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THE ROLE OF RECENT TECTONICS IN CONTROLLING THE DEEP-SEATED GRAVITATIONAL DEFORMATION OF MOUNT FRASCARE (CENTRAL APENNINES)

ABSTRACT: ARINGOLI D., GENTILI B. & PAMBIANCHI G., *The role of recent tectonics in controlling the deep-seated gravitational deformation of Mount Frascare (Central Apennines).* (IT ISSN 0391-9838, 1996).

The Authors describe a detailed geomorphological investigation of a part of the right-hand slope of the Fiastrone stream (right tributary of Chienti River) deformed by evident mass movements, whose evolution could have affected the stream, which is occupied by an artificial basin.

The analyzed area is located on the roof unit of the Sibillini Mountains thrust and includes the formations belonging to the Umbro-Marchean sequence, which shows a complex plicated setting structured by the compressive tectonic phase extending from Tortonian to Lower Pliocene, and then resumed in Upper Pliocene. Calcareous, marly-calcareous and marly sediments of the Lower Lias - Oligocene, affected by different joint sets, crop out. Some of these (shear joints) correspond with the field of compressive stress and are compatible with the plicated structures trending mainly N160°-180°E, N80°-100°E, and N40°-60°E, subvertically.

The analysis allowed the Authors to hypothesize a recent reactivation of the compressive structures occurring, however, by inversion of kinematics; besides, they also observed disjunctive elements of recent genesis such as extensional joints and high angle normal faults to which are associated modest individual displacements (decimetric), but with a notable general lowering trending mainly N140°-160°E and N60°-80°E.

In this stratigraphic-structural setting, there developed gravitational phenomena of different typologies responsible for the continuous modelling of the studied slope; the prevailing movements are represented by translational slides and by subordinated collapses; mountainward, the slope has been affected by an imposing phenomenon of deep-seated gravitational deformation. Favorable conditions for this kind of phenomena were the rapid and general uplifting of the area (very intense from the end of Lower Pleistocene) and, in the related hydrographic pattern, a downcutting which generated high relief values; the activation of mass movements is probably connected to particularly intense seismic events, both past and recent; in fact, in connection with the 1996 seismic sequence, fractures have been revealed in the upper part of the slope. The shear planes and/or zones are located in the mainly marly levels of the Marne a Fucoidi formation and, at some points in the tectonized band observed in the Scaglia rosata limestones. Moreover, an important role both in the activation and kinematics of the movements, seems to have been played by the presence of disjunctive elements created by recent tectonics and/or connected to normal reactivation of ancient compressive structures.

A further aim of the present work is to evidence the high hydrogeological risk represented by the artificial basin of the Fiastrone, which in extreme climatic conditions could interfere, or above all with high intensity seismic events, could interfere with the active or quiescent mass movements, and lead to a possible landslide evolution of the deep-seated slope deformation of Mount Frascare.

KEY WORDS: Deep-seated gravitational deformation, Neotectonics, Geomorphological risk, Central Apennines, Italy.

RIASSUNTO: ARINGOLI D., GENTILI B. & PAMBIANCHI G., *Il ruolo della tettonica recente nel controllo della deformazione gravitativa profonda del Monte Frascare (Appennino Centrale).* (IT ISSN 0391-9838, 1996).

Viene illustrata un'indagine geomorfologica di dettaglio relativa ad un tratto del versante destro del torrente Fiastrone (affluente di destra del fiume Chienti), deformato da evidenti movimenti di massa la cui evoluzione potrebbe interessare il citato corso d'acqua, occupato da un invaso artificiale (Lago del Fiastrone: diga ad arco).

