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ATLANTIC WATER IN THE LEVANTINE SEA

DOGU AKDENIZ'DE ATLANTIK SUYU

HÜSEYİN YÜCE

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Abstract

Atlantic Water (AW) in the Levantine Sea was investigated based upon Nansen cast data collected from cruises conducted in the region. AW is observed distinctly in the Levantine Sea in summer. Due to the oceanographic and meteorological factors destruction and disappearance of AW were observed especially in the eastern part of the Levantine Sea in winter. Distribution of the AW supports recent hypothesis of general circulation patterns proposed by Özsoy *et al.,* (1989).

Introduction

Levantine Sea is one of the four major basin of the Eastern Mediterranean. To the west, between Crete and Cyrenaica, it merges with the Ionian Sea through the Cretan Rise. The sill is flat and deep, averaging 1800 m for 60 % of its 300 km width (Hopkins, 1978). To the north it is bounded by Turkey and Cretan Island Arc, and to the south by Egypt and Libya. The Levantine Sea has a volume of 7.5 x 10 5 km 3 and has depths of 4300 m in a depression just southeast of Rhodes (Hopkins, 1978). Three types of water masses are observed in the Mediterranean. These are surface, intermediate and deep water. Mediterranean has an anti-estuarine circulation with water loss by evaporation being greater than water influx. Loss of water is balanced by surface water input from neigboring seas and especially from the Atlantic Ocean. Less saline and less dense surface water enters the Mediterranean as the surface layer flow, whereas more saline Mediterranean water exits as the bottom layer flow. Mediterranean is thus considered a machine exchanging less saline Atlantic Water (AW) with the highly saline intermediate water flowing out to the Atlantic Ocean at greater depth. This exiting water is mainly the

Levantine Intermediate Water (LIW). Mediterranean surface water attains its characteristics through the variations of AW after its entrance via the Strait of Gibraltar and its flow towards east and dispersal in the Eastern Mediterranean. The Atlantic water has been traced into the Eastern Mediterranean by observa- tions of a salinity minimum below the surface. With the effect of cold and dry continental air, decreasing temperature and further increasing salinity of surface water, evaporation in the northern part of the area cause a vertical winter circulation, resulting in the formation of an intermediate and a deep water layers in the Mediterranean basin. The Levantine Intermediate Water (LIW) during its spreading toward the west changes as it flows out to the Atlantic below the surface layer. This intermediate water mass of higher salinity is formed in the northern regions of the Levantine Sea and particularly southeastern Aegean Sea. Morcos (1972) presents strong evidence for LIW formation over a broader area, including the southern Levantine Sea. Generally LIW formation is considered to occur in the northern Levantine Sea on both sides of Rhodos in February and March, as was first noted by Nielsen (1972). But off the coast of Southern Turkey, especially Gulf of Antalya and east of it is also considered possible LIW formation areas (Marcos, 1972, Plakhin *et al* 1971; Özsoy *et al* 1981; Plakhin, 1972; Yüce 1987). Some other researches considered Southern Aegean Sea as the LIW formation area (Nielsen 1912; Plakhin 1971; Yüce 1987; Georgomplos 1989; Lacombe *et al* 1958, 1960; Wüst 1961; Miller 1963, 1972, 1974; Bruce *et al.*, 1965, Ovchinnikov *et al.*, 1965; Burman *et al.*, 1970). Some researchers suggested that the northern Levantine Sea may contribute to the deep water of Levantine Basin (Plakhin 1987; Yüce 1987; Lacombe *et al.*, 1980; Ovchinnikov *et al.*,1987; Burman *et al.*,1970; El Gindy *et al.*, 1985). Since sub-surface water masses attain their characteristic at the surface, it is important to investigate spreading and sea sonal variation of AW in the Levantine Sea in order to study intermediate and deep water formation. Utilizing AW as a tracer, which is characterized with its minimum salinity, it is also possible to deduce information for the general surface water circulation patterns and as a consequence review of existing circulation hypotheses. Therefore, in this study an account of the formation of water masses formation and a review of recent hypotheses on general circulation patterns in the Levantine Sea are given and the distribution of the AW was investigated utilizing Nansen cast data collected from some of the previous cruises conducted in the region.

Review of the surface water circulation

Mediterranean water balance is maintained by the inward flow of surface Atlantic water which is mainly North Atlantic origin. Inflowing Atlantic Water (AW) annual net transport is approximately 1.6 x 10 3 km 3 and shows seasonal variation in addition to small scale variations. The excess inflow season runs from March to October, totaling 10.4 x 10 3 km3. It has a maximum of approximately 1.6 x 10 3 km3 and shows a seasonal variation in addition to small scale variations, having a maximum in August and September. The excess outflow seasons extend from November to February and totals 8.8 x 103 km^3 (Ovchinnikov, 1984).

Atlantic waters are carried to the Eastern Mediterranean by permanent, practically zonal North African current system. A series of cyclonic eddies form north of the current system; a smaller branch of the Atlantic inflow deflects to the north and traced into the Ionan Sea.

The prevailing westerly winds favour this circulation pattern and relatively strong winds, acting on the limited areas, generate large eddies which are associated with vertical motions and play an important role in water mass formation by bringing underlying water parcels closer to the mixing regions.

The most detailed dynamical investigation of the Mediterranean circulation up to 1980's is conducted by Ovchinnikov and Fedoseyev (1965). This investigation was complemented by Ovchinnikov (1966) utilizing all available data sources. The recent, and so far the most delailed analysis of the circulation and water masses in the Levantine Sea has been carried out by Özsoy *et al.*, (1989, 1990) to which the reader referred for a review.

Basic characteristics of the depicted surface circulation of these investigations will be reviewed herein. Original current maps were schematically redrawn to show the major elements of the proposed current systems and to aid the comparison (Fig.1). According to Ovchinnikov and Fedoseyev (1965), during summer, between the Island of Crete and Africa a flow from the central basin of the Mediterranean into the Levantine Sea is observed (Fig. 1a).

AW enter the Levantine basin via the northern part of the Crete-African passage. Some indication of westward flow in the southern part is also observed. Some other features depicted in this map are cyclonic Rhodes gyre and shift of North African current, which is named by Özsoy *et al.*, (1989) as the Central Levantine Basin Current (CLBC), northward closer to Cyprus (Fig. 1a). During the winter, in the northern part of the Crete-African passage, a discharge of the waters from the eastern basin e.g.

Levantine Basin, into the central basin and in the southern part an inflow of waters Atlantic origin was observed by Ovchinnikov and Fedoseyev (1965). Rhodes gyre, a large anticylonic gyre along the coast of Egypt, two eddy-like features south and southwest of Cyprus are major elements of this circulation pattern (Fig.1a).

