(Article begins on next page)

SOME CASES OF DEEP-SEATED GRAVITATIONAL DEFORMATIONS IN THE AREA OF CORTINA D'AMPEZZO (DOLOMITES). IMPLICATIONS IN ENVIRONMENTAL RISK ASSESSMENT

MAURO SOLDATI & ALESSANDRO PASUTO

Mauro Soldati - Istituto di Geologia dell'Università di Modena.
Alessandro Pasuto - Istituto di Geologia Applicata - C.N.R., Padova.

Abstract

The Authors, after having analyzed the main morphological and structural features characterizing deep-seated gravitational deformations and presented some terminological problems, describe four cases of deep-seated gravitational deformations in the area of Cortina d'Ampezzo (Dolomites). Moreover the relationships between these phenomena, which often seem to favour the development of "collateral" slope movements, and environmental risk in an area valuable, both for its economic and landscape aspects, like Cortina d'Ampezzo, are examined.

Key words: deep-seated gravitational deformations, environmental risk, Cortina d'Ampezzo.

Riassunto

Alcuni casi di deformazioni gravitative profonde di versante nella zona di Cortina d'Ampezzo (Dolomiti). Implicazioni nella valutazione del rischio ambientale. Dopo aver analizzato i principali aspetti morfologici e strutturali caratterizzanti le Deformazioni Gravitative Profonde di Versante (D.G.P.V.) e presentato alcuni problemi relativi alla terminologia in uso, vengono descritti quattro casi di D.G.P.V. rilevati nella conca di Cortina d'Ampezzo (Dolomiti). Si esaminano poi le relazioni fra tali fenomeni, che spesso implicano lo sviluppo di movimenti franosi collaterali, e il rischio ambientale in un'area ad elevato valore economico e paesaggistico, quale quella di Cortina d'Ampezzo.

Termini chiave: Deformazioni Gravitative Profonde di Versante, rischio ambientale, Cortina d'Ampezzo.

1. INTRODUCTION

Lately the bibliography on deep-seated gravitational deformations has been rather enriched with references of researches carried out in numerous countries. These phenomena are in fact documented almost everywhere in the world since the end of the 1960s. In Italy, during the last ten years, there has been a remarkable development of the research in this field and a specific study group of the National Research Council of Italy has been established.

A bibliographical investigation carried out by the authors (*Pasuto & Soldati*, 1990) showed the existence of different scientific schools characterized by different approaches (geological, geomorphological, rheological, mechanical etc.) in the study of deep-seated gravitational deformations. Naturally, because of this, the terminology results quite varied; this may cause

Soldati M. & Pasuto A. (1991) - Some cases of deep-seated gravitational deformations in the area of Cortina d'Ampezzo (Dolomites). Implications in environmental risk assessment. *In: M. Panizza, M. Soldati & M.M. Coltellacci (eds.), "European Experimental Course on Applied Geomorphology, Vol. 2 - Proceedings", Istituto di Geologia, Università degli Studi di Modena, 91-104.*

problems with respect to a clear identification of the phenomena.

In order to achieve a better knowledge of the original meaning of some fundamental terms and definitions, within the Modena University and Padova C.N.R. research group, some fundamental papers written by the Austrian author *Zischinsky* (1969a; 1969b) have been translated into Italian.

Many terms have been used by different authors to indicate deep-seated gravitational phenomena. Among those the following ones should be pointed out: *Sackung*, firstly used by *Zischinsky* (1966); gravity faulting (*Beck*, 1968); depth creep of slopes and deep-reaching gravitational deformations (*Ter-Stepanian*, 1966; 1977); gravitational slope deformations (*Nemcok*, 1972); deep-seated creep deformations (*Mahr & Nemcok*, 1977); deep-seated gravitational slope deformations (*Malgot*, 1977); gravitational block-type movements (*Pasek*, 1974); gravitational spreading and gravitational creep (*Radbruch-Hall*, 1978) and the Italian term Deformazioni Gravitative Profonde di Versante (D.G.P.V.) (*Sorriso-Valvo*, 1984).

Of course it would be desirable that the researchers make an effort to standardize as much as possible the terminology, also in perspective of the possibility in the near future of studies, not only dealing with the identification and description of deep-seated gravitational phenomena, but also regarding

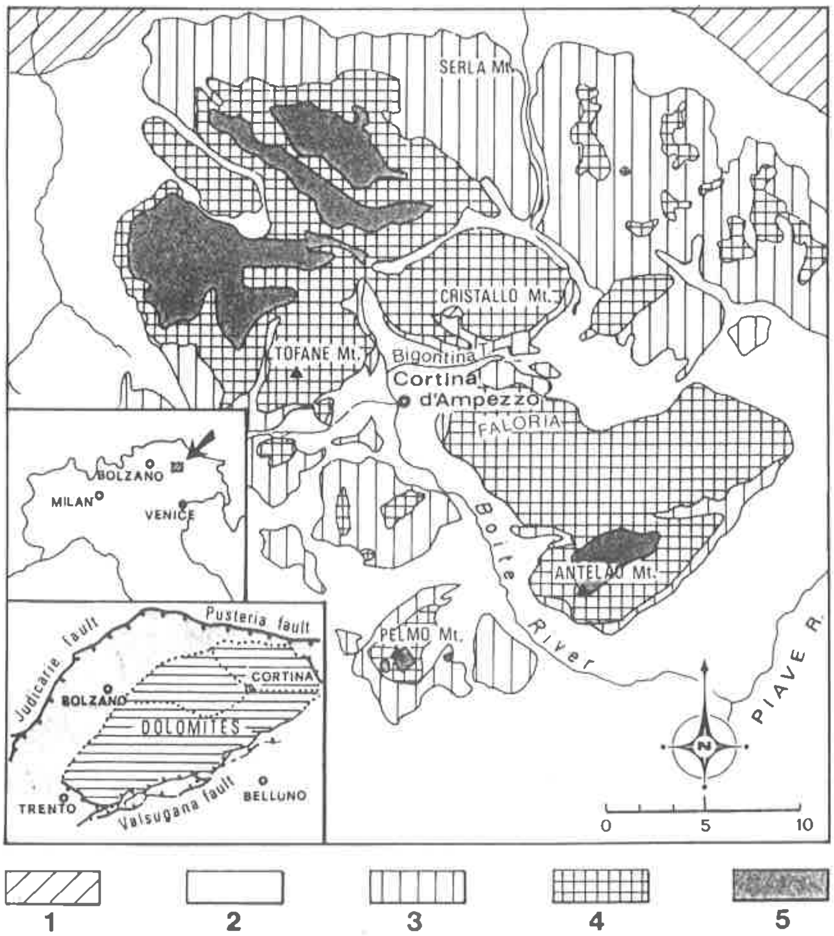

Fig. 1 - Geological setting of the area surrounding Cortina d'Ampezzo. Legend: 1) quartz phyllites of the crystalline basement (pre-Permian); 2) plastic formations (Lower Permian and Triassic); 3) Ladino-Carnian dolomites and Raibl Formation (Upper Carnian); 4) Dolomia Principale (Norian-Raethian?); 5) Calcari grigi (Lias).

the evaluation of the environmental hazard connected with their occurrence.