L'area analizzata si colloca nell'unità di tetto del sovrascorrimento dei Monti Sibillini e comprende i terreni appartenenti alla successione umbro-marchigiana, la quale mostra un complesso assetto di tipo plicativo strutturato dalla fase tettonica compressiva estesasi dal Tortoniano al Pliocene inferiore. Vi affiorano i sedimenti marini cretacico-paleogenici della Maiolica (Titonico superiore-Aptiano inferiore), delle Marne a Fucoidi (Aptiano inferiore-Cenomaniano inferiore) e della Scaglia bianca e rosata (Cenomaniano medio-Eocene medio); essi mostrano giaciture con deboli inclinazioni degli strati verso nord (area sommitale della piega), maggiori pendenze nella fascia più orientale (fianco rovescio della piega) e sono interessati da diverse famiglie di joints. Alcuni di essi (joints di taglio) risultano disposti secondo il campo di stress compressivo e sono compatibili con le strutture plicative: direzioni prevalenti N160°-180°E, N80°-100°E, N40°-60°E, subverticali.

I rilevamenti hanno permesso, inoltre, di ipotizzare una recente riattivazione delle strutture compressive avvenuta però mediante inversione della cinematica; inoltre, sono stati anche osservati elementi disgiuntivi di recente genesi, quali joints d'estensione e faglie dirette ad alto angolo alle quali sono associati singoli modesti rigetti (decimetrici), ma notevoli ribassamenti complessivi: direzioni prevalenti N140°-160°E e N60°-80°E.

In tale contesto stratigrafico-strutturale, si sono sviluppati fenomeni gravitativi di tipologie diverse responsabili del continuo rimodellamento del versante oggetto di studio; i movimenti prevalenti sono rappresentati da scorrimenti traslazionali e, in subordine, da crolli; più a monte il versante è interessato da un imponente fenomeno di deformazione gravitativa profonda. I fattori predisponenti detti fenomeni vengono individuati nel rapido e generalizzato sollevamento dell'area (particolarmente intenso dal-

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la fine del Pleistocene inferiore) e nel conseguente approfondimento della rete idrografica che ha generato elevati valori dell'energia di rilievo; la loro attivazione è connessa con ogni probabilità a sismi particolarmente intensi, sia passati che recenti; in concomitanza della sequenza sismica del 1996 si sono manifestate fratture nella porzione superiore del versante. I piani di taglio e/o le zone di deformazione duttile sono impostati nei livelli prevalentemente marnosi delle Marne a Fucoidi e, localmente, nelle fasce tettonizzate riconosciute all'interno della Scaglia. Inoltre, un importante ruolo, sia nell'attivazione che nella cinematica dei movimenti, sembra essere rivestito dagli elementi disgiuntivi di neoformazione e/o associati alla riattivazione in senso diretto di preesistenti strutture compressive.

Con il presente lavoro si intende evidenziare l'elevato rischio idrogeologico rappresentato dall'invaso artificiale del Fiastrone, in quanto sullo stesso potrebbero interferire, in condizioni climatiche estreme o in occasione di eventi sismici di elevata intensità, i movimenti di massa in atto e/o quiescenti e l'eventuale evoluzione in fenomeno franoso della deformazione gravitativa profonda di Monte Frascare.

TERMINI CHIAVE: Deformazione gravitativa profonda, Neotettonica, Rischio geomorfologico, Appennino centrale, Italia.

INTRODUCTION

A detailed geomorphological analysis of the part of the right-hand slope of the Fiastrone stream (upper Chienti basin), deformed by evident gravitational phenomena of different size, depth and type, is reported. This river transversally cuts the southern portion of the Marchean marly-calcareous ridge in the Central Apennines (figs 1 and 2).

In the high portion of the relief a deep-seated gravitational slope deformation is present; valleyward, this evolves in large-scale landslide phenomena, too. The deformational phenomena of Mount Frascare are already known in literature (COPPOLA & *alii*, 1978; CARRARO & *alii*, 1979; GENTILI & PAMBIANCHI, 1993; DRAMIS & *alii*, 1995), but the revealing in the area in recent times of new fractures has led the Authors to conduct new detailed geomorphological studies to understand better the deformational and morphoevolutive mechanisms and to define their activity. Such studies are supported by detailed meso-and microstructural analyses, and by unpublished data (kindly supplied by the OSSERVATORIO GEOFISICO DI MACERATA) about the recent seismic events, with epicenters located in the study area or in neighboring zones.

