2. Neotectonics and large-scale gravitational phenomena in the Umbria-Marche Apennines, Italy

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Introduction

The role played in the evolution of the relief by deep-seated gravitational deformations along slopes, has been pointed out by several authors who analysed their typology and distribution in different geological and geomorphological conditions (Jahn, 1964; Ter-Stepanian, 1966 and 1977; Zischinsky, 1969; Nemcok, 1972; Radbruch-Hall *et al.*, 1976; Mahr and Nemcok, 1977; Guerricchio and Melidoro, 1981; Sorriso-Valvo, 1984; Savage and Swolfs, 1986). These phenomena are particularly frequent in Italy, where they have been favoured by the noteworthy relief, the complex geologic structure, the tectonic and seismical activity, and the frequence of extreme rainfall characterising its territory (Dramis *et al.*, 1983; Sorriso-Valvo ed., 1984, 1987 and 1989). Some of them evolved into huge landslides of different type, or sometimes are connected to the latter by a cause/effect relationship.

Deep-seated gravitational deformations and their evolution into landslides

Deep-seated gravitational deformations and their related huge landslides are complex phenomena taking place through a wide variety of mechanisms whose genesis and evolution are controlled by several factors, among which structure, relief, and tectonic and seismic activity have a particular importance (Terzaghi, 1962; Radbruch-Hall *et al.*, 1976; Solonenko, 1977; Radbruch-Hall, 1978; Dramis *et al.*, 1983; Carton *et al.*, 1987; Savage and Varnes, 1987).
The most typical morphological elements of deep-seated gravitational deformations are the following (Radbruch-Hall *et al.*, 1976; Mahr and Nemcok, 1977; Radbruch-Hall, 1978; Dramis *et al.*, 1983; Pieruccini, 1988; Dramis and Sorriso-Valvo, 1994):

a) surface extension is generally ranging around at least 1 square km;
b) thickness of deformed mass ranges around several tens (or sometimes hundreds) metres;
c) displacements are reduced with respect to the volume of involved materials;
d) a continuous shear surface delimiting the deformed mass is lacking;
e) evolution is very slow, happening in "geologic" times with long periods of inactivity or extremely reduced activity, alternated with short and sudden activations, often as a consequence of earthquakes or extreme rainfall;
f) deformational mechanism is continuous creep, with accelerations and creep ruptures;
g) kinematics is almost always influenced by active or residual regional stress and high confined pressure;
h) topography has a reduced influence whilst structure plays a strong control on the location and typology of the deformation;
i) deformed slopes are often invoved in more surficial (secondary) landslides.

The most recurrent deformational typologies are sackungs, lateral spreadings and deep-seated block slides (Jahn, 1964; Zischinsky, 1966 and 1969; Varnes, 1978; Dramis and Sorriso-Valvo, 1994).
Sackungs are connected with rock flows affecting huge jointed or stratified rigid masses, which can be considered homogeneous as a whole. These, being loaded for extremely long

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periods by their own weight may slowly deformate, in analogy to what happens during tectonic folding. It is easy to understand that to activate these deformational phenomena, slopes have to be high enough to induce strong gravitational stress in the bedrock, and resistant enough to maintain their overall stability. Gravitational stress produces shear surfaces, often coinciding with existing tectonic discontinuities (joints, faults, thrust or backthrust planes) in the surficial portion of the slopes, whilst more in depth the high pressure induces plastic deformation, without a proper yelding surface (Mahr and Nemcok, 1977). The highermost portion of the deformed slope is affected by extensional stress which produces high angle shear planes, to which counterslope steps and graben-like trenches, are associated. The lowermost portion of the slope is affected by compressional stress determining bulging and, sometimes, low-angle shear planes (Nemcok, 1972; Mahr, 1977; Ter-Stepanian, 1977; Guerricchio and Melidoro, 1981; Savage and Swolfs, 1986; Savage and Varnes, 1987).

Surface effects on the upper part of the slopes are very similar to those produced by listric faults, making it difficult to recognise them properly in the field. On the other hand, on slopes (such as those produced by normal faults) disposed perpendicularly to the minimum stress, extensional and gravitational stresses being consistent can undergo feedback phenomena, mostly in coincidence with strong earthquakes (Dramis *et al.*, 1982).

Lateral spreads are characterised by horizontal extension of the relief, balanced by shear or tensile fractures and may happen in the following ways.

a) Bilateral spread: gravitational deformations produce a bilateral extension of the relief without generating any shear surface or basal flow zone. Double ridges locally found at the top of high and elongated reliefs modeled in rigid and "homogeneous" rocks have been attributed to these phenomena (Jahn, 1964). Another deep-seated gravitational deformation with bilateral extension of the relief but associated with both trench-like depressions at the summit and shear planes at the base, has been described by Beck (1968) and included by Varnes (1978) in his classification of mass movements.
b) Tectonic-gravitational spread: gravitational deformations affect morpho-structural reliefs produced by active thrusting. Spreading starts as a consequence of tectonics but then evolves because of gravity, predisposing conditions favourable to a successive activation of huge landslides (Dramis and Sorriso-Valvo, 1994).
c) Deep-seated block spread: deformations involve rigid and thick rocky masses overlying sub-horizontal less-competent layers (Cruden and Varnes, 1993). In these conditions, gravitational stresses can trigger plastic flows (sometimes combined with extrusion phenomena) in the underlying material, causing rupture into blocks of the rigid masses, often following existing discontinuities. Blocks can experience subsidence, limited traslation, rotation, tilting or downlifting, giving origin to counterslopes, steps and trenches in this case too.

Deep-seated block slides (Varnes, 1978; Agnesi *et al.*, 1987; Dramis *et al.*, 1987) are characterised by relatively small displacements of overall intact and thick rigid blocks overlying faintly sloping less competent layers. Their main surface effects are large scarps and trenches, in the upper and intermediate portion of the slope, and bulging associated with frequent shear planes with geometry typical for a reverse fault, in its lowermost portion.

