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PRELIMINARY STUDY ON THE SLUMP STRUCTURES OF THE EARLY OLIGOCENE SEDIMENTS OF THE PRE-APULIAN ZONE (ANTIPAXOS ISLAND, NORTH-WESTERN GREECE)

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Abstract

A spectacular slump is observed in the Alpine sediments of the Antipaxos Island (Pre-Apulian zone, Western Greece). It can be followed in a zone of about 2000 m, in the eastern coast of the island. The slumped unit exposure length extends for more than 200 m, and is directly overlain and underlain by undeformed strata. The slump has an average thickness of 15 m and is composed, as the surrounding undeformed units, of calcareous mudstones and fine-grained calcareous sandstones. Synsedimentary folds that very often are transformed to contorted beds affect slump sediments. Fold and contorted bed axes present a NNW-SSE direction, coinciding with the general direction of the Pre-Apulian zone. Slump and overlain/underlain undeformed sediments originate from the flux of clastic mainly pelagic/neritic biogenic particles, emanating from turbidity currents. More than 50 samples have been collected and analyzed for calcareous nannofossil content. All samples were featured by the contemporaneous presence of abundant nannofossil flora implying the biostratigraphic correlation with the NP23 nannofossil biozone. The biostratigraphic assignment places the slump and the surrounding sediments to the Early Oligocene. As the Pre-Apulian zone corresponds to the slope between the Apulian Platform and the Ionian Basin, the presence of the slump is directly related to the same age sloping and tectonic mobility of this domain. The Antipaxos turbidites sediments are well integrated to the flysch deposition of the external Hellenide foreland basin system.

Key words: *synsedimentary mass flow, Early Oligocene, synsedimentary folds, contorted beds, debris flow, slope, forebulge, foreland basin system.*

1. Introduction

This paper concerns the spectacular slump horizon observed in Paxi and especially in Antipaxos Island. The mass flows described here correspond to a broad zone, 10 to 15 m thick, of synsedimentary folds and contorted beds which are rarely accompanied by debris flows. This zone is clearly framed on bottom and top by sub-horizontal undeformed beds, implying the close relationship with synsedimentary deformation and redeposition mostly of cohesive material. The Antipaxos slump is confined to distinct stratigraphic horizons and indicates that it is related to major events (e.g. earthquakes; tectonic instability; quite important dip slope, etc.) which may cause synsedimentary deformation structures and cohesive mass flows contemporaneously.

2. Geological setting

Antipaxos Island belongs to the Pre-Apulian zone. This zone corresponds to the most external domain of the Hellenic fold-and-thrust belt (Fig. 1). It has traditionally been considered as a relatively

