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Messinian mass-wasting products of Northwestern Apennine foothills: from debris flows to huge slided masses in response to increasing relief steepness of an accretionary wedge

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Studies on continental margins report more and more examples of recent and fossil "chaotic bodies" which are commonly composed by different types of mass-wasting products (debris-flow, mud-flow, slumps, slided mass, rock-fall) either genetically-related in a single wasting event or resulting from multi-stage events. Therefore, the development of a single chaotic body can be understood only by the analysis of distribution and emplacement timing of different and composing types of mass-wasting products; these analysis might be difficult in remote-sensing and low resolution surveys. Throughout extensive stratigraphic and structural studies, integrating surface and subsurface data, the architecture and progressive development of Messinian mass-wasting products outcropping on the Northwestern Apennine foothills could be defined. In early Messinian, allochthonous units, coming from south and overriding the Oligocene-Miocene foredeep deposits, reached the southern edge of the Northwestern Apennines foredeep/wedge-top basins. These basins were filled mainly by shelfal to turbiditic deposits and they record the Messinian salinity crisis with evaporitic deposits; primary evaporites are deposited on intra-basinal highs and in perched basins at the toe of the allochthonous units. The intra-Messinian tectonic pulse further shortened these basins which started to be filled by masses moving from destabilized allochthonous units located to the south. Where preserved unaffected by surface instabilities, the allochthonous units are a complex stack of tectonic slices with ages ranging from lower Cretaceous to lower Eocene (Ligurian units) unconformably overlaid by middle Eocene-late Miocene shelfal to coastal deposits (epi-Ligurian units).

In late Messinian, the chaotic masses started to be sealed by turbiditic, shelfal and fluvio-deltaic deposits which preserve them till present days.

The Messinian mass-wasting products of Northwestern Apennine foothills, restored the post-Messinian deformations, form two major lens-shape bodies, elongated parallel to the foothills' structures; each of them has a minimum extension of few kilometers and estimated volumes of about $100km^3$. The two major bodies, probably made by coalescing chaotic masses, have similar internal characters. From the bottom, they start with monogenic gypsum arenite or breccia; locally, major blocks forming the breccia show primary depositional features with bedding surfaces marked by cm-thick horizons of clay or gypsum-clay above which growth-aligned gypsum-geminate form meter thick beds. These clastic gypsum bodies are interpreted as debris flows containing olistolites derived from nearby intra-basinal highs. The major volumes of these debris flows are in the external zone of chaotic bodies where they lay directly on top of foredeep/wedge-top deposits. On the contrary, in the internal zone of the same chaotic bodies, there are only isolated, decametric olistolites of primary-gypsum surrounded by a “melange” of allochthounous units, which likely constituted their original substratum. Going upward, the chaotic masses are made by pieces of dismembered allochthonous units; these pieces constitute the largest and widespread volume of the chaotic bodies. The Ligurian units and the sealing epi-Ligurian units are stretched and the original tectonic stacking cross-cutted by faults that might reactivate ancient tectonic contacts, which act as preferential detachment levels. Kilometers-wide klippens of allochothonous units are considered huge slided masses that glided into foredeep/wedge-top basins. The slided masses depart from zones characterized by extensional faults, i.e. headwall scarps, located above buried anticline hinges of Oligocene-Miocene foredeep units. In the external zone of the chaotic bodies, the slided masses of allochthonous units form embricate structures that ride over embricate thrust-stacks of gypsum debris flows. Thus, the overall architecture of the chaotic bodies show a denudational area, located inside the Ligurian and epi-ligurian units, and an accumulative area, which coincides with the thrust-stacked allochthonous units and debris flows.

Concerning the emplacement timing of mass-wasting products, the gypsum resedimentation must precede the gliding of Ligurian and epi-Ligurian units inside the foredeep/wedge-top basins. In fact, the clastic gypsum is now accreted underneath the allochthonous units but, before, it was present on both allochthonous units and foredeep/wedge-top deposits. Then, the stratigraphic constraints and the available Messinian chronostratigraphic scheme, which, for the Apennines and Mediterranean area, has refined age dating based on biostratigraphy, magnetostratigraphy and radiometric age of a regional vulcanoclastic level, restrict the formation of the chaotic bodies to a time interval minor than 100.000 years; nonetheless, gyspum debris flows and slided masses might have been multiple and instantaneous events.

The types, architecture and emplacement timing of the above mass-wasting products suggest that the Messinian chaotic bodies of Northwestern Apennine foothills are driven mainly by gravitative processes and they reflect a progressive increase of relief steepness in an accretionary wedge. When the relief started to increase, the gypsum-bearing debris flows are the first product to be formed; continuing to rise, the relief allowed the sliding of huge masses of Ligurian and epi-ligurian units that scraped off and accreted both primary evaporites, deposited on intra-basinal highs or in perched basins, and gypsum debris flows, derived from primary evaporites. The relief was steepened during the intra-Messinian compressive pulse when the allochthonous units advanced and, simultaneously, the underlaying Oligocene-Miocene foredeep deposits uplifted.