Taking into account the characteristics of the above described phenomena, it is evident that only sackungs and lateral spreads, of type a (possibly less the Beck type) and b, fit well in the general definition of deep-seated gravitational deformation, whilst deep-seated block spreads and block slides should better be included among landslides, being characterised by displacements along more or less continuous yelding surfaces. Anyhow, taking into account the moderate entity of displacement with respect to dimension of involved masses and the extremely slow evolution with dominating creep phenomena, it has been decided to include the above said phenomena among

deep-seated gravitational movements, separating them from landslides s.s.
After a generally very long evolutionary phase, deep-seated gravitational phenomena can evolve in huge landslide movements of different types (Guerricchio and Melidoro, 1973; Radbruch-hall, 1978; Nemcok, 1982), often characterised by "scale" factors (Goguel, 1978). From this point of view, deep-seated gravitational deformations can be considered as preparing stages for huge gravitational collapses that, anyhow, not always complete their evolution (Hutchinson, 1988; Dramis and Sorriso-Valvo, 1994). The most striking phenomena are those connected with deep-seated block slides, whose evolution into translational slides can sometimes produce superimposition of terrains having dimensions comparable with those of tectonic phenomena (Nijman, 1971).

Geology and neotectonic evolution of the Umbria-Marche Apennines

The Umbria-Marche Apennines is a complex fold-and-overthrust arcuate belt with a NE vergence (Calamita and Deiana, 1988), created as a consequence of Neogene compressional tectonics which affected a thick sedimentary cover.
The latter includes at its base a thick (some 800 m) massive calcareous shelf complex (lower Lias), followed by a well stratified pelagic and emipelagic sequence (ca. 1400 m thick) made up of limestones, marly limestones, cherty limestones and marls (middle Lias - lower-middle Miocene). The sedimentation ends with more or less thick turbiditic terrains (Tortonian - lower Pliocene), with evaporitic and lagoon facies (Messinian) intercalated in its upper portion (Cantalamessa *et al.*, 1986).
The most striking surficial effects of compressional deformation are two main anticlinoric structures (the Umbria-Marche ridge s.s. to the West and the Marche ridge to the East), whose axes have an overall trend NW-SE to the North, and N-S up to NNE-SSW to the South. An important overthrust is that of the Sibillini Mts, which emplaced Mesozoic-Neogene terrains of the Apennine Ridge over the more external Tertiary deposits of the eastern area. Another overthrust (the Valnerina one) superposed terrains of the internal ridge over those of the Camerino basin, located in between the above said ridge and the easternmost anticlinoric structure. To the South, the Camerino synclinorium looses its identity and the two above said ridges merge in the Sibillini Mts. massif.
In the eastern sector of the area, in the peri-Adriatic belt, the compressional structures are unconformably covered by sands, conglomerates and pelites (lower Pliocene - lower Pleistocene), whose surficial setting follows a monocline gently dipping to the NE (Ori *et al.*, 1991). Over most of the area, the tectonic phase responsable for thrusting took place in the timespan middle Miocene - middle Pliocene, but it continued in more recent times along the Adriatic coast, where reverse faults and faint anticlinalic structures with eastern vergence (such as those of Porto San Giorgio, Polverigi and Senigallia) affecting Pleistocene deposits are present (Cantalamessa *et al.*, 1987). Listric normal faults lowering seawards the above sediments are sometimes associated to these structures.
Present-day activity of compression is still continuing in the easternmost part of the area, as testified by focal mechanisms of earthquakes (Gasparini *et al.*, 1985; Riguzzi *et al.*, 1989).
Starting from the upper Pliocene, the area experienced extensional tectonics, which, moving eastwards from West, was following compressional tectonics. In this way, normal faults, mostly trending in parallel to the Apennines and faulted blocks degrading towards the Tyrrenian Sea, have been generated. Extensional tectonics largely reactivated previous compressive discontinuities, producing noteworthy inversion phenomena, located at different depths (Nijman, 1971; Calamita and Pizzi, 199).
In the axial portion of the Apenninic belt, the extensional phase tooke place in continental conditions because of a general uplift started at the end of the compressive phase. In this

