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VERTICAL CHEMISTRY OF THE THREE DYNAMICALLY DIFFERENT REGIONS OF THE BLACK SEA

KARADENİZ'İN ÜÇ FARKLI DİNAMİK BÖLGESİNİN DÜŞEY KİMYASI

ÖZDEN BAŞTÜRK, SÜLEYMAN TUĞRUL, İLKAY SALİHOĞLU

Middle East Technical University, Institute of Marine Sciences (IMS-METU), Erdemli Icel, Turkey.

Key Words: Black Sea, chemical properties, upwelling, downwelling, rim current

Abstract

In the upper layer of the Black Sea, the vertical distributions of nutrients and dissolved oxygen display very characteristic features at specific density surfaces. Moreover, data from a survey in September 1991 indicate that the positions and magnitudes of these properties show small regional differences from the core of the cyclonic gyres towards the anticyclonic eddies established in the coastal regions. The nutricline always appeared at shallower depths but at greater density surfaces within the cyclonic gyres. The molar ratios of N:P reached peak values of as much as 100 at the upper boundary of the nitracline due to a consistent shift between the onsets of the nitracline and the phosphocline. The sub-surface phosphate minimum is a permanent feature of the cyclonic regions; however, it almost disappears in the meandering rim current, yielding lower concentrations at the depth of the deep phosphate maximum coinciding with the onset of the sulphidic waters.

Introduction

Recent investigations indicate dramatic changes have occurred in the principal biological and chemical properties of the Black Sea during last two decades due to various interacting factors. For instance, chemical pollution of the riverine inflows has resulted in intense eutrophication, especially in the northwestern and western shelf waters (Mee, 1992; Bodeanu, 1992) though the fresh water inputs have been reduced by about 50% in the last two decades (Tolmazin, 1985; Fashchuck and Ayzatullin, 1986). During the same period, the entire Black Sea ecosystem has been invaded by opportunistic organisms (Vinogradov *et al.*, 1989; Shuskina and Musaeva, 1990; Smayda, 1990). In addition to ecological changes in the productive surface layer, the upper boundary of the oxic/anoxic transition layer has risen toward the surface (Murray *et al.*, 1989; Tuğrul *et al.*, 1992).

However, since 60's the onset of sulphidic water over the deep basin has remained almost constant at about the same density surface (Tuğrul *et al.*, 1992; Saydam *et al.*, 1993; Baştürk *et al.*, 1994; Buesseler *et al.*, 1994) though its actual depth varies markedly with region (Bezberodov, 1990).

It is well known that the vertical chemistry of the Black Sea below the euphotic zone is principally determined by the variabilities in meso-scale circulations and the consequent hydrographic features. Accordingly, density dependent chemical profiles in the upper layer of the Black Sea have been found to be more informative in examining long-term, basinwide data (Murray *et al.*, 1989; Codispoti *et al.*, 1991; Tuğrul *et al.*, 1992; Oğuz *et al.*, 1991; Saydam *et al.*, 1993). However, the positions and magnitudes of the characteristic chemical features, such as the boundaries of the nutricline, oxycline, suboxic zone and the maxima and minima of phosphate and nitrate profiles, may be expected to exhibit noticeable and consistent spatial and temporal differences when density dependent profiles from hydrodynamically different regions are compared. To consider this, we here examine the basin-wide chemical data collected during the September-1991 cruise, together with the Knorr-1988 and Atlantis-1969 data sets.

Materials and Methods

Water samples were collected by rosette casts at pre-determined density surfaces. Nutrients were measured on board the R/V Bilim (IMS-Turkey) using a two-channel Technicon Autoanalyzer. Dissolved oxygen was determined by a semi-automatic Winkler titration modified slightly for low oxygen concentrations. Sampling flasks for the dissolved oxygen and hydrogen sulphide were flushed with argon gas and kept closed until the sub-sampling. Solutions containing standardized iodine solutions and sample water were titrated against the standardized thiosulfate solution as given in APHA-AWWA-WPCP Standard Methods (Greenberg *et al.*, 1985). A Sea-Bird Model-9 CTD probe provided physical data throughout HydroBlack-91 multi-ship cruise. Chemical and physical data of the R/V Knorr (USA) and R/V Atlantis (USA) cruises were taken from the reports of Friederich *et al.*, (1990) and Brewer (1971), respectively.

Results and Discussions

Spatial variabilities in the principal hydrochemical properties of the Black Sea upper layer extending down to the anoxic layer can be deduced from the comparison of composite profiles. Old and recent data sets were therefore grouped in three sub-regions, by taking into account the position of each station in terms of the dynamic height anomalies in cm at the 100 dbar level relative to the 900 dbar level (Fig. 1). The coordinates of sampling locations are listed in Table 1.

