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UPPER QUATERNARY SEDIMENTARY HISTORY AND GEOTECTONICS OF THE EASTERN PART OF CENTRAL AEGEAN SEA

V. Lykousis, P. Pavlakis, C. Anagnostou, G. Rousakis and M. Alexandri

ABSTRACT

Four oblique progradational delta sequences can be recognized below the S. Ikarian Basin, that were deposited during middle-upper Quaternary glacial stages (isotopic stages 2, 6 and possibly 12-8, 22-16). The topset to foreset transition of these sequences, located at 109.5, 152 and 212m below present sea-level, reflect continuous subsidence of 0.33 - 0.57m/ka. The mean sedimentation rates were estimated to 20 - 90cm/ka for the Upper Pleistocene turbiditic deposits, 10 - 60 cm/ka for the Post-isotopic 6 sediments and 8 - 30 cm/ka for the last - post glacial sediments (25ka - today). A pronounced deformational phase during the Pliocene - Lower Pleistocene within the S. Ikarian basin can be recognized. Within the N. Ikarian basin indications of Quaternary strike-slip deformations appeared that are related with en echelon of transpressional reverse faults.

ΣΥΝΟΨΗ

Στο Ν. Ικάριο πέλαγος αναγνωρίσθηκαν τέσσερις, προσχωματικού χαρακτήρα, προδελταϊκές στρωματογραφικές ενότητες που αποτέθησαν σε παγετώδεις περιόδους του Μέσου - Ανώτερου Τεταρτογενούς. Το όριο των αποθέσεων κορυφής με τις αποθέσεις μετώπου των Δέλτα που ευρίσκεται σε βάθος 109.5, 152 και 212m προϋποθέτει συνεχή καθίζηση με ταχύτητες 0.33 - 0.57 m/ka. Οι μέσες ταχύτητες ιζηματογένεσης κατά το Κατώτερο Τεταρτογενές (250.000 χρ. - σήμερα) αποθέσεις είναι 20 - 90 cm/ka, κατά τη διάρκεια των τελευταίων 128.000 χρ. 10 - 60 cm/ka και για τις Μετά - Βούρμιες αποθέσεις (25.000 χρ. έως σήμερα) είναι 8 - 30 cm/ka. Χαρακτηριστική φάση παραμόρφωσης παρατηρήθηκε στο Ν. Ικάριο πέλαγος πιθανόν κατά τη διάρκεια του Πλειόκαινου - Αν. Πλειστόκαινου ενώ παραμορφώσεις από οριζόντια ολίσθηση, συσχετιζόμενες με ακολουθία "διαγωνίου πιέσεως" ανάστροφων ρηγμάτων, παρατηρήθηκε στο Β. Ικάριο πέλαγος.

INTRODUCTION

The area under investigation is mainly the Eastern sector of Cyclades Plateau and the North and South Ikarian basin (Stanley and Perissoratis, 1977)(Fig. 1). The geodynamic evolution of the area (as the central Aegean domain) implies intense (Late Jurassic - Miocene) compressional deformation with vertical movements and block tilting (Angelier 1976, 1979; Papanikolaou, 1977, 1987). The extentional tectonic regime was established during Late Miocene or Lower Pliocene (Mercier et al. 1979) assosiated with normal and listric faulting and resulting in the formation of the central Aegean Sea

National Centre for Marine Research, Ag. Kosmas 166 04, ATHENS, GREECE

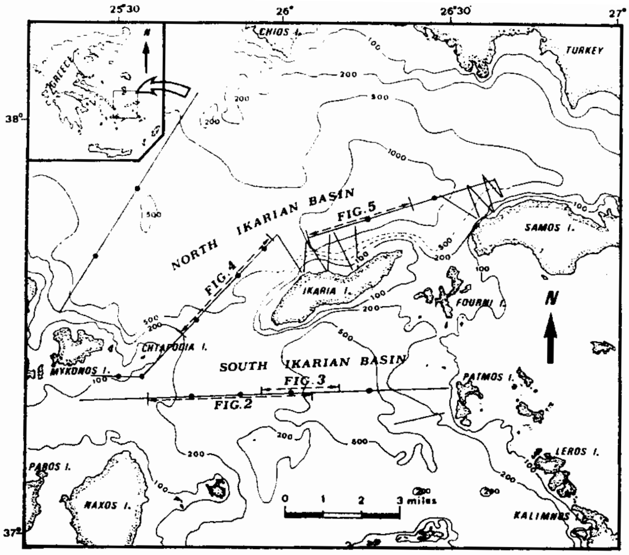

Fig. 1: Baythymetric map with seismic profiling tracks (solid lines), core locations and selected profiles used in the text (dashed lines).

