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DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS AND LARGE-SCALE LANDSLIDES IN ITALY

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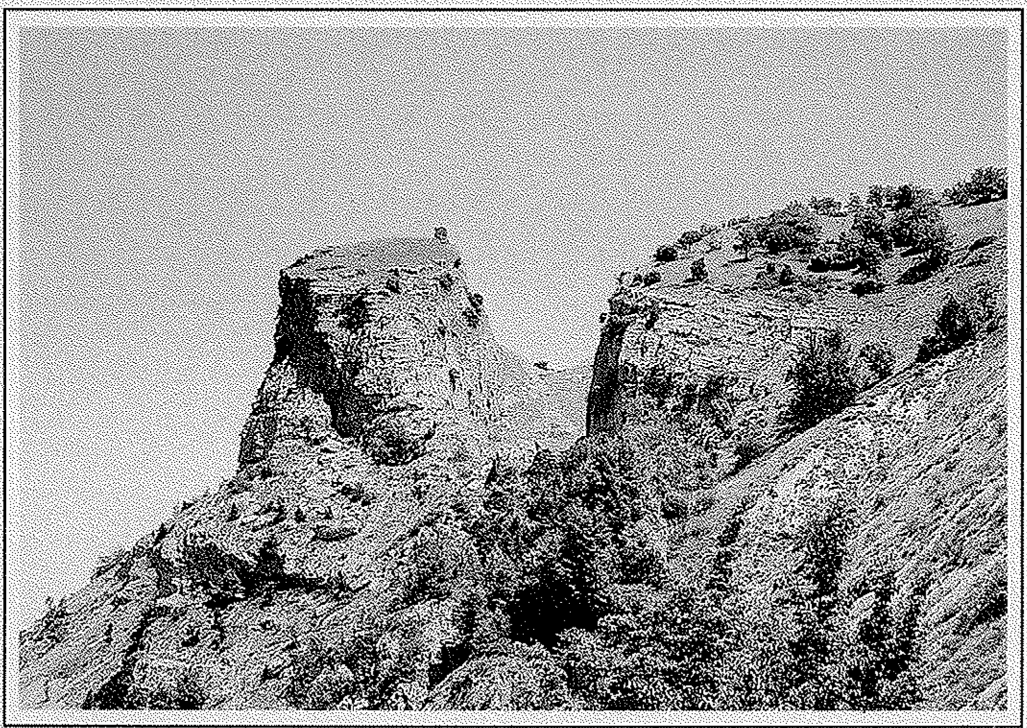

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DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS IN EMILIA-ROMAGNA AND VAL MARECCHIA

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Geological characteristics of the area

The area of investigation corresponds to the Po Valley side of the Northern Apennines, belonging to the Emilia-Romagna region, to a lesser extent to the Marche region and, only marginally, to Tuscany. This portion of the Apennines makes up the frontal part of the chain, which stretches also in the subsoil, buried by the Po Valley sediments, and is characterised by formations with a late north-vergent Tertiary tectonics, underlying the Middle Pliocene deposits along the outer margin of the chain.

The geological conditions are extremely complex, resulting from the piling up and thrusting of several tectonic units shifted, to various degrees, from SW to NE, that is from Ligurian and Tyrrhenian domains toward the Adriatic. West of Bologna and in the Marecchia valley the top of the chain (1500-2000 m a.s.l.) is made up of a sequence of Tuscan units, mostly formed by Tertiary arenaceous *flysch* sediments with basal clayey complexes. These rocks are overlain by Cretaceous-Eocene Ligurian units, made up of various *flysch* and lithologically complex shaly clayey formations: tectonical and sedimentary *mélanges*, olistostromes, *etc.*, partly with chaotic texture and abundant clayey matrix (Bettelli *et alii*, 1987). They are classified as fissured rock shales, showing tectonic shear planes.

In the western sector of the area considered and in the Marecchia valley the Miocenic Bismantova and San Marino-Monte Fumaiolo formations, belonging to the epi-Ligurian sequences (Upper Eocene-Tortonian), outcrop on top of the Ligurian units (Conti, 1989). They mainly show calcareous, arenaceous and calcarenitic *lithofacies* and are particularly widespread in the region, thus playing a major rôle also in the development of deep-seated gravitational slope deformations.

In the eastern sector of the region, between Bologna and Rimini (Marecchia valley), a prevalently arenaceous *flysch* outcrops: the Marnoso-Arenacea formation. Along the hill margin, at the border with the alluvial plain and the Adriatic, clayey and sandy sequences of the Plio-Pleistocenic cycle crop out.