Regional Variations in the Physical Properties: Fig.1 shows that, in September 1991, there existed two cyclonic gyres in the interiors of the eastern and western basins of the Black Sea; these gyres were separated from a series of anticyclonic eddies in coastal zones by the meandering rim current which was found to be as wide as 75 km and to possess an

Figure 1. Dynamic height anomalies in cm at 100 Dbar level relative to 900 Dbar level in September 1991

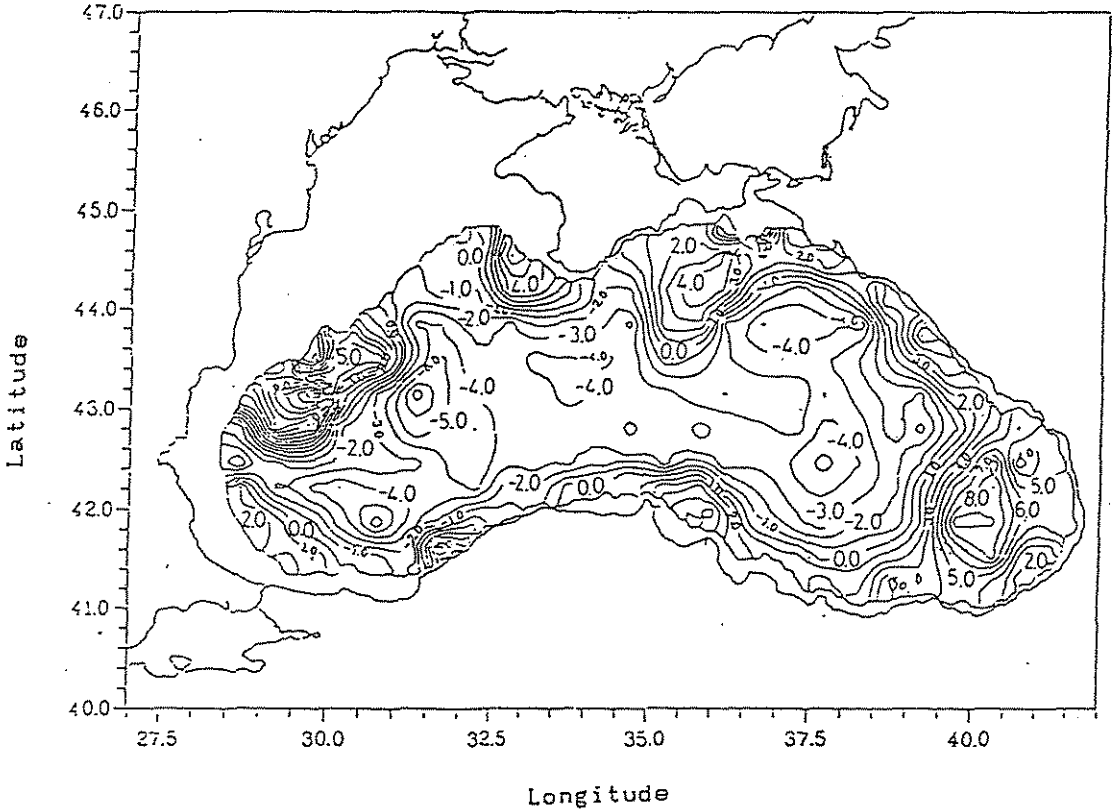


Table 1. The station names and coordinates used in the text for three different regions of the Black Sea and for three different cruises.

CYCLONIC GYRE			ANTICYCLONIC GYRE			RIM CURRENT		
Sta.	Lat.	Long.	Sta.	Lat.	Long.	Sta.	Lat.	Long
			R/V BILIM - 1991					
N30N45	43° 30'N	31° 45'E	L50Y15	41° 50'E	40° 15'E	L30W45	41° 30'N	38° 45'E
M50T45	42° 50'N	36° 45'E	L15Y15	41° 15'E	40° 15'E	L30W15	41° 30'N	38° 15'E
M10V15	42° 10'N	37° 15'E	L30X45	41° 30'E	39° 45'E	L15W15	41° 15'N	38° 15'E
M50P45	42° 50'N	32° 45'E	L30Y50	41° 30'E	40° 50'E	L32M13	41° 32'N	30° 13'E
M50N45	42° 50'N	31° 45'E	L30Y15	41° 30'E	40° 15'E	L30V45	41° 30'N	37° 45'E
M30N45	42° 30'N	31° 45'E	M10X45	42° 10'E	39° 45'E	L31V22	41° 31'N	37° 22'E
M30P15	42° 30'N	32° 15'E	L30X15	41° 30'E	39° 15'E	M19R45	42° 19'N	37° 45'E
N10R45	43° 10'N	34° 45'E	L50X15	41° 50'E	39° 15'E	L45T45	41° 45'N	36° 45'E
			R/V KNORR - 1988					
KNORR-1	41° 52'N	31° 19'E	KNORR-2	41° 31'N	40° 45'E	KNORR-3	41° 35'N	32° 00'E
			R/V ATLANTIS - 1969					
1444	43° 49'N	31° 41'N	1468	42° 00'N	40° 00'E	1431	42° 10'N	33° 00'E
1442	44° 45'N	31° 58'E	1469	41° 24'N	40° 41'E	1438	41° 58'N	35° 40'E
1446	42° 13'N	31° 29'E	1470	42° 02'N	41° 18'E	1440	42° 12'N	34° 21'E
1445	43° 08'N	31° 27'E	1477	41° 34'N	39° 03'E	1447	41° 22'N	30° 59'E

average speed of 20 cm/s in the surface layer (Oğuz *et al.,* 1993). The quasi-permanent anticyclonic Batumi eddy was located at the southeastern corner of the Black Sea where the boundary current moves offshore and the geostrophic surface currents exceed 30 cm/s (Oğuz *et al.,* 1991, 1993; Sur *et al.,* 1994).