During the summer and winter, the circulation of the surface waters of the Levantine Sea is very complex. Among the several types of circulation systems, the most intensive and stable ones are the Rhodes cyclonic and the Crete-Africa anticylonic circulation (Fig. 1a-b). At the eastern end, in agreement with traditional Nilsen (1912) description, Ovchinnikov and Fedoseyev (1965) indicate that most of the transport is eastward and clock-wise around Cyprus, with almost no southward flow along the Israel coast. Ovchinnikov (1966) Winter circulation pattern (Fig.1c) shows the same pattern with less emphasis on the smaller scale features. Ovchinnikov (1966),presenting a circulation map for the winter season only (Fig. 1c), claimed that summer cir-culation of the surface waters maintains the same basic features as in the winter. In fact, Ovchinnikov and Fedoseyev, (1965) supper layer circulation map for summer (Fig. 1b) shows reversal of upper layer current in the Crete-African passage, and shift of North African current toward north closer to Cyprus (Fig. 1c). Utilizing high quality data collected from an extensive, systematic survey programme consisting dense network of stations within the Physical Oceanography of Eastern Mediterranean (POEM) framework, Özsoy *et al.*, (1989, 1990) provided detailed description of a complex general circulation. Their studies revealed some of the previously unknown details of the general circulation of the Levantine Sea. It was shown by Özsoy *et al.*, (1989, 1990) that both in summer and winter, a quasi-permanent sub-basin scale gyres, including the Rhodes, Mersa Matruh and Shikmona

Gyres, to be of central importance in controlling the general circulation and its evaluation in time. The central Levantine Basin Current (CLBC), which appears to be the continuation of the North African Current, passes between the major circulation cells of the Rhodes and Mersa Matruh gyres, bifurcates more than once, and becomes partially entrained in the gyral circulation in the east. The cyclonic circulation of the Rhodes Gyre occupies an extensive area in the north, while the Mersa Matruh and Shikmona gyres, and part of the Central Levantine Basin Current make up a complex pattern of mainly anticylonic circulation in the southern basin. The surface circulation is in general agreement with the Ovchinnikov (1966) notion of anticylonic gyre lying south of the detached North African current and cyclonic current to its north (Fig.1c). It is only in the northern part of the Basin that the current gradually reorganizes and forms the Asia Minor Current. In general, main features of general circulation of Özsoy *et al.*, (1989) are in agreement with previous descriptions, but differences are observed at the extremities of the basin. Due to the nature of the data which previous studies are based upon, and lack of adequate data on the western part of the basin prevented Özsoy *et al.*, (1989, 1990) from resolving these discrepancies. In summer, at the western end of the basin, maps given by Özsoy *et al.*, (1989) shows the water flowing through northern section of the Cretan Passage in the opposite direction to the current which
Ovchinnikov *et al.*, (1966) depicted. Reviewing existing data and findings reveal that in summer the westward flowing current in the northern section of the Cretan Passage is well established. At the western end of the basin where the Ovchinnikov and Fedoseyev's (1965) summer circulation maps depict a cyclonic gyre, Özsoy *et al.*, (1989, 1990) found the large conspicuous Mersa Matruh anticyclonic gyre. At the eastern end, contrary to Ovchinnikov and Fedoseyev (1965). Özsoy *et al.*, (1989) indicates an anticyclonic Shikmona Gyre. Based upon analysis of previous Özsoy *et al.*, (1989 studies (Fig. 1a-c), one can consider that the Shikmona cylonic gyre is a well established feature contrary to Özsoy *et al.*, (1989) results, which indicates an anticyclonic circulation.

Distribution of Atlantic water in the levantine sea

Distribution of Atlantic Water, characterized with subsurface salinity minimum, can be used to review the general circulations systems. On the other hand surface distribution of the parameters also may give indications of upper layer circulation patterns. Therefore, before dealing with AW, it is considered useful to study the distributions of physical properties at the sea surface. Mean sea surface temperatures for different months are shown in Fig.2. Lowest surface temperatures are observed during February in the Southern Aegean Sea (Fig. 2a). Zonal surface temperatures distribution becomes meridional and increase further east during spring and summer. In summer, isotherms are directed north-south. In autumn, temperature increases in a northwest to southwest direction (Fig. 2). Higher surface salinities are observed in the northern part ot the Levantine sea along the Turkish coasts (Fig. 3). Lower salinities which may be due to Aegean Sea contribution, are observed in the southern and eastern part of the Aegean Sea. Predominance of low salinity water is observed in the southern part. Eastward directed isohalines, observed off the coast of Africa in spring and summer, indicate surface flow toward east at this time period. Low-salinity water originating from Nile Delta is due to the Nile effect which is diminished after the building of the Aswan Dam (Fig. 3). In March-May period higher surface salinity associated with lower surface temperature, is observed east and west of Rhodos Island. Iskenderun Gulf located in the northeastern part of the Levantine Sea is also a place where low-salinity surface water is observed. Observed zonal pressure gradient with meridional course of isobars directed towards the east in July and meridional pressure gradient with zonal course of isobars directed from north to south cause surface flow from west to east in summer and toward Adriatic in winter. The surface mean isotherms and isohalines show that in summer the surface water is directed from west to east and in winter from south to north (Zore Armanda, 1969). AW which is characterized with low salinity, traced with subsurface salinity minimum. T-S diagrammes for colder (January-April) and warmer (August-November) months are shown in Fig.4 in order to investigate presence of traditional organized cyclonic circulation pattern which is toward east in the south and toward west in the north. If that is the case then one can expect distribution to be along the isopycnal surfaces in the minimum salinity T-S diagram. In warm season, especially in summer, AW has lower salinities. In cool season AW is almost disappeared due to the cessation of penetration of this water toward Levantine Sea and due to vertical convection, or due to both effects. The scatter in the minimum salinity T-S diagramme of AW suggest existence of sub basin scale gyres and reject the presence of a basin wide cyclonic gyre. Staling of AW is not observed along the isopycinal surfaces due to the complexity of surface circulation. Another reason for scattering and variability in observed from the minimum salinity T-S diagram is the effect of vertical mixing rate of which varies from region to region, increasing in the formation areas of the water masses, especially when favourable conditions exist for the formation. The AW distribution characteristics can be shown along vertical sections and horizontal distribution of minumum salinity. The contour intervals (>38.90) in the salinity sections have been stretched so as to facilitate interpretation of AW that is identified with lower salinity. It is assumed that 38.90 ppt salinity indicates upper limit of AW. Along the easternmost north-south transect (Fig.5), transportation of AW with North African Current System is observed. AW enters Levantine Sea intensively along the coast of Africa. This is more pronounced in summer. AW is observed with higher salinities in the north of northern part which may be westward continuation of the cyclonic circulation. Low salinity water in the south of Crete may be Aegean water originated from the Northern Aegean Sea (Fig. 5). AW is observed in the south with a core at 50 m depth, extending to the middle of the Cretan passage. Low-salinity water to the north may be due to the Aegean Sea contribution. In the northern part of the Cretean passage observed low-salinity water may be an indication of AW flowing out of the Levantine basin but lower salinity value prevents to reach such a conclusion. Minimum salinity and its observational depth shown in Fig. 6 for Shikmona August 1967 data shows hugging of of low salinity water to the south. Tongue forms in the western and eastern indicate northward flow. In the north, higher minimum salinities are observed at greater depths. In the Aegean Sea and Gulf of Iskenderun, lower minimum salinity values are observed. This gives evidence of possible cyclonic circulation. Minimum salinity depth varies from 20 to 90 meters. Deeper part is located on the east of Cyprus and Crete while shallower values are observed in the Rhodes gyre area. Salinity transects for the western, central and eastern part of the Levantine Sea selected from