In fact, it is proved that deep-seated gravitational deformations are frequently associated with the development of collateral slope movements, which can sometimes evolve suddenly. If this happens in highly inhabited areas, like those here examined, problems connected with environmental risk have to be faced.

2. Geological setting of the area of Cortina d'Ampezzo

The Dolomites represent the innermost part of a S-vergent thrust chain, affected by different tectonic phases. Beside a syn-sedimentary tectonics documented by lateral and vertical variations in the Triassic and Jurassic stratigraphical sequence, the Dolomites have been interested by two "Alpine" compressional tectonic phases characterized by suborthogonal axes: the W-WSW- vergent Dinaric phase (pre Upper Oligocene-Lower Miocene) and the E-ESE-vergent Valsugana phase (post Lower Miocene); both the metamorphic basement and the overlying sedimentary cover were interested by the above mentioned tectonic deformations (*Doglioni*, 1987).

As a result of the complex paleogeography and tectonic history of the region, a clear influence of structure on the modelling of landforms can be observed. Moreover the setting of the main structural elements is favourable to the development of deep-seated gravitational phenomena; as a matter of fact, many trenches and crowns follow the trend of the tectonic lineaments.

The stratigraphical sequence outcropping in the area of Cortina d'Ampezzo (Fig. 1) covers a period of time ranging from Carnian to Lower Jurassic (*Bosellini*, 1989).

From the bottom to the top the following succession is observable (Fig. 2):

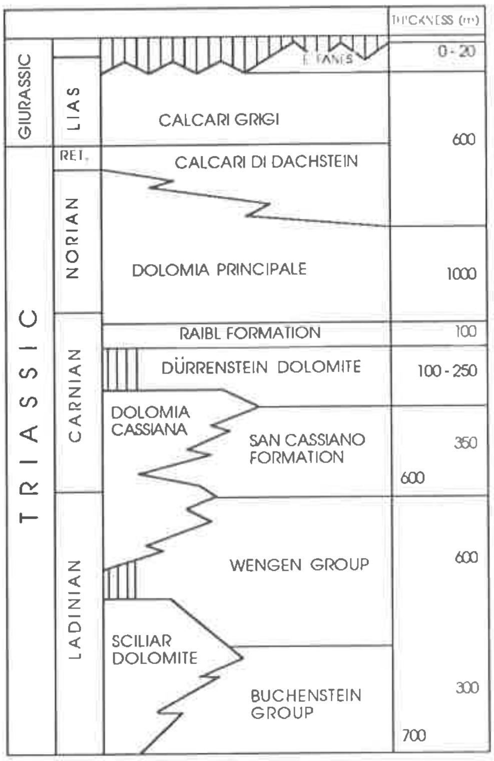

Fig. 2 - Stratigraphical sequence outcropping in the area surrounding Cortina d'Ampezzo.

- *San Cassiano Formation* (Middle-Upper Carnian). It consists of interbedded pelites, arenites and grey biocalcarenites. The arenitic lithotypes are prevalent in the peripheral zones of the Cortina d'Ampezzo area, while in the vicinity of the town variably consolidated clays are present. The thickness reaches 350 m.

- *Dolomia Cassiana* (Middle-Upper Carnian). It is represented by white greyish crystalline dolomites, which are generally massive. From a paleogeographic point of view, the formation can be considered a lateral unit of a platform progradating on the basin sediments of the San Cassiano Formation. The thickness is of about 250 m.

- *Dürrenstein Dolomite* (Upper Carnian). It consists of white stromatolitic dolomites, characterized by a decimetric layering. The sediments were deposited in shallow marine conditions. The thickness is on average 250 m.

- *Raibl Formation* (Upper Carnian). It

includes polychrome pelites and marls, afanitic limestones and microcrystalline dolomites. Because of their intense colour and high erodibility they produce evident morphological discontinuities, called "cenge", which separate the Dürrenstein Dolomite, at the bottom, from the Dolomia Principale, at the top. The thickness is of about 100 m.

- *Dolomia Principale* (Norian-Rhaethian?). This formation is widely represented in the area of Cortina d'Ampezzo, constituting the main mountain groups. It consists of white and grey cyclic dolomites, in which stromatolitic and massive lithozones are present. The sediments were deposited within carbonate tidal flats; in the investigated area the thickness reaches 1.000 m.

- *Calcari grigi* (Lias). The formation outcrops in the peaks of the Tofane, Sorapis and Antelao groups. It consists of bedded light grey micrite, bioclastic and oolitic limestones, widely affected by karst phenomena, both superficially and at depth.

The landforms are deeply influenced by the presence of lithotypes characterized by different geomechanical properties. The San Cassiano and Raibl Formations, because of the high clayey fraction, are gently modelled and, with respect to slope movements, are generally affected by flows. They outcrop in the middle and low altitude zones of the area of Cortina d'Ampezzo, where the urban development has been more intense. On the contrary, the calcareous and dolomitic formations give origin to the very steep and often subvertical rock walls, which surround Cortina d'Ampezzo and make up the main mountain groups, like Tofane, Croda da Lago, Sorapis and Cristallo.

