direction (NW-SE). We think that the deformation was first set up on the north-western portion of the slope; afterwards it shifted to the east, involving slope portions located more downhill. The movement could be triggered by the disequilibrium of the slope owing to the progressive deepening of the Magra River valley floor.

The area near the slope, to the south, is characterised by large and partially active mass movements, such as rock slides, involving the Helminthoid Flysch. Those mass movements might represent the result of a partial collapse of a pre-existing Dgsd. On the whole, the area affected by deformation processes may be estimated to be ca. 3.5 km^2 wide, with a thickness of 100-150 m.

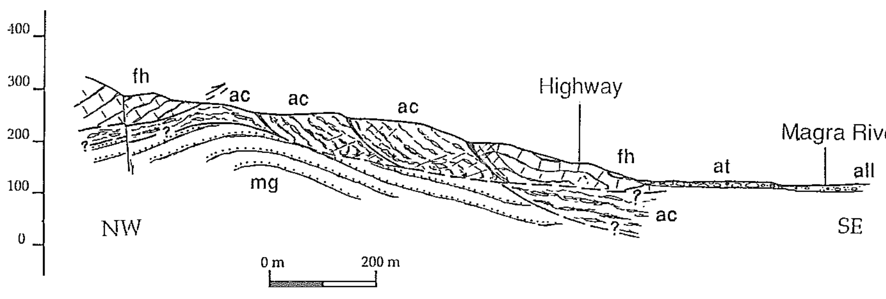
This Dgsd is considered to be or resemble mainly a rock flow. Nowadays, no evidence of activity was recognised on the slope affected by the Dgsd.

Area north-west of Bagnone - In this area deep-seated gravitational slope deformations occur prevalently in competent rocks (Helminthoid Flysch and Groppo del Vescovo Limestone) (D'AMATO AVANZI & *alii,* 1995a), which overlie mostly argillitic rocks (Argille e calcari Fm., base complex of the Helminthoid Flysch). They are mainly found in correspondence with NW-SE aligned normal faults, which define tectonic and mechanical weakness zones; the fault planes acted as preferential slide surfaces, thus favouring and directing gravitational deformations (fig. 4). In other cases, Dgsd are located along the flanks of transversal valleys, along transversal tectonic alignments, and are deeply cut in consequence of neotectonic uplift.

The main types are ascribed to slide/lateral spreading and rock flow, namely:

– the first-type phenomena affect the Villa di Sopra area (fig. 4, section 1), where the Helminthoid Flysch rests on

FIG. 3 - Geological section along the slope between Canossa and the Magra River (after D'AMATO AVANZI & PUCCINELLI, 1989, redrawn and partially modified) - mg: Macigno Fm. (sandstone). ac: Argille e calcari Fm. (shale). fh: Helminthoid Flysch (marl). at: alluvial terrace. all: present alluvial deposit.



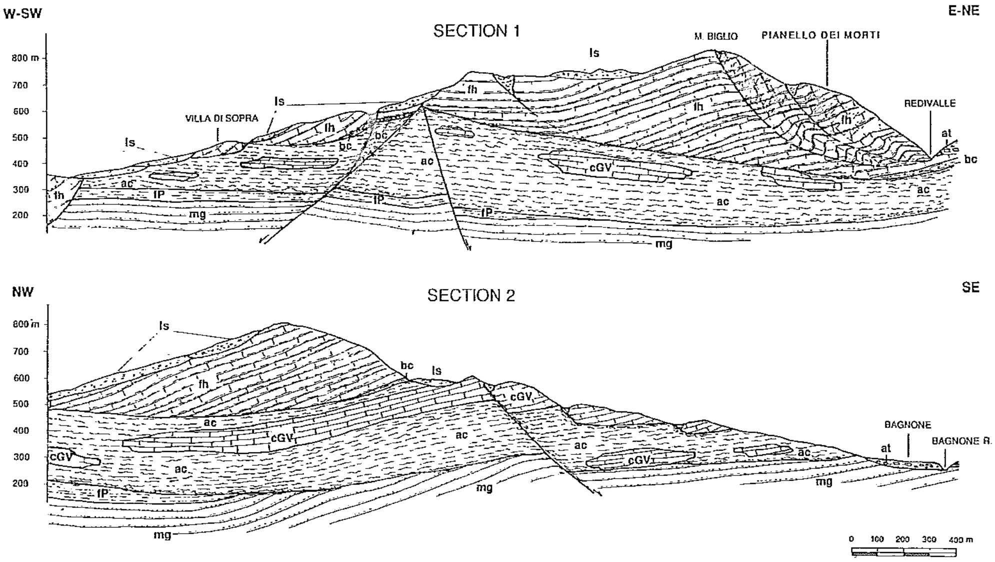


FIG. 4 - Geological sections in the area NW of Bagnone in the Magra Valley (after D'AMATO AVANZI & *alii,* 1995a, redrawn and partially modified) - mg: Macigno Fm. (sandstone). fP: Pontecchio Marl. ac: Argille e calcari Fm. (shale). cGV: Groppo del Vescovo Limestone. bc: pebbly mudstone (base complex). fh: Helminthoid Flysch (marl). at: Alluvial terrace. ls: landslide.