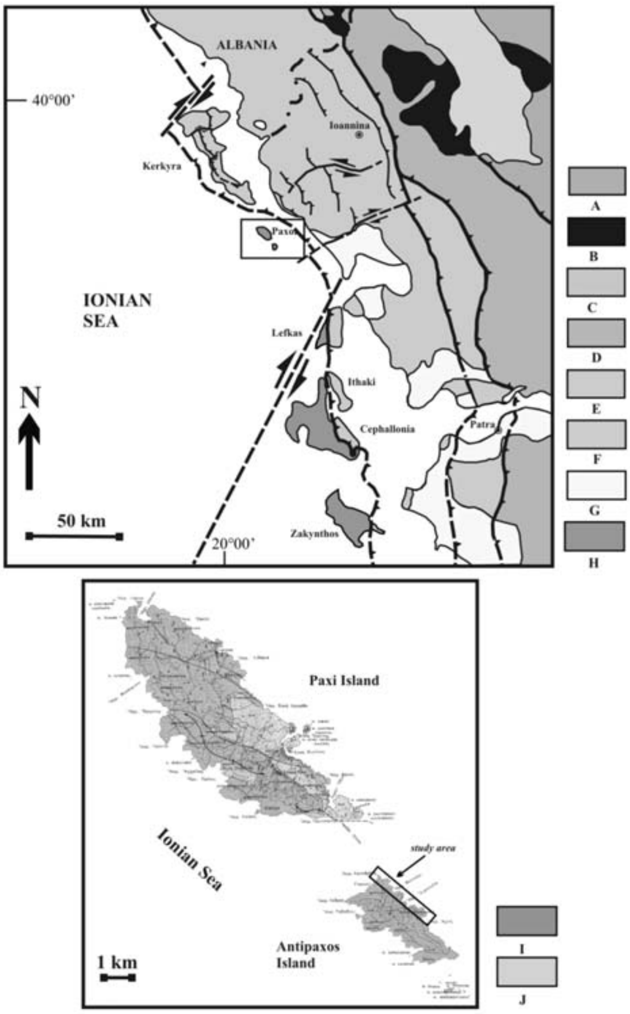

Fig. 1: On top, simplified geologic map of Western Greece (Karakitsios & Rigakis 2007). A. Pelagonian domain; B. Ophiolites; C. Mesohellenic molasse; D. Pindos zone; E. Gavrovo-Tripolis zone; F. Ionian zone; G. Neogene – Quaternany (post-Alpine sediments); H. Preapulian zone. On bottom, geological map of Paxi and Antipaxos Islands (adapted from Perry et al. 1960). I. Early Eocene - Early Miocene; J. Late Cretaceous - Middle Eocene.

uniform, Mesozoic – Cenozoic carbonate domain, transitional between the Apulian platform and the Ionian basin. Its general setting is complex as a result of intense tectonic deformation, including phases of extension, collision and flexural subsidence, with undetermined amounts of shortening and block rotation (Accordi et al., 1998). Outcropping successions differ in stratigraphic completeness, sedimentary development and faunal/floral content.

The depositional sequence in the Pre-Apulian zone (Fig. 2) begins with Triassic limestones containing intercalations of black shales and anhydrites. The oldest of these beds, according to borehole data (ESSO Hel., 1960), are dated as Toarcian to Bajocian. The stratigraphically lowest outcrops, located in Lefkas Island, comprise Lower Jurassic dolomites and Middle Jurassic cherts and bituminous shales (Bornovas, 1964; BP, 1971). The Upper Jurassic succession consists of white chalky limestones with dolomite intercalations, accompanied by rare cherts and organic-carbon rich black shales, containing

