Geogr. Fis. Dinam. Quat.
19 (1996), 359-368, 9 figg.

JANUSZ WASOWSKI (*) & MARIO PARISE (*)

SOME EVIDENCE AGAINST THE DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATION IN CARAMANICO TERME (Abruzzo, Italy)

ABSTRACT: WASOWSKI J. & PARISE M., *Some evidence against the deep-seated gravitational slope deformation in Caramanico Terme (Abruzzo, Italy)*. (IT ISSN 0391-9838, 1996).

The aim of this paper is to contribute to the discussion on the deep-seated gravitational slope deformations (Dgsd), by examining the case of the 1989 Caramanico landslide. The slide, which remobilized middle-lower portions of the slope capped by several tens of meter thick carbonate megabreccias, was originally interpreted as a deep movement linked to the Dgsd. In particular, several features, considered typical of a slope afflicted by Dgsd, were indicated in the zone upslope the main scarp of the 1989 event (series of scarps and uphill facing areas which appear to form trenches oriented parallel to the slope direction). The trenches were mapped upslope several carbonate breccia hills (hummocks), which in turn were interpreted as large blocks derived from the caprock plateau through a mechanism including deep-seated rotational failures followed by lateral spreading.

A detailed examination of the area, integrated with subsurface data, has led to the re-assessment of the morphological features and to an alternative interpretation of the slope evolution, without invoking the Dgsd phenomena. To argue against the Dgsd hypothesis, we offer a series of geomorphological, geological, geophysical and geomechanical evidences; following these considerations, the several tens of meter thick surficial deposits, comprising the carbonate breccia hummocks in the middle-upper parts of the slope, may be interpreted in the context of an ancient alluvial fan setting, which subsequently suffered a considerable degree of post-sedimentary disruption. In particular, two carbonate breccia units can be distinguished within the hummocks. These breccias are separated by a succession consisting of debris flow, water-laid and sieve-like sediments (including a paleosol), and therefore, register the occurrence of at least two distinctive depositional events, probably generated by mass movements.

(*) *Cnr, Centro di Studio sulle risorse idriche e la salvaguardia del territorio, Bari.*

The authors would like to thank several people of Caramanico Terme, and in particular the town's mayors Dott. F. d'Atri (former) and Dott. Fanelli, parish priest Don G. Liberatoscioli, Mr. V. Silvestri (Ufficio Tecnico del Comune), town's councilor B. Bucciferro, L. Trolla and L. D'Ettore (Consorzio di Bonifica Orta e Lavino), U. Palmerio (Comunità Montana della Maiella e del Morrone), and Mr. L. Pastore, for allowing them to examine unpublished data and documents. Thanks are due also to Proff. A. Guerricchio and F. Loiacono for several useful discussions on the Caramanico DGSD problem. The comments of the anonymous reviewer helped to clarify several problems and to improve the original manuscript.

KEY WORDS: Deep-seated gravitational slope deformation, Landslide, Megabreccia, Caramanico Terme, Abruzzo (Italy).

RIASSUNTO: WASOWSKI J. & PARISE M., *Il problema della deformazione gravitativa profonda di versante a Caramanico Terme (Abruzzo)*. (IT ISSN 0391-9838, 1996).

Il presente contributo si propone di fornire elementi per una discussione sul fenomeno delle deformazioni gravitative di versante, prendendo spunto dal caso della recente frana di Caramanico Terme (PE) del 1989, interpretata come un movimento di massa profondo legato a processi di Dgpv. La periferia SE di Caramanico è dominata da un rilievo la cui parte sommitale è costituita da un esteso (circa 2.5 km^2) e potente (fino a 100 m) deposito di megabrecce carbonatiche. Il contatto basale della placca di megabrecce con la circostante successione argillosa (Pliocene inferiore) non è osservabile a causa della presenza di abbondanti coperture detritiche; tuttavia, la geometria della sovrapposizione è molto probabilmente suborizzontale. Specialmente interessato da franosità è il versante O-SO della placca, lungo la cui porzione medio-bassa si è verificata la grande (circa 33 ha) frana di Caramanico dell'ottobre 1989. Nella zona a monte della scarpata principale della frana sono state riconosciute forme morfologiche ritenute diagnostiche di un versante interessato da Dgpv: tra queste, alcune trincee appaiono posizionate a monte di alcuni rilievi costituiti da brecce, i quali vengono così interpretati come grossi blocchi derivati dalla placca sommitale attraverso un meccanismo comprendente profondi scorrimenti rotazionali e successivo espandimento laterale.

Un rilevamento di dettaglio della zona, integrato con nuovi dati del sottosuolo, permette una rivalutazione delle evidenze morfologiche e un'interpretazione alternativa dell'evoluzione del versante, non necessariamente in chiave di Dgpv. Contro l'ipotesi Dgpv, si considerano i seguenti fattori:

1) le cosiddette trincee hanno una forma piuttosto irregolare e sono caratterizzate da assenza di ben definite scarpate, pertanto sembrano semplici depressioni a monte di antichi accumuli di frana; inoltre, il loro andamento risulta ovunque piuttosto incoerente con le direzioni ipotizzabili di trasporto dalla placca di megabrecce verso valle;

2) il più esteso rilievo di brecce nella parte medio-alta del versante è disposto in posizione marginale rispetto alla sua presunta collocazione originale (placca sommitale delle megabrecce); inoltre, semplici considerazioni spazio-volume riguardanti le sezioni in 2D indicano che il materiale prodotto dall'arretramento massimo ipotizzabile della placca di megabrecce sommitali (a prescindere dall'esatto meccanismo del processo) è insufficiente per giustificare il volume complessivo delle brecce;

3) gli accumuli dei materiali detritici nella parte medio-alta del versante conservano una successione litostratigrafica composta da due potenti livelli di brecce separati dai sedimenti attribuibili a *debris flow*, *water-laid* e *sieve deposits*, questi ultimi ritenuti diagnostici di un ambiente deposizionale di tipo conoide alluvionale;

4) in gran parte del versante, la giacitura dell'interfaccia substrato argilloso/coltri detritiche (sulla base delle correlazioni tra i sondaggi e i dati della sismica a rifrazione) appare piuttosto regolare a franapoggio, con un'inclinazione non superiore ai 10°;

5) i parametri geomeccanici del substrato argilloso, indicativi di una notevole resistenza, e le caratteristiche litologiche e strutturali delle megabrecce (in genere debolmente cementate e suscettibili alla disgregazione meccanica), tenderebbero ad escludere la possibilità di rotture profonde di tipo rotazionale e successivi spostamenti *in toto* di grandi blocchi di megabrecce.

Sulla base delle considerazioni esposte, la potente coltre detritica comprendente i rilievi di brecce nella parte medio-alta del versante potrebbe essere interpretata come originatasi in ambiente di paleoconoide alluvionale, con più (almeno due) eventi deposizionali associabili ai movimenti in massa.

TERMINI CHIAVE: Dgpv, Frana, Megabrecce, Caramanico Terme, Abruzzo.

