4. Gravitational phenomena triggered by the 1980 Southern Italy Earthquake

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Earthquake-triggered landslides in Italy

Several historic records and oral traditions exist of very large gravitational movements triggered by earthquakes in Italy (see, for example, Oddone, 1930; Cotecchia *et al.*, 1969; Govi, 1977; Dramis *et al*, 1982; Crescenti *et al.*, 1984).
In recent times it was possible to survey directly, with more scientific methods, surface effects of strong earthquakes (Panizza *et al.*, 1987), also comparing them with instrument records of the shock. In this way it was possible to understand (Radbruck-Hall and Varnes, 1976; Keefer, 1984) that the typology and dimension of triggered mass movements are strictly related to both litho-structural features of the site and characteristics of the shock, particularly with Arias intensity (Arias, 1970). It has also been outlined that many earthquake-induced mass movements are also connected with other seismic ground effects (such as fracturing and faulting).
As far as lithologic features are considered, the importance of identifying "engineering geological formations" has to be stressed (Cotecchia, 1978; Canuti *et al.*, 1988); research aiming to this end is presently being carried out throughout the Italian territory.
It has also been pointed out that earthquake-triggered mass movements may involve slopes already characterized by instability, but normally dormant or evolving at a very slow rate. Even though earthquakes can trigger phenomena of any kind and dimension (ranging from very small and shallow ground failures to huge landslides and deep-seated gravitational movements), a typical feature of earthquake related landslides (i.e. of phenomena which generally reactivate only as a consequence of strong seismic shocks) is their wide extension and elevated depth. These kind of mass movements, being activated only by extreme events (mainly strong earthquakes and, subordinately, intense rainfalls), typically show recurrent activity, alternating long steady periods with sudden reactivations.
Among earthquake-induced surface effects, lateral spreadings, causing progressive "graben like" sinking on hill tops, are reported (Solonenko, 1977; Dramis *et al.*, 1983).
Very important for the activation of landslides (and, of course, of earthquake-induced ones too) are also hydrogeological conditions (such as saturation of terrain, variations of piezometric level etc.). Particularly frequent on saturated sandy-silty sediments are liquefaction phenomena which can produce instability either directly (because of flow slides along saturated sandy-silty slopes) or indirectly (by allowing the mobilization of overlying terrains). This kind of landslides (Tinsley *et al.*, 1985) often involve deep-seated beds too, disturbing very large areas far away from the epicenter.

The southern Italy earthquake

The 1980 Earthquake in southern Italy The last highly energetic earthquake that affected the Italian peninsula happened in November 1980 (Deschamps and King, 1983; Westaway and Jackson, 1987) and involved a wide portion of the Campania and Basilicata regions, in southern Italy, even though it was perceived (III MCS) in a large part of the Italian territory. The main shock reached a magnitude of 6.8-6.9R and produced widespread and severe damage (for this event too the intensity was estimated around IX-X MCS), also causing about 4,000 casualties and many injuries.

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The source was a dip-slip normal fault with Apennine (NW-SE) strike and vergence towards the Tyrrhenian Sea (i.e. SW) and the focus was some 18 Km deep. The shock was, in many aspects, similar to those affecting more or less the same area in 1930 and 1962 (the latter reached intensity XMCS).

Coseismic surface faulting (Fig. 1) was recorded in the area (Cinque *et al.*, 1981; Bollettinari and Panizza, 1981; Pantosti and Valensise, 1990) as well as vertical movements (Cotecchia, 1982; Arca and Marchioni, 1983). More widespread were surface fractures (Fig. 2), mostly rectilinear and up to several kilometers long, that were created in a variety of lithologies (including loose material, such as alluvial deposits and inactive landslide bodies), both isolated and in parallel or joined groups, as a consequence of interference between seismic, tectonic and gravitational stress (Carmignani *et al.*, 1981; Dramis *et al.*, 1982). Many of these discontinuities opened as a reactivation of fractures created by past earthquakes (e.g. in 1930 and in 1962), as reported by several authors (Alfano, 1930; Oddone, 1930; Vari, 1930; Serva, 1981). Their opening frequently lead (both in 1980 and during past earthquakes) to gas emission (and, sometimes, ignition). Along some of them a sharp increase in Helium content of the soil has been recorded (Dramis *et al.*, 1982) that may indicate their depth (or at least their connection with deep-seated beds).

