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STRATIGRAPHY AND DATING OF A LARGE SLUMPING EVENT IN THE NORTHERN AEGEAN

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ABSTRACT

Continuous seismic (Air-Gun) subbotom profiling in the N.Aegean was revealed a large submarine translational slide. The failure zone is extended from about 300m depth down to 800 m and covers an area of 85 Km^2. The mean thickness of the slide reaches about 55 m and an estimated total volume of 4 Km^3 of Quaternary sediments have been slided along a distance of 6 to 7 Km.

Chronostratigraphic analysis of the acoustic reflectors imply that the slide plane is the muddy layer of late Pleistocene age (170-240 Ka BP). AMS dating of sediment cores provided indications that this major slide event occurred 5 to 6 Ka BP.

ΣΥΝΟΨΗ

Κατά την διάρκεια υποθαλάσσιων ερευνών στο Β. Αιγαίο με όργανα ακουστικής διασκόπισης ανακλάσεως (Air-Gun) διαπιστώθηκε η ύπαρξη μεγάλης έκτασης κατολίσθηση στην περιοχή μεταξύ των νήσων Θάσου – Λήμνου.

Η περιοχή της κατολίσθησης έχει έκταση περίπου 85 km^2 και σε βάθη από 300 έως 800m περίπου και κλίση του πυθμένα από 1° έως 2.9°. Το μέσο πάχος της κατολίσθησης είναι 55 m, ο συνολικός της όγκος περίπου 4 km^3 η δε μετακίνηση της εκτιμάται στα 6 έως 7 km κατά μήκος του πρανούς. Τα μορφολογικά της χαρακτηριστικά την κατατάσσουν (κυρίως) στην κατηγορία της επίπεδης ολίσθησης. Το κατώτατο τμήμα της κατολίσθησης έχει αναμοχλευθεί και παρουσιάζει λοφοειδή διαμόρφωση ενώ στο ανώτερο δεν παρουσιάζεται εσωτερική διατάραξη των παράλληλων οριζόντων (στρωματοποιημένων) των ιζημάτων.

Η ιζηματολογική ανάλυση των πυρήνων που λήφθηκαν στην περιοχή σε συνδυασμό με δυο ραδιοχρονολογήσεις (AMS) έδειξαν ότι η κατολίσθηση έγινε πιθανότατα πριν από 5 έως 6.000 έτη.

Εκτιμάται ότι το επίπεδο ολίσθησης είναι ένας ιλυοαργιλώδης ορίζοντας που έχει αποτεθεί πριν από 170 έως 240.000 έτη σε συνθήκες υψηλής στάθμης της θάλασσας (μεσοπαγετώσης περίοδος – οξυγονοισοτοπική περίοδος 7).

KEY WORDS: Translational slide; acoustic stratigraphy; slide plane; relative dating; N. Aegean Trough.

1. INTRODUCTION

Submarine slumping and mass wasting processes at active plate margins is one of the principal and the more complicated downslope sedimentation mechanism quantitatively and qualitatively (Prior and Coleman, 1982). Medium to large scale mass movements are the most commonly recognized sediment failures on continental slopes and are measuring hundrends of meters to kilometers in horizontal dimensions (Field and Edwards, 1980). Slumping processes is the main potential natural hazard to existing and future offshore engineering structures on the continental margins (Heezen et al., 1966; Bee and Audibert, 1980; Carlson et al., 1980; Coleman and Prior, 1981).

In the NE Mediterranean downslope slumping is related with the Quaternary evolution and the present seismotectonic regime of the Hellenic Arc and Trench system (Hudson and Fortuin, 1985; Lykousis, 1991a; Ferentinos, 1992). Active neotectonics imply high seismicity with strong earthquake shocks (M=6.0-7.0) and high peak ground accelerations (20-35%g) in the forearc margins, as well as in the back-arc grabens (basins) of the Aegean Sea (Makropoulos and Burton, 1985; Delibasis et al., 1987; Jackson and McKenzie, 1988).

The major objective of this paper is to present and analyze the characteristics and dynamics (potential initiation mechanisms, failure planes, relative timing) of a slumping that was recorded during a conventional cable route survey across the central sub-basin of the North Aegean trough. This mass failure event is, probably, the

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largest in terms of a single event that has been recognised in the Aegean domain.