INTRODUCTION

The deep-seated gravitational slope deformations - Dgsd appear to be widespread in Italy (ex. DRAMIS, 1984; DRAMIS & *alii,* 1985; CAVALLIN & *alii,* 1987; CRESCENTI & *alii,* 1994; SORRISO-VALVO, 1988, 1995, and references therein). In this paper we re-examine the case of the Civita hill which dominates the southern periphery of Caramanico Terme (Abruzzo). Its SW slope facing the Orta river valley was affected by a large (33 ha) and relatively deep (on the order of tens of meters) mass movement in 1989 (fig. 1). On the basis of mainly geomorphological data, BUCCOLINI & *alii* (1992) interpreted the 1989 landslide in the context of the Dgsd evolution of the entire slope. In particular, several features, considered typical of a slope afflicted by Dgsd, were indicated in the zone upslope the main scarp of the 1989 event (series of scarps and uphill facing areas which appear to form trenches oriented parallel to the slope direction).

Landsliding has been the main and frequently occurring geological hazard throughout the history of Caramanico Terme, and the slope in question has been the site of repeated mass movements in the past (*e.g.* ALMAGIÀ, 1910). However, a detailed landslide-oriented research of the area was conducted only after the 1989 event. In particular, over 20 deep boreholes (some exceeding 100 m depth) were drilled within and upslope the landslide limits. The borehole information, and additional data from geophysical investigation of the slope (seismic refraction and seismic reflection), helped to better define the stratigraphy and structure at depth. The integration of subsurface and surface-based data on the entire slope scale - a rather unfrequent opportunity, to our knowledge, among published case studies of deep-seated slope deformations - has led to the re-assessment of the morphological features and to an alternative interpretation of the slope evolution, without invoking the Dgsd phenomena.

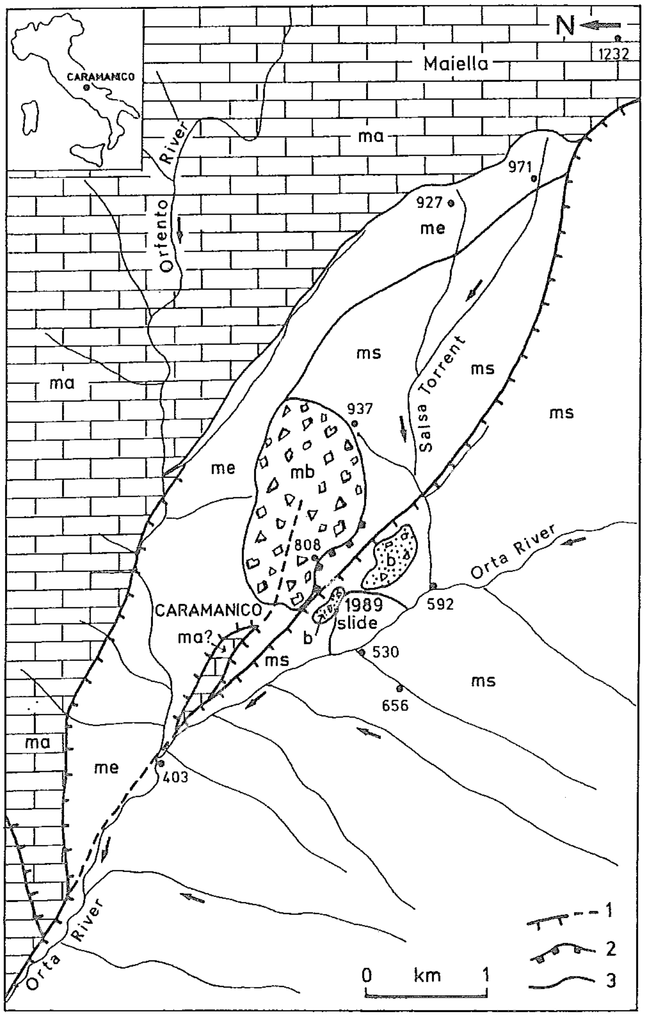


FIG. 1 - Simplified geological outline of the Caramanico area (modified from CATENACCI, 1974; GHISETTI & VEZZANI, 1983; WASOWSKI & FIORILLO, 1991, and VEZZANI & *alii*, 1993). Explanation: ma = Maiella Mt. carbonate succession (Cretaceous - Miocene); me = Maiella Mt. evaporitic succession represented by clayey-silty-sandy sediments with evaporitic limestone breccias and gypsum deposits (Messinian); ms = Caramanico depression deposits composed mainly by marly mudstones with sandstone intercalations (Early Pliocene); mb = Caramanico carbonate megabreccias (Villafranchian ?); b = two major accumulations of carbonate breccias and/or megabreccias including intercalations of well stratified water-laid and sieve-like sediments (Quaternary); 1 = fault (probable when dashed); 2 = main SW-facing scarp of the megabreccia caprock; 3 = lithological limit; arrows indicate directions of main watercourses. The Maiella mountainous range represents the main topographic relief in the area, with elevations rapidly increasing from the NW Maiella border (900 m a.s.l.) in the SE direction, to reach over 2000 m a.s.l.

GEOLOGICAL SETTING

Caramanico Terme is located in the Abruzzi Apennines intermontane basin (fig. 1), known in geological literature as the Caramanico-Campo di Giove depression (CATENACCI, 1974). The Quaternary neotectonic activity resulted in a general uplift of Central Italy, with the maximum upward movements registered in the Apennine mountains region (DEMANGEOT, 1965; AMBROSETTI & *alii*, 1982). According to DEMANGEOT (1965), the Abruzzi Apennines nearly doubled their elevation during this period. Furthermore, the high seismicity of the area (POSTPISCHL, 1985) suggests that neotectonic movements are still occurring. Thus the persistence of high local relief (up to 300 m in Caramanico) and strong river downcutting are the main geomorphic factors responsible of the widespread and recurrent landsliding.

The geo-structural setting of the Caramanico area and lithostratigraphic relations between the various units were recently discussed by WASOWSKI & FIORILLO (1991) in reference to slope instability. Therefore, here we will present only the data regarding the local geology of the Civita slope which was the site of the 1989 landslide. The rocks which crop out in the study area can be divided in three main groups:

1) somewhat marly mudstones (including up to 3 m thick sandstone intercalations), which form the local substratum; they are of Early Pliocene age (BUCCOLINI & *alii*, 1992);

2) up to 100 m thick and laterally extensive (approx. 2.5 km^2) deposits of carbonate megabreccias, probably of Villafranchian age (DEMANGEOT, 1965) and of inferred rock-avalanche origin (WASOWSKI, 1992); they form the caprock of the relief;

3) variably thick (from few to tens of meters) surficial materials (Quaternary) including mainly landslide debris, and secondly colluvial, alluvial and eluvial deposits.

It might be noted that, due to the presence of abundant slope debris, the exact nature of the basal contact of the megabreccias with the Early Pliocene mudstones is unknown.

THE DGSD PROBLEM

As emphasized by WASOWSKI (1992; in press), the chronic instability of the Civita slope is closely related to the particular hydrogeological setting determined by the presence of the argillaceous rocks underlying the thick surficial covers. In addition, the presence of a relatively competent megabreccia caprock controls the slope gradient and constitutes the potential source of new debris susceptibile to mass movements. It has been suggested (WASOWSKI & FIORILLO, 1991), and subsequently shown through inclinometer measurements (LOLLINO & WASOWSKI, 1994), that the top of the relatively impervious substratum can represent a basal slip surface of the sliding debris in the middle-upper portion of slopes.

The particular structure of the Civita slope (superposition of a relatively rigid unit over less competent materials) was considered by BUCCOLINI & *alii* (1992; 1994) to be a very favourable setting for the Dgsd. In fact, their reconstruction of the slope evolution relies on the rigid behaviour of the carbonate caprock; tectonic uplift and fluvial erosion at the slope base are other important factors.