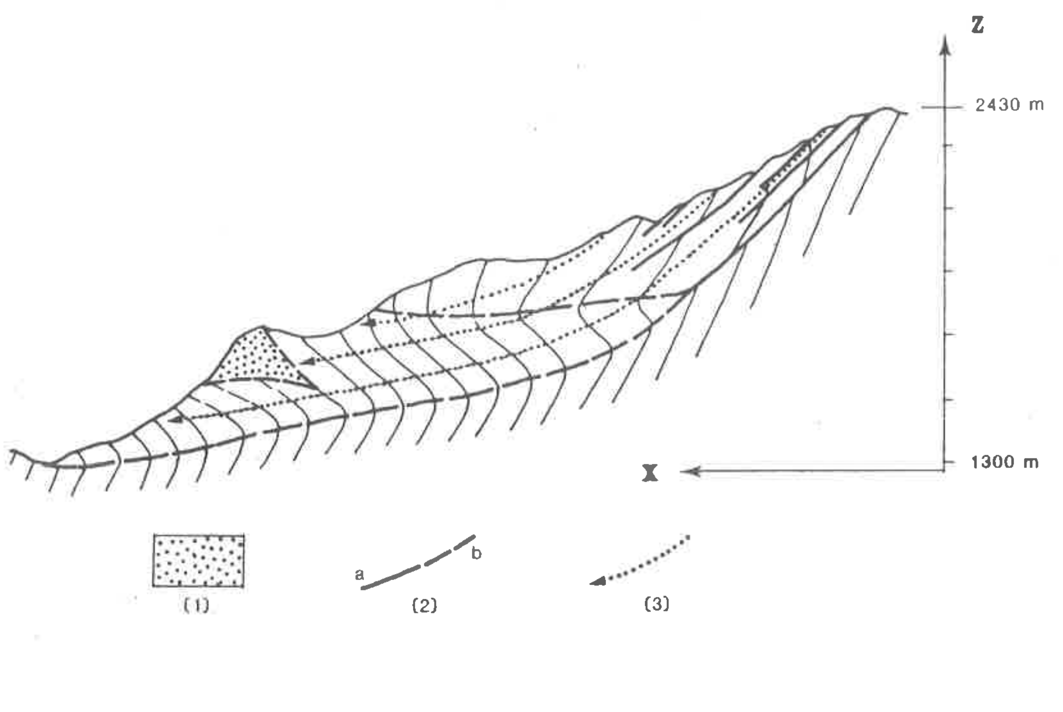

Fig. 3 - The *Sackung* of Matrei in East Tyrol (after *Zischinsky*, 1969b; modified). Legend: 1) massive carbonates; 2) actual (a) and potential (b) sliding surface; 3) flow line.

3. MORPHOLOGICAL AND STRUCTURAL FEATURES OF DEEP-SEATED GRAVITATIONAL DEFORMATIONS

Since several researchers have been studying deep-seated gravitational phenomena, it results that many terms have been used to define them, but not always with univocal meanings. Examining the literature about this subject, it becomes clear that often a single term has been used by different authors to indicate different, and sometimes not comparable, phenomena and, viceversa, different definitions have been attributed to similar phenomena.

For this reason it is opportune to specify that for deep-seated gravitational deformation we mean long-term slow deformations at depth without well defined sliding surfaces; it is evident that the presence of deformation does not necessarily involve the existence of movements. In fact, shear planes are generally not recognizable in the deepest parts of a slope; the latter, instead, appear to be affected by plastic deformations along bands characterized by shear surfaces, which can be considered of infinitesimal dimensions, considering the scale of the deformed slope. This situation is comparable to the "creep" phase according to *Terzaghi* (1950), which is clearly different from the "movement" or "landslide" phase of the same author.

The latter phase is characterized by the development of one or more well defined surfaces along which the displacement takes place and which separate the moving body from the stable parts of the slope. *Terzaghi*, in 1950, differentiated the examined phenomena stating that: "*A landslide is an event which takes place within a short period of time as soon as the stress conditions for the failure of the ground located beneath the slope are satisfied. By contrast, creep is more or less continuous process. A landslide represents the movement of a relatively small body of material with well-defined boundaries, whereas creep may involve the ground located beneath all the slopes in a whole region and no sharp boundary exists between stationary and moving material.*"

In most cases the first deformation phase is naturally followed by a sliding phase within which shear planes are recognizable. Of course the evolution time of the phenomena are hardly predictable and anyway extremely long.

As concerns the typology, we can individuate two main categories of deep-seated gravitational deformations: *Sackung* and lateral spread.

The *Sackung* can be described according to *Zischinsky* (1969) as a sagging of a slope due to visco-plastic deformations, taking place at depth. There are some morphological features characterizing this phenomenon. In the upper part of a slope affected by a *Sackung* twin ridges, trenches, gulls, scarplets, up-hill facing scarps, due to the presence of tension cracks, are recognizable. In the medium and lower part the slope is subjected to bulging and cambering, assuming in this case a convex shape. At the foot of the slope sub-horizontal fractures can be found (Fig. 3).

Lateral spread consists in the displacement of rocky blocks, which generally takes place along a discontinuity surface, which could be, for example, the contact between competent and incompetent rocks. However, cases of lateral spread without the presence of a defined spreading surface are known in the scientific literature. This is the case of hard and fractured rocks and schistose rocks. Typical morphological features of lateral spread are usually given by trenches and fractures, generally parallel to the slope ridge, twin ridges, piping, tilting and lowering of blocks, flowing (rifluimento) and bulging in plastic formations.

From an evolutive point of view, a *Sackung* can originate rotational and translational slides (Fig. 3), debris flows and debris avalanches, while lateral spread can evolve into block-slides, through subsequent stages, as represented in Fig. 4 (*Cancelli & Pellegrini*, 1987).

Generally, deep-seated gravitational deformations are deeply influenced in their origin and evolution by lithological and structural factors. In particular, considering the case of the Cortina d'Ampezzo area, the phenomena take place at the contact between the San Cassiano Formation and the Dolomia Cassiana and Dürrenstein Dolomia and at the contact between the Raibl Formation and the Dolomia Principale.

From a structural point of view, the main discontinuities of the deformed bodies and the trend of the principal tectonic lineaments (even at a regional scale) are generally congruent.

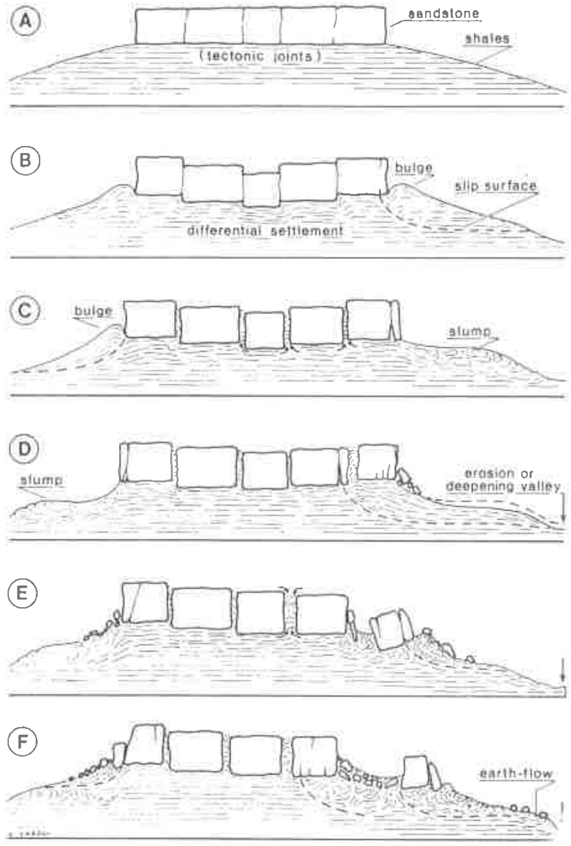

Fig. 4 - Evolution stages of a lateral spread affecting a rigid plateau which overlies plastic formations (after *Cancelli & Pellegrini*, 1987).

This seems to be proved also in the case of the Cortina d'Ampezzo area, where the tectonic influence is very intense.

A characteristic aspect of deep-seated gravitational deformations, which has not been underlined very often , consists in the occurrence of slope instability phenomena, which we defined "collateral" (*Menotti et al.*, 1990). They are represented by slope movements (especially flows in the investigated area), which sometimes may show an extremely rapid evolution and which are located at the margins of the area directly affected by deep-seated deformations. These phenomena seem to be connected with the modifications of the groundwater flow net and the stress conditions of a slope, due to active deformations. It is clear that more detailed studies would be necessary, in order to better correlate deep-seated deformations to collateral movements.

