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RELATIONSHIPS AMONG CLIMATE, UPLIFT AND PALAEO-LANDSLIDES GENERATION IN THE MELANDRO RIVER BASIN, SOUTHERN APENNINES, ITALY

ABSTRACT: MARTINO C. & SCHIATTARELLA M., *Relationships among climate, uplift and palaeo-landslides generation in the Melandro River basin, southern Apennines, Italy*. (IT ISSN 0391-9838, 2010).

The Melandro River valley is a tectonically controlled and uplifted basin located in the Italian southern Apennines. The goal of this paper is to point out ages and geomorphic features of two palaeo-landslides and to relate them with uplift rates and climate conditions of the axial zone of the chain during the Pleistocene. Uplift rates have been estimated using geomorphic data related to erosional gently dipping land surfaces. Landscape development has been driven by an alternation of stages of uplift and slack periods. Stability of base level of the erosion favoured the planation of land surfaces whereas unsteady base level resulted in widespread reduction of erosional flatlands. The oldest palaeosurface cuts Pliocene deposits at the tops of the mountains whereas the youngest surface is late Pleistocene in age. In the southern area of the basin a wide palaeo-landslide, whose foot is cut by a fragment of the middle Pleistocene land surface, forms a morphological high separating different sectors of the basin in which lower Pleistocene sediments were confined. The landslide can be therefore ascribed to the upper part of the early Pleistocene. Another palaeo-landslide, recognized in the northern sector of the basin, can be referred to the beginning of the late Pleistocene. The correlation between the ages of the two landslides and the temporal trend of the uplift rates allowed to hypothesize that mass movements occurred in response to uplift peaks, when slopes were destabilized by rapid relief growth, and after stages of deep weathering probably caused by warm-humid climate.

KEY WORDS: Geomorphology, Quaternary climate changes, Pleistocene landslides, southern Italy.

RIASSUNTO: MARTINO C. & SCHIATTARELLA M., *Relazioni tra clima, sollevamento tettonico e paleofranosità nel bacino del Fiume Melandro (Appennino meridionale, Italia)*. (IT ISSN 0391-9838, 2010).

L'obiettivo di questo lavoro è di delineare età e caratteri geomorfologici di due paleofrane della valle del Fiume Melandro, un bacino a controllo tettonico ubicato nella zona assiale dell'Appennino meridionale, al fine di correlarli con i tassi di sollevamento e le condizioni climatiche vigenti all'atto della generazione dei movimenti di massa. I tassi di sollevamento locale, in parte coincidenti con le velocità di incisione verticale dei corsi d'acqua, sono stati calcolati usando superfici erosionali e deposizionali morfologicamente sospese come marker di antichi livelli di base. L'evoluzione del paesaggio fisico è stata guidata dall'alternanza di periodi di mobilità verticale e di quiete tettonica: durante questi ultimi, la stabilità del livello di base dell'erosione consentiva la formazione di ampie superfici morfologiche sub-orizzontali o blandamente ondulate, fortemente reincise e sospese con la ripresa del sollevamento locale e/o regionale. Le due frane studiate possono essere attribuite al Pleistocene inferiore ed al Pleistocene superiore e la loro collocazione nell'andamento temporale dei tassi di sollevamento tettonico permette di ipotizzare che i movimenti di massa di cospicue proporzioni siano avvenuti in risposta a picchi nelle velocità di sollevamento, quando i versanti venivano destabilizzati dal rapido incremento del potenziale di rilievo, e dopo stadi di intensa alterazione, forse causata da condizioni climatiche caldo-umide.

TERMINI CHIAVE: Geomorfologia, Paleoclima quaternario, Frane pleistoceniche, Italia meridionale.