Furthermore, the 1989 Caramanico slide, which remobilized middle-lower portions of the slope, was interpreted as a deep movement linked to the Dgsd (cf. BUCCOLINI & *alii*, 1992). In particular, some features, considered typical of an area afflicted by Dgsd, were indicated in the zone upslope the main scarp of the 1989 event. These included trenches (and associated counterslope surfaces) mapped upslope some isolated hills composed of megabreccias, which, then, were interpreted as large blocks (max. dimension 450 m) derived from the caprock plateau through a mechanism including deep-seated rotational failure followed by lateral spreading (see fig. 9 in BUCCOLINI & *alii*, 1992). Although not explicitely stated by the above quoted Authors, the complex mechanism of slope evolution was proposed on the basis of the morpho-structural characteristics of the Orta river valley slope.

The detailed mapping of the area, integrated with new subsurface data, has led to the re-evaluation of the significance of the morphological features. Hereafter we present new geological and geomorphological evidence; based on these data, as well as on geophysical and geomechanical considerations, in the section «Discussion» we offer an alternative hypothesis for the evolution of the Civita slope, without invoking the Dgsd phenomena.

Geomorphological evidence

Geomorphological aspects are among those most frequently investigated in the field of Dgsd studies (SORRISO-VALVO, 1988). Since the 1960s, in fact, the recognition of morphological features such as double crests, uphill facing scarps, depressions, bulging and valley cambering, represents the first step in the identification of Dgsd (JAHN, 1964; ZISCHINSKY, 1966; 1969; BECK, 1968; NEMCOK, 1972; MAHR, 1977).

In the case of the Civita slope in Caramanico, the presence of «a series of scarps and uphill facing areas which appear to form trenches oriented parallel to the slope direction» (BUCCOLINI & *alii*, 1995), led to the interpretation of the overall slope as being affected by Dgsd phenomena; particular emphasis was given in the quoted paper to the trench features.

The term trench is widely used in the description of morphological features of large-scale slope movements and Dgsd. As originally used by U.S. Authors (RADBRUCH HALL & *alii*, 1976; 1977), the term refers to linear depressions, located in the upper or middle/upper portion of the slope; their development is related to the gravitational creep of rock masses (ZISCHINSKY, 1969; RADBRUCH HALL, 1978).

Similar topographic expressions, related to slope movements, were also described as «features resembling fault scarps» (BECK, 1968), «troughs» (TABOR, 1971) or «furrows» (MAHR, 1977). All the above quoted Authors describe these features as bounded on the upslope side by a normal scarp, and on the valley side by an uphill facing scarp, the latter being usually steeper; the intervening depression is often filled with rocky debris.

At the Civita slope, the forms that BUCCOLINI & *alii* (1995) indicate as «trenches» display a rather irregular, never linear, form and are characterized by lack of well defined scarps (fig. 3). Therefore, they might simply represent depressions formed upslope old slide bodies. In addition, no trench-like depressions are present within the megabreccia caprock. Instead, the deformations and failures ap-

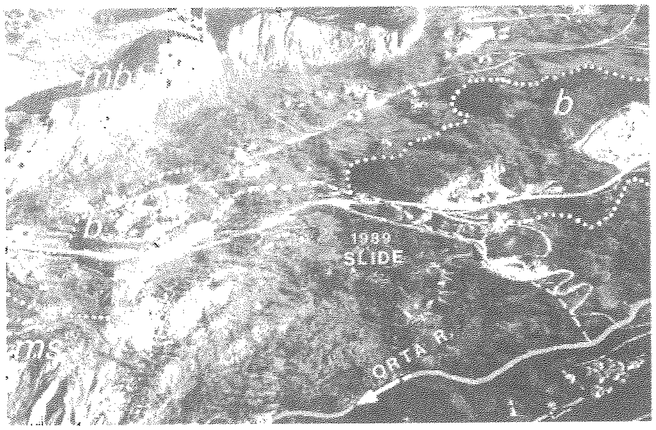


FIG. 2 - Oblique aerial view of the Civita slope showing the limits of the 1989 slide, the outcropping mudstone substratum (ms) at the lower left corner of the photo, the carbonate megabreccia (mb) caprock (upper left of the photo), and two major mid-slope accumulations of carbonate breccias and/or megabreccias (b) in the cemetery (left of center) and limestone quarries area (right of center).

pear to be limited only to a few meter wide zone along the edge of the caprock, which is affected by stress-relief fracturing (fig. 4).

The overall morphology of the slope downhill of the megabreccia caprock shows several interesting features. Besides talus and debris fans fed by the materials derived from the caprock, the landscape is characterized by irregular and rounded morphology (fig. 2). Hummocks and depressions, ranging in length from tens to hundreds of meters, and with local relief up to 30 meters, are present at the mid-slope; their spatial distribution does not show any kind of regular pattern (figs. 2 and 3). Such landforms, typical of rock-avalanche deposits (cf. among the others, HEIM, 1882; 1932; MC CONNELL & BROCK, 1904; VOIGHT, 1978 and references therein), usually constitute the middle and/or distal portion of the accumulation zones of such slope movements.

Another evidence against the emplacement of the hummocks via the Dgsd mechanism (including deep-seated rotational failure followed by lateral spreading) comes from the fact that the largest megabreccia hillock (max. dimension 450 m), present in the middle-upper portion of the slope (site of three quarries, fig. 3), is located in a peripheral position with respect to its presumed source area, *i.e.* the megabreccia caprock (fig. 2).

Geological evidence

The recently published results of the Caramanico landslide investigation (BUCCOLINI & *alii,* 1995) provided de-

