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DSGSDs induced by post-glacial decompression in central Apennine (Italy)

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Abstract During the last thirty years of studies in the field of mass movements located in the calcareous-marly and marly-sandy Apennines (Umbria-Marches and Latium-Abruzzi regions), over to a large number of landslides with different dimensions, even a lot of deep-seated gravitational slope deformations (DSGSDs) have been recognized and analysed. These phenomena are also located in that sector of central Italy affect by a cold climate during the past and actually temperate (central Apennine chain).

Keywords DSGSD, post-glacial decompression, numerical modeling, central Apennine.

General setting

The present note is addressed to the analysis of some deep-seated gravitational slope deformation (DSGSD phenomena along the Umbria-Marches-Abruzzi slopes (Sibillini Mountains, Laga Mountains and Gran Sasso d'Italia) modeled by the late Pleistocene glacial morphogenesis and the post-glacial decompression effects. In particular, we recognized this kind of phenomena in the mounts located in figure 1.

The above phenomena are located in the calcareous-marly and marly-sandy Apennines (Umbria-Marches and Latium-Abruzzi regions) which main characteristics are shown in figure 2.

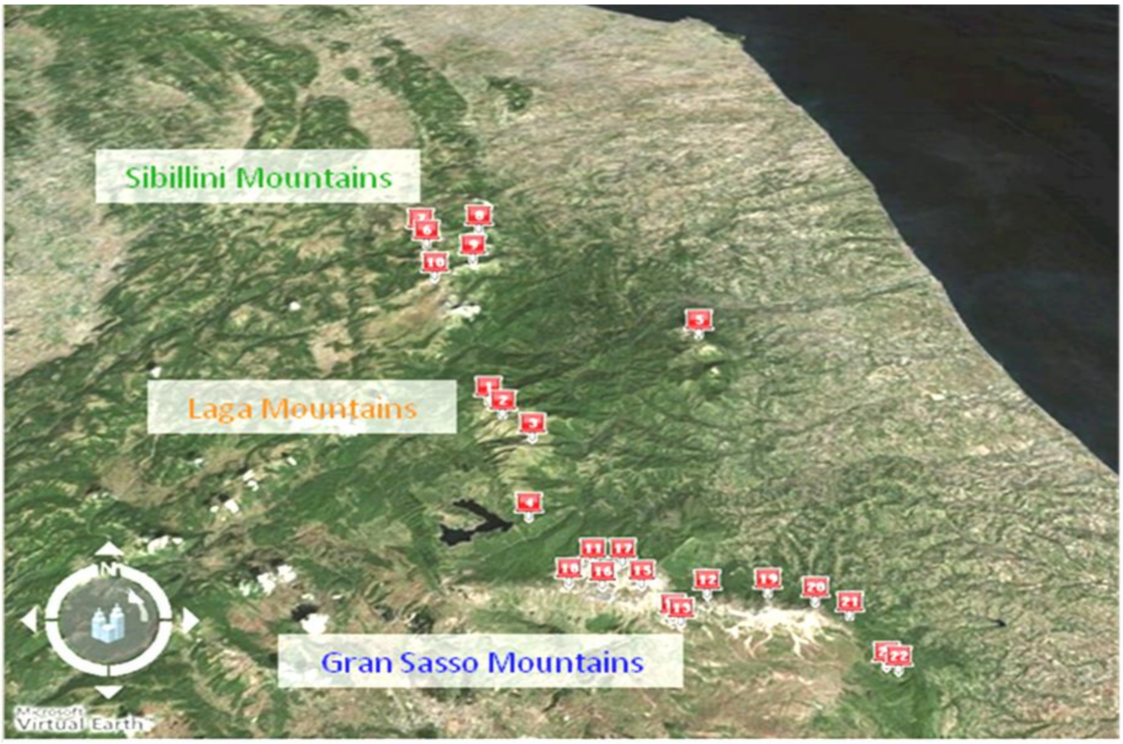

Figure 1 – localization of DSGSD phenomena in central Apennine recognized by authors on valleys of glacial origin.