grabens (basins) (N. and S. Ikarian basins, Lesvos basin etc.). According to a recent work of Mascle and Martin (1990) the Central Aegean display a "puzzle-like" morphological and structural pattern with variously oriented normal faults. The eastern part of the Central Aegean appears to be dominated by (NE-SW to ENE-WSW) structural trends, while the western part (S. Skiros basin, Kalogeri basin - Andros - Chios trends ridge etc.) displays NW-SE oriented extentional features. These trends clearly result from a NE-SW extension, therefore may progressively be activated as incipient translational fault zones as suggested by the local strike slip deformations. Strike - slip deformations have been suggested, as well, for the S. Aegean Sea (Pavlakis, 1992, Anagnostou et al. 1992). Subsequently Plio-Quaternary sediments were deposited within the slowly subsiding basins, as a result of rivers discharge and eustatically controlled delta progradation during Quaternary.

Although there have been several studies on Late Quaternary subsidence and sedimentary history in the N. Aegean ,the Central Aegean is very poorly studied. The Quaternary sedimentary evolution of the Aegean sediments have been examined mainly in the N. Aegean (Perissoratis and Mitropoulos, 1989; Perissoratis and T.H.V. Andel, 1988; Piper and Perissoratis, 1991; Lykousis, 1991) and along the Western coasts of Turkey from delta progradational patterns (Aksu and Piper, 1983; Aksu et al. 1987 a, b).

The purpose of this work is the investigation of the Middle-Late Quaternary sedimentary evolution in the eastern part of the central Aegean and the possible geotectonic implications during this period.

MATERIALS AND METHODOLOGY

The area was surveyed by using a 1 - 10in^3 Air-Gun (PAR BOLT) and a 3.5kHz (ORE LTD) high resolution profilers. The entire field work was carried out using the R/V "AEGAIO". Position fixing was obtained by satellite navigation (Global Position System - G.P.S. TRIMBLE 4000 SURVEYOR) with accuracy ±50m. A narrow beam (8°) echo sounder (FURUNO) was used during all the survey. Ten sediment gravity cores was recovered using a 3m BENTHOS INSTR. gravity corer for chronostratigraphic control and relative dating of the Late Quaternary stratigraphic horizons.

RESULTS AND DISCUSSION

Quaternary sequence stratigraphy

The continuous reflection seismic profiles (Air-Gun and 3.5kHz) have been studied according to the widely used method of Mitchum et al. (1977). This technique distinguishes different sediment sequences and depositional conditions based on the analysis of correlatable reflections, successive reflectors and associated uncomformities.

The characteristic seismic profile across the eastern margin of Cyclades to S. Ikaria basin (Fig. 2) revealed the existence of three characteristic major uncomformities, which define four successive progradational sequences (PS_1 - PS_4). These sequences display an oblique progradational configuration