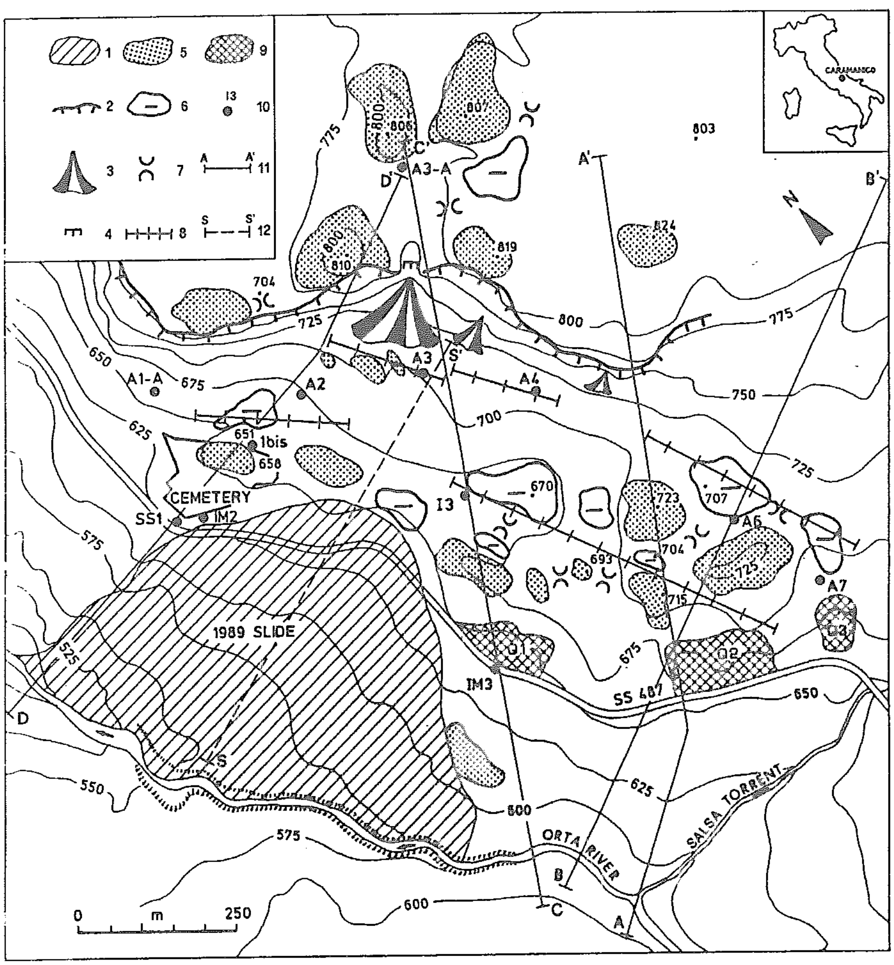
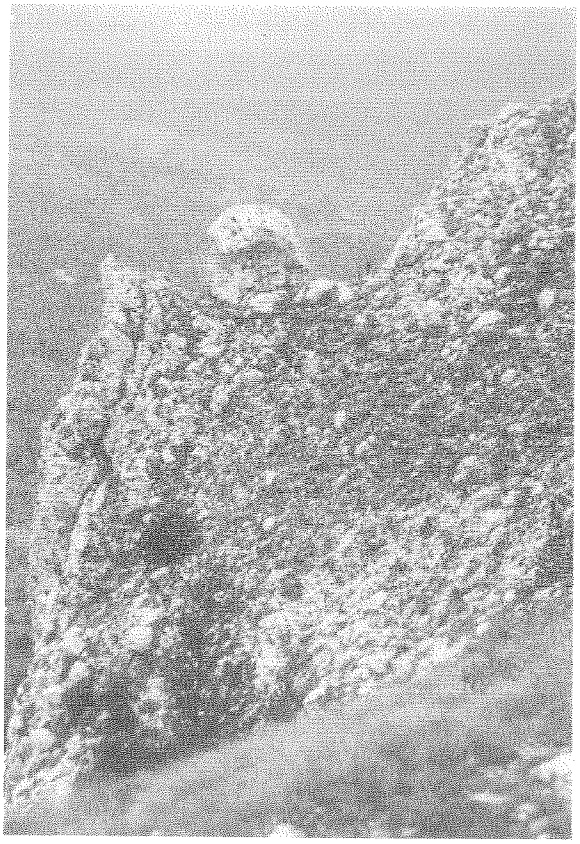


FIG. 3 - Simplified geomorphological map of the Civita versant: 1) area affected by 1989 slide; 2) main scarp of megabreccia caprock; 3) talus and debris fan; 4) valley step; 5) hummock; 6) depression; 7) saddle; 8) trench (redrawn from BUCCOLINI & *alii*, 1995); 9) quarry; 10) borehole; 11) geological profile; 12) seismic refraction line S-S'.



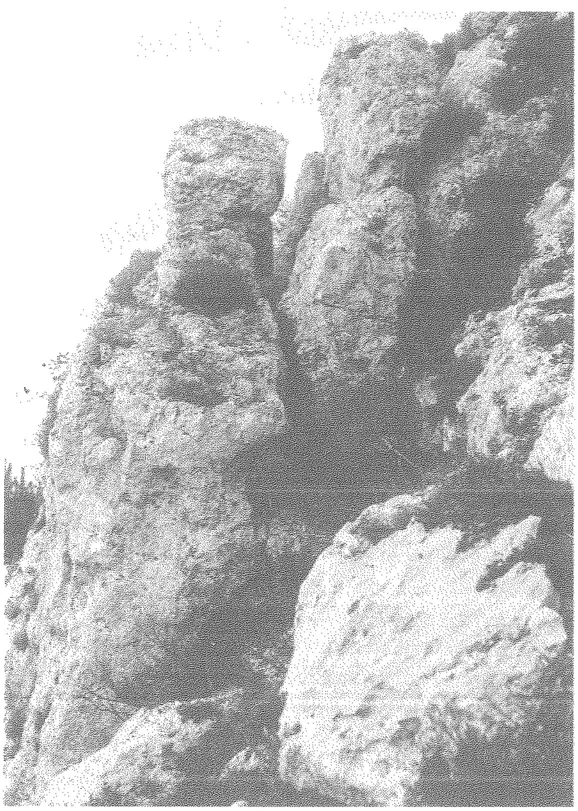


FIG. 4 - Two views of the SW scarp of the megabreccia caprock showing extension fractures subparallel to the rim of the caprock (upper photo), and topplings which with time evolve to rockfalls (lower photo).

tailed information on the local geology of the area. Furthermore, new subsurface data have become recently available from the boreholes executed upslope the Caramanico landslide during the investigation stage of the Anas tunnel project (BIGI, 1996). As regards the Dgsd problem, of particular interest is the middle slope, where the presence of very good quarry exposures and of new outcrops available on the right-lateral scarp of the 1989 Caramanico landslide (fig. 3) offers some additional constraints for the interpretation of the origin of the (mega) breccia hummocks.

The integration of surface geology and subsurface data (borehole stratigraphy and seismic refraction survey) on the whole slope scale is shown on four geological profiles (fig. 5). The profiles were traced purposely across the trench-like features and the two major (mega) breccia accumulations present in the middle-upper slope, and extended further uphill to their potential source area - the carbonate megabreccia caprock (figs. 2 and 3).

In general, the profiles reveal a multi-layer lithologic sequence within the detrital cover at mid-slope. The sequence is best documented in the quarry marked Q2 in fig. 3. In particular, the largest hummock is made of at least two (mega)breccia units (b1 and b2), which are separated by water-laid and sieve-like sediments (figs. 6 and 7; WASOWSKI, 1996). These types of deposits are typical of an alluvial fan environment (*e.g.* NEMEC & POSTMA, 1993). The alluvial fan setting is consistent also with the interpretation of the megabreccia caprock as rock-avalanche deposit (WASOWSKI, 1992), and with the presence of debris-flow sediments (carbonate clasts mixed in clayey material), which overlie the mudstone substratum in the lower and middle-upper part of the slope. Finally, the presence of dark red paleosol on top of the lower (mega)breccia unit - b1 in the quarry Q2 (fig. 6) suggests that considerable time might have elapsed before the deposition of the upper (mega) breccia (b2).

A similar lithologic succession was observed in quarry Q1 (profile C-C' in fig. 5), as well as within the second largest (mega)breccia hummock on which the local cemetery is built (figs. 2 and 3). In particular, the exposures along the main scarp of the 1989 landslide near the cemetery reveal the presence of both sieve-like and water-laid sediments. The latter are not to be confused with deposits of fluvial origin. Their association with sieve-like sediments and the presence of angular carbonate clasts favour the alluvial fan setting.

Due to the difficult access (subvertical slopes of the caprock margin), and the presence of abundant debris at the caprock base, it was not possible to determine whether the same units comprise the megabreccia plaque. However, the examination of the cores of a recently drilled borehole (A3-A in fig. 5) showed that the caprock megabreccias are underlain by a unit consisting of carbonate clasts set in argillaceous matrix. These sediments thus bear some similarities to the debris flows overlying the mudstone substratum at lower slope.

