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ON THE HELLENIC TROUGH STRUCTURE

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Introduction

The Hellenic Trough is one of the largest and most important geological structures of the Eastern Mediterranean. Stretching for approximately one thousand kilometres it is subdivided into two segments - eastern and western - having quite different nature. The eastern segment fringing the eastern part of the Crete Island and Karpathos and Rodos Islands, was formed under slip-strike deformations of the same direction. The origin of this segment is similar to that of the western (Komandorian) part of the Aleutian Trench in the Pacific. The formation of the western segment of the Hellenic Trough stretching NW-SE along the Peloponneses and Western Crete is connected with compression normal to the trough stretching and corresponding to the direction of convergence of the African and Aegean lithospheric plates (Hsü, Ryan, 1978; Biju-Duval et al., 1978; Papazachos, Comninakis, 1978; Le Pichon, Angelier, 1979; Le Pichon et al., 1979; Lyberis ety al., 1980; Rotstein, Ben-Avraham, 1985).

Though the Hellenic Trough due to its key position in the geological structure of the Eastern Mediterranean has attracted the attention of geologists for a long time and the geological-geophysical investigations, deep-sea drilling among them were carried out here, some problems, in particular those concerning the structure, composition and the age of the inner slope deposits remain unsolved.

In the summer of 1991 complex geological-geophysical investigations, including bathymetric survey, continuous seismic profi-

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ling, dredging and bottom sediments sampling within the Hellenic Trough western segment were fulfilled by geologists from the Institute of Lithosphere of the Russian Academy of Sciences during the cruise of the R/V "Antares" in the Mediterranean Sea.

The area to be investigated is situated about 30 miles west of the Crete Island (coordinates 25°30'-26°10'N and 22°15'-22°55'E) (Figure 1). The results of these investigations which add new information to the data obtained here earlier by French geologists (Group Ariane, 1979) are given below.

Bathymetry

The sea depths within the area vary from 900 to 4660 m with maximal values in the central part of the trough. Bathymetrically the area is found asymmetrical: the depth gradients in the SW-NE direction, i.e. across the Hellenic Trough slope are lower than those in the SE-NW direction, i.e. parallel to the trough axis. In the first case the depth ranges from 100 to 160 m per one km, in the second case - 400-500 m per one km.

In the western part of the area there exists an under-sea rise. This rather unusual morphological structure has a minimal depth amounting to 1600 m. The rise extends in the SW-NE direction. Its length reaches 26 km and the width - 7 km. The northwest and southeast slopes are characterized by significant steepness with angles in some cases reaching more than 50° and often complicated by vertical walls and scarps evidently of tens of meters high. The south-western extremity of the rise crosses the trough axial part at an angle of 90°, rising above its bottom more than thousand meters. Northwest of the rise there are two small more or less isometrical hills, their summits often reaching 2700m

The eastern part of the area under study is occupied by the sublongitudinal underwater plateau rising up to 900 m with steep