INTRODUCTION

Large palaeo-landslides from southern Italy have been studied from a geomorphological viewpoint by several Authors since the late fifties (see for example Guida & Iaccarino, 1984, and references therein), but their genetic relationships with tectonic activity, earthquakes, erosion base-level modifications, climate changes, and weathering conditions are still debated. In particular, it seems hard to relate the development of huge ancient landslides to specific time intervals during the Quaternary in which one or more of the above mentioned mechanisms could have produced the necessary conditions for the activation of such significant phenomena. The targets of this study are: i) the comprehension of the genetic links existing among ages, texture, weathered surfaces and geomorphic features of two Pleistocene large landslides located in a Quaternary

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valley of southern Italy; ii) the correlation of these characteristics with the values of uplift rates from the study area and with the major episodes of climate change, as deduced from the global sea-level reconstruction. The comparison between these different data-sets is in fact an useful tool to understand the landslide genetic mechanisms. In particular, such an approach may also permit to stress the role of huge past earthquakes in triggering mass movements (Keefer, 1984a, 1984b) as well as to discriminate the contribution of the climate as a control factor of landslide generation (Reneau & Dethier, 1996).

The investigated area is located in the Melandro River basin, a tectonic depression of the axial zone of the southern Apennines (fig. 1). This chain constitutes a Neogene fold-and-thrust belt strongly uplifted and fragmented by neotectonics, and therefore characterized by many Quaternary longitudinal and transversal morpho-structural depressions (Ortolani & *alii*, 1992). Among them, the Melandro River basin is particularly suitable to study palaeo-landslides generation by means of a geomorphological approach, because of the presence of both weathered erosional land surfaces and many morpho-structural markers which can be used for uplift rate estimates (Widdowson, 1997). The interplay between climate and tectonics is in fact considered since long time a basic key for the interpretation of the landscape evolution at different scales (Bloom, 1978; Ollier, 1981; Bull, 1991; Summerfield, 2000; Burbank & Anderson, 2001; Willett & *alii*, 2006).

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The southern Apennines are a northeast-verging fold-and-thrust belt, built on the western border of the African-Apulian plate (or *Adria microplate*, after Channel & *alii*, 1979) from late Oligocene - early Miocene times (Pescatore & *alii*, 1999). The orogenic belt is mainly composed of shallow-water and deep-sea sedimentary covers, deriving from Mesozoic - early Tertiary circum-Tethyan domains and from the Neogene-Pleistocene foredeep deposits. The thrusting in the frontal (eastern) part of the accretionary wedge has been followed by back-arc extension to the rear (Malinverno & Ryan, 1986). Contractional tectonics kept up to the early-middle Pleistocene in the external zone, as evidenced in some frontal sectors of the chain (Pieri & *alii*, 1997). The belt is strongly uplifted, as proved by both Pleistocene displaced deposits and ancient base levels of erosion at high elevations above the present-day sea-level (Schiattarella & *alii*, 2003, 2006), and fragmented by late Pliocene to Quaternary neotectonics (Schiattarella, 1998), and therefore articulated by development of longitudinal and transversal tectonic depressions (Ortolani & *alii*, 1992). The mountain belt tops are often characterized by gentle topography represented by relics of an ancient erosional land surface, which unconformably cuts lithological contacts, high-angle faults and other tectonic structures (Brancaccio & *alii*, 1991; Amato & Cinque, 1999; Schiattarella & *alii*, 2003, among others). The regional uplift suspended the ancient erosional base level to which this palaeo-landscape was related, triggering new morpho-evolutionary stages.

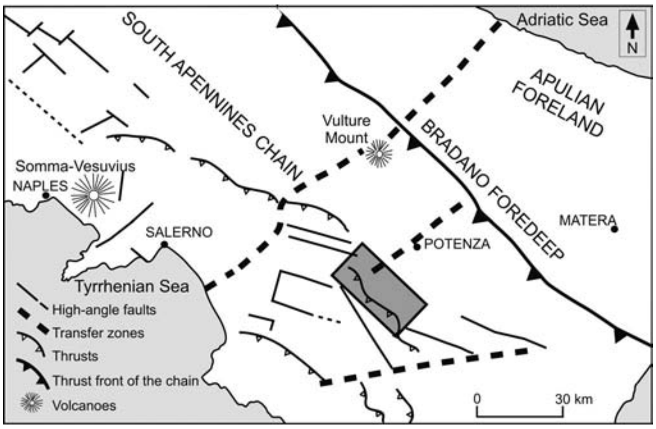


FIG. 1 - Tectonic sketch map of the southern Apennines, showing the study area as shaded box.

