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ON THE DYNAMICS OF THE SOUTHERN BLACK SEA

T. OGUZ, M. A. LATIF, H. I. SUR, E. OZSOY, U. UNLUATA

Institute of Marine Sciences
Middle East Technical University
P.O Box 28, Erdemli, 33731, Icel - TURKEY

ABSTRACT The geostrophic circulation and distributions of the Cold Intermediate and the Mediterranean water masses along the Turkish coast of the Black Sea are described on the basis of hydrographic data collected during 1987-1989 surveys of the R/V Bilim. The regional circulation was found to consist of a meandering rim current conforming mainly on the topographic slope and a series of anticyclonic eddies attached to the shelf break. The eddies, observed in the period of the surveys, seem to be quasi-permanent features and are controlled by the topography and also modified by the barotropic-baroclinic instability of the flow. Further details and structural variability of the circulation were inferred by satellite imagery. The distribution of the CIL waters was found to follow the regional circulation. The characteristics of the CIL are continually modified as it is advected eastward by the rim current and partially entrapped in the anticyclonic eddies. The CIL waters are identified by core temperatures of about 6.5 °C in the Bosphorus exit region and 7.0-7.2 °C in the southeastern part of the Black Sea. The Mediterranean underflow, crossing the the southwestern Black Sea shelf region, is subject to continuous mixing due to interaction with the CIL waters. By the time the Mediterranean effluent reaches the shelf break (at depths of 100-150m), it is identified by a colder and slightly less saline water mass relative to the ambient conditions. This modified water mass then intrudes into the deeper levels of the basin in the form of patches of colder and relatively oxygen-rich water, and leads to the partial ventilation of the subhalocline waters.

1. INTRODUCTION

With the lack of detailed, clearly-defined kinematics and dynamics of the circulation and inadequate understanding of the mechanisms related with the water mass formation, distribution of the Cold Intermediate and Mediterranean waters, the Black Sea is one of the least known regions of the world oceans. Our existing knowledge on

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the general oceanographic characteristics of the Black Sea is essentially based on the studies by Caspers (1957), Leonov (1960), Grasshoff (1975) and Sorokin (1983) with the main emphasis being given essentially to the chemical and biological processes. The hydrographic characteristics of the northwestern shelf and the Bosphorus entrance regions have been recently described by Tolmazin (1985a,b). The hydrography of the latter region and the interaction of the Black Sea with the Turkish Straits were discussed by Oguz et al. (1990a), Latif et al. (1990) and Unluata et al. (1990). Further details on the hydrographic characteristics of the Black Sea are given in Murray et al. (1989, 1990) and Ozsoy et al. (this volume).

One of the most extensive and systematic data set in the Black Sea was obtained during the 1988 Black Sea Expedition comprising a total of six cruises of R/V Knorr each of which was designed for a different specific purpose. Some of the results emerging from these multi-disiplinary studies are described in this volume. In addition to these studies, a series of hydrochemical studies was also carried out during 1987-1989 field campaings of the R/V Bilim of the Institute of Marine Sciences - Middle East Technical University along the Turkish coast of the Black Sea. The data collected comprises of four cruises of R/V Bilim, two of which were conducted during September 1988 and April 1989 and included the entire Turkish coastal waters of the southern Black Sea. The other two cruises were carried out during April 1987 and January 1989, occupying only half of the region to the west and east of the Cape of Sinop, respectively.

In the present paper, we report on some results obtained from the R/V Bilim data set on the principal hydrographic features of the southern Black Sea along the Turkish coast. The geostrophic circulations inferred from the hydrographic data will be described first. This is followed by a brief description of two important features of the Black Sea hydrography; namely the distribution of the Cold Intermediate and the Mediterranean water masses in the southern Black Sea.

2. OBSERVATIONS

The measurements were carried out using the high resolution Sea-Bird Electronics Model SBE 9 CTD system. The CTD system was lowered at a rate of about 0.5 ms^{-1} and sampled at a rate of 24 Hz resulting in the data collection at intervals of the order of a few centimeters. The downcast data was then subject to processing for despiking, filtering and bin-averaging (Ozsoy et al. 1989). The results presented in this paper are based on the processed data, bin-averaged around every one decibar.

The important features of the bathymetry along the Turkish coast of the southern Black Sea are shown in Figure 1a,b. The region is generally characterized by a narrow shelf which is often dissected by

submarine canyons, being deep channel intrusions into the coast. Major submarine canyons are located off the Bosphorus entrance and the Sakarya and Kizilirmak Rivers. The shelf, which is relatively wider west of the Sakarya Canyon (Figure 1a), becomes extremely narrow towards the east, except in localized regions off Sinop and the Yesilirmak and Kizilirmak Rivers. The obliquely offshore extension of the Yesilirmak shelf in the form of a submarine ridge, called Yesilirmak (Arkhangelsky) Ridge, is also a major topographic feature of the Black Sea (Figure 1b). As described in the following section, these topographic features give rise to a strong control on the peripherial current system.

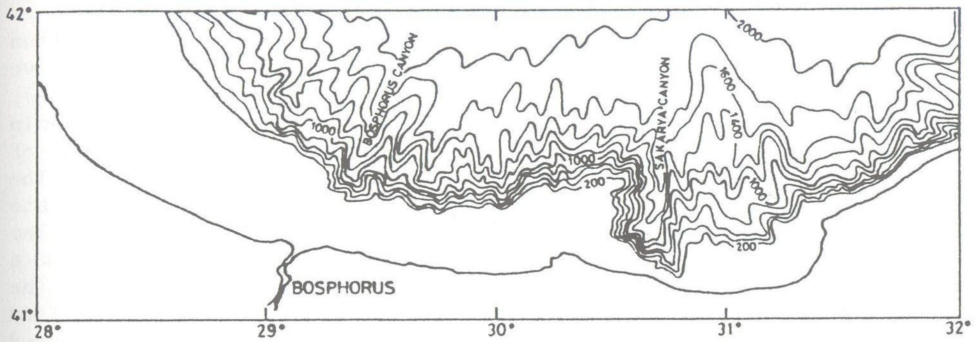

Figure 1a. Bottom topography of the Bosphorus and Sakarya Canyon regions in the southwestern Black Sea.

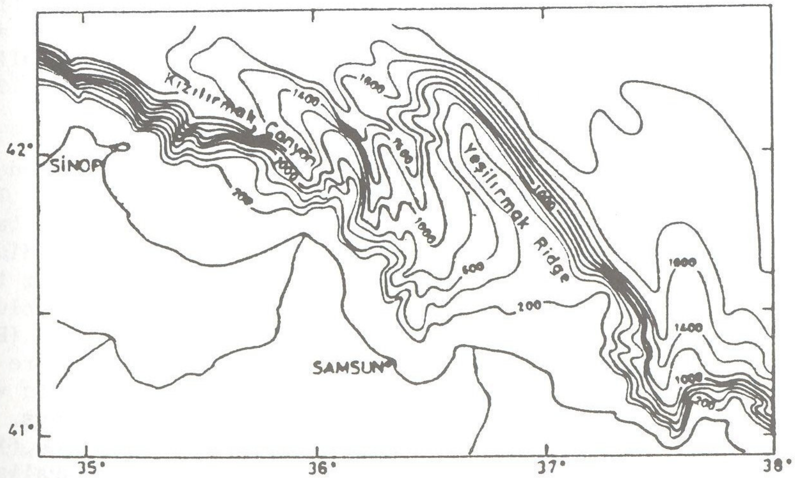

Figure 1b. Bottom topography of the Kizilirmak Canyon and Yesilirmak Ridge regions located to the east of the Cape of Sinop.