4. DEEP-SEATED GRAVITATIONAL DEFORMATIONS IN THE AREA OF CORTINA D'AMPEZZO

The main geological and geomorphological features characterizing four cases of deep-seated gravitational deformation will be here described.

4.1 The case of the Cinque Torri

The most evident phenomenon of deep-seated gravitational deformation in the investigated area is surely represented by the Cinque Torri. This is not only due to the fact that the Cinque Torri are isolated from the surrounding mountain groups and therefore easily visible from almost everywhere in the area of Cortina d'Ampezzo, but also because they show a very advanced stage of evolution.

They consist of some monoliths of Dolomia Principale, that were probably part of a single plateau at the initial stages of their evolution, which was then dissected.

The gravitational phenomena are mainly conditioned by the superposition of the Dolomia Principale of the Cinque Torri on an incompetent substratum, consisting in reddish marls and sandstones belonging to the Raibl Formation. This is the typical case of a superposition of hard and rigid rocks (Dolomia) on soft and plastic materials (San Cassiano Formation), a situation which is well known to be very favourable to the development of deep-seated gravitational deformations.

The Cinque Torri represent a case of lateral spread evolving into block slide, affecting a former plateau which was isolated by erosive processes active during the last glacial period.

The monoliths are now highly affected by degradational phenomena (mainly frost shattering), favouring the occurrence of rock falls and topples, which contribute to the nourishment of the scree slopes present at the base of the rock walls. Moreover very significant must be considered the bulges, affecting the plastic material of the Raibl Formation, induced by the overload caused by the dolomitic monoliths (Fig. 5).

This overload probably influenced the development of a large flow triggered by the Friuli earthquake in 1976.

The direction of the fractures and trenches separating the blocks follows the tectonic style of the area, which shows a system of discontinuities with NW-SE and NNE-SSW preferential directions. The strata of the Raibl Formation dip downstream with the same angle of the slope; this fact surely contributed to the splitting up of the plateau and to the tilting of the blocks.

The Torre Grande, the highest monolith (2.361 m upon sea level), characterized by almost vertical walls reaching the height of 150 m, is affected by open fractures which extend as far as the substratum; this leads to the subdivision of Torre Grande in some rock blocks which tend to be interested by spreading phenomena.

Remarkable displacements seem to have happened between the single monoliths; examining pictures taken in the first years of this century makes clear that the movement reached at least one metre.

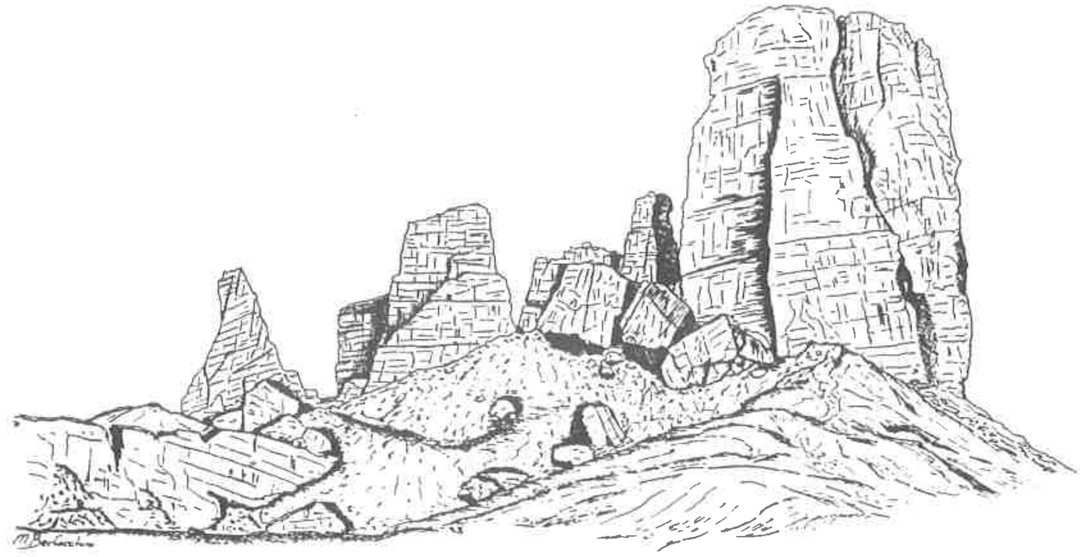

Fig. 5 - The Cinque Torri seen from the Rifugio Scoiattoli.

4.2 The case of the Lastoni di Formin.

The Lastoni di Formin group is located SW of Cortina d'Ampezzo on the right side of the Rio Falzarego (Fig. 1). It is part of the mountain group which includes M. Averau, M. Nuvolao and La Rocchetta.

The Lastoni di Formin can be described as a thick plate of Dürrenstein Dolomia and Dolomia Cassiana overlying the marls, arenites and clays of the San Cassiano Formation.

From a structural point of view, the strata show a NW-SE strike and dip gently to NE. Moreover, the area is characterized by a system of discontinuities which controls the dismemberment of the plate and many other gravitational deformations and slope movements within almost the entire basin of the Boite torrent.

The wide structural surface of the Lastoni di Formin is affected by deep-reaching fractures, whose direction runs parallel to the strike of the strata and consequently to the direction of the slope.

