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LANDSLIDING IN THE CRATI BASIN, CALABRIA, ITALY

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ABSTRACT

The Crati basin is flanked on either side by crystalline metamorphic rocks that have been subjected to intensive folding, shearing and crushing, and have hence lost much of their resistance.

The basin is filled with Neogene alternations of sand, clay and conglomerates, in a (sub)horizontal position. It is a tectonic depression separated from the metamorphic surroundings by major faults.

Post-Calabrian uplift of around 1000 metres, with differential movements superposed, accounts for rapid erosive incision that undercuts the slopes at the foot. Slopes have a further reduced stability on account of the loss of coherence in the metamorphics, of frequent faulting and of exposure of water in the slope face, often trapped by Tertiary clay layers and exposed after erosive incision. The main fault-scarp zones separating the basin from the surrounding metamorphics are zones of increased weakness.

All this accounts for an accumulated potential slope instability. Unstable slope zones are identified on air photos, whether they are presently moving or not. Zones in actual movement invariably make part of such larger zones of instability. This movement is mostly triggered off by cutting in the slope for purposes of road construction, frequent in this area under rapid development.

Nine characteristic landslides are discussed. The recognition at an early stage in the planning phase, of potentially unstable slope zones from air photos – followed by field verification – allows the foreseeing of difficulties of construction and maintainance of communication lines. This may thus contribute to prevent disasters.

Slope instability affects much of everyday life in Calabria. Landslides regularly cut communication lines and damage property, buildings, roads and arable lands with great frequency (fig. 1). It seems worth while to assemble criteria that afford a timely recognition of unstable slope zones, in order to reduce the peril that arises out of interference in these slopes. The present paper is based on observations in the Upper and Middle Crati basin during 1968. '69 and '70, in the Province of Cosenza, in the south-Italian region of Calabria.

Slopes in these parts are highly unstable in general, as a result of the interplay of several factors:

- The area has undergone complex tectonic deformation including overthrusting and nappe formation (Grandjaquet, Glangeaud & Dubois, 1961; Grandjaquet, 1962) leading to a marked reduction in coherence and strength of the metamorphic and igneous complexes in the area.
- The fault contacts between the igneous and metamorphic rocks, and the Tertiary basin deposits, are zones of weakness.
- Late-Tertiary and Quaternary uplift amounting to more than 1000 meters has caused strong erosive rejuvenation leading to rapid incision notably in the Tertiary basin deposits with resulting oversteepening of slopes and reduction of pressure at the slope-foot.
- The alternation of sand/gravel beds with clay deposits in the Tertiary sequence causes numerous aquifers and water traps in the sandy series, which is criss-crossed by a dense network of ravines. Water outcroppings at the slope face in these

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Fig. 1
House damaged as a result of sliding in marly clay.

ravines are the cause of many slide movements.

- Weathering during the later Tertiary and the early Quaternary has been intense and deep and has aggravated the reduction of strength notably in the crystalline rocks.
- Extensive parts are made of marly clays which are sensitive and highly mobile, even at low slope angles.

Build-up of slope instability is a slow and long-term process in which the above mentioned factors operate in addition to many others. Adjustment of the slope to a more stable gradient or profile does not take place automatically or as a continous process, but usually needs a trigger action to set off the motion towards a more equilibrized slope profile. This trigger action overcomes the umbral value of motivation and often thereafter a self-propelled movement of slope material takes place. The magnitude of this movement exceeds by far the magnitude of the interfering force that acted as a trigger.

Among these trigger actions we may mention, first and foremost, *interference by man* for constructional purposes. Furthermore, changes in underground water movement, including increased sub-surface flow as a result of intensive precipitation; interference with the natural vegetation for the reclamation of cultivable land; and, in this seismically active area, earth tremors.

In most of the cases observed, water in the slope had played a role, often a decisive one.

Recognition of slope movement becomes easier as the velocity of the movement increases: catastrophic movements are very spectacular. Of the slower movements, leaning trees or bent stems, leaning poles and fences, cracks in the vegetative cover, terracettes, etc., are well-known indicators. The *hummocky surfaces* with irregular closed depressions and incidental elevations, of sliding slope faces, often with water-logging detectable directly, or indirectly by vegetation analysis, are less easily recognized in the field, but they are of the highest indicative value. They are also recognizable on air photos, dependent on the scale, with the waterlogged parts showing up in distinct greytones, and the hummocky surface reflected by a change in photo texture.

In arable land, in pasture or forested areas, small-scale movements may pass nearly unnoticed, thus opening the way for more intensive damaging by the absence of remedial measures in an early stage of the sliding.

The road system, in the present area a dense network, is likewise affected by slope movements, but here, the movement is detected almost instantly. The road network, therefore, can be used as an important field indicator for slope movements. It was found that almost invariably movements noticed this way, concern parts of larger zones of instability, the existence of which is thus indicated. On the other hand, the very existence of the road means an interference in the setting of the slope, and the road itself may be a trigger factor. Yet, it will not trigger off movements if there is no pre-existent potential slope instability.

This is especially striking in cases of new road construction, frequent in this area under rapid development, where many catastrophic landslides are set off both by the cutting in the slope for the road tract, and by the loading of sensitive materials with the road bed.

Use of air photos in the detection of slope instability. The present paper is based on data gathered in three consecutive years of field surveys in the spring season, based on photo interpretation. These surveys were primarily aimed at an assessment of development possibilities in the Crati basin. In the course of these surveys, the role of slope instability soon became apparent, and this led to more detailed observations in the case of nine active slides described in the present paper.

The air photos available were on a scale of approximately 1 : 35,000; additional material available consisted of reliable geological maps at a scale of 1 : 25,000 and corresponding topographic maps.

It was found that, on photography of this scale, instable slope *zones* are easier to recognize than the actively moving parts of them which occupy too small an area as to be noticeable. The instable slope zone is recognized, o.a., by the presence of concentric circular cracks, by the hummocky surface giving rise to a characteristic texture in the photo image, and often by a darker greytone caused by water.

Frequently it was not possible to discern from the photos whether there was actual movement and if so, where precisely. But afterwards, in field checks it became apparent that all slides presently moving make part of larger zones of instability, and these zones had been identified on the air photos.

This may serve as a point of confirmation for those zones spotted and interpreted as unstable slopes, and which do not presently move. These are either potentially unstable, and will start moving upon interference by outside factors, or they are ancient slides, either dormant – which may be reactivated by interference – or fossil, i.e. stabilized that will not move again under present conditions.