In the southern Apennines, different Quaternary tectonic events have been recognized as responsible for the greatest part of the chain uplift. Several authors identified two main uplift stages in the early Pleistocene, whereas another relevant event marked by uplift occurred in the middle Pleistocene (D'Argenio & *alii*, 1986; Brancaccio & *alii*, 1991; Schiattarella & *alii*, 2003). Finally, in the late Pleistocene the chain was characterized by stability of the Tyrrhenian belt and uplift of the axial zone of the chain, the foredeep basin, and the foreland area (Westaway, 1993; Bordoni & Valensise, 1998; Schiattarella & *alii*, 2003, 2006).

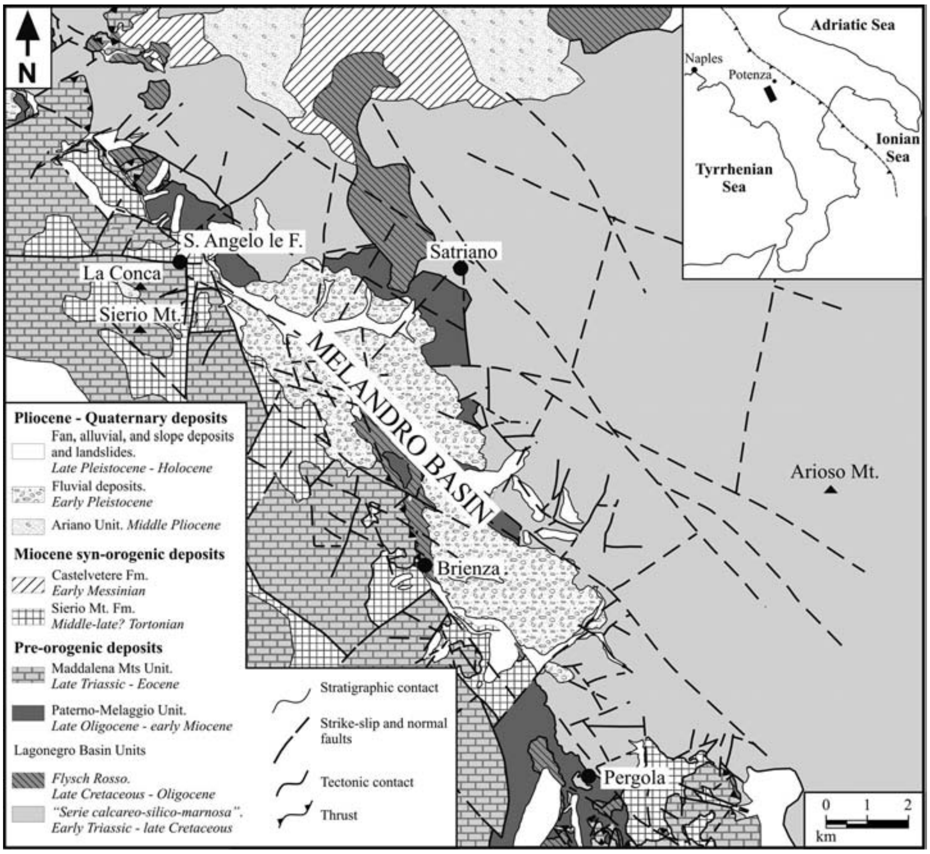
The Melandro River basin (fig. 2) is a tectonic depression located in the axial zone of the chain (Ortolani & *alii*, 1992). Two wide thrust sheets crop out in the area: the Maddalena Mts Unit and the Lagonegro units. The Maddalena Mts Unit is constituted by Triassic to Eocene shallow-water carbonates locally covered by upper Miocene siliciclastic sediments. It thrust the Lagonegro units and forms the western flank of the basin, whereas the Lagonegro units, prevalently constituted by deep-sea successions, form the entire eastern side of the valley.

Alluvial deposits crop out in the axial zone of the Melandro River basin and have been attributed to the early Pleistocene (Lippman Provansal, 1987). Giano & Martino (2003) recognized three litho-stratigraphic units separated by palaeosols and erosional surfaces. Several generations of erosional surfaces have been identified on both sides of the valley (fig. 3) and divided in four orders on the basis of geomorphological evidences (Schiattarella & *alii*, 2003; Martino & Schiattarella, 2006).

