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THE GREAT LANDSLIDE AT PORTELLA COLLA (MADONIE, SICILY)

ABSTRACT: AGNESI V., COSENTINO P., DI MAGGIO C., MACALUSO T. & ROTIGLIANO E., *The great landslide at Portella Colla (Madonie, Sicily).* (IT ISSN 0391-9838, 1996).

The South Western area of the Madonie Mountains is affected by large landslides; the major one developed starting from Portella Colla down to the Imera Settentrionale river, for a maximum length of about 6.2 km in a NE-SW direction. The study of the landslide, with the aim of reconstructing the geological, geomorphological and evolutionary aspects, has been carried out using integrated methodologies, including some geophysical investigations (in particular geoelectrical prospecting).

The landslide is complex and characterized by superficial and deep gravitational deformations. The movement began in the Upper Pliocene and it is still active. The origin and evolution of the landslide are linked to the geological structural setting of the area, as well as to the neotectonic activity and Quaternary climatic variations.

The tectonic compressive phases of the Middle Miocene have determined the overlapping of mesozoic dolomitic-calcareous bodies on prevalently clayey rocks of Tertiary age. In the Plio-Pleistocene, the original structural building was fragmentaried during tectonic phases producing calcareous blocks.

The geological setting and the instability caused by the increased relief energy, consequent to the last tectonic phase, constitute the main preparative causes for the beginning of the movement. In the Pleistocene, periods cooler than the actuals favoured a significant activity of the body of the landslide, due to the soil moisture. Furthermore, due to cryoclastic processes, an intensive degradation of the fractured limestones outcropping along the slopes has produced a large talus zone which partially covers the body of landslide.

The main recent activity of the landslide is linked to exceptional meteorological events, as they occurred in 1931, causing the movement of the front of the landslide. This moved forward about 30 m, reaching the Imera Settentrionale river and diverting the bed of the Rio Secco river. At the same time some flow-rate variations and shifts of water springs on the body of the landslide have been observed. Another large movement occurred in 1959 in an area called C.da S. Venera, along the right side of the landslide.

The present activity consists of modest movements, which generally occur with annual frequency; however, the permanent instability of the landslide confers to the whole area dangerous conditions, so that special constraints in the use of territory - as suggested by possible evolutionary scenarios - should be imposed.

KEY WORDS: Landslides, Deep-Seated Gravitational Slope Deformations, Madonie, Sicily.

RIASSUNTO: AGNESI V., COSENTINO P., DI MAGGIO C., MACALUSO T. & ROTIGLIANO E., *La grande frana di Portella Colla (Madonie, Sicilia).* (IT ISSN 0391-9838, 1996).

Il versante Sudoccidentale delle Madonie è interessato da estesi fenomeni gravitativi. Il più imponente si sviluppa tra Portella Colla ed il fiume Imera Settentrionale, secondo una direzione NE-SW e per una lunghezza massima di circa 6,2 km. Si tratta di un fenomeno complesso, caratterizzato da deformazioni gravitative sia superficiali che profonde, evolutosi in un arco di tempo compreso fra il Pliocene superiore e l'Attuale, la cui origine ed evoluzione sono connesse all'assetto geologico strutturale dell'area, all'attività neotettonica ed alle variazioni climatiche pleistoceniche.

Le fasi tettoniche compressive del Miocene medio hanno determinato la sovrapposizione di corpi carbonatici mesozoici su rocce prevalentemente argillose di età terziaria; l'edificio strutturale a falde è stato successivamente interessato dalle fasi tettoniche plio-pleistoceniche che ne hanno determinato lo smembramento dando luogo a blocchi calcareo-dolomitici disarticolati.

L'assetto strutturale ed il disequilibrio indotto dall'aumentata energia di rilievo, conseguente all'ultima fase tettonica, costituiscono le principali cause predisponenti per l'innesco del movimento. Il succedersi, durante il Pleistocene, di periodi più freschi dell'attuale ha favorito sia una notevole attività del corpo di frana, in relazione alle condizioni di maggiore umidità, sia l'intensa degradazione per crioclastismo dei calcari dolomitici fratturati che ha prodotto una imponente falda detritica che ricopre parzialmente il corpo di frana.

L'attività recente della frana è prevalentemente legata ad eventi meteorici eccezionali come quello del 1931 che ha comportato una riattivazione del fronte di frana; questo è avanzato mediamente di circa 30 m, raggiungendo il fiume Imera Settentrionale e deviando l'alveo del Rio Secco. In tale occasione si sono verificate variazioni nel regime e spostamenti dei punti di recapito in alcune sorgenti ubicate sul corpo di frana. Un'altra estesa riattivazione si è avuta nel 1959 in C.da S. Venera, lungo il

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V. Agnesi, C. Di Maggio and T. Macaluso conducted the geological and geomorphologic survey in the landslide and adjacent areas; P. Cosentino and E. Rotigliano gathered and interpreted the geoelectrical data; the general parts and the conclusions are by all the Authors.

fianco destro della frana. L'attività attuale consiste in modeste rimobilizzazioni che si producono con frequenza annuale.

