Journal of Nepal Geological Society, 2000, Vol. 22, pp. 463–470

The landslides of 5 May 1998 in Campania, Southern Italy– are they natural disasters or also man-induced phenomena?

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ABSTRACT

Following an intense and prolonged rainfall, debris flows occurred in the Sarno-Quindici region on 4 and 5 May 1998. They took place in an area where recent pyroclastic materials mantle the Mesozoic limestone bedrock. The debris flows extended up to 4 km into the surrounding lowlands and reached four towns causing severe destruction. Generally, they initiate as debris slides or debris avalanches, involving pyroclastic horizons and colluvial soils (0.5–2 m thick) on steep and vegetated slopes at the heads of gullies. These failures, whose slip surface generally coincides with the soil and rock interface, transformed very rapidly to debris flows.

Whilst the rainfall was undoubtedly a dominant factor in all of the instabilities, a large number of initial failures occurred where tracks have recently been cut into the pyroclastic veneers. These tracks interrupted the morphological and hydrogeological features of the slopes. The tracks had the cut slope angle significantly higher than that of already steep natural slope. It is thought, therefore, that these conditions have been the main cause of a great number of failures, and, therefore, the origin of the catastrophic flows concentrated within an area of 70 square kilometres.

INTRODUCTION

On 4 and 5 May 1998, the Sarno-Quindici area (20 km east of Naples, Southern Italy) was hit by flow-like mass movements, which occurred after a prolonged rainfall (Del Prete et al. 1998; Celico and Guadagno 1998). The movements took place in an area of the Campanian Apennines, mainly characterised by peculiar geological and morphological settings. In this area, recent pyroclastic deposits mantle the Mesozoic limestone massifs, which are often karstified. Over 100 initial slides transformed in flows of slurry, and then in hyperconcentrated stream flows, which reached the four towns of the surrounding lowlands, causing severe destruction and killing 161 people.

Del Prete et al. (1998) discussed a number of scenarios to highlight the possible causes and mechanisms of the movement. They gave importance particularly to the preceding rainfall patterns, possible perched water tables, physical properties of the recent pyroclastic deposits and underlying palaeosols, and the man-made changes in the morphology. In this paper the latter factor is analysed. Detailed fieldwork and aerial photo analyses were carried out in order to reveal morphology and geology of the failure areas. Soil samples were analysed for the determination of their geotechnical characteristics.

GEOLOGICAL SETTING

The Campanian Apennines are characterised by the presence of monoclinal ridges of limestone (Ippolito et al. 1975) belonging to the Mesozoic carbonate platforms (Fig. 1). The thickness of strata generally varies from a half to several