The dimensions of the fractures vary

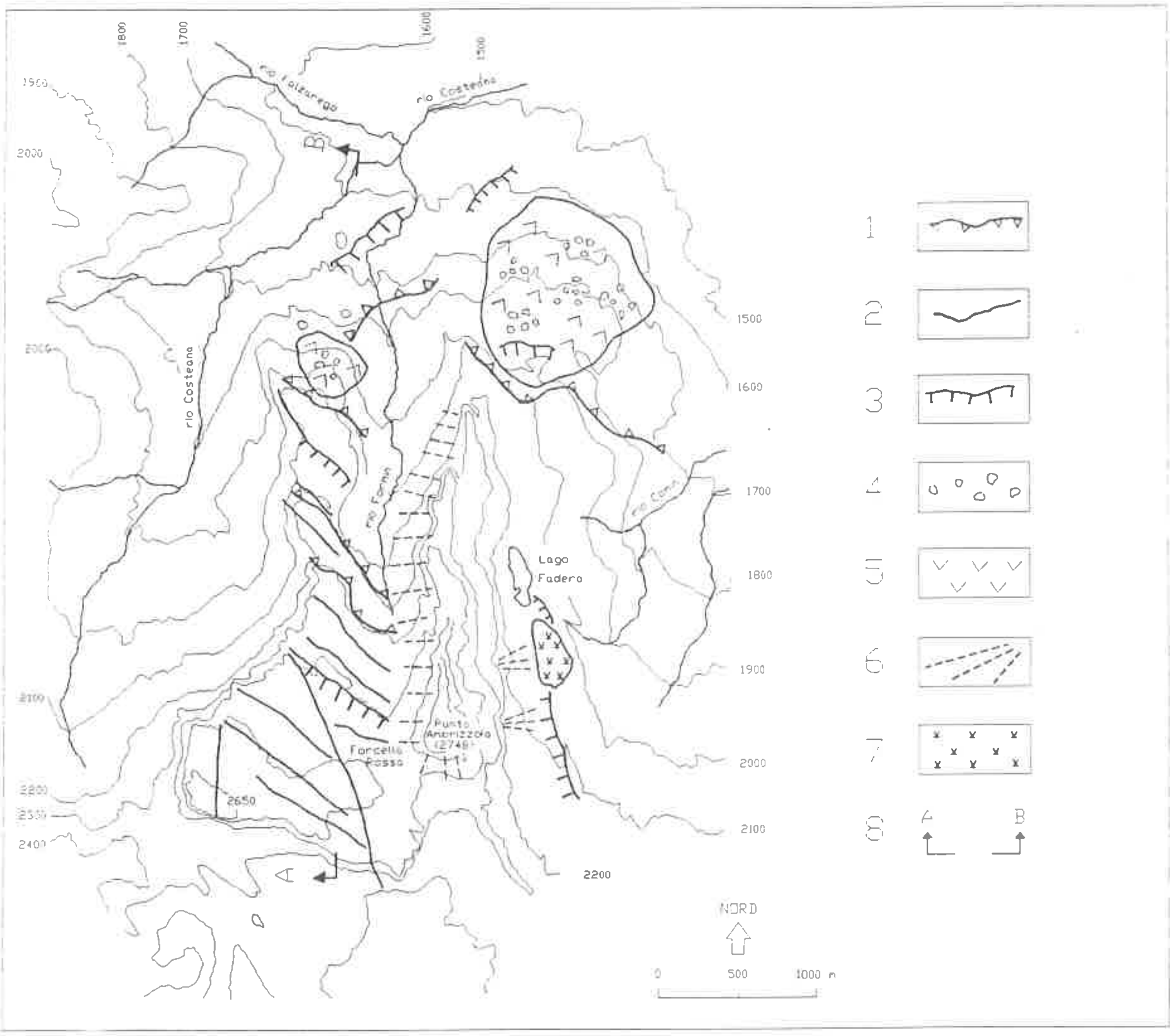

Fig. 6 - Morphological sketch of the Lastoni di Formin. Legend: 1) scarp; 2) trench; 3) up-hill facing scarp; 4) isolated block; 5) landslide; 6) scree slope; 7) lacustrine deposit; 8) section.

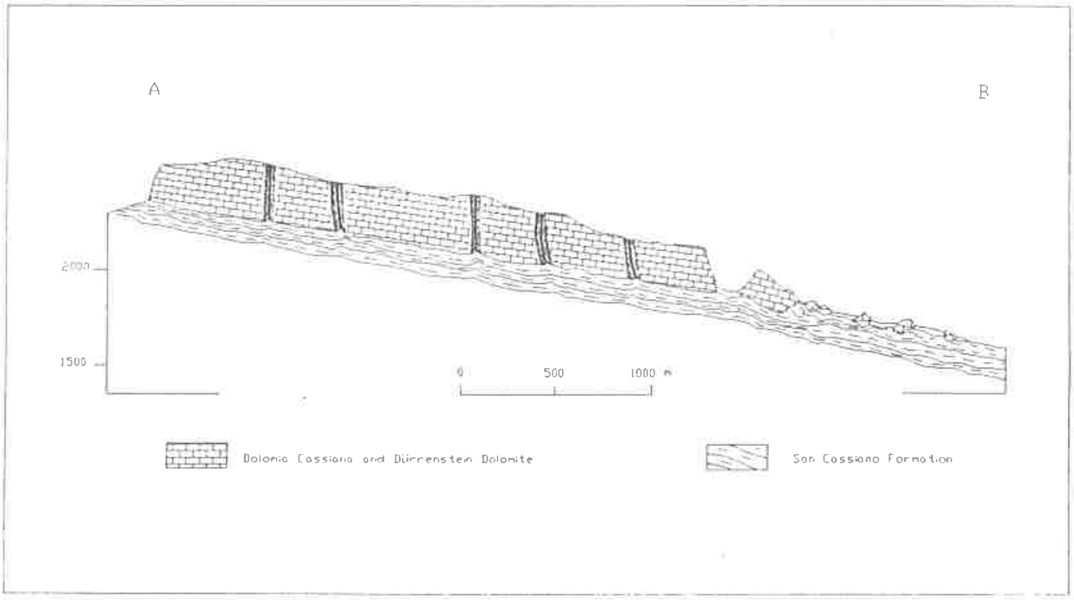

Fig. 7 - Schematic geological section of the Lastoni di Formin. Legend: 1) Dolomia Cassiana and Dürrenstein Dolomite; 2) San Cassiano Formation.

depending on the different evolutive stages of the phenomenon, which are quite clearly observable in the field (Figs. 6 and 7). In fact, in the upper part of the Lastoni di Formin there are trenches reaching a maximum width of about 1 m, while in the lower parts the trenches reach widths of decametric scale, with vertical displacements of similar entity.

The peculiarity of the case of deep-seated gravitational deformation here described consists in the presence of various stages of evolution at the same time. Lateral spread phenomena are prevalent in the upper part accompanied by a progressive displacement of the blocks downslope, which gives the slope a step-like morphology. In the lower parts of the slope, lateral spread evolves in block slide, while at the base of the slope "ordinary" slope movements, such as falls, topples and slides take place. This is demonstrated by the presence of several dolomitic monoliths and boulders (some of them reaching some hundreds of cubic metres) isolated from the rocky plate and toppled inside the wood at the foot of the slope.

4.3 The case of the Tofane group

The Tofane group consists of three major peaks: Tofana di Rozes (3.225 m), Tofana di Mezzo (3.324 m) and Tofana di Dentro (3.238 m), which are aligned with a NS direction. Like the other mountain groups in the area of Cortina d'Ampezzo, the Tofane are characterized by high subvertical walls, which reach the height of 1.000 m.

Deep-seated gravitational deformations take place at the south-eastern slope (Fig. 8), where also large blocks of Dolomia Principale are involved in block slide phenomena, occurring on a plastic substratum, that is the Raibl Formation. The rock blocks appear rather dismembered and show a variable setting of the strata because of their tilting. The distance of the blocks from the rock walls amounts to several tens of metres.

From a morphological point of view, on the whole slope up-hill facing scarps and bulges are present; the former are clearly observable along the topographic section (Fig. 9).