GEOMORPHOLOGICAL FEATURES OF THE LANDSLIDES

In the area of the Melandro River basin, two large landslides exhibiting peculiar characteristics have been

FIG. 2 - Geological sketch map of the Melandro River basin.



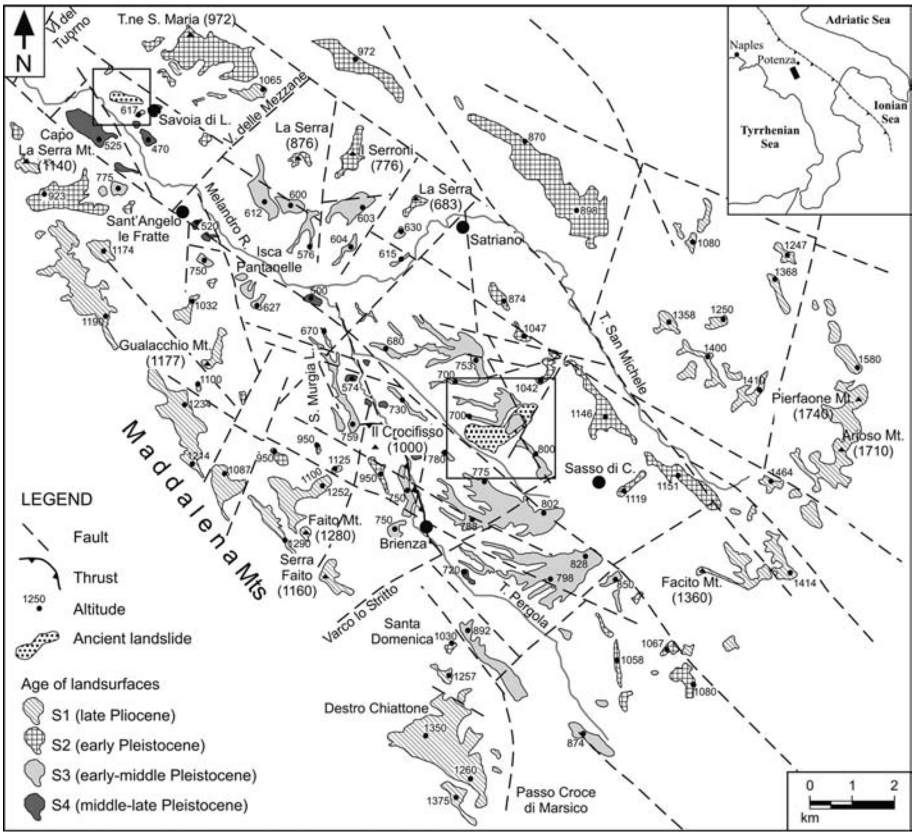


FIG. 3 - Morpho-structural map of the Melandro River basin (studied landslides in the frames).

mapped (fig. 4) on the grounds of modern criteria (Parise, 2001, and references therein) and classified following the internationally accepted schemes (Varnes, 1978; Cruden & Varnes, 1996). Both the landslides have to be ascribed to deep-seated roto-translational rock slides and are 0.12 and 0.7 km^2 in size, respectively in the northern and southern sectors of the valley (fig. 3). The larger landslide evolved to earth flow in its frontal part. Mass movements probably affected weathered rocks, as shown by some landslide deposit features (figs. 5 and 6). The same deposits are cut by erosional surfaces which are in turn deeply weathered.

In both cases, the landslide deposits are characterized by large rock blocks and fragmented beds dispersed in a fine-grained matrix (figs. 5 and 6). The rock blocks and beds belong to formations (i.e. *Scisti silicei* Fm and *Calcari con selce* Fm, *Lagonegro units*, Pescatore & *alii*, 1999, and references therein; see also Di Leo & *alii*, 2002, and Tanner & *alii*, 2006) which are rarely involved in bedrock slide in the present-day geomorphic system. In addition, the size of the landslides, the thickness of the landslide deposits, and the dimensions of the blocks are not common features in recent mass movements of the southern Apennines.