Circulation

The Black Sea general circulation is known to have essentially three different driving mechanisms; wind and thermohaline forcings at the sea surface and source-sink forcing through the Bosphorus Strait. The numerical studies given by Marchuk (1975), Moskalenko (1976), Stanev (1988, 1989) show that principal features of the quasi-steady circulation are governed by the curl of wind stress distribution. However, the numerical studies (Marchuk et al., 1975; Stanev, 1988, 1989) also provide a quantitative evidence that the thermohaline circulation constitutes an important component of the Black Sea general circulation and the thermohaline forcing may indeed generate surface currents comparable to wind generated currents.

The most prominent feature of the Black Sea general circulation is the presence of a basin-wide cyclonic circulation system which have been studied to some extent by Neumann (1942); Filippov (1968); Gamsakhurdiya and Sarkisyan (1976); Blatov et al. (1984); Tolmazin (1985a); Stanev (1988, 1989). These studies reveal the presence of markedly different seasonal circulation fields in the Black Sea. The summer circulation generally consists of two major and separate cyclonic gyral circulations in the western and eastern basins. The winter season, on the other hand, appears to be characterized by a more coherent picture of circulation over the entire Black Sea. The cyclonic boundary current system becomes stronger and better defined as compared to the summer case. The sub-basin scale gyres, observed in the summer, merge into one elongated cell covering the entire sea in the east-west direction. Only two mesoscale cyclonic eddies located at the centers of the basins with a typical dimension of about 100 km remain (see, for example, Figure 29 in Tolmazin 1985a). Embedded within the sub-basin scale cyclonic circulations, indications of temporally and spatially variable mesoscale features were also inferred from the hydrographic data (e.g. Fashchuk and Ayzatullin, 1986; Novaselov et al., 1987; Latun, 1989; Bezboradov et al., 1990) and the AVHRR satellite imagery (Oguz et al., 1990b).

In the present study, the geostropic circulation was obtained for each survey relative to the 300 dbar reference surface. This reference level was chosen because the CTD casts were generally taken to this level. The temperature and salinity fields, however, indicate little variations below 300m (see Murray et al., 1990), implying this choice covers most of the baroclinic signature of the water column. This is quantified by means of the baroclinic dynamical modal (BDM) analyses for September 1988 and April 1989 surveys (Figure 2) indicating that the baroclinic motion below the depth of 300m is very slow and appears to be of negligible magnitude. For both surveys, the zero crossings of the first BDM occur at about 300m. The first baroclinic mode contain approximately 90% of the total available potential energy and has a Rossby radius of deformation of 19 km.

Ageostrophic processes on the continental shelf are removed from

the analysis by assuming that the 300m isobath represents the coastal boundary of the region across which the geostrophic flow must vanish. This implies that streamlines must not cross the coastline and requires specification of a coastal stream function value (Milliff, 1989). This value is determined by choosing a typical density profile, representative of the density structure at stations close to the coast.

The geopotential anomaly map constructed in this way for the 10m depth level for the September 1988 survey is shown in Figure 3a. It displays a well-defined easterly flowing meandering rim current along the Anatolian coast. Embedded within this main flow are a series of mesoscale eddies attached to the shelf. The rim current is directed towards the Turkish coast from the north by following the steep topography along the edge of shelf. Off the Bosphorus entrance region, the jet apparently follows the Bosphorus Canyon topography (see Figure 1) and therefore swings sharply in the southwest direction toward the coast before it bifurcates. One branch then turns towards the east, while the other flows partly into the Bosphorus Strait and partly turns anticyclonically to form the mesoscale eddy to the northwest of the strait entrance. To the east of strait's entrance, the easterly branch turns offshore and meanders around the anticyclonic mesoscale eddy found in the Sakarya Canyon region. Thereafter, the flow continues further eastwards along the coast without much changes in its structure up to the 35^{0}E longitudional

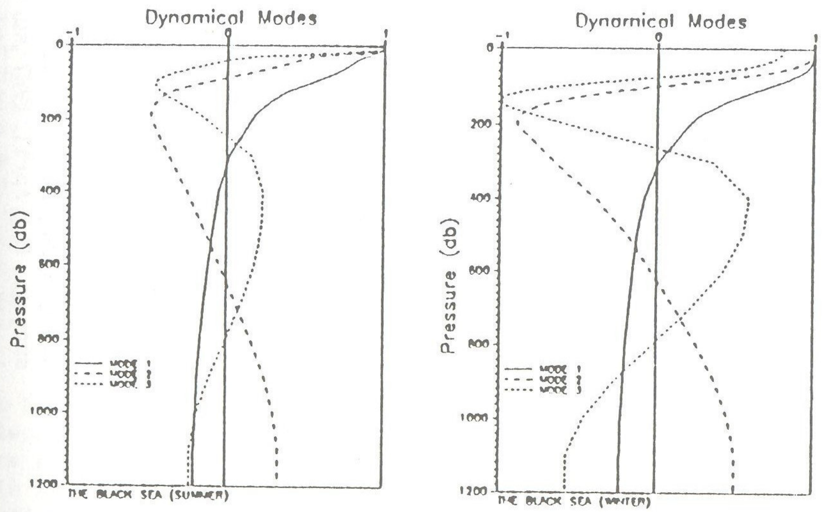

Figure 2. First three baroclinic dynamical mode amplitudes for the September 1988 and April 1989 surveys denoted in the figures by the summer and winter, respectively. The Brunt-Vaisala frequencies used in the solution of the vertical structure equation are based on the cruise-averaged density profiles.

