

SOME REMARKS ON THE REMOVAL RATES OF H₂S WITHIN THE SUBOXIC ZONE OF THE BLACK SEA

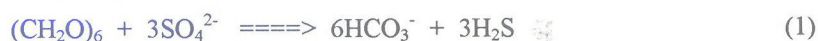
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Abstract. This work constitutes an initial effort for studying the removal and/or oxidation rates of hydrogen sulfide at different surfaces of the suboxic zone of the Black Sea. The measurements were made by mixing waters from the suboxic zone ($\sigma_\theta=15.70-16.20$) and from the upper layer of the anoxic zone ($\sigma_\theta=16.50$). The half-life of H₂S removal within the interior of cyclonic gyre was found to be twice that measured in the rim current region close to the Bosphorus northern exit, whereas the largest half-lives were measured in the anticyclonic eddy. Fine particle layer (FPL), as displayed by minima in the % light transmission, was also studied for the vertical distributions of particulate iron and manganese. In the cyclonic system, the FPL was not as pronounced as in the anticyclonic eddy. The concentrations of particulate Fe & Mn were also determined in order to visualize the mutual interactions between particulate forms of iron, manganese and hydrogen sulfide, in samples which were filtered through 1.2 μ m microfiber filters.

1. Introduction

Whenever the rate of supply of oxygen in a natural body of water can not cope with its consumption rate in organic matter oxidation, redox gradients which control the distribution of many major and minor elements in natural environments, develop, and reducing conditions occur. Formation of H₂S occurs in a variety of natural waters by catalytic actions of sulfate-reducing bacteria under anaerobic conditions during oxidation of sinking organic matter through sulfate reduction by a simple equation :



Oxic/anoxic boundaries of the stagnant, land-locked basins, especially that of the Black Sea have been of great interest to marine chemists because of its complicated chemistry and the opportunities offered for studying the redox processes which modify the speciation of many elements. A set of possible oxidation-reduction half reactions that may occur in the oxic/anoxic interface region are given in Table 1. Electron free

energy levels (Figure 1) of oxidized and reduced forms of oxygen, nitrogen, sulfur, carbon, manganese and iron can be calculated by using those half-reactions (Table 1).

TABLE 1. Set of possible oxidation-reduction reactions in the oxic/anoxic interface [1]

Reaction	pe^0	pe^0_w
$1/4 O_2(g) + H^+ + e^- = 1/2 H_2O$	20.75	13.00
$1/5 NO_3^- + 6/5 H^+ + e^- = 1/10 N_2(g) + 3/5 H_2O$	21.05	11.75
$1/2 NO_3^- + H^+ + e^- = 1/2 NO_2^- + 1/2 H_2O$	14.15	6.40
$1/2 MnO_2(s) + 2H^+ + e^- = 1/2 Mn^{2+} + H_2O$	20.80	5.30
$1/8 NO_3^- + 5/4 H^+ + e^- = 1/8 NH_4^+ + 3/8 H_2O$	14.90	5.21
$1/6 SO_4^{2-} + 4/3 H^+ + e^- = 1/48 S_8(col) + 2/3 H_2O$	5.90	-4.43
$1/8 SO_4^{2-} + 9/8 H^+ + e^- = 1/8 HS^- + 1/2 H_2O$	4.25	-4.47
$1/16 S_8(col) + 1/2 H^+ + e^- = 1/2 HS^-$	-0.80	-4.68
$1/6 N_2 + 4/3 H^+ + e^- = 1/3 NH_4^+$	4.68	-5.65
$Fe(OH)_3(am) + 3 H^+ + e^- = Fe^{2+} + 3 H_2O$	16.00	-7.25
$1/4 CO_2(g) + H^+ + e^- = 1/4 CH_2O + 1/4 H_2O$	-0.20	-7.95

NOTE: The equilibrium constants ($pe^0 = 1/n \log K$) are taken from Morel [1]. The pe^0_w (pH=7.75) values have been calculated for a pH value representative of the oxic/anoxic interface in the Black Sea[2]