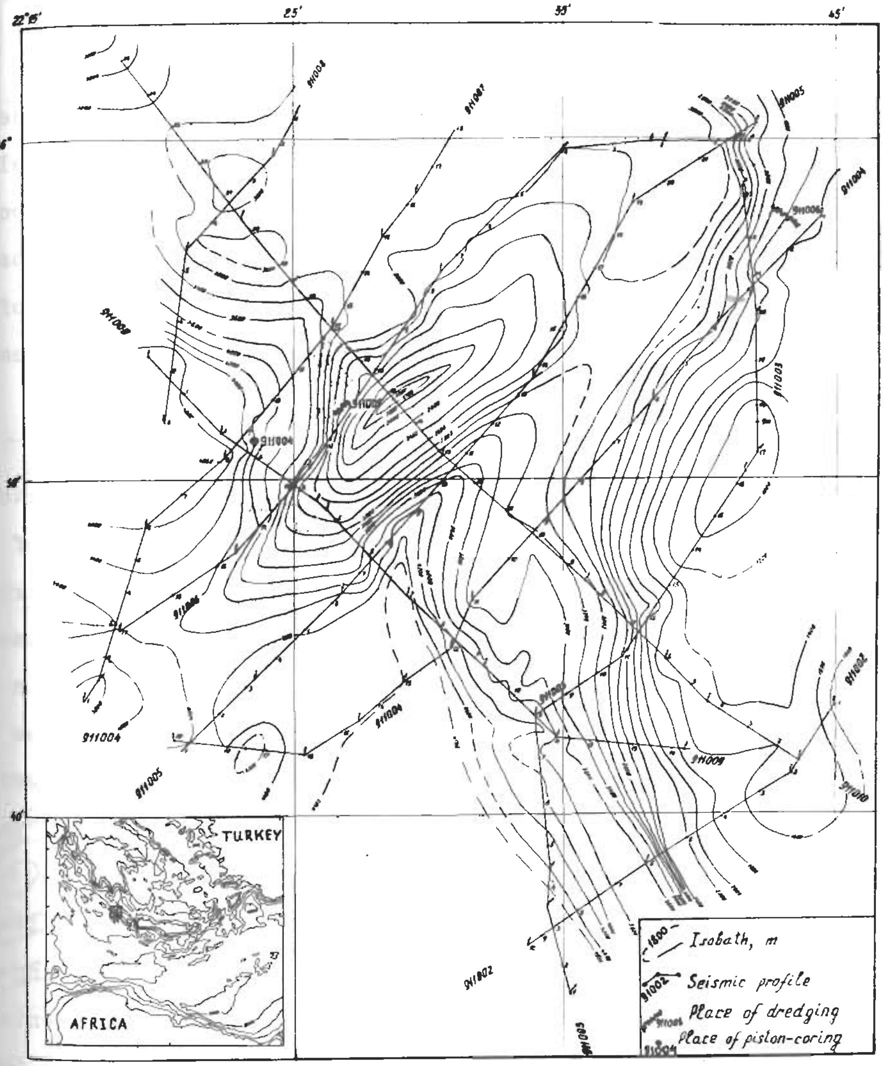

Fig. 1. Bathymetric map of the area studied during the R/V "Antares" 10th Leg.

western and southwestern slopes and the flattened southern slope (eastern slope is outside the area).

These two major morphological structures are divided by a flat valley of SW-NE stretching, 2900-4500 m deep and 4-6 wide.

The southwestern corner of the area is occupied by the Hellenic Trough valley oriented southeast - northwest. The trough bottom looks like a flat plain with the depths of 4500-4600 m crossed by the above-mentioned elongated undersea rise. The foot of the inner slope is flattened. Its steepness gradually increases towards the tops of the undersea rises within the slope.

Continuous seismic profiling

The recent sedimentary cover within the area is distributed very unevenly. Most part of the area is practically devoid of unconsolidated sediments. The map of sediments thickness distribution demonstrates that the zero isopach fringes undersea rises up to 3000-4000 m deep in the west and up to 1500-3000 deep in the east (Fig. 2). Within the flattened slopes with the angles up to 10° and near the tops of the rises the sediment thickness reaches usually 20-30 m, sometimes increasing up to 60-80 m. The maximal thickness (up to 300-600 m) is characteristic of the trough axial part and of the slope valleys opening into the trough.

There are two types of unconsolidated sediments differing in character of acoustic reflections (Figures 3-5). The sediments of the first type are represented by a relatively thin (less than 60-80 m) acoustically transparent homogeneous unlayered pile covering mainly flattened parts of the northwestern slope of the elongated rise in the west and near the plateau top part in the east. By the age these sediments evidently belong to the Holocene. Depending on the relief they either unconformably overlie the deposits of the acoustic basement or conformably rest on older