Lo studio della frana, mirato a ricostruirne gli aspetti geologici, geomorfologici ed evolutivi, è stato eseguito con metodologie integrate, che hanno incluso indagini geofisiche (in particolare prospezioni geoelettriche) su alcuni dei principali blocchi carbonatici coinvolti nel corpo di frana.

TERMINI CHIAVE: Frane, Deformazioni Gravitative Profonde di Versante, Madonie, Sicilia.

PREMISE

Studies conducted in the last fifteen years in Western Sicily have indicated the existence of phenomena of deep-seated gravitational slope deformation (Dsgsd) widely affecting the various sectors of the Sicilian chain (AGNESI, 1994). Geological and structural conditions have generated a state of instability particularly along the edges of areas of carbonate outcrops that tectonically overlie marly-clayey successions, where the competent rocks are less thick. As a result, Dsgsd morphoevolutionary mechanisms have started, causing landslide phenomena over a wide area and in some cases changes in the geomorphological setting of the entire relief (AGNESI & *alii,* 1995).

Studies on the geomorphological evolution of the Madonie mountains have identified several mass movements phenomena consisting of large and complex landslides which represent the dominant process in the geomorphological evolution of the slopes bordering the main relief (MACALUSO, 1995). The great landslide at Portella Colla, in the South-Western Madonie, is the most interesting example from the viewpoint of extent and typology. This landslide is a complex phenomenon characterized by deep-seated and superficial gravitational deformations which have developed over a period of time between the Upper Pliocene and the present day. Its origin and evolution are related to the geological structure, the elevated relief energy, and Pleistocenic and Holocenic climatic variations. The present movement of the landslide, which is on the whole quiet, consists of slight annual remobilizations (ALBANESE & COLOSIMO, 1971; SORRISO-VALVO & *alii,* 1994) and more extensive reactivations due to exceptional meteorological events, as it occurred in 1931 (CREMA, 1931; MIN. LAVORI PUBBLICI, 1933).