However the area interested by the

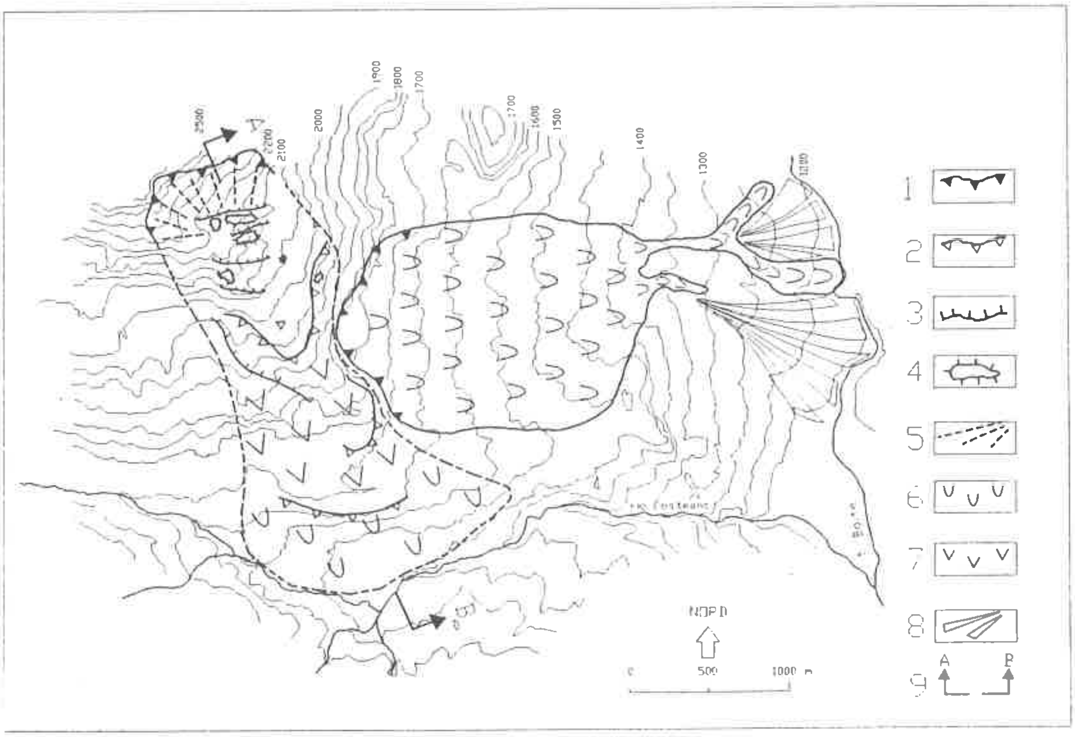

Fig. 8 - Morphological sketch of the south-eastern slope of the Tofane mountain group. Legend: 1) crown; 2) scarp; 3) up-hill facing scarp; 4) isolated block; 5) scree slope; 6) flow; 7) slide; 8) fan; 9) section.

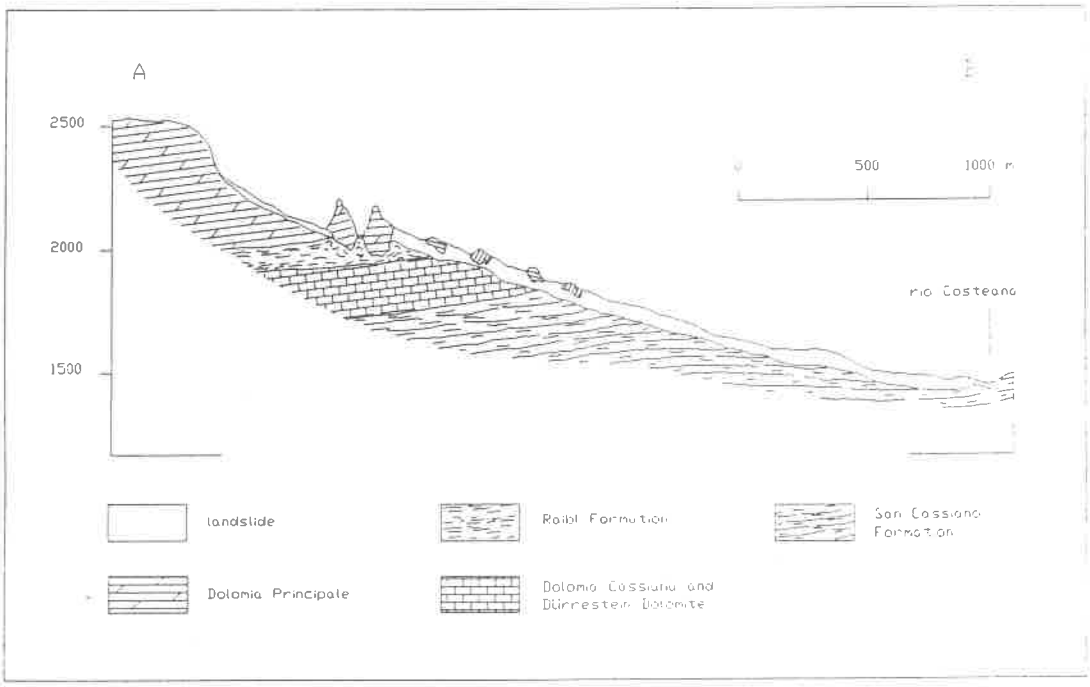

Fig. 9 - Schematic geological section of the south-eastern slope of the Tofane mountain group. Legend: 1) landslide; 2) Dolomia Principale; 3) Raibl Formation; 4) Dolomia Cassiana and Dürrenstein Dolomite; 5) San Cassiano Formation.

deformation, or even indirectly connected with it, results much larger; in our opinion, the slope movements which occur in the area around the deformed slopes and that we called "collateral" are very significant. In this case they consist in flows which arise at the base of the Dolomia walls and involve the Raibl Formation and the San Cassiano Formation. The displacements generally reach the velocity of a metre per year and the depth of 25-30 m and affect the entire slope as far as the Boite torrent.

The damages to the population induced by the above mentioned slope movements are very heavy above all because of their relatively high velocity.

4.4 The case of Monte Faloria

The Monte Faloria is situated on the eastern side of the area of Cortina d'Ampezzo. It represents the watershed between the Boite torrent and its tributary stream Bigontina (Fig. 1). The area is characterized by relevant differences in height (higher than 1.000 m), due to the presence of steep walls of Dolomia Principale overlying the marls and clays of the Raibl Formation. The Dolomia Principale shows a dense net of joints, which heavily modified the mechanic behaviour of the formation, thus weakening the rock strength.

Deep-seated gravitational deformations occur within the south-western slope (Figs. 10 and 11). In the highest parts numerous trenches, partially filled by large quantities of debris, are evident; this indicates a recent activity. These trenches show directions almost parallel to the slope with lengths reaching some hundreds of metres and depths of 30-40 m.