Composite depth profiles of temperature (T), salinity (S) and potential density (σ_θ) in Fig.2 for the cyclonic, anticyclonic and meandering rim current regions permit us to collate spatial changes in the vertical distributions of these properties over the basin. In the cyclonic gyres, the T, S and σ_θ profiles of individual stations were similar below 35-40 m, whereas the profiles from the anticyclonic eddies possessed remarkable local differences down to at least 200 m depth. However, below 70-80 meters, the profiles from the meandering rim current resemble those from the cyclonic gyres. These profiles clearly demonstrate that, below the seasonal pycnocline, there exists a nearly isohaline and relatively cool, isothermal water mass of some 10 meters thickness within the anticyclonic eddies; it becomes very thin in the cyclonic gyres (Fig. 2). The thickness of this layer also determines the thickness of the Cold Intermediate Layer (CIL) defined by the upper and lower 8 °C isothermals.

Various suggestions have appeared on the formation of the CIL over the Black Sea basin (Filippov, 1965; Ovchinnikov and Popov, 1986) and its subsequent advection (Oğuz *et al.,* 1993). The Brunt-Visl frequency was reported to be minimum at the depth of the σ_θ=14.7 isopycnal surface and reached maximum value below the 14.8 surface which corresponds not only to approximate base of the temperature minimum in the CIL, but also to the upper boundary of the permanent pycnocline (Buesseler *et al.,* 1994; Murray *et al.,* 1991). Thus, one suggests that the surface layer may be homogenized down to the 14.6-14.7 isopycnal surfaces by convective mixing processes during the winter period.

Regional Variations in the Chemical Properties: The vertical distributions of nutrients (o-PO_4 and NO_3+NO_2 (TNOx)) with respect to the water density are illustrated in Fig.3 for the cyclonic, anticyclonic and the rim current systems of the Black Sea. The composite profiles from the hydrodynamically different regions exhibit characteristically similar vertical features in the intermediate water column extending from the base of the euphotic zone to the upper anoxic layer as recently emphasized by Tuğrul et al.(1992), Murray et al.(in press) and Saydam et al.(1993). However, detailed examination of these density-dependent composite profiles has led to the identification of certain spatial differences both in the positions and concentrations of the principal chemical features that consistently appear at specific density surfaces as discussed below.

Distributions of Nutrient Elements: The o-PO_4 and TNOx concentrations of the productive surface waters of the Black Sea were both less than 0.1-0.2 µM due to the assimilation by autotrophic species (Fig. 3). The nutrient deficient layer extends down to the σ_θ=14.5-14.6 surfaces in the cyclonic gyres, but only to the σ_θ=14.2-14.3 surfaces in the other two systems (Fig. 2). Accordingly, the onset of the nutricline coinciding with the permanent pycnocline was located at different density surfaces. It appeared at greater density surfaces but at relatively shallower depths (25-30m) in the cyclonic gyres than

Figure 2. Composite depth dependent variations of temperature, salinity and sigma-t within dynamically different regions of the Black Sea. (A): cyclonic, (B): anti-cyclonic and (C): rim current for September-1991 period