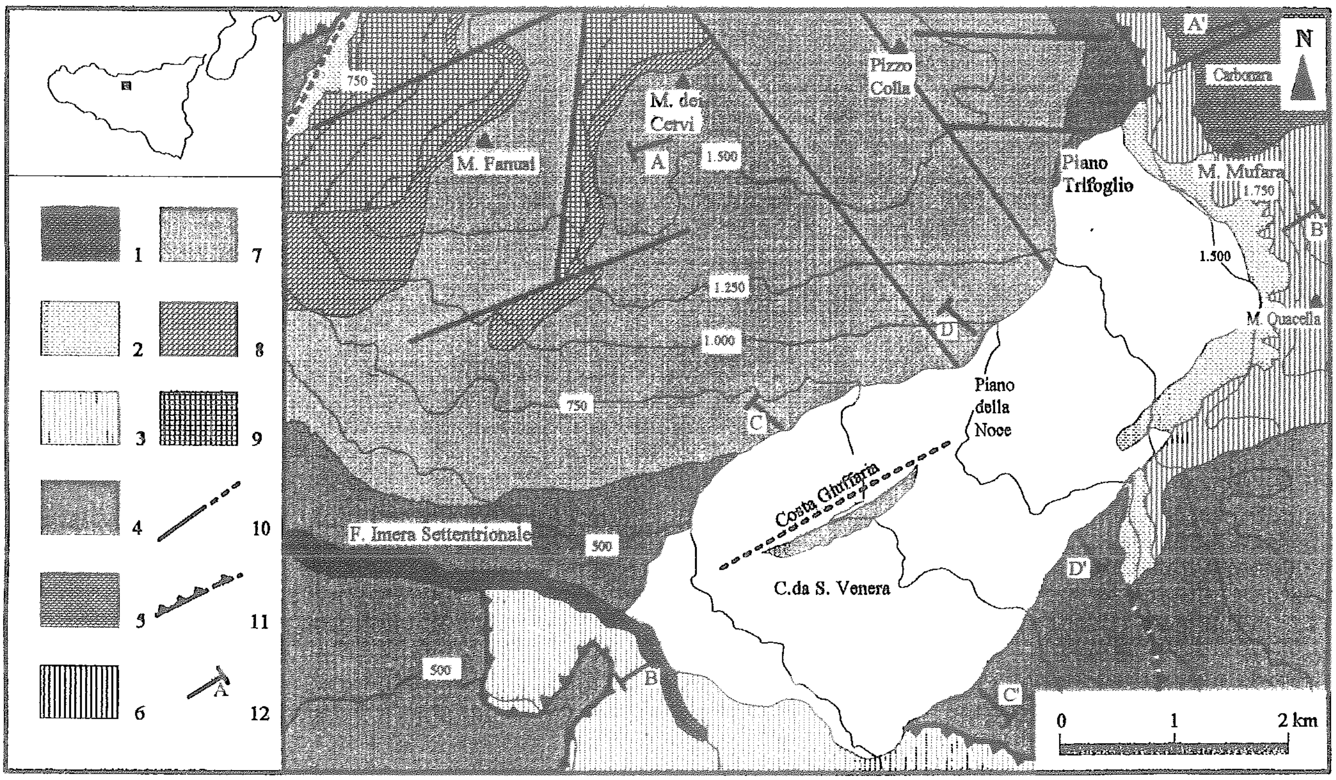

FIG. 1 - Structural-geological scheme. 1. Alluvial deposits (Recent) ; 2. talus deposits (Recent-Middle Pleistocene); Sicilide Unit : 3. clays and marls (Argille Variegate, Oligocene-Upper Cretaceous); Numidian Flysch: 4. clays, shales and sand marls with sandstones and conglomerates (Early Miocene-Upper Oligocene); Panormide Unit: 5. platform limestones (Liassic-Upper Triassic); 6. dolomitic limestones (Upper Triassic); Imerese Unit: 7. calcilutites and marls (Scaglia, Eocene-Upper Cretaceous), shales and marls (Formazione Crisanti, Early Cretaceous-Upper Liassic) with resedimented carbonate megabreccias; 8. dolomitic limestones (Formazione Fanusi, Upper Triassic); 9. cherty calcarenites and marly calcilutites and marls (Formazione Scillato, Upper Triassic); 10. fault; 11. overthrust; 12. geological section.

A better reconstruction of the geometry of the landslide has been obtained on the basis of geophysical prospecting consisting of five vertical electrical soundings (Ves) executed in the outcropping areas of some large carbonate blocks scattered on the landslide body.

GEOLOGICAL AND STRUCTURAL FEATURES

The area studied is characterized by the presence of rocks referable to the Sicilide, Numidian, Panormide, and Imerese domains which following neogenic deformations gave rise to a series of overlying tectonic units (ABATE & *alii*, 1988; CATALANO & D'ARGENIO, 1982; GRASSO & *alii*, 1978, figs. 1, 4).

The rocks deriving from the deformation of the Sicilide Domain consist of mainly marly-clayey deposits («*Argille Variegate*»), of basin environment, passing to calcilutites, calcarenites, calcareous breccias and quartzitic sandstones (Upper Cretaceous-Oligocene).

The sediments in the Panormide Domain are characteristic of carbonate platform and scarp environment and present a succession of clays, marls and calcilutites, limestones and dolomitic limestones, marly clays with layers of calcarenites and calcareous breccias (Carnian-Oligocene).

The Imerese succession is composed of basin deposits: clays and marly clays alternating with resedimented calcarenites and calcirudites, limestones and cherty dolomitic limestones, radiolarites, marls and cherty shales interspersed with limestone breccias and basaltic lava, calcilutites, calcarenites, and limestone shales (Upper Triassic-Oligocene).

The Numidian Flysch deposits cover in unconformity the rocks of the Panormide and Imerese domains and are characterized by turbidite successions consisting of alternated pelites and siltstones interspersed with conglomerates and sandstones (Upper Oligocene-Lower Miocene).

In the area there are also Late- and Post-Orogen outcrops consisting of clays, marls, sandstones and conglomerates of the «Terravecchia Formation» (Upper Tortonian-Lower Messinian).

The compressive Miocenic and Pliocenic tectonic phases gave rise to a series of overlying southward-verging tectonic units, causing the overthrust of the Sicilide Domain rocks above the units of Panormide Domain and the overthrust of the latter above the units of Imerese Domain. The extensional Plio-Pleistocenic tectonic phases caused the break-up of the geological bodies, with consequent block faulting, causing tectonic depressions and structural highs.

GEOMORPHOLOGICAL SETTING

In the area studied, in relation to the different lithological and tectonic characteristics, it is possible to identify four distinct sectors (fig. 2) affected by a different geomorphological evolution:

a) the Monte dei Cervi massif - this is characterized by brittle carbonate rocks alternated with ductile rocks (clays, marls and radiolarites). This structure has favoured the initiation of deep-seated gravitational deformation phenomena, namely lateral spread and rock-block slide, affecting both summit areas and slopes. The southern sector of the massif constitutes a structural slope, cut by cataclinal canyons of poor linear development, characterized by the presence at the base of flatirons;

b) the Pizzo Carbonara massif - this consists of limestone rocks and has undergone intense karst morphogenesis that has given rise to a landscape characterized by the considerable presence of dolines, sinks, dead valleys and polje, in varying stages of development;

c) the Monte Quacella massif - this is made up of intensely fractured dolomitic limestones, which are farinaceous in places. The South-Western slope is strongly degraded by mechanical disgregation phenomena which during the cooler periods of the Pleistocene showed strong intensity (HUGONIE, 1979). This has given rise to a considerable cemented and/or stratified debris drift. On the basis of its geometry, degree of cementation, and the roundness index of the clasts, the debris can be distinguished from bottom to top as:

- well cemented and stratified scree sloping about 25°-30°, with rounded clasts and the presence of carbonate concretions, corresponding to a more ancient cool phase;
- poorly cemented and well stratified deposits, arranged in talus sloping little more than 30°, with sharp-edged or scarcely rounded clasts, attributable to a more recent cool period;
- debris accumulations characterized by loose sharp-edged elements, of Holocenic and Present age;

d) the lower portions of the slopes, where the marly-clays outcrop - these are the site of numerous superficial gravitational phenomena, of the rotational slide - flow type; in the sector affected by the main landslide body the morphological setting is more complex due to the presence not only of clays and marls but also of considerable talus deposits and large dolomitic limestone blocks caught up in the movement.