framework, tectonic activity largely influenced the evolution of the landscape, where fault scarps dividing the relief into blocks (mostly in the SW of the area) show morphological evidence (Centamore *et al.*, 1980).
Combined action of apenninic normal faults and transversal faults which played as transfer elements (Calamita and Pizzi, 1992), produced intramontane tectonic depressions bordered by showy fault scarps. Starting from upper Pliocene - lower Pleistocene (Ge.Mi.Na., 1963; Blumetti and Dramis, 1992), these depressions hosted lacustrine basins whose sedimentary sequences add up to some hundreds m. Present-day activity of extensional tectonics is testified by both tectonic discontinuities, displacing also the most recent deposits (Calamita *et al.*, 1982; Blumetti *et al.*, 1993), and focal mechanisms of the strong earthquakes frequently affecting the area (Gasparini *et al.*, 1985).
Starting from the end of the lower Pleistocene and up to the present, the whole Central Italy has been involved in a faster uplift, even though with different rates (Demangeot, 1965; Ambrosetti *et al.*, 1982; Dufaure *et al.*, 1989; Dramis, 1992). As a consequence, marine deposits of the peri-Adriatic Pliocene-Pleistocene Basin assumed their typical monocline structure, reaching altitudes exceeding 200 m a.s.l. close to the coastline and up to more than 1.000 m a.s.l. mountainwards, at Mt. Ascensione (Cantalamessa *et al.*, 1987). Also along the Tyrrhenian side, altitudes up to some hundred metres of Pleistocene marine deposits and shorelines (Ambrosetti *et al.*, 1987; Alfonsi *et al.*, 1991) testify for the uplift. Along the axis of the Apennines, the uplift was even stronger, as demonstrated by the altitude of planation surfaces and continental terraced deposits correlated with Pleistocene sea levels (Dufaure *et al.*, 1989; Dramis, 1992).
Along the western side of the Apenninic belt, the uplift interacted with extensional tectonics enhancing the activity of existing normal faults and producing new ones featured by very long and straight apenninic lay-outs, sub-vertical planes and moderate displacements.
The erosion deepening caused by the uplift produced widespread phenomena of morphoselection, which throwing into morphologic relief the calcareous anticlinoric structures (Ciccacci *et al.*, 1985). This is particularly evident along the eastern side of the belt, where erosional phenomena created differences in height up to more than 1000 metres between the overthrust fronts and the terrigenous deposits located eastwards. The deepening was less strong along the Tyrrhenian side, because of the progressive lowering to the West of planation and deposition surfaces caused by normal faults (Dufaure *et al.*, 1989; Dramis, 1992).
The uplift manifested itself with different amplitude moving from North to South, thus determining in the area the creation transversally to the chain of three main morpho-structural undulations whose elevation progressively lowers moving from the South northwards (Dramis *et al.*, 1991). This is clearly shown by interpretation and altitudinal analysis of planation surfaces, and by sedimentological-stratigraphic analysis of Pliocene-Pleistocene marine closure deposits. Also the bedrock structure of the Apenninic calcareous ridges, which as previously said has an overall axial trend to the North, perfectly fits with the above morphological setting.
Transversal morphostructures are delimited by anti-apenninic faults, whose activity seems to have continued, with moviments varying in time, starting at least from the Tortonian up to the present. These discontinuities strongly influenced sedimentation in Miocene-Pliocene-Pleistocene basins and, after the emersion, the evolution of drainage network (Boccaletti *et al.*, 1983; Ciccacci *et al.*, 1985).
Recent and present activity of these trasversal tectonic elements seems to vary both in space and time: in fact, they show to have acted as normal, trans-tensive and trans-pressive. This can be explained both in an extensional stress field SW-NE, and in a compressional stress field N-S, either alternating or superimposing to the former (Centamore *et al.*, 1980; Calamita and Pizzi, 1992).

Historical seismicity of the area

Archive reserch allowed to point out the occurrence in the area of about 60 intense (VIII - IX MCS) earthquakes from 1000 to 1984, with a strong clustering of events in the last 150 years (Baratta, 1901; C.N.R., 1985).
Historical investigations also evidenced more ancient strong earthquakes such as the 102 B.C. Valnerina event, the 217 B.C. event of Val Tiberina (occurred during the Lake Trasimeno battle between the Hannibal and the Roman armies), and the VIII-IX MCS events which struck Spoleto in 446 and 801 B.C.
The strongest earthquakes occurred in the Norcia - Cascia area in 1328, 1703, 1719, 1730, 1783, 1859, 1979. Among these, the strongest ones (both X MCS) were the 1328 event (which destroyed Norcia, Preci and Montesanto) and the 1703 event (which caused about 10.000 victims in a vast area between Norcia and L'Aquila).
Another area affected by strong earthquakes is the Assisi-Foligno-Spoleto basin. Here, in 1832, a IX-X MCS event caused severe damages to the towns of Bevagna, Cannara and Foligno (Anonimous, 1832; Rutili Gentili, 1832; Mercalli, 1883).
A particularly destructive seismic period in Central Italy was XVI century, when two of the strongest earthquakes of the last millennium occurred: the already mentioned 1703 event (Norcia - L'Aquila), the 1781 event (Cagli-Pesaro), and the 1799 one (Camerino) (Osservatorio Geofisico dI Macerata, 1982-Com. Mont. Fabriano).

Typology and distribution of deep-seated gravitational deformations in the Umbria-Marche area

Systematic geomorphologic analysis of the Umbria-Marche area allowed to recognise a noticeable amount of deep-seated gravitational deformations and large-scale landslides of different type (Dramis *et al.*, 1995). Altogether, some 500 phenomena have been individuated, with a frequency of 0.06 per square km, a mean extension around 2 square km and a maximum area of about 15 square km.
In the area, the main genetic factors of these phenomena are the following:

a) bedrock geology is characterised by high thickness of massive calcareous and arenaceous rocks overlying levels less resistant or thinly stratified with thin pelitic intercalations;
b) structure derives from compressional tectonics to which the presence of strong residual stress and shear zones, along which large-scale gravitational displacements can occur, are connected;
c) the area recently underwent a strong uplift, mostly along the axial belt of the Apennines, where the presence of resistant rocks allowed the creation of high and steep slopes bordering either deep transversal valleys or overthrust fronts;
d) extensional tectonics originated high fault scarps which sometimes brought to the surface potential deep sliding planes, whilst compressional tectonics, still active along the coast, is producing folding along whose eastern sides huge gravitational phenomena can take place;
e) seismicity is quite high, mostly along the chain axes and, subordinately, along the Adriatic coast (Postpischl ed., 1985).

First activation and successive evolution of the deep-seated gravitational phenomena observed in the area can be dated only by means of relative methods, lacking any good datable element. Particularly useful to this end are the relationships between slope elements deformed or involved in large-scale landslides and stratified debris deposited in periglacial environment (Coltorti and Dramis, 1988), terraced alluvial deposits, lacustrine and morainic deposits. These relationships allow to set the first activation of many phenomena before the last

Pleistocene cold phases (or, at least, contemporarly to them), and, in many cases, to recognise Holocene reactivations (Carraro *et al.*, 1979; Dramis *et al.*, 1988; Gentili and Pambianchi, 1993). Only rarely historical or recent reactivations of the phenomena were obsreved, in coincidence of either earthquakes (Coppola *et al.*, 1978; Blumetti *et al.*, 1990) or extreme precipitations in the terrigenous lithotypes of the Adriatic belt (Coltorti *et al.*, 1985).