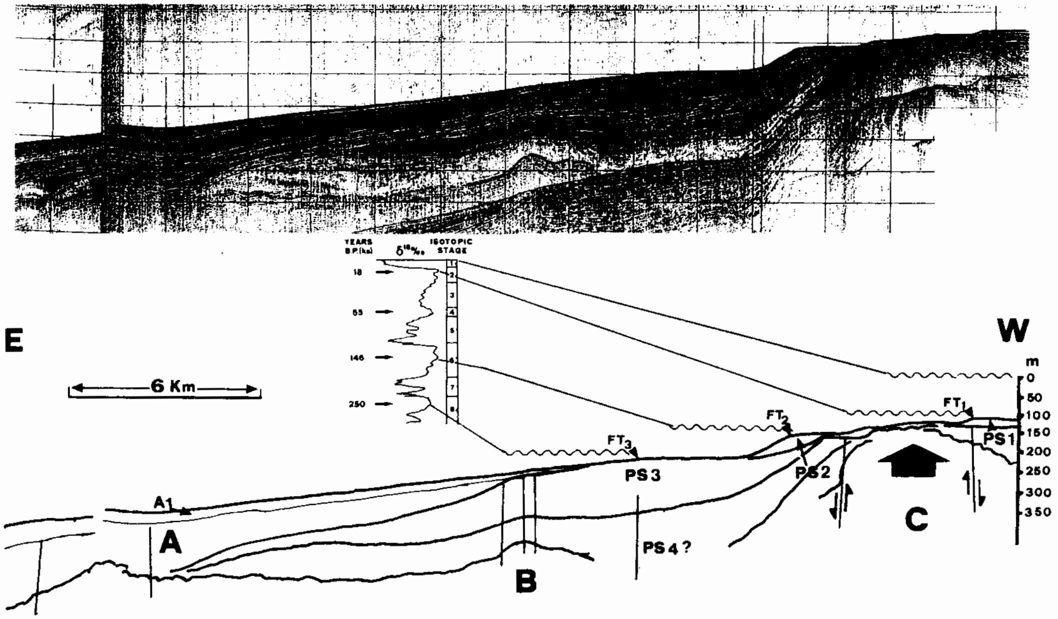

Fig. 2: Air - Gun seismic profile across the E. Cyclades margin to S. Ikarian basin with the characteristic depositional sequences and their chronostratigraphic corellation.

indicating prodeltaic sediment progradation during still stand of sea-level. These are interpreted as delta sequences that prograded basinward during low stands of sea-level (Pleistocene glacial stages), while the uncomformities that separate the depositional sequences represent major transgressions during interglacial stages. Similar sequences have been detected in the NW Aegean sea (Lykousis, 1991) and along the western coasts of Turkey (Aksu and Piper, 1983; Aksu et al., 1987a,b) and have been interpreted as Middle-Late Pleistocene prodelta sequences.

The topset to foreset transition (FT_1) of the shallowest prodelta sequence (PS_1) (Fig. 2), located in the shelf edge in a water depth of 109.5m (146ms), indicates the lowest stage of delta evolution during the late glacial (Late Wurm) maximum (c.18ka B.P.) and corresponds to the maximum fall of sea-level (c.110-120m) in isotopic stage 2 (2.2) (Chappell and Shackleton, 1986; Imbrie et al., 1984). The chronostratigraphically older (deeper) topset to foreset transition (FT_2), located in a water depth of 152m (203ms), indicates delta progradation (PS_2) during isotopic stage 6.1(c.146ka B.P.). The oldest lower edge of the topset to foreset transi-