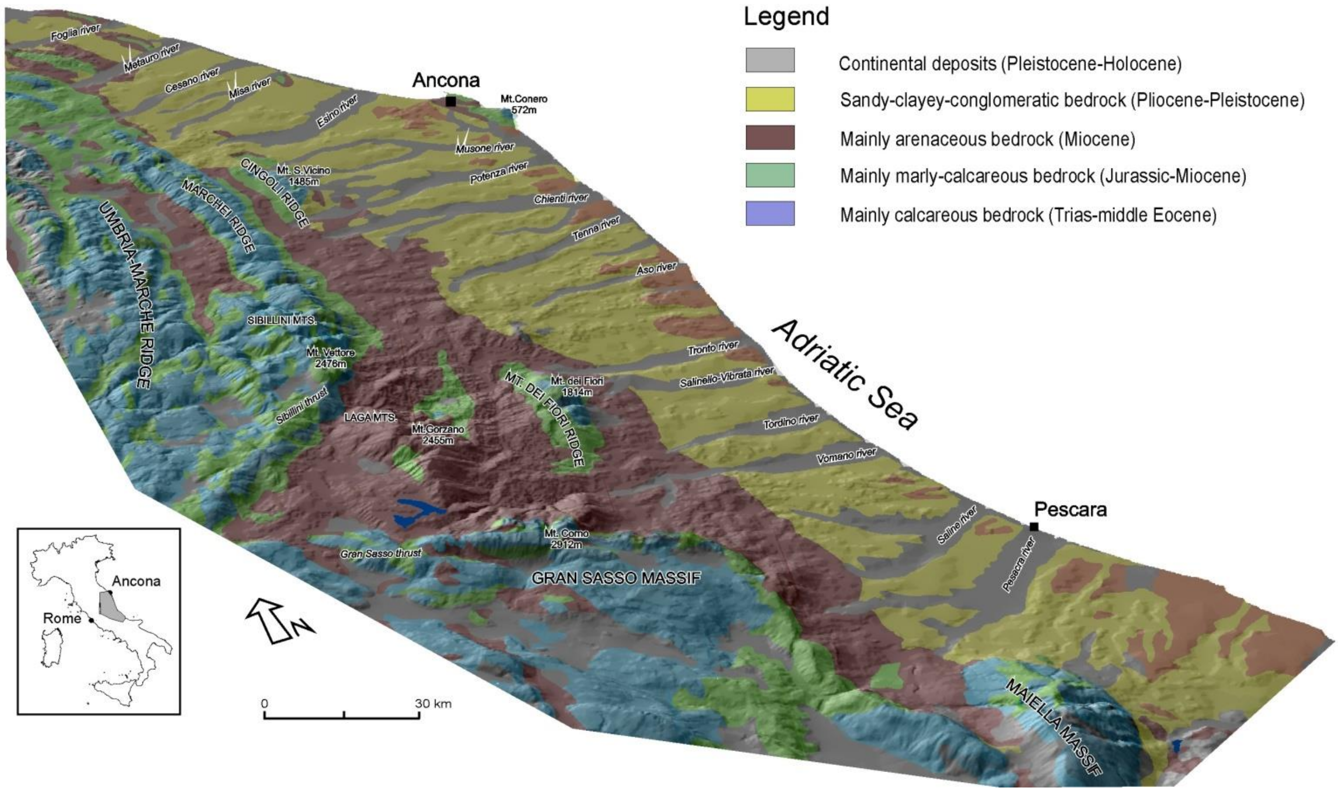

Figure 2- The study sector of central Italy, with main geological formations.

In this sector of central Italy, along the Gran Sasso d'Italia (the most elevated chain, 2912 m a.s.l.), the glacier of Calderone, which represents the only remaining trace of active glacial processes in the Apennine, is present. In the past, however, glacial morphogenesis has left numerous traces, modeling cirques and glacial valleys, also of great dimensions. Although not comparables with those alpines, cirques characterized by "walls" of hundredths meters and U-shaped valleys with difference in height from the top to the valley floor up to 600 m are visible.

Such gemorphological conditions, together with those litho-structural, favored the activation of large landslides and DSGSDs, particularly along the steepest slopes of the most elevated areas in addition to valley heads and ancient cirques areas (Fig. 3).