Academic Vavilov September 1959 data show presence of AW in the area. Fig.7a displays a salinity section to the east of Crete island. It shows AW at the center becoming thinner toward south. Observation depth is 60 m, with a thicknes of approximately 40 m. It shows AW in CLBC area, but cover a larger area and observed large quantity of AW may be due to CLBC which is a jet flow separating the Rhodes and Mersa Matruh Gyres. It shows AW circulating in a easterly direction in the north. Salinity section further east shows a patch of undiluted AW to the north and south of Cyprus may indicate the possibility of cyclonic circulation surrounding Cyprus. East-west salinity section of J.F. Pilsburg August 1969 data also support cyclonic circulation around Cyprus, but it does not flow toward east. Source of higher minimum salinity (39.0> S <38.95 ppt) observed east of Rhodes is different. It may come from west, deflecting toward north (Fig.7c). Minimum salinity and its observational depth, derived from the Shikmona September 1969 data, indicate westward flow in the south and eastward in the north (Fig.8). Effect of the Rhodes cyclonic gyre is reflected in the distributional pattern of minimum salinity and its observational depth in the east of Crete. There is a marked presence of AW in the south flowing east and deflecting toward north. AW is observed at greater depths in south, it becomes shallower in the area of Shikmona and Rhodes gyres. Doming of AW, with higher salinity, is observed in the center of Rhodes gyre. In the north of Cyprus low salinity AW water is trapped in the anticyclonic eddy in the area. Doming in the southeast of the Cyprus may support Ovchinnikov circulation pattern there. Salinity transect in the east of Crete gives the evidence of transportation of AW toward west in the north of the Cretan Passage. Two patches of AW is observed in the north shows branching of CLBC. In the south AW is observed at 75 m depth (Fig.9a). Salinity transect in the west of Cyprus shows presence of AW in the north and south of Cyprus and gives the evidence of cyclonic circulation around Cyprus. Shikmona November 1969 data shows northeasterly transport of AW west of Cyprus may be an indication of permanency of Shikmona Gyre. AW observed in the west of Antalya Gulf may be coming from south (Fig.9c). In winter, favourable conditions exist for the formation of intermediate water in the northern part, especially east of Crete, due to the presence of high surface salinity (>39.10 ppt) and lower temperature (<15.10 C) values (Fig.10a-b). This causes the formation of dense surface water and as a consequence vertical convection and destruction of AW which has a possibility to enter the region due to northward deflection in the central Ionian Sea caused by a pressure field. Consequently homogenous water layer is observed. This is evident from surface (Fig.10b) minimum-salinity distribution (Fig.10c) and its observational depth (Fig.10d). In the north, especially in the Levantine intermediate water-mass- formation areas, surface and subsurface salinity values are very close to each other and generally higher than 39.0 ppt. Destruction and disappearance of AW is also evident. Lower surface (Fig.10b) and subsurface salinity (Fig.10c) is observed in the south associated with higher temperatures compared to the north. Surface temperature gives additional evidence of the circulation systems. In the northwestern area, Rhodes cyclonic gyre is identified with dome of cold water. In the south, tongue like dis- tributions and fronts give indication of eddy like phenomenen. Warm water may be trapped within anticyclonic eddies. Higher minimum salinites are observed in the Rhodes cyclonic gyre. Higher minimum salinities and doming of cold isotherms with nearly uniform properties indicates permanent upwelling. AW does not pass 32 E longitude while turns to the northwest of Cyprus.

Depth of the minimum salinity is shallower, mainly observed at the surface, almost everywhere, except southeastern part, which is around 25 m. Southeastern part it reaches up to 75 m. depth. Salinity transect in the west of Cretan Passage shows the presence of AW in the south penetrating to a depth of 200 m. Low-sali- nity water observed in the north is AW which gives evidence of cyclonic gyre in the Cretan Passage area. Consequently doming of high salinity water is observed. Disapperance of AW in the Levantine Basin is evident in east-west salinity transect (Fig.11b). In the east of 27 E longititute water column does not posses AW. In the east AW deflects to the north in the Cretan Passage. Minimum salinity and its observational depth for late spring-early summer data of Shikmona 26 May-20 June 1968 give evidence of spreading of AW along the southern periphery. Local low-salinity water in the Antalya and İskenderun Gulfs are too low to be identified as AW. High minimum-salinity water core observed in the Rhodes Gyre area at comparatively deeper depths. This may be due to the vertical mixing of dense surface water. Patch of AW observed in the east of Cyprus. Minimum salinity and its observation depth is shown in Fig. 12 does not depict a cyclonic circulation in the north. But it may give evidence of northward flow in the north, eastward flow in the south. Destruction of AW in the north during winter may give rise to such a distribution.

Conclusions

Scatter in the minimum salinity T-S diagramme indicates that a basin wide cyclonic circulation is not present and gives evidence of presence of sub basin scale gyres. Observation of AW in summer in the area is evident due to the presence minimum salinity layer lower subsurface salinities. Effects of the salinity surface water of Black Sea origin can be observed in the eastern passages of Crete Island in autumn. Low salinity water observed in the northern part of Cretan Passage gives evidence of a cyclonic circulation in the area which confirms the summer circulation pattern put forward by Ovchinnikov and Fedoseyev (1965). In summer leaning of AW to the African coast and its deflection toward north in the western and eastern parts support the presence of a cyclonic circulation. This is in confirmity with Ovchinnikov and Fedoseyev (1965) circulation pattern (Fig. 1a) which show cyclonic circulation around Cyprus. AW becomes shallower in the Rhodes and Shikmona gyres area.

In winter favourable conditions exist for the formation of LIW in the north. AW is not observed in the eastern Levantine Sea during winter, which support findings of Özsoy *et al.*, (1989). Vertical convection gives rise to the destruction of AW which may enter to the region due to northward deflected flow. AW does not pass the 32 E longtitude. In spring low salinity water in the Antalya and İskenderun Gulfs are local in origin. High minimum salinity observed in the Rhodes gyre is due to the upwelling of high saline subsurface water.

Figure 1 Shematic depiction of surface circulation patterns to show main features of the (a) Winter Fedoseyev *et al.*, [21] (b) Summer Fedoseyev et al [21] (c) Winter Ovchinnikov [22] (d) Summer Özsoy et al [23] (e) Winter Ovchinnikov [20] surface circulations