The age of the two palaeo-landslides has been inferred considering their morpho-stratigraphic relationships with the Quaternary deposits and the related landscapes (e.g. the presence of Pleistocene fluvial conglomerate cut by the same erosional surfaces affecting the ancient landslides). The foot of the wider palaeo-landslide surveyed in the southern area of the basin (fig. 5) is clearly cut by a remnant of the middle Pleistocene land surface (S3 after Martino & Schiattarella, 2006). Furthermore, this palaeo-landslide formed a morphological high separating different sectors of the basin in which Pleistocene sediments were confined (fig. 2). Since basin infill has been attributed to the lower Pleistocene (Lippman Provansal, 1987; Giano & Martino, 2003), one can confidently conclude that mass movement was generated during the upper part of the early Pleistocene. The palaeo-landslide recognized in the northern sector of the basin (figs. 3 and 6) is morphologically inserted inside the middle-upper Pleistocene land surfaces (S4 after Martino & Schiattarella, 2006) and fossilized by upper Pleistocene fan deposits and small erosional surfaces located 25 m above the present-day valley floor. Further, another close and similar landslide deposit is fossilized by upper Pleistocene slope deposits, incised and suspended on the present-day talweg (inset in fig. 6). On this basis, the age of the northernmost palaeo-landslide can be ascribed to the beginning of the late Pleistocene.

