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LARGE SCALE GRAVITATIONAL PHENOMENA IN SOUTHERN-CENTRAL ITALY: GEOMORPHOLOGICAL FRAMEWORK, TRIGGERING FACTORS, TEMPORAL EVOLUTION, AND IMPACT ON HUMAN SETTLEMENTS

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F. Dramis, A. Prestininzi

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M. Del Prete, B. Gentili, F.M. Guadagno, P. Tacconi

Field Trip Guide Book - B08

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Pre-Congress **B08**

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Front Cover:
A debris flow tongue from the May 1988 Sarno catastrophic event (photo by F.M. Guadagno).

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Landslides in Italy

F. Dramis, A. Prestininzi

Introduction

Landslides are widespread in Italy due to the nature of the bedrock, which is largely made of soft rocks or densely-fractured hard rocks, the rugged topography and the frequent recurrence of high magnitude triggering factors, such as seismic shocks, and extreme rainfall events (Agnesi *et al.* 1982; Mazzalai, 1980; Canuti *et al.*, 1988; Catenacci, 1992; Dramis *et al.*, 1998).

In relation with the above-mentioned features, different types of landslides are produced, even if their spatial distribution and density are not homogeneous all over the Italian territory (Cotecchia, 1978; Canuti, 1983; Urciuoli, 1988; Dramis *et al.*, 2002). Figures 1.1 and 1.2 show distribution models of land susceptibility to fast moving and slow moving landslides in Italy, as obtained by hierarchic geomorphometric analysis (Bisci *et al.,* 2002; Bisci *et al.*, in preparation).

Deep-seated gravitational slope deformations (mainly lateral spreading and sackung phenomena) and large-scale landslides are both frequent in Italy (Crescenti *et al.*, 1994).

As far as climatic conditions are concerned, the Italian peninsula is often affected by the influence of humid-warm air masses coming from the west and south, to which heavy rainfall events (up to more than 2000 mm/year) are related. Long lasting precipitation (up to more than 500 mm in 72 hours), to which a large number of landslides and heavy floods are related, represent recurrent phenomena in the fall season (e.g. Polesine, 1951 and 1957, Reggio Calabria, 1953, Florence and Venice, 1966, Piemonte-Val d'Aosta, 1993, 2000). Also short-lived intense rainfall can locally trigger catastrophic landslides (e.g. Salerno-Amalfi, 1954; Mt. Etna, 1995, Versilia and Friuli, 1996; Sarno, 2000).

The high population density of mountain valleys, piedmont belts, and the location of numerous urban settlements on top of hills modeled in soft bedrock (Dramis *et al.*, 1993), emphasizes the socio-economic relevance of landslides, which often cause heavy damage and loss of human life. Well-known catastrophic landslides in Italy were those of Vajont (Müller, 1964), Ancona (Crescenti *et al.*, 1983; Coltorti *et al.*, 1985; Crescenti, 1986; Cotecchia, 1997), Valpola (Govi and Turrito, 1992; Dramis *et al.*, 1995) and Sarno (Celico and Guadagno, 1998;

Figure 1.1 - Distribution model of land susceptibility to fast moving landslides in Italy (after Bisci et al., in preparation).

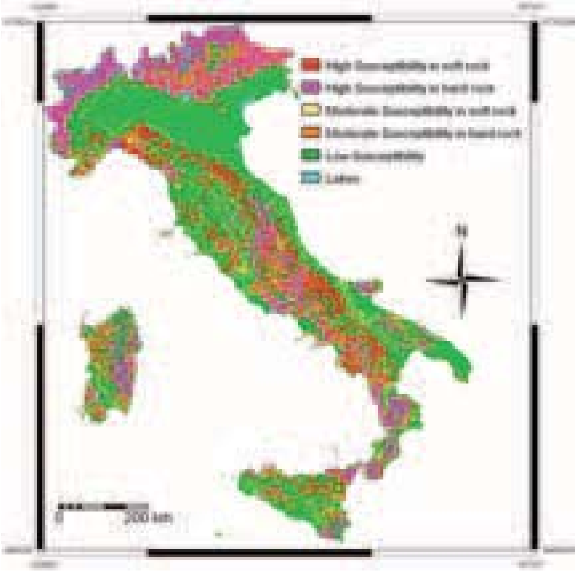


Figure 1.2 - Distribution model of land susceptibility to slow moving landslides in Italy (after Bisci et al., in preparation).

Guadagno *et al.*, 2000).

The damage caused by landslides and floods in Italy may be estimated in 1000-1500 € per year; according to a report issued by the Ministry of Public Works, from 1945 to 1990, landslides killed 2447 people, 32% of the total amount of victims caused by natural catastrophes. A large number of landslides involve urban settlements, with a significant risk for buildings and residents. In 1970, 1804 inhabited centers were officially listed as unstable, and 304 of them were compulsorily evacuated.

In fact, urban settlements, villages, or single houses are located in areas with high hazard levels, such as dormant landslide bodies or alluvial fans built up by recurrent debris/earth/mud flow. The reasons for these inappropriate locations are, only in part, due to mistakes made in ancient times, but are, in fact, in many cases, the result of recent urban developments and building activities, many of them carried out in the ignorance of any possible geo-environmental constrains, or even without any legal permission. Moreover, the repeated amnesties for infringements of building regulations, have simply resulted in the transferring of financial responsibilities from the builders to the national community.

However, only in recent times the importance of geo-environmental hazards has began to be fully acknowledged: in the 1960s, the National Research Council (CNR), created four Institutes for the Protection against Hydrogeological Hazard (IRPI) and, in the 1970s, the constitution of the Ministery of Civil Protection brought a further increase of activity in this field; a few years later, the CNR research project “Conservazione del Suolo” (Soil Conservation) started; in 1985, the Ministry of Civil Protection constituted the National Group for the Defense against Hydrogeological Catastrophes, which, in turn, launched a research program on inhabited centers affected by landslides and, in 1991-1992, a first systematic analysis of landslide distribution at a national level (AVI - Italian Project on Vulnerable Areas).

After the heavy sequence of catastrophic flooding and landslide events which struck Italy in the last decade (Piemonte 1994, Versilia 1996, Sarno 1998, Soverato 2000, Piemonte-Valle d’Aosta 2000, 2001), causing a large number of victims and over 50 billion euros-worth of damage, a significant contribution to the assessment of hydrogeological hazard in Italy was provided in 2000 by the Italian government with new environmental regulations (Law n. 365/2000, known as the “*Decreto Soverato*”). In this context, several River Basin Authorities have invested financial resources to produce landslide inventories, as well as recurrence (30, 50, 200 years) models of triggering rainfall and flooding events. These data are used to produce detailed maps of landslide and flooding hazard, in order to assess the risk levels of built-up areas and future hazard development areas.

The geological framework

The geological setting of Italy mostly represents the result of events which, in consecutive phases, originated the Alps and the Apennines. Both these chains were built up by the superimposition of various tectonic units. Most of the Alpine belt was formed during the Cretaceous - Eocene; successively, starting from Upper Oligocene – Miocene, the Apennines were formed. Compressional tectonics affected these latter mainly during the Miocene - Pliocene, migrating from the Tyrrhenian to the Adriatic sea. This phase was followed by both uplift and extensional tectonics; this latter produced block morphostructures to which intramontane tectonic depressions and wide fault escarpments are connected. Starting from the Lower Pleistocene, the Italian peninsula has been involved in a more generalized uplift (Dramis, 1992; D’Agostino *et al.*, 2001; Bartolini *et al.*, 2003). As a consequence, a general deepening of rivers has occurred, generating narrow deep valleys with high-steep slopes, favorable to landslide activation. In high relief areas, modeled on hard bedrock, deep-seated gravitational slope deformations (Sorriso-Valvo, 1979; Dramis *et al.*, 1985; Dramis and Sorriso-Valvo; 1994; Dramis *et al.*, 1995), were also frequently triggered. At present, most of the peninsula is still involved in extensional tectonics, as proved by focal mechanisms of earthquakes (Ritsema, 1970; Favali and Gasparini, 1985).

As testified by historical testimonies, oral traditions, and direct observation, a large number of landslides were triggered in connection with earthquakes (Oddone, 1930; Cotecchia *et al.*, 1969; Govi, 1977; Colombetti *et al.*, 1979; Cotecchia, 1981; Dramis *et al.*, 1982; Crescenti *et al.*, 1984; D’Elia *et al.*, 1985; Carton *et al.*, 1987; Prestininzi and Romeo, 2000).

Quaternary climates and human activity

Landslide susceptibility is also largely affected by weathering, erosion, and sedimentation processes induced by past climates.

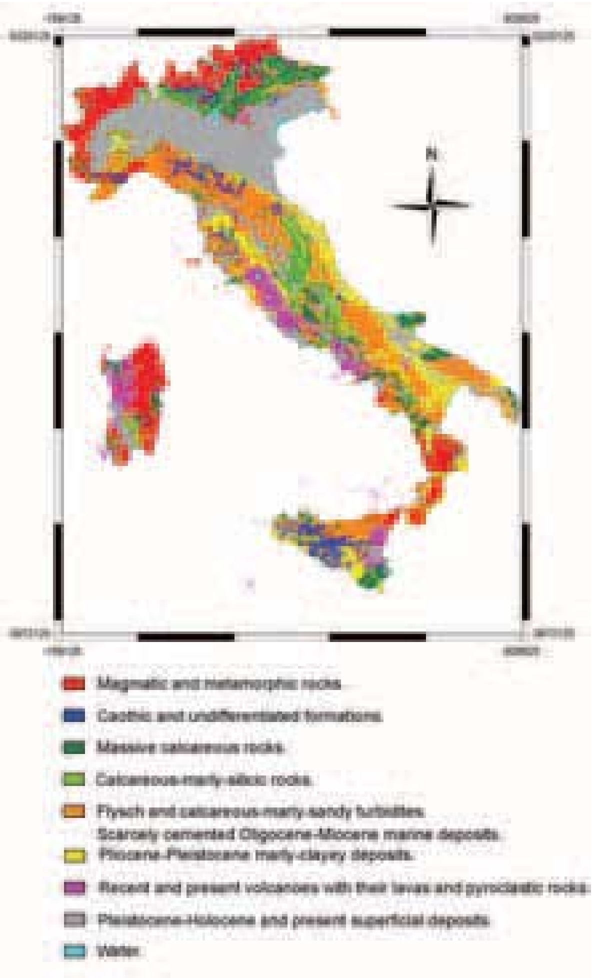


Figure 1.3 - Distribution of the main lithological complexes in Italy

During the Quaternary, climatic changes, along with uplift, produced successive conditions favorable and unfavorable to river valley deepening, thus establishing different slope stability conditions. The reduction of vegetation cover, connected to cold and arid climates, favored soil erosion and physical weathering; slopes were therefore covered by thick debris layers, moving downwards by rill erosion and superficial mass movements. Overloaded river water produced thick alluvial fillings, thus stabilizing slopes. New vegetation covers, connected with climatic amelioration, retarded soil erosion, allowed fluvial water, no longer loaded, to incise the previously-deposed materials and then, continuing the uplift, to deepen in the bedrock, thus inducing slope instability.

Many of the large scale landslides owe their first activation to the Holocene deepening of river channels (Dramis *et al*., 1992). Some of them show a step-like evolution, with short reactivation phases separated by long periods of inactivity. Postglacial alluvial filling of valleys largely stabilized those movements during the Holocene (Cotecchia, 1978).

After the retreat of Pleistocene glaciers, along the Alpine arc, conditions particularly favorable to landslide activation were established; the lack of lateral support to slopes originated collapses in moraine materials and in the bedrock, especially when this latter was fractured by tectonics and deformed by ice pressure (Panizza, 1973). Presently, similar phenomena are still very frequent, often representing high hazard situations. Moreover, in recent years, the role of degradation in triggering landslides in high mountain areas has been pointed out (Zimmerman and Haeberli, 1998; Dramis *et al*., 1995; Harris *et al*., 2003). Minor phases of erosion and filling, connected with climatic variations which occurred in historical times, also influenced landslide activity (Veggiani, 1981).

Human activity, which for a long time has been modifying the Italian territory, plays a primary role in landslide triggering (Canuti *et al*., 1979). Both modifications of slope geometry (due to earthworks, mining, and construction), and local enhancement of pore pressure in bedrock and overburden materials (due to water infiltration into the ground from water pipelines and sewerage leakage), are responsible for widespread slope instability in hilly areas (Dramis *et al*., 1993). Very recent river bed deepening, sometimes up to more than 10 meters, connected to both quarrying into river beds and other human activities such as dam construction, reafforestation etc. (Cocco *et al*., 1978; Conti *et al*., 1983) have triggered (or reactivated) several landslides (Dramis *et al*., 1979).

Geological factors of slope instability

The occurrence and frequency of different types of landslides are closely related to the mechanical properties of the outcropping rocks and eluvial-colluvial materials.

Taking into account landslide susceptibility, eight main lithological complexes may be recognized (Figure. 1.3).

a) Magmatic and metamorphic rocks

Different mineralogical and petrographical compositions make these rocks react differently to weathering. They are generally only modestly involved in gravitational phenomena, with the exception of rock falls (on escarpments) and (local) rock slides/avalanches. On high slopes, deep-seated slope deformations are frequent (Genevois and Prestininzi, 1979; Sorriso-Valvo, 1979; Crescenti *et al.*, 1994). At high elevations, frost shattering causes the emplacement of thick talus deposits at the escarpments toes.

Mountain slopes modeled in schists are locally involved in rotational and translational slides.

b) Caotic and undifferentiated formations

During geological times, these clayey rocks (which are widespread all along the Apennines) were strongly affected by tectonic and tectonic-gravitational deformations, which deeply disturbed their original structure, worsening their already poor mechanical properties. Therefore, this complex shows the highest frequency of landslide, even over gently dipping slopes. There rotational landslides and, less frequently, translational landslides, (which often make the transition into slow moving mud/earth flows at their toes), are widespread. These phenomena generally evolve slowly, even though they can experience sudden accelerations as a consequence of heavy and long-lasting rainfalls or earthquake shocks.

c) Massive calcareous rock

These rock are often interested by closely-spaced joint sets, and are locally affected by rock falls and block-slides, whose geometry is strongly controlled by structure. Such phenomena are common on high steep slopes (such as, deep narrow valley sides, coastal cliffs and fault escarpments). They are also frequent along the edges of hard rock slabs overlaying soft rocks, and affected by lateral spreading phenomena (e.g. silts and clays) (Manfredini *et al.*, 1980).

d) Calcareous-marly-silicic rocks

This complex is made of stratified units, whose lithology ranges from micritic limestones to jaspers, siliceous limestones, marly limestones, marls, and argillites. Their stability can vary according to lithological characteristics, jointing, structure, and occurrence of clayey interlayers along which shear planes can be generated. Lithoid materials show a situation very similar to the one described for the previous complex, while marly-clayey units, which are often covered by weathered materials up to several meters thick, appear to be more frequently affected by landslides. Those latter materials were mobilized during past colder periods by solifluction and slope wash processes and also because of, more recently, agricultural activity.

e) Flysch and calcareous-marly-sandy turbidites. Scarcely cemented Oligocene-Miocene marine deposits

The units of this complex are made up of alternations of materials differing in lithology, grain size and cohesion. Connected to them, a rough landscape with high reliefs and steep slopes, is generally found.