In addition, the considerable geomorphological danger connected with the possible activation of the mass movements of the slope should be emphasized; their interference with the underlying valleyfloor, where an artificial basin (Lake of the Fiastrone) is located, could lead to a condition of high risk in the area.

GEOLOGICAL-STRUCTURAL SETTING

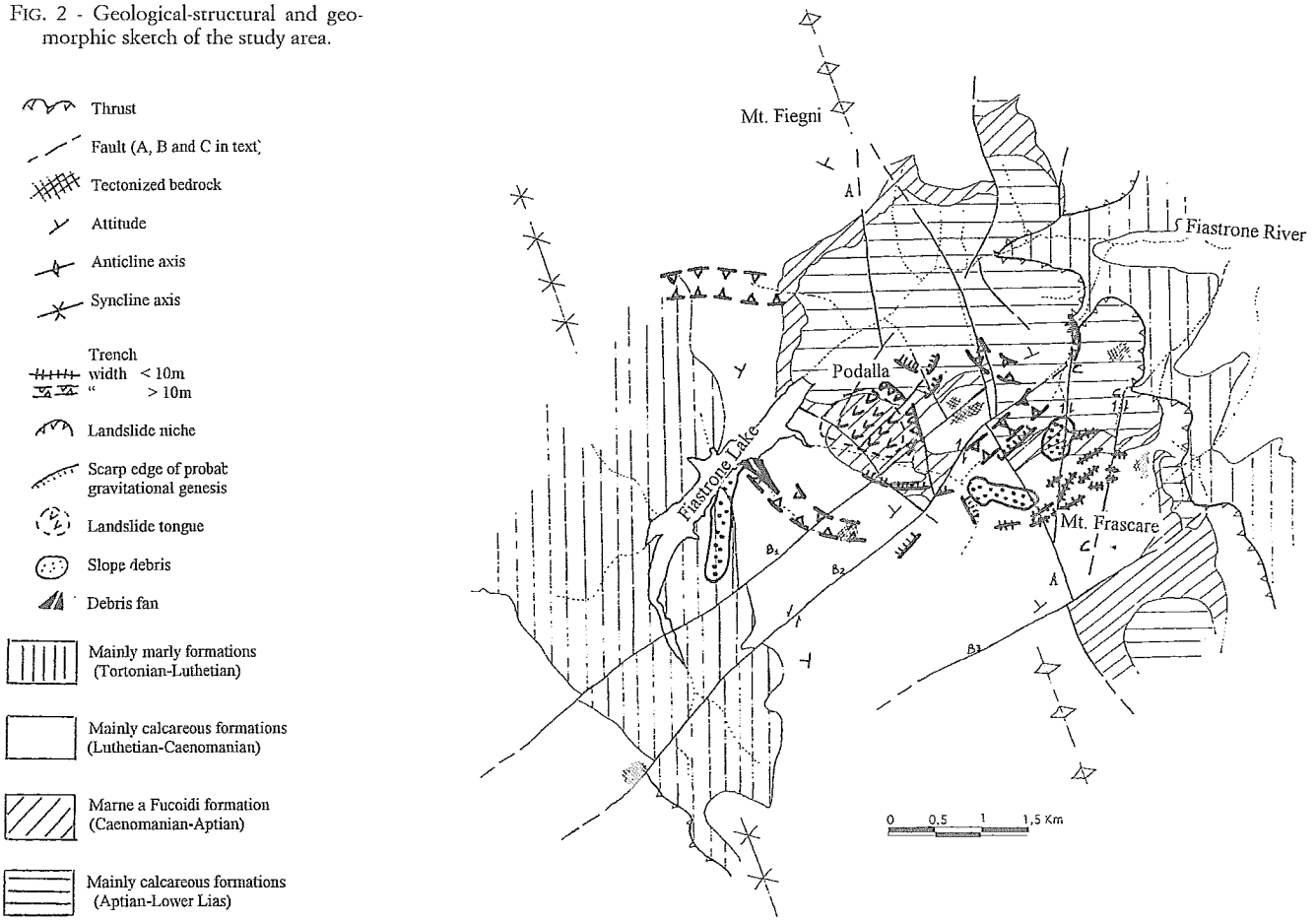
The analyzed area is located in the roof unit of the Sibillini Mountains thrust that led to the contact of prevalently calcareous formations of the Lower Lias-Upper Eocene interval, on the Oligocene marls in a compressive tectogenetic phase of the Tortonian-Lower Pliocene (CALAMITA, 1990).