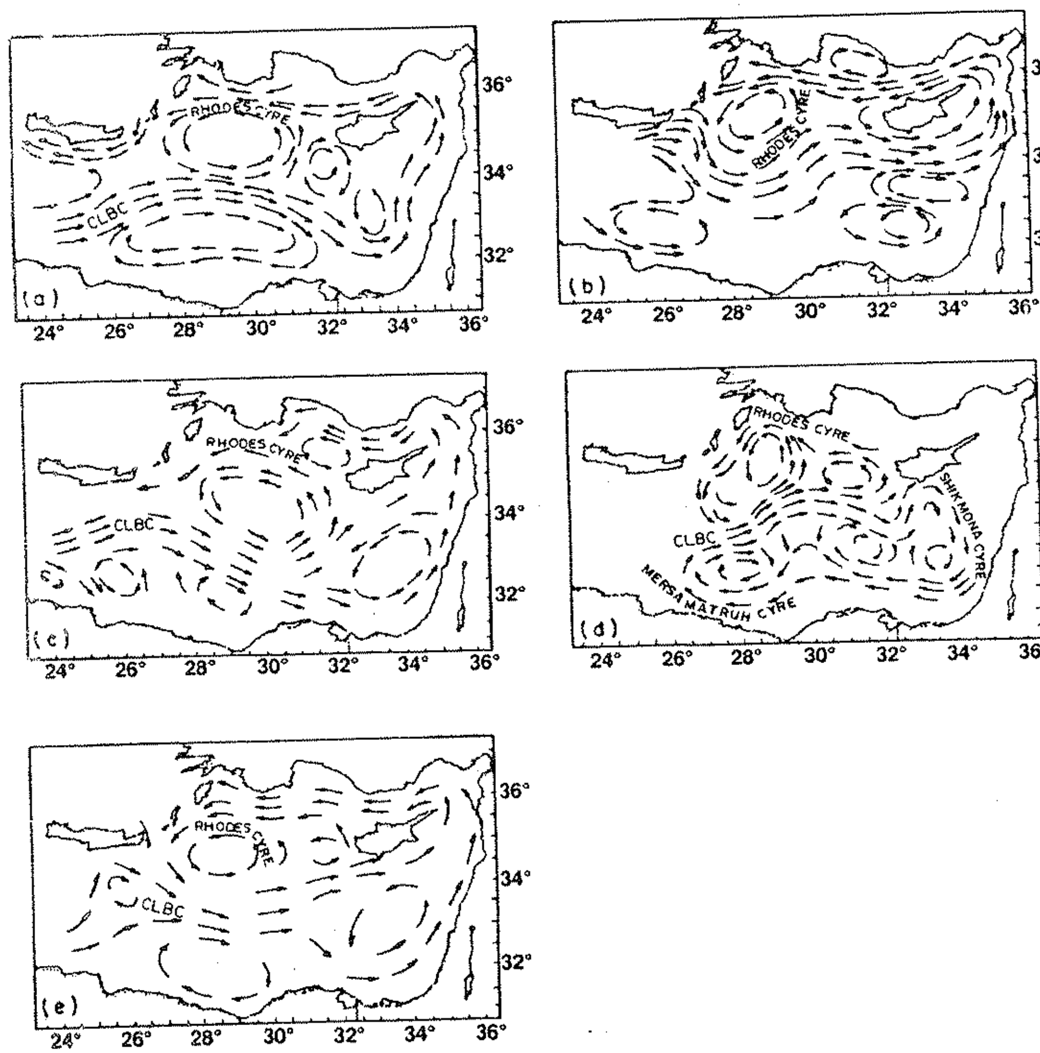


Figure 2 Monthly mean sea surface temperatures (After Becker [26])

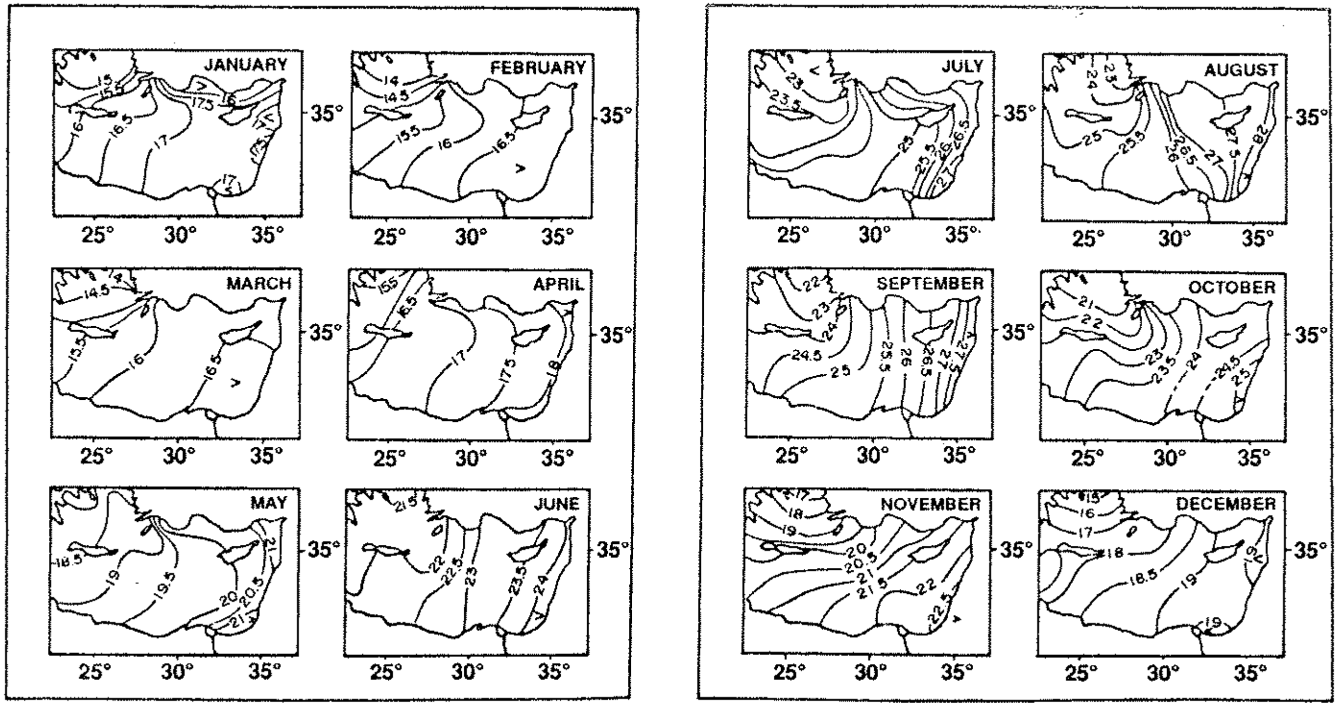


Figure 3 Seasonal mean surface salinity distribution (After Becker 27)