The geological profiles A-A' and C-C' follow the direction implying the link between the mid-slope (mega)breccias and their presumed source area - the megabreccia caprock bounded by a high SW-facing scarp (fig. 3). One of the most significant differences between the two profiles regards the remoulded clay-rich unit «d». As indicated on the profile C-C' (based on the borehole I3 stratigraphy), this unit becomes very thin (less than a meter) in the trench or depression located between the boreholes IM3 and A3 (which coincides also with the probable fault zone, cf. fig. 1). Furthermore, the stratified deposits «a» either become discontinuos upslope or, if the presence of potentially correlative deposits «a (?)» in borehole I3 is taken into account, thin from nearly 5 m recorded in quarry Q1 to less than 2 m upslope. It is interesting to note that a lithologically comparable unit of nearly the same thickness appears to be present at an almost identical depth in borehole A6 (fig. 3).

The most striking localized thinning of the layer «d», documented in borehole 1 bis, is shown in the geological profile D-D' (fig. 5), which runs across the cemetery area (fig. 3). This feature again results to be associated with a trench or depressed zone (site of the probable fault) and with a large (mega)breccia hillock (fig. 2).

Discussion

In this section we re-evaluate the available geological and geomorphological data and present some additional geomechanical and geophysical considerations to argue against the Dsgd hypothesis put forward by BUCCOLINI & *alii* (1992) to explain the evolution of the Civita slope in Caramanico Terme.

As shown on the four profiles in fig. 5, the mid-slope portion of the versant presents an overall continuity of the sedimentary succession, despite the post-depositional disruption caused by a long history of mass movements. This succession might be explained in the context of an alluvial fan evolution (WASOWSKI, 1996). Among the four profiles in fig. 5, the profile B-B' is of special interest for the discussion, because it follows the maximum slope and is perpendicular to the two trenches associated with the largest (mega)breccia hillock. Its direction, unlike those of the remaining profiles, is subparallel to the inferred transport direction of Civita hill caprock megabreccias, which WASOWSKI (1992) derived from the Maiella Mountains range (fig. 1). Furthermore, the mid-slope (mega)breccias exposed in the quarry Q2 appear more similar to the upper slope (mega)breccia deposits observed in the local road cuts (profile B-B' in fig. 5), than to the portion of the megabreccia caprock bounded by a much higher scarp and located at shorter distance from the hillock (cf. profile A-A' in fig. 5). Following this reasoning, at least part of the mid-slope surficial deposits could be regarded as approximately correlative with the caprock megabreccias (mb) and the underlying sediments of inferred alluvial fan origin (af ?), and thus derived from the same source area (Maiella). Alternatively, according to the Dgsd hypothesis (BUCCOLINI & *alii,* 1992), the large (mega) breccia hillock would represent simply a detached and downslope displaced portion of the caprock megabreccias (mb).

The profile A-A' (fig. 5) offers some more local relief needed to support the gravitational movement or Dgsd origin of the (mega)breccia hillock. In fact, it is tempting to draw a slip surface, starting from the high caprock scarp and continuing at depth either along the top of the mudstone substratum (ms) or along the base of the (mega) breccia unit b1. There are, however, some problems with this hypothesis:

1) the overall geometry of the lower (mega)breccias (b1) and the presence of several meters thick well stratified sediments, which separate the b1 unit from the upper (mega)breccias (b2), imply that the origin of these mid-slope surficial materials ought to be interpreted in the context of several depositional events; the differences in local stratigraphy between the quarry Q2 site and the borehole A6 (in particular the absence of the paleosol in the borehole and the probable thinning out of the unit «a» in an upslope direction), could be indicative of post-depositional disruption due to mass movement episodes or the neotectonic activity or both;

2) the downslope extent of the b1 unit and the overall volume of the hillock (mega)breccias b1 and b2 appear too large to be derived exclusively from the megabreccia caprock; the recession of the caprock (caused by the Dgsd or other gravity driven mechanism), however, could supply the sufficient volumes of carbonate debris for the b2 unit alone;

3) the profile A-A' does not follow the maximum slope, and, perhaps more importantly, is far from being perpendicular to the presumed trench features;

4) the suggested Villafranchian age of the Caramanico megabreccias (DEMANGEOT, 1965), as well as the presence of the buried paleosol separating the b1 and b2 deposits indicate that they originated in remote times, when the slope base level (Orta river) was most likely higher with respect to the present situation; furthermore, even at present time the steeply dipping valleyslopes on the opposite (SW) side of the Orta river tend to exclude the occurrence of very deep-seated rotational movements involving the entire slope; instead, rotational failures affect frequently the middle-lower parts of the slope oversteepened by the continuous erosion of the Orta river; as regards the middle-upper portion of the slope, it is easier to envision the translational landsliding taking place along the mudstone substratum/surficial cover interface (cf. LOLLINO & WASOWSKI, 1994).

The geological profile D-D' (fig. 5) is of special interest as it crosses the second largest (mega)breccia hillock in the cemetery area (fig. 2). The subsurface geometry of the surficial deposits in this area is well constrained by boreholes and helps to unravel the significance of the large variation in thickness of the unit «d». In particular, the thinning (down to less than one meter), and then rapid thickening of this unit (to an up to 40 m thick lens-shaped body), can be interpreted in the context of a mass movement phenomenon (depletion, mass transfer and accumulation). It is also possible that the same event gave origin to the thick carbonate (mega)breccias b1 and b2. Alternatively, the presence of the well-stratified deposits «a» apparently