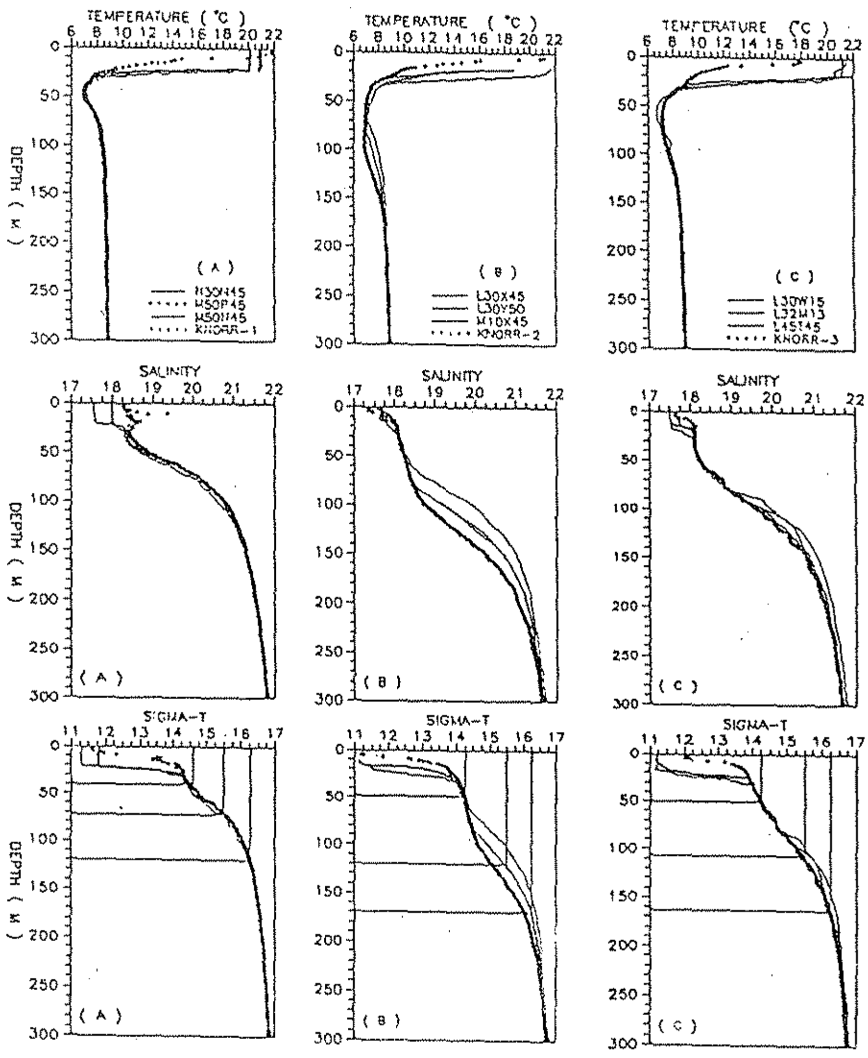
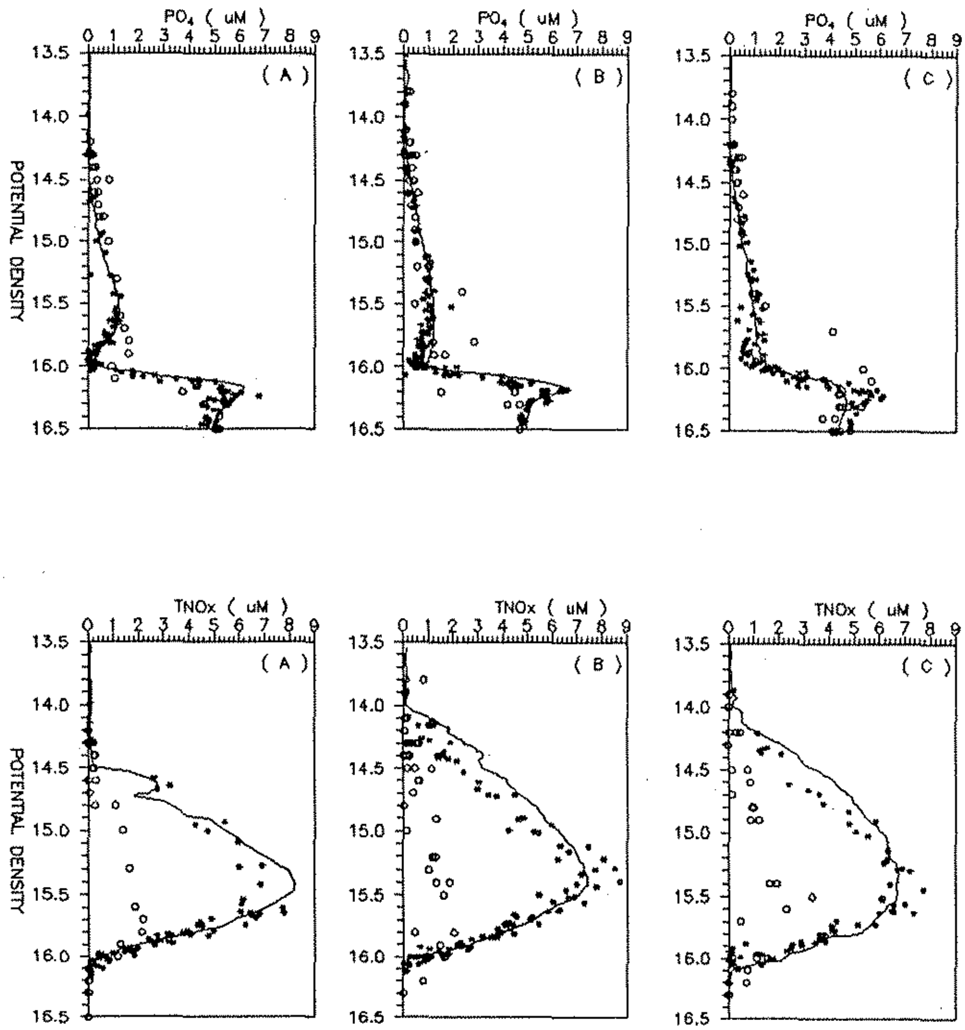


Figure 3. Composite potential density dependent variations of o-PO_4 and TNOx species within dynamically different regions of the Black Sea for (A): cyclonic, (B): anti-cyclonic and (C): rim current. (R/V Bilim (*), R/V Knorr (--) and R/V Atlantis (o))



those in the anticyclonic eddies and rim current where it was as deep as 40-60 meters (Fig. 2). Such a distinctive spatial difference in the onset of the nutricline is the result of the differences in the formation and position of the CIL in these regions. For instance, in the anticyclonic eddies, 1 μM o-PO_4 concentration was reached at about σ_θ=15.20 surface whereas it first appeared at the depth of σ_θ=15.4-15.5 surfaces within the cyclonic gyres (Fig. 3).