The mainly calcareous formations of this unit present a complex plicated setting with northward axial depression (direction of the axes N170°E). The formations have been affected by faults with the following directions: Apenninic-A = N150°-170°E, antiApenninic-B = N30°-50°E and, subordinataely, around N-S (C = N10°E) (figs 2 and 3a). The first, probably generated during the compressive tectonic phase of Lower Pliocene, are subsequently renewed (Pleistocene) in normal sense, lowering the structure westwards. The second (B = N30°-50°E), belonging to the same compressive tectogenetic phase, have more complex kinematics: the main movement is inverse (left-transpressive), but, in the area affected by these gravitational phenomenona, the recent kinematic indicators furnish elements that allow us to hypothesize, in that case too, a reactivation in normal sense of the movement (right-transtensive). The last ones (C = N10°E) are characterized by right-transtensive kinematics, are disposed en-echelon and could have been generated, because they interrupt the compressive structures above, during the reacti-vation (Upper-Pliocene), of the Sibillini Mountains thrust by a gravitational tectonics mechanism. Their right-transtensive movement caused a set of fractures: D = N40°- 60°E.

This complex lithostructural setting was affected, in Quaternary times, by an extensional tectonic phase, with a general uplifting of the area, that generated new discontinuities including partly also the existing ones (AMBROSETTI & *alii*, 1982; DRAMIS, 1992; DRAMIS & *alii*, 1995).

FIG. 1 - General view of the area.

FIG. 2 - Geological-structural and geomorphic skerch of the study area.



Different joints sets are also present (fig. 3b): some of them (shear-joints) are arranged according to the compressive stress field and are compatible with the plicated structures (main trends N160°-180°E, N80°-100°E, N40°-60°E, subvertical); others (extensional-joints), associated to the normal fault previously described (A), have main directions N140°-160°E and N60°-80°E. Besides, tectonized bands with high clayey contents inside the limestones have been recognized overlying the Marne a Fucoidi formation (fig. 2); these are probably attributable to the Neogenic compressive tectonics.

GEOMORPHOLOGICAL SETTING

The plicated structures of the prevalently calcareous rocks were eroded, during the Pliocene and almost exclusively in continental conditions, by mainly areal phenomena that produced an erosional surface with low relief. This ancient landscape, from the first upliftings of the Upper Pliocene and during the more substantial ones starting from Lower Pleistocene, was deeply deformed and cut down (CICCACCI & *alii*, 1985; DRAMIS & *alii*, 1992). In correspondence with an important antiApenninic tectonic line, the hydrographic net produced the gorge of the Fiastrone river that borders the study area to the north (COLTORTI & *alii*, 1996). These dissected geological structures formed slopes to the right of the hydrographic basin generally dipping out of the slope, and into the slope in the opposite slope.

The examined area, located on the slope dipping out of the slope, extending from Mount Frascare to the Fiastrone, is characterized by trenches, scarps, counterslope and landslides of large dimensions (fig. 4), while in the neighboring areas landslide tongues, slope debris, flat and «V»-shaped valleys and different anomalies of the hydrographic net are observed (figs 1 and 2).