THE GREAT LANDSLIDE AT PORTELLA COLLA

The main landslide phenomenon in the area involves the sector lying between Portella Colla - Monte Quacella and Rio Secco - bed of the Imera Settentrionale river (fig. 3).

The geological-structural setting of this sector is characterized by the overthrust of the Panormide Domain carbonate rocks above the clays of the Numidian Flysch. The overlying of rocks with different physical characteristics has created favourable conditions for the triggering of phenomena of instability on the slopes, giving rise to a complex landslide movement of vast proportions in a NE-SW direction.

The high frequency of landslides in the area has long been reported in the literature (CRINÒ, 1921), but it was OGNIBEN (1960) who identified the landslide phenomenon in all its extent and studied the role of geological and structural conditions in determining its causes. The landsli-

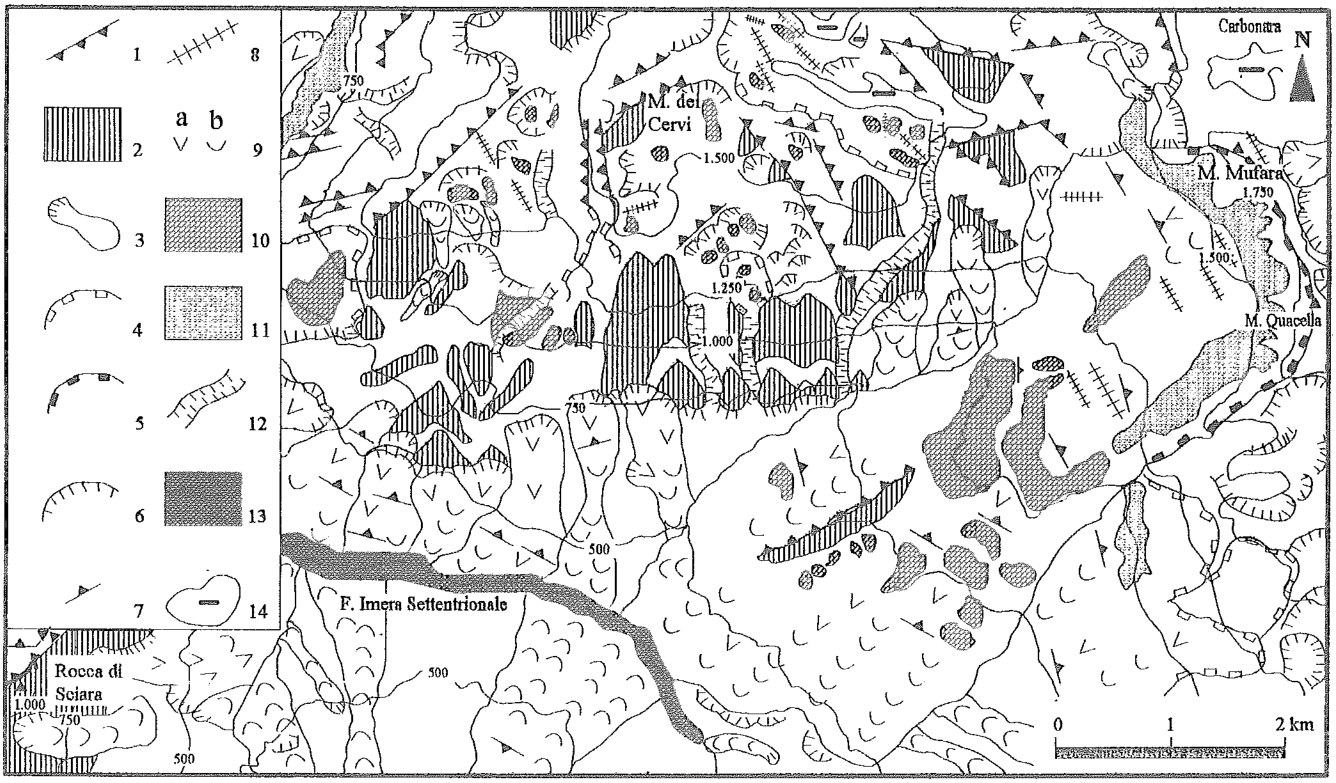

FIG. 2 - Geomorphological scheme. 1. Fault scarp or fault-line scarp edge; 2. structural slope; 3. boundary of main landslide body; 4. landslide scarp; 5. degraded landslide scarp; 6. landslide crown; 7. uphill-facing scarp; 8. trench; 9. landslide typology : a) slide, b) flow; 10. Block rafted in the landslide body; 11. talus deposit; 12. canyon ; 13. alluvial deposit; 14. karst depression.

de is the result of the combination of deep-seated and superficial gravitational movements characterized by different landslide bodies that have interacted at different times and with various degrees of activity. The result is the existence of a complex phenomenon, that has been investigated by surface geomorphological surveys and geoelectrical prospecting (figs. 3, 5) aimed at reconstructing its geometry. The landslide body, one of the most extensive in Sicily, has a maximum length of 6 250 m; the width ranges between 2 000 and 3 000 m in the middle-high zone, and reaches 2 500 m in the terminal area; it covers an area of 14.5 sq. km, with a mean thickness of about 60 m.