The principal translative tectonic stage took place during the late Miocene (Tortonian): no extensive folding or horizontal movements occurred after the Middle Pliocene. In the Upper Pliocene and Quaternary, normal faulting modelled the final relief of the Northern Apennines. During the last million of years B.P., the chain uplift has been of about 1 mm/year, the highest values being recorded along the border with the plain. The width of the Apennine chain from crest to plain is about 40-50 km, with altitudes ranging from 2000 m a.s.l. along the main watershed to 150 m at the foot of the hills. The tectonic evolution, together with the altimetric situation, are common to the whole Adriatic margin of the Apennines, thus determining its high propensity to landsliding.

The presence of lithologically and structurally complex formations, or mainly shaly *mélanges*, the altimetric gradient (increasing with time), the rainfall (700 to 2500 mm/year) are all factors of slope instability. The uplift of the chain, together with the high erodibility of the formations, determines a continuous deepening of the valley floors, thus increasing slope instability.

The most common and evident types of mass movements are given by slumps and slumps-earthflows; some earthflows are 6 to 7 km long and up to 1 km wide at the toe. In particular, within the area where the Ligurian units outcrop, significant parts of the territory (up to more than 50%) are affected by earthflows and slumps.

Up to now a systematic census of deep-seated gravitational slope deformations has not been carried out in the area studied. In fact these movements in recent geological maps have often been confused with tectonic features. The situations so far recognised seem to be determined by the superposition of competent formations (*flysch* of the Tuscan and Ligurian units, calcarenites, limestones and sandstones of the Bismantova and San Marino sequences) on mostly clayey complexes. In these conditions, deep-seated gravitational slope deformations are mainly given by lateral spreads and slumps affecting the whole formation thickness, up to 200 m and more.

In fairly homogeneous lithological conditions, such as in the arenaceous *flysch* of the Tuscan units, failure mechanisms similar to those described in the Slovak Carpathians by (Nemcok, 1972) and in Italy by Guerriccho & Melidoro (1979) are found. In the presence of high slope gradients, as on the main ridges of the chain, they can affect rock volumes up to several hundred metres and are ascribed to block slides or *Sackung*. In the Modena district Apennines the example of a crest trench on which a small lake was formed is well known (lake Pratignano, covering a surface of 42000 sq m).

On the whole, in the area considered sixteen examples of deep-seated gravitational slope deformations have been recognised and investigated.

An example of deep-seated gravitational slope deformation: the Semelano landslide (Modena-Apennines) (Fig. 12)

The geological conditions at Semelano (River Panaro valley, Province of Modena) are given by the outcropping of massive or roughly stratified Bismantova Sandstones (Lower Miocene), overlying a complex of shaly weak rocks corresponding to the formations of Argille a Palombini (Titonian?-Cenomanian) and Argille Varicolori (Cenomanian-Turonian). These prevalently clayey formations have been subjected to high load pressures and intense compressive stresses, resulting in a fissured overconsolidated state. They are affected by a dense shear plane network, quite evident at any scale, with scaly structure up to at least 10 mm.

The clay shales incorporate portions of arenaceous and calcareous fragments of the most varied dimensions, outcropping both in organized sequences and disorderly arrangements. On the surface these clay formations show a typical plastic behaviour but when located at a certain depth, in completely buried conditions, their consistency is much harder, allowing them to be classified as rockshales. Among clay minerals, smectite and kaolinite frequently prevail. Compared with samples taken from completely buried conditions, those directly outcropping show a lower amount of interlayer water, higher amount of stress minerals, higher mineralogical stability, higher micaceous-illitic component, lower illite/montmorillonite ratio and lower percentage of hydrate clay minerals in the 10 to 14≈ band. Owing to these conditions and mineralogical characteristics, these materials show high absorption potentials of free water with consequent volume increase and soil plasticization.

The geological situation at Semelano and the proposed evolution of its deep-seated gravitational deformation are illustrated in the following figures. The interpretation invokes a succession of slumps, alternated with lateral spreading phenomena. At present, on the front of the most lowered block, a large active earth flow is found. The main release structural element, forming the uppermost crown of the landslide area, corresponds to an important discontinuity originated by a direct fault that, consequently to the gravitational movement, appears as an "inverse" one.

Semelano Sandstone slab is subdivided into several blocks, the intensity of the subdivision increasing from the crown to the toe of the landslide. As a result, the single sandstone blocks show a disarranged bedding and progressive reduction in dimensions, from large blocks and boulders to a coarse slope debris. The most significant geomorphological features testifying the presence of a deep-seated gravitational movement are: open or closed depressions, erroneously interpreted as "polje" or dolines; an important spring (up to a 0.12 cu. m/s flow rate) with a hydraulic regime similar to that of a karst one; open cracks and gulls, some of which varies its opening with time. All these cracks show a triangular shape, enlarging with depth, as observed in other landslides.