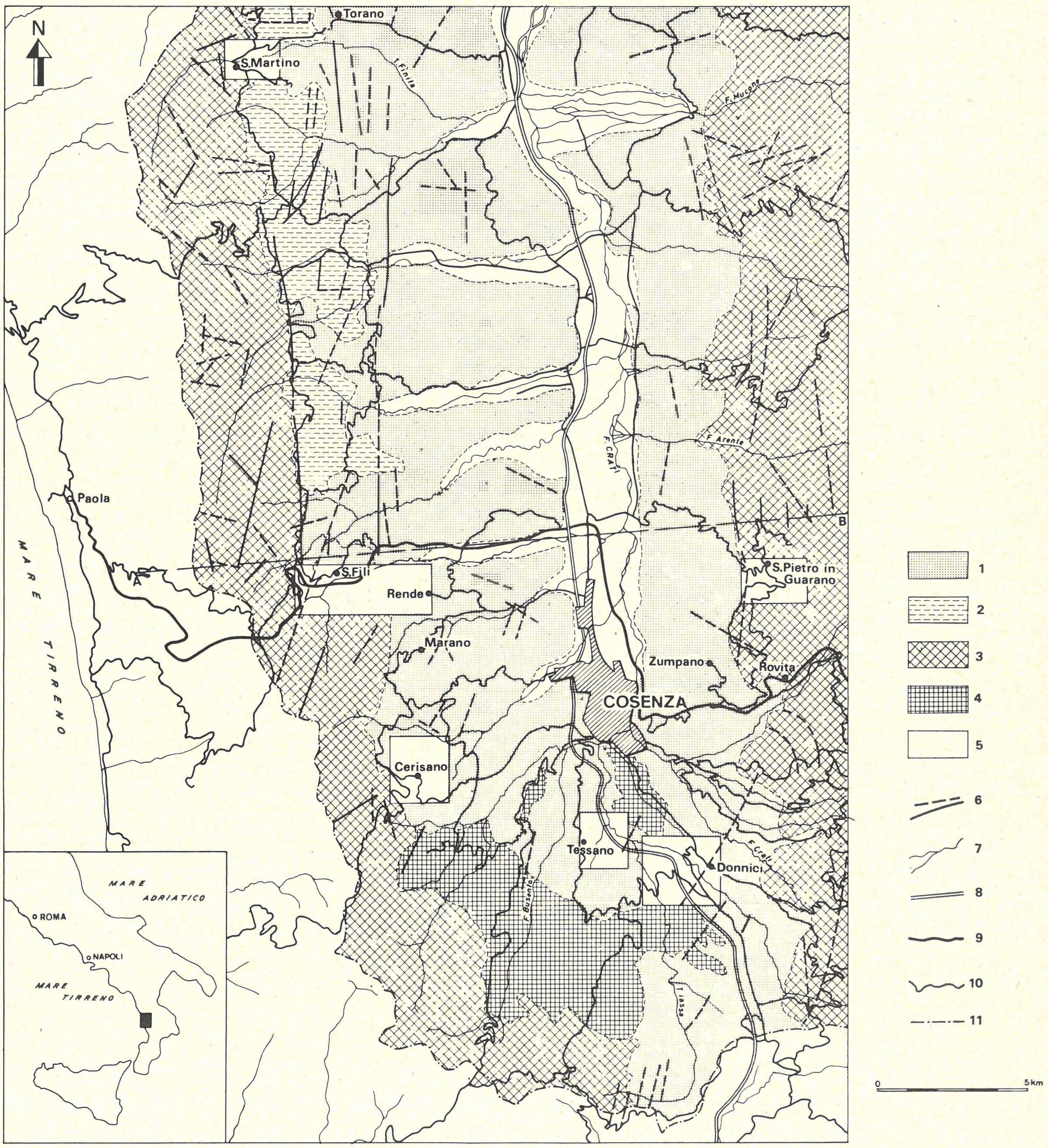
SUMMARY OF THE GEOLOGICAL AND STRUCTURAL DEVELOPMENT OF THE UPPER AND MIDDLE CRATI BASIN

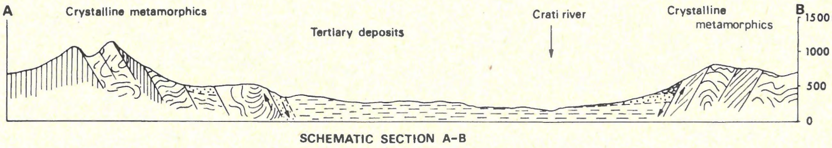
The Crati basin is a tectonic depression with S-N trend formed by downwarping and associated downfaulting in crystalline complexes that flank the basin both to the east and the west. These crystalline complexes are of Palaeozoic sedimentary origin, and were metamorphosed also during the Palaeozoic. Phases of dominantly acid intrusion, still of Palaeozoic age, followed this metamorphism in which several phases are recognized. Folding, uplift and erosion added their part to the complexity of the metamorphic schists and gneisses, and the granites of this age.

During the Tertiary, the crystalline complex was subjected to strong thrusting and nappe formation, with associated gravity sliding, near the end of the Lower Miocene and again in the Middle Miocene when the principal stress was W-E with local deflections to SW-NE. The downwarp and downfaulting of the Crati basin dates from these times; the resultant subsidence caused its infilling by marine sediments of Miocene age. A following phase of subsidence caused the deposition of series of Pliocene sediments, with the axis of sedimentation slightly shifted to the east. This sedimentation continued into the Calabrian. Both the Miocene and the Pliocene series show an alternation of gravels, sands and clays in various degrees of induration; the Miocene also shows banks of calcarenites, and, locally, of gypsum. In the dominantly sandy areas, clay layers act as water traps; in the clayey area, these clays are frequently marly. The deposits are normally horizontal, only near the contact zones and faults on the eastern and western margins do they show gentle dips, which locally may attain values of up to 30°.

The Calabrian sedimentation phase came to an end by the onset of uplifting movements which persist to the present day and have resulted in a gradual regional uplift of around 1000 metres. Phases of standstill are marked by numerous complicated terraces, in the coastal zones where eustatic movements and the uplift have interfered. But in the Crati basin such phases cannot be so readily recognized.

In fig. 2, the geological outlines of a part of the Crati basin are presented.





SCHEMATIC SECTION A–B

SUMMARY OF THE GEOMORPHOLOGICAL DEVELOPMENT OF THE AREA

The Fium Crati, principal drainage channel of the basin, follows the axis of the Crati basin downstream of Cosenza. This tract must have been established only after the termination of the Calabrian marine sedimentation. Its affluents from either side are older in their upstream tracts, established as they were in the surface of the crystalline area, which probably had emerge earlier. The principal tributary, Fium Mucone, descending from the Sila Plateau, has cut an impressive gorge with a height difference of some 1000 meters over a length of waterway of less than 25 kilometers. The Sila plateau is situated east of the Grati basin and drains partly into the Crati catchment (fig. 3).

The headward erosion of the Mucone River has caused the capture of an important component of the Sila drainage system, formerly directed towards the Ionian Sea, thereby further increasing the erosive capacity of the Mucone system.

There is little doubt as to the relation of this intensified erosion and the onset of the Calabrian and post-Calabrian uplift of the area. Intensification of erosion is evident as rejuvenation throughout the

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◀ Fig. 2
Map of part of the Crati basin, showing outline of geology. Blank areas are shown as detail maps in text.