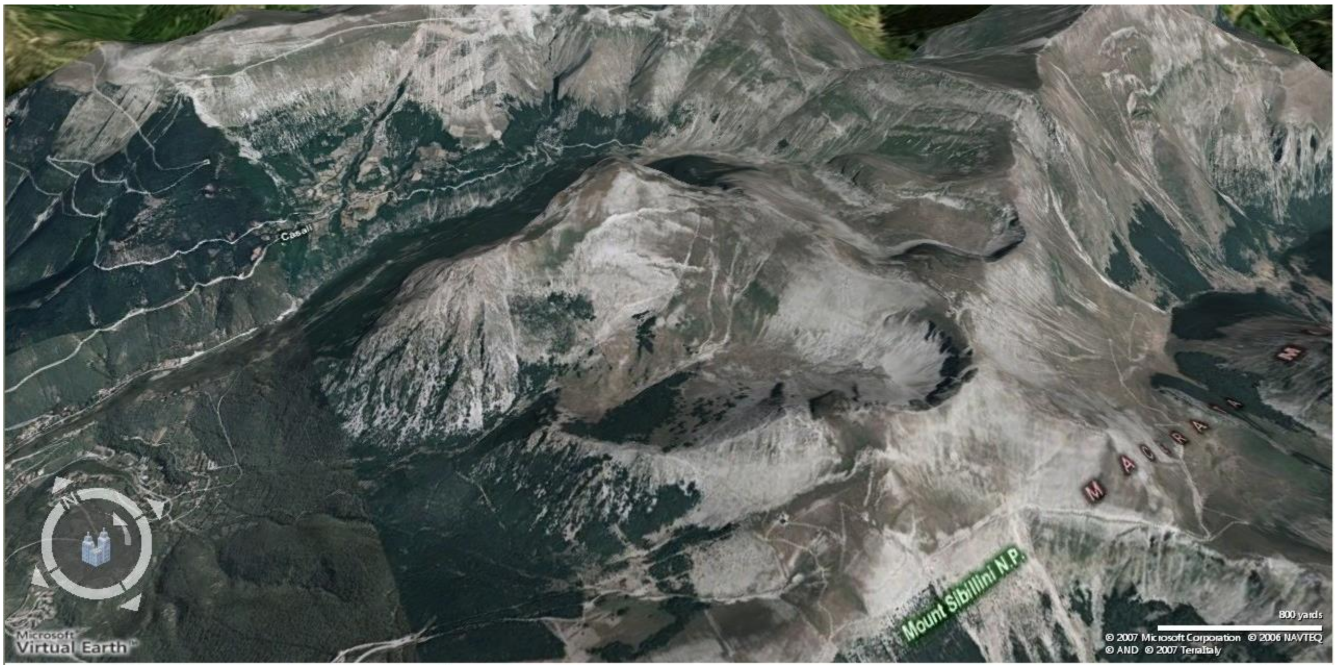

Figure 4 Aerial 3D-view of the central sector of Sibillini Mountains with a glacial macro-morphologies.

State of the art and methodology

The fundamental genetic factors of the DSGSD phenomena have been identified in; the particular geological settings (such as thrust fronts); the high relief and the seismic activity (both related to the intense neo-tectonic uplift of central Italy). Also the evolutionary models have been hypothesized: *lateral spreads* clearly prevail in the stony rocks intercalating or overlaying pelitic (or deeply tectonized or karstified) levels, sometimes driven by thrust planes, bedding or, more rarely, pre-depositional erosion surfaces. Rare *sackungs* are usually present in the thick and fractured rocky masses constituting the slopes with higher values of relief (Fig. 4).

Figure 4 Geomorphological evidences on the upper part of a DSGSD in central Apennine.

More in general along the glacial valleys, once the glacier died out or receded, DSGSDs occur where the glacier action has been more effective and has deeply modified the slope morphometry generating an high relief. In these areas, after the glacial retreat, high instability conditions occurred along the slopes, because of the absence of a support at the foot; fundamental are, however, the slope angle and the seismicity of the area.

The activation of mass movements along the glacial valleys is directly connected to the presence of glacier.

With regards to the litho-structural setting and to the distribution/state of the rock discontinuities (joints, karst features etc.), conditions favorable to the activation of the two principal mass movements typologies may occur along the slopes and on the area where cirques were present before the de-glaciation: a) rockfalls, slides and subordinately flows; b) deep seated gravitational slope deformations (DSGSDs). The above phenomena may be present also as a combination.

Rockfalls, slides and flows are very rapid and sudden processes, while DSGSDs need of a long period of preparation and show no many superficial geomorphological evidences.