top of the Argille e calcari Fm. following a subhorizontal contact surface. Apennine-directed, SW-dipping normal faults released large rock portions of Helminthoid Flysch, affecting an area of 0.8 km^2 and a thickness of over 100 m, along a low-gradient slope (about 13°). This Dgsd does not show signs of activity (filled up trenches, rounded off margins). Similar processes (fig. 4, section 2) affect the Canale-Agnetta area (Groppo del Vescovo Limestone on top of the Argille e calcari Fm. with subhorizontal contact surface). In this case too the phenomenon was favoured by the releasing action of an E-W, south dipping normal fault. The Dgsd affects an area of ca. 0.8 km^2 and a thickness exceeding 100 m, on a low-angle slope (about 13°). Also this gravitational deformation does not show signs of activity (filled up trenches, rounded off margins);

– rock flow-type processes are found particularly along the slope east of Mt. Biglio, which overstands the Redivalle stream (fig. 4, section 1). The slope is cut into the Helminthoid Flysch, which overlies the base complex (shale and argillite-matrix breccia). The slope upper part shows a brittle behaviour, with elongated depressions, trenches and crest splittings aligned with N-S and N 50° E directed fracture systems, with 60° east to subvertical slope angles. Conversely, the lower part shows ductile/brittle deformations, due to compression derived from gravitational movements. In fact, decimetric-scale folds were identified in this area: they show axes parallel to the slope direction and shear planes parallel to the course of the Redivalle stream. In spite of the lack of activity seemingly shown by the trenches, the appearance of extended cracks along the slope indicates a collapse-trending evolution, with possible damming of the riverbed.

Chioso - In this area, a Dgsd affects the Mt. Vaio relief (fig. 5), modelled in Helminthoid Flysch (thickness of about 300 m) lying on top of the Argille e calcari Fm. (BUTI & *alii,* 1995). Its main morphological features are trenches and double ridges localised near the top of Mt. Vaio. They follow the trends of two fracture systems: E-W, with non-active trenches filled up with debris and colluvium and NE-SW, with a well defined and much «fresher» double ridge. The mid-lower part of the slope is covered by large

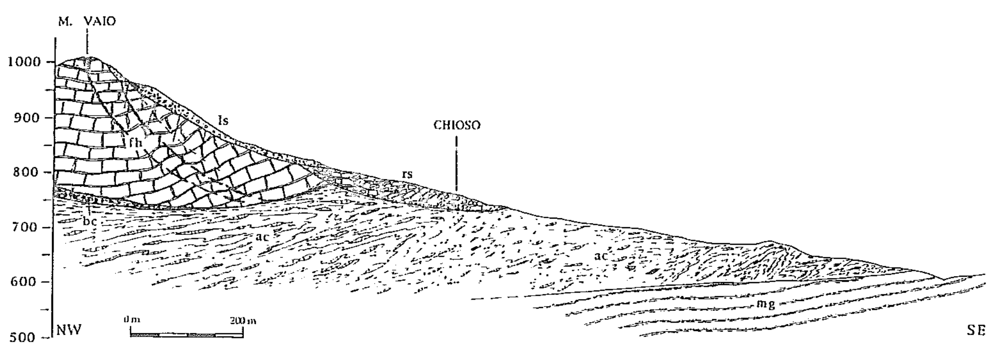


FIG. 5 - Geological section in the Chioso area, in the Magra Valley (after BUTI & *alii,* 1995, redrawn and partially modified) - mg: Macigno Fm. (sandstone). ac: Argille e calcari Fm. (shale). bc: pebbly mudstone (base complex). fh: Helminthoid Flysch (marl). rs: rock-block slide. ls: landslide.

landslide heaps (rock-block slide, flow), some of which are periodically subject to re-activations, thus presenting a serious risk for the Chioso village, which is already severely damaged. The freshness of the NE-SW trending trench on the top of Mt. Vaio may imply that the Dgsd could be still active. The activity of superficial landslide could also be connected to the Dgsd activity.