2. GEOLOGICAL SETTING

The North Aegean Trough (N.A.T.) is a 1 - 1.8 km deep ENE - WSW trending graben system with a series of three deep fault - bounded main sub - basins (Fig.1), characterized by extentional tectonics with an important strike slip component (Lyberis, 1984; Le Pichon et al. 1984; Mascle and Martin, 1990).

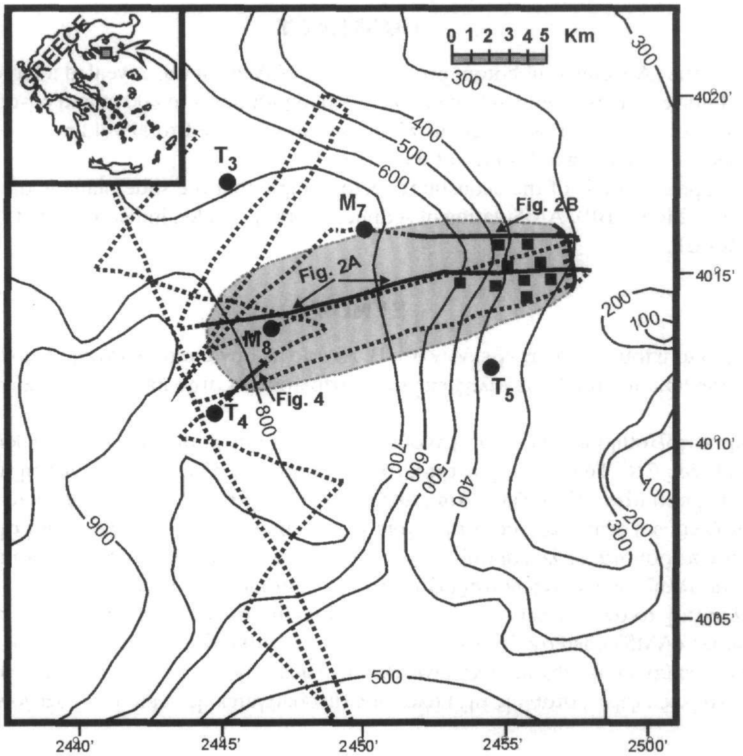

Fig.1. General bathymetric map with seismic continuous seismic profiling tracks, gravity (dots) and box coring (squares) in the greater region of the slide. The failure zone is deliniated by the shaded area. The selected seismic profiles that used in the text are also indicated.

It is interpreted as the westward extension of the North Anatolian fault (Dewey and Sengor, 1979) configuring the northern transform - type border of the Aegean microplate (Mercier et al., 1976; Mc Kenzie, 1978; Taymaz et al., 1991). Strike slip neotectonics and seismicity are closely related in the N.A.T. initiating strong shallow earthquakes (Papazachos and Papazachos 1989). During the last 30 years, four prominent seismic events (M>6.0) were reported and studied in detail in the central part of N.A.T. closely to the observed slumped deposits (Mc Kenzie, 1972, 1978; Jackson et al., 1982; Jackson and Mc Kenzie, 1984; Taymaz et al., 1991). Also nine very shallow earthquake motions (3-8 Km) of medium strength (M= 4.0-5.0) affected the area under investigation the period 1980-1989. These shallow earthquakes are able to induce, locally, high horizontal ground accelerations and to initiate slope sediment failures.

Quaternary sedimentological studies in the North Aegean have been carried out mainly by Perissoratis et al. (1987); Perissoratis and van Andel (1988); Lykousis and Chronis (1989a); Perissoratis and Mitropoulos (1989); Piper and Perissoratis (1991); Perissoratis and Piper (1992) and Lykousis (1991b). The thickness of the Late Quaternary sediments (late 150 ka) in the central part of the N.A.T. range from 30-50 m, while the mean subsidence rates due to neotectonics for the same period ranges from 0.3-1.5 m ka^{-1} with a mean value of 0.8 m ka^{-1} (Piper and Perissoratis 1991). Slope stability studies were performed by Lykousis and Chronis (1989b) in Late

Pleistocene prodelta deposits on the upper slope of thr NW Aegean (western termination of the N.A.T.).