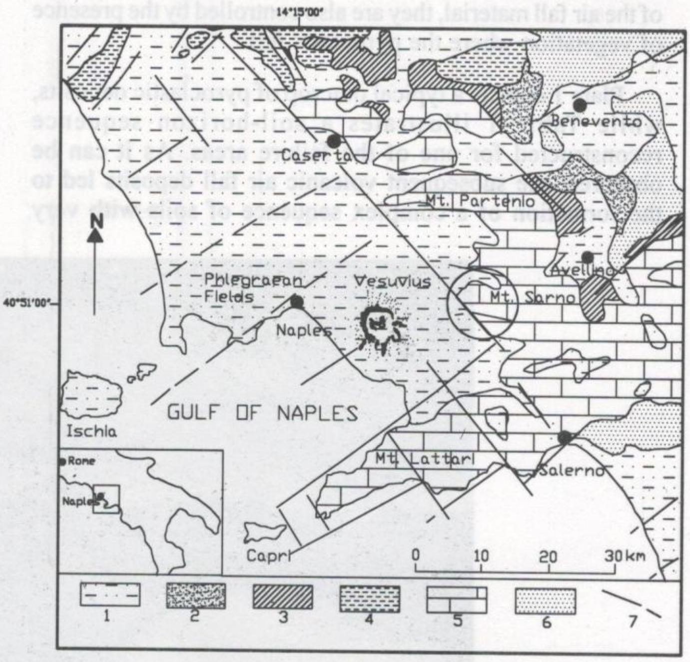

Fig. 1: Simplified geological map of the Campanian Apennines. Legend: 1) Plio-Pleistocene deposits; 2) Sandy clayey sequences (Tortonian-middle Pliocene); 3) Flysch units (Langhian-Tortonian); 4) Carbonate units of the internal platform (Trias-Paleocene); 5) Carbonate units of the external platform (Trias-Paleocene); 6) Sicilide units (Cretaceous-Eocene); and 7) Principal faults. The circle indicates the Pizzo d'Alvano area hit by debris flows.

metres. Joints, whose trend is generally NE-SW and NW-SE similar to the main fault features, ramify the sequence.

The watershed and, in particular, the fault scarps were mantled with pyroclastic materials of varying thickness, mainly during the periods of volcanic activity of the Somma–Vesuvius (Santacroce 1987; Sigurdisson et al. 1985; Lirer et al. 1973). In the landslide area of Mt. Picentini, Rolandi et al. (1998) have recognised volcanic deposits connected with the eruptions between 22,000 and 4,000 years BP. The air fall deposits of the great eruption of 79 AD are present in the area and, specifically, on the slopes of Mt. Lattari. In the past also, the landslides occurred on the pyroclastic deposits of this area (Civita et al. 1975; Guadagno 1991, Del Prete et al. 1998). The thickness of pyroclastic mantle varies from place to place owing to the changing depositional mechanisms. Besides the direction of prevailing winds, its deposition was controlled by the surface morphology, especially the slope angle. The air fall pyroclastic deposits covered the surface irregularities, creating a smooth topography, although steps are visible where limestone horizons form vertical faces.

Fig. 2 shows a typical aspect of the carbonate fault scarps with sub-vertical escarpments. The higher parts of the vegetated slopes are generally in the order of 40°–50°. Such steep slopes are not easy to explain, although they could have originally been related to the maximum angle of repose of the air fall material, they are also controlled by the presence of vegetation where the pyroclasts fell.

Plate 1 depicts a typical outcrop of pyroclastic deposits, while Table 1 illustrates a soil-horizon sequence reconstructed for one of the failure areas. As it can be observed, the subsequent volcanic air fall deposits led to the formation of a complex sequence of soils with very different characteristics in terms of their composition and geometry. In fact, the horizons are buried by pumice layers of different grain sizes and mineralogy. It must be stressed that the layers and horizons dip, as does the calcareous bedrock, parallel to the talus slopes.

It is important to put in evidence that this setting is fundamental to the development of landslides because of its dominant influence on the behaviour of the masses, from both mechanical and hydrological points of view. It can be compared to that of snow mantles in mountain areas. In the latter case, the snow is deposited in successive layers, as the winter progresses. Dissimilar physical properties characterise the snow layers. The snow layers with different

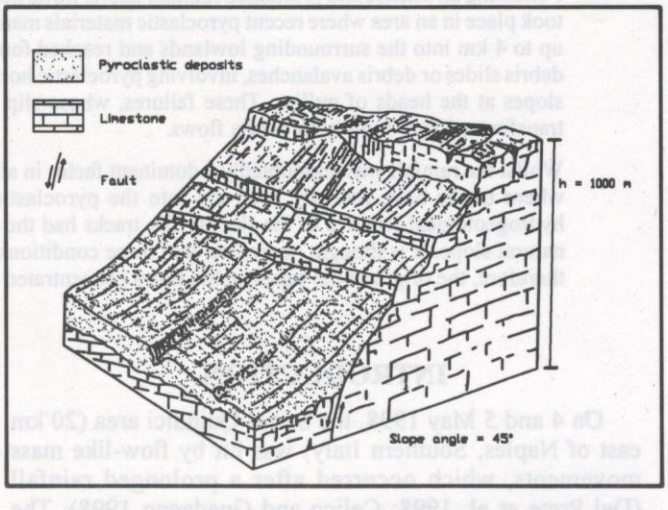

Fig. 2: Sketch showing the varying thickness of pyroclastic deposits on limestone fault scarp