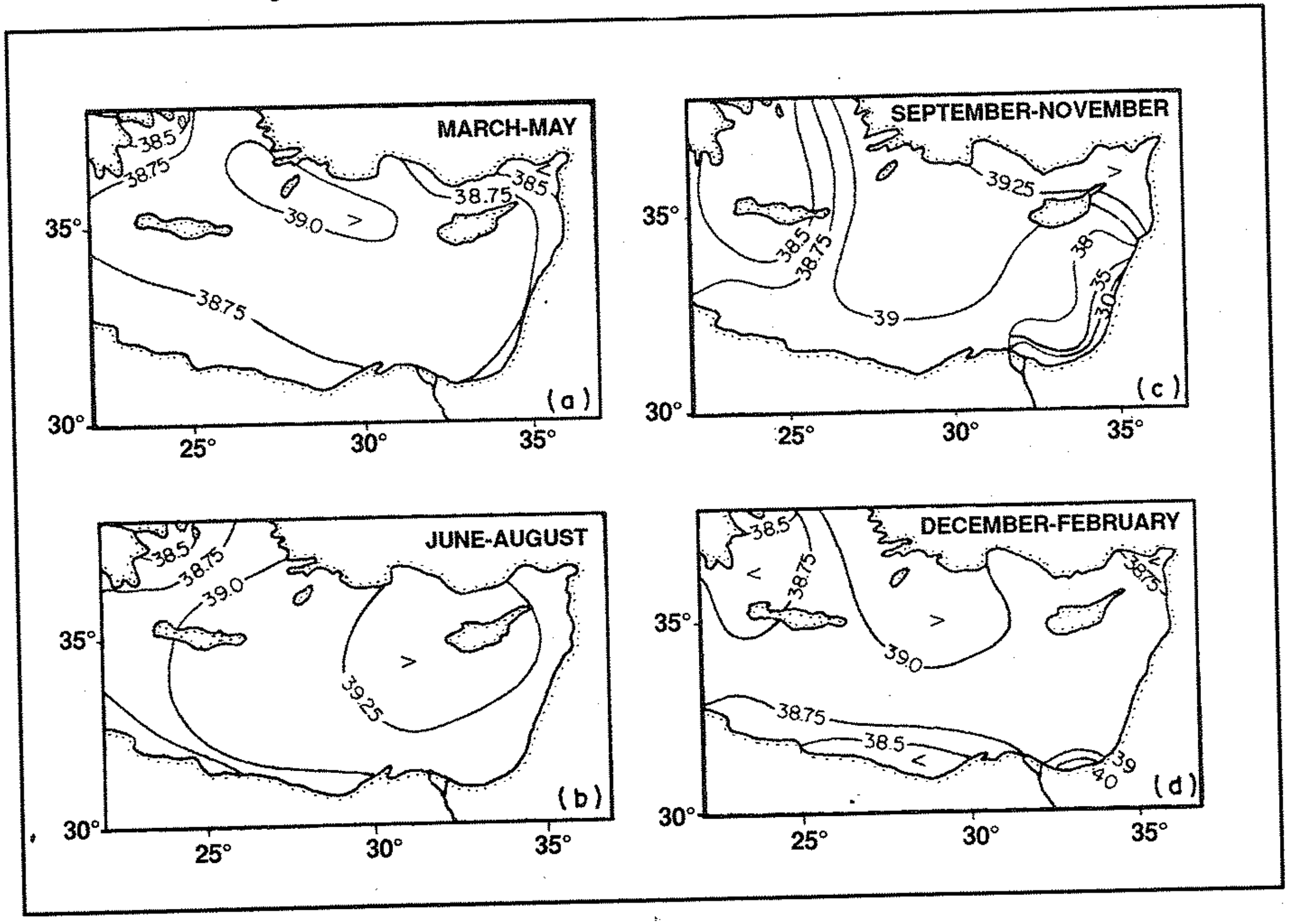


Figure 4 Minimum salinity T-S diagrammes (a) Warm season (August-November) (b) Cool season (January - April)

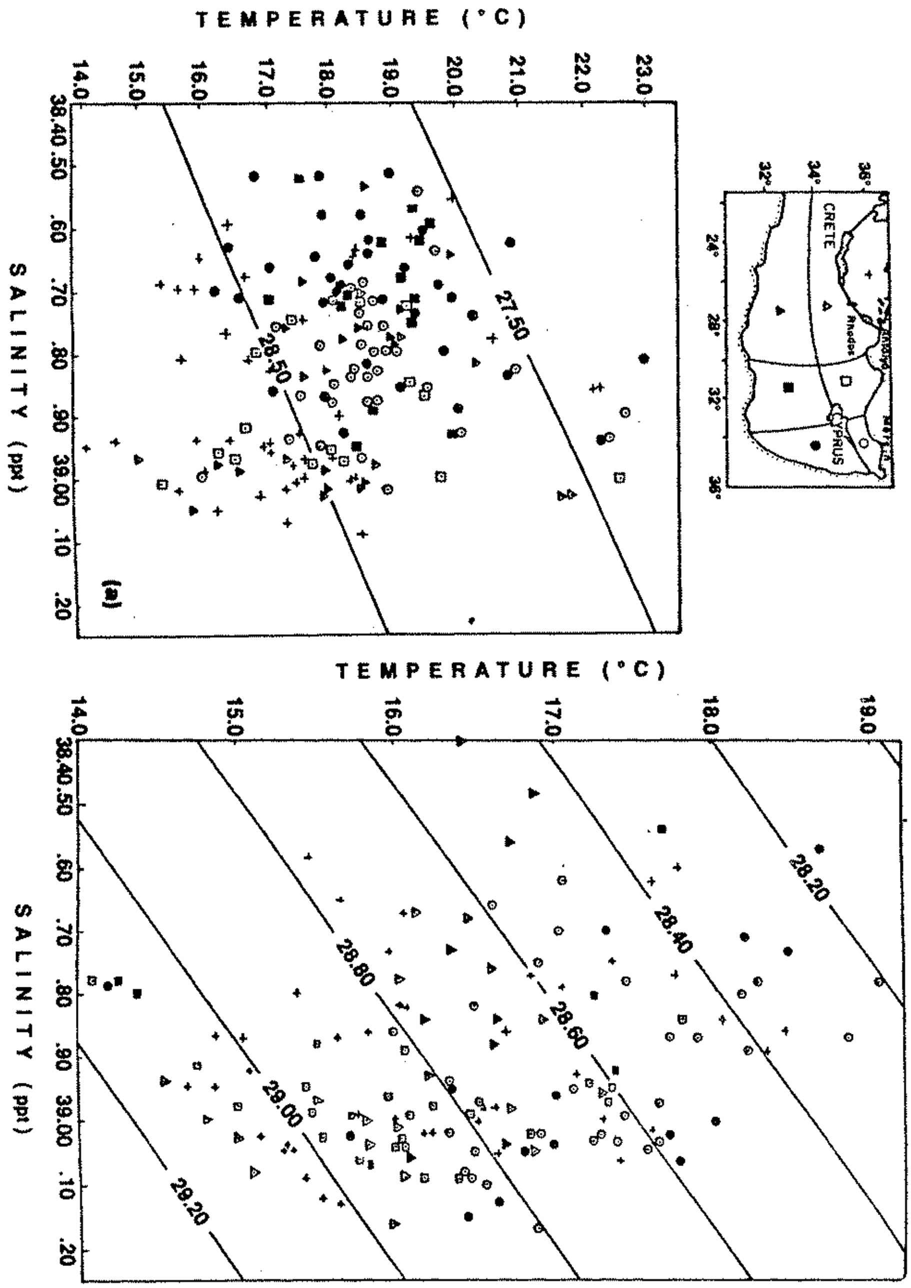


Figure 5 Salinity section in the eastern part (Akademik Verdnaski October 1974 data)