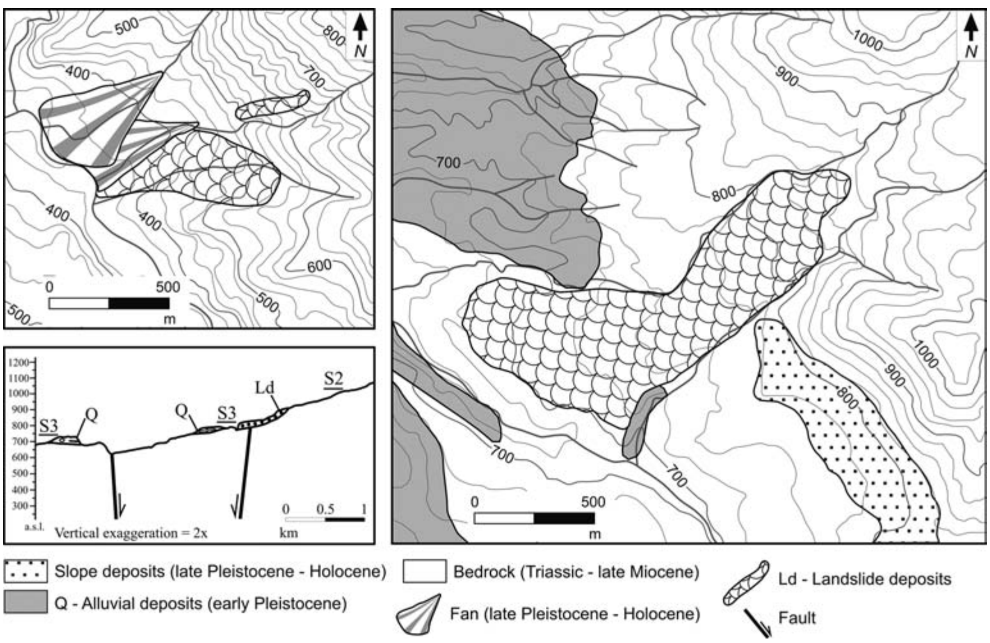
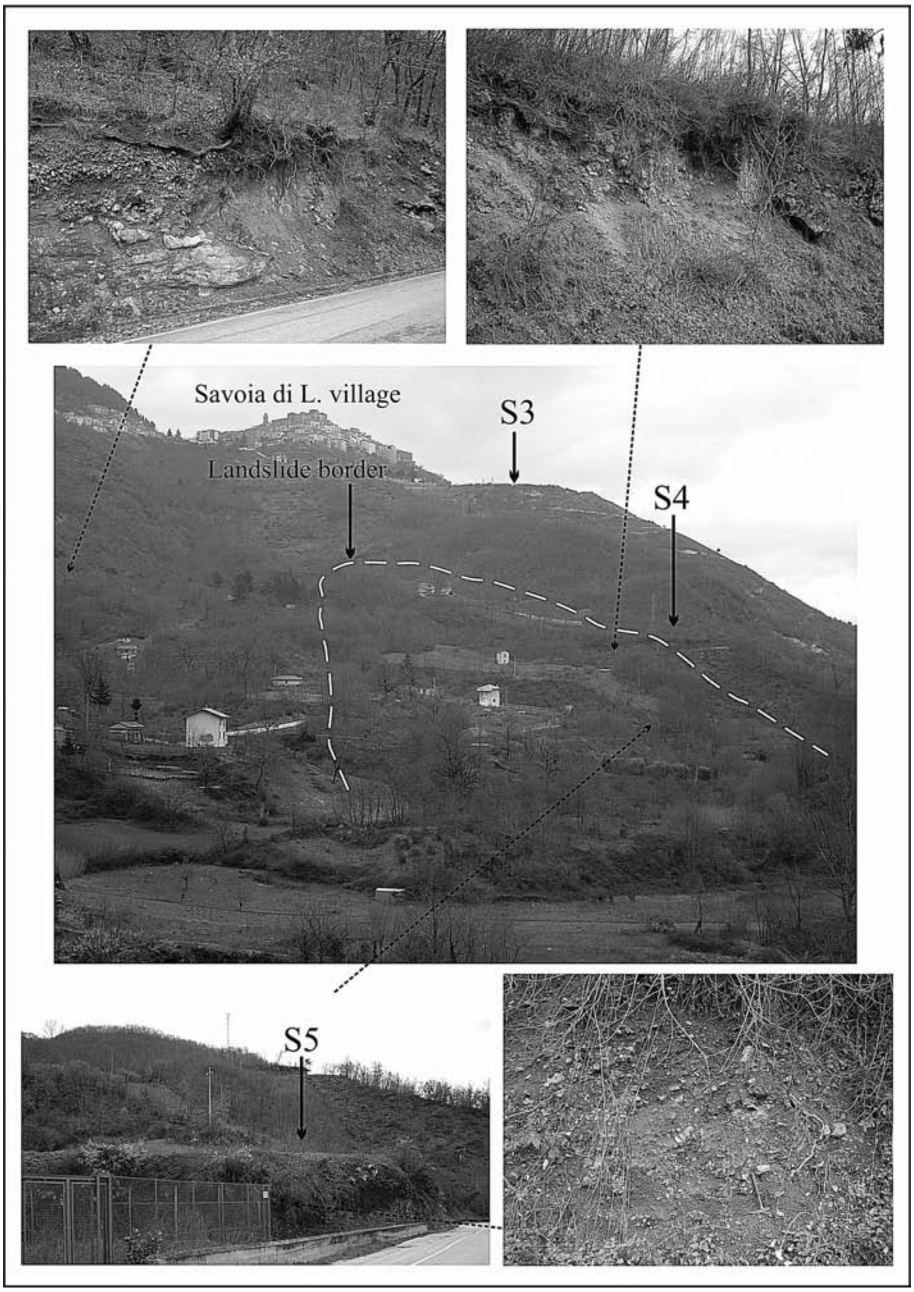


FIG. 4 - Geomorphological schemes of the studied landslides (see location in Fig. 3) and morpho-stratigraphic section through the central-southern sector of the Melandro River basin, showing the relationships between the erosional surfaces and the southernmost palaeo-landslide.

FIG. 5 - Palaeo-landslide (marked by the dashed line) in the southern area of the basin. The S3 land surface cuts the foot of the landslide. The inset shows the landslide deposits.

FIG. 6 - Palaeo-landslide in the northernmost part of the basin and its relationships with the other morphological features (erosional land surfaces and fluvial terraces). The pictures at the top of the central image illustrate the characteristics of the landslide deposit (to the right) and the stratigraphic relationships between slope and landslide deposits (to the left). The pictures at the bottom show the S5 terrace and its upper Pleistocene alluvial sediments.