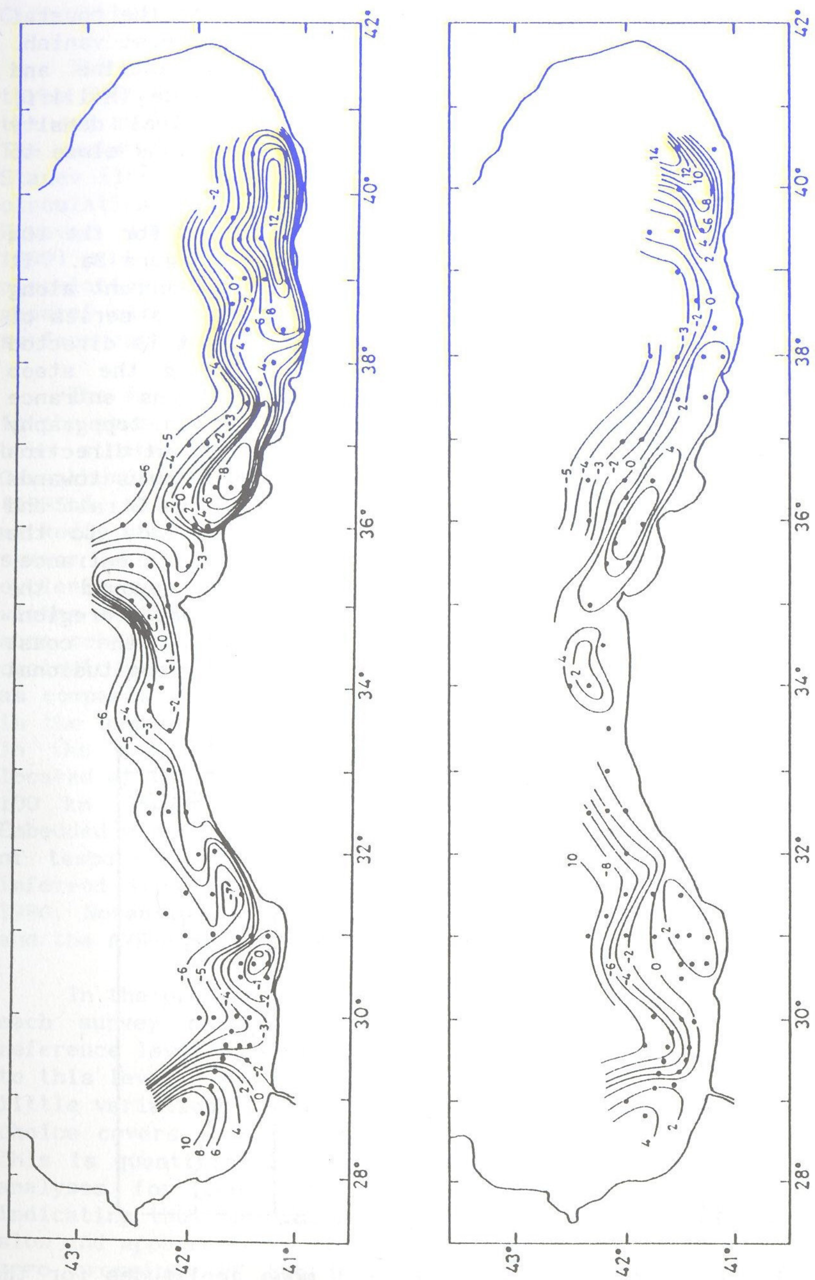

Figure 3. Geopotential anomaly (in dynamic cm) maps at 10m relative to 300m reference level for (a) September 1988 survey, (b) April 1989 survey, (c) April 1987 survey, (d) January 1989 survey. The station locations are shown by the dots.

section, where a part of it tends to deflect cyclonically to the north to become part of the large scale general circulation of the western basin typically observed in the summer surveys. The other part of the flow continues eastward around the mesoscale eddy located off the Cape of Sinop. The station resolution is however not sufficient to define the path of flow clearly in this region. The eddy has an anticyclonic sense of rotation and an elongated shape with westward extension of about 100 miles from the Cape of Sinop.

To the east of the Cape of Sinop, the coastally attached flow appears to be controlled by the topographic features such as the Kizilirmak Canyon and the Yesilirmak Ridge (c.f. Figure 1). In particular, a branch of the flow follows the topography of the Kizilirmak canyon, and makes a U-shaped turn around the canyon between about 36-37°E. The flow then proceeds along the eastern steep slope of the ridge, going around the anticyclonic eddy located off the Yesilirmak river. The rest of the flow continues along the Eastern Black Sea Escarpment, north of the large scale anticyclonic eddy, situated between 37°E and 41°E longitudes along the shelf.

The analyses of geopotential anomaly fields further indicate that vertical structure of the circulation does not change much towards the deeper levels. The geopotential anomaly fields at the depths of 100m and 200m (not shown here) depict essentially the same patterns of circulation except a gradual weakening in intensity.

A similar structure of the circulation was obtained from the April 1989 data (Figure 3b). Once again the jet coming into the Black Sea-Bosphorus junction region bifurcates and forms an anticyclonic eddy to the northwest of the entrance. The jet appears to be more intense as compared to the September 1988 survey, probably because the April 1989 survey corresponds to the period of increased inflow from the NWS region. The anticyclonic eddy appears to be relatively weaker and the eastward jet is better defined in this cruise, exhibiting comparatively less meandering off the Sakarya region. The eddy in the Sakarya region has an elongated shape, as a result of squeezing by the jet against the shelf. The shape of the streamlines strongly suggests that a part of the jet flow turns northwards at about 33°E to join the main cyclonic circulation of the western basin.

The splitting of the rim flow offshore of the Sinop region can not be defined satisfactorily due to lack of resolution in the station network. The anticyclonic eddy was again found to the west of the Cape ofSinop but it was relatively weaker and much smaller as compared with the September 1988 case. The anticyclonic eddy in the Yesilirmak River region has a structure similar to the September 1988 one. The eddy was, however, also slightly weaker. The anticyclonic eddy found earlier in the easternmost part of the sea has, in this survey, an elongated shape in the offshore direction from the coast.

The April 1987 cruise covered only the Anatolian coastal belt of the western Black Sea. As compared to the April 1989 case, the circulation pattern exhibits a weaker rim flow, and pronounced spatial variability towards the interior of the basin (Figure 3c). The flow pattern indicates presence of a more pronounced meandering rim current and the Sakarya and Sinop anticyclonic eddies. The eddy observed to the northwest of the Bosphorus Strait was, however, not reproduced due to lack of station network resolution.

The circulation for January 1989 (Figure 3d) representing winter conditions in the eastern Black Sea basin, reveals a pronounced cyclonic character implying the rim current contributes, to a large extent, to the large scale circulation of the eastern basin, rather than feeding the anticyclonic eddy along the coast. The other anticyclonic eddy off the Yesilirmak-Kizilirmak region also emerge at its previous location. Both of the eddies were however weaker as compared to their counterparts in the September 1988 and April 1989 surveys.