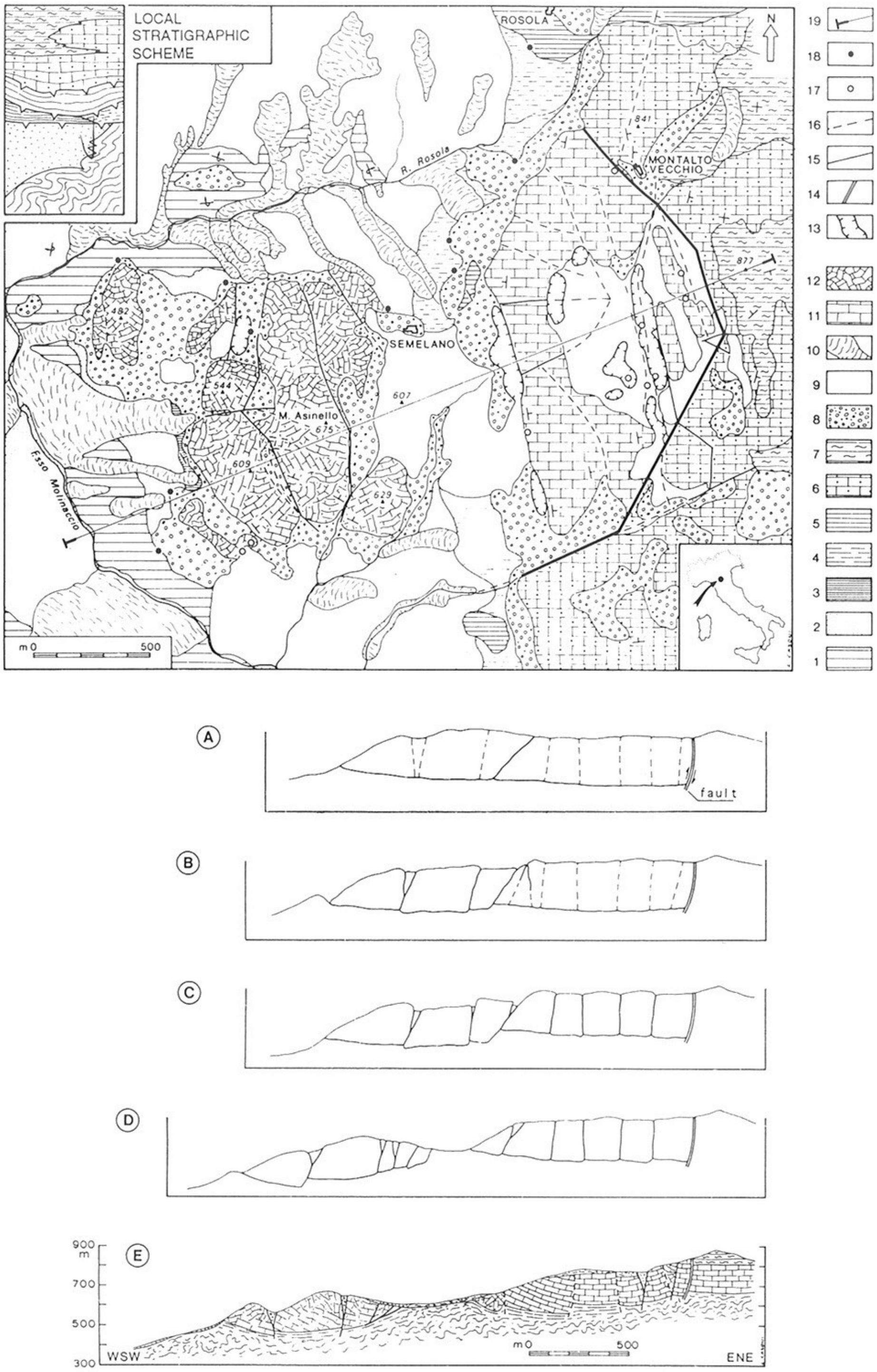

Fig. 12 - Geological-geomorphological map of the Semelano area: 1) Palombini clay shales (Titonian?-Cenomanian?); 2) Varicolori clay shales (Cenomanian-Turonian); 3) Montepiano formation-Eocene); 4) Canossa olistostrome (Upper Oligocene); 5) Antognola formation (Upper Oligocene); Bismantova formation: calcareous sandstones (Lower Miocene); 7) Bismantova formation: siltites with arenaceous beds (Middle Miocene); 8) slope debris; 9) colluvial deposits; 10) earth flows; 11) portions of Bismantova formation involved in landslides; 12) rock block slumps; 13) pseudo-dolines; 14) fault-controlled landslide margins; 15) main joints and cracks; 16) secondary joints and cracks; 17) gulls, widened fissures and holes; 18) springs; 19) geological section (after Cancelli et alii, 1987); A-B-C-D-E - evolutionary stages of the deep-seated gravitational phenomenon up to the present along the section.

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