The sub-basin composite o-PO_4 profiles (Fig. 3) exhibit two characteristic maxima and a sub-surface minimum within the suboxic zone; the upper maximum is relatively broad, reaching to peak values between the 15.5-15.7 isopycnal surfaces in the cyclonic and anticyclonic regions. This feature almost disappears in the rim current frontal zone. Below the upper, relatively sharp maxima of the cyclonic regions, the profiles display a steep decreasing trend down to the σ_θ=15.85-15.90 surfaces. In this zone, the concentrations were as low as 0.05-0.10 μM in the core of the cyclonic gyres, but increased towards the peripheries as a result of intense vertical and horizontal mixings. Thus, the sub-surface phosphate minimum, yielding a mean of 0.21 μM for the cyclonic gyres, weakens significantly in the anticyclonic regions (0.97 μM) and becomes almost undetectable in the rim current zone, where phosphate concentrations were in the range of 1.0-1.2 μM between σ_θ=15.85-15.95 surfaces (Table 2 and Fig. 3). This minimum has been suggested to arise from the scavenging of dissolved phosphate ions by metal (primarily Fe and Mn) oxides as they sink through the oxic waters into the reductive, anoxic zone (Shaffer, 1986; Spencer and Brewer, 1971) or alternatively by dissolved Mn(II) (Tebo, 1991) and Mn(III) ions (Luther, 1991) in vertically stable systems. In fact, the contact of the sub-oxic zone with the reducing sediments of the coastal margins (Kempe *et al.,* 1991) introduces reduced Fe and Mn species to the oxic layer where the oxidized metal compounds may be expected to export more phosphate from the oxic into the anoxic layer than in the offshore waters. This suggestion is supported by the larger concentrations of particulate Mn-oxide observed within the suboxic zone of the coastal margins (Tebo, 1991). However, the strong boundary current near the Anatolian coast enhances the vertical and horizontal mixing and inhibits the development of the phosphate minimum within the suboxic zone (Codispoti *et al.,* 1991). However, it is as yet unclear what major bio-mediated chemical processes contribute to the formation of the characteristic phosphate minima within the suboxic zone of cyclonic gyres.

The phosphate concentration increases steeply within the base of the suboxic zone irrespective of location (Fig. 3); the concentrations, as low as 0.1-1.2 μM in the sub-surface minimum zone, reach to peak values of 5-7 μM at the σ_θ=16.20-16.25 surfaces and then decrease slowly in the upper anoxic waters. The maxima consistently appear at the sulphidic water boundary throughout the deep basin, probably resulting from dissolution of the phosphate-associated metal oxides in the anoxic waters (Shaffer, 1986; Codispoti *et al.,* 1991). The disappearance of the sub-surface phosphate minimum within the rim current zone, together with the lower values of the deep phosphate maxima at the sulphidic boundary, strongly suggests that a significant quantity of phosphate is exported from the upper anoxic water into the suboxic zone of the coastal waters and then were

probably advected by the meandering rim current towards the interior of the basin as was suggested by Lewis and Landing (1991).
Composite TNOx vs density profiles (Fig. 3) demonstrate that in the anticyclonic eddies and the rim current, the nitracline onset was located at the $\sigma\theta$=14.2-14.3 surfaces whereas it was at the σ_θ=14.4-14.5 surfaces within the cyclonic gyres, corresponding nearly to the base of the euphotic zone. The prominent nitrate maximum which is a permanent property of the basin were consistently established between the σ_θ=15.35-15.45 surfaces throughout the basin; the averages of the peak values were 8.00 and 7.84 µM for the cyclonic and anticyclonic regions, and 7.80 µM for the rim current (Fig. 3 and Table 2). It should be noted that the nitrate maxima were always located at the base of the oxycline where DO concentration dropped to suboxic values of 20-30 µM and the phosphate concentrations being as high as 1.06-1.14 µM (Table 2). The TNOx concentrations declined to 0.1-0.2 µM within the suboxic/anoxic transition zone and eventually to undetectable levels in the upper anoxic water.

A detailed examination of the nutrient profiles reveals a noticeable shift between the onsets of TNOx and $P0_4$ gradients. The phosphocline commenced at deeper density surfaces, a shift of about 0.1-0.2 σ_θ units, compared to the nitracline (σ_θ=14.2-14.5) for all three regions. It should also be noted that the onsets of the reactive silicate gradient (Fig. 4) coincide with the nitracline onsets for three regions. Such a consistent shift between the onsets of TNOx and o-$P0_4$ gradients always occurs within the upper CIL where the average salinity was 18.49, 18.19 and 18.21 ppt for the cyclonic, anticyclonic and rim current regions, respectively.
The depth-integrated totals of TNOx, o-PO_4 and DO and the corresponding molar TNOx:PO_4 ratios between the oxycline and the suboxic zone of the three regions are given in Table 3. The oxygen and nutrient contents of the oxycline were much larger in the anticyclonic than in the cyclonic region; it originates principally from large differences between the oxycline were much larger in the anticyclonic than in the cyclonic region; it originates principally from large differences between the oxycline (thus nutricline) thicknesses of these dynamically different regions where the peak values of chemical concentrations were comparable. The nutricline thickness increases from 30-40 m in the cyclonic to about 70-80 in the anticyclonic regions (Fig. 2). In the suboxic zone, the depth-integrated DO and o-PO_4 values were still larger in the anticyclonic regions, but the TNOx estimates appeared to be comparable (Table 3). The TNOx:PO_4 ratios estimated from the regressions in the oxycline ranged merely between 7.0 and 8.2, which were much less than the conventional Redfield Ratio of 16 estimated for the oceans. The ratio decreased to levels of 4.5-6.6. within the suboxic zone of the Black Sea due to the suppression of TNOx removal by intense denitrification over the $P0_4$ removal to the anoxic waters.