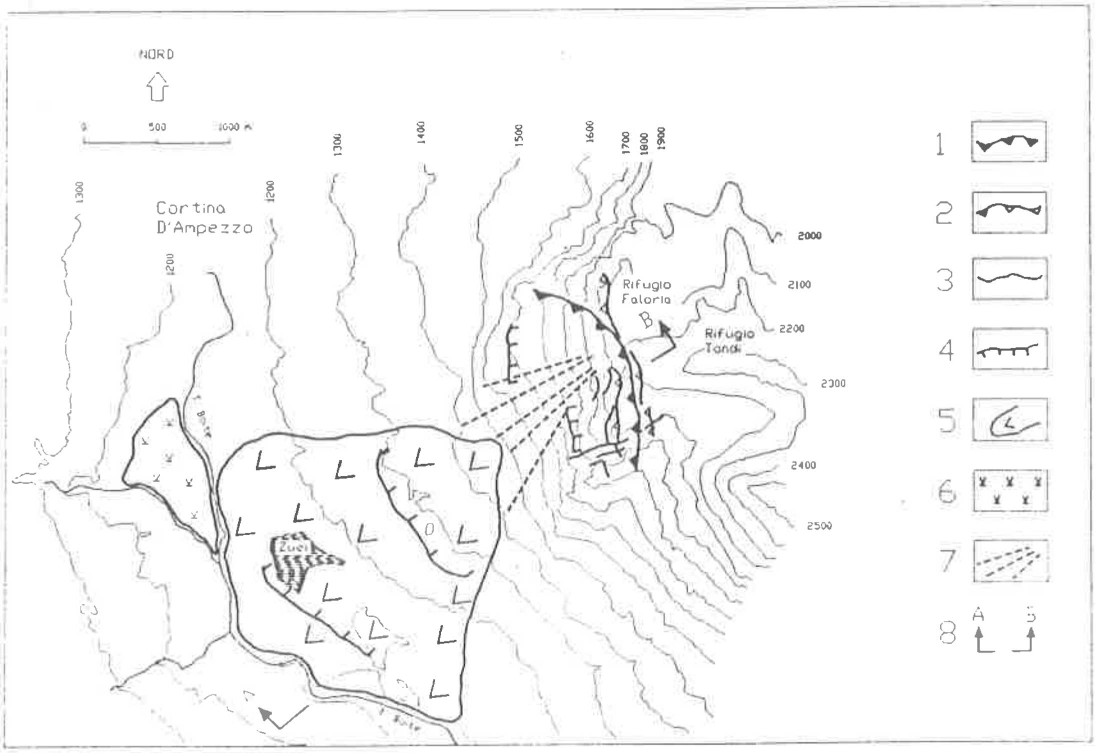

Fig. 10 - Morphological sketch of the south-western slope of the M. Faloria. Legend: 1) crown; 2) scarp; 3) trench; 4) up-hill facing scarp; 5) landslide; 6) lacustrine deposit; 7) scree slope; 8) section.

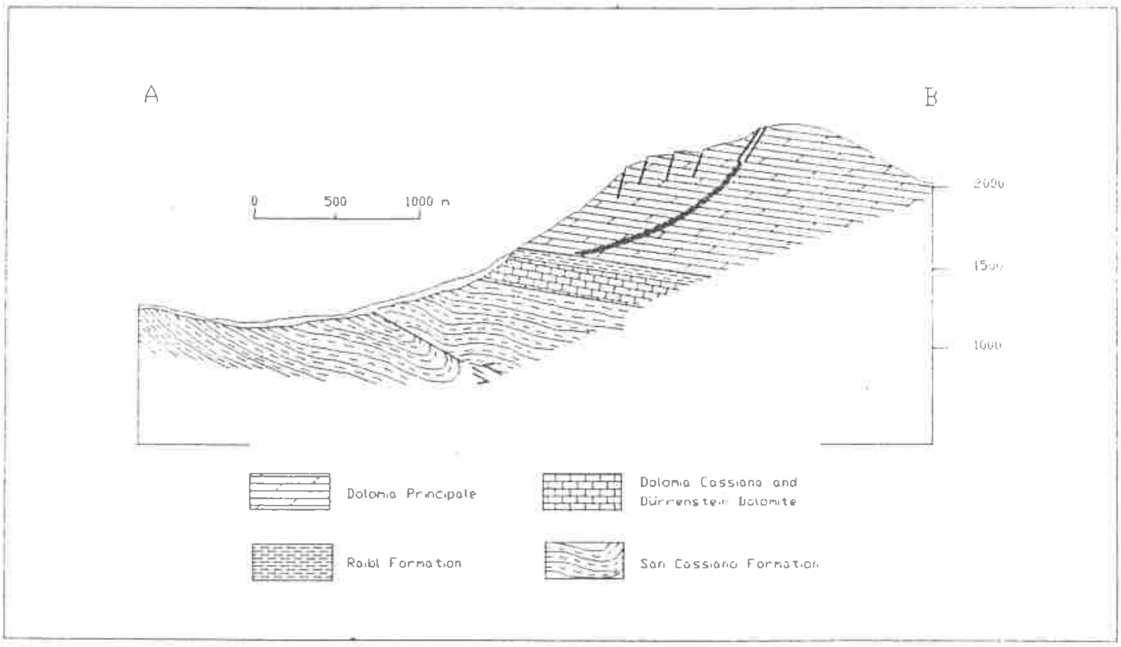

Fig. 11 - Schematic geological section of the south-western slope of the M. Faloria. Legend: 1) Dolomia Principale; 2) Raibl Formation; 3) Dolomia Cassiana and Dürrenstein Dolomite; 4) San Cassiano Formation.

In the southern part many fractures perpendicular to the slope direction are also present. The structural conditions lead to the formation of rock prisms, which are very unstable. These fractures are probably connected with phenomena of de-compression deriving from the melting of the glacier occupying the Val Orita. Glacio-pressure implications in the development of rock deformations in the dolomitic area have been underlined by *Panizza* (1973). The author considered, among others, the case of the Monte Faloria slopes, which seem to have been deformed by the pressure exerted by the converging glacier tongues coming from the Boite, Bigontina and Costeana valleys during the Late Würmian period. According to *Panizza*, the glacio pressure deformations seem to have taken place in correspondence with structural discontinu-ities, such as bedding and fissure planes, favouring disjointing phenomena of the rock masses, thus creating surfaces of potential displacements.

As regards the typology, we could consider the present phenomenon as a *Sackung*; actually a sector of the slope has encountered a sudden evolution, repres-ented by a rock avalanche. This landslide caused the obstruction of the valley with consequent formation of a lake and diversion of the Boite torrent.

The lower parts of the slope, beside the accumulation due to the rock avalanche, are covered by scree slope deposits, thus preventing the observation of any morpho-logical element connected with the presence of eventual shear surfaces.

5. RELATIONSHIPS BETWEEN DEEP-SEATED GRAVITATIONAL DEFORMATIONS AND ENVIRONMENTAL RISK

An aspect that seems to have been overlooked in the previous studies concerns the implications in environmental risk deriving from the occurrence of deep-seated gravitational deformations.

As regards this aspect, the area of Cortina d'Ampezzo represents an exemplary case because of the coexistence of a high geomorphological hazard with an extreme vulnerability of the region.