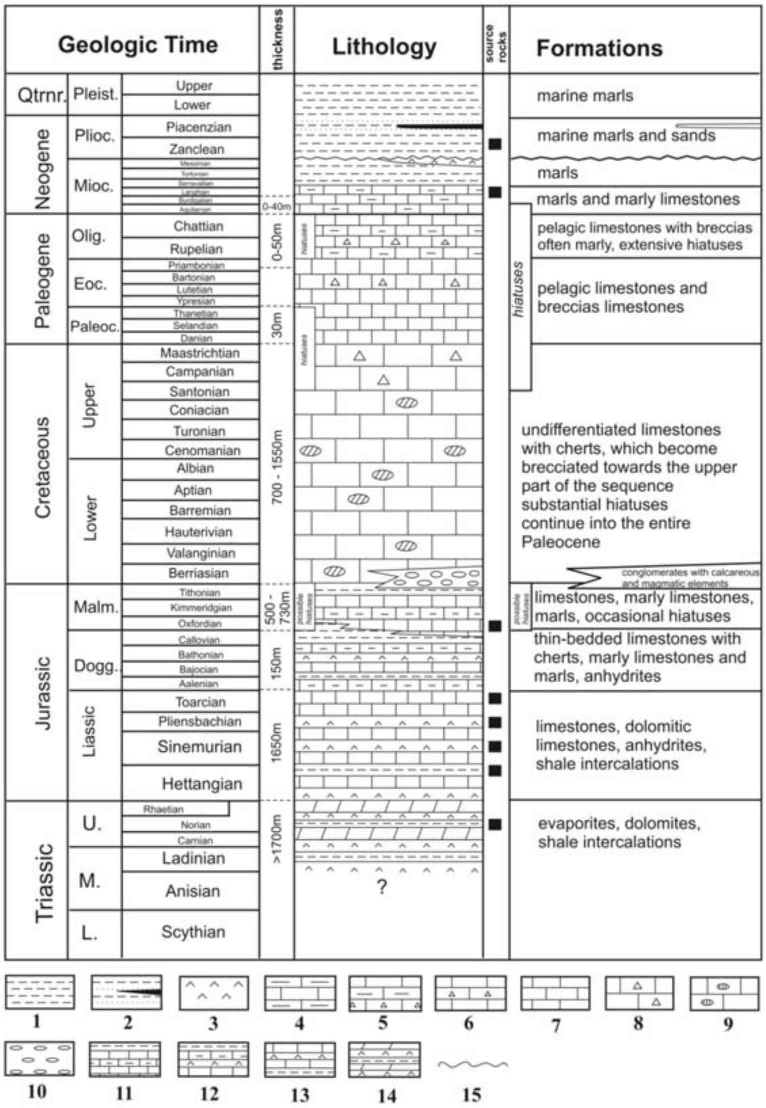

Fig. 2: Synthetic lithostratigraphic column of the Preapulian zone (Karakitsios & Rigakis 2007).
1: marine marls; 2: marine marls and sand (in black: lignite intercalations); 3: evaporites; 4: limestones often marly; 5: pelagic limestones or marly limestones with breccia intervals; 6: mixed pelagic-neritic limestones sometimes with breccias; 7: pelagic limestones; 8: mixed pelagic-neritic calcareous sediments with rudist fragments; 9: pelagic limestones with nodules and rare cherty intercalations; 10: conglomerates with calcareous and magmatic elements; 11: pelagic limestones, often marly; 12: limestones, shales and basal anhydrites; 13: limestones and dolomitic limestones, anhydrites and shale intercalations; 14: evaporites with shale intercalations, 15: unconformity.

planktonic species (Calpionellidae) together with benthic foraminifera and algal species. Borehole data from Zakynthos Island indicates the presence in the basal Cretaceous of conglomerates derived from carbonate and magmatic rocks. Lower Cretaceous limestones and dolomites crop out only on Cephallonia Island, and their facies is less pelagic than age-equivalent Ionian facies. The depositional environment throughout the Cenomanian-Turonian interval is indicated by the presence of rudist fragments, benthic foraminifera and algal species. During the Campanian-Maastrichtian, however, the platy limestones gradually become chalky with thin argillaceous layers. They contain, especially towards the top of this formation, planktonic foraminifera such as Globotruncanidae, in addition to rudist fragments. This co-existence indicates the presence of intra-platform basins characterizing the slope between the Apulian Platform and the Ionian Basin. Paleocene micritic limestones with planktic foraminifera were described by BP (1971) in the Pre-Apulian zone. Mirkou (1974) noted that these Paleocene units sometimes rest on Santonian or Maastrichtian limestones, and that neritic-facies microbreccias and brecciated limestones that occur at their base. This indicates intense tectonic activity which resulted in the differentiation of the Pre-Apulian zone into relatively deep-water and relatively shallow (sometimes emergent) areas, which provided the breccias material. The Lower Eocene comprises pelagic limestones with marl intercalations. The Upper Eocene consists of massive limestones with algae, bryozoans, corals, echinoids and large foraminifera. Oligocene sediments were deposited in small basins (tectonic grabens) between larger or smaller emergent areas, which were locally eroded, reflecting tectonic instability which continued throughout the Oligocene. During the Oligocene-Aquitanian, the diversification of foraminiferal assemblages suggests the presence of subsiding foreland basins. Finally, in the late Early Miocene, progressive deepening occurred, flooding the former carbonate slope (or carbonate ramp: Accordi et al., 1998).