The TNOx gradient within the oxycline appeared to range from 0.207 µM/m for cyclonic gyres to 0.123 µM/m for anticyclonic eddies and 0.133 µM/m for rim current system, due to a two-fold regional difference in the nutricline thickness. Below the TNOx maxima, the nitrate depletion rate changed insignificantly with region, from an estimated 0.216 µM/m in the anticyclonic eddies to 0.227 and 0.240 µM/m for the cyclonic gyres and the rim current regions. This suggests that the TNOx losses from the suboxic zone are comparable

Table 2. Averages of saturated dissolved oxygen (SDO), dissolved oxygen (DO), o-PO_4 and TNOx concentrations andcorresponding averaged depths of the density surfaces (DDS) within dynamically different regions of the Black Sea.

POTENTIAL DENSITY SURFACE INTERVALS									
	σ_θ = 14.20 - 14.30			σ_θ = 15.35 - 15.45			σ_θ = 15.95 - 16.00		
	A	B	C	A	B	C	A	B	C
SDO	331.7	340.6	336.8	327.0	327.1	327.2	321.8	321.8	321.9
DO	323.4	279.8	261.6	21.7	30.2	21.7	3.7	3.3	4.9
o-PO_4	0.02	0.02	0.01	1.07	1.06	1.14	0.21	0.97	1.20
TNOx	0.14	1.23	1.16	8.00	7.84	7.80	1.29	0.93	0.97
DDS	28-32	46-62	40-47	67-69	121-124	90-96	95-99	154-157	119-124

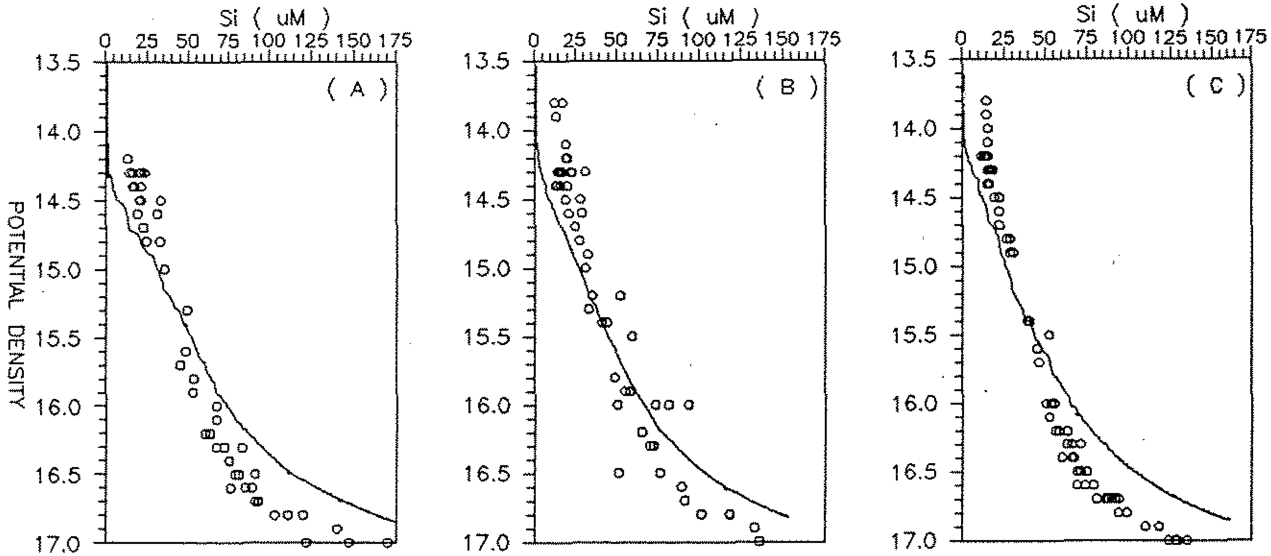
(A): Cyclonic gyre, (B): Anticyclonic gyre, (C): Rim current

Table 3. Depth integrated totals of dissolved oxygen (DO), o-PO_4 and TNOx concentrations within σ_θ =14.30-15.40 and σ_θ =15.41-15.95 isopycnal surfaces for different dynamic regions of the Black Sea (All are in units of x 10^{-3} moles.m^{-2})

	σ_θ = 14.30 - 15.40			σ_θ = 15.41 - 15.95		
	A	B	C	A	B	C
DO	3371.7	7494.1	4837.0	298.8	602.3	391.2
PO_4	12.4	23.9	21.3	19.9	27.3	28.3
TNOx	86.9	196.1	151.3	130.8	143.7	128.3
N/P	7.0	8.2	7.1	6.6	5.3	4.5