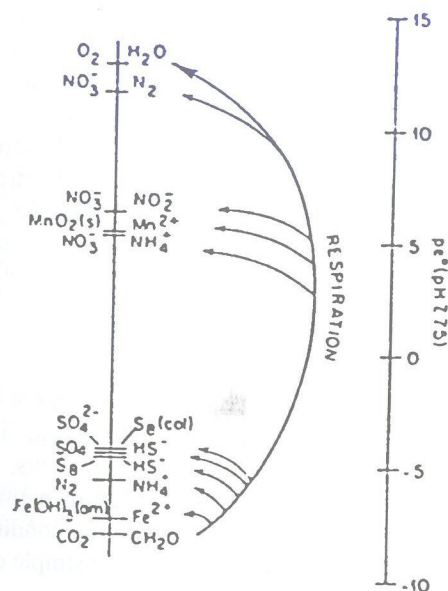


Figure 1. Electron free energy levels calculated for the approximate pH of the oxic-anoxic interface of the Black Sea (pH=7.75). Dissolved species other than H^+ are assumed to have unit activity. The strongest oxidants are at the top, and strongest reductants are at the bottom. Such diagrams are a simple way to evaluate the feasibility of redox reactions. For example, ammonia and Mn^{2+} oxidation by nitrate may be feasible, but the actual free energy available will depend on the in-situ concentrations at the site of reaction. All such reactions are, most likely, mediated by bacteria. The vertical separation of the different oxidants from organic matter (CH_2O) is proportional to the energy available from the different respiration reactions [3].

Such diagrams illustrating the ideal sequence of chemical species which may be observed in an unperturbed system at equilibrium were first introduced by Stumm and Morgan [3]. It is usually not possible to observe this ideal sequence of redox species, as predicted in Figure 1, due to the low resolution of redox reactions. Although the biochemical oxidation of H_2S within the transition zone of the Black Sea has been studied by many workers [4-9], there are still many questions about the spatial and temporal variations in the properties of the oxic/anoxic transition zone. Solution of these problems depends, particularly, on the accuracy of the H_2S determination and on the oxidation kinetics of it.

Oxidation of H_2S within the suboxic waters of the Black Sea has been attributed to the direct oxidation by MnO_2 (s) and possibly by $FeOOH$ (s) formed by bacteria in overlying oxic waters [8]. Luther *et al.*, [9] proposed that dissolved $Mn(III)$ was responsible. Sulfide loss experiments done by Luther *et al.* [9] also suggested the abiotic, rather than biotic, oxidation of H_2S in the suboxic zone of the Black Sea. They also suggested that the mechanism of sulfide oxidation is based on the ligand-centered oxidation of $Mn(II)$ (Richert *et al.*, 1988 cited in [9]), since only "metal-complexed" forms of sulfide, especially as MnS , are observed at the top of the sulfidic zone. On the other hand, Millero [8] claims that the faster removal rates of H_2S are largely due to the oxidation of Fe^{2+} that forms particulate $Fe^{3+} O_2^-$ radical and possibly $FeHS^+$ which accelerate the oxidation of H_2S .

In this work, removal rates of hydrogen sulfide, not directly by free dissolved oxygen, but by in-situ redox sensitive elements present at different isopycnal surfaces within the suboxic layer of the Black Sea were studied.

2. Materials and Methods

In order to understand the contributions of the biochemical mechanisms and possible spatial variations in the rates of H_2S removal processes, a series of field measurements were made within the suboxic zones of the dynamically different regions of the Black Sea during March-April and September-October, 1995 cruises of R/V Bilim (IMS). The studied stations are M07W45 (42° 07'N-38° 45'E) within the cyclonic gyre, L50Y45 (41° 50'N-40° 45'E) within the anticyclonic eddy and station L32L29 (41° 32'N-29° 29'E) within the meandering rim current.