The head of the landslide (the crown reaches a maximum height of 1 650 m a.s.l.) is located along the great amphitheatre-shaped scarp flanking the Western slopes of Monte Mufara and Monte Quacella; the morphological setting of this scarp, which reaches a height of 70 m, is the result of landslide phenomena and also of the action of cryoclastic processes. These processes, very intensive during the cooler periods, have caused a scarp retreating; during these periods high activities phases on the landslide have been registered, characterized by a conspicuous removal of the debris from the slope base. The debris is in fact present, both as a covering talus over the landslide and as a directly involved volume inside the landslide body.

A crown of depletion associated to a well kept uphill-facing area can be seen at Piano Trifoglio (1 460 m a.s.l.); this is due to the existence of a rotational slide movement that has affected the most cemented talus.

The middle-high sector of the landslide is characterized by the presence of variously rotated large dolomitic limestone blocks partially covered with debris; geoelectrical prospecting have given evidence that the blocks are disarticulated and rest on an clayey substrate. They vary in thickness, as it has been shown by V.E.S., reaching about 130 m in the zone of Piano della Noce (1 025 m a.s.l. - V.E.S. 2, fig. 5). Numerous other morphological indications, such as uphill-facing areas and open trenches, denote the existence of block-type slope movement phenomena (PASEK, 1974; ZARUBA & MENCL, 1969).

The middle-low sector is characterized by the presence of clayey rocks affected by more superficial movements of slide and flow type that have caused numerous «ancillar» landslides, undulations, uphill- and downhill-facing steps, uphill-facing scarps and depressions.

The toe of the landslide is located along the bed of the Imera Settentrionale river at a height of 360 m a.s.l.. In the lower sector of the landslides, the small Costa Giuffaria ridge is of particular importance in the dynamics of the movement: this relief, lying NE-SW, is a morphological

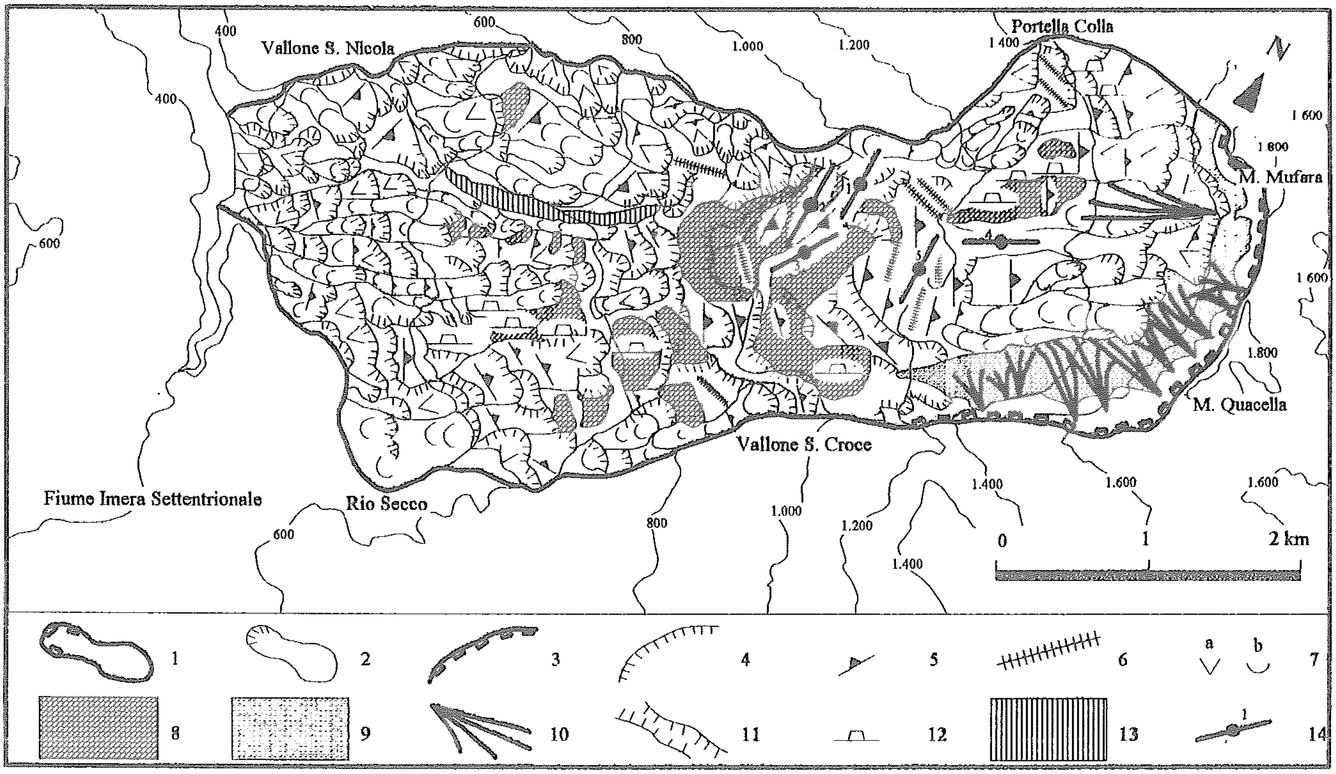

FIG. 3 - The great landslide at Portella Colla. Geomorphological scheme. 1. Boundary of the main landslide body; 2. boundary of ancillary landslide body; 3. main landslide scarp (degraded); 4. ancillary landslide crown; 5. uphill-facing scar; 6. trench; 7. landslide typology : a) slide, b) flow; 8. block rafted in the landslide body; 9. talus deposit; 10. debris cone; 11. canyon; 12. quarry; 13. marly-calcareous substratum; 14. V.E.S. location.

and structural high which has determined the division of the landslide into two distinct tongues. In the sector immediately downvalley from the ridge a lee-ride zone has thus been created where recent movement have not been observed.