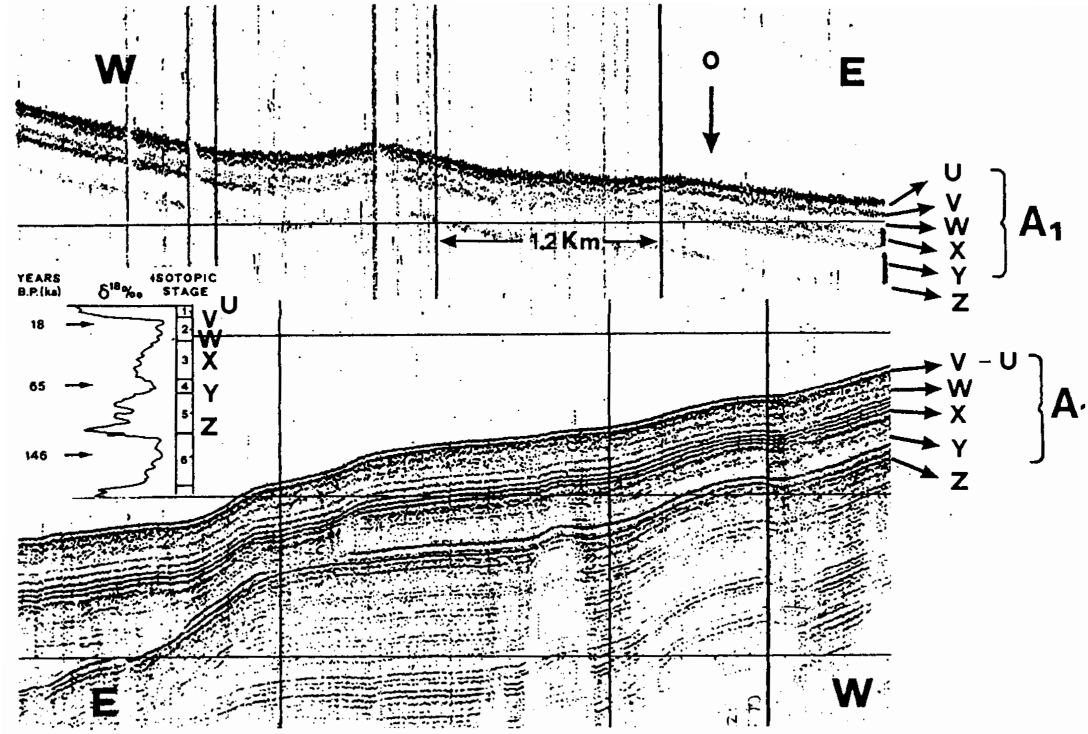

Fig. 3: 3.5kHz (upper) and Air-Gun (lower) profiles from the S. Ikarian basin with the characteristic Late Pleistocene reflectors.

tion (FT_3) of the delta sequence PS_3 (212m below the present sea-level) is interpreted to represent the latest stage of delta progradation during isotopic stage 8.2 (c.25ka B.P.). The possible fourth delta sequence (PS_4) that was recognized is partly deformed and eroded, and is assumed to be of Early Middle-Pleistocene age. A sequence of deformed reflectors (B) appears below the fourth prodelta sequence that most probably represent, Upper Pliocene - Lower Pleistocene deposits while the pre - Alpine basement (C) is emerged below the sea bed of the eastern margin of Cyclades.

From the reflection character (well stratified, continuous, intense, parallel - subparallel) of the seismic sequence (A) clinoforms, it is inferred that the basin deposited sediments are mainly turbiditites (Fig. 2). These have been deposited during low sea level stands, as slope to basin sandy and/or silty turbidites, (distal turbidites) initiated on the edge of palaeoprodelta platforms from river plumes during stormy conditions. During interglacial stages (high sea level stand) appreciably thinner (a few meters) and finer grained (muddy) hemipelagic sediments were deposited. The uppermost part of the seismic sequence (A) is characterized by decreased stratification and continuity of the seismic reflectors (A_1) indicating differentiation of sedimentary conditions and probably of sediment texture (Fig. 2). High resolution profiles from this area display a sequence of alternating stratified and transparent or semitransparent intervals (Fig. 3). This stratigraphically distinct seismic unit is identified by a basic uncomformity and a series of parallel and stratified reflectors (Z) that can be traced along the basin and the slopes of S. and N. Ikarian basins. The regional package of these reflectors (Z) in the base of the seismic unit

(A_1) display similar reflection configuration with the widespread reflectors (Cu) in the basins of N. Aegean sea (Piper and Perissoratis, 1991). The top of this reflector is correlated with the termination of glacial period (end of isotopic stage 6.1 c. 128ka B.P.). The reflectors (Z) is assumed to be of the same age, representing low stand deep-sea turbiditic sediments, chrono stratigraphically equivalent to the (PS_2) prodeltaic sequence.

The upper surface of the stratified reflectors (Z) can be traced within the Late-Quaternary sediments of the eastern margin of S. Ikarian basin as the upper termination of the prograding sequence (PS_3) (stage 6.1) and marks the initiation of the 6 to5 stage transgression (Fig. 2).

A section of seismically transparent - semitransparent sequence appeared above the stratified reflectors (Z) (Fig. 3) that terminates upward to another package of stratified reflectors (X). This transparent sequence (Y) represent principally muddy hemipelagic sediments deposited during high sea-level stand (isotopic stages 5.5 to 3.3) for a period of about 70.000 years (c.120 - 50ka B.P). The well stratified reflectors (X) correspond to a relatively low sea level stand in isotopic stages 3.2 - 3.1 (about 50 - 30ka B.P.). Their lower and uppermost boundary reflectors can be correlated with the b_L and b_u reflectors from the N. Aegean sea sediments (Piper and Perissoratis, 1991). During the following short period of relatively higher sea-level (stage 3) sediments of semitransparent to transparent character on seismic records were deposited (W). This sequence is upward bounded by a thin but strong stratified reflector (V) that reflect sandy-silty mud turbidites that were deposited during the late glacial (stage 2.2.) about 25-18ka B.P.During this period the sea-level was somewhat 110 - 120m below the present and the sediments deposits are mainly slope to basin turbidites, initiated from the deltaic prograding deposits on the shelf break (PS_1). Short sediment cores (2-3m), recovered from the western margin of S. Ikarian was confirmed the age of the reflector (V). Within a subbottom sediment depth of 2 - 2.5m (subbottom depth of reflector x as well) the Y - 5 ash layer was recognized and was estimated to have been deposited in the Aegean Sea 18 - 25ka B.P. (Cramp et al., 1989). The reflector (V) marks, as well, the rapid post glacial transgression (stages 2.0 - 1.0) and is buried below the near bottom post - Wurmian muddy sediments (transparent section U).