3. DATA AND METHODS

The study area was surveyed in terms of subbottom profiling by a 1-40 cu.in. Air-Gun (PAR BOLT U.S.). The Air-Gun was operated with the 5 or 10 cu.in. chamber with the signal filtered at 200-1100 Hz for optimum penetration and higher resolution of the Late Quaternary reflectors, and the better identification of the potential slip planes (layers). Selected gravity coring was scheduled with a BENTHOS INST.(U.S.A) gravity corer, after a preliminary onboard seismic profiling interpretation. Most sampling attempts in the scarp and along the glide zone failed, possibly due to the exposed hard Pleistocene slide plane and/or the stiff mud clasts and slide debris. Sediment cores were recovered from the greater undisturbed Late Pleistocene slope and basin sediments and the toe of the slide while one core was obtained from the northern edge of the slide plane/scarp foot. Box core was used for supplementary sampling where the gravity coring failed, especially along the slide surface and the scarp slope covered by the stiff mud debris.

Sections of split cores was X-rayed using a Faxitron (U.S.) X-Ray cabinet. Grain-size analysis was performed by the SEDIGRAPH laser technique (Micrometrics 5100) at regular intervals along the split cores. Selected samples was analysed for organic carbon and total carbonates content with a CHN Analyser (Fisons EA 1108).

The field work was carried out with the R/V AEGAEO during 1989, 1994 and 2000 navigated by a TRIMBLE 4000 Surveyor D.G.P.S. system (accuracy ± 5m).

4. RESULTS

4.1. Slide geometry (morphology)

The morphological characteristics of the failure zone were revealed from the study of detailed multibeam bathymetry and images, conventional echo sounding and continuous seismic profiling records. The slide and the related failure zone is highly complex in terms of morphology and vertical profile appearance indicating, apparently, variability in the sliding processes. The failure zone that trends WSW is extended between 300 to 800m depth with slope gradients from 1° - 2.9° (mean 1.8°) covering an area of 85 Km^2 (mean length 16.5 Km, mean width 5.3 Km)(Fig. 1). The boundaries along the flanks of the slide are relatively well defined especially towards the shallower parts of the failure zone.

The uppermost part of the failure zone is about 4-4.5 km wide and consists mainly from a well defined slide scarp (headwall) that has an average slope of 6° and an approximate (mean) relative high of 40-50 m (estimated from the continuous subbottom profiling, Fig. 2A,B). The subbottom stratified acoustic reflectors are clearly truncated by the slide scarp. Slide debris (SLD) of about 0.2 Km^3 in volume have been accumulated to the foot of the scarp, while slab like slumped sediment masses (slide blocks) appears on the glide zone (depths from 320-600 m) especially in the northern part of the failure (Fig. 2B). These blocks of about 0.7 Km^3 in volume retained the initial sediment strata of alternating stratified and relatively transparent reflectors equivalent to those that have been truncated by the slide scarp. The glide plane appears to be a sequence of well stratified reflectors that are extended upwards and constitutes the base of the slide scarp.

In the deeper (and larger) part of the failure zone (extended from 650-800 m) the slumped sediments have resulted in a well defined seabed elevation of 10-15 m high lahibiting characteristic hummocky bottom topography (Fig. 2A). In the seismic profiles this zone display characteristic hyperbolic and chaotic internal reflections throughout the disturbed sediment mass implying intense remolding of the sediment strata (Stuart and Gaughey, 1977). The thickness of this lower part of the slide range from 40-85 m (mean 55 m), their aerial extension is about 45 Km^3 and the estimated volume exceeds the 2.7 Km^3. The hyperbolic and chaotic reflections terminate abruptly downslope where a sequence of stratified undisturbed reflectors that have been regarded as the base of the potential glide plane of the failure. In the lowermost edge of the failure zone these hyperbolic and chaotic reflections appears to split in two or three patches and to prograde over the underling intermediate stratified reflectors distructing only the poorly stratified or partly transparent reflectors. This indicates presence of weak layers over the intense and stratified reflectors and along the base of the acoustically transparent layers as already noted by Lykousis (1991a) and Perissoratis and Papadopoulos (1999). Consequently the major and secondary glide planes are the transitional zones between the basal strongly stratified reflectors (stiff-relatively coarser sediment layers) and the overlay acoustically transparent and/or poorly stratified reflections (weaker-muddy layers with higher water content and lower shear strength).