The thickness of the Pre-Apulian series, in both outcrop and borehole data show that it is increasing from north to south (ESSO Hel., 1960). This observation translates the different position of the Ionian Islands in the transitional slope, represented by this zone, between the Apulian platform to the southwest and the Ionian basin to the northeast. So that, Paxi and Antipaxos Islands to the North, presenting a more basinal character, are closer to the Ionian basin, while the eastern half of the Zakynthos Island, with a more neritic character, is closer to the Apulian platform. In fact, the western part of Zakynthos already belongs to the Apulian platform, as it is composed by late Cretaceous neritic limestone with rudists.

Accordi et al. (1998) investigated the structural control on carbonate deposition and distinguished six tectono-sedimentary sectors within the Pre-Apulian zone, which was studied in the Paliki peninsula of Cephallonia Island. The boundaries of these sectors were identified by lithologic and stratigraphic discontinuities. The relationship between the different sectors is somewhat hypothetical, although, according to the above authors, they probably correspond to a number of tectonically obliterated areas of unknown extent. A general trend can be hypothesized for the study area, passing from a Late Cretaceous rimmed platform to a Paleocene homoclinal carbonate ramp. In the Paleocene, local tectonic subsidence together with eustatic sea-level changes and biological controls on the carbonate "factory" resulted in a deposition of a range of shallow-water to slope deposits, punctuated by episodes of emergence. Furthermore, the presence of a hiatus representing the greater part of the Eocene can be demonstrated in the same area.

Structures developed in the Pre-Apulian zone (mainly on the islands of Cephallonia and Zakynthos) may be accommodated within a simple model of continued foreland-directed migration of Hellenide (Alpine) thrusting during the Late Neogene and Quaternary (Accordi et al. 1998, Karakitsios & Rigakis 2007). Initial activity on the Ionian thrust can be dated as Early Pliocene, and the main thrusts (and some of the backthrusts) observed in the Pre-Apulian zone (e.g. on Cephallonia and Zakynthos Islands) are of late Pliocene and Pleistocene ages (Hug, 1969; Nikolaou, 1986; Underhill, 1989). Although, a foreland-propagating fold and thrust system in the northern external Hellenides segmented the former continental margin basin in Zakynthos and permitted diapiric intrusion of Triassic gypsum along thrust ramps, resulting in the development of coeval extentional basins, with increasing rates of subsidence from the Pliocene to Quaternary (Zelilidis et al. 1998).

Antipaxos Island is characterized by 80-90-meter-thick outcrops of a thin-bedded pelagic marly limestones succession, often microbecciated. The only geological studies concerning Paxos and Antipaxos Islands are the geological reports made by Esso Hellenic (Perry et al. 1960), AGIP (Rizzini & Balduzzi 1983) and Hellenic Petroleum geologists (Stylianou et al. 1986). The geological mapping of the Paxos sheet was accomplished by Perry et al. (1960). In this map (Fig. 1) the age range attributed to all of the Paxos Island outcrops is the Late Eocene-Early Miocene.

3. Slump description - Sedimentology

The slump horizon is clearly framed both on bottom (Fig. 3g) and top (Fig. 3a, f) by sub-horizontal undeformed beds. The thickness of the Early Oligocene slump horizon is 10 to 15 m (Fig. 3), its visible length is more than 200 m, forming a NW-SE direction zone which follows for about 2 km to the eastern coast of the island. The slump horizon is characterised by synsedimentary folds (Fig. 3) often transformed in contorted beds (Fig. 3b, c, e). The axes of synsedinendary folds and rotated beds present an NNW-SSE direction, parallel to extension of the Pre-Apulian zone and in general that of the external Hellenides. In some cases debris flows with big elements are observed (Fig. 3d). Load structures are present in the substrate unlithified plastic beds as the result of big contortions formed by slumped material (Fig. 3e). Stratigraphic gaps are implied in cases where the undeformed beds framing the slump are in direct contact, because the missing strata have been removed as slump. In general, stratigraphic successions characterised by broad and thick slumps, are expected to present secondary unconformities due to the removal of slumped beds. This case is necessary to be tested by a further detailed stratigraphic and sedimentological study. Slump horizons are characterised by downward sliding as a single mass, usually accompanied with backward rotation relative to the slope along which movement took place. The viscosity contrast of marl-limestone alternation caused development of slumping structures during gravitational redeposition. The most pronounced deformation within the slumped units occurred in semi-liquid muds (injection of marls into the cores of slump folds proves poor lithification prior to deformation). Early lithified beds were deformed in a ductile or brittle-ductile mode. In this case rare reverse faults with eastward divergence are observed.