Fig. 1. 1980 Southern Italy Surface fault and historical eartquakes

However, the most outstanding phenomena triggered by the earthquake were mass movements of different type (Cantalamessa et al., 1981; Cherubini et al., 1981; Cotecchia, 1981, 1982; Genevois and Prestininzi, 1981; Agnesi et al., 1983; Crescenti et al., 1984; Bisci and Dramis, 1993), at least partially determined by the quite high relief of the area, the poor geotechnical characteristics of most of the outcropping rock and the high water content of terrains (due to heavy rainfall in the days preceding the seismic event). These movements often appear to be connected with the above described ground fractures too and quite frequently affected entire slopes. These gravitational phenomena mainly moved immediately after the earthquake and their activity lasted only for a short period; most of them represent the reactivation of landslides activated by past earthquakes.

Calcareous formations were locally mobilized, quite close to the epicenter (such as at Castelgrande, Nusco, Valva, Bella-Muro Lucano, Balvano-San Gregorio Magno etc.). More frequent and widespread were mass movements on Tertiary flysch (such as at Laurenzana, Sant'Angelo le Fratte, Teora, Oliveto Lucano etc.) and on Pliocene-Quaternary deposits (such as at Bisaccia, Avigliano, Tricarico, Accettura, Balvano, Lioni, etc.).

Particularly frequent among seismically-induced landslides were huge block slide phenomena that are generally bounded by ground fractures (Fig. 3) which in many cases continue also beyond the sliding body, sometimes reaching the opposite slope (Dramis *et al.*, 1982). These phenomena, which generally experienced a sudden activation and show a long body (up to 2-3 Km), often being associated with other gravitational phenomena (most of an earth flows

Fig. 2. Earthquake induced ground fracture cutting a house

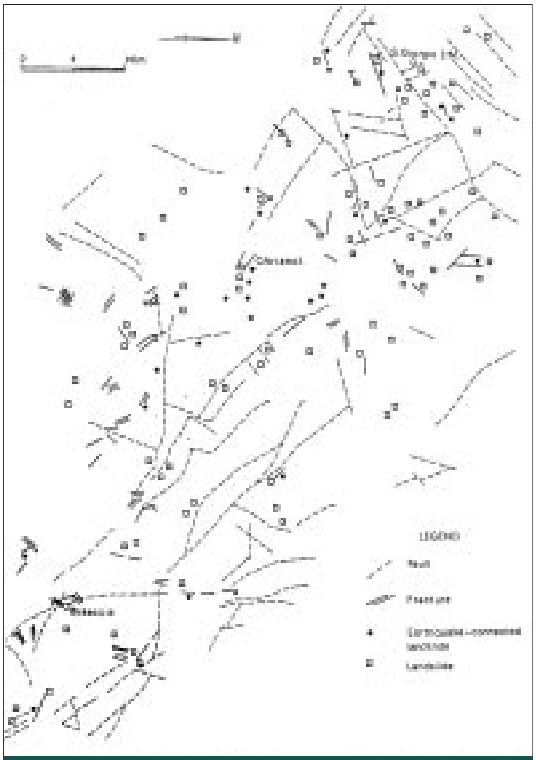

Fig. 3. Pattern of fractures and landslides induced by the 1980 Southern Italy earthquake between S. Giorgio la Molara and Bisaccia

and subordinately, mud flows and rotational slides). Block slides whose movement direction showed significant differences from the slope gradient were also recognized. Lateral spreads and deep-seated slope deformations were diffusely recorded too, as well as translational slides, earth flows and topples.