Glacial retreat is usually very rapid (with respect to their formation); if this process is recent, DSGSD activation may occur with minor and less evident superficial geomorphological evidences

In order to reach such objectives, in addition to the systemic and detailed geologic-geomorphic surveys and to the processing of the relative models, this kind of study uses a complex numerical calculation methodology in order to characterize the dynamic evolution on significant sections of actual cases.

The used numerical code (FLAC_2D, 2000) is a finite differences bi-dimensional numerical analysis method. The examined slopes are discretized by tetrahedral elements, the physical-mechanical behaviour of every element has to answer to a pre-established rule of stress/deformation (linear or not-linear), in reply to the applied forces and/or to the contour conditions.

The numerical methods offers a lot of information on strain and stress conditions inside the system. In this particular case it is possible to represent the actual models optimizing the properties and the behaviours. The geological system representation is fundamental in order to analyse the behaviour of a phenomenon and its evolution.

This kind of study allows us to attribute to the decompression forces related to receding glacial tongues a predominant role in comparison with the other genetic factors; besides, it aims to establish if these forces represent an activation or a predisposing factor (as pointed out for the Alps) of the above phenomena.

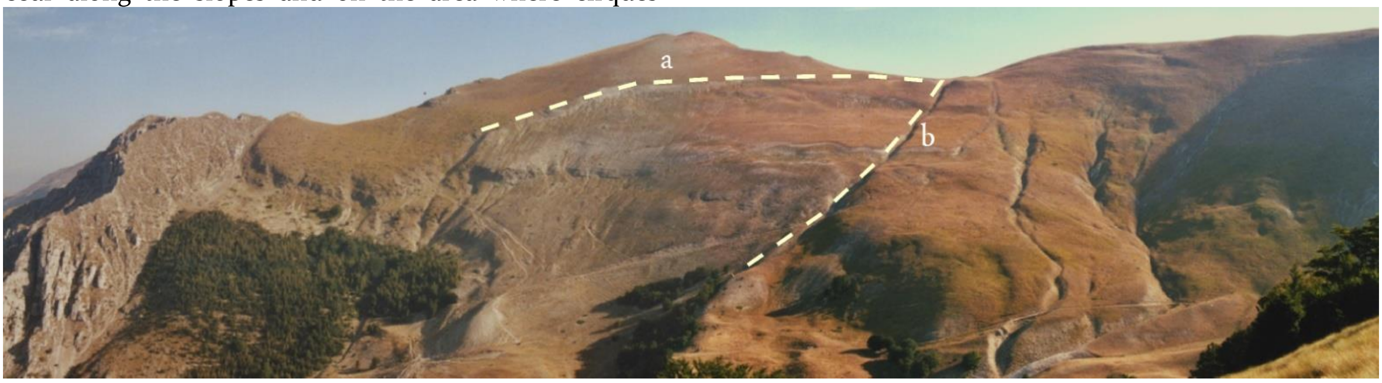

Figure 5 – Western slope of the Mount Bove with geomorphological processes of different genesis and the gravitational deformation in the central portion; a and b are the main discontinuities which bound the phenomenon

Study cases

Different study cases have been analyzed. Some of them show very evident traces of glacial activity and slopes deformed by gravity as a consequence of glacier retreat.

The case of Mount Bove (Fig.5) is an excellent example: the high relief and the elevated slope angle triggered a deformation which involved the entire calcareous slope, with a shear zone developed within a low-resistant marly bend. In this case a fundamental role is played also by the structural setting of the slope, where the presence of a significant discontinuities (a, and b in Fig.5) partly bounded the phenomenon.

Figure 6 The Gran Sasso Massif: main landforms and localities.

A numerical modeling, on the other hand, has been attempted in other contexts. A beautiful example is that of the DSGSD of Campo Pericoli, near the Gran Sasso Massif, where the last active glacier of central Apennine is present (Fig. 6 and 7): this phenomenon will be briefly discussed in the present work.

Figure 7 View from North of the Campo Pericoli deformation and the Gran Sasso Massif.

From a lithologic point of view, the site is characterized by mainly calcareous formations, partly karstified, overlying marly levels with minor resistance characteristics (see tab.1)

Table 1 Main geotechnical parameters used in the numerical modeling (Limestones lithotypes correspond to the Maiolica and the Calcareniti a Entrochi formations; Marly lithotypes are given by the Verde Ammonitico formation).