The trenches characterizing the Mt. Frascare northern slope (fig. 5a) have a trend similar to the «D» type fractures (fig. 5b) and present rather varied dimensions (lengths up to 800 m, width up to 20 m and more, and depth up to 10m). The greater ones are prevalently occupied by debris and vegetation, while the small recent ones are less open and deprived, or almost so, of debris and vegetation. In this area, about two years ago, some new fractures were caused (fig. 6), with trends comparable to the trenches, up to 50 m long, in some cases up to 50 cm wide, and with indeterminable depth.

Northwestward, between Mt. Frascare and the village of Podalla, big scarps, counterslopes and undulations are

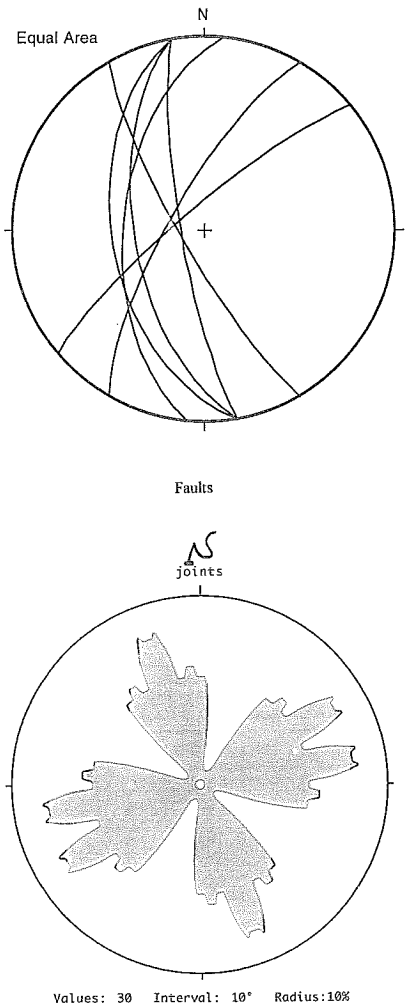


FIG. 3 - Main structural elements: a) faults stereonet; b) joints rose diagram.

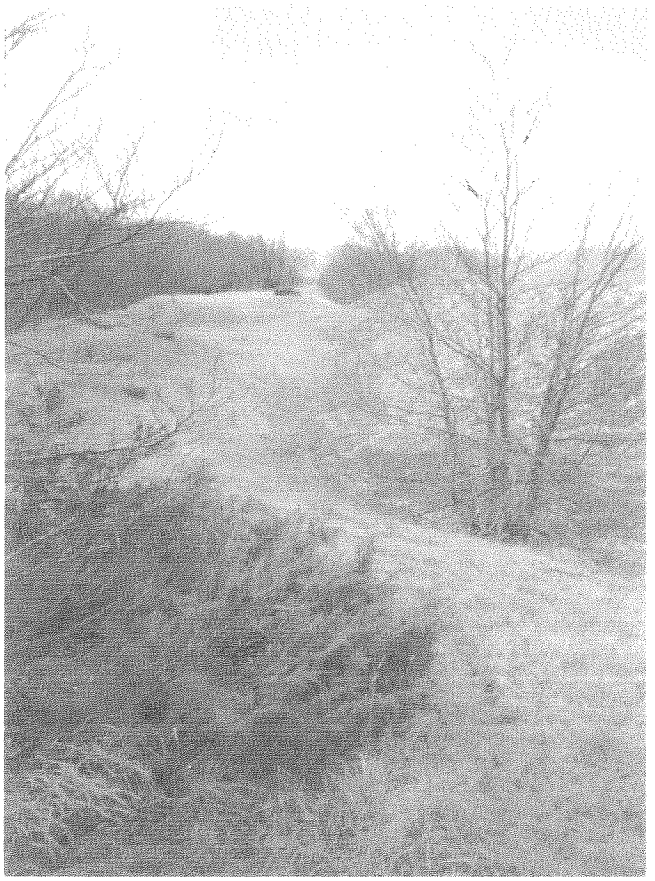
noted, mainly due to the present tectonic elements (faults A and B, fig. 2). Still more valleyward, there is an abrupt increase of the slope inclination of even more than 40°, where, down to the Fiastrone valley floor, landlside niches, prevalently due to collapse but currently quiescent, are observed.