Plate 1: Typical pyroclastic deposits depicting the variation in thickness of individual layers

Table 1: Stratigraphic column of the pyroclastic deposits in the area of the Pizzo d'Alvano and their geotechnical data

DEPHT (cm)	HORIZONS		Specific gravity Gs	Dry unit weight γ_d (kN/m^3)	Water content w (%)	Void ratio e	Degree of saturation S (%)	Clay fraction CF (%)	Percent sizer finer than 60μ	Liquid limit W_L (%)	Plasticity index PI (%)	Organic matter O.M. (%)
0 - 25	■	A	2,690	8,25	40,3	2,26	48,0	9	35	63,2	13,54	6,6
25 - 47	▥	Bw1	2,705	6,88	58,1	2,93	53,6	11	36	71,7	12,86	6,6
47 - 70	■	Bw2	2,646	8,70	36,3	2,04	82,0	0	9	-	-	7,8
70 - 125	░	C1	2,460	-	31,2	-	-	0	4	-	-	3,7
125 - 142	░	C2	2,512	-	31,0	-	-	0	4	-	-	3,6
142 - 165	▤	Ab	2,654	6,70	51,8	2,96	46,4	0	-	-	-	10,0
165 - 185	▧	Bwb1	2,666	6,60	67,0	2,86	62,4	16	54	75,7	16,80	8,5
185 - 230	■	Bwb2	2,678	8,00	64,8	2,35	74,0	15	54	62,2	15,10	7,6
230 - +	▦											

densities may be superimposed, and icy layers or even cavities may be buried. Actually, voids may occur also in pyroclastic layers or horizons, considering that they have been subjected to soil formation processes. The root decay may lead to the process of void formation in the soil.

The pyroclastic mantle has facilitated the growth of widespread vegetation on the calcareous slopes otherwise not very fertile, as shown by the bare areas where the limestone is not covered by pyroclastic deposits. The people have developed horse chestnut and hazelnut plantations on these thin veneers since the Roman times. In previous times, access to the plantations was on foot and hence only limited pathways were created. More recently however (in the last 20 years), larger tracks have been developed for vehicular access. The roadways are being cut into the pyroclastic mantles by disposing of the materials on the downhill side. Whilst some of the tracks ascend in a zigzag manner, many are almost parallel to the contour.

GEOTECHNICAL CHARACTERISTICS OF PYROCLASTIC SOILS

The pyroclastic soils and horizons overlying the carbonate ridges have variable lithological characteristics. In general, the fall deposits are of tephritic–fonolitic pumice and scoria. The geological surveys have shown that they have suffered greatly from the effects of pedogenesis as well as erosion and rill-wash. The latter have transported the materials towards the slope base.

Table 1 shows a typical soil profile as well as geotechnical properties of a failure zone on the slopes of Quindici. As it can be seen, while the pumice levels are granular and well graded, the soil horizons are cohesive, instead. It is apparent that the two units also differ considerably in their index and physico-volumetric properties such as shear strength and permeability. But, the pumice soils have also special properties due to the presence of intra-particle voids. Esposito and Guadagno (1998) have stressed the peculiar physical characteristics of the pumices and of connected deposits. The pumice has interconnected voids that cause suction and, consequently, complex diffusion of water in it.