Landslides are frequent, varying in their typology according to slope lithology, structure, and geomorphological setting. Particularly unstable are the alternations of sandy and clayey layers; these latter, in fact, constitute potential slipping surfaces along which translational slides frequently occur, being favored by presence of pressured water within the arenaceous layers. Also, rotational slides and slow earth/mud flows are frequent, mainly where pelitic facies prevail, and in areas strongly affected by tectonic activity. Arenaceous lithotypes are much more stable, even though rock falls may occur on steep slopes and escarpments.

Reliefs modeled in Oligocene-Miocene scarcely-cemented formations are often affected by slow mud/earth flows, even though, especially in higher relief areas, translational and rotational slides are not rare.

f) Pliocene-Pleistocene mainly clayey deposits

This group gathers consolidated clayey terrains, affected by the latest compressive phases and uplifted to sometimes high elevations, as well as scarcely consolidated or loose lacustrine materials, affected only by the more recent extensional tectonics. These latter deposits normally constitute low hills, having been uplifted to a minor elevation.

Rotational and translational slides, affecting both bedrock and eluvial-colluvial covers, and often evolving into mud flows, are widespread. Slow-moving earth/mud flows widely involve the eluvial/colluvial covers of hill slopes (Bertini *et al.*, 1984 and 1986). Rock falls locally affect the edges of scarps modeled on arenaceous-conglomeratic. Along the Adriatic and Ionian coastal cliffs, deep-seated slope deformations and large-scale landslides are present (Crescenti *et al.*, 1983; Cancelli *et al.*, 1984; Coltorti *et al.*, 1985; Dramis and Sorriso-Valvo, 1994; Dramis *et al.*, 1995).

Figure 1.4 - The landslide affected towns which will be visited in the field trip.

g) Recent and present volcanoes, with their lavas and pyroclastic rocks

These rocks have very different characteristics, varying from dense massive lavas (sometimes closely fractured by tectonics or cooling), to loose tuff layers. Quaternary pyroclastic layers are particularly affected by various types of landslides, especially where they overlay clayey materials (e.g. withdrawal phenomena affecting the borders of thick tuff slabs (Tommasi *et al.*, 1986; Conversini *et al.*, 1995). A particular condition of instability, due to the presence of quickly weathered and scarcely coherent pyroclastic materials overlying steep lithoid slopes, can generate extremely dangerous earth/mud flows (Celico *et al.*, 1986; Guadagno, 1991; Celico and Guadagno, 1998; Guadagno *et al.*, 2000).

h) Pleistocene, Holocene and present superficial deposits

These materials are very heterogeneous in grain size and clay content; also their distribution is quite various, sometimes leaning against slopes, sometimes being terraced or constituting valley floors and plains. Their stability is strictly connected to their physical characteristics, to those of the underlying bedrock and, most of all, to their morphological position.

In higher relief areas, different types of gravitational phenomena (mainly slides, debris avalanches and, most of all, debris/earth/mud flows) occur (more frequently over crystalline bedrocks), mostly in connection with exceptional meteoric and seismic events. Very frequent are fast-moving landslides which affect moraine deposits, mostly when they overly metamorphic schist rocks. In densely-populated Alpine valleys, debris flows and debris avalanches can assume a catastrophic character, also because built-up areas are often located at the mouth of deep gullies along which the debris moves down (Dramis *et al.*, 2002).

Minor gravitational movements (soil slips) affecting mainly shallow eluvial and colluvial materials along mountain slopes are widely triggered by heavy and prolonged rainfalls (Govi *et al.*, 1985).

The Field Trip

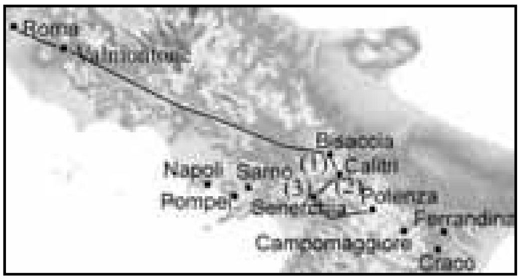
The field trip will include five excursion days (August 15-19), from Valmontone (30 km south of Rome) to Florence (Figure. 1.4). During this period, a number of huge landslides affecting urban settlements will be visited, The first trip day will examine the towns of Bisaccia, Calitri, and Senerchia (in Irpinia, Campania Region), deeply involved in gravitational movements triggered by the November 1980 Southern Italy earthquake. The second day topics will be those related to the unstable towns of Craco, Campomaggiore, and Ferrandina, in the Bradanica Trough (Basilicata Region). The third day will start with a visit to the archeological roman settlement of Pompei, buried by the Vesuvius eruption of 79 A.D., followed by a scientific stop in the area of Sarno, struck by catastrophic mudflows in May, 1998. On the fourth day, two huge landslides mobilitating the urban settlements of the Marche Region (Ancona, on the Adriatic coast, and Montelparo, in the peri-Adriatic Plio-Pleistocene hilly belt) will be examined.

Finally, the last day will be completely spent in examining the historical town of Orvieto (Umbria Region), whose perimetral escarpments are heavily affected by landslide movements.

Field trip schedule

First Day *- 8 a.m. Transfer by bus from Valmontone (Rome) - Centro di Eccellenza CERI to Irpinia-Potenza.*
Bisaccia.
Lunch on the road.
Calitri.
Senerchia.
Dinner and overnight in Potenza.
Second Day *- 8 a.m. Transfer by bus to Bradanica-Pompei.*
Campomaggiore.
Craco.
Lunch on the road.
Ferrandina.
Dinner and overnight in Pompei.
Third Day *- 8 a.m. Transfer by bus to Sarno-S. Benedetto del Tronto.*
Visit to the archeological site of Pompei.
Lunch at Pompei.
Sarno.
Dinner and overnight in S. Benedetto del Tronto.
Fourth Day *- 8 a.m. Transfer by bus to Orvieto.*
Montelparo.
Lunch on the road.
Ancona.
Dinner and overnight in Orvieto.
Fifth Day *- 8 a.m. Orvieto*
Lunch in Orvieto.
Transfer by bus to Florence-end of the excursion.

Field itinerary



DAY 1

From Valmontone (Rome) to Potenza
Gravitational Phenomena Triggered by the November 1980 Southern Italy Earthquake

Introduction

F. Dramis, B. Gentili, G. Pambianchi

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 has been possible to survey directly, with more scientific methods, surface effects of strong earthquakes, also comparing them with instrument records of the shock. In this way it has been possible to understand (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 lithological features are considered, the importance of identifying "engineering geological formations" has to be stressed (Cotecchia, 1978; Canuti *et al.*, 1988); research 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 which are 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

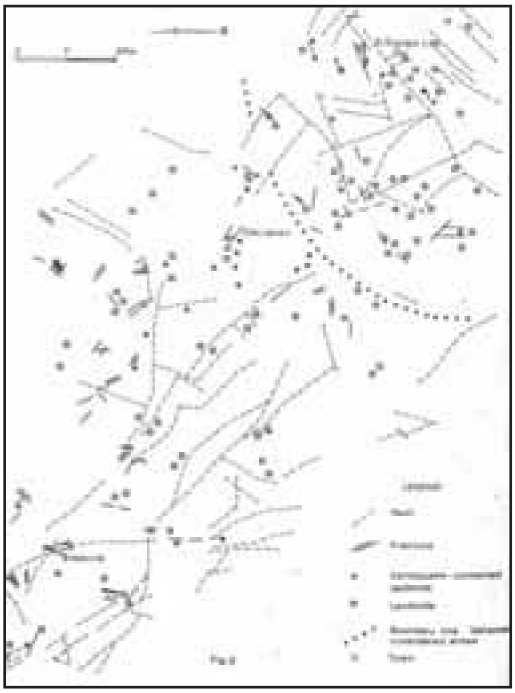


Figure. 2.1 - Earthquake-induced ground fracture in the Ariano Irpino area (after Dramis et al., 1982, modified)

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). These kind of landslides (Tinsley *et al.*, 1985) often involve deep-seated beds too, disturbing very large areas far away from the epicenter.

The 1980 Southern Italy earthquake

F. Dramis, B. Gentili, G. Pambianchi

A strong earthquake (M = 6.8-6.9) struck southern Italy in November 1980 (Westaway and Jackson, 1987), heavily involving a wide portion of the Campania and Basilicata regions, even though it was registered (up to III MCS) in a large part of the Italian peninsula. The earthquake, whose macroseismic intensity in the epicentral area was estimated at around IX-X MCS, produced widespread and severe damage, about 4000 casualties and many injuries.

The source was a dip-slip normal fault with Apennine (NW-SE) strike and SW dip, towards the Tyrrhenian Sea. 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. Co-seismic surface faulting 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).

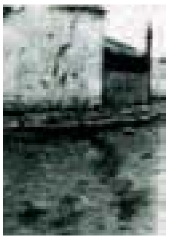


Figure 2.2 Earthquake induced ground fracture, cutting a house

Widespread were surface fractures, both isolated or joined in groups (Figures. 2.1–2.2), up to several kilometers long. Theyw opened in a variety of lithologies (including loose superficial material, such as alluvial deposits and inactive landslide bodies) 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 the 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 crustal levels).

However, the most outstanding phenomena triggered by the earthquake were mass movements of different types (Cantalamessa *et al.*, 1981; Cherubini *et al.*, 1981; Cotecchia, 1981, 1982; Genevois and Prestininzi, 1981; Agnesi *et al.*, 1983; Crescenti *et al.*, 1984; D’Elia *et al.*, 1985; Bisci and Dramis, 1993;

Figure 2.3 - The town of Bisaccia.

Dramis and Blumetti, in press). They were, at least, partially determined by the quite high relief of the area, the poor geotechnical properties of most of the outcropping rocks and the high water content of the terrains (due to heavy rainfall in the days preceding the seismic event).

These movements often appeared to be connected with the above described ground fractures (Cantalamessa *et al.*, 1981; Genevois and Prestininzi, 1981; Dramis *et al.*, 1982; Bisci and Dramis, 1993). 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.).

The Bisaccia landslide

F. Dramis, B. Gentili, G. Pambianchi.

An important mass movement triggered by the 1980 southern Italy earthquake was the deep-seated sliding (Crescenti et al., 1984) that involved most of the town of Bisaccia (Figure. 2.3), located quite far away from the epicenter (the earthquake here reached only a VII MCS intensity). This town is built up over a terrace-like platform made up of a 50 m thick polygenic conglomerate (Pliocene), overlying strongly disturbed allochtonous clays (Varicoloured Clays - Argille Varicolori) of Late Miocene age.

Immediately downslope of this depression, there is a 13th century tower, deeply emplaced in the conglomerate bedrock and strongly tilted upslope: On the clayey slopes bordering the conglomerate platform, counterslopes and depressions are frequent. A 40 m high escarpment divides the town into two parts: the historical center (in the lower sector) and the modern sector (in the upper one) (Figures. 2.4-2.5). At its foot, a 20 m deep trench partly overlying the clayey substratum, is present. The filling materials are quite recent, as testified by the finding of masonry fragments near the bottom by exploration boreholes.

The geomorphological framework of the town area can be interpreted as that of a deep-seated multiple rotational slide, within a mass involved in a slow, lateral spreading process. This complex deformation process caused the fragmentation of the conglomerate platform into blocks more or less turned counterslope as well as that of the high escarpment and the trench at its base (Crescenti *et al.*, 1984).

Figure 2.4 - The high escarpment which divides the old town from the modern one (out of picture, on the left side). Minor escarpments are visible within the built-up area. All of them can be interpreted as landslide scarps.

All along the historical center, coseismic ground fractures and scarplets, mostly corresponding to the margins of the conglomerate blocks, have been recognized. They have experienced recurrent reactivation in the occasion of past seismic events, as clearly testified by detailed maps of surface effects carried out by municipality technicians immediately after the previous strong earthquake events (1930 and 1962).

Damage to the built-up area was generally not extreme, even if widely diffused. In fact, many artifacts were simply tilted together with the underlying conglomerate blocks, without suffering complete destruction. The most relevant disruptive

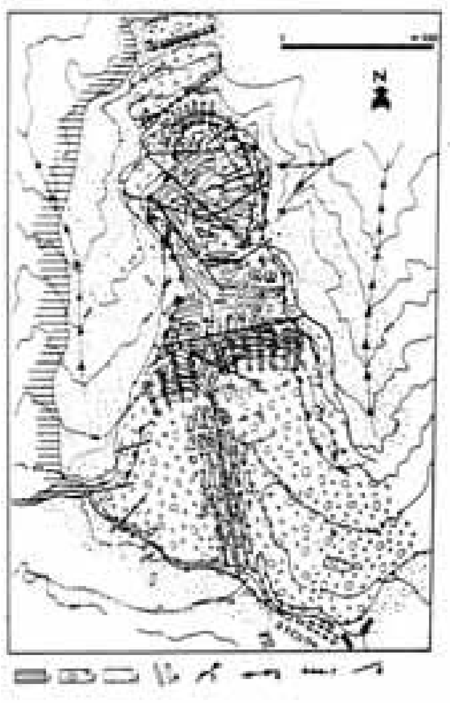


Figure 2.5 - Schematic geomorphological map of the Bisaccia area.
Legend: 1. "varicoloured clays"; 2. conglomerates; 3. debris; 4. main landslide escarpment; 5. edge of the conglomerate platform scarp retreating by mass movements; 6. stream erosion; 7. trench; 8. minor landslide scarps and fractures reactivated by the November 1980 earthquake (after Crescenti et al., 1984, modified).

Figure 2.6 - Damage along a reactivated scarplet.

effects occurred in connection with the earthquake reactivated ground fractures and scarplets (Figure. 2.6) and all along the edges of the conglomerate platform, where a number of buildings collapsed, as a consequence of local falls and slumps.

Visit itinerary

The visit to Bisaccia will include:

Stop 1:

General view of the town from the west (New Bisaccia-Piano Regolatore locality).

Stop 2:

Observations on damaged buildings within the main trench at the escarpment which divides the modern town from the historical one.

Stop 3:

Walk in the historical center to see the earthquake-triggered ground fractures, scarplets and the related damage.

The landslide complex of Calitri

M. Del Prete

The town of Calitri lies in the Southern Apennines on the left bank of the Ofanto River valley, about 100 km east of Naples.

The bedrock of the built-up area consists of sands in lenses within the upper parts of the Blue Clays (Argille Azzurre) siltites, in which further, olistostromic lenses of more plastic, Varicoloured Clays (Argille Varicolori) occur. The slope where the town is placed has an average inclination of approximately 10°, its relief is 245 m from the top (595 m a.s.l.) to the foot (350 m a.s.l.) close to the river. The bedrock layering dips 20°-30° eastward and is significantly affected by tectonic disturbances.