The extremely complex and articulated morphology of this great landslide and the geometric relationships between the various rocks are composing it indicate a state of activity of extremely long duration. The initiation of the movement must be attributed to conditions of tectonic activity and to morphoclimatic contexts unlike those prevailing today. Recent movements are related to exceptional meteorological events, the most significant of which was 1931's flood (MIN. DEI LAVORI PUBBLICI, 1933).

On 21, 22 and 23 February 1931 Sicily was hit by an exceptional flood, the highest rainfall being recorded in this southern sector of the Western Madonie. The rain gauge at Polizzi Generosa, 1 km SE from the study zone, recorded in those three days 305 mm of rain, with 161 mm on one single day (the 22nd). This event caused the reactivation of a large part of the landslide, giving rise to horizontal movements ranging between 20 and 60 m, the deviation of the Rio Secco, and the temporary blockage of the Imera Settentrionale river, with the formation of a small lake. The movements caused the shifting of some springs and variations in water yield (MIN. LAVORI PUBBLICI, 1934), damaged numerous houses, and destroyed crops, roads and a bridge. The landslide movement continued for several weeks after the flood.

In the last few years work has been carried out on the lower portions of the landslide, without however taking the overall view of the phenomenon into account, with the result that the effects on the general stability of the area have been negligible, with continuing conditions of geomorphological hazard.

RESULTS OF THE GEOPHYSICAL PROSPECTING

Five vertical electrical soundings were performed in the locations shown on the map and with the azimuths indicated (fig. 3), with Schlumberger-type electrode array. High sampling density (ten points for each logarithmic decade) and at least double «embrayages» to check errors due to contacts between voltage electrodes (M and N). Ves have been carried out using a geo-resistivity meter with a sensitivity of 0.1 mV and 0.1 mA and a stacking procedure to increase the signal to noise ratio. As can be seen from the graphs of the data obtained (fig. 5), where the effects due to the «embrayages» have been eliminated, it is not easy to fit the experimental data with the theoretical curves derived from electrically homogeneous and horizontally layered models. This is because the pattern of the theoretical curves derived from such models do not show the rather high frequency effects that characterise the experimental data.

The number and the density of the geoelectrical data obtained are not however sufficient to attempt inversions using more complex bi- and tri-dimensional models. It was therefore decided to proceed on the following assumptions:

1. the experimental data come from models that can be regarded as a *deformation* of the layered model; this kind of deformation may be due also to topographical errors (COSENTINO & RIGGIO, 1977);
2. the data can thus be inverted by finding the values of inversion parameters (thickness and resistivity of the layers) which produce the theoretical curves most consistent with the experimental data. The number of layers was established on the principle of the lowest possible that satisfying (with appreciably significant improvements) the trend of the data;
3. the differences between experimental data and interpolating theoretical curves are thought to be due to normal measuring errors and in particular to the differences between the optimised interpretative model and the real situation of the investigated volume, also considering that the morphology of the terrain surface was not flat.

It can be stated that on the whole, although the interpretations do not reliably reveal all the single discontinuities along the vertical axis - some lateral discontinuities may inevitably have been interpreted as vertical discontinuities because of the restricted lateral extension of the investigated geological and geomorphological structures - they do however indicate some general and particular characteristics of the landslide area.

The very limited lateral homogeneity of the shallower structures makes in fact not possible to execute a good spatial correlation between the geoelectrical interpretative models, obtained for the different Ves locations: these models constitute in this case just a «single spot» detection for the electrical resistivity distribution inside the investigated volumes and close to the vertical axis passing through the middle point of each array.

Nevertheless according to the geoelectrical informations it has been possible to draw the geological section exploiting the geophysical constraints (fig. 4). It is in fact possible to observe these vertical and/or lateral disconti-