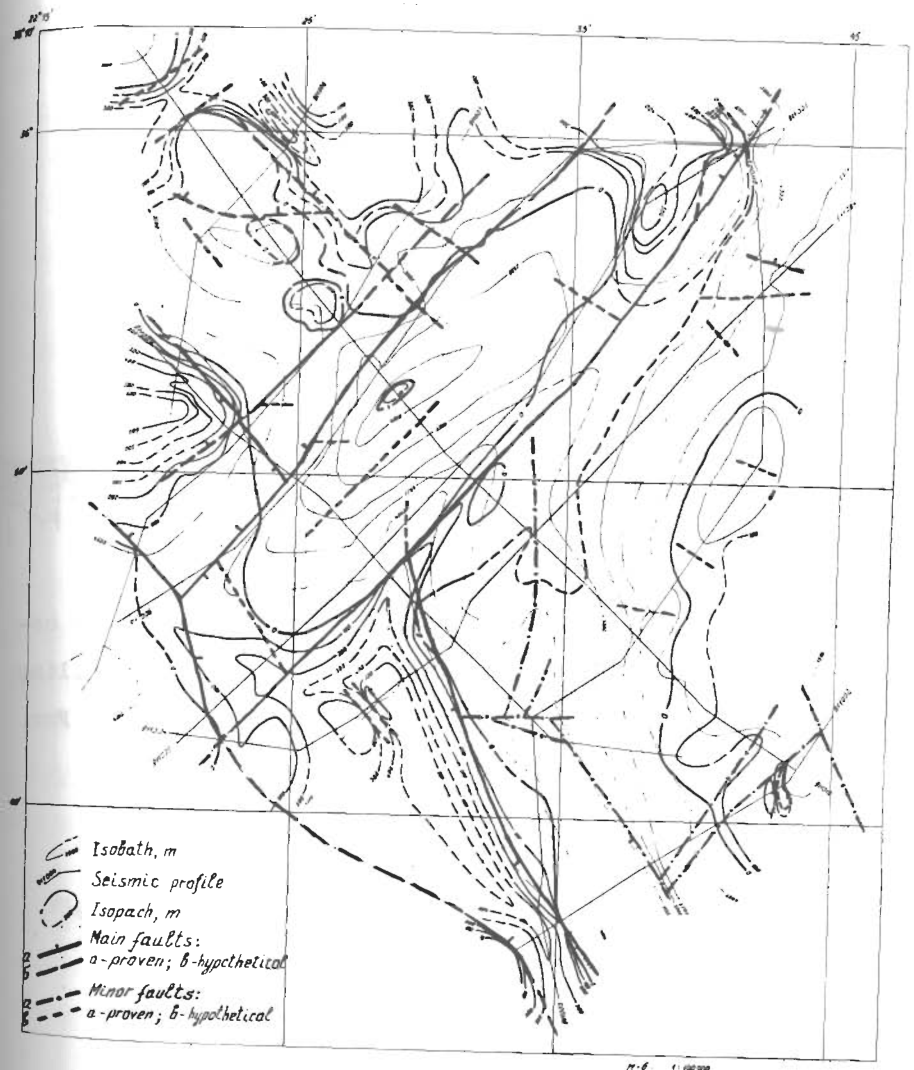

Fig. 2. Isotopachs map of the unconsolidated sedimentary cover (in meters) and faults.

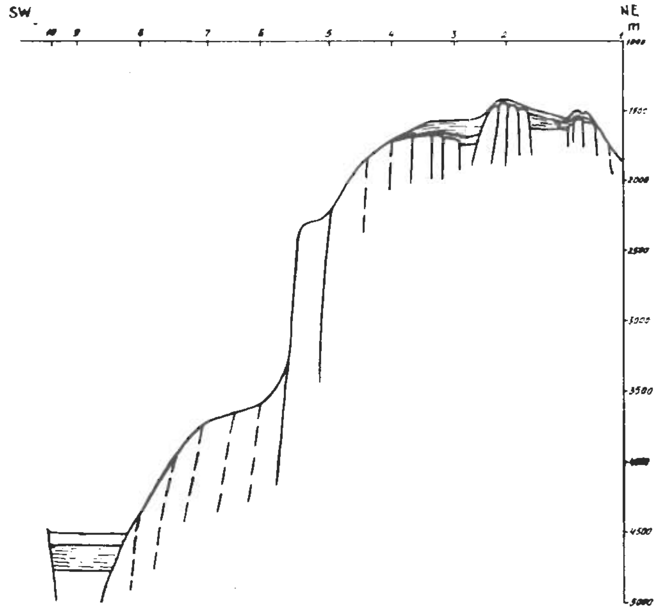

Fig. 3. Scheme of the acoustic basement and the sedimentary cover structure according to continuous seismic profiling (Profile 911002). The position of the profile see: For position of the profile see Figs.1, 2.