The Ofanto River flows approximately in the same direction. Therefore, its left valley side consists, in broad terms, of ridges of sand alternating with zones of clay, forming side valleys. The landslide complex which affected Calitri (Figures 7-8) occupies one of these side valleys.

The Quaternary history of this part of the Ofanto valley, and in particular that of its river terraces, has been investigated by Del Prete and Trisorio Liuzzi (1981). Remnants of high terraces are present on both sides of the valley at various elevations. The present flood-plain terrace on the left bank of the river below Calitri is located at around 360 m a.s.l., and has been partly overridden by the mudslides which form the lower element of the Calitri landslide complex. A fragment of an earlier terrace is located at around 400-410 m a.s.l. on the same river bank, about 500 m downstream. The available data on annual precipitation at the Calitri station have averaged about 760 mm over the period 1930-1972.

The landslides which affected Calitri in connection with the November 23, 1980 earthquake consisted predominantly of the reactivation of parts of a complex of pre-existing old slides (Figures 2.9-2.10). Surface features produced by the movements (such as scarps, cracks, and shears) have been carefully mapped on the ground and from vertical stereo aerial photographs (taken in 1974 and in December 1980) by Del Prete. The slide scarps and boundaries shown on Figure. 2.8 represent a simplified summary of these observations.

Currently, four main elements can be distinguished:

1. a major, deep-seated slide, with a volume of the order of 20 x 10^6 m^3, occupying the upper two-thirds of the valley slope (ca. 240 m in total vertical height), with its rear scarp in the old town and its toe 55 to 75 m above river level;
2. associated secondary slides around the rear scarp of the main slide (1); of these, the most important are those which extend north-northeast (2a) and north-northwest (2b) of the main slide;
3. shallower slides in the steeper toe area of the main slide, which supply material to the head of the following mass movements;
4. shallow translational mudslides, which form part of the colluvial apron extending down to the River Ofanto. The active parts of these mudslides are about 10 m thick, and protrude into the left side of the river.

Information on the timings and durations of the above listed mass movements is incomplete. This may be partly because the earthquake struck after dark (at about 7.35 p.m., local time) and partly because a thorough and prompt examination of the witnesses of these events does not seem to have been carried out because of the prevailing panic. The limited impression we received from our discussions in April 1982 was that, at least in the main square of the old town, cracks appeared on the line of the main rear (scarp R, 2..8) at about the time of the main earthquake shock, and that slow downward movements of the ground on the southern side of these cracks proceeded for several hours to produce the eventual, near-vertical displacements of 1 to 2 m in that vicinity. In the new part of the town, affected by the north-northwestern secondary slide (2b, above), the evidence suggests that the first crack appeared at about 8.00 p.m., local time, and that by midnight the subsidence of the head of that slide had produced a vertical scarp about 0.8 m high.

Significant movements of the main slide (1) and its secondary slides (2a and 2b) appear to have been essentially completed within about 24 hours. As suggested previously, slide 2b may have been of the same type as the first slide.

Beyond the boundaries of the above-mentioned active slides, lie areas of old slides and mudslides (Figure. 2.8), which were not reactivated by the earthquake.

Despite the several uncertainties outlined above, preliminary stability analyses were made on both the main landslide and the mudslide at its foot. For the main landslide, the depth/length ratio (d/L) was about 0.14: the Conventional Method could thus be used without involving large errors (Skempton and Hutchinson, 1969). As the piezometric pressures acting on the slip surface was poorly defined, the calculations were carried out for a range of assumed r_u values, *i.e.* 0.48 (approximating to a winter ground-water level coinciding, on average, with ground level), 0.36 and 0.24. The value of ℑ is taken as 20.6 kN/m^3. As the 1980 landslide involved a renewal of movement on a pre-existing slip surface, it is appropriate to use residual shear strengths. In view of the fairly low breadth/length ratio (B/L) of this slide of roughly 0.6, and its considerable depth, three-dimensional stability analyses were carried out in addition to the usual two-dimensional ones. The results of various back-analyses of the stability of the main landslide, on slip surface RT (Figure. 2.8), assuming that its winter factor of safety is 1.0 and taking $c'_r = 0$, are summarized below, and in Tab. 2.1. In the three-dimensional analyses, the values taken for K and Be (breadth of equivalent rectangular sliding body) are 2/3 and 360 m, respectively.

Assumed value of r_u	♦’$_r$ required for F = 1.0, with $c'_r = 0$	
	Two-dimensional analysis	Approximate three-dimensional analysis, with K = 2/3
0.48	15.1°	12.9°
0.36	12.2°	10.2°
0.24	10.1°	8.5°

Tab. 2.1 - Back-analyses of the stability of the main landslide and the active mudslide at Calitri.

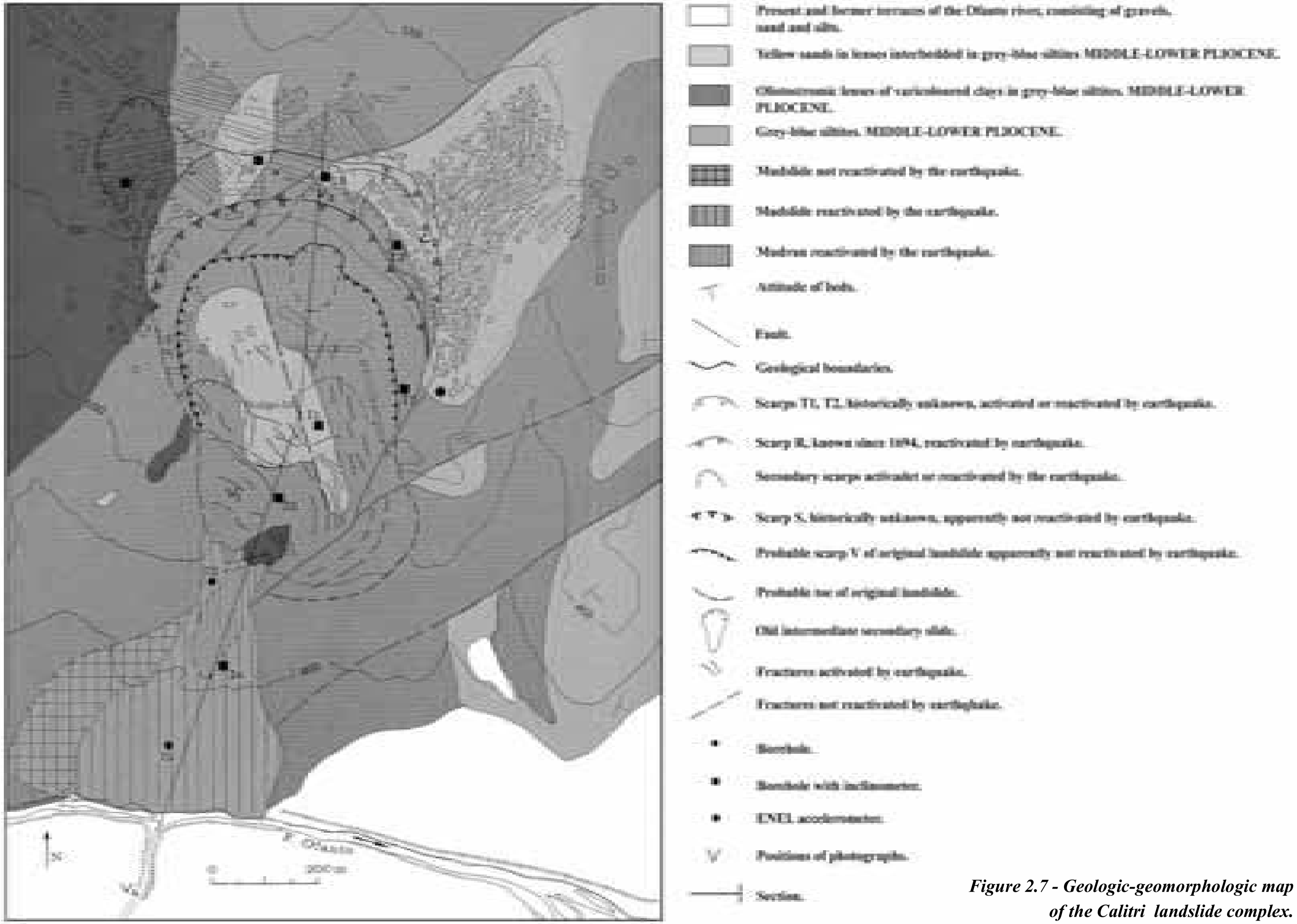


Figure 2.7 - Geologic-geomorphologic map of the Calitri landslide complex.

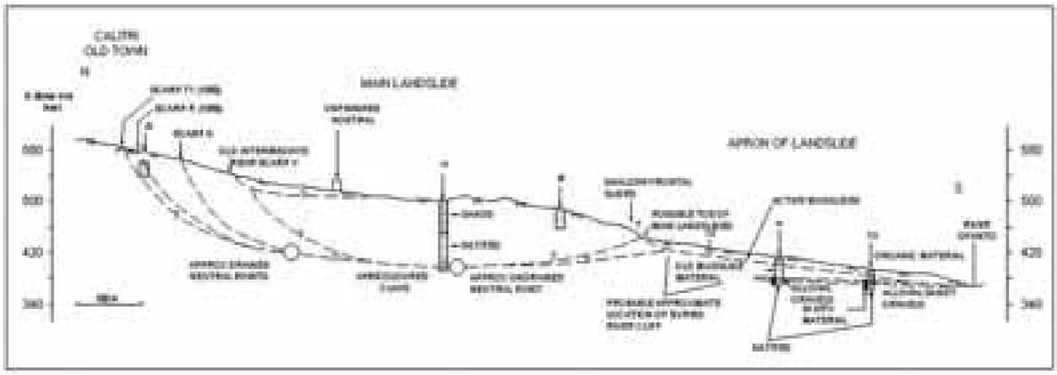


Figure 2.8 - A section along the main landslide of Calitri.

Visit itinerary

The visit to Calitri will include:

Stop 1:

General view of the town from the football field, and introduction to the geological-geomorphologic context of the earthquake-induced landslide movements.

Stop 2:

Walk along the main landslide body.

Stop 3:

View of the main landslide toe.

The landslide of Senerchia

M. Del Prete

The town of Senerchia (Avellino Province) is situated in a Southern Apennine region characterized by high geological hazard. Senerchia was very badly hit during the earthquake which struck Campania and Lucania on November 23, 1980. Especially in the southern part of the town, constructed on faulted and disjointed Quaternary debris materials, all the quite inadequate buildings collapsed with the loss of many lives.

The high geological hazard is attributable not only to the frequency of earthquakes here, but also to the fact that extensive areas are affected by mass movements. One of such instance is the Serra dell'Acquara mudslide, which was reactivated following the 1980 earthquake (Cotecchia and Del Prete, 1984). However, these huge mass movements, which fringed the built-up area, are only the most evident manifestations among other landslides – latent in some cases - threatening the town.

Senerchia lies on the right-hand side of the upper Sele Valley, on the tectonic boundary between the Jurassic dolomites and limestones of the Panormide Complex, and the Cretaceous-Eocene pelite and Flysch Units of the Sicilide Complex (Figure. 2.9). The two complexes form superimposed allochthonous units, the deepest being the Panormide limestones, tectonically overlain by the Sicilide Units downthrown in the Sele Valley graben. In this area, the Panormide Unit is made of dolomitic limestones and calcareous dolomites.

Figure 2.9 - Simplified geological map of the Senerchia area. Legend:
10: Alluvial deposits (Quaternary);
22a: Sicilide Units (Eocene-Upper Cretaceous);
35: Shallow-water limestones and subordinate dolomites (Eocene-Upper Triassic) (after Bigi et al., 1992).

These rocks as a whole have been subjected to extensive and very widespread networks of tectonic joints that, in most cases, have obliterated the bedding almost completely. Indeed, the rock masses are so finely fragmented that they frequently have a floury appearance. The fracturing of bedrock has also produced macroscopic effects, such as megablocks several dozen cubic meters in size.

Ground surveys and information obtained from borehole logs in this area indicate that the Sicilide Unit can be distinguished in two different parts: one of which with the pelitic component decidedly predominant; the other, instead, consisting of stratified sequences of Varicoloured Clays, alternating with beds of sandstone, marly limestone and limestone.

The mainly clayey part widely occurs in the area affected by the huge Serra dell'Acquara mudslide: it consists of Varicoloured Clays with subordinate rocky interbeds, such as marly limestones, light-coloured calcilutites, and thin, generally badly-shattered sandstone beds.

Lying right up against the tectonic contact between the limestones and the Sicilide Unit, is the Quaternary detrital slab on which Senerchia was built. This slab can be considered as an accumulation of fault breccia, talus, and hillside wash. The slope which has provided the detrital material over a long geological period is bounded by a fault running along the eastern side of the Mt. Cervialto limestone horst.

The Serra dell'Acquara mudslide, reactivated by the 1980 earthquake, is one of the largest mass movements in the whole earthquake-stricken area. It fringes the built-up area, running along a fault line which separates the Sicilide Unit from the detrital slab on which Senerchia stands (Figure. 2.10). reactivation of a landslide mass that had lain quiescent for at least 40 years, as confirmed by the age of the 29 rural houses destroyed. It could well be, however, that the slide had remained quiescent even longer than the period indicated by the age of these houses. Indeed, it would be more reasonable to go back to the 1930 earthquake. Though there is no certain proof of the veracity of this assumption, it is supported by the recollections of some of the older local inhabitants. What is certain, however, is that no appreciable remobilization occurred over the last forty years, even following periods of very heavy rain. This fact is certainly borne out by the survival of numerous old houses along the whole length of the slide, and the stories collected of past events.

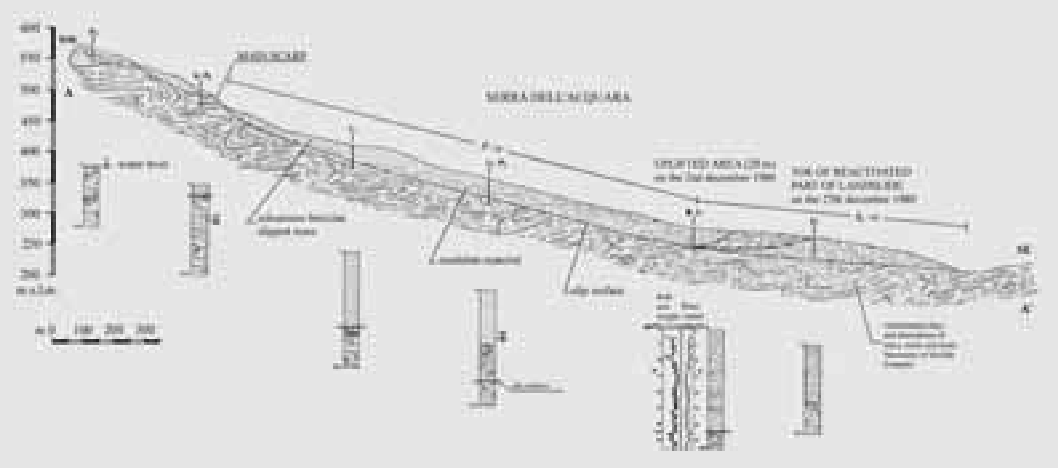


Figure 2.10 - A section along the Senerchia landslide.