Cases of huge landslides induced by the 1980 earthquake in southern Italy

San Giorgio la Molara

Among the several landslides caused by the shock, particularly significant looks to be the huge phenomenon that occurred near the town of San Giorgio la Molara (not very close to the epicenter), that moved a few minutes after the earthquake, causing displacements of some tens of meters.
It was a more or less a global reactivation of a some 3 Km long dormant movement interesting pelitic-arenaceous terrains that also in the past (as in 1688, 1805 and 1930) reactivated only as a consequence of strong earthquakes (Dramis *et al.*, 1982).
In the neighboring area, along the Tammaro River (Fig. 4), several other phenomena of slope instability and deformation were recorded (Genevois and Prestininzi, 1982) on Miocene sediments (gray and variegated marls and argillites with calcarenitic beds), among which a big block slide (whose upper portion moved as a huge earth flow) and several slump-earth flows (in the upper part of the slopes), translational and rotational slides and earth flows (in the lower part). In the same area, many fractures (among which one can be followed for some 4 Km) and counterslope ponds were also recognized.

Fig. 4. Tammaro river bridge deformed by earthquake induced landsliding.

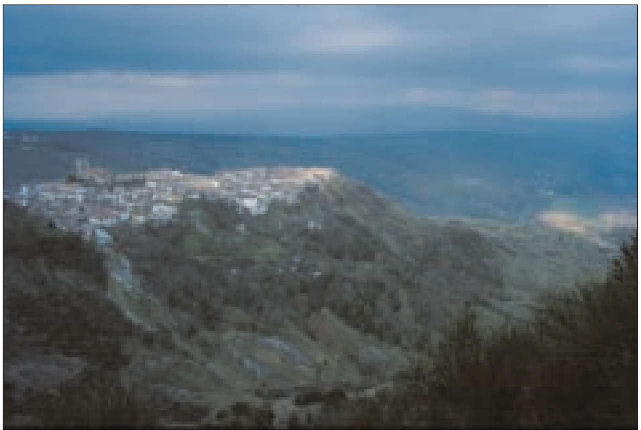

Fig. 5. View of Bisaccia cut by a gravitational scarp

Bisaccia

Another important mass movements was the multiple deep-seated sliding that involved most of the town of Bisaccia (Crescenti *et al.*, 1984), located quite far away from the epicenter (the earthquake here reached only a VII MCS intensity) and built up over a clastic formation of a Quaternary age (polygenic conglomerate with abundant sandy-clayey matrix) overlying strongly disturbed allochtonous clays (Miocene "Varicolori" clays) and divided by a some 40 m high escarpment (Figs. 5-6). Along the slopes, modeled in the clayey deposits, counterslopes and depressions, often fined by alluvial and colluvial material, are frequent. This complex phenomenon was also the reactivation of a dormant one that in the past had shown recurrent activations in correspondence of major earthquakes. Also most of the ground fractures recognized along the sliding body (including buildings) experienced in the past recurrent seismic reactivation, as testified by a detailed mapping of surface effects carried out by the municipality immediately after previous events (1930 and 1962).
Damage to buildings was not extreme because of the typology of the movement (many artefacts were simply rotated together with soil wedges but not destroyed). It has to be pointed out that in Italy several other examples exist of villages and towns built .over the body of dormant landslides that in the past have been shown to reactivate during earthquakes.

Trevico

Quite different is the mass movement recognized in Trevico (Carton *et al.*, 1987), typical of places where solid bedrock (such as limestone, sandstones etc.) outcrops and they are characterized by a high value of relief (mountainous areas). It is a deep-seated lateral spreading (Figs. 7-8-9) affecting conglomerates overlying clays and consisting in the deepening (up to some decimeters) of a small graben-like depression (some 50 m long, about 15 m wide ad 2 m deep) located on the top of an hill. Surficial ruptures look to be related to deep-seated shearing surfaces and the trench formed because the ridges spread aside; it was not directly generated by tectonic phenomena but is of a gravitational origin (Dramis and Sorriso-Valvo, 1983.
As also hypothesized for other similar phenomena, it is not probable that the movement could be due to oriented acceleration only; it seems more likely that other mechanisms (probably

connected with the presence of water) contributed to the genesis of this deep-seated gravitational deformation. Also this movement in the past experienced recurrent reactivation in connection with seismic activity. graben-like features like this one, and having the same step-like evolution, have also been observed elsewhere, such as in Algeria after the El Asnam earthquake (7.3 Ms) in 1980 (Dramis and Sorriso-Valvo, 1983).