Deep-seated graviational phenomena and large-scale landslides along Western (fault) slopes of the Apenninic ridges

Many cases of deep-seated gravitational deformations can be observed along the western sides of both the calcareous Apenninic belts and the massive arenaceous Laga Mts. Particularly important are the sackung and block slide phenomena found in the Sibillini Mts., along the large fault slopes bordering to the East the Cascia, Norcia and Castelluccio depressions, and the SW slope of Mt. Fema.

On the highermost portion of these slopes, counterslope steps, scarps and trenches are present, in addition to open fissures, from some ten centimetres up to a few metres wide, whose freshness is testified by lack of debris inside them

Threnches, scarps, steps and couterslopes, located at the top of slopes, together with huge landslides, partially covered by stratified debris, characterise the Mt. Alvagnano -Castel S. Maria structure (Fig.1) to the South (Blumetti *et al.*, 1990). Seismic and historical data testify for an evident reactivation of some landforms during the 1703 earthquake (X MCS), whilst less intensive surface effects were produced by the 1979 event.

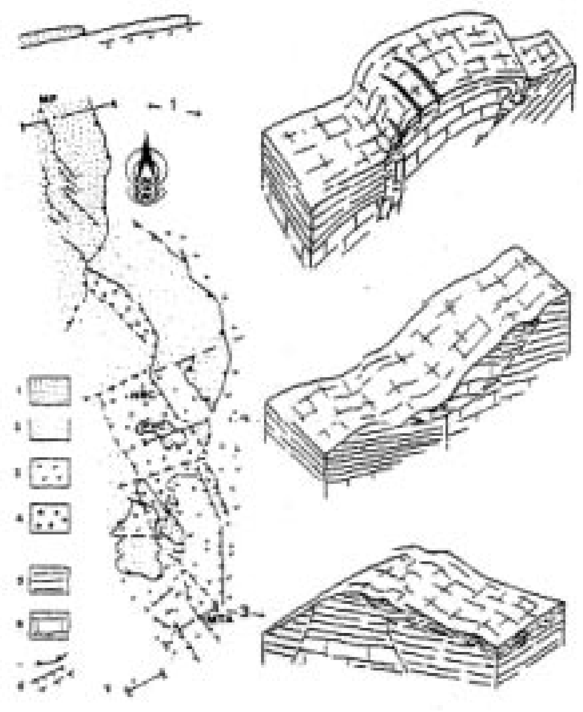


Fig. 1. Structural sketch of the Mount Fema-Mont Alvagnano area, and cross-section representing deep seated gravitational deformation and large scale landslides on its western fault slopes: 1)upper overthrusted units; 2) middle overthrusted units; 3) lower units; 4) deposits filling the depression; 5) limestones and marly limestones (Middle Lias-Miocene); 6) limestones (Lower Lias); 7) overthrust; 8) normal fault; 9) cross-section traces: MF – Mt. Fema; MTA – Mt. Alvagnano; NRC – Norcia; PVC – Poggio Valaccone.

The above seems to testify for a step-like evolution of deep-seated gravitational deformations in correspondance with major earthquakes. It also seems possibe to attribute the origin of the huge landslide accumulations found at the base of fault slopes (Blumetti *et al.*, 1993) to collapse of rocky masses previously affected by deep-seated gravitational deformations, probably as a consequence of past earthquakes.

Block spreads and deep-seated block slides, sometimes evolving into huge translational slides, found along the NW side of Mt. Gorzano (Monti della Laga), a little South of the Sibillini Mts., are connected with fragmentation of thick arenaceous bodies into blocks, due to normal faults (Dramis *et al.*, 1987).

Other gravitational phenomena, found along the large fault slopes bordering to the East the intermontane tectonic depressions, are huge translational slides, probably deriving from deep-seated block slides. Those developed as a consequence of exhumation of potential sliding surfaces, corresponding to previous compressional shear planes (Nijman, 1971), operated by the above said border faults. A showy example is possibly represented by the small relief of Poggio Valaccone, located at the base of a fault slope bordering to the East the Norcia depression (Fig.1). A similar but smaller phenomenon has been recognised along the eastern slope of the Castelluccio basin.

Deep-seated graviational deformations and large-scale landslides along the eastern slopes of ridges and overthrust front

Gravitational morphogenesis reaches its maximum development on the eastern slopes of calcareous ridges, along oversteepened sides of both folded structures and overthrust fronts. Along these slopes, steps, trenches, undulations and intense fracturing can be observed, together with large scale landslide scarps; at the foot of the slopes, wide and thick landslide scree deposits, sometimes coalescing, overlie marly-clayey levels of the most recent terrains of the Umbria-Marche Succession. Generally, those deposits are often covered by upper Pleistocene stratified slope-waste deposits, which sometimes are tilted counterslope; the two units are locally interfingered thus testifying for an ancient origin of the movement and for its successive reactivations (Coppola *et al.*, 1978; Gentili and Pambianchi, 1993). Main causes of these complex gravitational movements are to be found in the intense tectonic deformation of the bedrock, which has been folded and overthrusted, and in the presence of residual compressional stresses. Recent uplift with connected creation of erosional differences of height, favoured the activation of bilateral spreadings of the type described by Jahn (1964), which originated double ridges, lateral spreads and sackungs, mainly along slopes modelled on thick stratified calcareous formations; also deep-seated block slides, along either existing shear planes or zones, or marly-clayey stratigraphic levels, were activated which, because of strong altitude differences, easily evolved into large-scale gravitational collapses.