The particular weakness of the slope where the mass movement originated in geological time is attributable not only to the above mentioned tectonic discontinuity, but also to the unfavorable hydrogeological situation found along the upstream tectonic contact between the carbonate aquifer and the Sicilide aquiclude. The barrier springs that occur here pour out enormous quantities of water into the unstable basin below (200 l/sec).

The shocks recorded on November 23, 1980, reactivated this 2500 m long, 500 m wide mudslide, mobilizing an estimated volume of around 28 x 10^6 m^3. The slip surface wholly lies in the pelitic Flysch of the Sicilide Unit at a maximum depth of 33 m, as indicated by borehole and nuclear logging data. Comparison of aerial photographs taken before and after the 1980 earthquake, clearly reveal the

Following the main shock of November 23, 1980, the mudslide was gradually remobilized. The movement started from upstream and slowly spread downstream, over a period of a couple of weeks. The first cracks appeared in a secondary zone of depletion along the Oliveto Citra road, which had to be closed. The Mt. Stella aqueduct was also cut some fifteen hours after the main shock, while almost at the same time the main scarp was formed in the 475-490 m contour area.

As a result of these various events the long mudslide occupying the channel was slowly set in motion, and started slipping downhill. The slide, formed of Sicilide Clays overlain by broken masses of calcareous breccias, exhibits very evident shear boundaries, thus indicating quite clearly how it was reactivated. In the initial phase, the material slipped almost as a single mass, as can be deduced by the fact that trees and houses standing thereon were shifted several meters without being destroyed.

The main moving mass, on which local secondary movements of remoulded, muddy material were superimposed, eventually came to exert pressure on the pre-existing zone of accumulation, causing an uplift of around 20 m, along the line of contact. It is precisely here that very evident failure surfaces were created when the superior equilibrium limit state was exceeded. Remobilization of the accumulation zone thus occurred about one month after the main shock.

Back analysis, at limit equilibrium conditions, was run on the mudslide channel, using the infinite slope method, since the topographic surface is well defined at a depth of 25 m. Table 2.2 sets forth the results of the two- and three-dimensional analyses.

Assumed value of m (r_u)	♦'$_r$ required for F = 1.0, with c'$_r$ = 0	
	Two-dimensional analysis	Approximate three-dimensional analysis, with K = 2/3
1.0 (0.54)	16.0°	15.5°
0.8 (0.43)	13.0°	12.5°
0.6 (0.33)	10.8°	10.4°
0.4 (0.22)	9.3°	9.0°
0.2 (0.11)	8.2°	7.9°

Tab. 2.2. Results of back analysis using the infinite slope method

Visit itinerary

The visit to Bisaccia will include the following itinerary:

Stop 1:

General view of the landslide from its left side, and general discussion on its geological-geomorphological context.

Stop 2:

Close view of the calcareous breccias on which the historical center of Senerchia is founded.

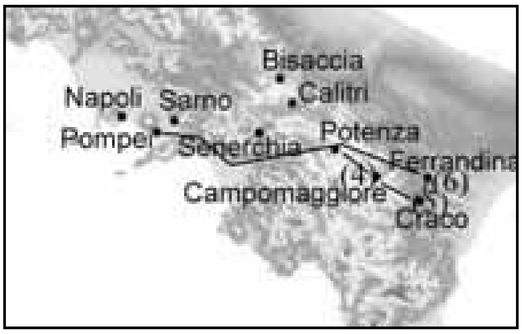
Stop 3:

Close view of the main landslide scarp.

Stop 4:

View of the landslide toe.

Field itinerary



DAY 2

From Potenza to Pompei

The Landslide of Campomaggiore

M. Del Prete

In the Campomaggiore area, two lithological complexes outcrop: the Flysch Complex (including the Red Flysch, the Numidian Flysch, and the Serra Palazzo formations), and the Varicoloured Clays (Argille Varicolori) Complex. The Red Flysch Formation (Aquitanian) consists of calcirudites and calcarenites, with more or less closely-knit alternations of limestones, marly limestones, marls, and clays. The Numidian Flysch Formation (Langhian), consists of a clayey-sandy member (alternations of dark-grey marly clays with quartz-arenites and calcarenites), and a mainly quartz-arenite member, with thin interbeds of marly clay. The Serra Palazzo Formation (Langhian-Tortonian), consists of clayey-sandy alternations, sometimes with limestone or predominantly of sandstone interbeds. The Flysch Complex is here tectonically overlain by the Varicoloured Clays Complex (Sicilide Complex) of probable Upper Cretaceous age. It consists mainly of clays and marly clays, with intercalations of limestones, marly limestones, and calcarenites.

A succession of tectonic events has created an imbricated series of slices formed by the quartz-arenites and marls and marly clays of the Numidian Flysch, which are relatively more rigid, with the varicoloured clays sandwiched between the slices. The varicoloured clays are the most unstable materials, being characterized by a low shear strength. The clay minerals which are there present, consist of interbedded, illite-smectite and abundant

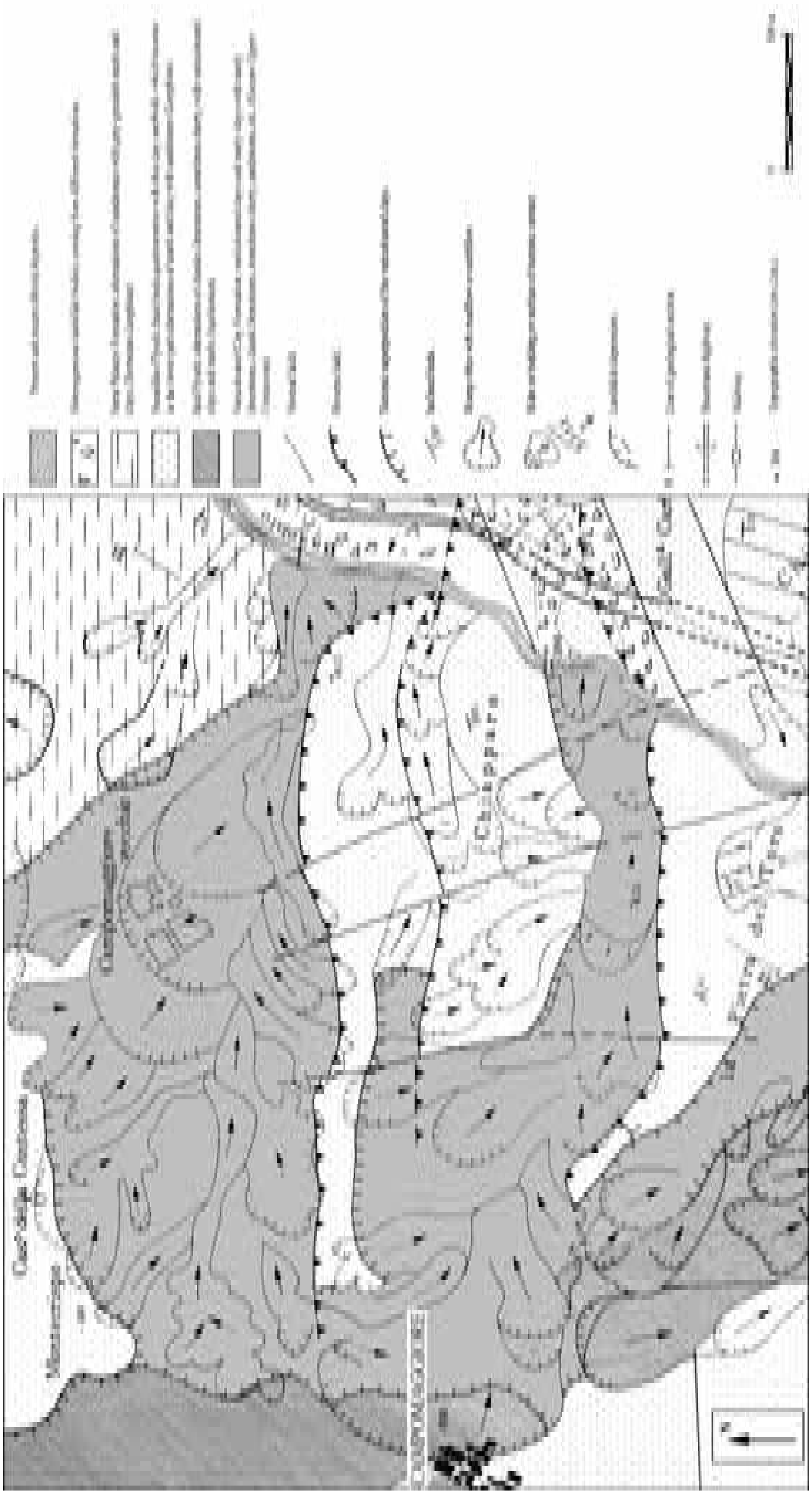


Figure 3.1 - Geomorphologic sketch of the Campomaggiore area.

smectite, with illite and kaolinite in fair quantities and subordinate quantities of chlorite.

The geological structure and the clayey bedrock are the main factors which cause translational slides on such a large scale that they may be confused with tectonic phenomena. These slides occur on the tectonic contact between the Numidian Flysch and the Varicoloured Clays, along the bedding planes of the former, and along the rupture surfaces of previous landslides. In addition to these translational slides, also rotational slips associated with mudslides and earthflows affect the varicoloured clays and the marly clays of the Numidian Flysch.

Particularly interesting for their catastrophic effects and peculiar characteristics, are the gravitational movements which involved the Varicoloured Clays at Campomaggiore Vecchio (Figure 3.1). In the upper part of the slope (Montecrispo and Casino della Contessa localities), a number of landslide features, referable to rotational slide and flow movements, are present. They appear to be relatively old, since they are displaced by more recent movements. The escarpment following the 550 m contour line, is related to a large-scale rotational slide, responsible for the emplacement of the wide landslide terrace, over which the village of Campomaggiore Vecchio was incautiously founded.

The small valley with its right side made of stiff quartz-arenites (Numidian Flysch Formation), and the left one made of sticky marly-arenaceous alternations (Serra Palazzo Formation), acted as a narrow neck, which prevented a free rapid evolution of the rotational slides, causing the disruption of landslide bodies. This evolution has repeatedly occurred over time, as far as the backward erosion of the lower small valley-induced instability conditions in the upslope.

A noteworthy case of landslide reactivation was that of Campomaggiore Vecchio. As reported by the contemporary chronicles, during the night of February 10, 1884, the whole village, which at that time included ca. 250 houses, moved down slowly as a unique body, so that no inhabitants were killed or injured. Some buildings were damaged, more or less heavily, but not one collapsed. On the contrary, the road from the railway station to the village was greatly pulled out of shape and even fragmented into pieces.

Unfortunately, no reliable information is available on the triggering rainfall, since the only possible reference meteo-station (that of Potenza) was installed later, in 1889. However, from oral tradition, local testimonies reported that the landslide occurred in connection with heavy rain.

The village was evacuated and rebuilt on a new site (the present Campomaggiore), about 3 km south of the old one.

Visit itinerary

The visit itinerary of the Campomaggiore Vecchio landslide will include:

Stop 1:

Panoramic view of the landslide from Campomaggiore Nuovo and introduction to the geological-geomorphological context of the area.

Walk across the displaced village of Campomaggiore Vecchio to see the landslide effects on structures and buildings.

The Landslide of Craco

M. Del Prete (University of Basilicata, Potenza)

The village of Craco (Figure. 3.2) is located at 390 m a.s.l. on an undulating hilly ridge running northwest-southeast, which divide the valleys of the Bruscata and Salandrella rivers.

Figure 3.2 - The village of Craco.

In the upper parts of the ridge, conglomerates and conglomeratic sands of the Lower Pliocene age outcrop, and transgressively overlay the Varicolored Clays (Argille Varicolori) of the Sicilide Complex (Cretaceous-Eocene). This older succession is in tectonic contact with the Blue Clays (Argille Azzurre) of Pliocene age, which outcrop in the middle and lower parts of the slopes (Figure. 3.3).

The conglomerates with polygenic elements, which have a median diameter of about 10 cm, are characterized by medium to high cementation. They contain sandy beds and sandy lenses which, in some places, indicate the attitudes of the strata. The top of the south-eastern hill is made of conglomeratic sands, which pass laterally to conglomerates. The maximum thickness of conglomerates is about 30 m.

The Varicolored Clays are represented by smectitic and kaolinitic clays, red, green, and grey in color, including tectonically-disarticulated packs of Apennine Flysch units. The thickness of the Varicolored Clays cannot be evaluated, due to the generally chaotic assemblage. The Pliocene clays have a typical blue color, and form very wide outcrops surrounding the hill of Craco. They consist of heavily over-consolidated illitic clays, with some sandy and silty interlayers, which enable the indistinct stratification to be locally observed.

On the south-western flank of the hilly ridge, a clearcut fault scarp divides the Pliocene Blue Clays from the Varicolored Clays. The latter have a chaotic attitude, and are covered by a rigid conglomeratic cap, which is divided by faults and fractures into three parts forming three adjacent hilltops with different attitudes. Whereas the strata in the outer hilltops show small inclinations, those of the middle one are arranged in a narrow anticline fold. A fault running along the axial plane of this anticline is responsible for the sub-vertical layering of the north-eastern flank, and the low south-westward dip in south-western flank. According to Lentini (1969), the Craco Varicolored Clays and conglomerates belong to the Metaponto Nappe, superposed on the Blue Clays of the Bradanica Foretrough.

The southwestern slope of the hills at Craco may be subdivided into three zones which are morphologically well-differentiated by their geological constitution. The parts where the conglomerates outcrop, such as between the crest and the 103 State Road, where most of the old Craco village is located, have a rocky aspect with vertical faces corresponding to fault or fracture planes.

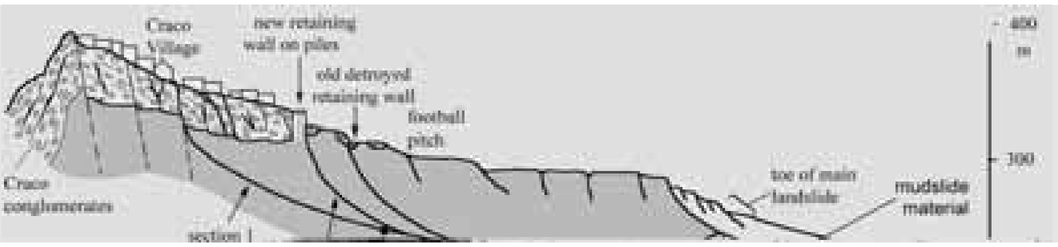


Figure 3.3 - Schematic geological map of the Craco-Ferrandina area.
Legend: 7: Marine and alluvial deposits (Quaternary);
13-14a: Undifferentiated terrigenous and marine deposits, calcarenites (Lower Pleistocene-Upper/Middle Pliocene);
22b: Sicilide Units (Eocene-Upper Cretaceous) (after Bigi et al., 1992).