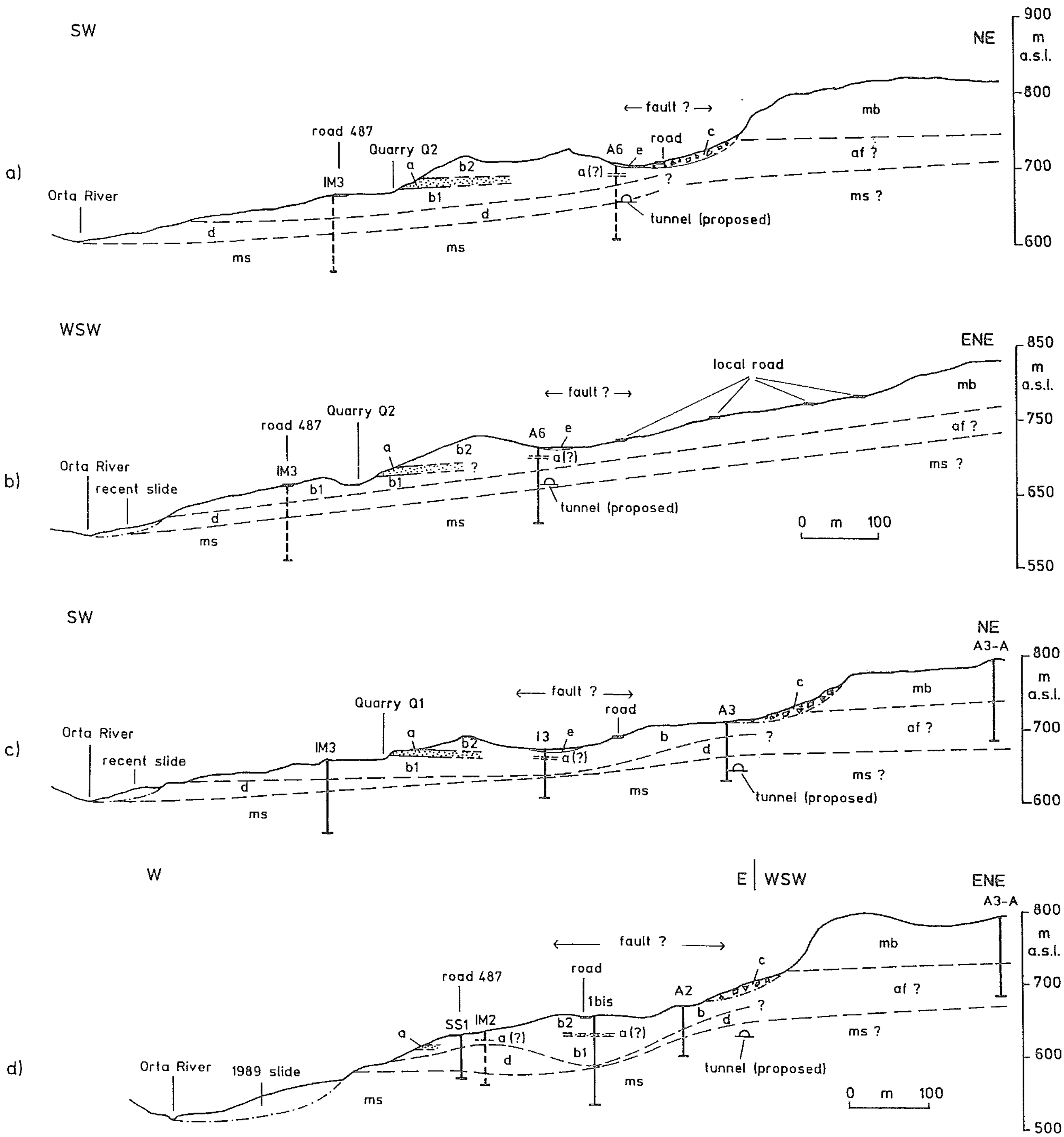


FIG. 5 - Four geological profiles of the Civita slope: a) = profile A-A', b) = BB', c) = CC', d) = DD' (see fig.. 3 for location). Symbols: ms = mudstone substratum; d = remoulded clay-rich materials containing variable amounts of carbonate clasts, of inferred mass movement origin (debris- or earth-flow); af ? = alluvial fan origin (?) clay-rich silty sandy deposits intercepted in borehole A3-A, containing variable admixtures of carbonate debris (from isolated clasts to a few meter thick intercalations); clasts become subrounded in the lowest 1/3 portion of the borehole; mb = megabreccia caprock; b1 and b2 = lower and upper carbonate (mega)breccia, respectively (cf. fig. 6); a = well stratified water-laid, sieve-like and debris flow deposits rich in carbonate clasts, of inferred alluvial fan origin; a (?) = deposits potentially correlative with «a» - the recognition of these sediments in borehole cores is much less certain than in outcrop, and, in case of poor core recovery, their distinction from simple carbonate debris may be impossible; b = undifferentiated carbonate (mega)breccia; e = eluvium; c = recent carbonate debris of rock fall and debris flow origin; I3, IM2, IM3, 1 bis, and SS1 represent some of the boreholes (dashed when projected) drilled during the 1989 Caramanico landslide geognostic campaign (BUCCOLINI & *alii,* 1995); boreholes marked with prefix «A» were executed during the investigation stage of the Anas tunnel project (BIGI, 1996); note the proposed tunnel locations on the profiles. The subsurface limits of various lithological units are reliably defined only within a short distance from the boreholes and outcrops (continuous line), and elsewhere interpolated or extrapolated (dashed line). The dashed-dotted line indicates the probable subsurface limits of recent mass movements. The range in the possible locations of the fault (or fault zone) reflects somewhat different positions of the apparently regional extent fault (cf. fig. 1), shown as probable tectonic discontinuity on the official State Geological Survey map of the area (CATENACCI, 1974), or as normal fault on the more recent geological map of the NE Abruzzi region (VEZZANI & *alii,* 1993).

FIG. 6 - Lithologic succession outcropping in the large quarry marked Q2 in fig. 3. Note two (mega)breccia units (b1 and b2) separated by well stratified deposits of inferred alluvial fan origin. A dark, few tens of cm thick paleosol overlies the top of the unit b1.

overlying the b1 unit indicates that the upper b2 (mega) breccias might have originated sometime later, due to subsequent retrogressive slope failure(s).

Therefore, the unusually thick mid-slope carbonate (mega)breccias in the cemetery area appear to have been derived directly from the megabreccia caprock. The present geometry of the deposit «d» can be reconciled with the occurence of a deep rotational movement or movements, which reached the mudstone substratum and were responsible for the recession of the megabreccia caprock. The simple 2D space-volume considerations are compatible with this interpretation and indicate that the main scarp of the original slope failure might have been located somewhere upslope the borehole A2 (fig. 5).

It is also interesting to note that the subsurface geometry of the local mudstone substratum and the overlying thick surficial deposits in the cemetery area are indicative of the suspended nature of this mass movement material. Following this assumption one can speculate that the base of slope level (Orta river), contemporaneous with this depositional event, was probably a few tens of meters higher with respect to the present situation.

Important evidence against the Dgsd model comes also from considering the lithological and structural characteristics of the caprock. The caprock megabreccias are moderately to poorly cemented, and, due to locally intensive fracturing, contain materials which are easily dismembered into small elements (fig. 8). Furthermore, the presence of densely spaced (typically on a meter scale) extensional joints, subparallel to the main scarp of the caprock, favours its degradation and recession via toppling and rockfall mechanisms (figs. 4 and 8).

FIG. 7 - Close-up view of the water-laid and sieve-like deposits present in the quarry Q2.

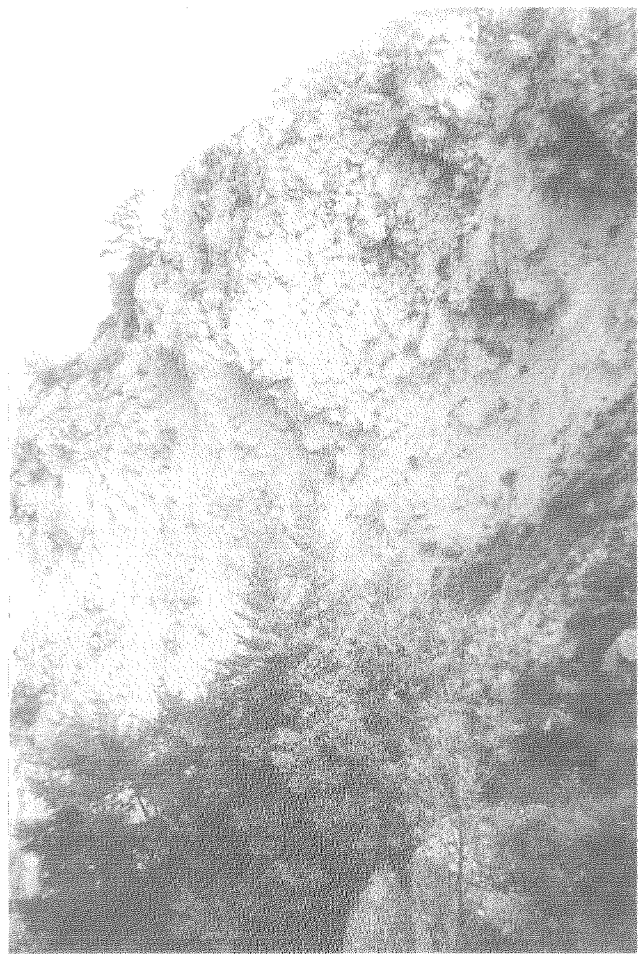


FIG. 8 - Portion of an upper rim of the caprock showing the site of a relatively recent rockfall. Note weakly cemented and friable appearance of the megabreccia material.