Table 1

Foreset to topset transitions	Isotopic Events	NW Aegean (Lykousis 1991)	N.Aegean (Piper & Perissoratis, 1991)	Kusadasi Bay(Aksu et.al, 1987)	Izmir-Bay (Aksu et al. 1987)	E. Aegean (This Study)
FT_1(18kaBP) FT_2(145kaBP) FT_3(250kaBP)	2.2 6.1 8	120m 240m 430m	~125m	112.5m ~173m	112.5m 169m 236m	109.5m 152m 212m
Subsidence rates						
FT_2- FT_1 FT_3 - FT_2		0.95m/ka 1.8m/ka	0.3-1.5 m/ka	0.48m/ka	0.45m/ka	0.33m/ka 0.57m /ka

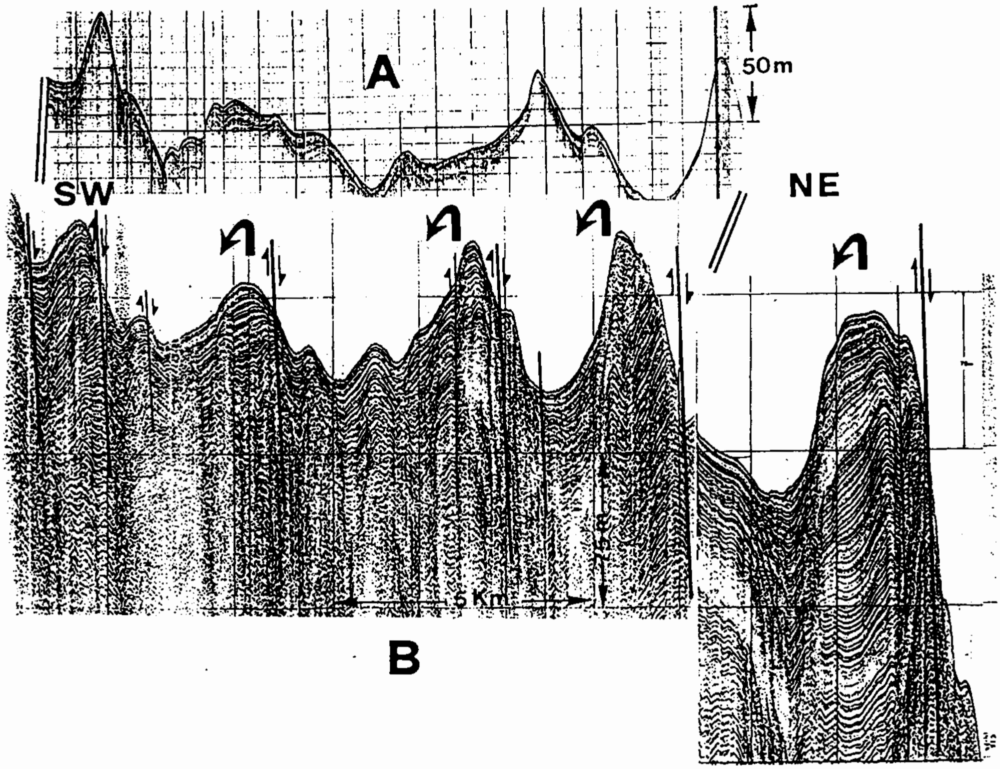

Fig. 4: Characteristic tilted blocks and associated reverse faults from the N. Ikarian basin.