Downhill from the 103 State Road, in correspondence with the Varicolored Clays outcrop, the slope angle becomes very low, until the fault-scarp dividing the Varicolored Clays and the Blue Clays is reached; here the slope angle suddenly increases.

Three ditches, originating near the contact between the conglomerates and Varicolored Clays, incise the slope. In the outcropping area of the Varicolored Clays, these ditches are large and open, but in correspondence with the fault scarp, they become very narrow. Beyond the fault scarp, they assume the typical aspect of ditches in "badlands" areas.

Three main landslides affect the Varicolored Clays of the three valleys. These movements are very large and have considerable similarity since:

1. the slip surfaces are essentially in Varicolored Clays;
2. the crowns of the landslides reach the conglomeratic cap;
3. the foot of each landslide is situated in the narrow part of the valleys in correspondence with the fault scarp.

The central of these landslides was instrumental in destroying the oldest parts of the village of Craco. It shows the characteristic features of a retrogressive landslip, with a very long mudslide originating from its toe (Figure 3.4). The complete length of the movement is about 1.1 km, and its maximum depth is estimated to be 70 m. From the top of the hill, three scarps can be observed, the highest of which reaches the church of the village, at an elevation of 356 m a.s.l. A second scarp is visible immediately downhill of the retaining wall, which was constructed in 1969-70. A third scarp is situated at an elevation of 310 m, in correspondence with a destroyed wall, built in 1888 to protect the 103 State Road. Downhill from these scarps, the landslide becomes very wide, with two lateral lobes, until it reaches a maximum width of 400 m. At the previously mentioned fault-scarp, the landslide narrows to a width of 40 m.

Figure 3.4 - Geological section along the Craco landslides.

The landslide-triggering effects of the huge (I=X Mercalli Scale) earthquake, which struck the Craco-Pisticci area in 1688, are unknown. Nevertheless it is highly probable that the damage assessment of the earthquake was strongly influenced by the activation (or reactivation) of the numerous landslides in the area, including the central landslide of Craco.

The earliest reliable records refer to the construction of a retaining wall in 1888 to protect the 103 State Road from the landslide. The wall had a thickness of 3.5 m, and was constructed with arches, the columns of which were reported to be founded at a depth of 18 m. The records state that immediately after the construction of the wall, it suffered a vertical displacement of about 20 cm.

There are no other records of landslide activity until 1931, when it was found necessary to carry out some supporting operations to the wall. In 1954, after a long period, apparently free of landslide activity, a football pitch was built on the landslide terrace downhill of the retaining wall. The construction of the football pitch required quite extensive leveling operations including the placing of some meters thickness of fill in order to flatten the ground surface.

In November 1959, the area of Craco experienced exceptionally heavy rainfall, as indicated by measurements taken at the nearby monitoring station at Pisticci; the rainfall exceeded 400 mm in five consecutive days. This exceptional rainfall was followed by a total reactivation of the landslide, causing complete destruction of the football pitch, and extensive displacement of the wall, and producing some cracks in houses uphill from the wall. At the toe of the landslide, the uplift exceeded 20 m.

Further acute reactivation and development of the landslide, occurred in December 1963 and January 1995 and January 1965, making the situation of the village critical. In December 1963, the wall protecting the 103 State Road suffered a vertical displacement of 2 m and a horizontal translation of 1 m, so that the road became almost unusable. Many houses uphill from the road suffered subsidence and were severely damaged due to the activation of the two lateral landslides. In many cases, the damage was so heavy that the houses had to be abandoned. Even more serious damage developed from the January 1965 reactivation, which caused the evacuation of 153 houses. Following this period of damage, a Government Order (D.P.R.), was issued for the total evacuation of the village. This Order was made partial only in 1968, and new stabilizing measures were financed. These involved the total demolition of the old retaining wall and the construction of a new wall, consisting of a 60 m long and 4 m wide reinforced concrete platform, founded on lines of thick (800 mm) reinforced contiguous piles, deeply founded in the clays.

Subsequently, during the fall of 1970, some small movements were recorded in Craco. In April 1971, the total collapse of the inhabited area took place. Two large scars opened, one in Garibaldi Square, and the second downhill from church. The new retaining wall suffered considerable translation, and sank more than 2 m. Its western wing was sheared at its extremity, while a sinking of about 15 m of the ground downhill of the wall exposed the piles. The two lateral landslides were also strongly reactivated, and the village was totally abandoned.

Visit itinerary

The visit itinerary of Craco will include:

Stop 1:

Gweneral view of the town from Bruscata River collapsed bridge.

Stop 2:

Close view of the landslide crown.

The Unstable Centre of Ferrandina

F. Bozzano, A. Prestininzi, G. Scarascia Mugnozza

The geological-geomorphological context

The southernmost section of the Padano-Adriatic Foretrough, known as the Bradanica Trough (Fossa Bradanica) Foreland is a structural depression, placed between the Apennine and Apulia (from the present location of Bari, to the North, and the Gulf of Taranto, to the South). It is filled with a ca. 3000 m thick sandy-pelitic sequence, whose uppermost part belongs to the Bradanica Cycle (Lower - Middle Pleistocene). The most recent deposits are made of sands and conglomerates (Figure 3.5) (Valentini, 1979, 1995; Genevois et al., 1984; Bozzano and Scarascia Mugnozza, 1994).

The rapid uplift which has involved the area since the Middle Pleistocene (Cosentino and Gliozzi, 1988; Amato, 2000) and the SW-NE tectonic shortening of the Apennine chain, connected with active compression against the stable Apulian Foreland, gave rise to NW-SE trending "undulations", which hosted the valleys of the main rivers. The interaction between glacio-eustatic sea level changes and regional uplift caused the formation of eight different terraces in the peri-Ionian coastal belt (Figure 3.5).

The main river valleys (Bradano, Basento, Cavone Agri, and Sinni rivers) generally show flat-shaped valley floors, and are divided by flat-topped and plateau-like ridges. Gentle valley slopes are downcut in a clayey bedrock (Blue Clays - Argille Azzurre, made up of clayey strata, interbedded with silty and sandy levels, whose frequency and thickness increase upwards. The upper section of the hillslopes are overlain by the above-mentioned coarse grain deposits, whose overall thickness ranges between few meters and, locally, 90 m.

Most urban settlements of the area were founded on such flat-topped hills and have their borders generally coinciding with the plateau edges. Along each

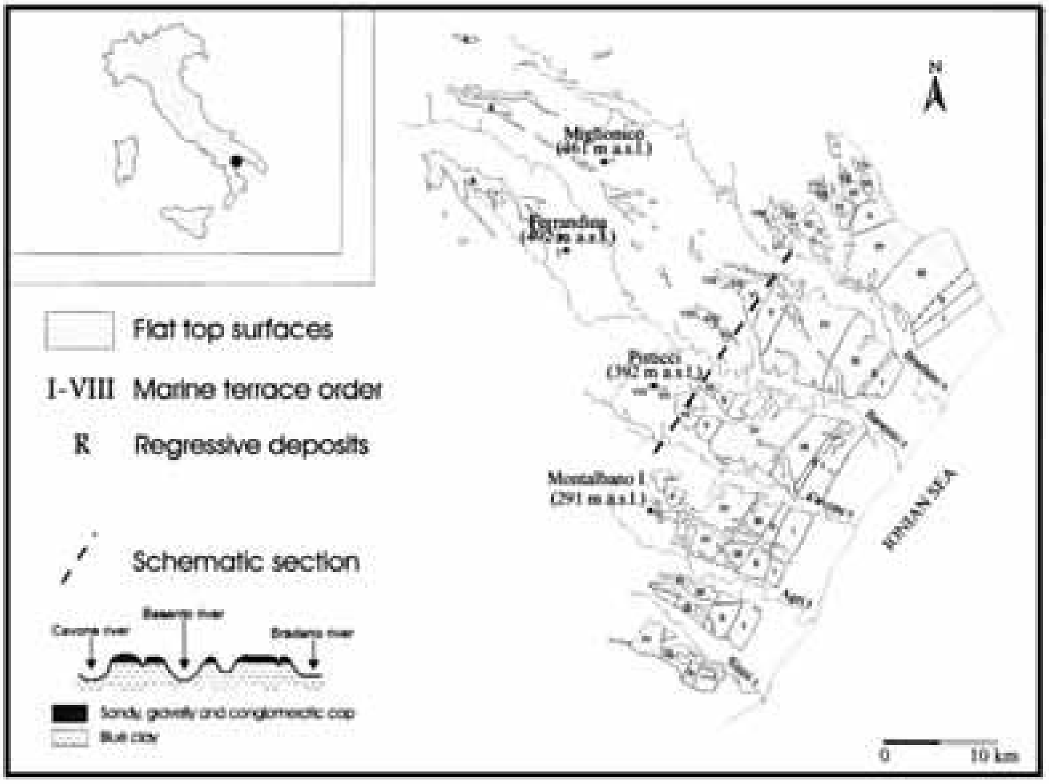


Figure 3.5 - Geomorphologic sketch of the Ferrandina area.

interfluvial ridge, the preservation of the original top surfaces significantly increases from the inner areas to the present coastal plain (Figure 3.5). As an example, around Miglionico and Pisticci, the top surfaces are respectively represented by a narrow ridge and by an ellipse shaped relic. Here, the Blue Clays slopes show marked badland topography. Close to the Ionian sea, terraced marine deposits widely outcrop, covering the upper parts of the clayey interfluvial ridges.

The degree of retreat of the flat hilltops depends on the lithology and age of the uppermost deposits, as well as on the elevation of the summit surfaces (Bozzano *et al.*, 1989; Bozzano and Scarascia Mugnozza, 1994; Bozzano *et al.*, 1996). Estimated rates of this process range between 0.2 and 3 m/century (Valentini, 1995).

In such a morphodynamic scenario, each slope movement represents an acme event which assumes great importance as regards hazard conditions of urban areas in terms of both return period of landslides and the degree of retrogression of the cliff edges.

The Castelluccio landslide at Ferrandina

The town of Ferrandina is located at 492 m a.s.l. over a flat-topped hill on the right watershed of the Basento River. The bedrock consists of 90 m thick sandy-conglomerates overlaying the Blue Clays which outcrop all around the hillslopes below the top layer escarpment. The town hill is largely affected by slope erosion and landslides, the most important of which involved the locality of Castelluccio in January 1960, after a period of heavy rainfall which caused a sudden increase of river discharge into the surrounding area (more than 1400 m^3/sec in the Basento River).

The displaced mass was ca. 400 m wide and 950 m long, excluding the distal portion, which moved as a flow over ca. 1000 m down to the Basento River. The movement involved the top sandy-conglomeratic level, and the underlying blue clays; the maximum estimated depth of the sliding surface was 100 m (Bozzano, 1992).

The slope failure mechanism was mainly related to the contrast in deformation between the rigid cap (sandy-conglomerates) and the softer substratum (overconsolidated clay), characterized by strain-softening behavior. Obvious effects of this deformation contrast were subvertical tension cracks parallel to the cliff trend (Cherubini et al., 1984). Moreover, the difference in permeability between the clayey substratum and the overlying coarse grain subhorizontal strata, determined the hydraulic boundary conditions inside the slope, and significantly influenced the pore pressure distribution, thus contributing to the triggering of the movement.

The slope movements can be classified as a multiple rotational slip (Hutchinson, 1988) along a single surface. The slope evolution appears to be related to new generated movements which, however, reactivate previous landslide bodies though a mechanism of retrogressive retreat along a single sliding surface. A section of the landslide slope (Figure. 3.6) shows a sequence of ancient landslide heaps, buried under eluvial-colluvial materials.

This situation is also present in most slopes of the

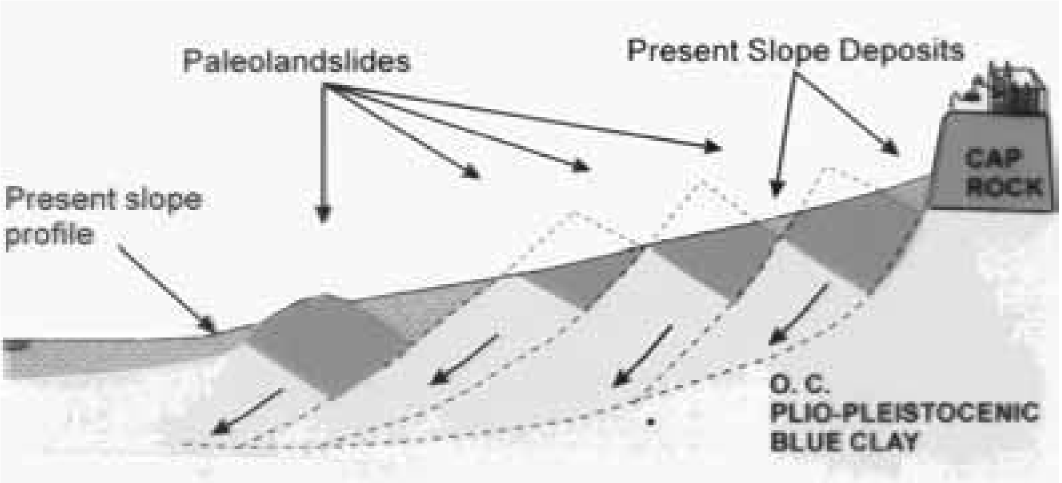


Figure 3.6 - Section along the Castelluccio slope, showing the occurrence of ancient landslides remobilized by the landslide.

surrounding area, where the Blue Clays are overlain by a stiff sandy-conglomerate cap.

Visit itinerary

Stop 1:

Close view of the Castelluccio landslide crown, and general view of the landslide area.

Stop 2:

Observation of the mobilized slope materials in a section on the left side of the Casteluccio landslide.

Field itinerary

DAY 3

From Pompei to San Benedetto del Tronto

Pompei and the 79 A.D. Eruption of Vesuvius

P. Molin

Vesuvius is probably the most famous volcano in the world owing to its largely documented eruptive history, and because of its spectacular almost continuous activity which lasted for around three centuries until 1944; and, of course, because of Pompei, one of the best preserved archaeological sites in the world.

During the Quaternary, the Tyrrhenian margin of central and southern Italy was strongly characterized by the development of K- rich volcanoes. This activity started around 2 My BP, and lasted until the present day, with the historical eruptions of Vesuvius, the Flegrean Fields, and the Island of Ischia (Santacroce, 1987, and references herein).

Vesuvius can be considered quite a young volcano, since it is not older than 30-35,000 yr BP. In the past, its general shape was very different from the present one, that is, a regular cone, surrounded by an older apparatus, called Mount Somma (Figure 4.1). Indeed, the slopes of Mount Somma are the relics of an older volcano, whose activity ended with a summit caldera collapse. Inside this caldera, the more recent cone of Vesuvius has built up.