(A): Cyclonic gyre, (B): Anticyclonic gyre, (C): Rim current

Figure 4. Composite potential density dependent variations of silicate within dynamically different regions of the Black Sea for (A): cyclonic, (B): anti-cyclonic and (C): rim current. (R/V Bilim (*), R/V Knorr (--) and R/V Atlantis (o))



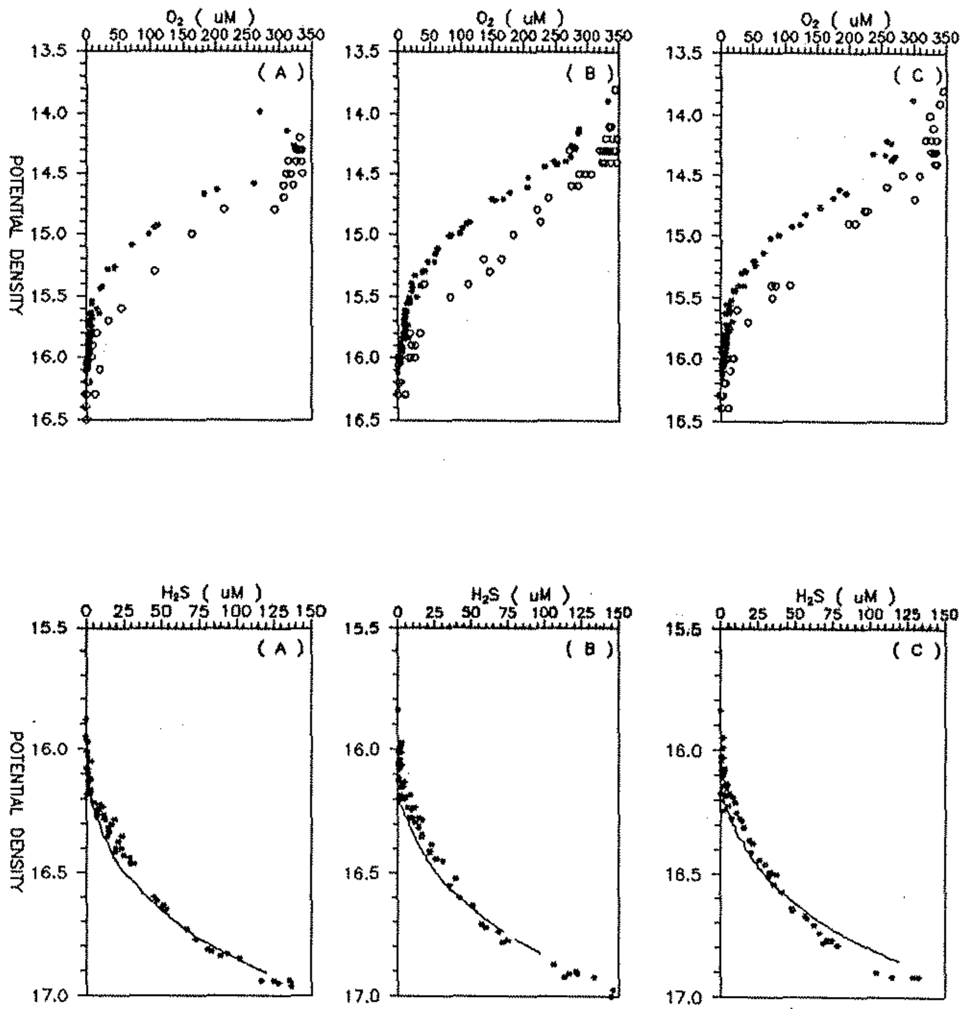
throughout the basin, whereas the phosphate gradient changes markedly with region due to the spatial variability in the redox-dependent processes. Light transmittance data measured during the Knorr-88 and Bilim-91 cruises support this suggestion because regionally varying intensities of minima were recorded within the anoxic interface, indicating the existence of a fine particle layer between 15.95-16.20 surfaces. The pronounced transmission minima in the rim current zone have most probably originated from the resuspension of sedimentary particles by vertical mixing and horizontal advection induced by the strong boundary currents attached to the coastal zone which in turn prevent the formation of the sub-surface phosphate minimum (Kempe *et al.*, 1991).

Dissolved Oxygen and Hydrogen Sulphide: Sub-basinwide dissolved oxygen profiles (Fig. 5) indicate that the DO concentrations, ranging between 250-350 μM in the productive surface layer, decreased steeply to suboxic values of 20-30 μM at the 15.4-15.5 density surfaces where the nitrate maximum was established (Table 2). However, the upper boundary of the oxycline was observed at greater density surfaces (σ_θ=14.4-14.5) within the cyclonic gyres whereas it was established just below σ_θ=14.2-14.3 within the anticyclonic eddies and the rim current region. These surfaces are naturally expected to define the nutricline onset. Because of the spatial shift in the onset of the oxycline, the DO gradients estimated from the composite profiles in Fig. 5 change markedly with region, from 7.94 μM/m within the cyclonic to 3.57 μM/m for the anticyclonic regions and to 4.60 μM/m for the rim current. Because of insufficient ventilation, the DO concentrations decline slowly from 20-30 μM at the base of the main oxycline (σ_θ=15.4-15.5) to <5 μM at the 15.9-16.0 isopycnal surfaces, with the lower gradient values in a range between 0.84-0.93 μM/m for the anticyclonic and the rim current regions and of 0.61 μM/m for the cyclonic region. This oxygen-poor water mass defines the boundaries of the suboxic zone extending from the main oxycline at σ_θ=15.4-15.5 surfaces to the sulphidic water onset at σ_θ=16.15-16.20 surface throughout the deep basin.