Basin subsidence and accumulation rates

The foreset to topset transitions that were observed in the eastern margin of Cyclades and S. Ikarian basin lie shallower a few meters from similar transitions in W. Turkey and a few tens of meters from N. Aegean Sea (Table 1). This implies relative differential subsidence rates between the associated margins of these areas. By comparing the vertical displacement from topset to foreset transition of two successive delta sequences, we can estimate the relative subsidence rates, assuming similar low stands of sea-level, with an uncertainty of no more than 20m. This is the approximate water depth where the recent transitions are formed in the Aegean sea. Accordingly the relative subsidence from the isotopic stage 6.2 (146ka B.P.) glacial maxima) to isotopic stage 2.2 (18ka B.P. - Late Wurm glacial maxima) is 0.34m/ka (42.5m subsidence/130ka). This value is lower than the corresponding values from the NW Aegean, N. Aegean and W. Turkey margin (0.95m/ka, 0.3 - 1.5m/ka and 0.45 - 0.48m/ka respectively). The relative subsidence from isotopic stage 8 (c. 250ka B.P.) to isotopic stage 6.1 (146ka B.P. is 0.57m/ka (60m subsidence/104ka) a value appreciably lower than that of NW Aegean Sea margin (1.8m/ka)(Table 1).

The thickness of prodelta sequences decreases from 150m (PS_3) to about 30m (PS_1) indicating significant decreasing of the E. Cyclades drainage systems (restriction of subaerial land) during the subsidence particularly from isotopic stages 8 to 6.2. This is associated with lower depositional rates and restriction of delta progradation.

The mean upper Pleistocene sedimentation rates, calculated from the

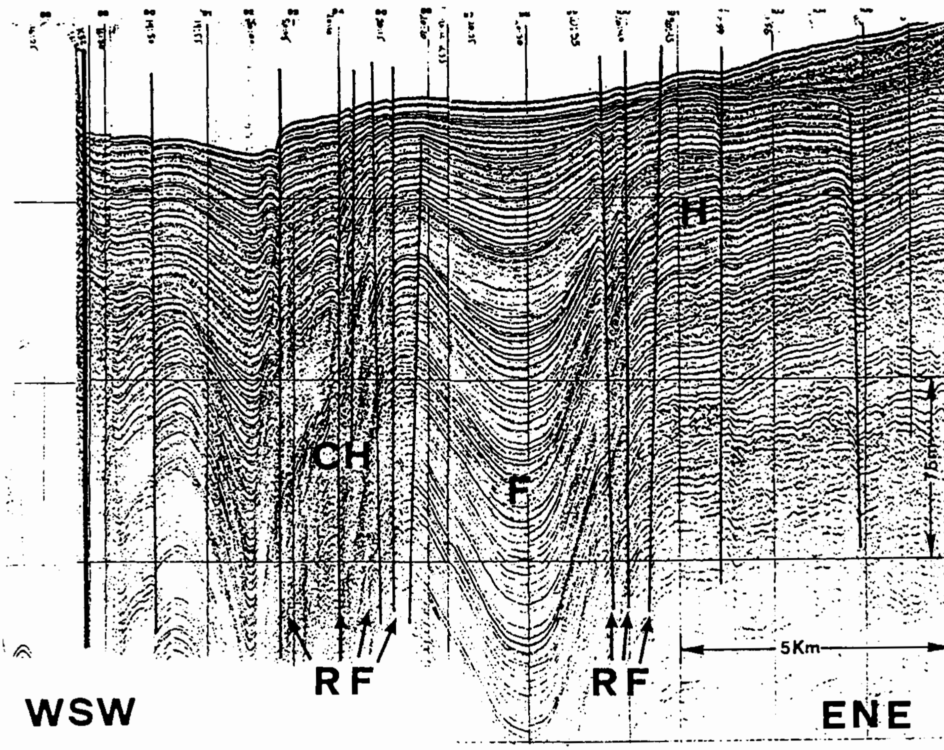

Fig. 5: Air-Gun profile from the N. Ikarian basin displaying intense surficial strike-slip deformation (for location see Fig. 1).