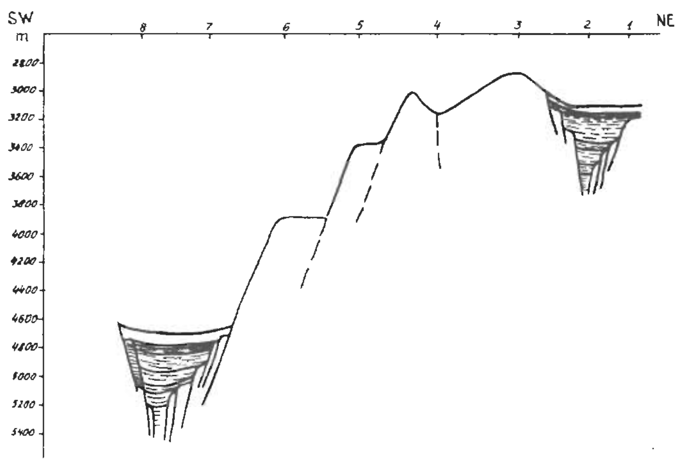

Fig. 4. Scheme of the acoustic besement and the sedimentary cover according to continuous seismic profiling (Profile 911008) position of the profile see Figs. 1, 2.

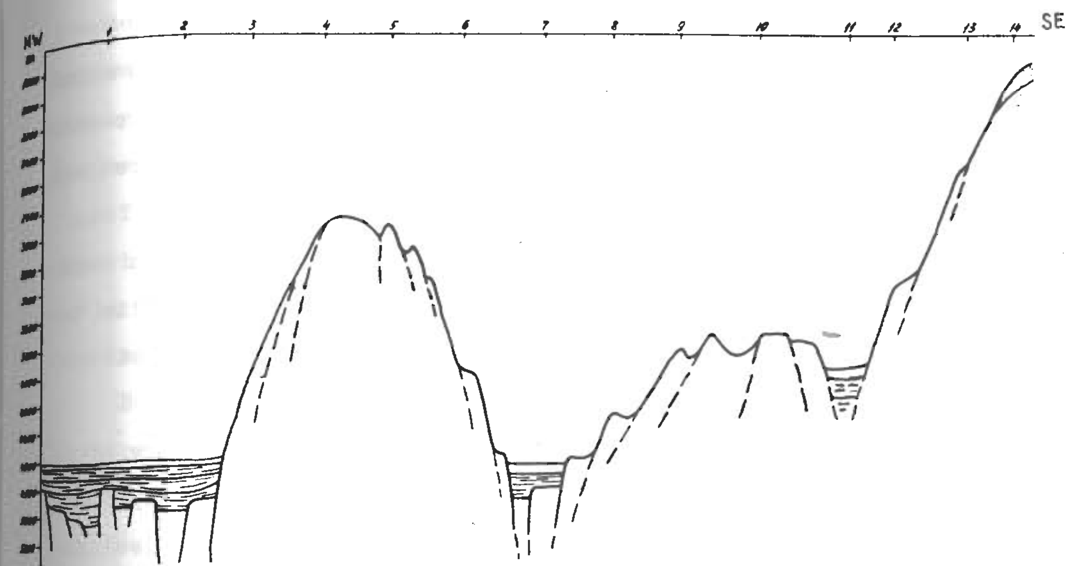

Fig. 5. Scheme of the acoustic basement and the sedimentary cover according to continuous seismic profiling (Profile 911009). The position of the profile see Figs. 1, 2).

sediments of the unconsolidated cover. The sediments of the second type are mainly distributed within the Hellenic Trough axial part and in intermontane valleys. Their maximal thickness reaches 680 m. By its acoustic properties these sediments are layered and depending on the structural and morphological position one can establish from 2 to 7 layers. These sediments are sometimes weakly deformed and everywhere they are underlain by the acoustic basement rocks. The age of the sediments is most probably Pleistocene.