DISCUSSION AND CONCLUSIONS

The uplift rates estimated in the study area have been calculated using geomorphological, stratigraphical and structural data. They partly correspond to vertical incision rates (Burbank & Anderson, 2001), estimated on the grounds of geomorphic data (elevation values, ages and arrangement of erosional gently dipping land surfaces and other morphotectonic indicators as suspended valleys, gorges, convex slopes, and strath terraces). The morpho-structural evolution of the Melandro basin is characterized by stages of uplift alternated with slack periods in which the erosional surfaces developed. In particular, four orders of erosional surfaces have been detected through field survey and geomorphological analysis (fig. 3). The age of these surfaces have been defined on the basis of morpho-stratigraphic relationships with Pliocene to Quaternary deposits. Specifically, the oldest palaeosurface (S1) cuts the Pliocene deposits at the tops of the Maddalena Mountains whereas the intermediate surface (S3) cuts the lower Pleistocene deposits filling the main depression of the Melandro River basin. Another order of erosional flat surfaces (S2) is interposed between the oldest and intermediate surfaces: its morpho-stratigraphic position suggests to ascribe the genesis of this erosional landscape to the early Pleistocene. Finally, the youngest surface (S4) is late Pleistocene in age, as verified for similar terraces in adjacent areas (Schiattarella & *alii*, 2003). Local, less extended, fluvial terraces (S5 after Martino & Schiattarella, 2006) are also present in the basin.

The uplift rates have been calculated using the difference in height between the absolute (sea level) or local (present-day talweg) erosion base levels and the several generations of land surfaces. Further, in this study we calculated also the stage (or partitioned) uplift (cf. Schiattarella & *alii*, 2006) on the basis of the difference in elevation between a given order of land surfaces and that immediately younger, with the aim of considering the trend in specific time intervals. The stage uplift is characterized by two increments: the first during the upper part of the early Pleistocene and the second during the late Pleistocene (fig. 7).

The correlation between the ages of the palaeo-landslides surveyed in the Melandro basin and the temporal trend of the stage uplift rates allowed to hypothesize that the landslides occurred in response to peaks in the tectonic uplift, responsible for the deactivation and raising of the different land surfaces, when strong earthquakes were probably more frequent and the mountain slopes destabilized by rapid relief growth (see Keefer, 2002, for a large review on these topics). On the other hand, the peculiar features of the slide material seem to be due to the deep weathering of the bedrock that a warm-humid climate could have caused during periods of increase in temperature (fig. 8) and before the tectonic crises, as shown by two positive peaks in the most recent reconstructions of the

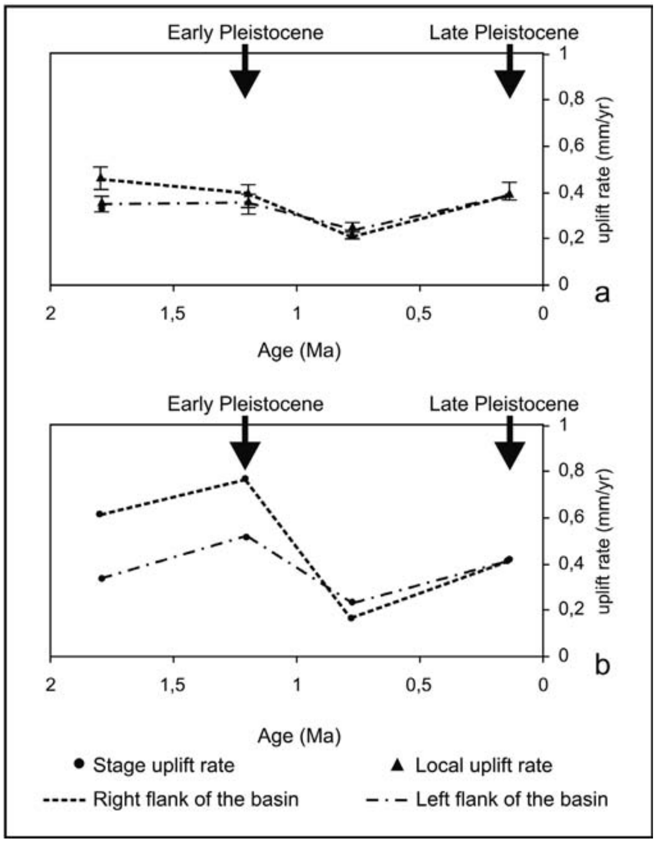


FIG. 7 - Local (a) and stage (b) uplift rates (i.e. vertical incision rates), as deduced by geomorphic and geological markers (error bars are reported just for the local uplift rates/vertical incision rates).