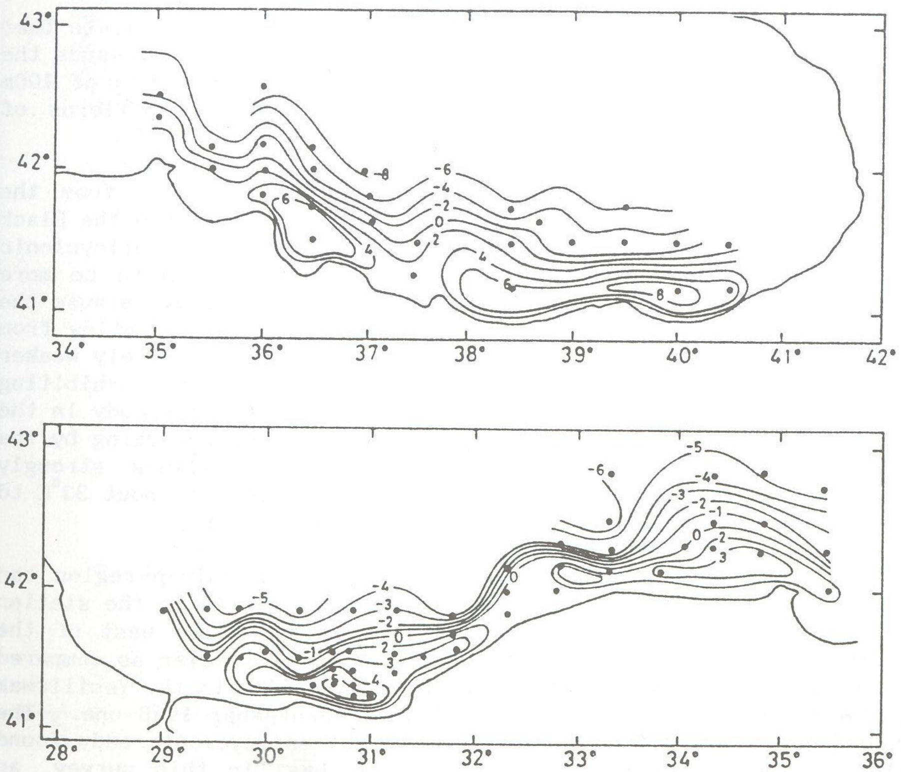

Figure 3. Continued

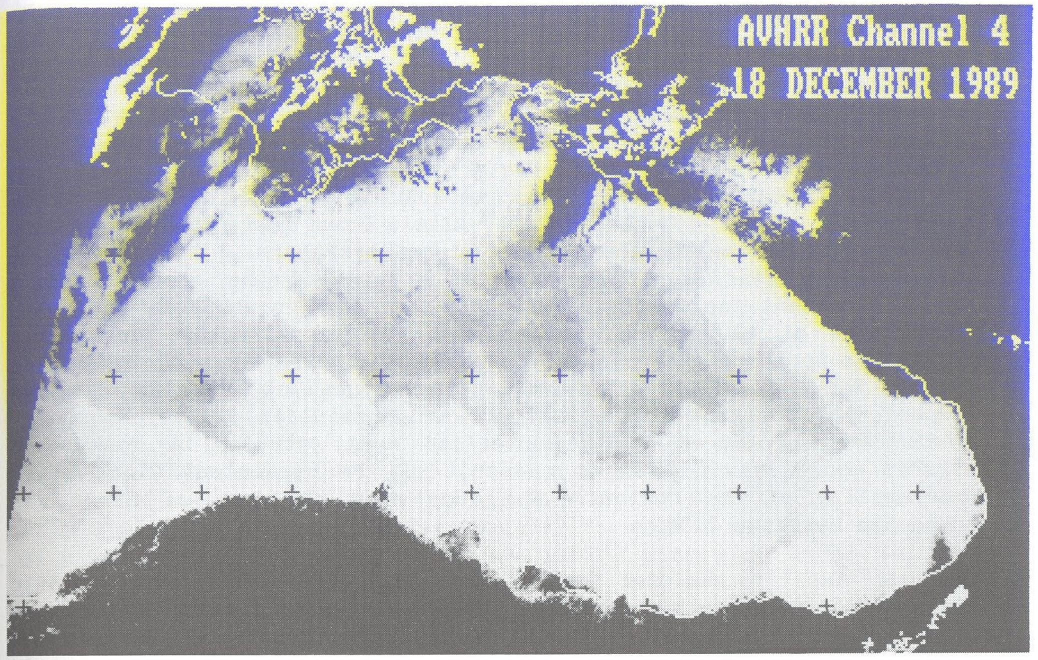

Figure 4a. NOAA AVHRR Channel 4 (thermal) image of the Black Sea for 18 December 1989. The darker areas are the colder radiated temperatures.

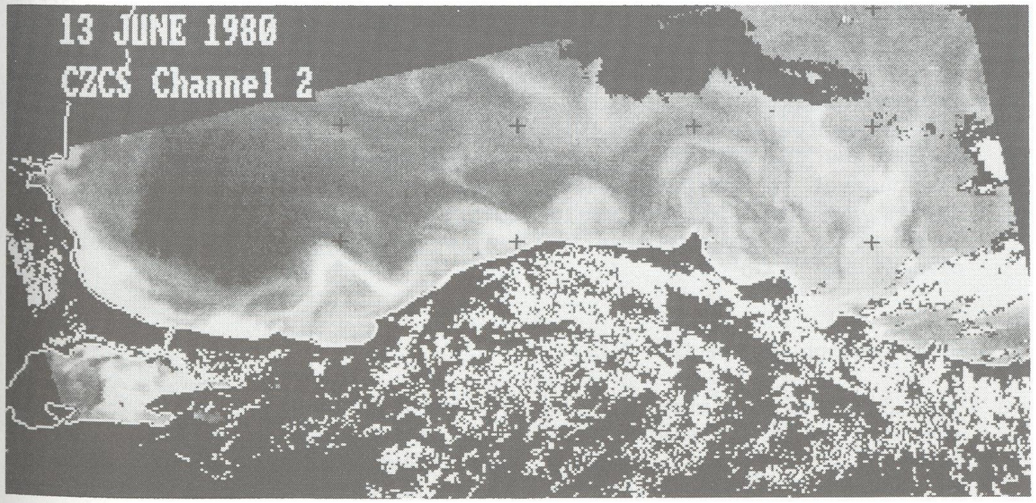

Figure 4b. NIMBUS 7 CZCS Channel 2 image of the Turkish coastal waters of the Black Sea during 13 June 1980.

The present surveys therefore show that the boundary current system meanders along the Anatolian coast and forms a series of quasi-permanent anticyclonic eddies. The eddies off the Bosphorus Strait and in the Sakarya and Kizilirmak regions apparently coincide with regions of considerable topographic variations related to the canyon type features. The topographic steering mechanism therefore appears to be an important factor in shaping the regional flow structure. While the Sakarya and Yesilirmak eddies are new features not known earlier, existence of the others have been reported in some earlier studies of the Soviet oceanographers. Hydrographic observations near the Bulgarian shelf revealed the presence of a quasi-permanent anticyclonic feature to the south of the 43°N (Trukhchev et al., 1985). This anticyclonic structure apparently forms the northern extension of the Bosphorus eddy depicted in Figures 3a-c. The eddy situated in the easternmost end of the Black Sea was reported by Sorokin (1983), Fashchuk and Ayzatullin (1986), Novaselov (1987) and repoduced in the numerical model studies by Moskalenko (1976) and Stanev (1988) as a result of the persistent wind stress variability of the region. The eddy near the Cape of Sinop was reported by Latun (1989).