Legend 1: Tertiary sequence of gravels, sands and clays, subhorizontal except near the mountain fringes. Densely dissected and ravined area. In places capped by Calabrian terraces and by fans (not shown).
2: (Marly) clay areas, subject to intense sliding. Long, unstable slopes, topographic depressions.
3: Areas of dominantly crystalline metamorphic and igneous rocks, forming the mountains that flank the Crati basin on either side.
4: (Thin) Tertiary on blocks of crystalline metamorphics; fractured area, deeply ravined.
5: Valley floors, terraces and fans, not differentiated.
6: Faults / Lineations — only main lines shown
7: Streams
8: Autostrada
9: Highway
10: Other important road
11: Crati divide

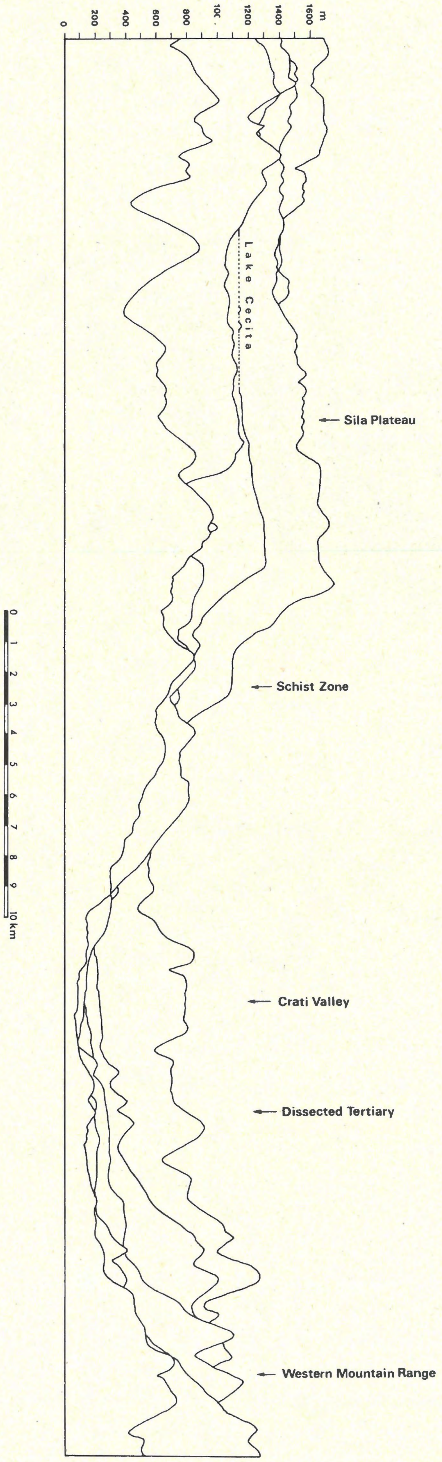


Fig. 3
Projected profiles across Crati basin, looking southward.

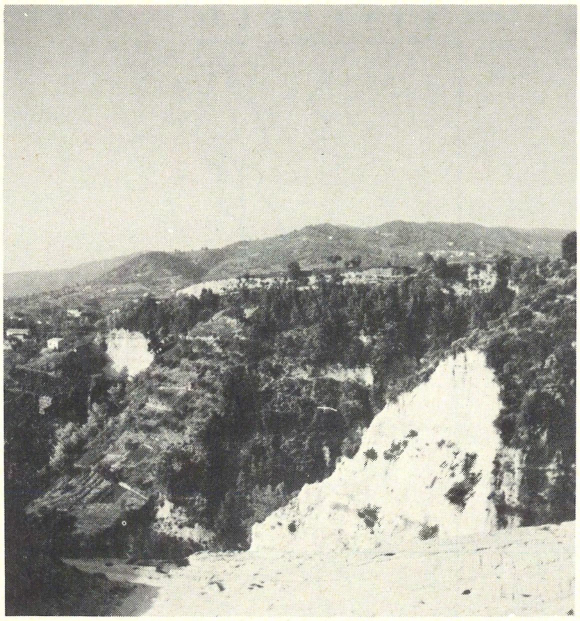


Fig. 4
Ravines in Tertiary basin deposits.

area. Intensive ravining is noted in practically all of the Tertiary sandy and gravelly deposits (fig. 4), whereas the fault-bounded clay areas in the west manifest themselves as a series of actual depressions.

The network of erosion channels in the Tertiary basin seems to have originated on an erosion surface of Calabrian age, characterized by deep and red weathering profiles. The age of this surface could not, as yet, be precisely determined; it may be younger than Calabrian. Remnants of this erosion surface are found at levels between 200 and 1000 meters a.s.l. Localized tectonics, both with an E-W and with a N-S trend, can be held responsible for this complication of the regional uplift.

The result of the uplift and the associated rejuvenated incision has been the almost complete dissection of the Tertiary basin deposits, which in a good many cases now stand in oversteepened and therefore, unstable slopes. Undercutting by streams at the foot of slopes provokes numerous slides; slope instability is further increased by the frequent trapping of water over clay layers in the (sub)-horizontal sequence of strata.

TABLE 1
Probability of heavy rainfall, in mm., with duration from 15 minutes to 5 days.
Station Cosenza, Average Rainfall 1041 mm/year.

	hours							days			
Duration	$\frac{1}{4}$	$\frac{1}{2}$	1	3	6	12	24	2	3	4	5
Recurrence: Once in											
1 year							50	70	80	92	105
3 years	17	20	23	31	37	53	74	90	108	115	120
5 years	18	24	28	35	42	56	78	100	115	126	140
10 years	21	30	35	42	49	63	88	110	130	150	156
30 years	26	34	44	61	72	80	103	125	170	195	220

From "A survey of the development potentialities of the Crati basin", 1969, ITC-Unesco Centre for Integrated Surveys.

RAINFALL

Although the present climate has little to do with the built-up instability of slopes, which results from past processes and climates, it is a factor in triggering off slope movements. Here, again, the combination of factors rather than one single factor should be considered. Exceptionally heavy rainfall may saturate the slope-forming materials to such depths that mass movements are provoked. Also, increased spring discharge as a result of this, provokes movements in potentially unstable slopes.

Of the climatic factors, rainfall intensity and the duration of heavy precipitation, are the most active in this respect. In table 1, the probability of heavy rainfall, in mm., with duration from 15 minutes to 5 days, is calculated.

Landslides in the area occur often after sustained intensive precipitation, largely concentrated in the winter months, comprising the period between October and March, in which some 65% of the total annual precipitation falls.