Deep-seated graviational deformations and large-scale landslides along the slopes of transversal valleys

Deep-seated gravitational deformations and large-scale landslides are present, even though with less frequency, also inside the chain, where deep incisions transversal to its axis caused by fast and intense uplift allowed the intersection at various heights of slopes with potential sliding surfaces, mostly represented by marly layers dividing more rigid calcareous beds. The overall bedding accordingly to the slope, due to the general northward dipping of the structures, favoured the activation of huge block spreads and deep-seated slides on southern valley-sides (Dramis *et al.*, 1988; Gentili and Pambianchi, 1993). Somewhere, sackung phenomena have been recognised too (Coppola *et al.*, 1978). One of the most representative examples of deep-seated gravitational deformation can be found along the portion of the Marche ridge in between the Fiastrone and Chienti Rivers, slightly South of Camerino (Dramis *et al.*, 1988; Gentili *et al.*, 1992). There, at the base of the slope, modeled in marly limestone, shearing planes and counterslope tilting of Holocene alluvial deposits can be observed. In its median portion, the

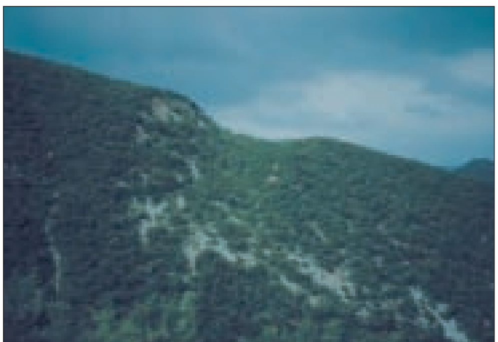


Fig. 2. The Valdiea trench

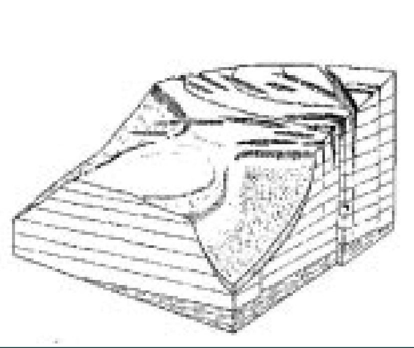


Fig. 3. The Mt. Frascare deep-seated gravitational slope deformation

slope showss a trench whose freshness suggests a very recent activation of the deformation (Fig. 2). This is further confirmed by oral tradition among local people, speaking of reactivation of the deformation as a consequence of the strong 1741arthquake (IX MCS). Slightly mountainward along the valley bottom, an alluvial terrace of the same order contains lacustrine silty and clayey levels with abundant vegetal remnants, whose age is comprised between 27,000 and 30,000 years b.p. (Damiani and Moretti, 1968). This demonstrates the step-like activation of the landslides during the deposition of upper Pleistocene alluvial deposits.
Sometimes, the connection with recently active transversal discontinuities is particularly evident. Particularly interesting for this are the deep-seated gravitational phenomena characterising the northern slope of Mt. Frascare , on the right side of the Fiastrone River (Fig. 3). In the uppermost part of a slope affected by a wide block spread, involving marly-calcareous levels overlying marls, steps and trenches trending SSW-NNE are present, following an en échelon system transversal with respect to the slope and fitting with a right transcurrent displacement of the N-S trending faults which cross the area.
Somewhere else, finally, relationships between gravitational deformation and tectonic displacement are not clear, phenomena being possibly induced only by high relief. Such is the case of the NW slope of Mt. Le Siere (North of Fabriano), modeled in thinly stratified marly limestones and affected at its summit by a showy sackung.

Cases of historical and recent reactivation of gravitational phenomena in the area

Historical research, mostly focussed on the Valnerina area, pointed out reports of earthquake triggered gravitational phenomena.
For example, from the 1328 earthquake collapses of "mountains" and "opening of "abysses" in the ground were reported (Villani, 1848; Baratta, 1901). Probably some particularly fresh morphological elements in the area (such as scarplets, trenches and landslide bodies) could be related to this event.
Baratta (1901) reported that during the 1703 earthquake, Mt. Alvagnano, close to Norcia, was strongly affected by surface deformation over a belt more than 1500 yards large and about 32 palms. Geomorphological features on top of the hilltop (such small fresh scarplets within a large trench), connected with the reactivation of a deep seated gravitational slope deformation, have been referred to that event (Blumetti *et al.*, 1990).
In connection with the 1703 earthquake, the same author reported about the opening of a long and wide ground fracture on Mt. Corvo, close to the Leonessa tectonic depression, and a deep hole on top of Mt. Amaro, in the sorroundings of Sigillo. Field geomorphological evidences seem to be consistent with the historical record.. In particular, the presence in the area of a deep depression with loose debris at the bottom supports the hypothesis that it was related to the collapse of a karstic cave in the Scaglia Rosata limestone. A similar depression, denominated “buca del terremoto” (earthquake hole), was produced in the Scaglia Rosata limestone may be observed close to Camerino, on top of Mt. Colleluce. Nothwistanding the reference to earthquake in the landform name, there is no historical record of any seismic event connected with the possible collapse.

Finally, three huge landslides were triggered in the area of Mt. Nerone - Piobbico during the catastrophic earthquake of 1781 (Bisci *et al.*, 1995).
Concerning the reactivation of deep-seated gravitational slope deformations, A showy example can be found along the portion of the Marche ridge in between the Fiastrone and Chienti Rivers, slightly South of Camerino (Dramis *et al.*, 1988; Gentili *et al.*, 1992; Gentili and Pambianchi, 1993). There, at the slope feet, two shearing planes can be observed within the lowermost member of the rigid marly-calcareous Scaglia Rosata, whose uppermost portion show a mountainward dip, tilting in the same direction the Holocene fan deposits too. In its median portion, the slope has a thench whose freshness suggests a recent activation of the deformation. This is further confirmed by oral tradition among local people, speaking of a reactivation of the deformation as a consequence of the 1741 earthquake (Dramis *et al.*, 1995) and, possibly, the 1799 earthquake. Slightly mountainward along the valley bottom, an alluvial terrace of the same order contains lacustrine silty and clayey levels with abundant vegetal remnants, whose age is comprised between 27.000 and 30.000 yaers B.P. (Damiani and Moretti, 1968). This demonstrated a step-like activation of the landslides during the deposition of upper Pleistocene alluvial deposits (Dramis *et al.*, 1988). About 500 m to the south (close to Valdiea), a huge mass of Scaglia Rosata limestone, related to a gravitational event, overlies the above mentioned alluvial materials.