In addition to the features emerging from the quasi-synoptic hydrographic data, the satellite imagery provides further details on the structural variability of the Black Sea circulation. Examples of AVHRR-infrared and CZCS imagery displying such features are shown in Figure 4a,b. The imagery investigated indicates that the circulation involves, in general, a well-defined meandering rim current and strongly interacting eddy fields confined over the shelf/slope topography. The size of the eddies ranges from sub-basin scale gyres to sub-mesoscale features interconnected with each other by jets and filaments with offshore extension of about 100 km. The features appear to evolve continuously in time through instabilities which may be generated by the vertical shear between the stronger upper layer flow advecting waters of CIL and weaker flow in the subhalocline waters and the horizontal shear originated from the weakening of the rim current in the offshore direction. Interaction of the mesoscale eddies and other smaller scale features with the mean flow is seen to lead to a highly energetic and temporally variable picture of circulation.

Distribution of the CIL Waters

An important issue of the present-day Black Sea oceanography is the apparently systematic rise observed in position of the interface separating the saltier and unoxic subhalocline waters of the Mediterranean origin from the oxygen-rich and less saline surface waters. Since the surface layer consists of the oxygen-rich waters of the CIL immediately above the interface, the distribution of the CIL may provide information on the position of the anoxic interface in response to the dynamics of the basin. Evidently, the distribution of

the oxygen-carrying CIL has important implications on the health and ecological aspects of the Black Sea.

It has been proposed that the waters of the CIL are formed in the northwestern shelf region of the Black Sea, and in the proximity of the Kerch Strait (Tolmazin 1985a) and at the centers of the cyclonic eddies found within the interior of the basin (Ovchinnikov and Popov, 1987). The process of CIL formation is closely associated with the vertical convection in the upper levels of the water column as a result of the combination of appropriate meteorological and hydrodynamical conditions. Once the CIL is formed, it is eventually advected around the basin by the general circulation.

CTD measurements carried out at an offshore station, M35T00 located at 42°35'N and 36°00'E in 14 January 1989 provide a typical example of convectively generated mixed layer formation of the cold intermediate water at the central parts of the basin. Figure 5 displays a surface mixed layer of about 60m characterized by uniform values of temperature, salinity and density of 6.8 °C, 18.5 ppt and 14.5 sigma-theta units, respectively. It should be noted that the data given by Ovchinnikov and Popov (1987) were also close to this site. The characteristic values of the temperature, salinity and density reported were 6.5-7.0°C, 18.50-18.53 ppt and 14.50-14.55 sigma-theta which are very close to the mixed layer values observed at station M35T00.

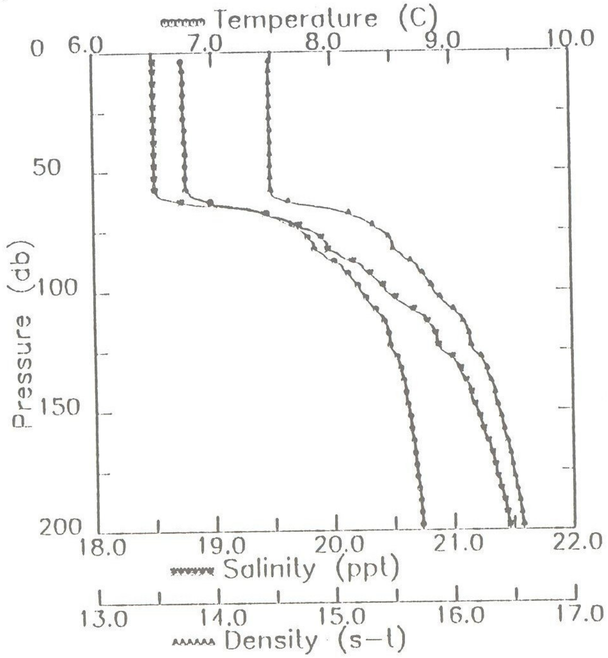

Figure 5. Temperature, salinity and density profiles representing a convectively generated winter time mixed layer formation during 14 January 1989. The data is taken at an offshore station of tha analysis region located at 42° 35'N and 36°E.

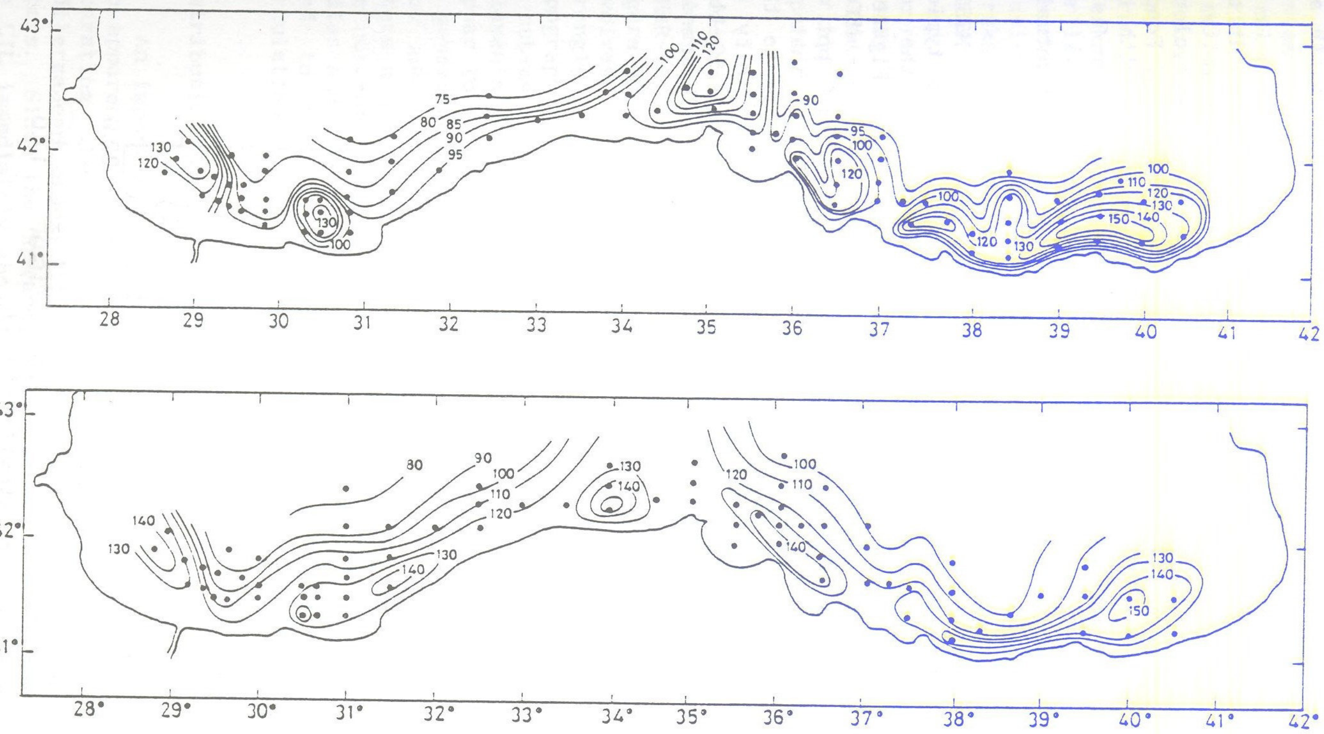

Figure 6. Topography of the 8°C temperature surface showing the horizontal distribution of the base of the CIL along the Turkish coast of the Black Sea for (a) September 1988 survey, (b) April 1989 survey.