Disjunctive tectonics is a most characteristic feature of the area (Fig. 2). The faults can be most clearly traced by the structural patterns of the lower layered unit of the unconsolidated sedimentary cover, filling graben-like deeps. The latter are formed by a series of stepped faults. The fault surfaces are usually vertical or steeply falling to meet each other half-way (Fig. 3). The number of such faults can amount up to ten. Most often they reach the bottom at the border parts of grabens where the sedimentary cover wedges out. Closer to the central part of the grabens the faults disappear under the youngest acoustically transparent (Holocene) layer or at lower levels deforming slightly the overlying ones. At the places where the acoustic basement reaches the bottom surface the faults are traced by the scarps along them.

The main tectonic features within the area are represented by faults stretching SE-NW and bordering upon the Hellenic Trough and by faults which stretch normally to the former making up secondary structures within the trough inner slope. Its southwestern tectonic boundary is traced fragmentarily by continuous seismic profiling and is partly drawn conventionally. The fault surface is dipping to the northeast at the angle of 75-80°. The

northeast tectonic boundary with the fault surface dipping southwestward at the same angle is traced in the form of two almost straight subparallel faults, which in fact represent a fault zone composed of a series of closely spaced faults.

This fault zone is clearly traced trough the entire area except its central part within the elongated underwater rise which is in fact a tectonic block bordered by faults with subvertical displacers stretching NE.

Besides these major faults forming the general structural pattern there is a series of smaller faults usually being parallel to the major ones.

Rocks and sediments

Though the significant part of the area is practically devoid of unconsolidated sediments and marked by wide distribution of steep slopes with vertical scarps, the dredging doens't always bring success here and is often accompanied by the loss of dredging equipment which is evidently due to such patterns of slopes and peculiarities of the rocks exposed here at the bottom.

Earlier the Pliocene-Pleistocene carbonate rocks containing fragments of shallow-water benthonic foraminifers and mollusks were dredged by the French expedition in the area under study (Group Ariane, 1979). Further to the southeast near the Crete Island the same expedition obtained samples of marls and limestones mainly of late Miocene age.

During the "Antares" expedition we picked up sedimentary rocks at three sites: two of them (St. 911004, 911005) - on the western slope of the undersea rise in the western part of the area and the third (St. 911006) - on the plateau slope in its eastern part (Fig. 1; Table).

A few fragments of sedimentary rocks were obtained at St.

Location and Characteristics of the Dredged Sedimentary Rocks

Station / Sample	Coordinates: latitude N	Coordinates: longitude E	Depth m	Lithology	Age
911004	35°50'98	22°23'26	3800		
4/1				Gray thin-laminated marl	unclear
4/2				Light-gray massive limestone with poorly preserved planktonic foraminifera	Miocene (?)
911005	35°51'93	22°26'69	1575-1700		
5/1				Dark-gray marblized limestone with shells of planktonic foraminifera, often recrystallised	Middle-Late Miocene (?)
5/2				Light-gray marl with planktonic foraminifera	Middle-Late Miocene
5/3				Cream-coloured, light-brown marl with scarce planktonic foraminifera	Middle-Late Miocene
911006	35°57'83	22°47'85	1400-1950		
6/1				Gray marblized limestone	Pliocene
6/2				White, yellowish-white and light gray foraminiferal-nannoplanktonic chalk	Pliocene-Pleistocene

911004, among them gray laminated marl with an admixture of transparent quartz grains and rare tiny mica platelets, and light gray massive micritic marmorized limestone were present. The latter contained planktonic foraminifers. Due to their poor preservation conventionally determined were Globigerinoides subquadratus, Globigerina bradyi, indicating the Miocene age of the rocks.

The dredging at Site 911005 has brought dark gray microcrystalline marmorized limestone with crystallized shells of planktonic foraminifers, among them Globigerinoides aff. subquadratus, G. aff. obliquus, G. aff. sacculifer, G. aff. trilobus, indicating middle-late Miocene age.

Bare specimens of middle-late Miocene Globigerinoides subquadratus and Globigerina nepenthes are also encountered in samples of white and pale marl. The richest assemblage of planktonic foraminifers, including Globigerinoides trilobus, Globorotalia siakensis, G. acostaensis, G. obliquus extremus, G. sacculifer, G. subquadratus, Globigerina nepenthes, Orbulina suturalis, O. universa is encountered in light-gray marl samples with vague lamination and spots of Fe-oxides. The composition of this assemblage suggest the middle-late Miocene age of the rocks.