The geomorphological hazard is mainly induced by the geotechnical properties of the outcropping geological formations, as it was mentioned above, by the high relief energy and by the effects of the intense glacialism which interested the area during the Würmian period.

The vulnerability of the area is overall connected with intense human activities, mainly due to the presence of considerable tourism and sport settlements, which determined an enlargement of the mountain villages and the development of infrastructures (roads, ski-tracks) (*Panizza*, 1990).

The high degree of environmental risk of the investigated area is witnessed by repeated slope movements, occurred in the past, that caused high damage to the population (*Panizza & Zardini*, 1986; *Pampanini*, 1921).

The studies concerning the assessment of geomorphological hazard in the area of Cortina d'Ampezzo have not considered yet the relationships between deep-seated gravitational deformations and the occurrence of landslides. In our opinion, tight correlations, at least in the investigated area, exist between the presence of slow deformations at depth and the development of collateral movements. The latter mainly consist in flows which may evolve even suddenly and cause severe damages. Anyway other different types of slope movements are documented; in the specific case, the rock avalanche of Monte Faloria can be cited.

It is likely that the collateral phenomena are connected with modifications induced by deep-seated deformations of both the groundwater flow nets and the structural characteristics of the rock masses (formation of new systems of discontinuities, production of mylonites and cataclasites, variation of strata setting etc.).

The knowledge of the existence of links between slope instability and deep-seated gravitational deformations appear to be fundamental when stabilization and monitoring of single landslides are to be planned. If the possible influence of deep-seated deformations is not considered, the risk is to make stabilization projects, which result incomplete and non-effective in long terms. It is clear that resolutive interventions aiming to mitigate the effects of deep-seated gravitational phenomena are not possible at the moment.

Actually new methods for the detection and survey of deep-seated deformations must be further experimented; they consist in high precision topographical measurements regularly repeated (even annually), considering the possibility of satellite surveying systems; structural analysis of rock masses in order to show eventual variations of the attitude of the strata and individuate connections with the regional tectonic style; measurements of the ground helium concentrations (*Guerricchio et al.*, 1986).

However, it seems opportune to pass from a simple detection and description phase to the measurement of displacements, individuation of significative factors and their quantification in order to formulate an acceptable evolution kinematic model.

Acknowledgements

We would like to thank prof. Mario Panizza for the critical rewiew of the manuscript and dr. Sandro Silvano, dr. Giovanni Tosatti and dr. Chiara Siorpaes for their fundamental advice.

References

BECK A.C. (1968) - *Gravity faulting as a mechanism of topographic adjustment.* N.Z. Jl. Geol. Geophys., 11(1), 191-199.

BOSELLINI A. (1989) - *La storia geologica delle Dolomiti,* Ed. Dolomiti, 148 pp.

CANCELLI A. & PELLEGRINI M. (1987) - *Deep-Seated Gravitational Deformations in the Northern Apennines, Italy.* Proc. 5th ICFL, Australia & New Zealand, 1-8.

DOGLIONI C. (1987) - *Tectonics of the Dolomites (Southern Alps - Northern Italy).* J. Struct. Geol., 9, 181-193.

GUERRICCHIO A., MELIDORO G. & RIZZO V. (1986) - *Prime osservazioni strumentali delle deformazioni dei pendii e delle manifestazioni profonde nella Valle di Maratea (Basilicata, Italy).* Geol. Tecnica, Anno 1, 4, 35-48.

MAHR T. & NEMCOK A. (1977) - *Deep-seated creep deformations in the crystalline cores of the Tatry Mts.* Bull. IAEG., 16, 104-106.

MALGOT J. (1977) - *Deep-seated gravitational slope deformations in neovolcanic mountain ranges of Slovakia.* Bull. IAEG., 16, 106-109.

MENOTTI R.M., PASUTO A., SILVANO S., SIORPAES C. & SOLDATI M. (1990) - *Guida alle escursioni del IV Seminario. Cortina d'Ampezzo (BL), 25-28 settembre 1990.* C.N.R. Gruppo Informale D.G.P.V.; C.N.R. Istituto di Geologia Applicata, Padova, 22 pp.

NEMCOK A. (1972) - *Gravitational Slope Deformation in High Mountains.* Proc. 24th Int. Geol. Congr., Montreal, Sect. 13, 132-141.

PAMPANINI R. (1921) - *La frana del Monte Antelao (21 aprile 1814).* L'Universo, Istituto Geografico Militare, Firenze, 883-892.

PANIZZA M. (1973) - *Glacio pressure implications in the production of landslides in the dolomitic area.* Geol. Appl. e Idrogeol., 8(1), 289-297.

PANIZZA M. (1990) - *Geomorfologia applicata al rischio e all'impatto ambientali. Un esempio nelle Dolomiti (Italia).* 1ª Reunión Nacional de Geomorfología, Teruel, España, 1-16.

PANIZZA M. & ZARDINI R. with coll. of SPAMPANI M. (1986) - *La grande frana su cui è sorta Cortina d'Ampezzo.* Ed. Dolomiti Cortina, 101 pp.

PASEK J. (1974) - *Gravitational block-type movements.* Proc. 2nd Int. Congr. IAEG., São Paulo, Brasil, V-PC-1.1 - V-PC-1.9.

PASUTO A. & SOLDATI M. (1990) - *Rassegna bibliografica sulle Deformazioni Gravitative Profonde di Versante.* Il Quaternario, 3(2), 131-140.

RADBRUCH-HALL D.H. (1978) - *Gravitational creep of rock masses on slopes.* In: B. Voight (ed.), *Rockslides and avalanches,* Elsevier, Amsterdam, 1, 607-675.

SORRISO-VALVO M. (ed.) (1984) - *Atti del I seminario sul tema "Deformazioni gravitative profonde di versante".* Boll. Soc. Geol. It., 103, 667-729.

TER-STEPANIAN G. (1966) - *Types of depth creep of slopes in rock masses.* Proc. 1st Conf. Int. Soc. Rock Mech., Lisbon, Sect. 2, 157-160.

TER-STEPANIAN G. (1977) - *Deep-reaching gravitational deformation of mountain slopes.* Bull. IAEG., 16, 87-94.

TERZAGHI K. (1950) - *Mechanism of landslides.* In: Paige S. (ed.), *Application of geology to engineering practice (Berkey Volume),* Geol. Soc. of America, 83-123.

ZISCHINSKY U. (1966) - *On the deformation of high slopes.* Proc. 1st Conf. Int. Soc. Rock Mech., Lisbon, Sect. 2, 179-185.

ZISCHINSKY U. (1969a) - *Bergzerreißung und Talzuschub,* Geol. Rund., 58(3), 974-983 (Italian transl., *Bergzerreißung e Talzuschub,* Il Quaternario, 4(1b), 1991, 215-222.

ZISCHINSKY U. (1969b) - *Über Sackungen.* Rock Mech., 1(1), 30-52.