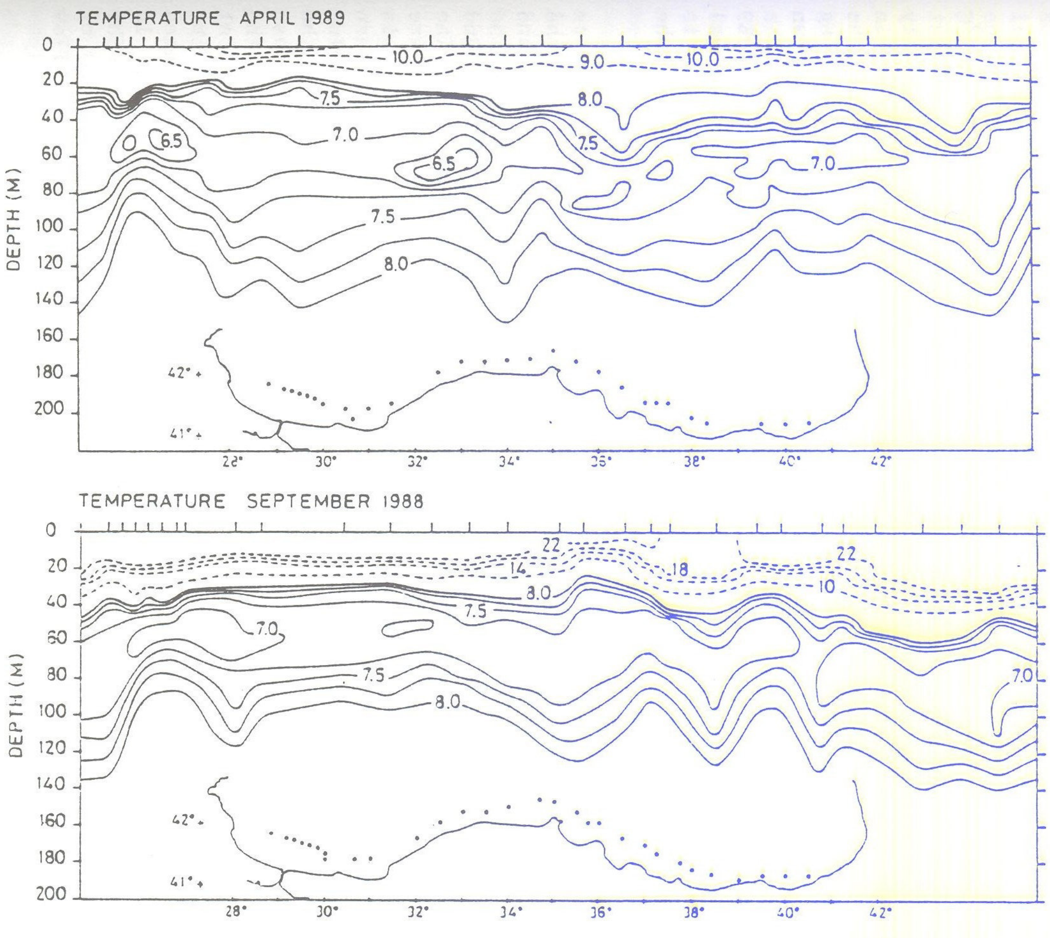

Figure 7. Vertical section of temperature along the shelf break of the Turkish coast of the Black Sea for (a) April 1989 survey, (b) September 1988 survey.

The distribution of the CIL along the Turkish coastal waters of the Black Sea appears to follow closely the pattern of regional circulation. This is clearly depicted in Figure 6a,b for the September 1988 and April 1989 surveys by means of the depth of the 8°C temperature corresponding to the base of the CIL. It is shown that the thickness of the CIL presents a considerable spatial inhomogeneity within the analysis region. It varies markedly, by more than 50m, in the offshore direction with shallower layer toward the interior. The coastally-attached anticyclonic eddies identified in the preceeding section forms the deep pools of cold intermediate water extending down to depths of about 130-150m. The thickness of the CIL has also a seasonal dependence with deeper CIL being observed in the April 1989 (winter) survey as compared to that of the September 1988 (summer) case. The deepest CIL, with depths extending down to 150m, is observed within the anticyclonic eddy found at the eastern end of the coast.

The vertical structure of the CIL along the Turkish coastal waters is further illustrated by the temperature cross sections for the September 1988 and April 1989 surveys representing the summer and winter cases, respectively. In the April 1989 survey following the winter period of new CIL formation, the CIL is relatively thicker and starts below a shallow surface waters of about 25m (Figure 7a). The CIL extends down to the depth range of 100-150m; deeper layers are found within the anticyclonic eddies. The core of the CIL is identified by the temperature values of 6.50-7.00°C in the western basin and the values greater than 7.0°C in the eastern basin. Two isolated patches of colder waters with $T \simeq 6.50°C$ are noted off the Bosphorus entrance region and between the Sakarya and Sinop eddies. As shown by the April 1989 circulation pattern (c.f. Figure 3b), the meandering peripherial flow field has sharp turns toward the coast at these two locations. Such turns in the rim current allows for the protrution of the interior waters toward the coast and associated intrusions of extra CIL waters from the interior of the basin, in addition to those transported into the region by the rim current. The region outside the Bosphorus Strait is further characterized by upwelling which takes place in response to the bifurcation of the flow as described in the previous section.

In the September 1988 case, we observe the summer conditions characterized with the reduction in the amount of the supply of newly formed CIL waters into the analyses region. This is noted in Figure 7b by the thinner and warmer CIL as compared to that of April 1989. The upper 8°C isotherm is located at deeper levels below the seasonal thermocline; at about 40m in the western and 50m in the eastern basin. The lower 8°C isotherm is found at comparatively higher levels; typically at about 100m. The core temperature values are increased as well by about 0.25-0.50°C.

Distribution of the Mediterranean Waters

The distribution of the Mediterranean waters in the Black Sea studied during the past few decades by Bogdanova (1961), Tolmazin (1985b), Yuce (1990), Latif et al. (1990). These studies, concentrated essentially on the Black Sea-Bosphorus junction region, contributed to the understanding the way in which the Mediterranean effluent disperses in the shelf. It was found that the effluent issuing from the Bosphorus Strait is transported into the Black Sea confined in a narrow channel on the sea bed essentially on a continuous basis throughout the year. The effluent, after leaving the channel, follows persistently a north-northwestern track in the shelf, spreads out as a thin layer at the bottom, becomes highly diluted and is eventually incorporated in the general circulation. There was, however, no observational study giving a satisfactory account of the Mediterranean effluent beyond the shelf break as it disperses within the interior of the basin. Bogdanova (1961) and Boguslavisky (1982) are claimed to observe warm lenses of Mediterranean water within the interior of the basin. The details of the measurements were, however, not given and the results, according to our opinion, are difficult to believe. A discussion of these findings can be found in Tolmazin (1985a).