The activity of Vesuvius alternates long periods of quiescence with Plinian eruptions, and small-size, effusive and slightly explosive events (Bonasia *et al.*, 1984). Since the XV century, Vesuvius was persistently active until the last effusion in 1944. This period of activity was characterized by several cycles, each one of which began after a time lap of no more than 7 years (Bonasia *et al.*, 1984). Generally

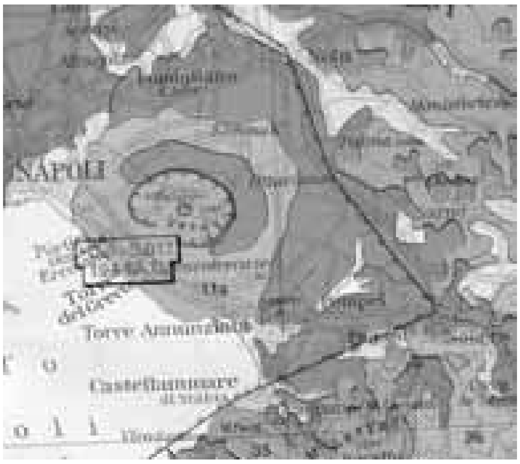


Figure 4.1 - Schematic geological map of Mt. Somma – Vesuvius area. Legend: 11a Potassic vulcanics: undersaturated (Quaternary); 11b: volcanites with hydromagmatic facies (Quaternary); 35-36: Shallow-water limestones and subordinate dolomites (Eocene-Upper Triassic). (after Bigi et al., 1992).

Figure 4.2 - Excavation of Pompei with Vesuvius in the background.

Figure 4. 3 - Fresco painting found in Pompei, showing Vesuvius before the eruption of 79 A.D. (from the Osservatorio Vesuviano web site).

speaking, every cycle started with gentle effusive and Strombolian activity, and ended with lava fountains and an explosive eruption, characterized by a higher effusion rate, and by the formation of an eruptive column of 5-15 km (Santacroce, 1987).

On August 24, 79 A.D., Vesuvius began its activity after a quiescence of around eight centuries, erupting more or less 4 km^3 of pumice and ash within 30 hours. The eruption started around 1 p.m., with the opening of the conduct through several explosions following the interacting of the groundwater with the upwelling magma. An eruptive column of pumices, ash, gasses, and lithics rose from the volcano to a height of 15-20 km. This phase of the eruption continued until 8 a.m., and was characterized by frequent earthquakes, and by a thick pumice fall deposition. Owing to the apparent pause in the eruption, at night several people went back their homes, but in the morning the activity began again, with the collapse of the eruptive column, and the generation of pyroclastic flows, a dense and very hot mixture of pumice and ash, that exited from the crater and very quickly flowed down the sides of the volcano, destroying everything in the area of Ercolano, Pompei and Stabia (Figure. 4.4). At the end of the morning of August the 25th, several pyroclastic flows continued to form, whose deposits completely buried the towns surrounding the volcano, whereas a dense cloud of ash spread in the atmosphere and reached Capo Miseno (Giacomelli and Scandone, 2001).

After the pyroclastic flows, the magmatic chamber top collapsed, and the groundwater infiltrated the hot rocks previously warmed up by the magma, inducing a succession of explosions (Santacroce, 1987). The overall process must have taken just a few days. The eruption was described by Pliny the Younger in two famous letters to Tacitus, that represent an important report for volcanological studies. In the letters, he recounted the death of his uncle, Pliny the Elder, who left Miseno by boat to help some friends. That is why this kind of phenomenon, so violent and destructive, is referred to as a "plinian" eruption.

For a while after the end of the eruption, the deposition of huge amounts of loose materials resulted in very dangerous effects (Giacomelli and Scandone, 2001). Heavy rains soaked and mobilised tephra on the steep slopes of the volcano, generating "lahars" –flows of dense mud mixed with coarse materials. These mud streams, flowing along the main channels of the surface drainage, as far as 5-7 km from the sourcing areas, induced severe damage in the zones surrounding Vesuvius (Santacroce, 1987).

The most complete record of the eruptive events is preserved in the Oplontis ("Poppea's villa") excavation. Here, the stratigraphy can be generalised into an eruptive sequence that progresses through pumice fall, pumice flow, ash flow, pyroclastic surge and mud deposits (Santacroce, 1987).

After two thousands of years, geology, archaeology, and historical sources tell us of a tragedy that lasted just a few days, and report that the most dangerous phase of an explosive eruption can be over very quickly, and can also occur several hours after the beginning of the eruption. Therefore, the 79 A.D. Pompei eruption suggests to us how dangerous

Figure 4.4 - Casts of some victims in Pompei (from the Osservatorio Vesuviano web site).

Vesuvius still is, especially taking into consideration the surrounding belt of dense urban settlements.

The Sarno catastrophe

F. M. Guadagno.

On 5-6 May 1998, after prolonged rainfall, a large number of landslides occurred, at different times, in the area of the towns of Sarno, Quindici, Siano, and Bracigliano, situated at or near the base of the slope of Pizzo d'Alvano, and caused the death of 161 people (Figure. 4.5).

This destructive event is just one of the last events that characteristically involve the pyroclastic material present along the limestone Campanian Apennines slopes (Figures. 4.6-4.7).

The volcanoclastic airfall deposits were placed, in varying thicknesses, during periods of volcanic activity of the Somma-Vesuvius and Phlegraean Fields. Their cyclic deposition, separated by periods of weathering, creates a complex sequence of soils. The individual layers have contrasting characteristics in terms of lithology, grain size, and thickness. This layered

Figure 4.5 - Photo of debris avalanche paths reaching the town limits of Sarno.

Figure 4.6 - Pyroclastic materials overlying the limestone slopes in the Sarno area.

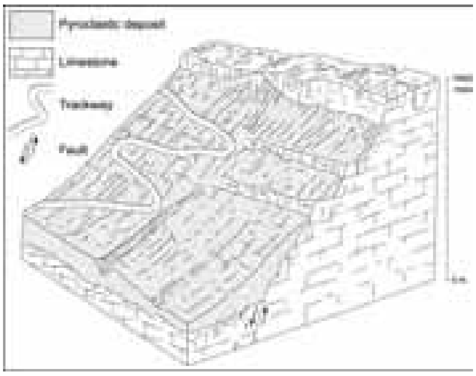


Figure 4.7 - A block diagram showing the peculiar geomorphologic setting in the Campanian Apennines (after Celico et al., 1986, modified)

structure is fundamental to the development of landslide phenomena, as it controls the mechanical and hydrological behavior of the slopes. During the 1998 Sarno-Quindici event, several millions of m^3 of slope materials were displaced in the landslides, and were classified as debris avalanches and debris flows, following Hungr *et al.* (2001) (Figure. 4.8).

They started off as shallow initial debris slides, that then expanded, by incorporating material and water from the slope, to become fluid debris avalanches. Many became channelized, and developed into debris flows. The initial movements took place on the steepest parts of the Pizzo d'Alvano slopes, on surfaces inclined at 40°-50°, often at the heads of gullies. The locations of the instabilities appear to have been controlled by the presence of natural scarps and artificial trackways cutting the slopes (Figure. 4.9) (Guadagno, 2000).

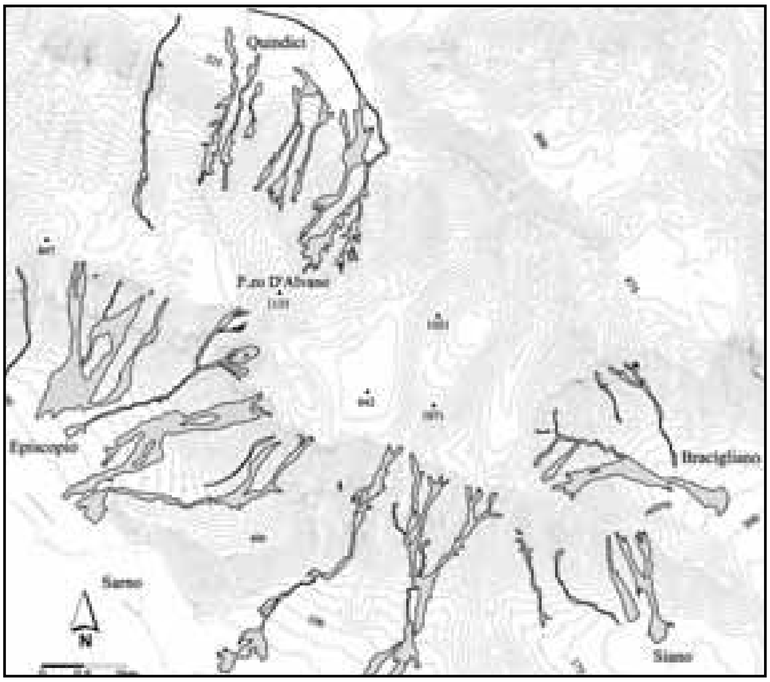


Figure 4.8 - Pattern of the 1998 flows along the Pizzo d'Alvano ridges

Figure 4.9 - A flow movement started from a road cut.

About 60% of the initial slides occurred a short distance above or below the cut slope of a trackway, located within the pyroclastic mantle. About 178 initial failures (Guadagno *et al.*, 2003a), combined to form more than twenty long debris flows, with sufficient mobility to reach built-up areas near the base of the slopes. Shortly after initiation, the landslides acquired considerable velocity, eroding pyroclastic horizons and colluvial soils (0.5-2 m thick), from the sides and base of the paths. As a result of the progressive increase in width, the upper reaches of many of the paths exhibit a triangular shape in plan, typical of debris avalanche scars. The maximum widths of the individual debris avalanche scars reached as much as 380 m (Revellino *et al.*, 2003). Most of the flows become channelized in the gullied terrain of the mid-slopes, at angles of 20 to 35°. In a typical gully sector, the path was 10-20 m wide at the base, bordered by steep slopes. Vegetation damage indicates that the flow depth was typically of the order of 5-6 m in these confined reaches.

Several bends in the flow paths give an estimated maximum flow velocity of more than 15 m/s. On leaving the gullies, the flows issued onto relatively gently-sloping fans or aprons, consisting of pyroclastic material. The origin of these geomorphologic features is uncertain, but the presence of fresh and relatively well-sorted pumice layers within them suggests that they were at least partly built simultaneously with the deposition of the tephra. Their shape is smooth and their typical slope angle is 10° to 15°. It is possible that colluvium, *i.e.* old debris flow fan and apron deposits, exists within these features, predating the deposition of the present pyroclastic mantle. The present slope morphology may thus mimic the paleomorphology of the older deposits.

Flow depths were typically of the order of 4-5 m in this zone. Organic debris was discarded at the upstream margin of the urbanized areas. The velocities decayed fairly rapidly, following the onset of deposition. The maximum thickness of the deposits was of 3.5 - 4 m in the central part of the flow paths. Contemporary video clips recorded in the distal parts of the deposition areas show flow fronts moving through narrow streets at several meters per second.

The material arriving in the deposition area was dense, but extremely fluid. In several instances, rooms were filled with mud to a depth of several meters through door and window openings. Some of the flows reached established drainage pathways and incorporated additional surface water, eventually transforming into debris floods (hyperconcentrated streamflow) in the distal reaches of the deposition areas (Pierson and Costa, 1987).

Visit itinerary

The visit to the Sarno area will include the following itinerary:

Stop 1:

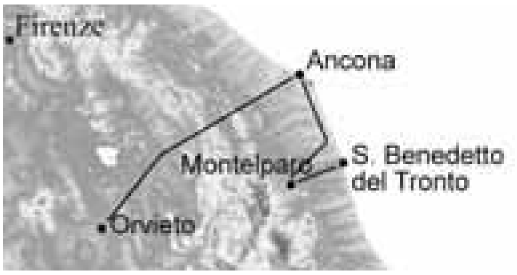
Short talk on Sarno landslides; environment and occurrence in front of the mobilized slope;

Stop 2:

Impact area and observation of the damage on buildings and structures;

Walk along a channel and observation of the material involved in landsliding and the transit area morphology.

Field itinerary



DAY 4

From San Benedetto del Tronto to Orvieto

A large-scale landslide affecting an ancient village in Central Italy: the Montelparo landslide

M.-G. Angeli, F. Pontoni, F. Dramis

The medieval village of Montelparo is located in a hilly area of the Marche Region, to the east of the Apennine chain. It is affected by a large translational landslide that has developed from 580 m a.s.l. to 340 m a.s.l., with a length varying between 700 and 1100 m and an average width of 600 m (Figure 5.1).

Figure 5.1 - Frontal view of the landslide area

The landslide body is part of a monocline, dipping 10°-12° NE, made of well-stratified sandstones, overlying a deep-seated clayey bedrock. A system of direct faults and the erosion operated by the Fosso di S. Andrea stream, flowing at the toe of the slope have favored the detachment of the sandstone slab (up to 65-70 m thick) sliding on a clayey sloping slip surface, and the formation of a well-marked depression, filled with debris material on top of the hill (Figure 5.2). The lowermost part of the sliding slab, much thinner than the upper one, is characterized by a progressive disruption into blocks, divided by cracks (up to 3-5 m deep and 2-3 m wide).

In other words, the Montelparo hill is split into

Figure 5.2 - Graben structure (the horizontal arrow indicates the moving part of the village)

two parts: the uphill part that is stable, whereas the downhill part is slowly moving as a whole (the buildings do not show any major tilting fracturing). In the intermediate area, a process of continuous settlement occurs (Angeli, 1981). This last area is known in geotechnical literature as a graben, on the basis of the classification done by Skempton and Hutchinson (1969). On the northern flank of the hill, the upper limit of the depression is exposed, showing the sub-vertical plane cut into the bedrock in contact with the filling debris.

Damages induced by the landslide in the built-up area have been documented since the XVII century. An important reactivation of the movement in coincidence with the high intensity earthquake which struck the area in 1703, is reported in the historical literature (Pastori, 1781). Major damages to buildings occurred only within this slowly expanding depression and along its margins (Figures 5.3-5.4).

Leveling surveys carried out from May 1977 to March 1979 established that along the trench, vertical displacements of 20-25 cm took place. The average speed varied from 0.3 cm/month for the first 16 months, to ca. 2.5 cm/month for the remaining 6 months. In addition, precision topographic surveys, carried out in 1980, showed horizontal displacements of up to 2-3 cm (Angeli *et al,* 1996). By comparing a cadastral map dating back to 1935, and a new map derived from aerial photographs, dated 1970, it was established that, in 35 years, the trench had widened by about 3 m, at an average rate of 8 cm/year.

In the short term, the critical hydraulic conditions are similar to the ones occurring in rockslides, where a triangular water pressure diagram operates inside the graben area (on the subvertical face of the moving mass), and a rectangular one acts on the sloping clayey slip surface. An indirect confirmation of this mechanism was provided by the acceleration of the movement in coincidence with a rainfall critical event occurring in December 1999, when significant piezometric peaks were also recorded. According to the mechanism invoked, any increase in water level makes the water thrusts (on the rear of the landslide body and at its base) increase exponentially. Hence the importance of mantaining the water levels permanently low, well below the critical values.

The main control works (Angeli and Pontoni, 2000; Angeli *et al*., 2002) belong to the category of the deep drainage, useful to increase the shear strength on the slip surface (Figure 5.5).