LANDSLIDES

In the foregoing it has been attempted to summarize the factors that determine the physical setting in which the landslides of the area occur. It will be clear that conditions for landsliding are exceptional

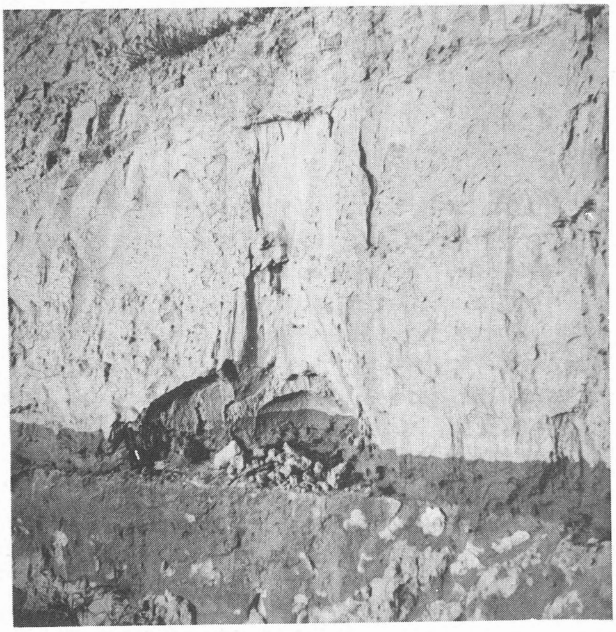


Fig. 5
Clay in Tertiary sequence acts as water trap and saturates sand above, resulting in pelitic rock fall.

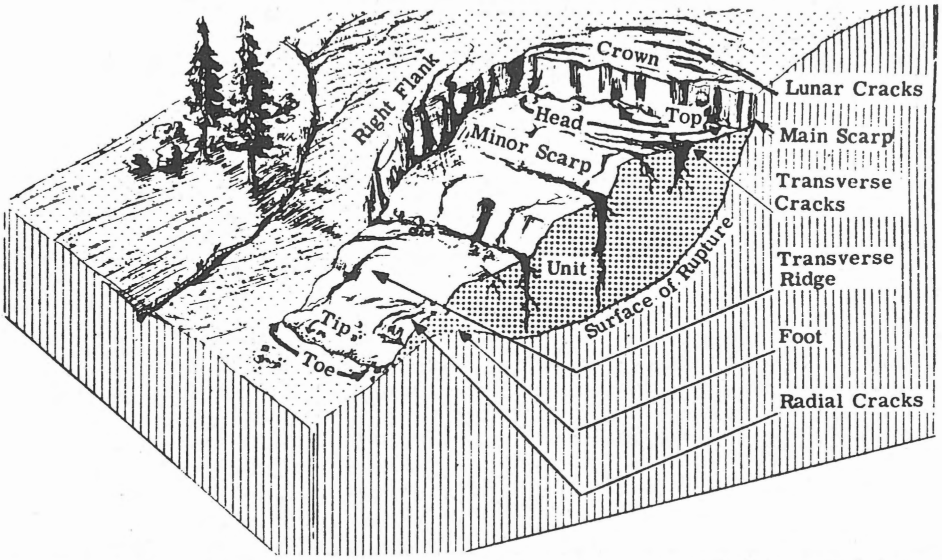
well fulfilled here, with the combination of reduction of strength of crystalline rocks through tectonic crushing and shearing, and deep weathering, frequent water trapping in the Tertiary deposits (fig. 5), fault boundaries between rock types, differential neotectonics, regional uplift resulting in erosive undercutting and oversteepening of slopes, earth tremors, and, additionally, considerable deforestation and overgrazing.

Landslides are differently defined by different authors; Cleaves' definition may be quoted here: "A landslide is the downward and outward movement of slopeforming materials, composed of rock, soil, artificial fill, or combinations of these materials" (1961). A generalized diagram, derived from Cleaves (1961) shows the general nomenclature applicable to landslides, as also used in the present paper (fig. 6).

The type of movement has its own peculiarities in each landslide and basically, each landslide is a unique case and should be studied as such.

In Calabria, we recognize

- *active slides,* which are presently moving
- *dormant slides,* which have moved during the recent past but do not move now; they have not yet



Length - Horizontal distance, crown to toe.
Width - Horizontal distance, flank to flank.
Height - Vertical distance, toe to crown.

Depth - Thickness of slide mass, between foot and crown. (Foot is line of intersection between the lower part of the surface of rupture and the original ground surface.)

Fig. 6
Nomenclature of landslides, after Cleaves.

reached a state of equilibrium that precludes further movements, and therefore, they can be reactivated, e.g. by excavations in the slope.

- *fossilized slides,* which have moved in the past but are now stabilized in a natural way.
- *potential slides,* zones of accumulated slope instability, dangerous because they are near the "umbral value", which is easily passed by a single factor, which then becomes the trigger act which sets the slope into motion.

In the Crati basin, the category of active slides could be further subdivided into those which were actually moving at the time of the survey, and those which can be established as mobile parts of unstable slope zones, without showing actual movement during the survey.

Records of landslides

No systematic records of slope movements exist in the area of study, even though landsliding accounts for considerable damages each year.

Work to check rampant erosion (including landsliding) has gathered momentum over the past fifteen years, and certain basins, like that of the Fiume Arente, have been singled out by the Opera Sila for intensive study of the erosion phenomena (in which

TABLE 2
Landslides treated for correction in middle Crati Basin and Sibari Plain.

Year	Number of slides treated	Surface involved (Ha.)	Nature of damages	Value of damages (L.It.)	Expense incurred for treatment (L.It.)
1966	10	23	Localized phenomena affecting uninhabited land under extensive agriculture; Subsidence of roads and structures; Damages to houses.	11.000.000,–	6.900.000,–
1967	10	18	Affecting uninhabited terrain under extensive agriculture	7.200.000,–	5.400.000,–
1968	6	22	Affecting uninhabited land under extensive agriculture; Subsidence of roads and structures	8.800.000,–	6.600.000,–

Source: Provincia di Cosenza, Ufficio 'Consorzio do Bonifica della Piana di Sibari e della Media Valle del Crati'.

TABLE 3
Landslides treated for correction in the province of Cosenza.

Year	Number of landslides treated, and total surface involved		Type of damage caused by the landslides	Cost of treatment L.It.
	No.	Ha.		
1966	39	173.16.96	Affecting fallow land and cultivated areas with damages to crops and infrastructure	131.465.375,–
1967	38	183.28.55	–do–	132.941.124,–
1968	27	207.90.56	–do–	101.790.358,–

Source: Provincia di Cosenza, Ufficio: Ispettorato Ripartimentale delle Foreste.

landslides are comprised) along wich reforestation and other control measures.

Since 1966, records regarding the number of landslides treated and the damages done in the Sibari Plain (north of our area of interest) and the Middle Crati Valley have been accumulated. This, however, is not a full representation of the landsliding phenomena but only of those that have been given some treatment for systematization (table 2). In table 3, landslides treated for rectification by the Forest Department in the whole of the Province of Cosenza (comprising an area much larger than the Crati basin) are listed.

Roads in the area are controlled partly by the Italian Government (Azienda Nazionale Autonoma delle Strade, ANAS), and partly by provincial and municipal authorities.