The pyroclastic soil horizons also have special properties attributed to their mineralogy (Kitagawa 1971). The horizons contain allophane soils (Maeda et al. 1977), as demonstrated in the volcanic soils of the Campanian area (Terribile et al. 1999). These soils have high values of liquid limit but lower clay content (Table 1). Their specific characteristics were noticed during the direct shear tests. Although the materials appear to be over-consolidated (OCR>5), probably due to suction phenomena, the tests do not show significant values of cohesion (Fig. 3). Moreover, the residual shear strength is particularly high (j_r>25°) and is similar to the peak shear

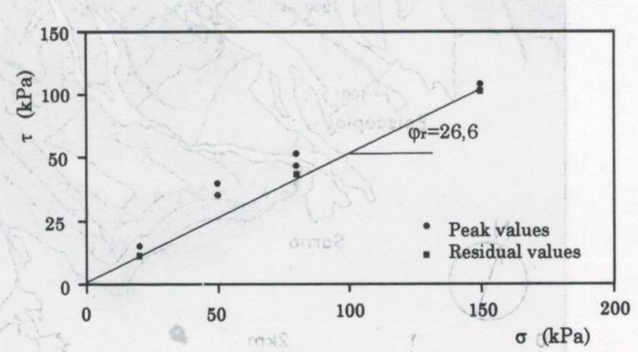

Fig. 3: Typical data of direct shear tests on samples of soil horizons

strength. The high residual strength may partially explain the stability of the pyroclastic mantles in the absence of pore pressure on steep slopes.

Hence, the sequences of pyroclastic layers covering the calcareous slopes should be considered as complex deposits, not only because of their local geometrical characteristics, but also because of their mechanical and hydrogeological behaviours. In particular, the latter is of specific interest, as it can induce the situations that trigger slope instabilities.

HILLSLOPE FAILURES

Fig. 4 illustrates the catastrophic events that hit the Pizzo d'Alvano ridges, at the base of which there are the towns of Quindici and Sarno. According to Cruden and Varnes (1996), these landslides may be classified as complex ones (being a rapid evolution of initial slides or debris avalanches into debris flows). They were initiated on upper slopes and were transformed to viscous fluid flows (Ellen and Fleming 1987), which might have travelled at a speed of several tens of kilometres per hour (Plate 2).

During the flows, the landslide materials scraped off vegetation and soils, so that the volume of moving material tended to increase, and, proceeding towards the base of the slopes, the phenomena evolved into hyperconcentrated stream flow (Pearson and Costa 1987). In many cases, the material overflowed the gullies because of its high velocity.

In the kinematic reconstruction of the events, a point of great importance appears to be the type of initial movement of the phenomena. The studies carried out at more than 100 initial failure sites show that the initial movements can be classified as debris slides or avalanches of very modest volume (<2 m^3) on pyroclastic layers with 40°–50° slopes. Generally, the slip surface coincides with the contact between the pyroclastic deposits and the underlying bedrock, but the slip surfaces passing through the top of palaeosols are also observed. A number of these small mass movements reached the gullies and contributed to the development of more than twenty debris flows, which reached the villages situated at the foot of the slopes. Others took place along straight hill slopes and therefore did not transform into channelled flows.