Thus, considering the large dimensions (often exceeding 100 m in width and length) of the (mega)breccia outcrops at mid-slope, it is difficult to envision a mechanism through which large blocks detached from the caprock might have been transported downhill as intact coherent bodies. The explanation proposed by BUCCOLINI & *alii* (1992; 1994), which foresees large scale deep-seated rotational failures followed by lateral spreading, may not be easily applicable to intensely fractured breccia-type caprocks.

One should also consider the mechanical properties of the mudstone substratum. The laboratory tests showed that the mudstone is characterised by rather high friction angles varying from 46° to 25.4° (17.5° residual), and effective cohesion ranging from 71 to 15 kPa (BUCCOLINI & *alii*, 1991; 1995). These mechanical parameters, implying a high frictional resistence of the substratum, represent a major problem for the hypothesis of deep-seated sliding; according to HUTCHINSON (1993, pers. com.), such hard argillaceous substratum would tend to exclude the occurrence of deep rotational failure. Clearly, the problem of the Civita caprock failures (whether or not involving the deep-seated deformations in the substratum) should be further investigated from a geomechanical point of view, by taking into account the geotechnical properties of the mudstones as well as those of the megabreccias.

It should be noted that the detailed examination of borehole stratigraphies revealed the presence of variably thick shear zones within the mudstone substratum, and that some of these features were thought to be associated with the deep-seated landsliding (WASOWSKI & FIORILLO, 1991). The major problems with this hypothesis are the following:

1) the inferred hole-to-hole correlations of the shear zones cannot be demonstrated in the absence of the adequate litho-stratigraphic markers;

2) the presence of the shear zones next to the Orta river at depths exceeding 40 m, tends to preclude the landslide origin;

3) the lack of movements on the deep shear zones as revealed by the *post-mortem* inclinometer monitoring of the 1989 landslide (LOLLINO & WASOWSKI, 1994).

Finally, it should be remembered that the Dgsd model of the Civita slope evolution requires large-scale deformation of the substratum. The published geological profiles (BUCCOLINI & *alii*, 1995), however, show that in most portions of the slope the interface surficial cover/mudstone substratum is quite regular with dipslope not exceeding 10°. Similar bedrock/cover geometry can be observed on a seismic refraction profile of the slope (fig. 9). This fact may not favour the Dgsd hypothesis and, in particular, the presence of deep-reaching rotational movements.

CONCLUDING REMARKS

Since the early 1980s, a great number of articles describing the Dgsd cases has been published in the Italian geomorphological and geological scientific literature. On the other hand, to our knowledge, works which question the occurrence of a specific Dgsd phenomenon appear to be extremely rare. One should keep in mind, however, that in some slope cases, especially where the large scale failure(s) had already taken place, it might be unrewarding and perhaps unnecessary to seek the evidence in favour or against Dgsd.

Because of the wealth of subsurface data, the case of Caramanico Terme is well suited for a discussion. Furthermore, the question whether or not we are faced with Dgsd in Caramanico has some important practical implications. The main reasons are the following:

1) the 1989 slide has not been stabilized and still represents a serious hazard to infrastructures (including the local cemetery) and several dwelling houses located upslope;

2) a new engineering project contemplating the construction of a roadway tunnel in the middle-upper part of the versant (upslope the mainscarp of the 1989 slide) is currently in the pre-development stage of investigation.

The presented geological and geomorphological data, though indicative of a long history of more or less deep mass movements on the Civita slope, provide several arguments against the Dgsd hypothesis. Following the general recommendations of SORRISO-VALVO (1988) and CRESCENTI & *alii* (1994), it is suggested that the geomorphological evidence alone may be insufficient to prove or disprove the presence of Dgsd in Caramanico. Finally, it is believed that a geomechanical study, including perhaps a numerical modelling, may furnish some useful constraints for the reconstruction of the evolution of the slope in question.

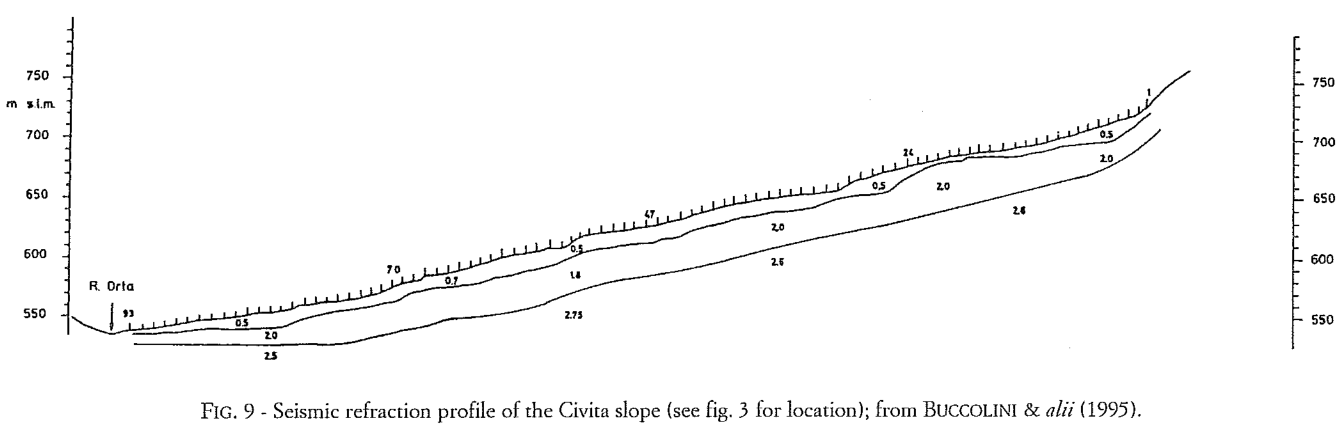


FIG. 9 - Seismic refraction profile of the Civita slope (see fig. 3 for location); from BUCCOLINI & *alii* (1995).

REFERENCES

ALMAGIÀ R. (1910) - *Studi geografici sulle frane in Italia.* Mem. Soc. Geogr. It., 13, 431 pp.

AMBROSETTI P., CARRARO F., DEIANA G. & DRAMIS F. (1982) - *Il sollevamento dell'Italia centrale tra il Pleistocene inferiore e il Pleistocene medio.* CNR, Prog. Fin. Geodinamica, Contributi conclusivi per la realizzazione della Carta Neotettonica d'Italia, pt. 2, 219-223.

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

BIGI G. (ed.) (1996) - *Progetto dei lavori urgenti di eliminazione della interruzione per frana al km 19 + 500 mediante variante in galleria.* Consultants' report, 102 pp.