As far as ANAS-controlled roads are concerned, records of road-affecting landslides for the Upper and Middle Crati basin, which is the part considered for the present study, show 34 active slides, affecting around 760 hectares of land. This picture, is not complete since only those slides affecting ANAS-controlled roads were considered.

Characteristic landslides in the area

For reasons of scale, not all the landslides mapped during the surveys, and amounting to dozens, can be shown in the map included with this paper.

Nine characteristic slides have been singled out for a more detailed examination. Their locations are shown in fig. 2, and in the relevant detail maps. For each slide, the geology of its surroundings and further particulars regarding its setting and the cause of sliding are given. The number of each slide corresponds with the number shown in the detail maps.

1. *Rende*

Opposite the village of Rende, a landslide occurs which has resulted in spectacular road damage (figs. 7 & 8).

The toe of the slide is undercut by the same stream which is also responsible for the oversteepening of the slope in which the slide has ultimately occurred.

Height of the slide, toe to crown, is approximately 150 meters;
Length, toe to crown, horizontal distance, approx. 200 meters.

The gradient of the slide, thus, is in the order of 75%, corresponding to a slope angle of 37° of the slid surface. This figure must be seen as an average, as in each slide, short-range changes of slope occur between the extremities of vertical and horizontal surfaces, or even slopes contrary to the general slope direction of the slide.

The cause of the slope instability lies in:

a. the occurrence of bands of clay interbedded in a sequence of Calabrian sands and sandstone in a semi-consolidated state, dipping 7° to the northeast. Above the clay layers, the profile of the slope face is waterlogged.

Fig. 7
Map showing landslides and geological setting in Rende-San Fili area (cf. fig. 2).

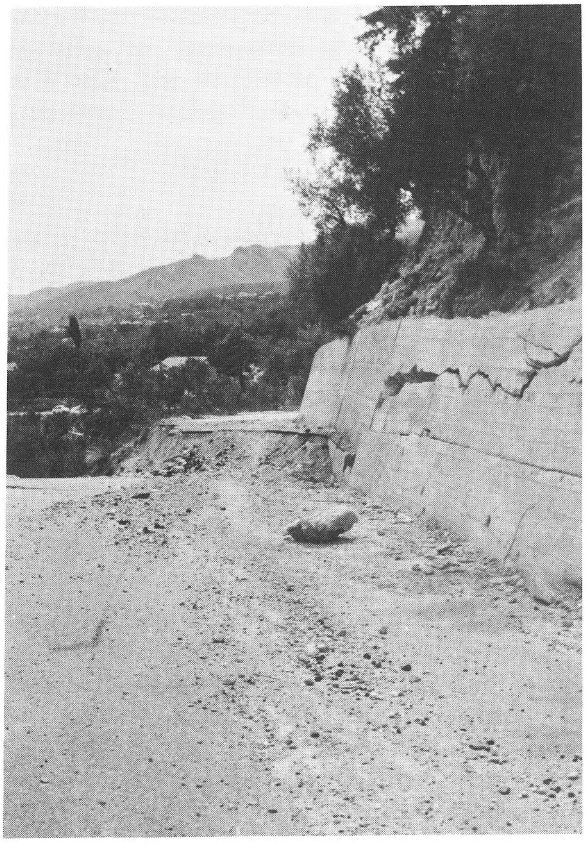


Fig. 8
Road destruction as a result of landslide opposite Rende (cf. fig. 7).

b. exposure of this sequence in an erosional escarpment (due to undercutting as a result of rejuvenation mentioned above), facing northeast and east.

The cause of the actual sliding is the cutting in the slope face for a new road connecting Rende with Marano. The slope has failed where the road excavation intersects with the clay bands in the waterlogged profile. The slide can be typified as a pelitic rock slide. The first movement took place in 1969 after the excavation work, resulting in repairable damage. In 1970, the slide was re-activated, resulting in the complete destruction of the road.

2 & 3 *San Fili*

Along a newly constructed road from Cosenza to Paola, two similar slides occur where the road is excavated in the right bank slope of a gorge, opposite the village of San Fili. The toes of both slides are undercut by the stream in the gorge, Torrente Emoli.

Heights, crown to toe: slide 2, 80 metres; slide 3, 150 metres.
Lengths, crown to toe, horizontal equivalent: slide 2, 200 metres; slide 3, 250 metres.

The gradients are about 40% and 60% for slide 2 and 3, respectively, corresponding to average terrain slopes of 22° and 31°. Here, too, the slid and ruptured surface of the slide shows large deviations from this figure.

The cause of the slope instability is, in both cases,
a. the undercutting at the foot of the slope by the T. Emoli, resulting from rejuvenated incision,
b. the loss of coherence in the crystalline metamorphic rocks, that in both instances form the slope, due to their having been crushed in the tectonic past, and to the nearness of the fault contact between the Tertiary basin deposits and the crystalline metamorphics. In slide 3, the larger of the two, a spring horizon is cut about 20 meters below the crown.

Fig. 9
Major landslide (No 3) opposite San Fili. Note that forest was cut *after* slide in the course of corrective measures.

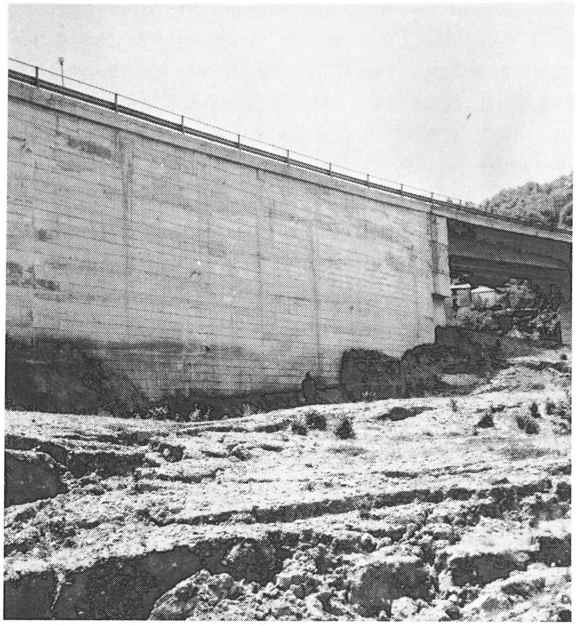


Fig. 10
Slide at San Fili bridgehead (no 4).

The cause of the actual sliding is, in both cases, cutting in the slope for the new road. It is of interest to note that the failed slopes were under forest prior to the road cutting, and the slope failure took place in spite of the forest cover. The slides can be characterized as rock debris slides (figs. 7 & 9). First movements took place in 1969, after the road had been completed. Movements renewed in 1970, causing extensive road damage.

4. *San Fili, bridgehead* (fig. 7)

A newly constructed bridge in the same highway to Paola spans a valley in which the contact occurs between the crystalline metamorphics, and the Miocene marly clays.