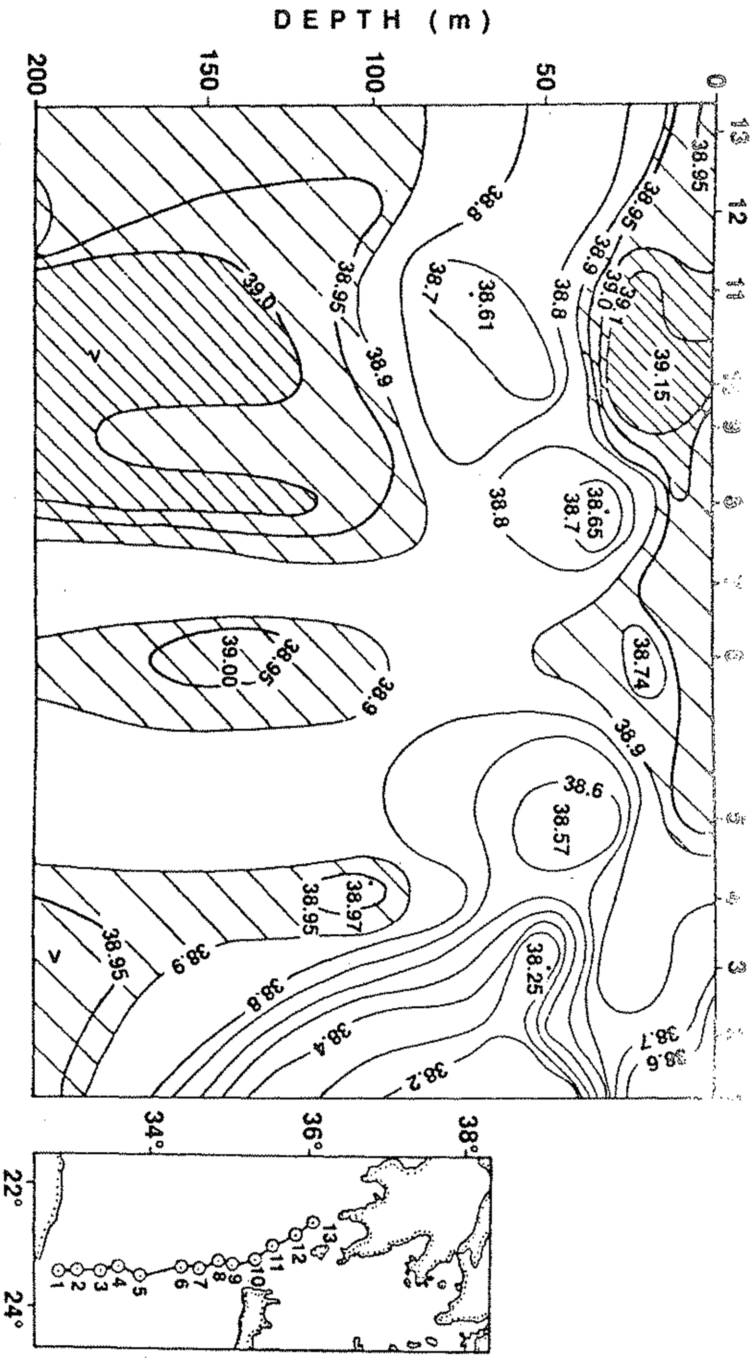


Figure 6 (a) Minimum salinity (b) Minimum salinity depth (Shikmona 18 August- 9 September 1967 data)

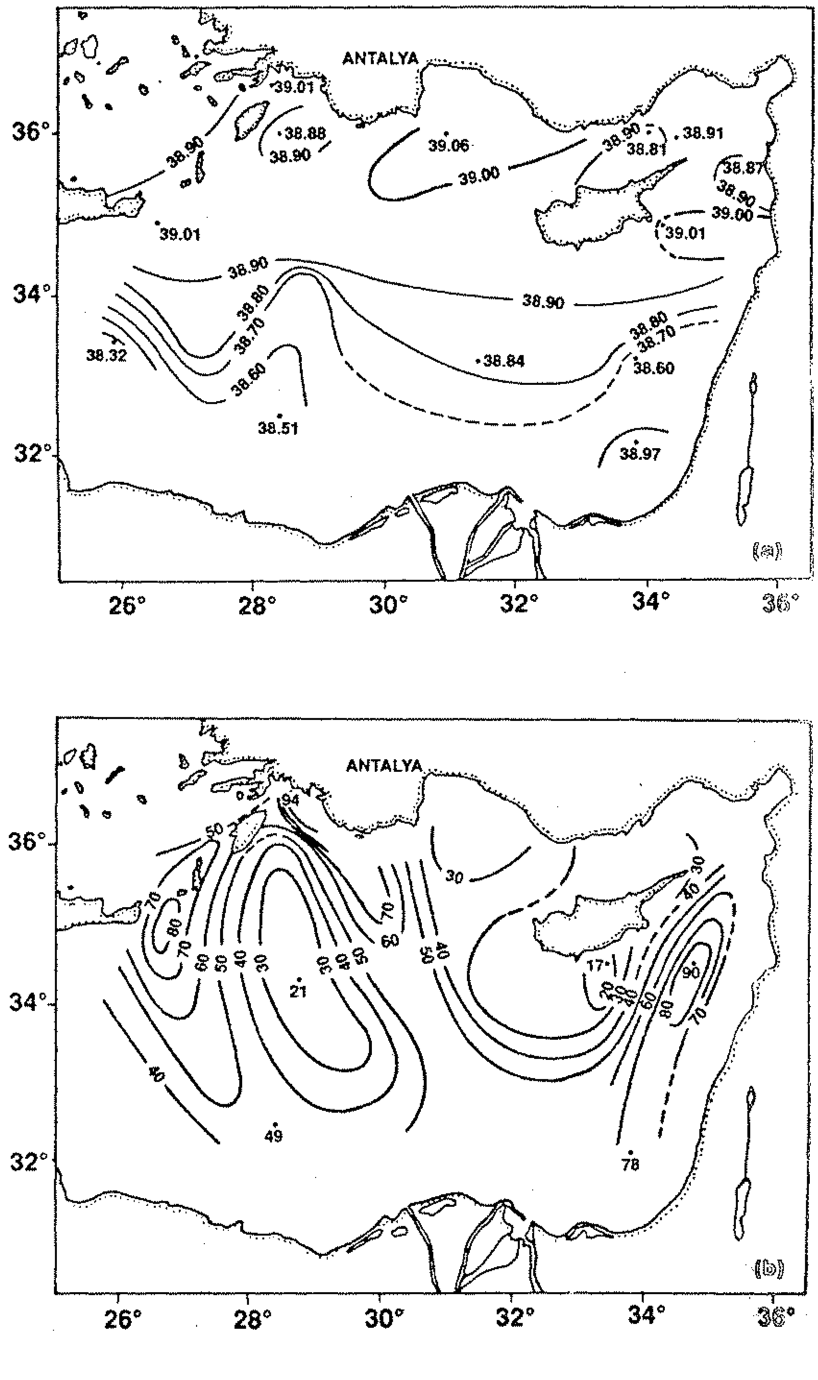


Figure 7 Salinity sections (a,b) Akademik Vavilov September 1956 data (c) J.F. Pillsbury, August 1965 data.

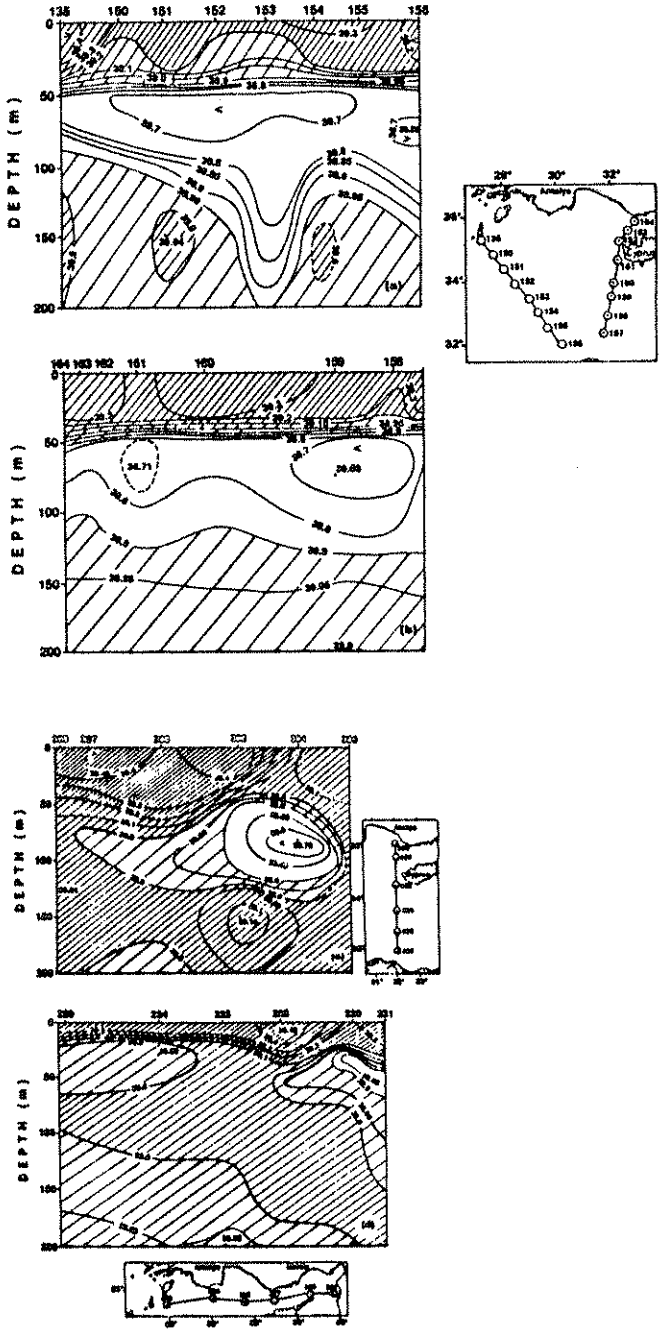


Figure 8 (a) Minimum salinity and (b) minimum salinity depth (Shikmona November 1969 data)