thickness of Post-isotopic 8 undifferentiated sediments (50 to 230m seismic sequence A) (Fig. 2) range between 90cm/ka in E. Cyclades margin to 80cm/ka within the south and north Ikarian basins. The maximum thickness of the seismic unit (A_1) is 12.5 to 40m (Fig. 3) on the margin basins of the south and north Ikarian, implying mean sedimentation rates from 10cm/ka (12.5m/128ka) in the upper slopes to 30cm/ka (40m/128ka). Within the south and north Ikarian basins the thickness of the seismic unit (A_1) is up to 60 - 80m and the corresponding mean sedimentation rates range from 45cm/ka to 60cm/ka. The thickness of these sediments is fairly comparable with the thickness of similar in age sediments of the North Aegean sea (20 - 50m) (Piper and Perissoratis, 1991). The Post Wurmian deposits (25ka - today) are displayed by the transparent-semitransparent uppermost section (U) of seismic unit (A_1). The thickness of these sediments range from 2 - 7m and corresponding values of mean sedimentation rates are estimated from 8 - 15 cm/ka on the basin margins up to 30cm/ka (locally) within the basins.

Geotectonic implications

Intense deformational processes were observed in seismic profiles from the deeper parts of the N. Ikarian basin (Fig. 4, 5) that seem to be related with the NE - SW strike - slip zone suggested by Mascle and Martin (1990).

A series of tilted blocks resulted from reverse faulting was illustrated in the seismic profiles (Fig. 4) with increasing fault offset towards the NE. This deformational processes could be interpreted as the surficial result of en echelon of transpresional reverse faults with a relatively similar mechanism with that described by Reading (1980) for the San Andrea's fault. Further evidence for strike slip deformations is displayed in Fig. 5 from the deeper part of N. Ikarian basin. A series of reverse faults (R.F.) associated with horsts (H), folded reflectors (F) as well as with deeper chaotic reflectors (CH) implies local subsidence and horizontal slip movements. The synsedimentary character, of these deformations indicates constant and continuous tectonic activity throughout the Late Quaternary, up to today.

From the deformed reflectors of the seismic sequence (B) and the prograding sequence PS_4 below the Eastern Cyclades margin (Fig. 2), as well as, the relatively undeformed prograding sequences (PS_1 - PS_3) it is concluded that the deformational processes were active until Lower - Middle Pleistocene. From the Middle - Pleistocene continuous slow subsidence is taking place in the Eastern margin of S. Ikarian basin. A pronounced N - S horst resulted from the uplift of pre- Alpine basement (C) was detected below the upper slope of Eastern margin of Cyclades between the north cape of Naxos I. and the small Chtapodia I. (Fig. 1).

CONCLUSIONS

Sea-level changes and geotectonic activity have contributed to the Middle -Late Quaternary sedimentary evolution in the Eastern part of the central Aegean Sea. Sea-level fluctuations and tectonic subsidence are the predominant factors controlling the development of offshore, sediment sequences in the S. Ikarian basin and their associated margins while geotectonics related with strike slip deformations are the principal factors in the evolution of the N. Ikarian basin.

During the Middle-Late Quaternary four major prograded delta sequences were deposited on the eastern Cyclades margin (western margin of S. Ikarian basin) corresponding to four major sea-level lowstands during four successive glacial maxima. Topset to forset transition in the late three delta sequences located at c.109.5, 152 and 212m respectively, below the present sea-level, suggest continuous subsidence, which has been estimated at 0.33 - 0.57 m/ka for the Upper Pleistocene.

The mean sedimentation rates were estimated to 20-90 cm/ka for the late 250ka, 10-60 cm/ka for the late 128ka and 8 - 30 cm/ka for the last - post glacial sediments (25 ka - today).

A pronounced deformational phase during the Upper Pliocene-Lower Pleistocene can be recognized within S. Ikarian basin. Within the N. Ikarian basin indications of Quaternary strike -slip deformations appeared that are related with en echelon of reverse faults.

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REFERENCES

AKSU, A.E. and PIPER, D.J.W. (1983). Progradation of the Late Quaternary Gediz Delta, Turkey. Marine Geology, 54, 1 -25.