The slump horizon is composed of the same lithofacies as the surrounding undeformed units. The dominant lithology corresponds to pelagic marly limestone often microbecciated, organized in a thin-bedded succession. According to the sedimentological investigations these sediments originate from the flux of clastic mainly pelagic/neritic biogenic particles, emanating from turbidity currents. Bioclasts range in age from the Late Cretaceous to the Early Eocene. Neritic clasts clearly demonstrate the deposition of benthic material derived from the eroded Apulian platform, which was transported by turbidity currents.

Turbidites are represented by sharp-based graded beds with a foraminiferal packstone lower part passing up into foram-wackestone/mudstone (Fig. 4). The formed sediments present a well-stratified facies of platy-marly limestones.

4. The age of the slump involved strata

Over than fifty samples recovered from the most clayey beds of the slump horizon and its undeformed base, have been studied for calcareous nannofossil biostratigraphic analysis, in order to date the Pre-Apulian calcareous sequences exposed on Antipaxos Island. Smear slides for calcareous nannofossil analysis have been prepared following the standard preparation technique of Perch Nielsen (1985). To obtain accurate biostratigraphic estimations, up to 100 fields of view have been investigated per slide, counting at least 500 specimens, with a Leica DMLSP optical polarising light

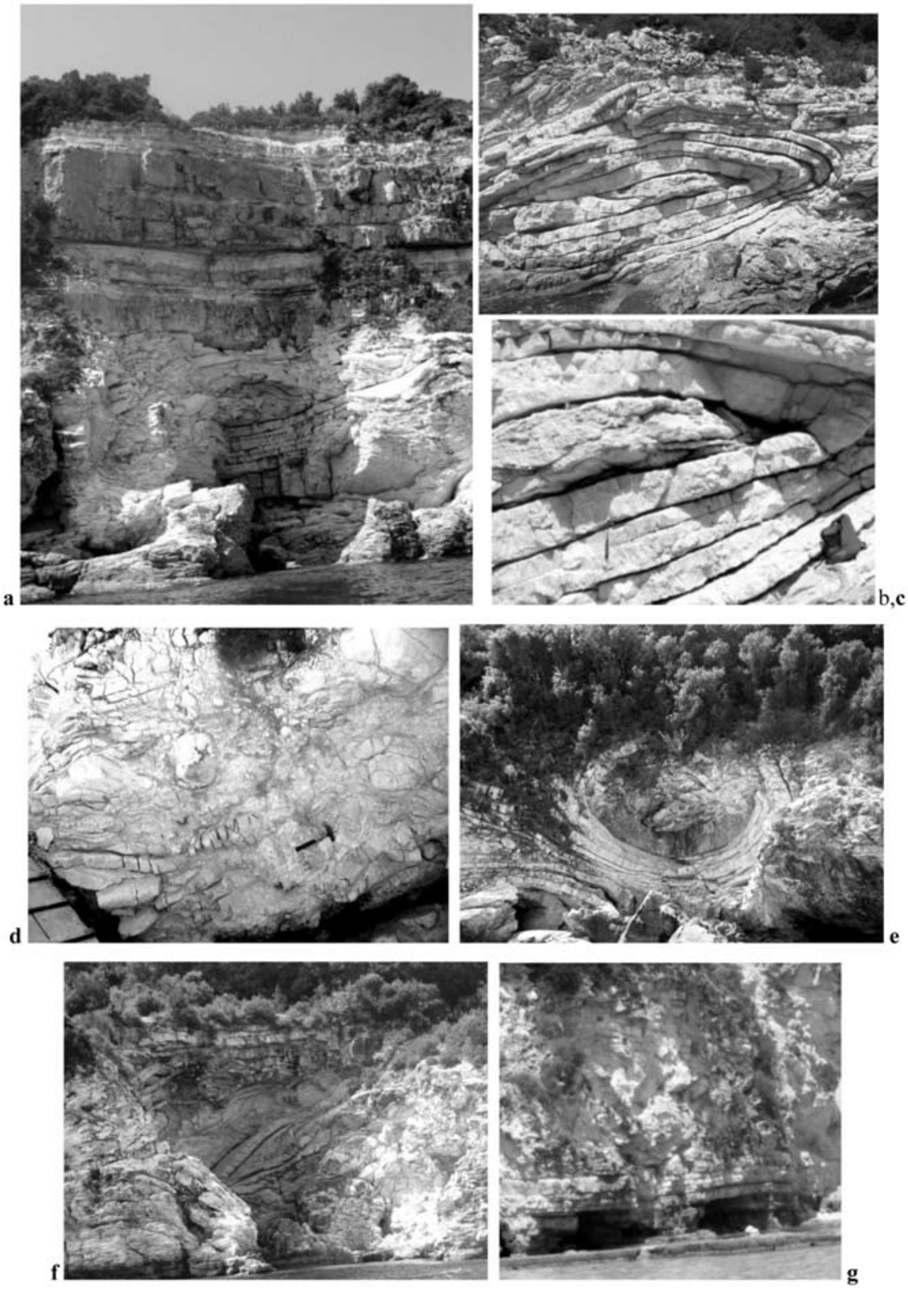

Fig. 3: Slump horizon as seen in outcrop. Slump framed on top (a,f) and bottom (g) by undeformed beds; Contortion (b) and detail (c); Debris flows with big elements (d); Load structures which were developed in the substrate unlithified plastic beds when the slumped material formed big contortions (e).

microscope at 1250x. Nannofossil state of preservation was overall very good and abundances were high. Semiquantitative abundances of the taxa encountered were recorded as follows: A, abundant: more than one specimen every field of view; C, common: 1 specimen/10 fields of view; R, rare: 1 specimen/ 50 fields of view; P, present: 1 specimen/ >100 fields of view; RW, reworked specimens.

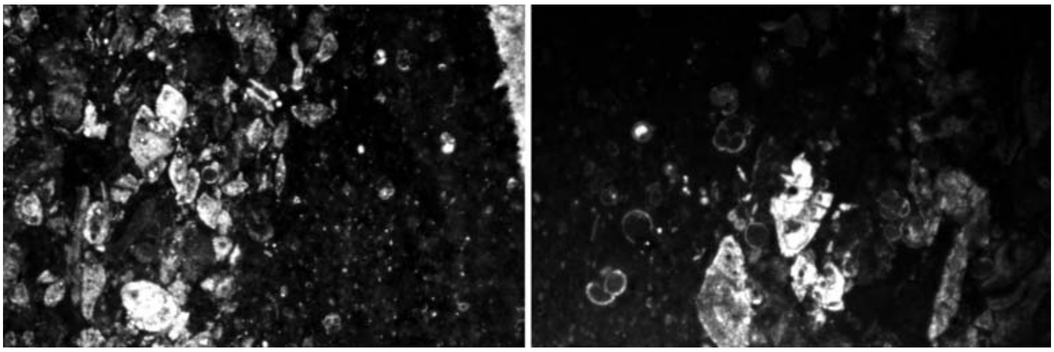

Fig. 4: Pelagic/neritic biogenic particles, emanating from turbidity currents. Bioclasts range in age from the Late Cretaceous to the Early Eocene.