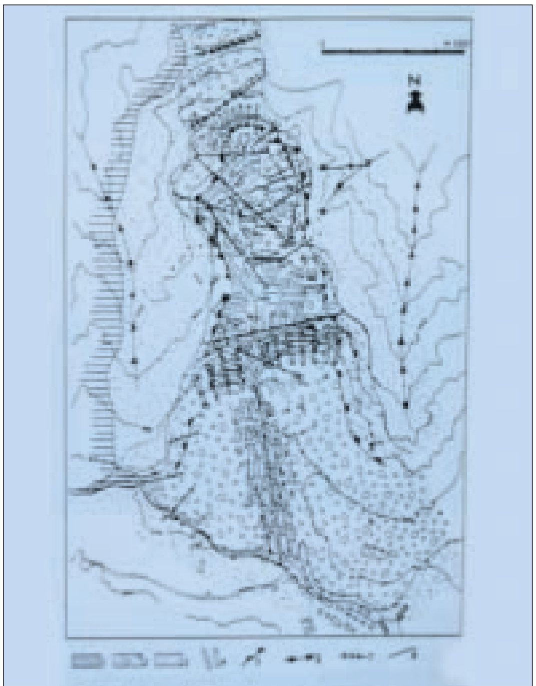

Fig. 6. Simplified geomorphic map of the Bisaccia area:
1 - "Varicolori" clays;
2 - conglomerates;
3 - debris;
4 - main landslide escarpment;
5 - erosional scarps retreating by mass movement;
6 - stream erosion;
7 - trench;
8 - fault or fracture (after Crescenti et al. 1984).

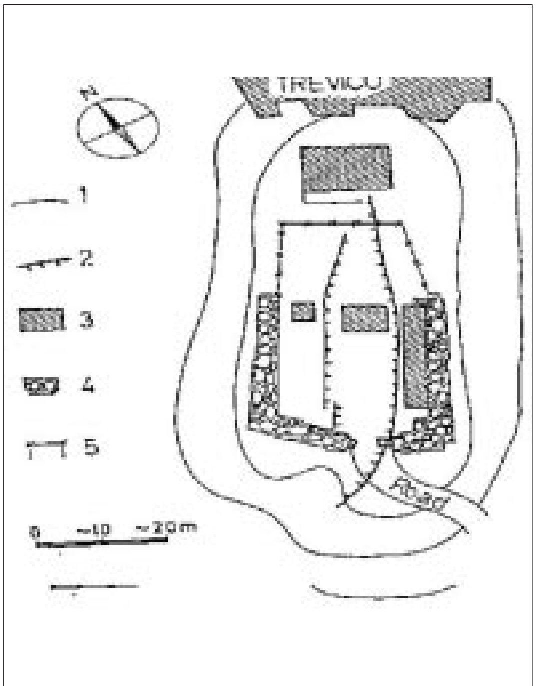

Fig. 7. Sketch of the graben–like depression:
1 - approximate contour line;
2 - trench scarp;
3 - building;
4 - castle ruins;
5 - fence (alter Dramis and Sorriso- Valvo, 1983).

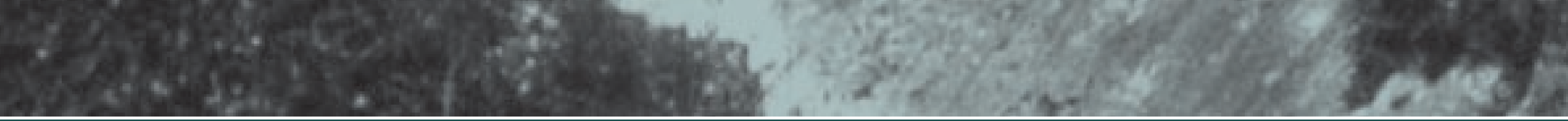

Fig. 8. A ground fracture cutting the stairs of the meteo station at Trevico

Fig. 9. Scarplet along the border of the graben-like depression within the Trevico earthquake reactivated lateral-spreading