Near the village of Podalla, a vast quiescent landlside tongue, due to translational sliding of prevalently calcareous levels on the underlying Marne a Fucoidi is observe The separation niche of this phenomenon is currently affected by numerous collapses. Southwestward of Podalla, a big trench is arranged according to the direction of the slope in its upper portion; this continues valleyward with an abrupt deviation, forming a very anomalous small curvilinear valley with a flat and very wide bottom (Valle Terra Nera, fig. 2). In fact, the hydrographic net is of short length, not hierarchized, and deprived of an adequate imbriferous basin; besides, at the foot of the slope an asymmetrically shaped fan deposit is observed suggesting an eastward migration of the stream.

DISCUSSION

The analysis of the faults trending N10°E (C faults) allowed us to establish that they were probably active, right transtensive, following the structuring of the compressive elements that they had interrupted. This activity could habe initiated in Upper Pliocene, during the tectono-gravitational reactivation of the Sibillini Mountains thrust and have resumed with the Lower-Middle Pleistocene intense uplifting that has notably tilted the whole structure northward. The dynamics of these tectonic elements (faults of group C) caused the «D» type fractures (fig. 2) that, subsequent to the fast and intense Pleistocenic uplifting, conditioned the deep-seated gravitational slope deformation and transformed these fractures into trenches. The jointing produced in the last two years, partially conditioned by these structures (C faults) and still probably active (gravitational tectonics) seems to be probably connected to the seismic activity that affected the area in recent times. From the elaboration of the Earthquakes Catalogue data (PFG, modified), for the study area, isointensity lines of 7 and 9, MCS scale, for times going back, respectively, 50 and 1000 years (POSTPISCHL, 1995; GENTILI & PAMBIAN-

FIG. 4 - Counterslope and undulation between the Fiastrone river and Mt. Frascare.



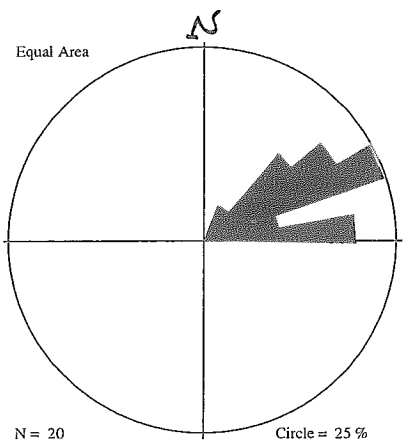


FIG. 5 - a) trench (Mt. Frascare); b) rose diagram of the main trench directions (Mt. Frascare).

CHI, 1993). Moreover, during the last three years, earthquakes (up to the VI degree, MCS scale) have occurred with epicenters located slightly eastward. In the last decade, instrumental shocks with almost daily frequence have been recorded (unpublished data from the OSSERVATORIO GEOFISICO DI MACERATA).

The anti Apenninic faults (B = N 30°-50°E) present, as already said, a more complex kinematics, showing a prevailing inverse movement, generally left-transpressive with plane immersion to the northwest. In the area affected by gravitational phenomena, on the fault plane, cropping out almost subvertically, the more recent kinematics show, instead, extensional behavior with right components. Besides the slightly arched trend with concavity mountainward, that one of these tectonic elements (B2) shows in the area affected by gravitational remodelling seems particularly meaningful. This arched trend, the extensional features, and the verticalization of the fault plane are interpreted as deformations due to the gravitational phenomena that involve the studied part of the slope (fig. 7).

The group A faults, belonging, as already said, to the tectogenetic compressive phase, have, since the first substantial upliftings (Lower Pleistocene) and together with the previous B ones, probably conditioned the gravitational phenomena that caused the most notable and characteristic geomorphological elements (fig. 2). The normal movements of small entity that accompany the these tectonic elements can be interpreted as a consequence of the gravitational phenomena that determined the shift valleyward of big calcareous plates.