SERCHIO VALLEY

Mt. Castri - The deformational process identified along the SE slope of Mt. Castri, near Corfino (north-eastern Serchio Valley) can be recognisable mainly by the presence of a wide trench near the mountain top; other trenches and tension cracks can be observed at intermediate altitudes (DALLAN & *alii,* 1991).

The slope is modelled in the Tuscan Sequence in correspondence with the core of an overturned anticline: thick strata of the Macigno Fm. (sandstone with a total thickness of ca. 200 m), with dip-downstream bedding at low angle rest on the Scaglia rossa Fm. (shales). This lithostratigraphic discontinuity separates rock types of very different physic-mechanical properties and exerts an important structural control (fig. 6). That structural attitude certainly favoured the triggering of block-slide movements, which were activated when the intense deepening of the Castiglione riverbed occurred, reacting to the recent uplift of the Apennine chain.

An area of about 2 km^2 is affected by the deformation, with a thickness exceeding 200 m. The average inclination of the main failure surface is ca. 16°, slightly lower than the slope average angle (about 20°). At the lowermost portion of the slope a failure surface is not visible, because probably compressional stress mainly determined bulging. The main trenches do not appear to be active. Along the slope tension cracks are recognisable: they are up to some decametres in length, with a width and depth of some metres and «fresh» look; they probably are important hints of a tendency to the movement re-activation, with possible damming of the riverbed.

San Romano in Garfagnana - The area of San Romano is characterised by several large mass movements (D'AMATO AVANZI & *alii,* 1995b) and by vast debris covers which conceal most of the outcrops. In the middle portion of the slope, trenches elongated parallel to one of the normal faults which bound to the NE the Serchio Valley depression are recognisable. These trenches are filled up with debris, colluvial and marshy deposit and do not show signs of activity. They are probably the result of a Dgsd process affecting intensely deformed, thin-bedded and highly ductile rocks (Argille e calcari Fm., shales). Also because of the particularly well developed anthropic activities, other morphological features typical of deep-seated gravitational slope deformations are not observable, although some convexities in the mid-lower portion could be ascribed to bulges. The morphological configuration of this phenomenon and the lithological characteristics of the rocks affected, which are intensely deformed and considerably ductile, are compatible with a rock flow (fig. 7). The slope angle is relatively low (about 10°).

On the basis of the trench filling (mentioned above), we think that this example of Dgsd has been dormant for a long time. The lack of activity is probably confirmed by the buildings and structures placed in the trenches, which do not show any damage.

Abetone Pass-Val di Luce area (Tuscan-Emilian Apennines) - In this territory, situated across the Tuscan-Emilian Apennine ridge, various cases of Dgsd affecting both slopes were recognised; they were studied in detail by CAREDIO & *alii* (1997) (this volume). These phenomena are identifiable because of some typical geomorphological features (in particular, trenches, reverse slopes, double ridges); they are all characterised by evident structural conditioning, such as attitude of the arenaceous formation (Macigno Fm., thick, dip-downstream sandstone layers alternated with thinner pelite beds) and presence of normal faults. Deep slope movements take place along the normal fault planes which intersect the slope in various directions, giving way to prevailing rock flows (fig. 8). By contrast, a shear surface may originate along a pelite intercalation, originating a block slide.

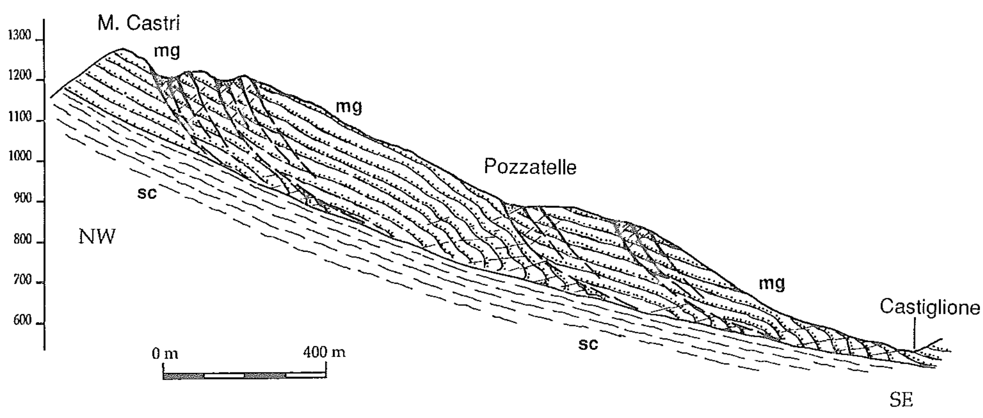


FIG. 6 - Geological section along the SE slope of Mt. Castri in the Serchio Valley (after DALLAN & *alii,* 1991, redrawn and partially modified) - mg: Macigno Fm. (sandstone). sc: Scaglia rossa Fm. (shale).