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Slope movements triggered by the 1980 Irpinia Earthquake

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Slope instability phenomena have long been a constant feature in the Southern Apennines of Italy, with earthquakes and meteoric events representing the main triggering factors. Landslides often have resulted in dreadful losses both in economic terms and in terms of human lives. In particular, history of Irpinia has always been accompanied by catastrophic seismic events that therefore played a significant role in contributing to determine the low socio-economical development of the region, ehich is essentially based on rural economy. The occurrence of these earthquakes, affecting an environment which was already characterised by widespread landsliding due to local geology and tectonic history, exhacerbated the predisposition of the territory to slope movements activity.
The outcropping lithologies in Irpinia can be grouped as follows:

1) Alluvial deposits (Pleistocene - Holocene). They are present along the courses of the Sele and Ofanto Rivers and their main tributaries.
2) Conglomerates, sands and grey-blue clays of Lower-Middle Pliocene. These rocks, representing regressive successions, crop out on both sides of the Ofanto River, and form the hills on which several towns are located.
3) Shales, marls, chert limestones, sandstones, varicoloured clays, and clayey-marly-arenaceous flysch of the Molise - Lucanian basin (Upper Cretaceous - Paleocene). The flysch successions constitute the majority of the outcropping rocks, and show prevailing clayey lithofacies. These materials, with marked heterogeneity and anisotropy induced by a long geological and tectonic history, are defined in the current geotechnical literature as "structurally complex formations" (Esu, 1977). In relation to their peculiar mechanical and geotechnical behaviour, they are very susceptible to macroscopic slope deformation and to mass movement in general.
4) Limestones, dolomitic limestones and dolomites (Trias - Cretaceous). Carbonate terrains form the Picentini Mountains and the Mt. Ogna - Mt. Marzano ridge.

Morphology of this portion of the Southern Apennines is strongly dependent on structural and neotectonic evolution of the study area: two different landscapes are recognizable, one typical of the carbonate domains, the other of the terrigenous materials. A carbonate landscape, with high energy relief, occurs along the eastern and western margins of the Sele valley, characterized by steep and sometimes subvertical slopes; it has a hydrographic network whose rectangular pattern testifies strong structural control. Water courses develop following the network of faults and fractures, and they are often entrenched as a consequence of the rapid Plio-Quaternary orogenic uplift, which, in the Picentini area, is on the order of several hundred meters (Capaldi *and others*, 1988). The areas where carbonate materials crop out are only marginally influenced by mass movements; these include mostly rockfalls and topples limited to the steep slopes bordering the calcareous massifs (Fig. 1).
The landscape carved in the terrigenous deposits is characterized by low-medium acclivity slopes, and by widespread creep and landslide phenomena. The hydrographic network shows a dendritic pattern only partly controlled by tectonic discontinuities. In this landscape it is possible to identify several orders of terraces and remnants of ancient erosional surfaces formed as a consequence of different phases of rivers downcutting.
Mass movements represent the main geomorphic process active in the area. In fact, landslides varying in age, dimensions and state of activity, are present on most slopes. Complex landslides, starting as rotational or translational slides in the upper portions and evolving to flow in the medium-lower sectors, are widespread. Main scarps of landslides are often located in

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the proximity of the contact between the flysch and carbonate deposits; the presence of multiple coalescing crowns testifies to the occurrence of several episodes of movement. The larger landslides are characterized by elongated bodies, which reach the base of the slopes; gravitational phenomena of small dimensions, but with more evident activity, are often superimposed on these, or develop at their margins.
The 23 November 1980 earthquake triggered numerous slope movements in the flysch terranes cropping out in the upper valley of the Sele River, and in the Ofanto River as well. The majority of these phenomena were reactivations of ancient or dormant mass movements; the spatial distribution of slope failures, which are mainly of the slide-flow type, appears to be strongly dependent on factors such as the presence of old landslide masses, the structural and hydrogeological setting, and the direction along which the horizontal components of the seismic ground motion were greatest.