Mainly gray marmorized limestones and yellow-white to light-gray foraminiferal nannoplanktonic chalk in subordinate quantity were dredged at St. 911006 in the northeast part of the area. Both rock types are heavily bioturbated and covered with thin crust of Mn oxides. The chalk contains small specimens of Globigerinoides ruber, Globigerina pachyderma, Globorotalia tosaensis. The last species dates the rocks as Pliocene. The limestones contain still a more diverse assemblage of planktonic foraminifers, among them Globorotalia inflata, Globigerinoides ruber, G. helicinus, G. conglobatus, Globigerina bulloides, G. pachyderma, Orbulina universa which due to the absence of Pliocene zonal species (Globorotalia margaritae, G. miocenica, G. tosaensis, Globigerinoides fistulosus) and Pleistocene ones (Globorotalia truncatulinoides) allow to date the age of the sediments as Pliocene-Pleistocene. Together with planktonic species diverse benthonic forms (Hoeglundina elegans, Uvigerina peregrina, Cibicidoides kullenbergi, C. wuellerstorfi, C. sp., Pyrgo sp., Quinqueloculina sp., Elphidium sp.) are present indicating relatively shallow-water conditions of the sediment accumulation at that time.

The recent sediments within the area are represented by calcareous foraminiferal nannoplanktonic ooze with numerous planktonic and benthonic foraminifers of good preservation. The planktonic assemblage includes Globorotalia crassaformis, Globigerina bulloides, Globigerinoides ruber, G. trilobus, G. elongatus, Globigerinella aequilateralis, Sphaeroidinella dehiscens, Orbulina universa and other species typical of recent bottom sediments of the Mediterranean Sea. Most often among benthonic foraminifers are Siphotextularia sp., Martinottiella sp., Sigmoilopsis schumbergeri, Melonis affinis, Gyroidina orbicularis, Cibicidoides wuellerstorfi, Oridorsalis tenerus characteristic of the lower bathyal zone.

Discussion

The Hellenic Trough differs notably in structure from typical deep-water pacific type trenches adjacent to active volcanic arcs. The difference is first of all observed in its cross- section of a case-like form unlike the V-like form, most characteristic of extensional structures than of compressional ones. Along the axis, the trough doesn't represent continuous valley but it is cut with well-pronounced transverse rises with tops rising above the trough bottom more than 1 km. The axial part of the trough is

filled with thick (up to 600 m) unconsolidated horizontally layered sediments.

At the same time the general arc-like form of the trough, large depth often considerably higher than that of the adjacent areas of the bottom, the specific distribution of seismic activity, though the seismofocal zone dipping northwards, reaches the depth but 150-180 km, and the presence of the outer non-volcanic Crete arc and the inner volcanic arc with specific calc-alkaline magmatism (Pe-Piper, Piper; 1989) separated by the forearc Crete basin, suggest the existence here of a subduction zone. Compressional patterns are stressed also by strong tectonic fracturing of deposits within the trough area, wide development of thrusts to the north (Morelli, 1978; Monopolis, Bruneton, 1982) and the existence of a peculiar Mediterranean Ridge bordering on the trough in the south, its origin being related to the Miocene sediments merging (Biju-Duval et al., 1978).

The accretionary wedge typical of subduction zones, is absent here, so suggesting that the subduction here results in tectonic erosion and not accretion. Hole 127 drilled during Leg 13 of the Glomar Challendger at the foot of the Hellenic Trough inner slope recovered blocks of Early Cretaceous limestones and dolomites (Maync, 1973) inside the Pliocene calcareous oozes overlain by thick (more than 400 m) unconsolidated Quaternary sediments. Two alternative hypotheses has been put forward to explain the nature of this block (Hsü, Ryan, 1973). The first of them states, that the blocks are fragments of the tectonic melange, consisting of non-coeval deposits and believed to be a result of recent underthrusting of the Ionian Plate under the Aegean one. The other hypothesis argues, saying that the blocks are of olistostrome origin considering that the Lower Cretaceous limestones exotic blocks slipped along the slope to its foot.