Visit itinerary

The following observation itinerary will be held in Montelparo:

Stop 1:

General view of the town with particular emphasis on the built-up hilltop profile interrupted by the trench;

Stop 2:

Close up view of the wall crossing the trench;

Walk in the town to see the effects of the deep seated movement,

Stop 3:

Close up view of a section showing the trench filling materials.

The Ancona Landslide

F. Dramis, G. Pambianchi, B. Gentili

Along the Adriatic coast, trenches parallel with the coastline, locally bordered by fractures and steps lowering seawards, have been found in wave-cut cliffs, presently inactive and separated from the sea through a narrow coast belt.

These landforms are frequent on the northeastern slopes of compressive structures with an Adriatic vergence, made up of lower-Middle Pleistocene clayey-sandy-conglomeratic terrains (Cantalamessa *et al*, 1987). These structures are still active, as testified by the hypocentral mechanisms of earthquakes which recently affected the area (Gasparini *et al*, 1985; Riguzzi *et al*, 1989).

The origin of the above landforms is to be referred mainly to deep-seated gravitational deformations (tectonic-gravitational spreading), induced by active compressional tectonics (Dramis and Sorriso-Valvo, 1994). Within this framework, large scale rotational-translational landslides and listric faults, lowering toward the Adriatic Sea, are produced (Coltorti *et al*, 1984).

One of the most representative examples of the above-mentioned phenomena is the deep-seated gravitational slope deformation which involved the north-facing slope of Montagnolo Hill, in the western outskirts of Ancona. Here, on the evening of the 13th December 1982, after a period of heavy rain, a huge landslide took place (Figures 5.6-5.7-5.8), over an area of more than 3.4 km^2, from about 170 m a.s.l. to the Adriatic coast (Crescenti *et al,* 1983; Coltorti *et al,* 1984; Crescenti*,* 1986).

The phase of rapid deformation, which started without warning, lasted only a few hours, and was followed by a longer period of settling. More than 280 buildings were injured beyond repair, and many of them collapsed completely (Figure. 5.9). The Adriatic railway, along the coastline, was damaged over a distance of about 1.7 km (Figure. 5.10). Luckily, there were no victims.

The slope hit by the landslide has had a long history of gravitational movements (Bracci, 1773; Segrè, 1920) (Figure 5.11). In 1858, it was the site of a landslide even larger than the recent one (De Bosis, 1859). More shallow mass movements, still large in an absolute sense, have occurred in the landslide area. Of these, the Barducci mudflow is well known for its continuous activity, and the damage it has wreaked on the coastal road and railway (Segrè, 1920).

From a stratigraphic point of view, the lithotypes outcropping on the landslide-affected slope are the following:

1) Lower to Middle Pliocene deposits (grey-blue marly clays, 20-40 cm thick, alternated with grey or grey-black compact sands, up to 60 cm thick);

2) Pleistocene deposits, consisting of five transgressive-regressive cycles of pelitic-arenaceous units, with a total thickness of about 20 m.

The area has been uplifted starting at the end of Early Pleistocene. Coquinic panchina and sands at the top of the clayey beds (Montagnolo Hill, 250 m a.s.l.) are probably related to the early stages of the uplift.

From a geomorphological point of view, the study area displays an overall smoothed morphology, with moderate relief and gentle slopes. The observation of aerial photographs, taken before the event of December 1982, shows a characteristic landslide morphology, with trenches, scarps, steps, undrained depressions, and reverse slopes (Figure 5.12). Moreover aerial photo analysis showed that several deep open fractures and flexural scarps were produced after 1956 and before 1979, in the area of the main detachment zone of the 1982 landslide. It is most likely that similar surface displacement was related to the 1972-74 earthquake sequence (Cotecchia, 1997).

Figure 5.3 - Rupture in the wall which crosses the Montelparo trench. The buildings on the left side are located in the stable portion of the hill; the rupture indicates the upper margin of the trench.

Figure 5.4 - The progressive enlargement of the Montelparo trench from 1812 to 1970.

The rainfall period that occurred in Ancona 10 days before the catastrophic 1982 landslide was characterized by an amount of precipitation not particularly relevant from the hydrologic point of view. Therefore, a fundamental role for the generation of the 1982 landslide was played by the co-seismic opening of the numerous fractures.

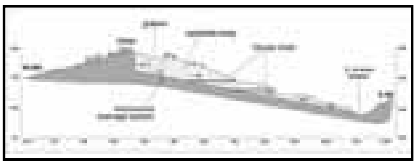


Figure 5.5 - Diagrammatic cross-section with the main control works planned.

Figure 5.6 - Aerial view of the December 1982 Ancona landslide.

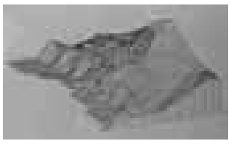


Figure 5.7 - Digital elevation model of the Ancona landslide, showing the main escarpments and trenches.

Figure 5.8 - View of the upper trench, with the main scarp in the foreground, and “antithetic” scarplets and fractures in the background.

Figure 5. 9 - Heavily-damaged buildings in the 1982 landslide affected area.

Visit itinerary

The visit itinerary to the Ancona landslides will include:

Stop 1:

General view of the landslide slope from the edge of the main scarp;

Stop 2:

A walk down the main landslide scarp to the upper trench.

Stop 3:

Close up view of tilted and crushed water wells in the trench.

Stop 4:

A walk from the upper trench to the lower trench; view of landslide secondary scarps and damaged buildings.

Stop 5:

Close up view of a 16th century post-house, showing the cumulative effects of past landslide movements.

Field itinerary

DAY 5

From Orvieto to Florence

Orvieto: a Case of an Unstable Town

C. Cencetti, P. Conversini, P. Tacconi

Introduction

Orvieto, one of the major historic-artistic towns of Central Italy, lies in the province of Terni, about 100 km north of Rome, at the boundary between the Regions of Umbria and Latium.

The town was built by the Etruscans in the IX-VIII century B.C., over a small tuffaceous cliff (about 1.3 km^2 in area). The town suffers from instability conditions, due to the particular geological and geomorphological features that are the main cause of the landslides affecting the cliff's perimeter.

The mass movements have produced, over time, a slow but inexorable degradation of the historic town, by progressively reducing its size.

Figure 5.10 - Damage to the Adriatic railway at the landslide toe.

The aim of this excursion day is that of illustrating the geological-geomorphologic features of Orvieto's Cliff, explaining the causes of the town's instability, and describing the works (the majority of which were realized recently) aimed at the conservation and consolidation of the cliff and the historic center of town.

Regional geologic setting

Orvieto's Cliff (Figure. 6.1) is an erosional relict of the edge of the *Alfina Tuffaceous Plateau*, a product of the volcanic activity, related to the Tyrrhenian rifting, which affected central-western Italy during the Middle Pleistocene. Its eruptive center (Vulsini Volcanic Complex) corresponded to the present-day Bolsena Lake (Alvarez, 1975; Varekamp, 1980; Faraone and Stoppa, 1988; Lavecchia, 1988).

The stratigraphic series of the Orvieto area (Figure.

Figure 5.11 - A 16th century post-house, showing the cumulative effects of recurrent landslide movements on the Montagnolo slope.

6.2) is upward characterized (Pialli *et al.*, 1978; Conversini *et al.*, 1995) by marine clays, sediments in fluvial-lacustrine facies of thin thickness (*Albornoz Series*) and, at the top, by the tuffaceous plate, constituting the Cliff properly named (*the "Rupe"*).

The tuffaceous cliff sustaining Orvieto is elliptical in shape, with its major axis orientated ENE-WSW. It lies sub-horizontally, with vertical or sub-vertical walls, higher along the south-western side. Its measurements are 1500 m in length, about 700 m in width, and between 40 and 70 m in thickness (Basilici *et al.*, 2000).

The Cliff lies on the top of a hill modeled over marine clays of Pliocene age, gently sloping (15°-18°) to the River Paglia alluvial plain. Clastic sediments (talus), produced by physical weathering of the tuff, surround the base of the whole Orvieto Cliff, and are variously distributed along the slopes overlying the clayey bedrock.

Gullies, up to 10-15 m deep, locally incise the clayey bedrock, starting from the upper limit of the cliff.

The landslides of Orvieto

The instability of Orvieto has been known since the XII century (Vinassa de Regny, 1904; Verri, 1905; Lotti, 1908; Martini and Margottini, 2000).

It is closely related to the lithological characteristics of the tuffaceous rock, and of its clayey substratum. Along the hill slopes, where the basal clays are covered by clastic detritial sediments, rotational and translational slides involve the two different lithotypes, separately or together. The main cause of these landslides is the process of saturation of the clastic sediments, or of the upper portion of the clays. This situation is related to the presence of a water table, whose base level is represented by the clays themselves. Instead, along the perimeter of the tuffaceous plate, the rupture mechanisms are referable to lowerings of marginal slices along the upper edge, rock falls or topples in the middle-upper portion of the cliff, and basal ruptures of blocks of various size (Figure 6.3).

The rupture mechanisms of the cliff are related to the distribution of cracks in the tuffaceous rock. The cracks, which are clearly visible along the whole of the cliff perimeter, are the consequence of the cooling phase of the pyroclastic high-temperature flow (Manfredini *et al.*, 1980; Cestelli Guidi *et al.*, 1983;

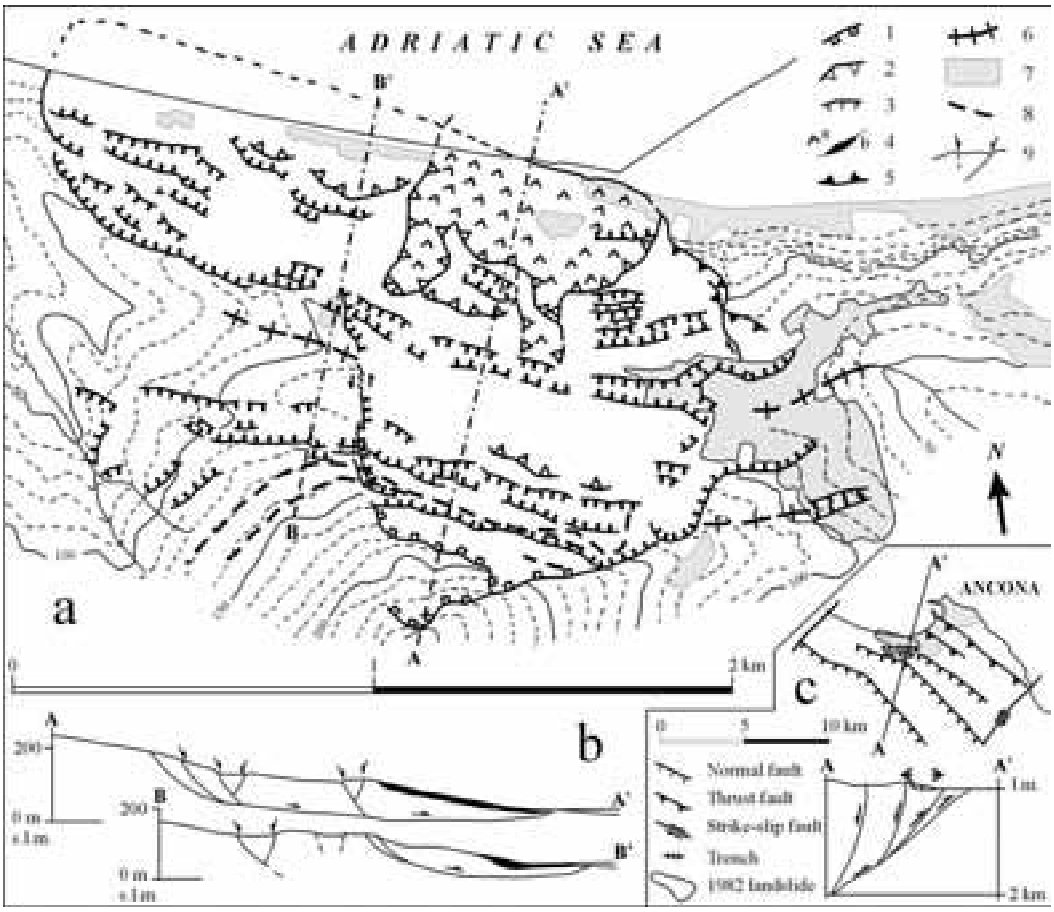


Figure 5.12 - Geomorphological sketch (a) of the Ancona landslide slope (after Dramis and Blumetti, in press); b. Landslide sections; c. Tectonic pattern.

Lembo Fazio *et al.*, 1984; Regione Umbria, 1990).
Also, human activity has played an important role in the instability of Orvieto, owing to the exploitation of the tuff of the cliff. With respect to this problem, the concessions by local Authorities for quarrying “pozzolana” (a typical tuff of Orvieto) inside the Cliff are very important.

Remedial measures

The Royal Decree of March 7, 1937 included Orvieto in the list of towns *“to be preserved at a total expense of the State”*. Nevertheless, until the mid 1970s, remedial work was sporadic and aimed at remedying urgent and risky local situations (Pane and Martini, 1997). In 1977, the Umbria Region established a global program aimed at a definitive consolidation of Orvieto, through a monitoring of the Cliff and its slopes.