	γ unit weight KN/m^3	ϕ friction angle (°)	c cohesion MPa	E Young modulus GPa
Limestones	24	45	2,5	50
Marls	23	40	1,0	10

The geotechnical parameters used are significant not so much from their absolute value as from the differences between the two categories.

The study of the deformation has been carried out by means of a 2D finite difference numerical modeling (FLAC_2D software distributed by Itasca) in order to determine the main elements which led to the present configuration. In the modeling also the decompression connected to glacier retreat, supposed changing from 4.5 to 0.5 Mpa taking into account the maximum height reached by the glacier, has been simulated.

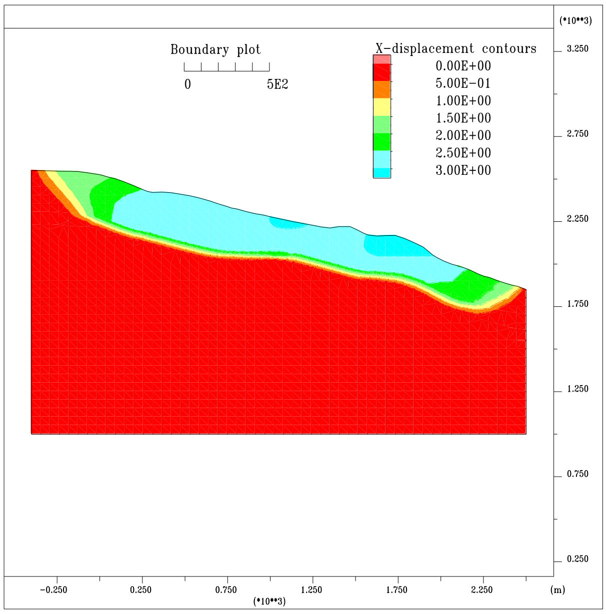

Figure 8a X-displacement resulting from numerical modeling.

In the figures 8a and 8b, some results obtained by the numerical simulation are shown; very interesting is the displacement observed in x and y, almost totally congruent with the morphologies observed in the field.

The study, in this case, allowed us to formulate a genetic-evolutive hypothesis (Fig. 9) where two different phases, have been theorized: in the first one, occurred at the end of late Pleistocene when the glacier was still present, the combined action of ice, sub-glacial waters and karst weathered and weakened the calcareous rocks; in a second phase, subsequent to glacial retreat, the lack of a lateral support and the high relief caused a strong decompression of the slopes and a slow deformation of the entire mass along the less resistant marly level and using the discontinuities previously reworked.

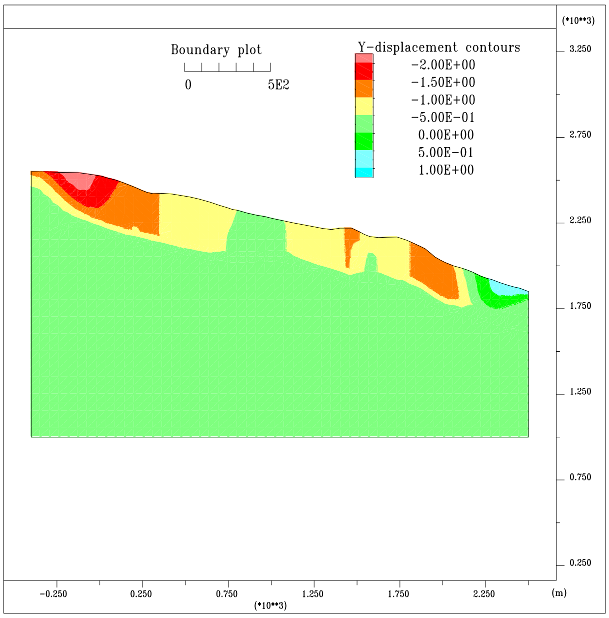

Figure 8b Y-displacement resulting from numerical modeling.

Conclusions

The study, which used data coming from the DSGSD database built by the authors for central Apennine, allowed to recognize some cases (less than 10% of the total DSGSD analyzed) in which glacial activity can be ascribed as a fundamental genetic factor. Its role results from the combinations of several processes, summarized in Fig. 9: abundant circulation of groundwaters, deep karst, volumetric changes, forces of decompression; all of these are connected to climate variations.