The concrete eastern bridgehead is flanked and filled by dumped rock debris derived from nearby road cutting. The total weight has caused overloading of the underlying Miocene marly clays, which have failed. The dumped material has, in turn, slid with the clays, though the bridgehead itself had, in 1970, not been affected (fig. 10). The marly clays have in general a very low compressive strength, which explains their easy sliding.

The *height* of the slide is about 35 metres; its length is around 200 metres, giving a gradient of 17½% or an average slope angle of some 10°, which illustrates the mobility of the marly clays. The first movement was observed in 1970, the bridge had been completed about two years earlier.

5. *Tessano* (fig. 11)

In the village of Tessano, a landslide cut the main road in the spring of 1970 and the main scarp stood less than 1 metre from the houses of the village (fig. 12).

The west bank of the Vallone Fridizza, a tributary to the Fiume Iassa, one of the affluents of the Crati, is in a state of collapse as a result of oversteepening by erosive rejuvenation. The height difference of this bank is some 200 metres over a horizontal equivalent of 500 metres, giving a terrain gradient of 40% or an average slope angle of 22°.

The zone of acute unstability below the village of

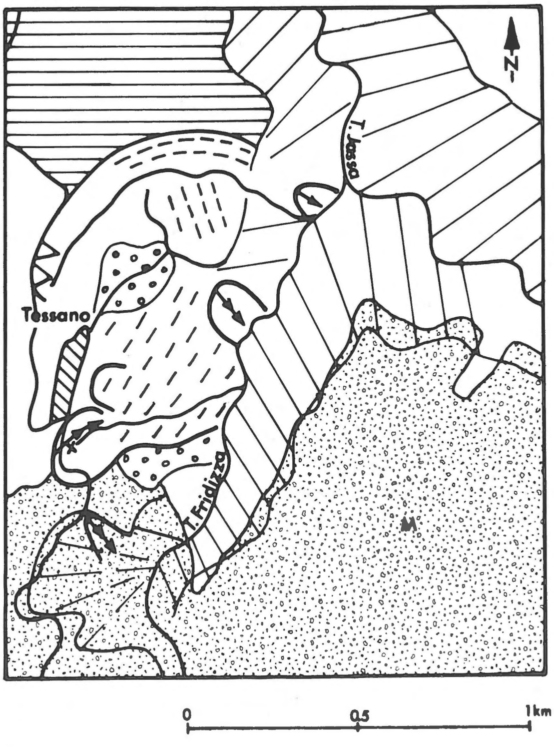


Fig. 11
Showing landslides, unstable slopes and geological setting of the Tessano area (cf. fig. 2).

Fig. 12
Head scarp of recent Tessano slide.

Tessano is about 750 metres wide, and shows signs of intensive sliding in the recent and remoter past.

Miocene conglomerates and sandstones overlie crystalline biotite schists, and in places, slid blocks entirely made of Miocene rocks are found on the slope consisting of metamorphic rocks.

The cause of the slope instability is thus made clear; the present slide, though spectacular, is but a small expression of the instability of the slope as a whole and must be seen as the normal continuation of the gradual collapse of this slope. A spring in the slide face may have contributed to the actual motivation of the part.

6. *Donnici* (fig. 13)

A large zone of unstable slopes, more than 3 km. in width, faces the village of Donnici, on the south bank of the Torrente Albicello (fig. 13). This zone consists of Calabrian conglomerates overlying Calabrian sandstone; both are semi-consolidated, horizontally bedded. This part is traversed by the newly constructed autostrada from Cosenza to the south. In this zone, both active and potential sliding is noted, and the construction of the autostrada has met with problems.

The cause of slope instability in this zone is the oversteepening as a result of headward progressing of rejuvenated erosion in a southerly direction. A high level Calabrian plateau near the southern divide (fig. 2) is the preserved remnant of the undissected terrain which, after uplift, is being progressively attacked by erosion, resulting in oversteepening and undercutting of slopes, and thus increasing the slope instability.

In the present zone, water infiltration enhances the slope instability. Signs of sliding on a large scale in the somewhat earlier past are abundant, and the zone is to be considered a dormant slide (fig. 14).

Cause of the actual sliding. The dormant slide has been re-activated as a result of tampering with the natural slope conditions in the course of the autostrada. As a result, expensive control measures have been necessary. Anchoring of the road bed has been done by deep concrete pillars driven into the unstable slope material on the downslope side of the road; a

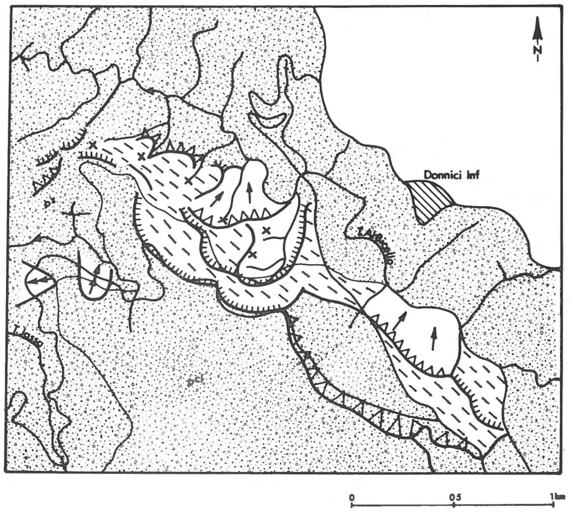


Fig. 13
Map showing Donnici sliding zone and setting of surroundings (cf. fig. 2).

roofed gallery underneath the head scarp protects a stretch of road about 150 m long (fig. 15); moreover, several minor stabilizing works have been carried out.

Height: the sliding zone has a varying height over its 3 kilometres width, and in it, several individual zones of active sliding and acute slope instability can be recognized, as shown in fig. 13. As an average the height of the sliding zone may be taken as 115 metres.

Length: the length of the slide zone varies between 475 and 750 metres horizontal equivalent, giving terrain gradients between 41% and 65%, corresponding to average slope angles between 22° and 33°.

7. *San Pietro in Guarano* (fig. 16)

This spectacular slide is located in the metamorphic schists and gneisses, on the south bank of the Fosso Corno, facing the village of San Pietro in Guarano.

Cause of the slope instability: The gorge is deeply incised into crystalline (metamorphic) country rock which is intensily crushed and cracked; directions of schistosity vary widely from place to place, at short range.

Erosive rejuvenation, again, is mainly responsible for the oversteepening of the gorge; uplift has initiated the process. Midway in the slide, groundwater seeps out, and it appears that this groundwater horizon plays a role in mobilizing the slope cover.

Cause of the actual sliding: the contact with the Tertiary basin deposits is at less than 500 metres from the slide, in a steep escarpment. It could not be established as a fault contact as yet.

Signs of slope instability are plentiful on both banks of the gorge, and the particular reason for this landslide to occur at this location may be the postulated passage of a faultline through this zone (fig. 16). There are many points that are unstable to the same degree, and where the same might happen any time.