The R/V Bilim cruises during 1987-1989 also made it possible to explore certain features of the Mediterranean effluent beyond the shelf region, immediately outside the Bosphorus Strait. It was observed consistently in all of the surveys that the Mediterranean water appears in the form of intrusions of colder and more oxygenated waters into the ambient Black Sea waters. Frontal interactions take place between the two water masses and give rise to quasi-horizontal interleavings. Such intrusive features effectively provide a mechanism for partial ventilation of the subhalocline waters.

Characterization of the Mediterranean waters by relatively lower temperature values than those of the ambient waters is an interesting feature and requires a further explanation. It was shown by Yuce (1990) and Latif et al. (1990) and will also be shown here that the Mediterranean water enters the shelf from the narrow underwater channel in the form of a warmer and saltier effluent with typical values of 12-13°C and 30 ppt. As the effluent crosses the shelf, it is subject to continuous interaction with the shelf waters of the CIL origin having temperatures of about 7.0-7.5°C. This interaction apparently causes a gradual cooling and dilution of the effluent. Figure 8a present clearly the reduction in the temperature and salinity values of the effluent from about 13°C and 35ppt at a point (station K0A) between the Bosphorus exit and the sill within the underwater channel to 8.8°C and 22.8 ppt at a station (L25L15) near the shelf break. Comparing the latter values with those at the same levels of the nearby ambient waters uninfluenced by the effluent (Figure 8b), we note a considerable modification in the characteristic of the Mediterranean underflow but it still retains the

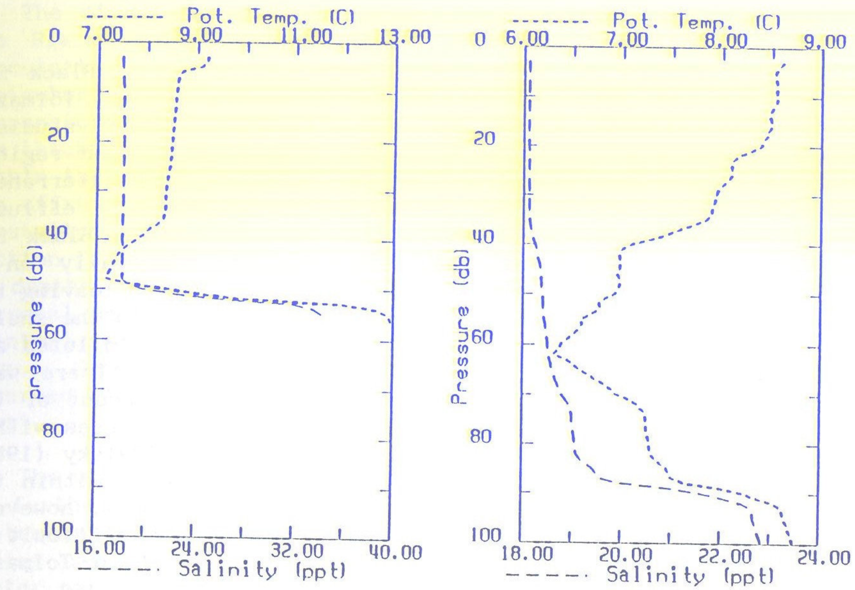

Figure 8a. Temperature and salinity profiles during April 1989 at two locations; at station KOA found immediately outside the Bosphorus exit and upstream of the sill (left) and at station L25L15 located at 41° 25'N and 29° 15'E, near the shelf break. See the location map in Figure 10 for positions of stations

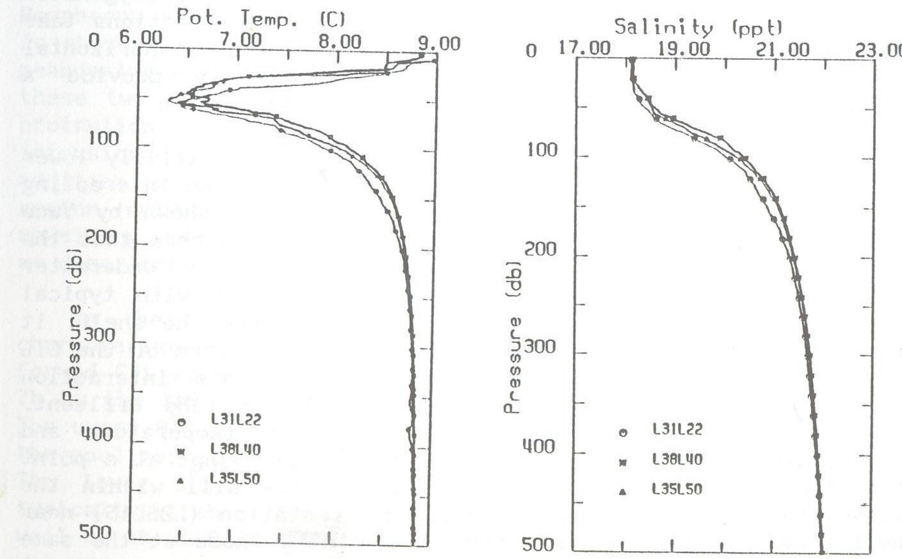

Figure 8b. Temperature and salinity profiles during April 1989 at three stations L31L22 (41° 31'N and 29° 22'E), L38L40 (41° 38'N and 29° 40'E) and L35L50 (41°35'N and 29° 50'E) located outside the Bosphorus exit. See the location map in Figure 10 for positions of stations

identity of being slightly warmer and saltier as compared to the ambient waters having T≈8.0°C and S≈20.5 ppt at the depths of 90-100m.

The shelf break region (i.e. the depths of about 100-150m) constitutes a narrow zone where a further rapid and significant transformation takes place on the characteristics of the effluent. This region in fact corresponds to the pycnocline zone of the ambient waters where the temperature and salinity decrease rapidly by about 0.5°C and 1.0ppt, respectively (Figure 8b). Interaction of the effluent with the interfacial waters of the region therefore allows for further dilution and cooling of the effluent. Consequently, an almost complete mixing is accomplished in salinity whereas the modified Mediterranean water attains slightly cooler values. This yields sinking of the effluent into the deeper levels of the basin in the form of colder patches up to its density level. The profiles presented in Figure 9 show the conditions at stations L27L30 and L25L40 located near station L25L15 typifying the conditions at the shelf break (c.f. Figure 8a). The temperature profile reveals pronounced multiple layering between 150m and 300m with temperature differences up to 0.3 °C. A signature of possibly older intrusions is also noted at deeper levels (between 300m and 500m) in the figures.