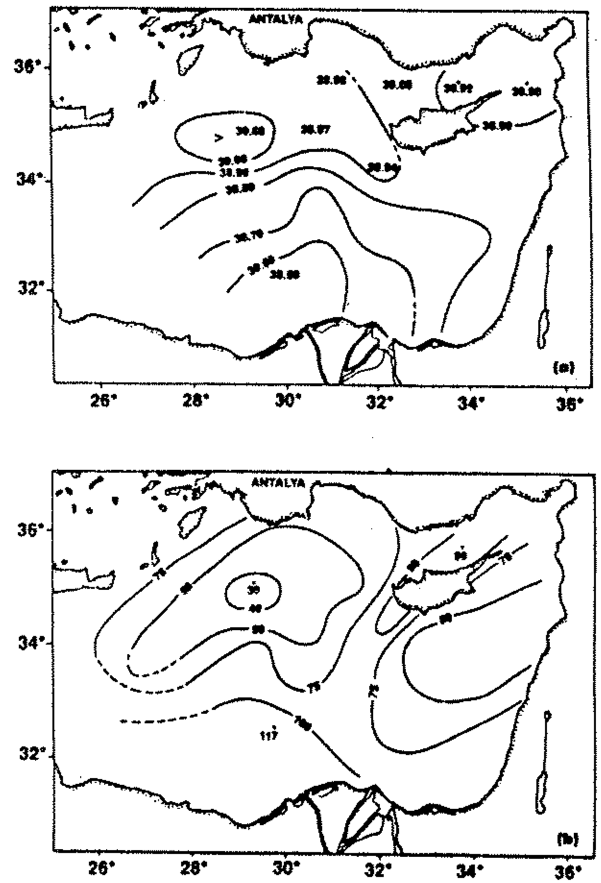


Figure 9 Salinity transects (a,b) Chain October 1961 data, (c) Shikmona November 1964 data

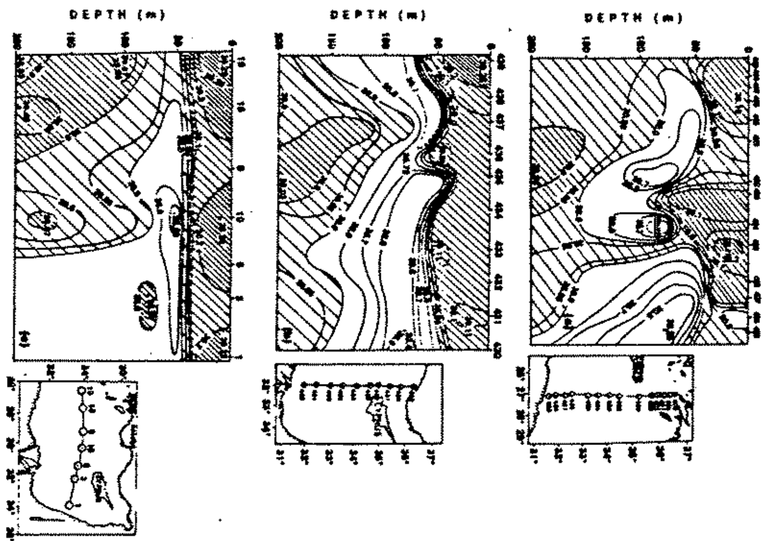


Figure 10 Surface (a) temperature (b) salinity (c) minimum salinity (d)minimum salinity depth (Vavilov Vasily Goldvin 3 March-4 April 1977 data)

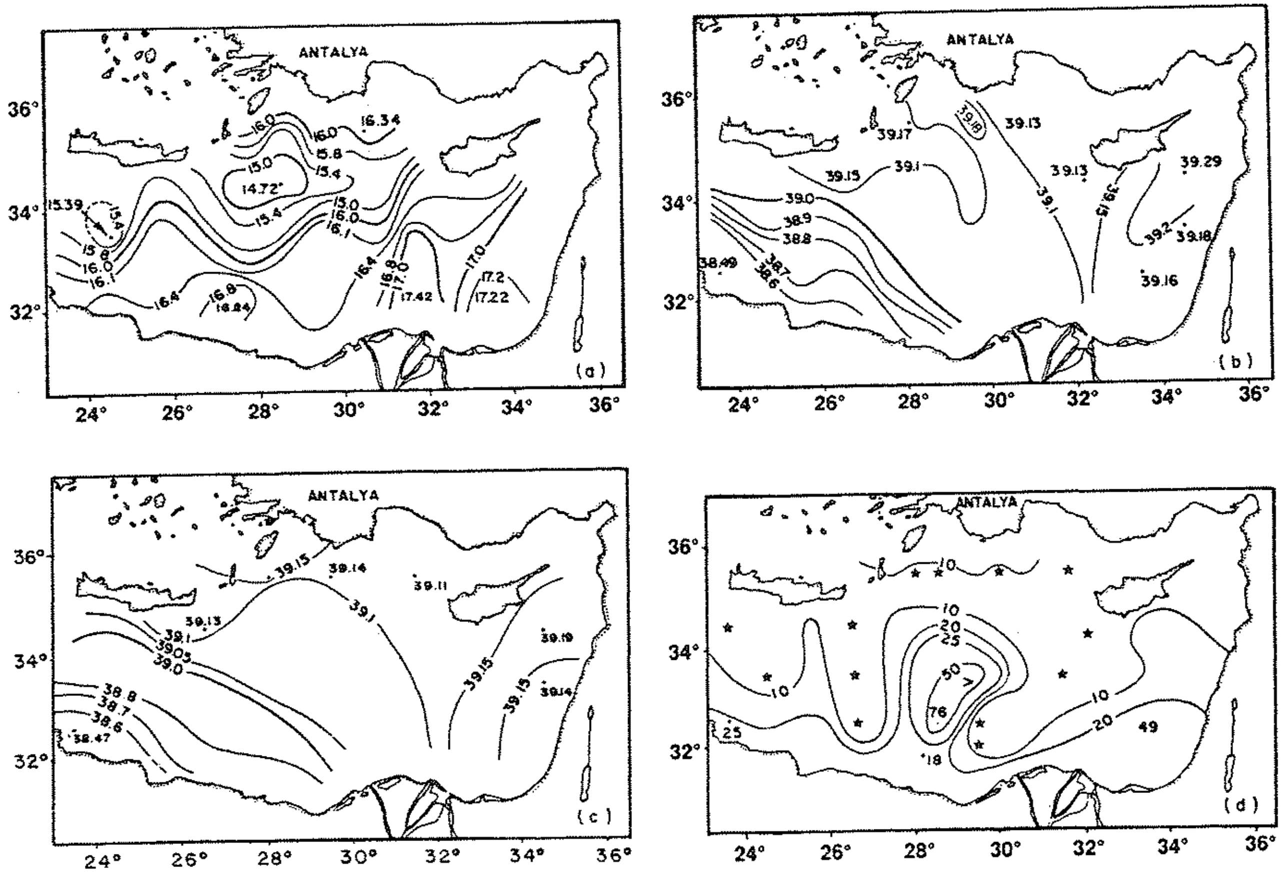


Figure 11 Salinity transects (a) Atlantis (March-April 1948) (b) Vavilov Goldvin March-April 1977