Fig. 4. Fracture on the Mt. Fema south-western slope reactovated by 1979 Norcia earthquake

Another possible historical reactivation of deep-seated gravitational slope deformation is that of the 1866 earthquake (VIII MCS) wich struck the area of Spoleto. Concerning this event reported that on the eastern side of the Spoleto tectonic depression (between Spoleto and Campello) "the mountain was opened over one mile length". Field survey confirmed the presence in the area of trenches up to 2 km long, parallel to the slope and clearly connected with deep-seated gravitational deformation. The extreme freshness of these features seems to testify a possible reactivation in very recent times.
A showy reactivation of a sackung type gravitational deformation, connected to the 1979 earthquake (VIII MCS) was that observed by oral testimonies of local people. who reported about the opening of cracks and the reactivation of trench scarplets on the slopes of Mt. Fema (Dramis *et al.*, 1995; Fig. 4).
During the same earthquake, a number of ground fractures, more than 100 m long, were produced also along the northward continuation of the trench of Mt. Alvagnano, close to the town of Norcia (Blumetti *et al.*, 1990).

Deep-seated graviational deformations and large-scale landslides along the Adriatic Coast.

Along the Adriatic coast, trenches trending in parallel with the coastline and sometimes delimited by fractures, and steps lowering seawards, almost identical to fault scarplets, have been found in wave-cut cliffs, generally no more active and separed by the sea through small beaches. These landforms are frequent along NE slopes of compressional structures with an Adriatic vergence, made up of lower-middle Pleistocene clayey-arenaceous-conglomeratic terrains (Cantalamessa *et al.*, 1987), presently still active as testified by hypocentral depth and

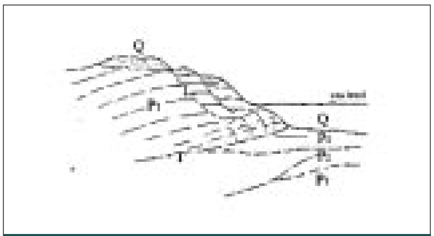


Fig. 5. Cross-setion of a deep-seated gravitational deformation along the Adriatic coast: P_1 - Lower Pliocene; P_2 - Middle Pliocebe; Q - Quaternary; T - Thrust, L - Listric fault

focal mechanisms of earthquakes (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 the compressional tectonics which prosecutes in uplifting the structures (Dramis and Sorriso-Valvo, 1994). Within this framework, large scale rotational-traslational landslides and listric faults lowering toward the Adriatic Sea are also produced, whose morphological surface effects can be easily confused among them and with those caused by deep-seated gravitational deformations (Coltorti *et al.*, 1985; Guerricchio, 1988) (Fig.5).

Along slopes affected by deep-seated gravitational deformations and/or listric faults, large-scale landslides are present whose activity is step-like, with long dormant periods separated by brief movements. Those reactivations are connected with evolutionary steps of deeper phenomena and seem to be mainly triggered by extreme rainfall (Coltorti *et al.*, 1985).

One of the most representative examples of deep-seated gravitational slope deformation can be observed near the town of Ancona. On the evening of the 13th December 1982, after a period of particularly heavy rain, a huge landslide took place on the north-facing slope of Montagnolo Hill, in the western outskirts of Ancona, 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 ed., 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 damaged beyond repair and many of them collapsed completely. The Adriatic railway, along the coastline, was damaged over a distance of about 1.7 Km. Luckily, there were no victims.

The slope hit by the landslide has had a long history of gravitational movements (Bracci, 1773; Segrè, 1920). In 1858 it was the site of a landslide even larger than the recent one (De Bosis, 1859). Other smaller landslides, still large in an absolute sense, have occurred in the same area. Of these, the "Barducci" landslide, a flow type mass-movement, has been known for a long time, because its continual and intense activity produced visible damage to the coastal road and railway (Segrè, 1920).

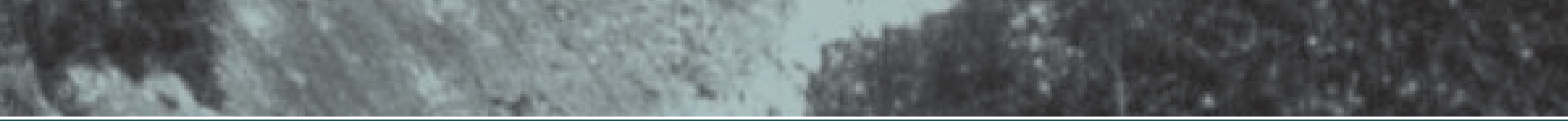
From a stratigraphic point of view the lithotypes outcropping are the following:

1) Lower and 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-arenacoeus units with a total thickness of about 20 m.

The area has been uplifted starting by the end of Early Pleistocene. Coquinic panchina and sands at the top of the clayey beds are probably related to the early stages of the uplift. These deposits are found at the top of Montagnolo Hill (250 m a.s.l.) and at more than 350 m in the surrounding area.

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. Downslope, a rugged foot-slope zone extends towards the sea; the steepening of the foot-slope seems to be accounted for by sea erosion, before building of the harbour embankment and along-shore protective measures.