The changes in the molar ratios of AOU:N:P estimated from the averages given for the σ_θ=14.2-14.3 and σ_θ=15.35-15.40 density surfaces (Table 2) are 283:7.5:1 and 227:6.4:1 for the cyclonic and anticyclonic regions, respectively, and 195:5.9:1 for the rim current. These ratios differ significantly from the conventional estimates of 175:16:1 for the deep ocean (Takahashi *et al.*, 1985). In other words, besides oxygen losses due to the oxidation of organic matter, losses from the thin oxycline to the suboxic zone by diffusive processes are much larger in the cyclonic gyres than in the anticyclonic eddies. However, in the rim current frontal zone, such losses are compensated by oxygen inputs from the upper, oxic layer. Comparison of ratios also reveals that the nitrate losses from the nutricline exceed the phosphate removal even though the chemical composition of biogenic particles deviates to some extent from the Redfield ratio as observed in the Sea of Marmara fed by the surface inflow from the western Black Sea (Polat, 1995).

Although the ratios of the AOU:TNOx between 14.2 and 15.4 density surfaces are nearly the same, 38:1, 36:1 and 33:1 for cyclonic, anticyclonic and rim current regions, they differ significantly between the 15.4 and 16.0 surfaces where the lowest value (1.9:1) was observed in cyclonic gyres compared to those in anticyclonic (3.2:1) and rim current

Figure 5. Composite potential density dependent variations of dissolved oxygen and hydrogen sulfide within (A): cyclonic, (B): anti-cyclonic and (C): rim current regions of the Black Sea. (R/V Bilim (*) and R/V Knorr (--))



regions (3.1:1), implying that the nitrogen removal by the denitrification processes exceeds that of oxygen. In other words, the main oxidant for the oxidation of reduced species, such as Fe(II), Mn(II), H_2S and even NH_4 diffusing from the anoxic zone, as was suggested by Murray *et al.*, (in press), is the TNOx rather than very low levels of dissolved oxygen.

Composite profiles of H_2S derived from the titrimetric measurements are illustrated in Fig. 5, together with the high-precision data of the Knorr-88 cruise obtained by continuous profiling system. Comparison of profiles strongly suggests that concentrations from the HydroBlack-91 cruise were consistently overestimated by at least 5 μM within the low-lying anoxic waters due to inadequate estimation of the system blank in the anoxic transition layer. According to HydroBlack-91 data, the sulphidic water with a concentration of 3-5 μM H_2S first appears at the 16.10-16.15 isopycnal surfaces whereas it was recorded consistently at nearly σ_θ16.2 surface during the Knorr-88 cruise throughout the deep basin. Between the 16.10-16.15 and 16.30 isopycnal surfaces, the mean gradients of the composite H_2S profiles were estimated as 0.73 μM/m for the cyclonic, 0.58 μM/m for the anticyclonic and 0.51 μM/m for the rim current frontal zones (including the uncertainty arising from analytical artifacts), whereas the Knorr-88 data indicate much less regional differences in the H_2S gradients in the upper anoxic waters.

Özet

Karadeniz üst tabaka sularında besin tuzları ve çözünmüş oksijen konsantrasyonlarının düşey dağılımları belirli yoğunluk (σ_θ) yüzeylerinde özgün dağılım özellikleri göstermektedir. Eylül-1991 saha çalışmalarının sonuçlarından, bu özelliklerin büyüklük ve düşey konumlarının, siklonik bölge merkezlerinden kıyısal bölgelerde gözlenen anti-siklonik bölgelere gidildikçe bazı bölgesel farklılıklar gösterdiği; yine besin tuzlarının, siklonik döngülerde anti-siklonik döngülere oranla daima daha sığ derinliklerde fakat daha yüksek σ_θ değerlerinde artmaya başladığı anlaşılmaltadır. Molar N/P oranları, nitraklin (nitracline) tabakası üst kesimlerinde tepe değerlerine ulaşmakta olup bu oran bazen 100'u aşabilmektedir. Sözkonusu tepe değerleri, nitraklin ve fosfoklin tabakalarının başlangıç yoğunluk yüzeyleri arasındaki 0.1 σ_θ birimlik kaymadan kaynaklanmaktadır. Yüzey-altı tabakada gözlenen PO_4-minimum tabakasının siklonik bölgelerde belirgin bir şekilde gözlenmesine rağmen, bu tabaka oluşumu anti-siklon bölgelerinde azalmakta, kıyısal akıntı (Rim current) bölgesinde, anoksik tabaka üst sınırının (σ_θ=16.15-16.20) gözlenen PO_4-maksimumundaki azalmaya paralel olarak, tamamen yok olmaktadır.

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