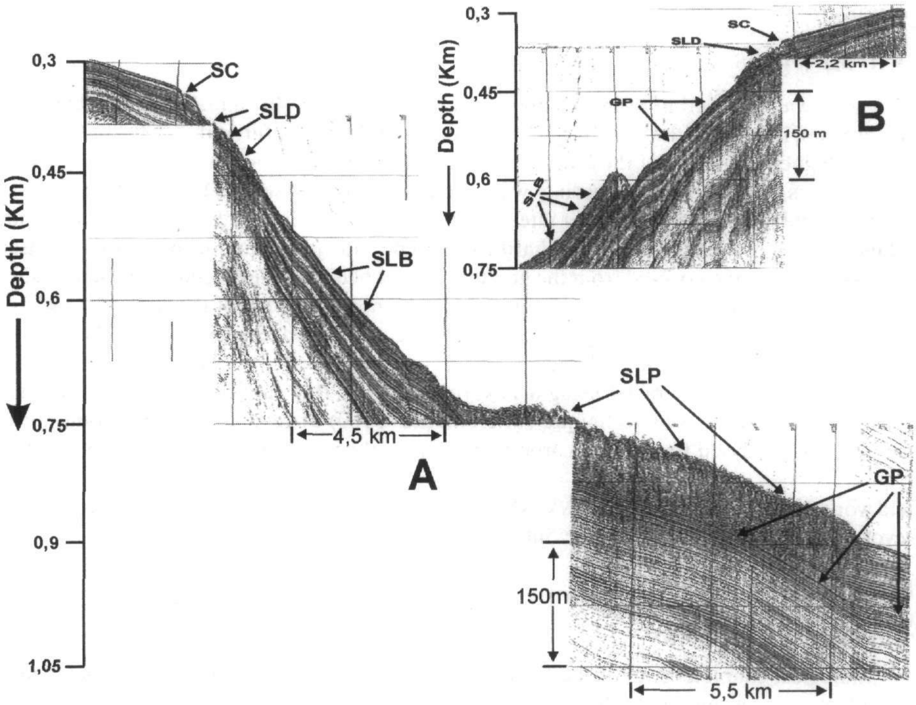

Fig.2. Downslope Air-Gun subbottom profiles of the failure zone showinging all the general appearance and characteristics of the slide. Slide scarp (SC) debris (SLD), glide plane (GP), slab slide (SLB) and the remolted toe of the slide (SLP) with haotic and hyperbolic reflectors are indicated.

The observed failure is a rather typical translational slide of bedded sediments with about 4 Km^3 of downslope moved sediments along a distance of 6 to 7 Km over a well defined glide plane. The overall morphological characteristics of the slide resemble to that of Curritue translational slide in the Mid-Atlantic continental slope (Prior et al., 1986) despite the volume differences. The overall structure and characteristics (scarps, block slides-olistoliths, slide debris, weak layers as glide planes) indicates a failure mechanism similar to that described in the review paper on the origin and behavor of submarine slub slides (O'Leary, 1991).

4.2. Sediment cores

Three gravity sediment cores were recovered from the undisturbed slope sediments, from which one was taken from the lower part of the slide (region of hyperbolic reflectors) and one from the sidewall scarp (Fig. 1). A number of box corings were carried out in the exposed gliding surface, since gravity coring attempts failed to obtain more than 20 to 30 cm of homogenous muddy sediments.

The cores T5,T3 and T4 taken from different depths in the slope surrounding the slide (depths 360 m, 670 m and 880 m) is assumed to represent the regional (relatively to the slide) shallow stratigraphy and geotechnical conditions. Texturally these three representative sediment cores display the typical N. Aegean shallow sediment sequence stratigraphy (Fig. 3). Four basic upward sediment sequences are distinguished: a) The Late glacial stiff silty-mud layer (>about 16 Ka BP), (b) The lower Pre-Holocene muddy layer (9.2-about 16 Ka BP), c) The thinner intermediate Early Holocene sapropelic layer (9.2-6.4 Ka BP from Perissoratis and Piper, 1992) and d) The upper Late Holocene muddy horizon (<6.4 BP Ka BP). The upper Late Holocene layer is from 55 cm thick in the shallower T5 core (360 m) to 110 and 140 cm thick in the other two lower slope cores (core T3 and core T4 respectively). Since sapropelic layer deposition was terminated about 6.4 Ka BP the calculated regional mean Late Holocene sedimentation rates are about 10 Ka cm^{-1} in the upper slope and from 15-25 Ka cm^{-1} in the lower slope environment. The short core M8 (depth 820m) taken from the toe of the slide did not provide any additional information regarding the remolting character of this part of the slide.