Height: from crown to toe, the slide is more than 170 metres high.

◀ Fig. 14
Panoramic view of slide zone from Donnici village.

Fig. 15
Roofed gallery to protect autostrada from sliding masses of head scarp.

Length: the horizontal equivalent distance, crown to toe, is 240 metres, giving the slid terrain an average gradient of 70%, corresponding to an average slope angle of 35°. It will be noted that the lower part (cf. fig. 17) has a much steeper gradient as it forms part of the gorge. Undercutting at the toe maintains this steep angle. The head scarp is clearly distinguishable, and has near-vertical backwalls (fig. 17, 18).

Further remarks: The road leading to San Pietro in Guarano, from the State Road 107, passes through the slide zone, and may had an influence in first mobilizing the slide.

The slide has been active for over 35 years, repeatedly causing road damage. Only in 1962, the road became damaged beyond repair, and an alternative road had to be constructed away from the gorge.

This deviation route leads behind the village of Altavilla, which is situated at the crown of the landslide.

The houses of this village of Altavilla, visible in fig. 17, at the crown of the slide, have found themselves in an increasingly perilous position as the slide grew and extended headward. In 1970 the houses were evacuated and their occupants resettled in newly built quarters elsewhere in the village.

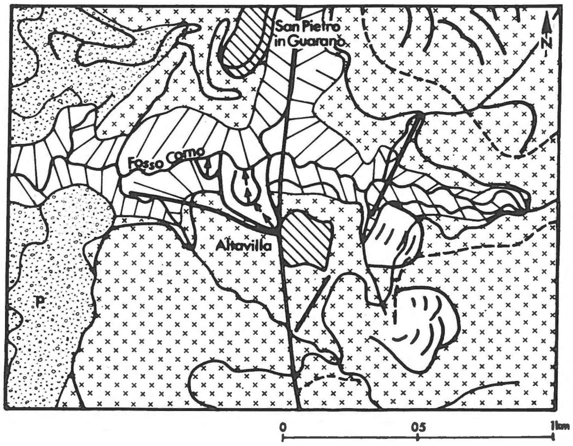


Fig. 16
Map showing geological setting of San Pietro area, with main slide below Altavilla and other potential slide zones.

8. *San Martino* (fig. 19)

Three landslides are located close to each other at the western mountain foot where the Torrente Finita breaks out of the mountains to enter the Tertiary-filled foreland. Both the mountain terrain and the foreland are intensely faulted, the latter with a dominantly S-N trend. (fig. 2).

Fig. 17
San Pietro slide, seen from San Pietro village.

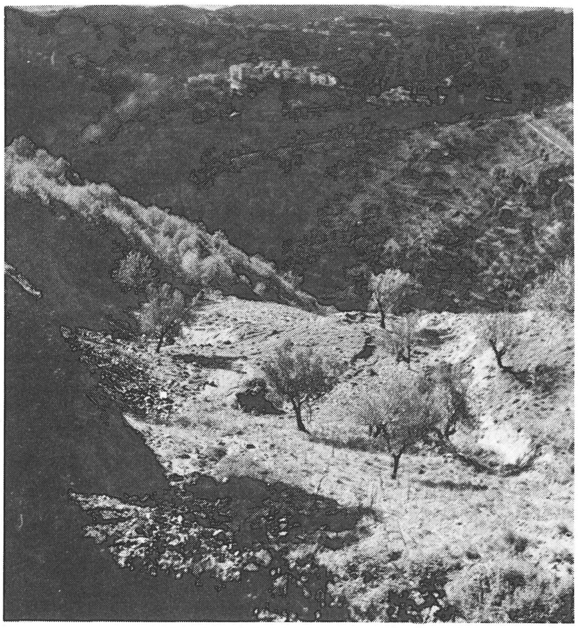


Fig. 18
San Pietro slide, seen from head scarp at Altavilla.

In fig. 19, the three active slides are indicated A, B, and C respectively.

Slide A has a height, crown to toe, of 160 metres and a length of 650 metres, corresponding to a gradient of 25% or an average slope angle of 14°. It cuts the road from San Martino to San Giacomo (fig. 19) over a width of 200 metres. The whole slide is located in mobile slope material in phyllades and green epidote schists, at the precise location of a faultline. The latter is the cause of the slope's instability in spite of its gentle gradient; the actual sliding is caused by water seepage at the faultline.

The same faultline borders a patch of downfaulted Pliocene silty and marly clay which is highly mobile and reduces the pressure at the foot of the slope. The infiltrating water has set the schist fragments of the slope, along the faultline, in motion.

Slide B is located nearby, and cuts the road from Torano to San Martino, just below the junction with the S. Martino – S. Giacomo road, over a width of 300 metres (cf. fig. 2). The height of this slide is 115 m, its length 400 m, its gradient 29% corresponding to an average slope angle of 16° for the slid material. A fault contact between the crystalline schists and the mid-Pliocene silty clays, combined with the mobility of the latter, set off the slide, which mainly affects the Pliocene clayey material. A streamlet follows the faultline, and the whole slope is undercut at the base by the T. Finita.

Slide C is located on the righthand bank of the T. Finita, and is caused by bank collapse following undercutting by the stream in the same Pliocene clays, which are overlain by younger, presumably Pleistocene alluvial fan deposits. This zone has a width of around 300 metres, and is located in the extension of a confirmed fault, again between the schists and the downfaulted Pliocene clays; the fault itself appears to be hidden here underneath the fan gravels.

In summary, it is clear that these three slides are basically to be ascribed to the downfaulted patch of mobile and sensitive Pliocene clay, surrounded on all sides by metamorphic schists, and with the swiftly eroding T. Finita running straight across the downfaulted patch.

9. *Cerisano*

The village of Cerisano, southwest of Cosenza, lies atop of a large sliding zone in Quaternary conglomerates, which may be considered as re-worked piedmont-fan deposits. Fan terraces of this kind are plentiful along the western mountain front; in most of

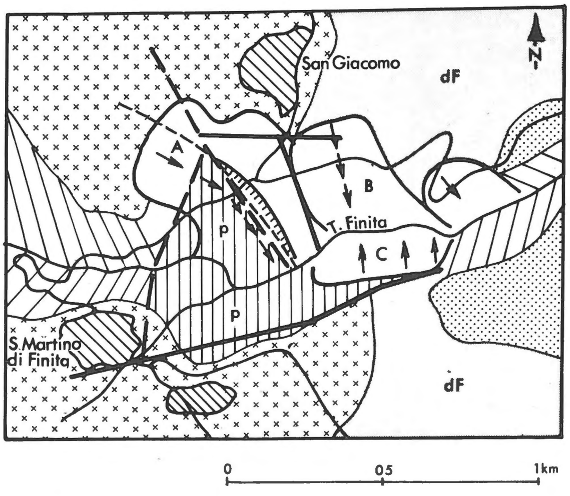


Fig. 19
Map showing slides and geological setting of San Martino area (cf. fig. 2).

them the original fan surface is still preserved showing a surface slope coinciding with the depositional slope of around 7°.