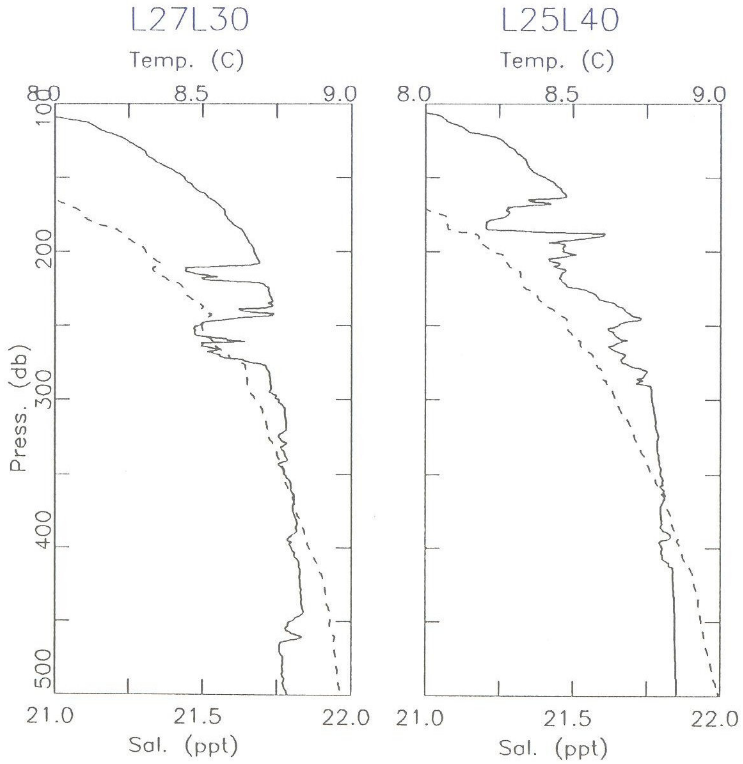

Figure 9. Temperature and salinity profiles during April 1989 at two stations L27L30 (41° 27'N and 29° 30'E) and L25L40 (41° 25'N and 29° 40'E) located near the shelf break adjacent to station L25L15. See the location map in Figure 10 for positions of stations

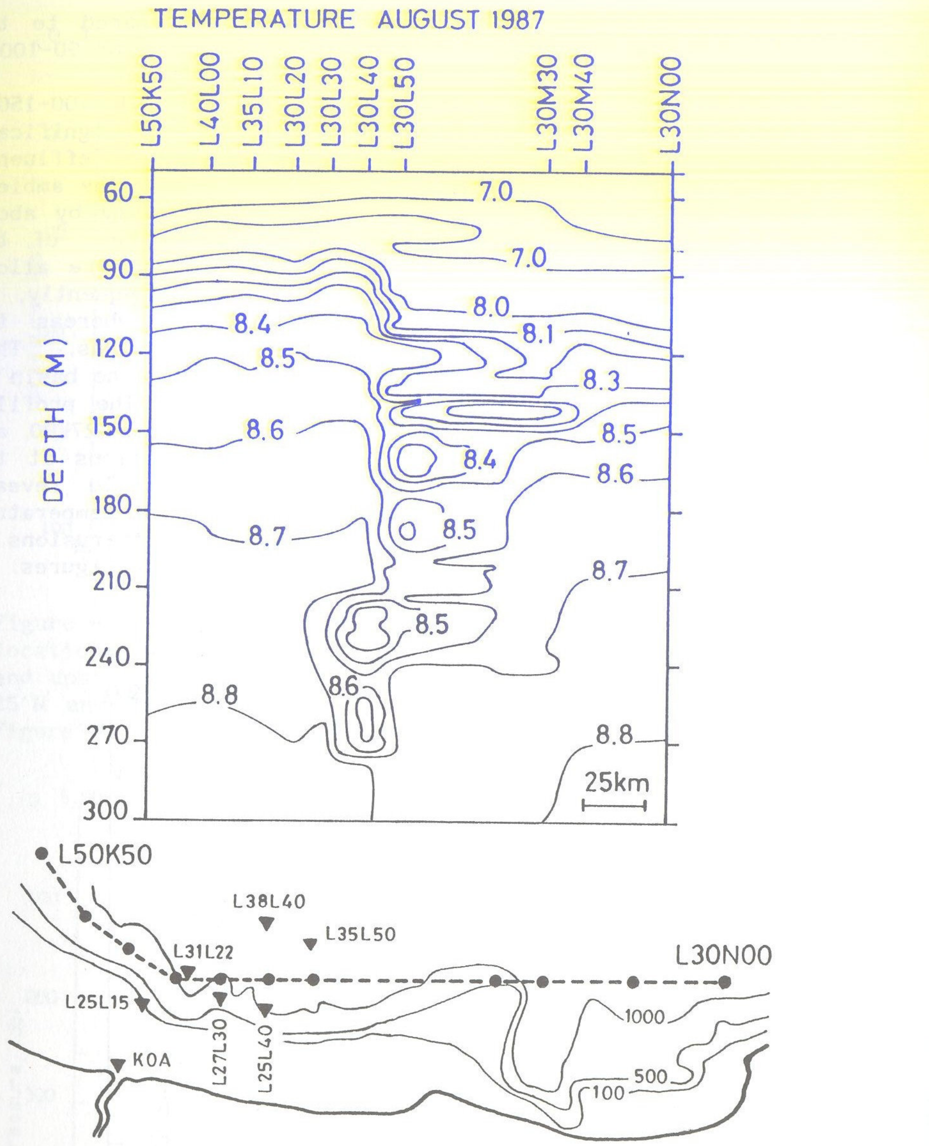

Figure 10. Temperature transect showing intrusions of modified Mediterranean water along a section of the continental slope, in the Bosphorus and Sakarya Canyons region during August 1987.

We believe the phenomenon described above constitutes the mechanism responsible for the sinking of the Mediterranean waters in the form of discrete multiple layers toward the deeper levels of the basin. The intensity and extent of the intrusions will obviously depend on the intensity of the mixing of the Mediterranean waters with the waters of the CIL and of the pycnocline immediately below. Further evidence for the intrusions and the role of a double diffusive ambient environment on the mixing processes are given by Ozsoy et al. (this volume).

Inspection of our 1987-1989 data set presents a clear evidence that intrusive structures are obiquitous beyond the shelf break to the east of the Bosphorus exit-canyon axis. We also note that most pronounced intrusions take place along the main axis of the rim current which advects the modified Mediterranean water further east, away from the Bosphorus junction region. Intrusions with different intensity and at various depths were noted in the data within the entire southwestern Black Sea waters.

The frontal interaction of Mediterranean and ambient waters and resulting quasi-horizontal interleavings are further illustrated by the temperature transect displayed in Figure 10 along a section extending across the continental slope off the Bosphorus exit region. The temperature front located close to station L30L40 separate the ambient waters from the colder waters of the Mediterranean origin intruding down to depths of 275m. Intrusions are noted to be most pronounced immediately outside the Bosphorus exit but extend toward the east up to station L20N00 located in the vicinity of the Sakarya Canyon.

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