Our observations enable us to suggest that the gravitation processes played a significat role in the formation of the relief of the trough inner slope with well defined scarps. There is a reason to consider that the transverse elongated under sea rise crossing the trough axial part represent one of such large blocks transported down the slope by gravity.

Our data together with the results of dredging during the French expedition (Group Ariane, 1979) show that the Hellenic Trough inner slope is composed of middle-upper Miocene marls and limestones to have been accumulated probably in relatively deep-water environment, and shallow-water marls, micritic limestones and foraminiferal nannoplanktonic chalk of Pliocene and Pleistocene age. It is interesting to note the absence here of the Messinian evaporite deposits widely distributed south of the Trough within the Ionian Basin as well as to the north of it in the Aegean Sea. This enables us to conclude that during the Messinian this region underwent absolute or relative uplifting as a result of deformations, affected Hellenids including Peloponneses and Crete in Pre-Messinian time.

The general block structure of the area with differential movements between neighbouring blocks up to 3-4 km, seen on sesmic profiles, has formed quite recently during the Quaternary. The structural patterns are outlined by faults parallel to the trough axis and by transverse faults stretching SW-NE which contributed to dividing the inner slope into rises and valley-like deeps.

In conclusion it is necessary to stress that the nature of the Hellenic Trough and the structure of its inner slope remain to a great extent unclear and require further complex invistigations. The latter is most likely composed of thrust complexes of

Hellenids outer zones deformed during the late Miocene (Attic) tectonic epoch which was followed by extension increased during the Pleistocene.

References

Biju-Duval B., Letouzev J., Montadert L. 1978. Structure and evolution of the Mediterranean basins. Initial Reports of the DSDP. Wash. (D.C.) US Govt. printing office, vol. 42, pt A, p. 951-981.

Groupe Ariane, 1979. Resultats de dragages sur la bordure externe de l'arc Hellenique (Mediterranee orientale). Marine Geology, vol. 32, p. 291-310.

Hsü K.J., Ryan W.B.F., 1973. Summary of the evidence for extentional and compressional tectonics in the Mediterranean. Initial Reports of the DSDP. Wash. (D.C.) US Govt. Printing office, vol. 13, pt 2, p. 1011-1019.

Le Pichon X., Angelier J., 1979. The Hellenic arc and trench system: a key to the neotectonic evolution of the Eastern Mediterranean area. Tectonophysics, vol. 60, p. 1-42.

Le Pichon X., et al., 1979. From subduction to transform motion. A seabeam survey of the Hellenic trench system. Earth Planet. Sci. Lett., vol. 1, N 44, p. 441-450.

Lyberis N., et al., 1980. Interpretation d'un fosse de subduction a partir des leves bathymetrignes an sondeur multifaisceaux "Sea Beam": l'exemple du fosse hellenique. C.R. somm. Soc. Geol. France, fasc. 5, p. 167-170.

Maync W., 1973. Lower Cretaceous limestones from the Hellenic Trough, Ionian Basin (Site 127). Initial Reports of the DSDP. Wash. (D.C.) US Govt. Printing office, vol. 13, pt 2, p. 1112-1135.

Monopolis D., Bruneton A., 1982. Ionian Sea (Western Greece): its structural outline deduced from drilling and geophysical data. Tectonophysics, vol. 83, p. 227-242.

Morelli C., 1978. Eastern Mediterranean: geophysical results and implications. Tectonophysics, vol. 46, p. 333-346.

Paparachos B.C., Comninakis P.E., 1978. Deep structure and tectonics of the Eastern Mediterranean. Tectonophysics, vol. 46, p. 285-296.

Pe-Piper G., Piper D.J.W., 1989. Spatial and temporal variation in Late Cenozoic back-arc volcanic rocks, Aegean Sea region. Tectonophysics, vol. 169, p. 113-134.

Rotstein Y., Ben-Avraham Z., 1985. Accretionary processes at subduction zones in the Eastern Mediterranean. Tectonophysics, vol. 112, p. 551-561.

Ryan W.B.F., Hsü K.J., et al., 1973. Initial Reports of the Deep Sea Drilling Project. Wash. (D.C.):US Govt. Printing office, vol. 13, 514 p.