The box cores retrieved a few tens of centimeters in thickness that consist of a basal admixture of very stiff

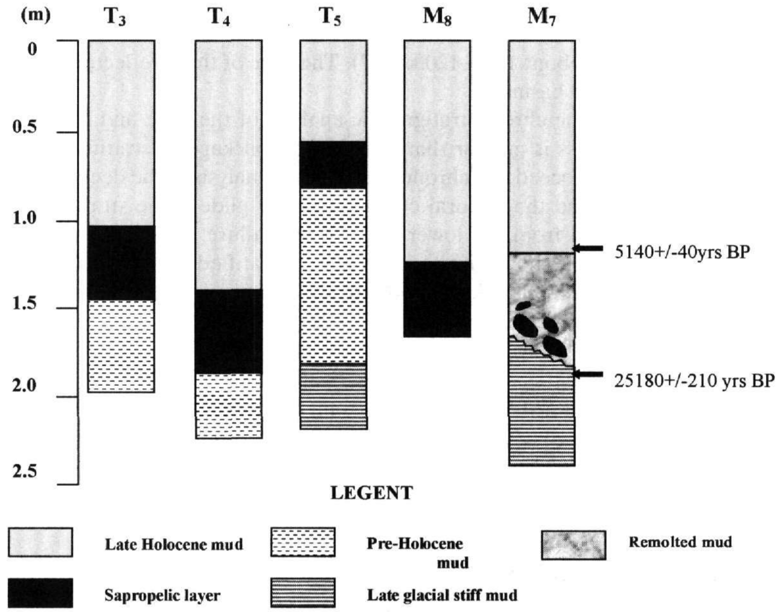

Fig.3. Basic textural and stratigraphic characteristics along the cores taken from the upper (T5, 360m) and lower slope(T3, 670m and T4, 880m),the toe of the slide (M8, 820m) and the side slide scarp (M7,720m).

mud clasts and an overlay of homogeneous hemipelagic mud drape. The mud clasts probably are glide debris and should be compared with the "friable clay" that was sampled from the glide plane of Currituc slide (Prior et al., 1986). The homogeneous mud drape is expected to have been deposited after the termination of the failure processes. The thin muddy veneer that covers the stiff mud clasts (and possibly drapes the entire glide plane) and the regional sedimentation rates for the upper slope environment (around 10 cm Ka^{-1}) indicates a relatively recent (Early Holocene) age of the slumping event in the N. Aegean.

Important information was revealed from the core sampled from the northern sidewall scarp (core M7, depth 720m)(Fig. 3). This core displayed two different muddy sections in terms of textural characteristics. The upper (130 cm) part (section 1) is a homogeneous clayey pelagic mud and the lower (150-250 cm, section 2) is a stiff mud sediment layer of greenish gray color (10GY). Also the upper most part of the section 2 (130-155cm) display a rather reworked texture with organic mud clasts. Organic carbon values of these clasts range between 1.5-1.9% revealing the sapropelic origin (character) of the mud clasts. The reworked section is underlined by two gravity fault "cracks" indicating that the sediment core has penetrated a gravity fault zone, since the core M7 recovered from the lower scarp of the slide sidewall. AMS ^{14}C dates from the base of the section 1 yielded an age of 5140 ± 120 years BP (BETA-148979) and an age of 25180 + 410 years BP (BETA-148980) for the section 2 (within the gravity fault zone) implying a sidewall gravity fault process between Early Holocene-Latest Pleistocene. This is in agreement with the Early Holocene age of the major failure event that was postulated from the thickness of muddy drape of the glide plane and the estimated Holocene sedimentation rates.

4.3 Seismic chronostratigraphy and glide plane

The relative timing of the late Quaternary seismic reflectors in the N. Aegean have been performed by Piper and Perissoratis (1991) in their detailed study for the Late Quaternary sedimentation on the North Aegean. The authors correlate basin wide sequences of reflectors with major transgressive/regressive periods during the late 150 ka (oxygen isotopic stages 6.3 to 2)(Imbrie et al., 1984; Chappell and Scackleton, 1986)(Fig. 4). The total subbottom thickness of these sequences is 35m in the slopes and around 55m in the deep basins. The reflectors are differentiated in packages of strong stratified and transparent/poorly stratified reflectors. The stratified reflectors represent sandy to silty turbidites that was deposited during low sea level stands (oxygen isotopic stages 2 – 3.2 and 6.5 – 6) and the transparent reflect hemipelagic mud deposition during high sea level stands (interglacial periods, isotopic stages 3, 5, 1). Poorly stratified reflectors reflect probably smaller fluctuations of sea level during the extended interglacial period from isotopic stage 3.3 – 5 (about 70 ka). The deeper recognized package of reflectors (Cu, Cs, CL) represent the top and base of the turbidite sequences that was deposited during isotopic stages 6.5 – 6 (about 170 – 120 ka BP). The base of these reflectors is located in at about 33 m subbottom on slopes and 55 m in basins.