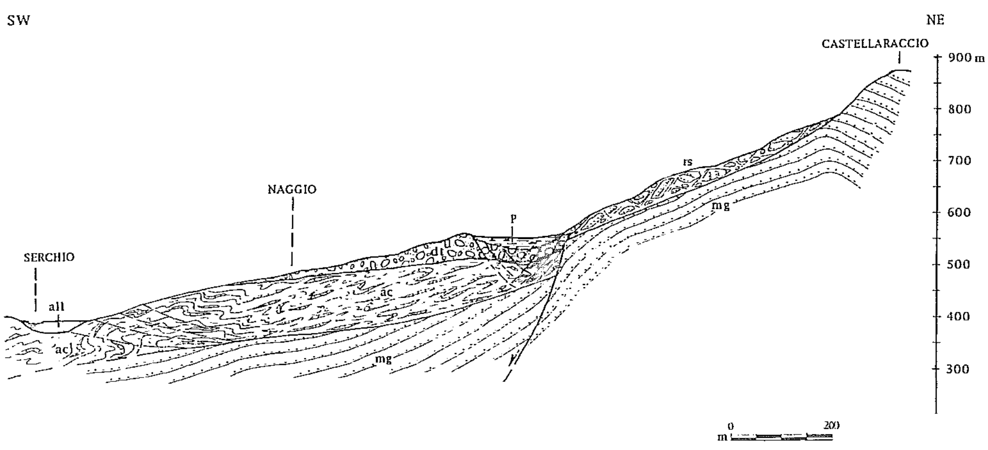


FIG. 7 - Geological section of S. Romano in Garfagnana slope (Serchio Valley) (after D'AMATO AVANZI & *alii,* 1995b, redrawn and partially modified) - mg: Macigno Fm. (sandstone). ac: Argille e calcari Fm. (shale). p: marshy deposit. dt: debris. all: present alluvial deposit. rs: rock-block slide.

CONCLUSIONS

The cases described above, although found in similar geological environments and often identical rock types, frequently show different - and not easy to be interpreted - geometrical characteristics. Geognostic data of any kind are in fact missing in the general setting of the cases considered; therefore, it is sometimes difficult to attribute them with absolute certainty to the above mentioned Dgsd typologies (rock flow, lateral spreading, block slide). For the moment we do not propose other types of classification, which would be based on a relatively small number of cases. Thus, the results are summarized below.