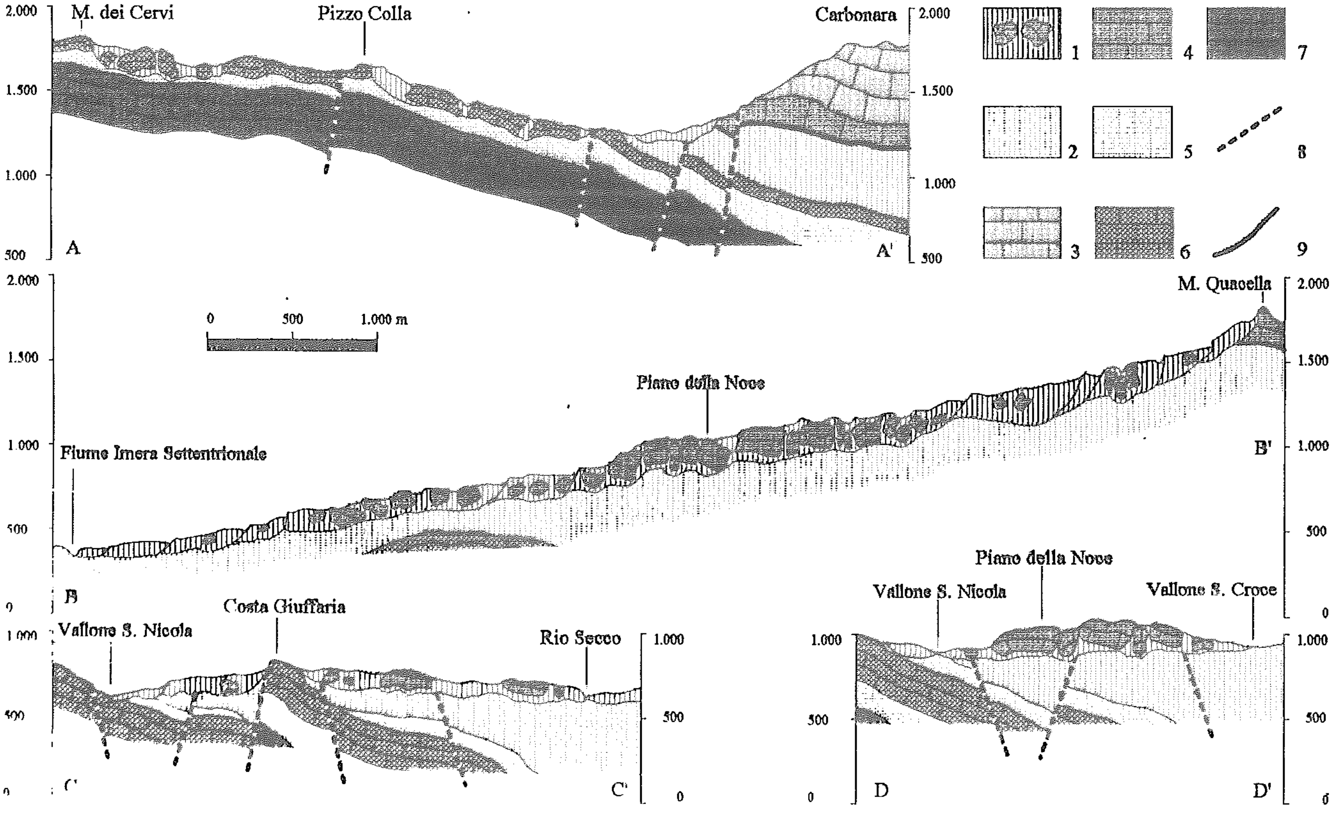

FIG. 4 - Geological sections. 1. Landslide debris; Numidian Flysch: 2. clay, shale and sand marl (Early Miocene-Upper Oligocene); Panormide Unit: 3. platform limestone (Liassic-Upper Triassic); 4. dolomitic limestone (Upper Triassic); Imerese Unit: 5. calcilutite and marl (Scaglia, Eocene-Upper Cretaceous), shale and marl (Formazione Crisanti, Early Cretaceous-Upper Liassic); 6. resedimented carbonate megabreccias (Mesozoic); 7. dolomitic limestone (Formazione Fanusi, Upper Triassic), cherty calcarenite and marly calcilutite and marl (Formazione Scillato, Upper Triassic); 8. fault; 9. overthrust.

nuities, which reliably confirm some characteristics of the geoelectrical (and therefore lithological) chaotic structure of the landslide, and to distinguish, even if only roughly, resistive (carbonate) structures from more conductive structures (clays, humid debris or highly saturated fractured). It is possible in particular to observe that the depth of the more important outcrops of carbonate rocks, as approximately estimated by the quantitative interpretation, makes it possible to reconstruct a scheme of the structure of the landslide that is fully consistent