This concept was applied for the chronostratigraphic analysis of the slide and the estimated "age" of the glide zone. Since the slide thickness is greater than the deepest package of stratified reflectors identified by Piper and Perissoratis (1991), we proceed in a chronostratigraphic analysis of the deeper reflectors. This enables us to identify the relative "age" and the textural character of the glide plane stratigraphic section. Figure 4 illustrates the stratigraphic section from the lower edge of the failure zone and the basinward undisturbed subbottom strata. This seismic profile shows an alteration of well stratified and acoustically transparent to poorly stratified intervals. Three major stratified packages and three transparent intervals were identified to a subbottom depth of 100 – 110 ms (75 – 85 m) that is the maximum depth of sediment disturbance of the sliding processes. The thin reflector represents silty – sandy turbidite sequences of the relatively short duration stage 2 (late glacial maximum). Reflectors bu and bL marks the top and base of silty mud turbidites that was deposited during the isotopic stage 4 (about 70 – 55 ka BP). Accordingly the strong reflectors Cu and CL that is the upper and lower end of a thick package of stratified reflectors indicates turbidite deposition at glacial stage 6 (about 170 – 130 ka

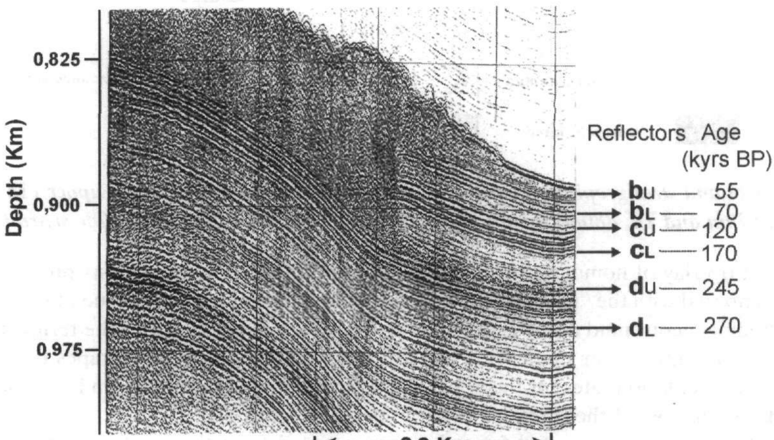

Fig.4. Cronostratigraphic analysis subbottom reflectors. The glide plane corresponds to the du reflector.

BP). The lower package of thick and well stratified reflectors (reflectors du to dL) correlates to major low sea level stand turbidite sequences (stage 8, about 290 – 245 ka BP). The uppermost reflector du that is traced upward to the base of the slide scarp serves the undisturbed base of the remolted slide masses. Consequently the glide plane should be the lower part of the transparent layer that correspons to interglacial hemipelagic muds (high sea level stand – stage 7) that have been deposited about 240-170 Ka BP. The very stiff semiconsolidated mud clasts recovered from the exposed gliding surface could probably be debris from this intergacial muddy layer. As indicated in Fig.4 weak layers (secondary glide planes) could be the trasparent sections of the seismic profiles that have been deposited during inerglacial high sea level stands (isotopic stages 7, 5, 3) when the sediment input and the sedimentation rates were lower. This implies initiation and evolution of the failure along the base of "weak" interglacial muddy layers and progradation of the failure over the shear resistant stratified glacial packages.

5. CONCLUSIONS

- The morphological, and stratigraphic characteristics of the large failure event in the N. Aegean leads to the conclusion that this is a typical translational slide of well bedded sediments.
- The overall dimensions of the slide (volume 45 Km^3, aerial extension 85 Km^2, mean thickness 55 m, downslope movement 6-7 Km) implies that it could be regarded as a large scale slump. Actually it is the largest single slump event recognized so far in the Central and North Aegean sea and probably the entire Aegean.
- The glide plane is a well defined basal surface in the seismic profiles. Relative chronostratigraphic analysis coupled with surface sediment cores indicated that the over lying muddy layer was deposited about 170-240

Ka BP during the interglacial stage 7 (high sea level stand).

- AMS dating in one sediment core (above and below slide scarp) integrated with the sedimentary information from the sediment cores indicates a major slide event around 5 to 6 Ka BP.

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