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Some remarks on the relations between the 1972 Ancona earthquake sequence and the Ancona landslide

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Most relevant issues under discussion in this stop

The visit to the Ancona landslide allow to clearly document the central role played by earthquake tectonic deformation and surface rupture in the evolution of large-scale landslides. The comprehensive study of this landslide performed in the last 20 years unequivocally shows that rainfall alone would not have been able to produce the catastrophic landslide event occurred on December 13, 1982. Therefore, this is an excellent case for a meaningful discussion of the relations between surface effects of coseismic faulting and very deep-seated gravitational processes (the following section is modified from Brunamonte, 2001).
The continuously increasing knowledge about the tectonic structures that are actively deforming the earth surface, defined as capable faults in IAEA (1991) and recently mapped in Italy by Vittori et al. (1997) and Michetti et al. (2000), provides new interpretative tools for the analysis of the relationships among the structural setting of the topographic relief and the landslide development. The role of the recent fragile tectonics has been essentially investigated up to now from the point of view of the assessment of the seismic potential of a geologic structure. However, active tectonic ground faulting and fracturing deeply influence the bedrock mechanic behavior, and may also represent a fundamental factor for the localization of sizeable gravitational phenomena. The study of large recent bedrock gravity movements, such as the Ancona 1982 landslide that we are visiting during this stop, demonstrated that the landslide evolution, especially the location of the main detachment zone, and the hydrogeological setting responsible for the (re)activation of the gravitational movements, are dominated by pre-existing faults having dimensions at the same scale of the affected slopes (Cotecchia, 1997; Brunamonte, 1997). In these conditions, faults showing young displacement, typically related to coseismic surface rupture phenomena, control the predisposition of the slope to fail. The occurrence of repeated, moderate to strong ($M \geq 5$) earthquakes plays a critical role in the slope geomorphic evolution, either through the periodic fracture remobilization and allowing a hydrogeological circulation at the scale of the whole slope even within very-low permeability terrains. However, where the lithology is mostly composed by clay, the effects of the seismicity are masked by the interaction with the surface processes, which very effectively model the landscape, and habitually cancel the morphological evidence of coseismic tectonic ruptures within few days to few weeks after the causative earthquake. Moreover, it should be noted that in most cases the determining cause that eventually triggers the landslide reactivation is the rise of the water table due to a period of heavy rainfall.

Seismological data and surface fractures during the 1972 earthquake

Figure 1 shows the focal mechanisms of several moderate to strong earthquakes in Central Italy. The solutions for the Ancona 1972 sequence (see also Table 1) clearly show a strike-slip, compressional style of faulting, in agreement with the Adriatic foredeep setting. The earthquake sequence in fact lasted for about two years, from 1972 to 1974. Typical focal depths in the Ancona area ranges between 4 – 8 km. The 1972 sequence is typical for the

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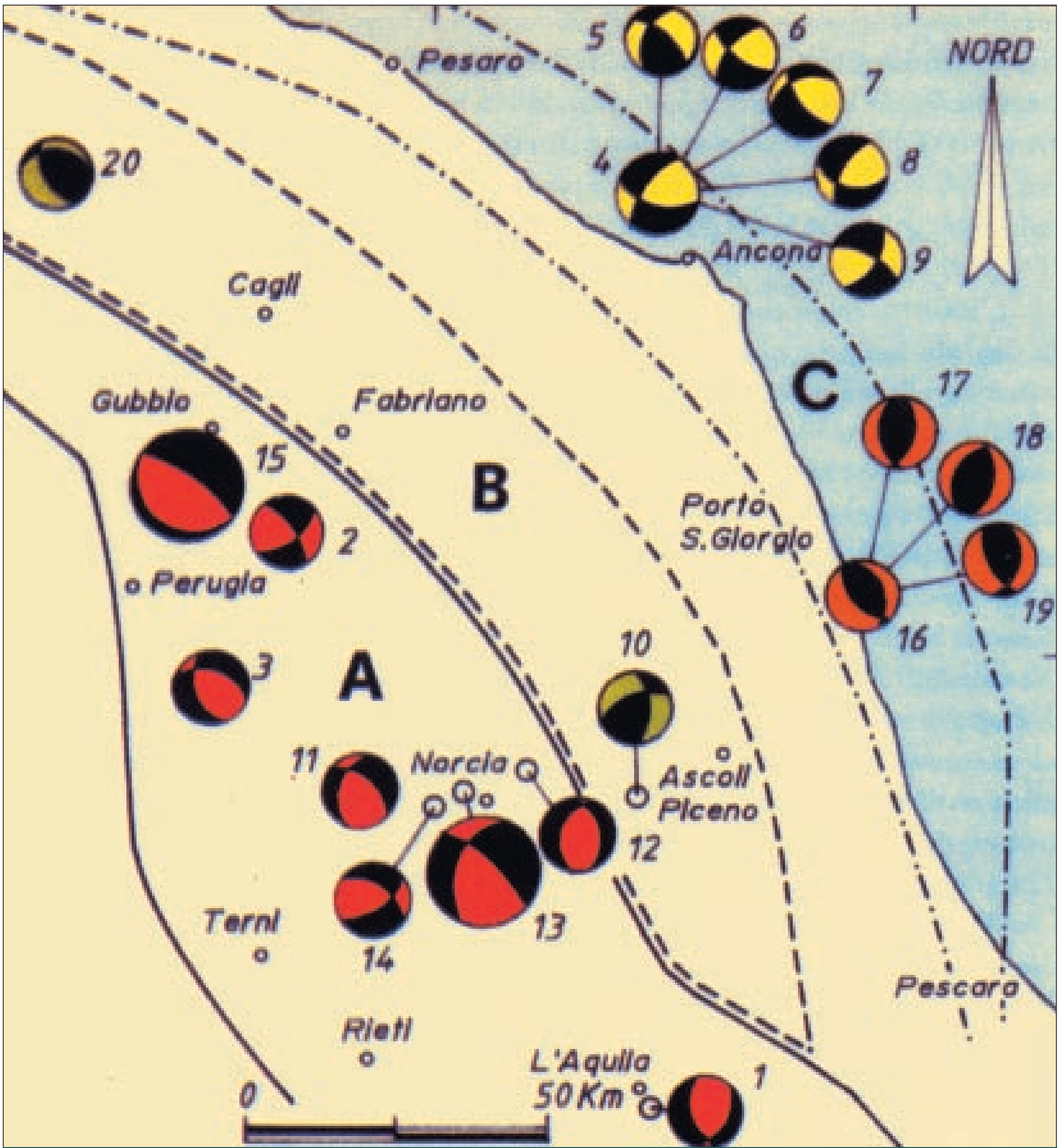