AKSU, A.E., PIPER, D.J.W. and KONUK, T. (1987). Quaternary growth patterns of Buyuk Menderes and Kucuk Menderes deltas, Western Turkey. Sed. Geol-

ogy, 52, 227 - 250.
AKSU, A.E., PIPER, D.J.W. and KONUK, T. (1987). Late Quaternary tectonic and sedimentary history of Outer Izmir and Candarli bays, western Turkey. Marine Geology, 76, 89 - 104.
ANAGNOSTOU, C., SIOULAS, A., KARAGEORGIS, A., PAVLAKIS, P. and ALEXANDRI, M. (1993). Tectonic of the marine area S.W. of Milos I. based upon lithoseismic profiling data. Proc. 4th Nat. Symp. Oceanogr. Fish.: 109 - 112.
ANGELIER, J. (1976). Sur l' alternance mio-plio-quaternaire de mouvements extensifs et compressifs en Egee orientale: L'ile de Samos (Grece). C.R. Acad. sci., Paris, ser. D, 283, 463 - 466.
ANGELIER, J. (1979). Neotectonique de l' arc Egeen. These Doct., niv. Paris VI (Soc. Geol. Nord, 3).
CHAPPELL, J. and SHACKLETON, N.J. (1986). Oxygen isotopes and sea-level. Nature, 323, 137 - 140.
CRAMP, A., VITALIANO, C.J. and COLLINS, M.B. (1989). Identification and dispersion of the Campanian ash layer (CY-5) in the sediments of the eastern Mediterranean: Geo-Marine Letters, 9, 19 - 25.
IMBRIE, J., HAYS, J.D., MARTINSON, D.G., McINTYRE, A., MIX, A.C., MORLEY, J.J., PISIAS, N.G., PRELL, W.L. and SHACKLETON, N.J. (1984). The orbital theory of Pleistocene climate: support from a revised chronology of the marine ä^{18}O record. In: A. BERGER, J. IMBRIE, J., HAYS, G., KUKLA and B. SALTZMAN (eds). Milankovitch and climate, 269 - 305. Dordrecht, Riedel.
LYKOUSIS, V. (1991). Sea-level changes and sedimentary evolution during the Quaternary in the Northwest Aegean continental margin, Greece. Spec. Publ. int Ass. Sediment., 12, 123 - 131.
MASCLE, J. and MARTIN, L. (1990). Shallow structure and recent evolution of the Aegean Sea: A synthesis based on continuous reflection profiles. Marine Geology, 94, 271 - 299.
MITCHUM, J.R.M., VAIL, P.R. and THOMPSON III, S. (1977). Seismic stratigraphy and global changes of sea-level. Part 2: The depositional sequence as a basic unit for stratigraphic analysis. In: C.E. PAYTON (ed.) Seismic stratigraphy, Application to Hydrocarbon Exploration. Mem., Am. Assoc. Pet. Geol., 25, 53 -62.
MERCIER, J.L., DELIBASSIS, N., GAUTHIER, A., JARRIGE, J.J., LEMEILLE, F., PHILIP, H., SEBRIE R,M. and SOREL, D. (1979). La neotectonique de l' arc egeen. Revue de Geol. dyn. Geogr. phys., 21, 67 - 92.
PAPANIKOLAOU, D. (1977). Contribution to the Geology of Ikaria Island, Aegean Sea. Ann. Geol. Pay Hell., XXIX/1, 1 - 28.
PAPANIKOLAOU, D. (1987). Tectonic evolution of the Cycladic blueschist belt (Aegean Sea, Greece). In: H.C. HELGESON (ed.) Chemical Transport in Metasomatic Processes, 429 - 450, D. Riedel P.C.
PAVLAKIS, P. (1992). Southern Aegean: Marine geophysical survey and stochastic/deterministic approach of its tectonic-geodynamic-geothermal structure. Ph.D. Thesis University of Athens. pp. 238.
PERISSORATIS, C. and MITROPOULOS, D. (1989). Late Quaternary evolution of the northern Aegean shelf: Quaternary Research, 32, 36 - 50.
PERISSORATIS, C. and Van ANDEL, T.H. (1988). Late Pleistocene uncomformity in the Gulf of Kavalla, northern Aegean, Greece: Marine Geology, 81, 53 - 61.

PIPER, D.J.W. and PERISSORATIS, C. (1991). Late Quaternary sedimentation on the North Aegean continental margin, Greece. Bull. Am. Ass. Pet. Geol., 75, 46 - 61.

READING, H.G. (1980). Characteristics and recognition of strike slip fault systems. In. P.F. BALANCE and H.G. READING (eds). Sedimentation in oblique-slip mobile zones. Intern. Assoc. Sedim. Spec. Publ. 4, 7 - 26.

STANLEY, J.S. and PERISSORATIS, C. (1977). Aegean ridge barrier and basin sedimentation patterns. Marine Geology, 24, 97 - 107.