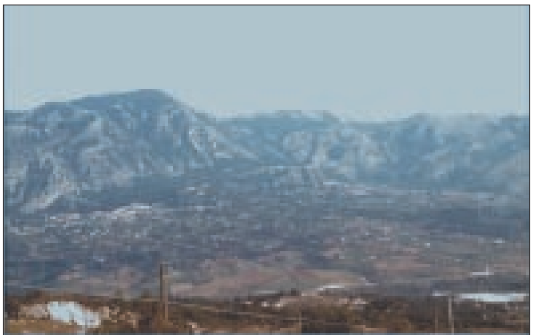


Fig. 1. Mt. Valva – Mt. Marzano – Mt. Ogna ridge, bounding the eastern side of the upper valley of the Sele River. From left to right, the towns of Valva, Collianello (at the top of the prominent rocky spur), and Colliano are visible. One of the rockfalls triggered by the 1980 earthquake is shown by the white scar and path in the carbonate slope uphill from Collianello. Note the very different landscape between the carbonate mountains and the valley carved in flyschioid (mostly clayey) materials.

The Calitri Landslide

The Calitri hill (Fig. 2) is characterized by a Pliocene regressive succession including clays and silty grey-blue clays, soft sandstones, sands and conglomerates. In the middle-lower portion of the hilly relief as well as in some areas of the town scaly clays outcrop. They consist of a chaotical sequence of dark grey clays with reddish and green patches and stone-inclusions composed of marly calcareous rocks and calcirudites (Red Flysch or Varicoloured Clays). The relationships occurring between the Varicoloured Clays and other formations are presumably of tectonic origin. However, the detection of their exact nature is by no means easy, due to the occurrence of countless landslides.
Within the described lithotypes, silty-marly clays interbedded with sandstones and Varicoloured Clays appear considerably fissured and deformed. This contrasts significantly with the relatively less disturbed structural setting of Pliocene grey-blue clays.
The area surrounding Calitri has been historically hit by landslides which are periodically reactivated by major meteoric and/or seismic events (HUTCHINSON & DEL PRETE, 1985; BUDETTA *and others*, 1990).
The widespread failures are closely related to the occurrence of clayey lithologies, poor geotechnical characteristics (chiefly Varicoloured Clays), countless tectonic discontinuities, highly-permeable materials (conglomerates and sandstones) overlying pelitic deposits (Pliocene clays and Varicoloured Clays), and markedly steep slopes. The most landslide-prone sections coincide with outcrops of Varicoloured Clays or their contact zones with the overlaying lithotypes.
Calitri is well known in the recent Italian engineering geology literature as the site of one of the largest deep-seated mass movements remobilized by the 1980 Irpinia seismic event (Fig. 2). The Calitri landslide (approximately 850 m long and up to 100 m deep), located at a distance of less than 20 km from the 1980 epicenter, has been extensively studied by HUTCHINSON & DEL PRETE (1985), and by CRESPELLANI *and others* (1996).
The reactivation of the Calitri landslide on November 23rd, 1980, destroyed or seriously dam-

Fig. 2. Calitri hill, from the Ofanto river valley. The 1980 Calitri landslide is still recognisable in the center of the photo.

aged over 100 houses and caused the death of 7 people. Within the body of the Calitri landslide, HUTCHINSON & DEL PRETE (1985) distinguished four main elements:

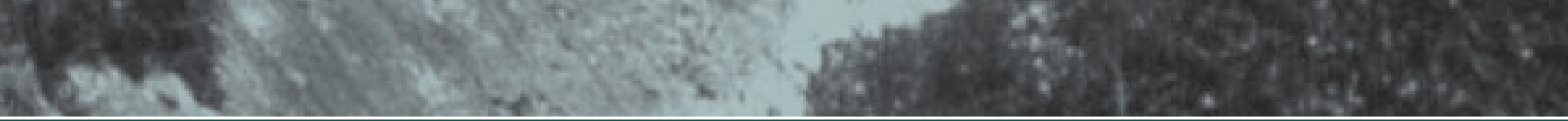
1) a major, deep-seated slide, with a volume on the order of 20 x 10^6 m^3, occupying the upper two-thirds of the valley slope, with its main scarp in the old town. It shows a part-rotational, part-translational character, and its depth has been estimated at about 100 meters;
2) associated secondary retrogressive slides around the rear scarp of the main slide;
3) shallow slides in the toe area of the main slide, which supply material in the head area of the fourth element:
4) shallow translational mudslides which form part of the colluvial apron extending down to the Ofanto River.

According to eyewitness accounts reported by HUTCHINSON & DEL PRETE (1985), cracks appeared along the main scarp about at the time of the main earthquake shock; slow downward movements of the ground then proceeded for several hour to produce the eventual, near-vertical displacements of 1 to 2 meters in that vicinity. Significant movements of the main slide and its secondary slides appear to have been essentially completed within about 24 hours.
At present, the 1980 Calitri landslide shows only local and fairly superficial movements. However, some damage to structures present within the affected area indicates much deeper deformations. Superficial phenomena are generally seasonal, and provoked by major spring-time meteoric events. Many other slope movements affect today the Calitri municipality: most of them are related to outcrops of Varicoloured Clays and to their difference in permeability with overlying materials. In many cases, active landslips are also related to anthropogenic activities on the slopes. In recent years, however, landsliding activity seems largely reduced and chiefly dependent on meteoric events (PARISE & WASOWSKI, 1998). As far as the great Calitri landslide is concerned, it is currently affected by superficial landsliding and erosional phenomena, which, given their location in the middle-lower section of the main body, might prove destabilizing in the long run.
Despite the typically slow evolution of mass movements and, therefore, corresponding low risks involved, the space distribution of failures conditions directly the town development and the construction of new road networks in the neighbouring areas.

The upper Sele river valley

The largest slope movements triggered by the 1980 Irpinia earthquake in the Sele valley are the Buoninventre landslide, near Caposele, and the Serra dell'Acquara landslide, near Senerchia.
The **"Buoninventre" landslide** (named after the main locality affected by the slide, in the municipality of Caposele) is one of the largest mass movements triggered by the 23rd November, 1980 Irpinia earthquake (BUDETTA, 1983; CARRARA *and others*, 1986; COTECCHIA *and others*, 1986). The site is located in the upper reaches of the Sele river, at a distance of less than 10 km from