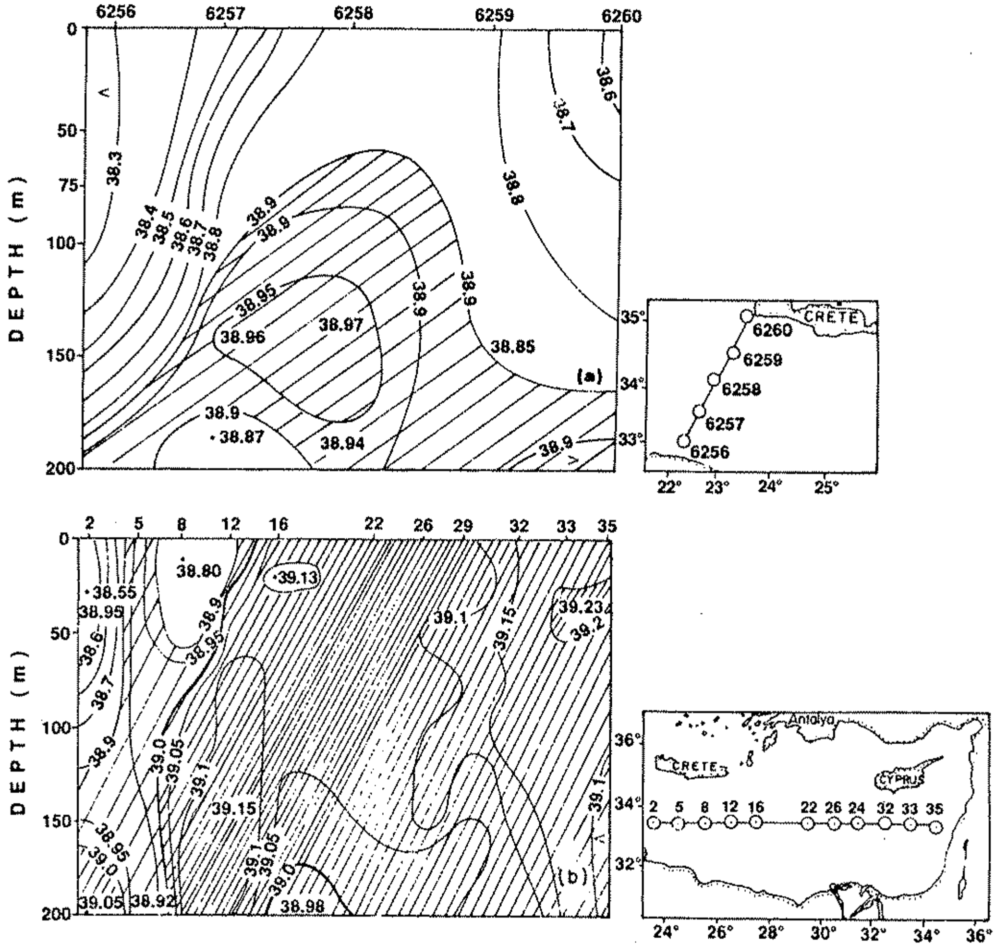
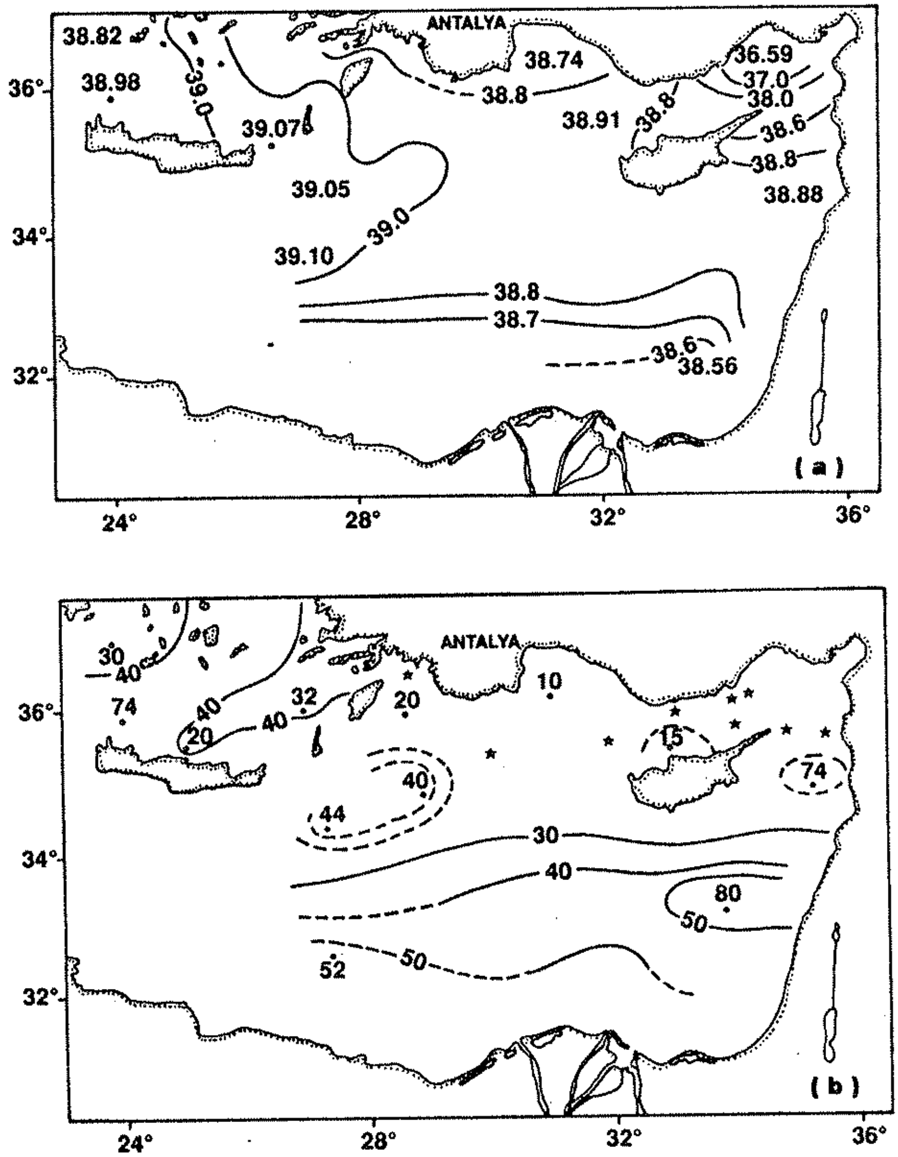


Figure 12 (a) Minimum salinity and (b) minimum salinity depth (Shikmona;21 May-20 June data) stars represent surface.



Özet

Bölgede yapılan başlıca seferlerden elde edilen Nansen indirimi verilerine dayalı olarak Atlantik suyu (AW) Doğu Akdeniz (Levant Denizi)'nde incelenmiştir. AW Levant Denizi'nde yaz mevsiminde daha belirgin olarak gözlenmektedir. Oşinografik ve meteorolojik faktörlere bağlı olarak özellikle Levant Denizi'nin doğusunda kış mevsiminde AW'ın ortadan kalktığı ve yok olduğu gözlenmektedir. Atlantik suyu dağılımı Özsoy ve ark. (1989) tarafından ileri sürülen genel sirkülasyon paternini destekler niteliktedir.

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