The taxonomy of the determined calcareous nannofossil species has been based on Aubry (1984, 1988, 1989, 1990); Perch-Nielsen (1985). The nannofossil and biostratigraphic results are based on the biozonal schemes of Martini (1971), as they have been incorporated in the magnetobiochronologic framework of Berggren et al. (1995) and revised by Luterbacher et al. (2004). Numerical ages of biozone boundaries are given according to Luterbacher et al. (2004).

All the studied samples were featured by the contemporaneous presence of abundant *Cyclicargolithus floridanus* and Reticulofenestra bisecta, common *Sphenolithus predistentus*, rare *Sphenolithus distentus* and rather small forms of *Cyclicargolithus abisectus*, implying the biostratigraphic correlation with the NP23 nannofossil biozone. This biozone is bracketed by the bioevents of the highest occurrence (HO) of *Ericsonia formosa* at its base and the lowest occurrence (LO) of *Sphenolithus ciperoensis* at its top (Martini, 1971). It spans between 32.4-30.1 Ma, pointing to Early Oligocene age.

5. Discussion and Conclusions

Sub-aquatic slumps are structures in which sedimentary beds are deformed and the upstream part is torn away in detached lump (the form is not always recognizable) and extended (Reading 1986). The escarpment produced on the upstream part may then be subject to submarine erosion and then covered by gap with younger sediments. This gap represents the age interval of the slumped stratigraphic unit plus the age of the eroded sediment trance. The downstream part is characterized by intense deformation of the beds in synsedimentary folds, contortions and reverse faults, as the slippage generates compression. Minor earthquakes may prompt the formation of slumps on the slope, or the slope's lack of stiffness to resist an excess sedimentary load. Certain geological series of the past include impressive sequences that witness to active synsedimentary tectonics (Bally 1983). Any type of sediment can slump. In certain cases, the slump fold heads are dissociated and the less cohesive material then participates in other types of gravity-driven deposits (e.g. debris-flow; Strachan 2008). In the literature the causes triggering the slump movement are attributed to (Chamley 1990): earthquakes; tectonic uplift or depression; quite important dip slope; fast deposition that causes load excess; various nature of sediments which present different degree of consolidation or load excess, e.g. sands of higher density upstream, clays of lesser density downstream; high water content in the sediments (water saturated); rapid biochemical organic matter degradation with gas production in the sediment; substrate deformation due to evaporite mass rising. In our case the only certain factors are the dip slope and tectonic instability of the Ple-Apulian zone.

It has so far been generally accepted that the Pre-Apulian zone lacks typical flysch sediments. However, the observed progressive passage from the Ionian typical flysch to the more calcareous, age-equivalent, facies in the Pre-Apulian zone (BP, 1971) indicates that Oligocene Pre-Apulian sediments correspond to an atypical distal flysch unit (Karakitsios & Rigakis 2007). The partial or complete absence of this unit from some areas is due to the fact that these areas corresponded to the most external part of the forebulge depozone in the Hellenide foreland basin system (*sensu* DeCelles & Giles 1996), which has possibly been eroded (Karakitsios & Rigakis 2007). The observed Early Oligocene marly limestone turbidite sediments in Antipaxos Island are coeval to the typical Ionian flysch, whose thickness in the external western part of the Ionian zone is reduced and more calcareous, due to its paleogeographic position in the outer foredeep depozone (*sensu* Mutti et al. 2003). The Antipaxos turbidites composed by pelagic/neritic clasts favour the paleogeographic position of this domain east of the forebulge depozone corresponding to the western marginal part of the Apulian platform whose erosion supplies the turbidite material deposited in the Pre-Apulian slop. Consequently, the Antipaxos turbidites sediments are well integrated to the flysch deposition of the external Hellenide foreland basin system.

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