The main works, completed at present, are all aimed at mitigating the hill’s natural morphological evolution, and eliminating the negative effects of human activity. They may be summarized as follow (Lunardi and Fornaro, 1980; Pane and Martini, 1997 – Figure 6.4):

- stabilization of the landslides along the slopes (by means of deep drainage wells and trenches, retaining structures, and slope reshaping);
- hydraulic improvement of the gullies (by means of reshaping, partial coating, and check dams);
- hydraulic and landscape reclamation, to control the erosive action of the waters (by means of reafforestation, springs

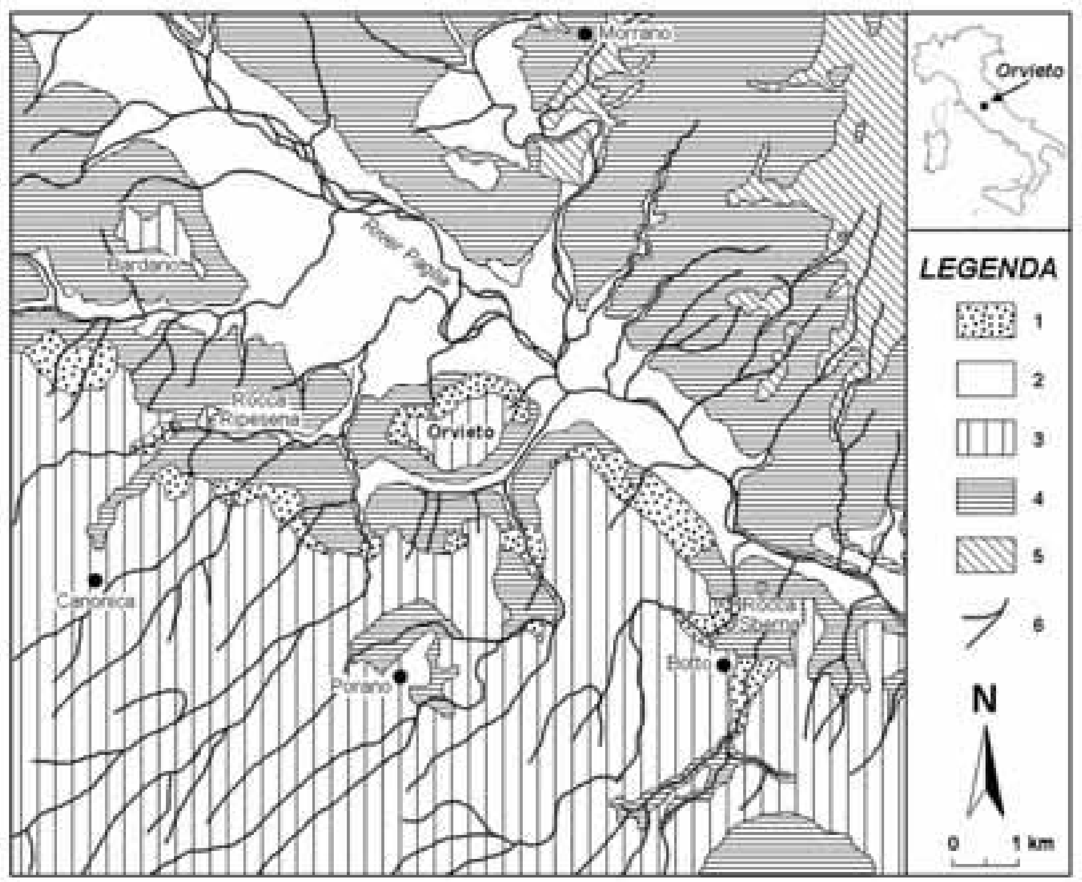


Figure 6.1 - Geological sketch of the Orvieto area. Legend: 1. talus (Holocene); 2. recent and present alluvial sediments, also terraced (Holocene - Upper Pleistocene); 3. volcanic rocks of the Alfina Plateau (Middle Pleistocene); 4. gravels, sands, and clays (marine clastic sediments, Lower Pleistocene – Pliocene); 5. marls and sandstones (pre-Pliocene bedrock); 6: Paglia River and its main tributaries

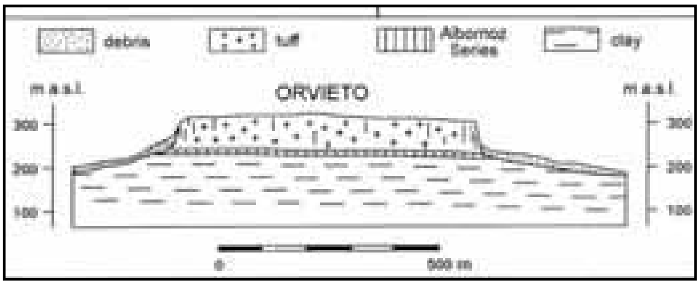


Figure 6.2 - Schematic geological section of the Orvieto Cliff (after Conversini et al., 1995, modified).

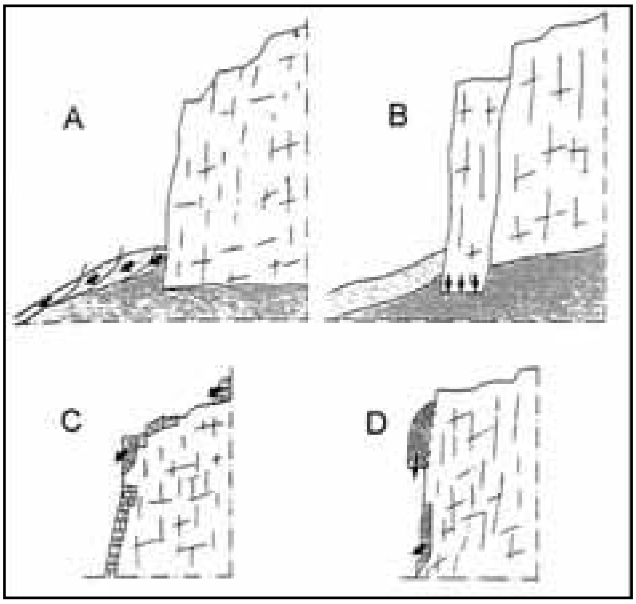
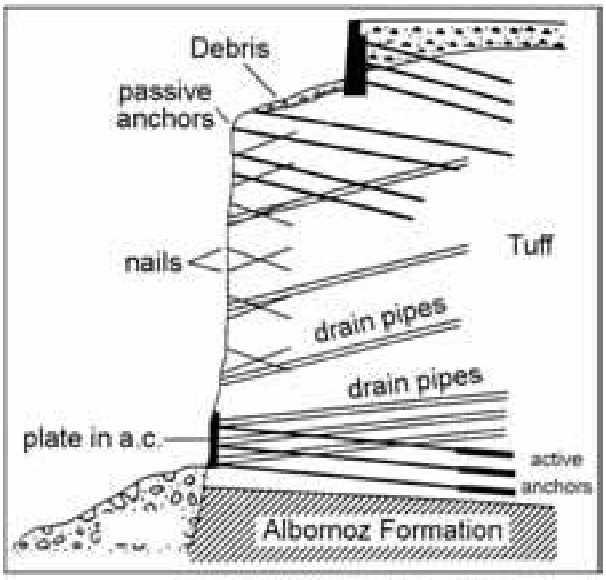


Figure 6.3 - Typical mechanisms of instability: A. rotational slides at the cliff's toe; B. lowering of marginal slices; C. topples and rollings; D. falls and basal ruptures (after Regione Umbria, 1990).

Figure 6.4 - Scheme of stabilization works along the cliff (from



interception, waterproof channeling etc.);

- strengthening of the tuffaceous cliff (by means of active and passive anchors, nails, and drain pipes);
- consolidation of the underground cavities;
- complete substitution of the old aqueduct and sewage system;
- strengthening and restoration of the historic walls founded close to the cliff brow.

At the same time, the Umbria Region installed a network of instruments for hydrological, geotechnical and topographic measurements, within a "Permanent Observatory for the Control and Maintenance of the Orvieto Cliff" (Pane and Martini, 1997).

Visit itinerary

The visit itinerary provides seven observation stops, as in the attached map (Figure 6.5):

Stop 1:

at the parking lot in front of Etruscan Necropolis. This viewpoint lets us examine the characteristics of the cliff on its NE slope. The morphological contrast, due to selective erosion processes, between the tuffaceous plate (with tabular morphology, such as it can

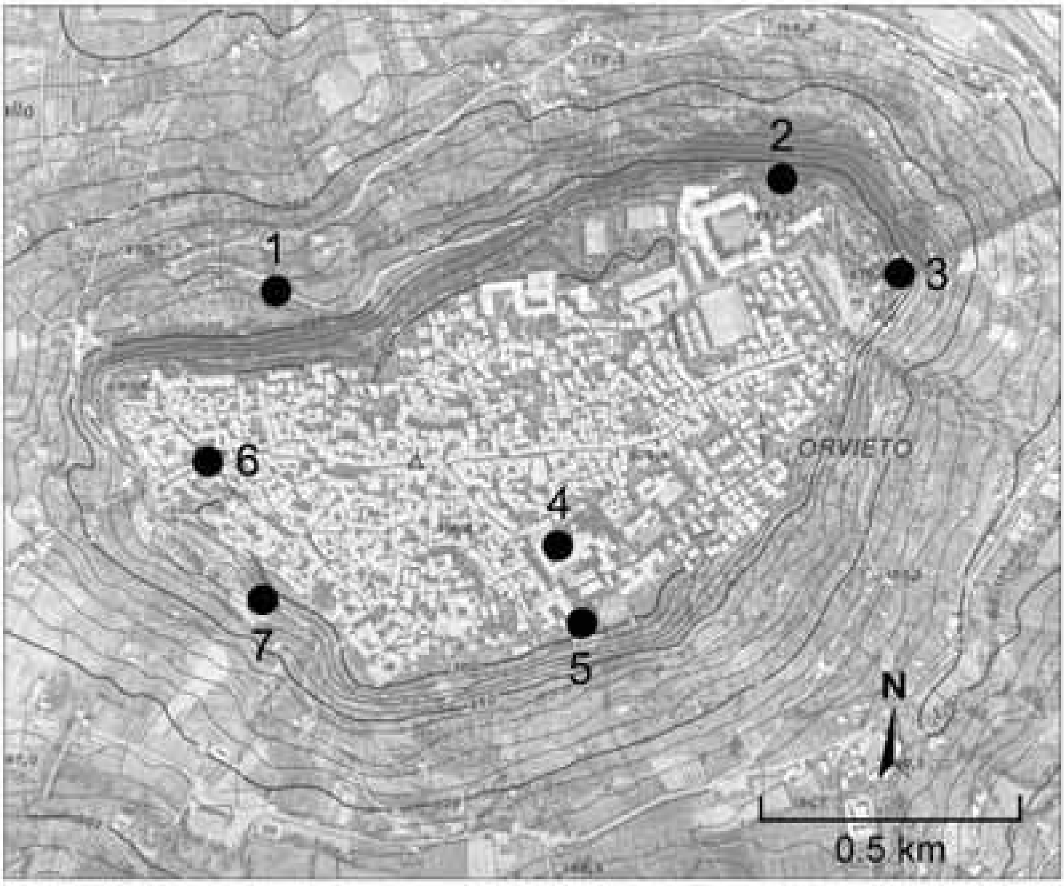


Figure 6.5 - The observation stops along the field itinerary.

be compared to a *mesa*), and the hill slopes (cut by deep gullies), can be observed.

Stop 2:

Visit to the Etruscan Necropolis.

Stop 3:

Panoramic view from Cahen Place towards north, of the Valley of the Paglia River, which flows at the toe of Orvieto Hill; it is possible to observe the badland morphology affecting the Pliocene marine clays outcropping on the left bank of the river. Many badlands areas were reclaimed by human effort, with the aim of assigning marginal lands to agriculture. Turning to face toward WNW, Bardano's *mesa*, Rocca Ripesena's *butte,* and erosional processes in progress, are clearly visible too.

Stop 4:

Visit to the Fortress and St. Patrizio's Well. The Well was planned by Antonio da Sangallo il Giovane, to let the Orvieto inhabitants draw water, in ancient times, by means of pack animals.

Stop 5:

The Cathedral, the most important expression of Gothic art in Umbria.

Stop 6:

Visit to two wide caves located within the Cliff, excavated × since Etruscan age.

Stop 7:

Visit to Cava's Well, probably of Etruscan origin, regained by Pope Clemente VII; in the immediate neighborhood of the Well there exists an ancient pottery, active between the end of the XIV century and the middle of the XVI century, regained at present after a difficult excavation and open to the public.

Stop 8:

Walk along the toe of the cliff, where it is possible to examine the strengthening works of the cliff carried out so far, and the installed monitoring instruments. The vertical cracks in the volcanic rock are also visible as well as the reinforcement measures aimed at avoiding the disastrous fall of tuffaceous blocks. In the past, reinforcement and supporting works were carried out using flasks to separate the cracked blocks and sustaining, by means of breast walls, the others, thus preserving a precarious equilibrium. Afterwards, starting in the 1970s, nails and anchors, placed at various heights, were used, whose heads, at the end of the interventions, were hidden by means of tuffaceous mortars. These works enabled the cliff to reacquire its natural look.

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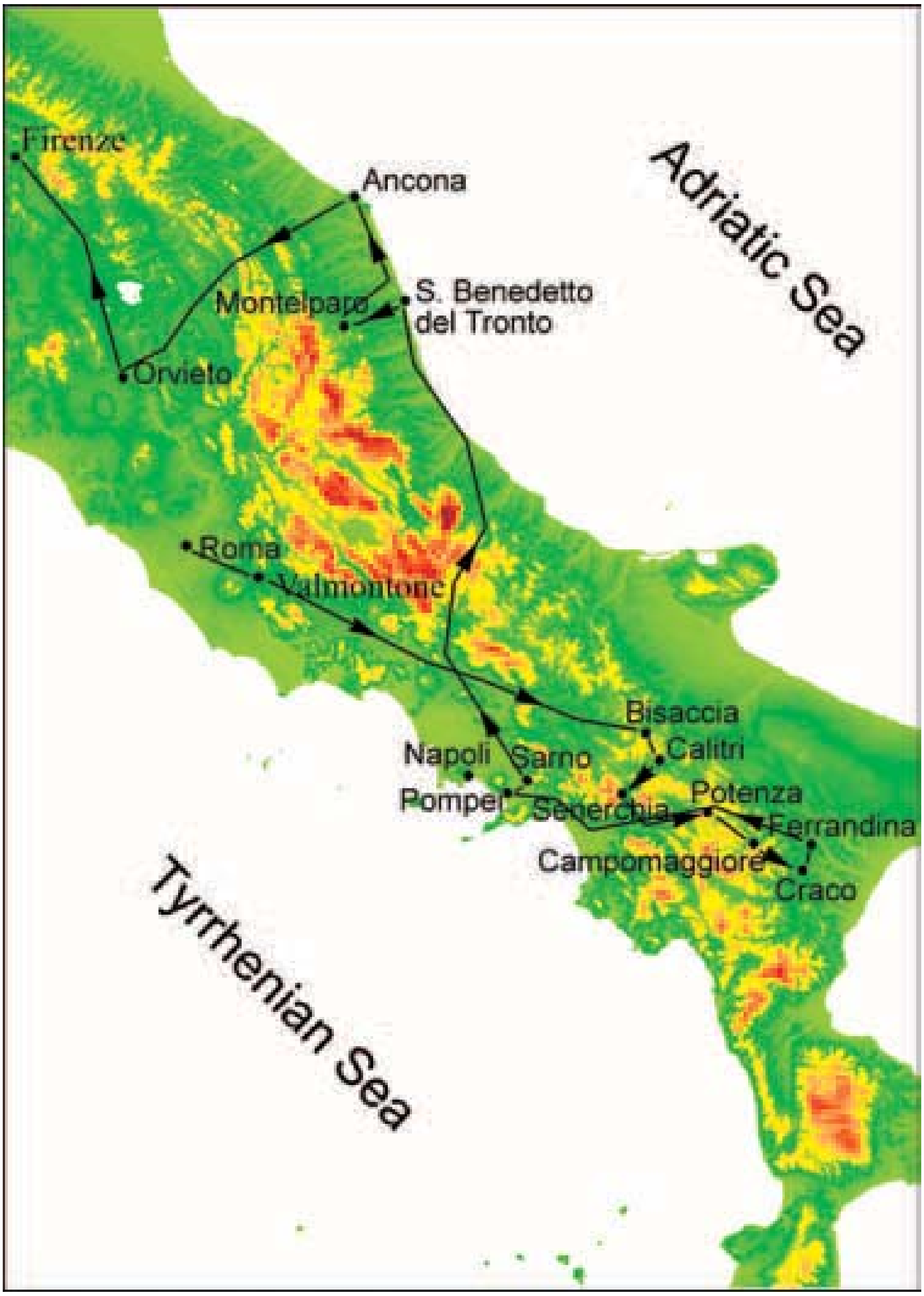
field trip itinerary

32nd INTERNATIONAL GEOLOGICAL CONGRESS

FIELD TRIP MAP



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