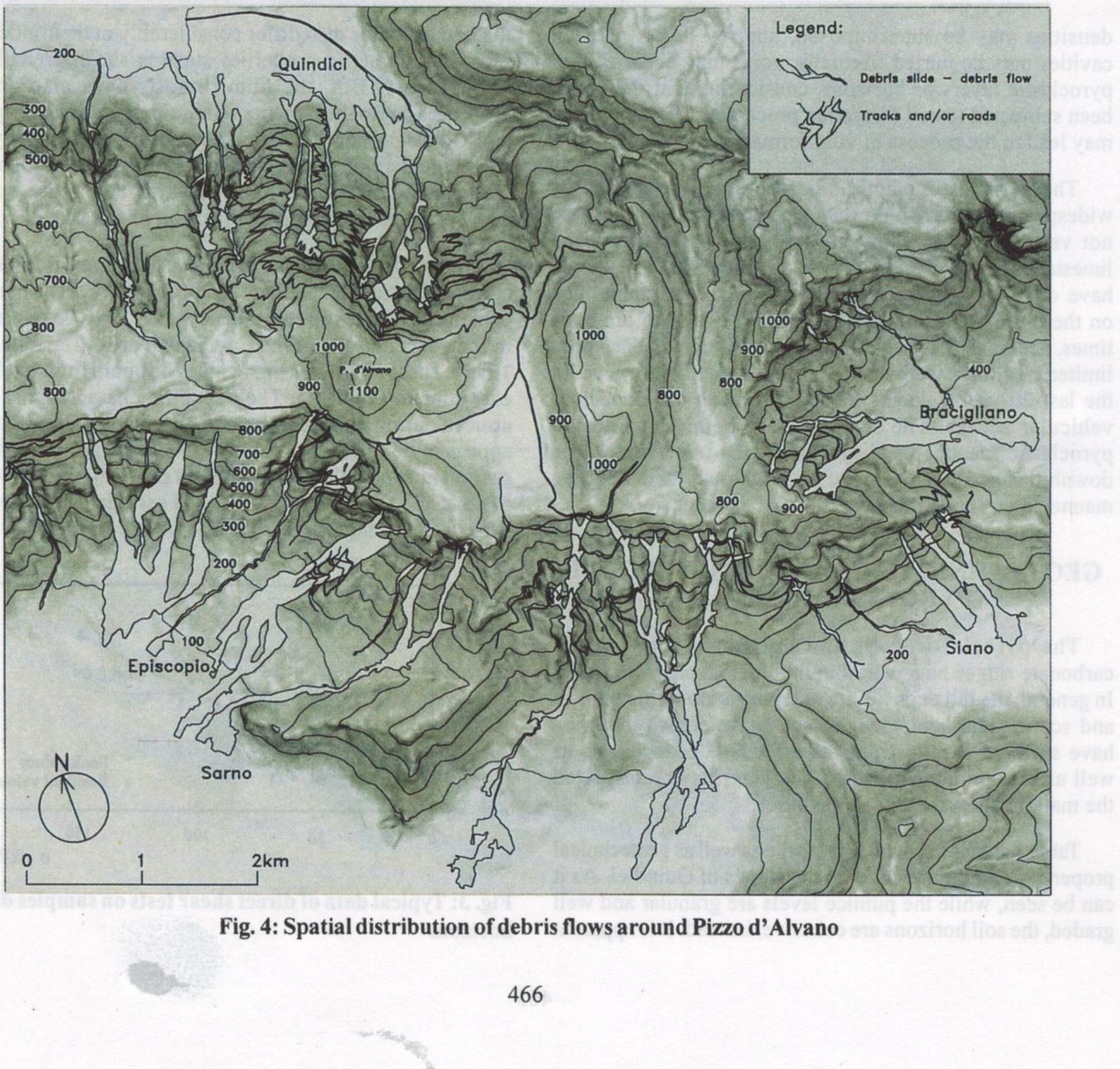

Fig. 4: Spatial distribution of debris flows around Pizzo d'Alvano

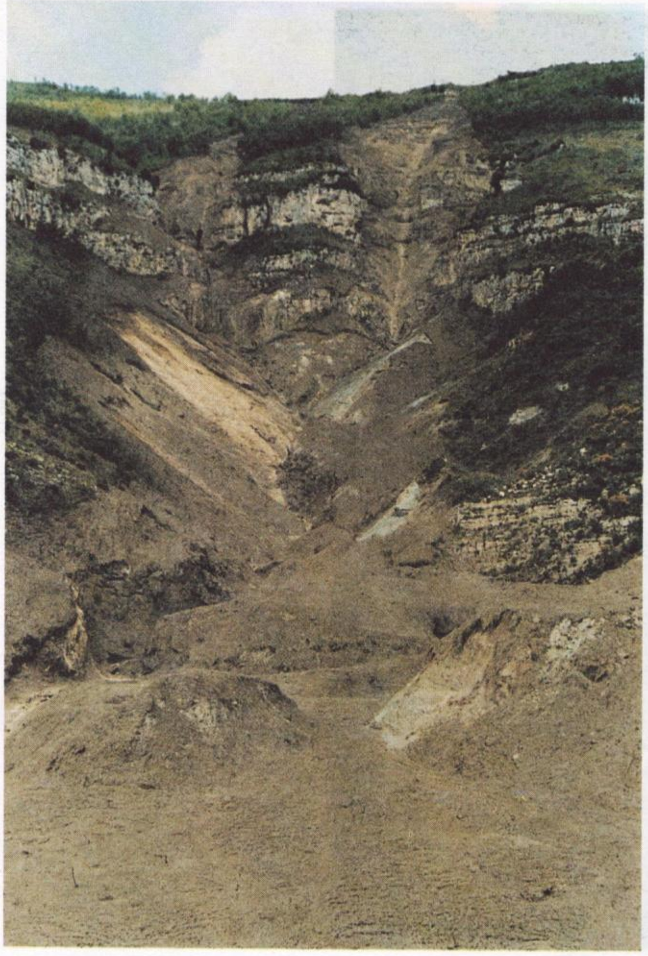

Plate 2: View of the gullies involved in the flows. A track is also seen at the top of the slope.

Often the shape of the failures is that of an isosceles triangle. This evidences a widening of the involved area. Besides, the initial phenomenon can be considered as a fall due to the local topographical setting in same cases. This could consequently have triggered undrained failure in the underlying masses, due to the sudden loading of saturated material (Hutchinson 1986; Sassa 1998). The passage of the masses along the gullies, also with a high velocity, has caused erosion and associated landslides along the banks. These translational slides, which have fed the flows, show a plume-shaped pattern of failure.

As stated earlier, the initial instabilities were induced by the presence of discontinuities, either natural or artificial, in the pyroclastic mantles. Fig. 5 illustrates the typical situation observed at the crown of the initial slides. They are therefore to be considered as source phenomena. The first case (Fig. 5A) shows a situation near a lithological escarpment. The soil layers on top of the escarpment fell down involving the underlying pyroclastic mass (Plate 3). The second case (Fig. 5B) represents the instabilities occurring on the climb section of tracks. In particular, the cuts in the pyroclastic veneer have induced movements with different geometry, both on the up- and downhill sides. The creation of the tracks around the slopes has produced an angle significantly greater than that of the already steep gradient.

In the first case (Fig. 5A), the movement is similar to the natural condition (Plate 4). It can be classified as a rather rapid translational soil slide involving a pyroclastic mass. In the second case (Fig. 5B), instead, the movement was caused by the surcharge of the material accumulated on the valley side for the construction of the tracks. It must be stressed that these soils were heaped on the slope without any precautionary measures. Along the tracks of the study area, the signs of instability are still visible today (Plate 5).

The detailed survey carried out on the higher parts of seven gullies (about 60 failure), both on the Quindici and Sarno slopes, has shown that many (75%) initial slides are associated with the track excavation. In particular, about 48% of the instabilities involve the cut slopes, and the remaining 27% the initial instabilities are on the fill material. These data highlight the critical role played by the tracks in triggering the landslides, which have also involved the slopes of adjoining areas (Plate 6). They also collect the runoff, which can infiltrate into the more permeable layer leading to the formation of pore water pressure.