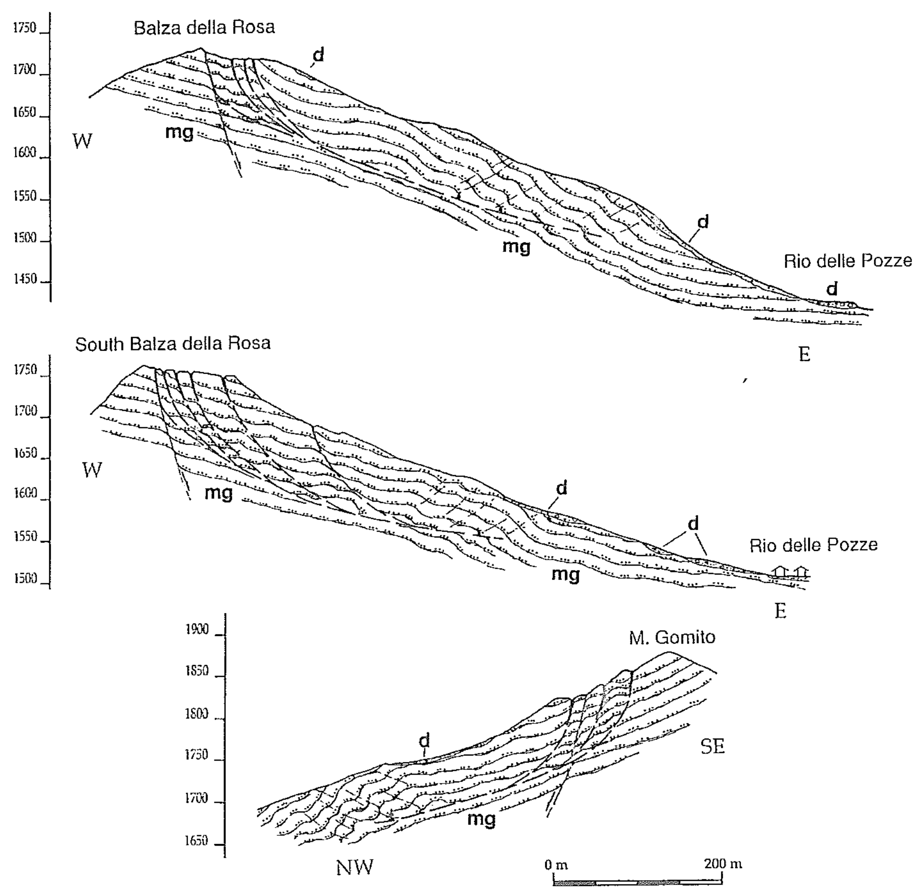


FIG. 8 - Geological sections of the area SW of the Abetone Pass, Serchio Valley (after CAREDIO & *alii,* 1997, redrawn and partially modified) - mg: Macigno Fm. (sandstone). d: Quaternary deposit.

Rock flow (Sackung)

In this category the following cases should be included:
– the Dgsd of Canossa in the Magra Valley area, where large, mainly calcareous and marly-calcareous rock bodies are involved. These movements started along low-angle fault surfaces (fig. 3);
– the deep-seated movements of the eastern slope of Mt. Biglio, near Bagnone in the Magra Valley, where competent rocks (Helminthoid Flysch) are superimposed on shales (Argille e calcari Fm.); the movements are also favoured by the presence of fracture systems (N-S, and N50°E), which intersect the flysch (fig. 4, section 1) and the Dgsd near Chioso, where Helminthoid Flysch is superimposed on the Argille e calcari Fm. (fig. 5);
– Sackung-type phenomena which affect the shales along the San Romano in Garfagnana (Serchio Valley) slope, in proximity of one of the main faults bounding to the NE the tectonic depression of the Serchio Valley (fig. 7);
– the Dgsd of the Abetone Pass area (Balza della Rosa, north of the Passo di Annibale and SW of Mt. Gomito). Competent rocks (Macigno Fm., sandstone) are directly affected along NW-SE and SW-NE fracture systems, thus originating a direct movement along the bisector of the angle formed by the two discontinuity systems (fig. 8).

Lateral spreading

This kind of deformation may be associated with block slide movements and mainly affects competent formations overlying ductile rock types:
– in the Villa di Sopra area (near Bagnone, in the Magra Valley) (fig. 4, section 1), the Helminthoid Flysch, overlying prevalently argillitic rock types (Argille e calcari Fm.), is directly affected;
– in the Canale-Agnetta area (fig. 4, section 2), the gravitational deformations involve the Groppo del Vescovo Limestone, which overlie the Argille e calcari Fm. (shale).

Block slide

– It was in particular found on Mt. Castri (fig. 6), in the Serchio Valley, where competent rock types (Macigno Fm., sandstone) overlie formations showing a ductile mechanical behaviour (Scaglia rossa Fm., shale).

The present short treatment of Dgsd of north-western Tuscany has emphasized the role played by the geological-structural attitude of different formations in the development of deep-seated gravitational slope deformations. The areas investigated have been subject to recent uplift (Middle/Upper Pleistocene-Holocene) and show at present high relief energy, prevalently erosive fluvial activity, conspicuous rainfall values and high seismicity.

A geological configuration, often subject to Dgsd, is characterised by the presence of competent rocks superimposed on rock types with a ductile behaviour. In particular, when the contact surface is subhorizontal lateral spreading processes prevail, often accompanied by block slides. These deformations are in most cases favoured by the occurrence of normal faults which, besides contributing to the rock physic-mechanical decline, release large rock bodies, often conditioning their trends of movement.

Less frequent and more difficult to be identified are the Sackung-type phenomena, which affect slopes modelled in competent rocks with pervasive cleavage. These rock types are often affected by fault systems, along which zones characterised by higher structural weakness are developed, thus favouring the slope gravitational adjustments.

Finally, the evaluation of the state of activity of deep-seated gravitational slope deformations in this territory can present serious difficulties, owing to the intermittent movement character of these phenomena; there are periods of immobility or imperceptible movements alternating with paroxysmal phases due to earthquakes or climatic crises. A considerable amount of the Dgsd here studied are believed to be non active, because of debris filling up the trenches and no evidence of movement in the past decades; only a few of the Dgsd show evidences of activity.

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