Finally, it would seem that also the deep-seated gravitational slope deformation affecting the area southeast of Po-

FIG. 6 - Recent fractures (Mt. Frascare).

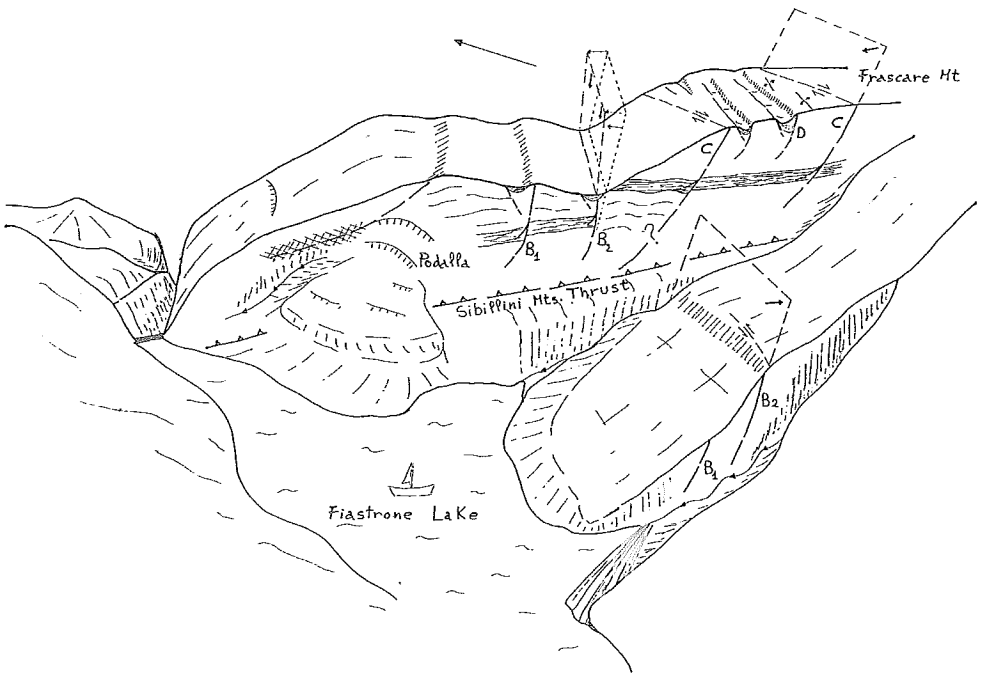


FIG. 7 - Interpretative block diagramm of the morphotectonic and morphodynamic evolution of the area.

dalla could have been connected with the conditioning and Quaternary activity of these tectonic elements. This area is, in fact, characterized by a large curvilinear trench to which the «opening» of the anomalous wide valley (Valle Terra Nera) is connected.

The studies quoted above, essentially about the phenomenon of deep-seated gravitational slope deformation of Mt. Frascare, attributed this phenomenon to stratigraphical discontinuity (overlap of thick and rigid calcareous masses on ductile marly levels), to topographical features (elevated relief values) and to seismic and tectonic displacement, both compressive and extensional; for the latter a Quaternary activity with right-transcurrent kinematics was hypothesized.

The present work confirms the importance of the genetic factors and extends the area affected by the gravitational phenomena; it also identifies for the area studied, as already reported for neighboring areas (GENTILI & *alii*, 1992), a deeper and wider control element (the Sibillini Mts. thrust plane). In particular, it shows, through detailed meso and microstructural as well as geomorphological analysis, the neotectonic activity and the right strike slip of the faults trending approx. N-S (C group faults). To the activity of these, which are responsible for the genesis of the «D» type fractures and therefore of the trenches that characterize the other slope of Mt. Frascare, the genesis of the described deformational phenomenon is therefore connected (fig. 7). The study shows, besides, that the phenomenon is active and therefore con-stitutes a condition of considerable geomorphological hazard which is associated at the foot of deformed slope with an equally high risk for the valley area, in view of the presence of an artificial basin (fig. 1).

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