the epicenter of the earthquake: the area is geologically characterized by outcroppings of structurally complex formations severely affected by landsliding, whose main remobilizations appear to be related to meteoric and/or seismic events, or to anthropic actions.
The Buoninventre landslide is a complex slope movement, with length of about 3 km, made by multiple rotational and translational slides, whose deposits feed a wide flow-body. With an estimated volume of about 25 x 10^6 m^3 (COTECCHIA *and others*, 1986), the slide involves mainly old landslide materials, and, in addition, intensely folded and jointed rocks of turbidite origin (alternations of calcarenites, sandstones, marly limestones and clays). The chaotic setting of most of the outcropping lithologies, together with the high susceptibility to slope movements, derive from the complex geologic history of the area.
The availability of multi-year aerial photo coverage (1955, 1981, 1990 and 1995) in appropriate scale (ranging from about 1:30,000 to about 1:8,000) helped in assessing the morphological changes occurred in the last 40 years at Buoninventre site. Each stereopair of aerial photos was interpreted and a geomorphological map produced for each year. Hummocky topography, changes in the drainage surficial network, scarps, cracks, uphill facing areas, ponds were among the main features used to recognize and delimit areas with major degree of mass movements.
Comparison of the landslide activity maps in different years pointed out at Buoninventre site to an areal frequency of active landsliding which increased more than two and a half times following the 1980 seismic event. This increase is very similar to that registered in the Calitri area (PARISE AND WASOWSKI, 1999), which is not surprising considering that the epicentral distances of these two sites were comparably short (within 20 km).
Recent field obervations, including inclinometer measurements (PARISE & WASOWSKI, 1996), demonstrated that the main slide body at Buoninventre is stable. The earlier stabilization of the Buoninventre mass movement is most likely linked to the human activity in the area. In fact, in the mid-eighties, several large diameter drains were realized within the landslide body. In addition, the area affcted by the movement was shortly regained as an agricultural land. This meant a construction of an efficient network of simple surficial drainage works, and, importantly, their continuous maintenance.
Like in the Calitri case, the examination of the evolutionary trend of the Buoninventre landslide area reveals the sharp increase in mass movements activity related to the 1980 earthquake. Moreover, the overall landslide areal frequency (active and inactive movements) remained about constant in the years following 1980, which again indicated the persistency of the geomorphic changes caused by the seismic event.
The town of **Senerchia**, located on the west side of the Sele valley, is built on a Middle Quaternary detrital slab, lying on the boundary between the Mount Cervialto water-bearing carbonate horst and the Unità Sicilidi occupying the Sele graben. The geological and structural setting of the area, with the tectonic contact between the carbonate massif and the flysch deposits, where the latter plug the large aquifer in the limestones and dolomites, are the main factors of the widespread presence of landslides on the eastern slope of the Picentini Mountains. Significant surface faulting was observed along the Quaternary normal fault which border the mountain front (Figs.4 and 5). It is worth noting that the old village of Senerchia was located just across this normal fault.
Indeed, Senerchia was very badly hit by the 1980 earthquake. There was serious loss of life owing to the collapse of the whole southern part built on the variously faulted and dislocated detrital slab. In addition, the slab has been affected on the southern side by one of the largest mass movements reactivated by the 1980 earthquake, the Serra dell'Acquara mudslide (MAUGERI *and others*, 1982). Following the main shock on 23rd November 1980, the mudslide was gradually remobilized over a period of a couple of weeks. The subsequent shocks reactivated a 2,500 m long, and up to 500 m wide mudslide mobilizing a mass of about



28 x 10^6 m^3. The slip surface lies entirely in the pelitic-flysch sequence of Unità Sicilidi, at maximum depth of 33 m.
The phenomenon started from upstream and slowly spread downstream. In the initial phase the material slipped almost as a single mass. The main moving mass, on which local secondary movements of remoulded muddy material were superimposed, possibly came to exert pressure on the pre-existing zone of accumulation, causing an uplift of about 20 m along the line of contact. Remobilization of the zone of accumulation thus occurred about a month after the main shock. The weakness of the slope where the mass movement started derives from the structural setting, characterized by the presence of several tectonic discontinuities, and from the unfavourable hydrogeological situation which occurs upstream along the tectonic contact between the carbonate aquifer and the aquiclude formed by the flysch materials: the barrier springs that occur there pour out enormous quantities of water (200 l/s) into the unstable basin below.
Comparison of aerial photographs taken before and after the 1980 earthquake clearly reveal the reactivation of a landslide mass that had been dormant at least for the last 40 years, as confirmed by the age of several rural houses destroyed. However, it could well be that the slide had remained dormant even longer, so that probably it is not wrong to go back in time to the 1930 earthquake for its last movement preceeding the 1980 seismic event. What is certain, however, is that no appreciable remobilization occurred over the last forty years before 1980, even though several periods of very heavy rainfalls took place.

Fig. 3. Surface faulting along the bedrock fault scarp near Senerchia: reactivated fault plane affecting striated, poorly cemented, eboulis, and displacement of the roadway. Photo taken on 04.04.1981, at close distance along the road behind the village; courtesy of Prof. Albert Pissart.

Fig. 4. Surface faulting along the bedrock fault scarp near Senerchia: free-face at the base of the limestone fault plane. Photo taken on 04.04.1981, at close distance along the road behind the village; courtesy of Prof. Albert Pissart. Note the close similarity with the free-face produced during the 1997 Colfiorito earthquakes at the Costa bedrock fault scarp (see 3. Camerino (MC) - Colfiorito (PG), Fig. 7).

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