Here, in the Cerisano area, the material appears to have been re-worked. It is in consistent but slow motion, slow enough to allow the land to be tilled or laid in orchards or vineyards. The upper scar lies just below Cerisano village and is marked by a spring horizon and an escarpment.

The unstable terrain slides in the direction of the Torrente Renacchio, a tributary to the T. Campagnano. The sliding zone has a length of 1150 metres and a height varying from 130 (at the upstream end) to 170 m at the downstream side, seen in relation to the T. Renacchio. The average height may be taken as 150 meters, which results in a gradient of 13%, corresponding to an average slope angle of 7°. This, incidentally, is the same angle as that of the Pleistocene fan deposits and their surface slope in preserved parts.

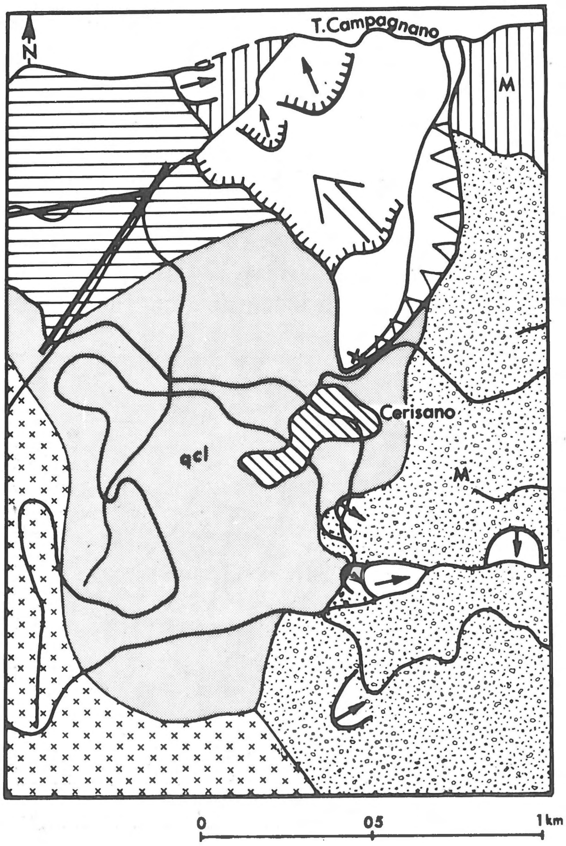


Fig. 20
Map showing slide zones and geological setting of Cerisano area (cf. fig. 2).

Miocene evaporitic limestone, sandstone and conglomerates constitute the eastern border of the actively sliding zone.

Erosive undercutting at the foot of the slope has undoubtedly added its part to the degradation of these fan deposits.

Numerous smaller landslides occur in this zone as a result of the unstability of the material.

CONCLUSIONS

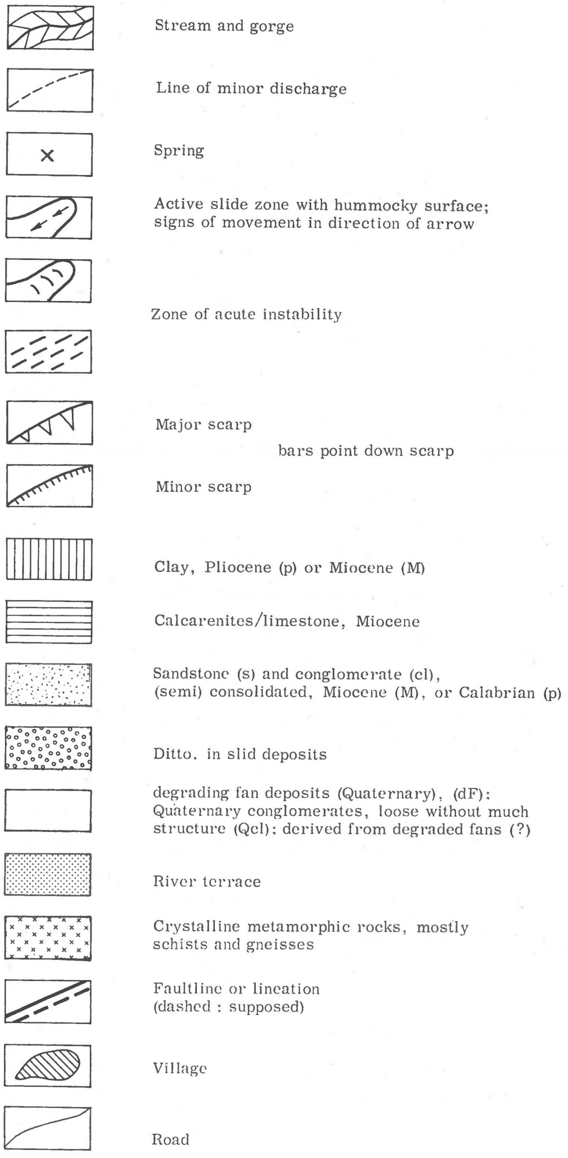
The tectonic history of the Crati basin excercises a profound influence on the slope stability: the accumulated instability of slopes is to be ascribed to the combined effects of loss of resistance of normally hard rocks, due to their tectonic past, to deep and intense weathering, and to erosive incision as a result of regional and differential uplift. The latter results in oversteepening of slopes on the one hand, and undercutting at the foot, on the other.

The occurrence of haphazard clay banks in the Tertiary sequence which act as a water trap, complicates the sub-surface water movement. Exposure of underground water in slope faces as a result of incision and ravining, is frequent and adds to the slope instability.

Rock resistance and sub-surface water movement are, moreover, greatly influenced by the presence of numerous faults and fault contacts in the area.

In such a situation, one single factor can act as the trigger that sets the potentially unstable slope in motion. In this area the trigger has often been human interference in the slope for purposes of road construction. Intensive precipitation has also been found to act as a motivating force.

In the detection of unstable and potentially dangerous slopes, air photo interpretation is a valuable technique. An experienced photo-interpreter will be able to extract very precise information from the aerial photographs as to the location and the extent of dangerous slopes. Here, as in most surveys, the sequence may be recommended that a general review of the area of study be made on small-scale photography, from which the necessary background information is obtained, along with a general appreciation of slope types and slope (in)stability. This should be followed by detailed studies on photography at a



Legend for Figs. 7, 11, 13, 16, 19, 20.

much larger scale of those areas that have been recognized as possibly unstable on the small-scale photography.

Field checks remain indispensable and should be undertaken at an early stage in the survey.

It has been found that the activily moving parts, with very few exceptions, make part of larger zones of slope instability. It is these zones that are detected from the aerial photos; from the point of view of planning it makes little difference whether they are actually moving or not. If they are not moving at the time of the survey, their detection as a potential slide zone on the air photos is even more important since it allows the foreseeing and, possibly, avoiding or prevention of difficulties during constructions.

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