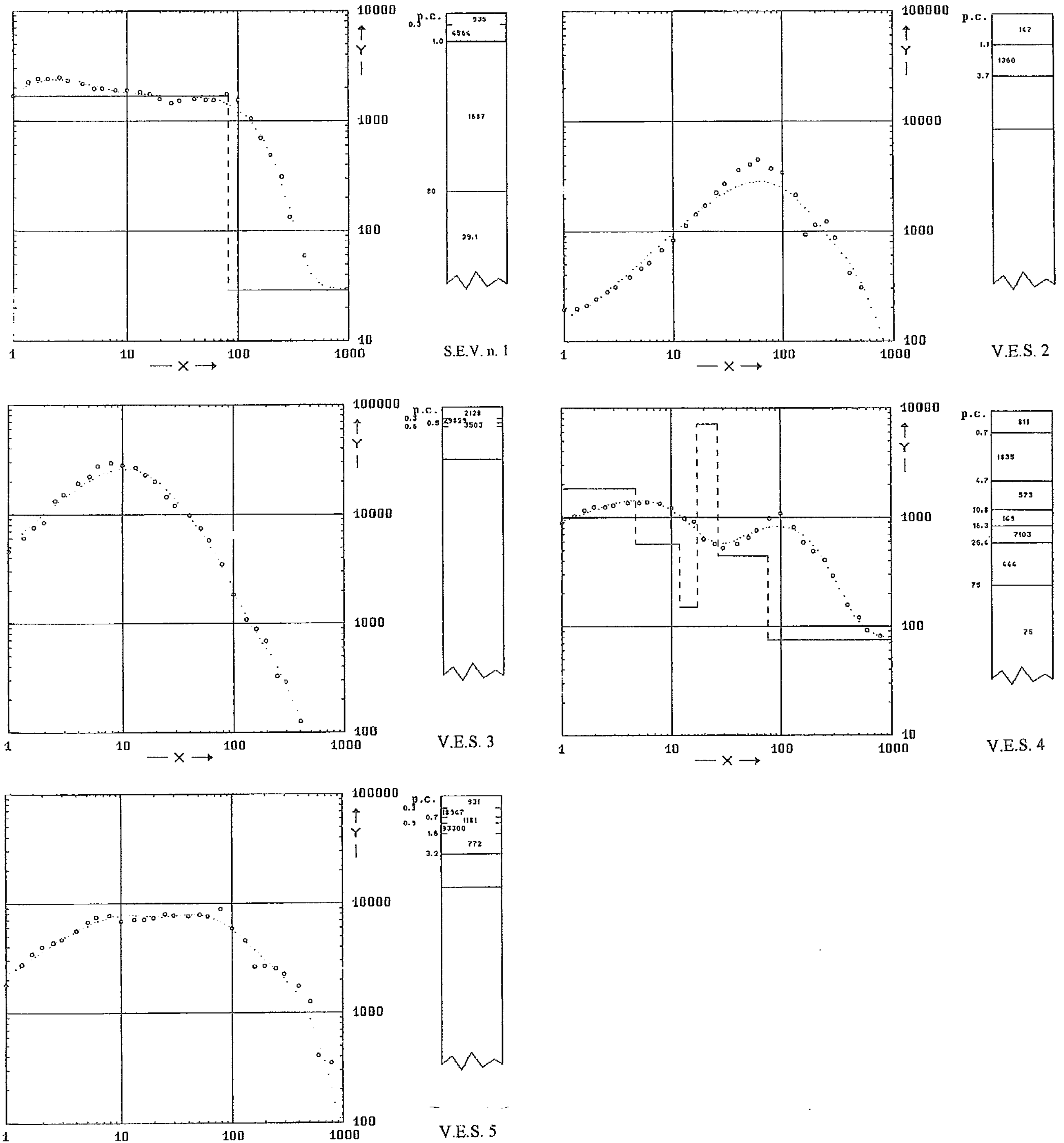

FIG. 5 - Graphs of the V.E.S. experimental and interpretative curves. For location see fig. 3.

with the interpretative hypotheses based on geomorphological data.

A final consideration may be done regarding to the physical conditions of the investigated formations: the very high resistivity values (both those actually measured and those interpreted) suggest the presence of strongly tectonized rocks, probably interspersed with various clasts; these layers are characterized by a moderate circulation of groundwater, that is not sufficient to determine saturation of the carbonate rocks.

CONCLUSIONS

The great landslide at Portella Colla presents various types of movement and can therefore be classified as a complex phenomenon (Varnes, 1978). The head of the landslide is subject to falls, rotational slide, and rock-block slide slope movements. The landslide body incorporates a number of large dolomitic limestone blocks about a hundred metres thick (fig. 4). The clayey component in the middle-low sectors and the debris component in the zone of depletion have been involved in slide and flow movements that have caused numerous more superficial landslides in the main body of the landslide.

The factors that have favoured the process of deep-seated gravitational deformation are related to the geological setting of the area. This setting is the result of two distinct tectonic phases (compressional and extensional) that caused the overlying of rocks of different lithotechnical features and their successive block-faulting. The phenomena of uplift and subsequent selective erosion caused an increase in relief energy. This leds to landslide movement when the area emerged (Upper Pliocene?). The first movements caused the translation of the large carbonate blocks which today are to be found widely, disarticulated, rotated, and distributed throughout the landslide body which presents numerous trenches and uphill-facing areas, especially in the Piano della Noce sector.

Successively, the periods of greatest activity occurred during the cooler climatic phases of the Pleistocene. These meteorological conditions favoured the action of cryoclastic processes, with the production of considerable quantities of debris at the foot of the subvertical slopes and of the landslide scarps already identified. This debris added to the weight of the landslide body had consequently initiated new movements affecting the underlying clayey rocks, also as a result of higher humidity conditions. Rotational slide and flow phenomena therefore occurred, affecting the stratified and/or cemented drift and giving rise to frequent uphill-facing scarps and depressions at Piano Trifoglio and at the foot of what is known as the Quacella Amphitheatre.

The most recent remobilizations are related to exceptional meteorological events, as in February 1931 and in 1958, when considerable movement was recorded. The present remobilization, due to wetter seasonal cycles, involves limited landslide areas, affecting the middle and the lower sectors constituted by marly-clay rocks.

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