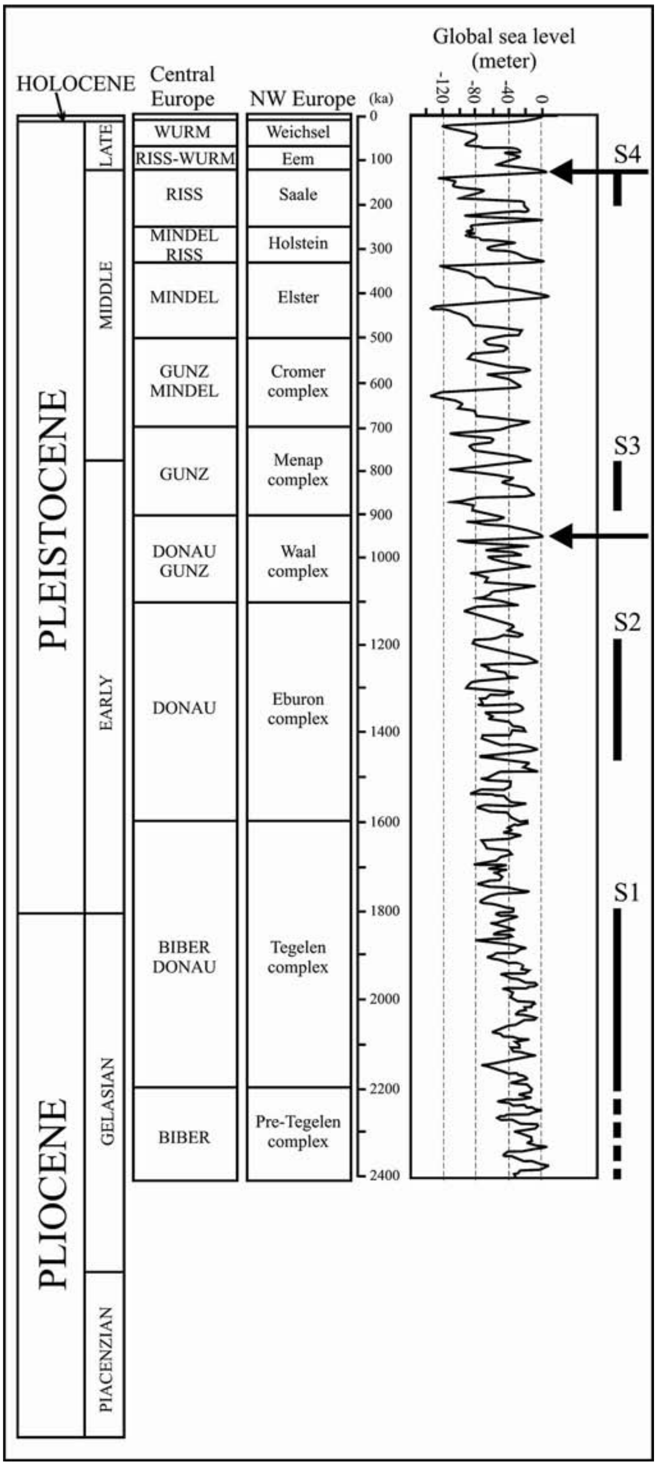


FIG. 8 - The warm-humid events (black arrows) in the global sea level curve (modified after Bintanja & *alii*, 2005, for the last 1 Ma, and reconstructed for the remaining part by means of marine oxygen-18 isotope curve after Gradstein & *alii*, 2004), responsible for the intense weathering of the bedrock developed before landslides generation.

Quaternary global sea-level changes (Gradstein & *alii*, 2004; Bintanja & *alii*, 2005). It is remarkable to note that the oldest peak, included in the Donau-Günz interglacial stage, coincides with the formation of a sapropel, widely diffused in the Mediterranean area, which has an age spanning from 960 to 955 ka (Meyers & Arnaboldi, 2005), whereas the youngest peak represents the debut of the Riss-Würm interglacial stage and marks the beginning of the late Pleistocene (Tyrrhenian marine stage).

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