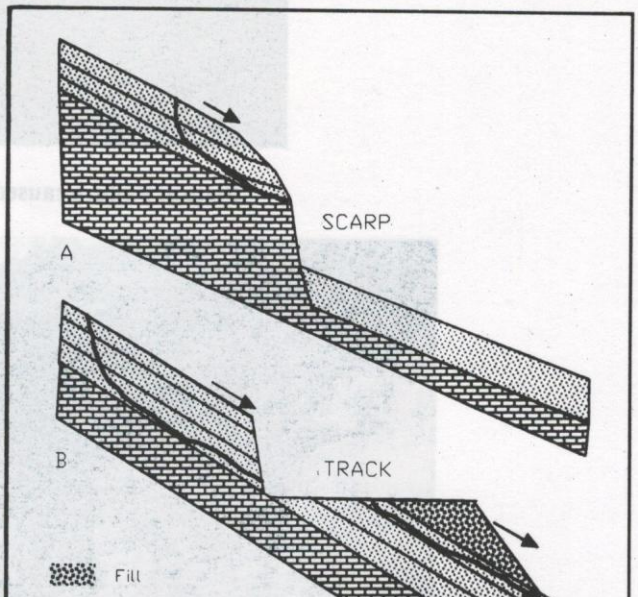

Fig. 5: Schematic cross-section showing the situation after a track is cut through the pyroclastic cover and the excavated material is thrown downhill. The mechanism of instability is also shown.

Plate 3: Failure caused by the presence of a scarp

Plate 4: Typical failure above a track

Plate 5: Failure along a track

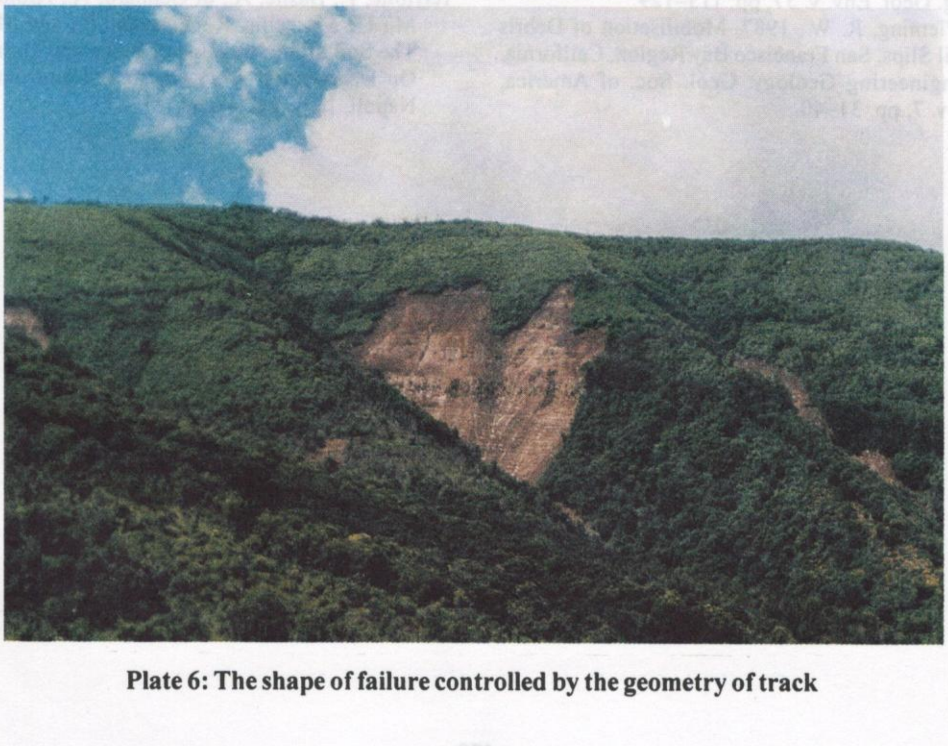

Plate 6: The shape of failure controlled by the geometry of track

CONCLUSIONS

Field evidence indicates that the channelled debris flows, which have hit the Sarno-Quindici area, were generated from one or more initial instabilities in the higher reaches of each gully. The instabilities have involved the pyroclastic soils and horizons (deposited from the successive eruption of Somma-Vesuvius), which form a more-or-less continuous mantle over the Cretaceous limestone massifs.

If the rainfall was undoubtedly a dominant factor in all of the failures, a determining factor was the construction of tracks in the last twenty years to facilitate vehicular access to the plantations on the hill slopes. The initial instabilities that can be classified as debris slides or debris avalanches were also related to the topographical discontinuities, both natural and man-induced, in the pyroclastic cover. These failures may be compared to the snow avalanches, in which perturbation can be an important factor.

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