BUCCOLINI M., CRESCENTI U. & SCIARRA N. (1992) - *La frana di Caramanico Terme dell'ottobre 1989: nota preliminare.* Boll. Soc. Geol. It., 111, 181-191.

BUCCOLINI M., FIORILLO F., LOLLINO G., SCIARRA N. & WASOWSKI J. (1991) - *La frana di Caramanico Terme: risultati preliminari dell'indagine geologica-tecnica.* Atti I Conv. Naz. Giov. Ric. in Geol. Appl., Gargnano (BS), 27-36.

BUCCOLINI M., CRESCENTI U. & SCIARRA N. (1994) - *Deep-seated gravitational slope and large scale mass movements in Abruzzi.* In: CRESCENTI U., DRAMIS F., PRESTININZI A. & SORRISO-VALVO M. (eds) - «Deep-seated gravitational slope deformations and large-scale landslides in Italy». Spec. Vol. for Int. Congr. Iaeg, Lisboa, 46-50.

BUCCOLINI M., FIORILLO F., LOLLINO G., RUSI S., SCIARRA N. & WASOWSKI J. (1995) - *La frana di Caramanico Terme dell'ottobre 1989.* Volume Speciale, Dipartimento di Scienze, Università «G. d'Annunzio», Pescara, 52 pp.

CATENACCI E. (1974) - *Note illustrative della carta geologica d'Italia, Foglio 147 - Lanciano.* Serv. Geol. d'It., Roma, 87 pp.

CAVALLIN A., CRESCENTI U., DRAMIS F., PRESTININZI A. & SORRISO-VALVO M. (1987) - *Tipologia e diffusione delle deformazioni gravitative profonde di versante in Italia: prime valutazioni.* Mem. Soc. Geol. It., 37 (1), 241-252.

CRESCENTI U., DRAMIS F., PRESTININZI A. & SORRISO-VALVO M. (1994) - *Deep-seated gravitational slope deformations and large-scale landslides in Italy.* Spec. vol. for Int. Congr. Iaeg, Lisboa, 71 pp.

DEMANGEOT J. (1965) - *Geomorphologie des Abruzzes Adriatiques.* Mem. et Docum. Centre de Rech. 1, Docum. Cartogr. et Geogr. H.S., Paris, 403 pp.

DRAMIS F. (1984) - *Aspetti geomorfologici e fattori genetici delle deformazioni gravitative profonde.* Boll. Soc. Geol. It., 103, 681-687.

DRAMIS F., MAIFREDI P. & SORRISO-VALVO M. (1985) - *Deformazioni gravitative profonde di versante. Aspetti geomorfologici e loro diffusione in Italia.* Geol. Appl. Idrogeol., 20 (2), 377-390.

GHISETTI F. & VEZZANI L. (1983) - *Deformazioni pellicolari mioceniche e plioceniche nei domini strutturali esterni dell'Appennino centro-meridionale (Maiellla ed arco Morrone - Gran Sasso).* Mem. Soc. Geol. It., 26, 563-577.

HEIM A. (1882) - *Der Bergsturz von Elm.* Zeit. Deutsch. Geol. Ges., 34, 74-115.

HEIM A. (1932) - *Bergsturz und Menschenleben.* Fretz und Wesmuth, Zurich, 218 pp. [English translation by SKERMER N.A. (1989) - *Landslides and human lives.* BiTech Publishers ltd., Vancouver, B.C., 195 pp.].

JAHN A. (1964) - *Slopes morphological features resulting from gravitation.* Zeit. Geomorphol., suppl. 5, 59-72.

LOLLINO G. & WASOWSKI J. (1994) - *Deep inclinometer monitoring of a partially remobilized old landslide complex: case of Caramanico Terme, south-central Italy.* Proc. 7th Int. Congr. Iaeg, Balkema, Rotterdam, 1451- 1458.

MAHR T. (1977) - *Deep-reaching gravitational deformations of high mountain slopes.* Bull. Int. Ass. Eng. Geol., 16, 121-127.

MC CONNELL R.G. & BROCK R.W. (1904) - *Report on the great rockslide at Frank, Alberta, Canada.* Can. Dept. Inter., Ann. Rep. 1902 - 1903, 8, 17 pp.

NEMCOK A. (1972) - *Gravitational slope deformation in high mountains.* Proc. 24th Int. Geol. Congr., Montreal, sect. 13, 132-141.

NEMEC W. & POSTMA G. (1993) - *Quaternary alluvial fans in southwestern Crete: sedimentation processes and geomorphic evolution.* Spec. Publs. Int. Ass. Sediment., 17, 235-276.

POSTPISCHL D. (ed.) (1985) - *Catalogo dei terremoti italiani dall'anno 1000 al 1980.* CNR, Progetto Finalizzato Geodinamica, Bologna, 164 pp.

RADBRUCH HALL D.H. (1978) - *Gravitational creep of rock masses on slopes.* In: VOIGHT B. (ed.) (1978) - «Rockslides and avalanches, 1: natural phenomena». Dev. Geotech. Eng. 14A, Elsevier, Amsterdam, 607-657.

RADBRUCH HALL D.H., VARNES D.J. & SAVAGE W.Z. (1976) - *Gravitational spreading of steep-sided ridges («Sackung») in Western United States.* Bull. Int. Ass. Eng. Geol., 14, 23-35.

RADBRUCH HALL D.H., VARNES D.J. & COLTON R.B. (1977) - *Gravitational spreading of steep-sided ridges («Sackung») in Colorado.* Journ. Res. U.S. Geol. Survey, 5 (3), 359-363.

SORRISO-VALVO M. (1988) - *Studi sulle deformazioni gravitative profonde di versante in Italia.* Mem. Soc. Geol. It., 41, 877-888.

SORRISO-VALVO M. (1995) - *Considerazioni sul limite tra deformazione gravitativa profonda di versante e frana.* Mem. Soc. Geol. It. , 50, 179-185.

TABOR R.W. (1971) - *Origin of ridge-top depressions by large-scale creep in the Olympic Mountains, Washington.* Geol. Soc. Am. Bull., 82, 1811-1822.

VEZZANI L., CASNEDI R. & GHISETTI F. (1993) - *Carta geologica dell'Abruzzo nord-orientale.* Selca Firenze.

VOIGHT B. (ed.) (1978) - *Rockslides and avalanches, 1: natural phenomena.* Dev. Geotech. Eng. 14A, Elsevier, Amsterdam, 833 pp.

WASOWSKI J. (1992) - *Origine delle megabrecce di Caramanico Terme (PE) e implicazioni per la stabilità della parte nuova dell'abitato* (riassunto esteso). Riassunti II Conv. Naz. Giov. Ric. in Geol. Appl., Viterbo, 70-72.

WASOWSKI J. (1996) - *Recent landslide problems in the town of Caramanico Terme, Italy.* Proc. 7th Internat. Symp. on Landslides, Trondheim, Norway, 1, 403-409.

WASOWSKI J. (in press) - *Understanding landslide-rainfall relationships in man-modified environments: a case history from Caramanico Terme (Italy).* Environ. Geol.

WASOWSKI J. & FIORILLO F. (1991) - *Aspetti geostrutturali e franosità del versante destro dell'Orta nei pressi di Caramanico.* Mem. Soc. Geol. It., 47, 665-678.

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

ZISCHINSKY U. (1969) - *Uber Sackungen.* Rock Mechanics, 1, 30-52.