A further intention was to establish if these processes represent a predisposing or activation factor (as pointed out for the Alps). The present data, according to other authors, let us to attribute to these processes a prevailing role in both preparation and predisposition of the above mentioned phenomena.

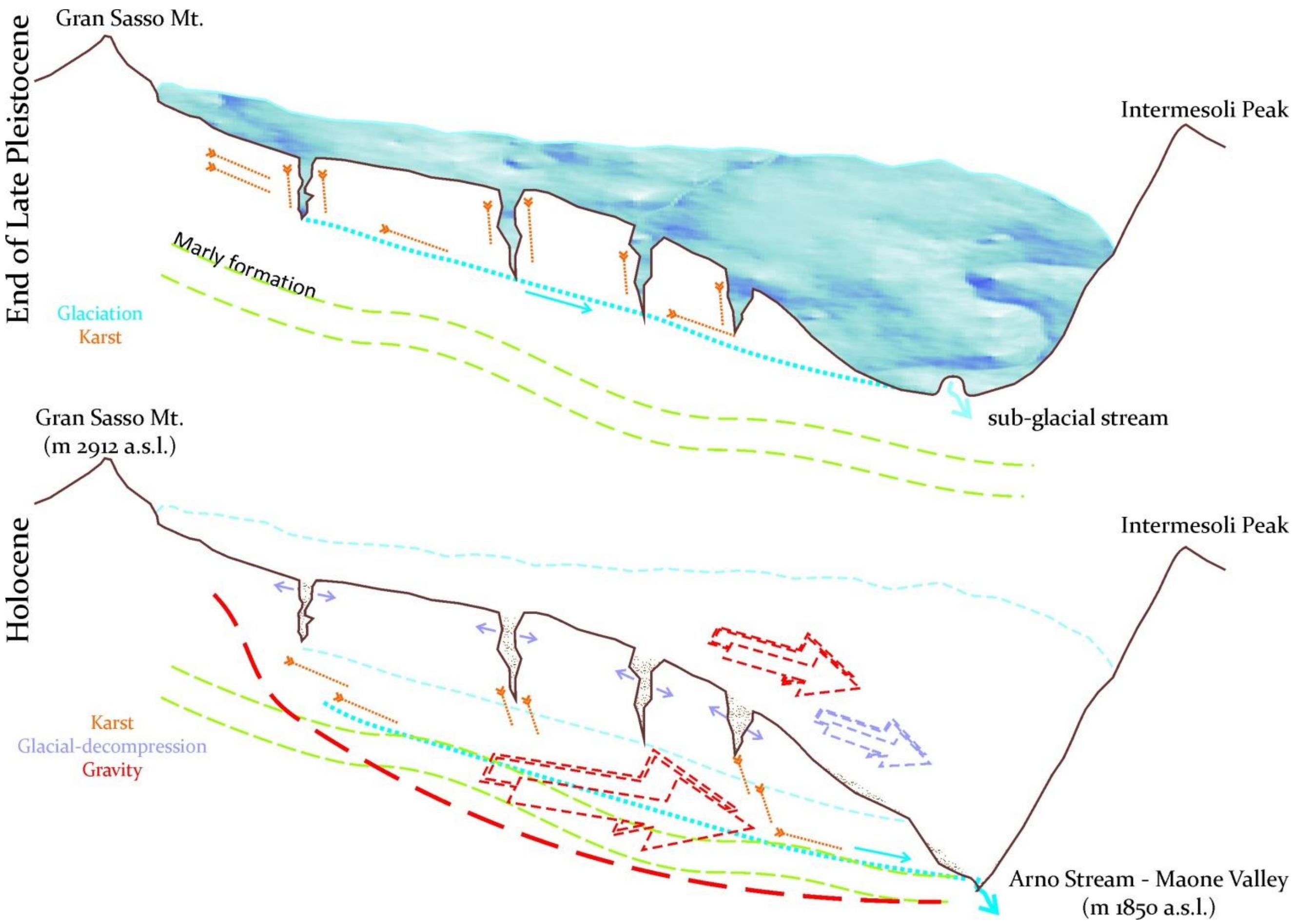

Figure 9 Hypothesis genetic-evolutionary of the gravitational deformation in glacial valley in central Apennine.

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