Figure 1. Fochal mechanisms for damaging seismic events in the period 1958-1987 in the Umbria Marche region (after Brozzetti and Lavecchia, 1994). Numbers 4 to 9 refer to the 1972 Ancona earthquake sequence. A) extensional tectonic setting of the Apennine mountain belt; B) transitional Apennine piedmont zone; C) compressional tectonic setting of the Adriatic foredeep.

Ancona region, similar events being well documented in the historical catalogues.
The examination of two airphoto coverages demonstrated 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 (Fig. 2). Most likely, similar surface displacement should be related to the 1972-74 earthquake sequence (Cotecchia, 1997). The rainfall period that occurred in Ancona 10 days before the catastrophic 1982 landslide has been 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 has been played by the coseismic opening of the numerous tectonic fractures illustrated by the analysis

Table 1: Most relevant earthquakes of the Ancona, 1972, seismic sequence (after Catalogue of Strong Italian Earthquakes on the Web, ING-SGA, http://storing.ingrm.it/cft/index.htm)

date	time	lat	long	Io	Imax	sites	ref	epicentral zone
1972 01 25	20 25 11	43.62	13.35	6.0	7.0	24	102	Medio Adriatico
1972 02 04	02 42 53	43.58	13.30	7.5	8.0	75	102	Medio Adriatico
1972 02 04	09 19 04	43.58	13.28	7.5	7.5	56	102	Medio Adriatico
1972 02 05	01 27 00	43.60	13.50	6.0	7.0	2	102	Medio Adriatico
1972 02 05	07 08 42	43.65	13.33	7.0	7.0	6	102	Medio Adriatico
1972 02 05	15 14 48	43.60	13.50	6.0	7.0	3	102	Medio Adriatico
1972 02 06	01 34 14	43.60	13.50	7.0	7.0	1	102	Medio Adriatico
1972 06 14	18 55 46	43.58	13.42	8.0	8.0	17	102	Medio Adriatico

of pre- and post-earthquake airphoto coverages.

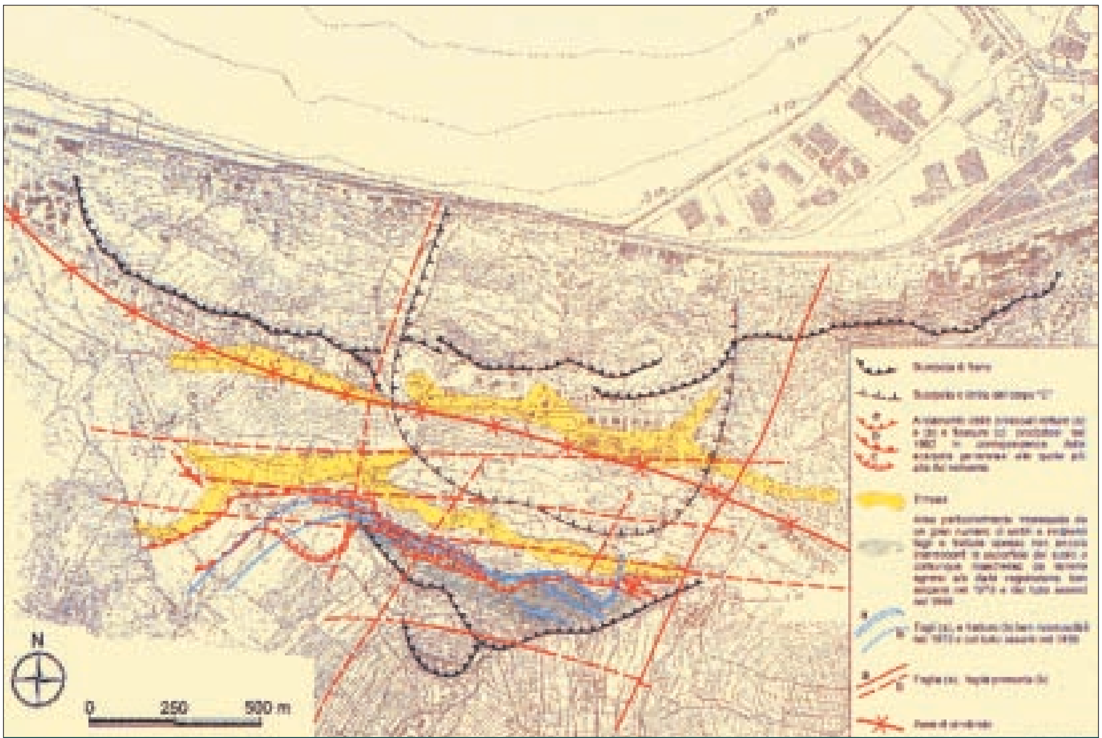

Figure 2. Main geomorphic features in the area of the Ancona landslide, including the location of fractures and flexural scarps most likely generated during the 1972 earthquake sequence (modified after Cotecchia, 1997).

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