Sulfide containing waters sampled from the 16.50 σ_θ surface were mixed immediately in serum bottles, which were pre-flushed with argon gas and sealed with aluminum capped silicon septa, with the waters of low H_2S concentration ($<0.5 \mu M$) taken from different density surfaces of the suboxic zone (between $\sigma_\theta=15.70$ and 16.20 surfaces) of each region. Sample transfer to serum bottles were made directly into the sealed bottles through silicon tubing attached to a large cannula. The ratio of $\sigma_\theta=16.50$ surface water to that of suboxic layer was kept constant for attaining about 10 μM initial sulfide concentration within the sample bottles. Sulfide concentrations in each set of serum bottles were measured immediately by the spectrophotometric method of Cline [10] to obtain initial sulfide concentrations. The rest of the sample bottles, which

were kept at a constant temperature, were analyzed at definite time intervals. Results of these oxidation experiments are summarized in Table 2.

In order to determine particulate iron and manganese concentrations, 5 liters of sea water samples were filtered through 1.2 μm microfiber filters by vacuum filtration immediately after collection. These filters were put in petri dishes and kept refrigerated until analysis. Filtered samples were digested at around 120 $^{\circ}\text{C}$ and then were analyzed for their particulate trace metal contents by GBC-906 model automatic atomic absorption spectrophotometer (AAS) equipped with an auto-sampler and the signal output is routed to a computer.

Dissolved oxygen concentrations were determined by using recently modified conventional Winkler titrations [11].

3. Results and Discussions

3.1. REMOVAL AND/OR OXIDATION OF H_2S

The rate of oxidation of hydrogen sulfide in an air saturated solution was found to be first order

$$d[\text{H}_2\text{S}]_T/dT = -k_1[\text{H}_2\text{S}]_T \quad (2)$$

with respect to $[\text{H}_2\text{S}]_T$ [8]. By using concentration values shown in Table 2, changes in sulfide concentrations of the mixtures $\{\ln [\text{H}_2\text{S}] / [\text{H}_2\text{S}]_0\}$ were plotted as a function of time in Figure 2 for each region. Here, $[\text{H}_2\text{S}]$ represents the hydrogen sulfide concentration at time t and $[\text{H}_2\text{S}]_0$ at the initial time (the concentration immediately after mixing). The half-lives of H_2S removal processes for the individual mixtures were calculated by inserting the slopes of the curves, which are the rate constants (k_1 , min^{-1}) displayed in Figs. 2a-c, into equation

$$t_{1/2} = 0.693/k_1 \quad (3)$$

Field measurements for the H_2S removal rates within the suboxic zones of dynamically different regions of the Black Sea showed that the removal rates through biochemical processes in the interior of the anticyclonic eddies are slow and variable, depending on the density surface ($t_{1/2} = 2.3 - 15.4$ hours), compared to those measured in the cyclonic gyre ($t_{1/2} = 2.5 - 3.4$ hours). The shortest half-lives were measured at the station located within the meandering rim current ($t_{1/2} = 1.2 - 1.3$ hours) (see Table 3). Factors responsible for these different oxidation and/or removal rates are not known exactly at present. However, the possibility of direct oxidation by the dissolved oxygen (schematically described by the reactions; $\text{H}_2\text{S} + 1/2 \text{O}_2 \rightarrow \text{S}^0 + \text{H}_2\text{O}$ and $\text{H}_2\text{S} + 2\text{O}_2 \rightarrow \text{SO}_4^{2-} + 2\text{H}^+$) diffusing from the overlying oxic zone seems to be very low or, the half-life is independent of dissolved oxygen concentration (DO), because our findings for the suboxic zone of the cyclonic gyre ($t_{1/2} = 2.8$ hours) having DO concentrations less than 50 μM were similar to those reported by Millero [8] who found 2.2 ± 0.2 hours for the rate of the H_2S removal and/or oxidation in an saturated sea water (150 $\mu\text{M} < \text{DO}$

$< 200 \mu\text{M}$). Similar measurements of Luther *et al.* [9] and Jorgensen *et al.* [12] indicated that the oxidation of H_2S in the anoxic interface of the Black Sea occurs without consuming oxygen.

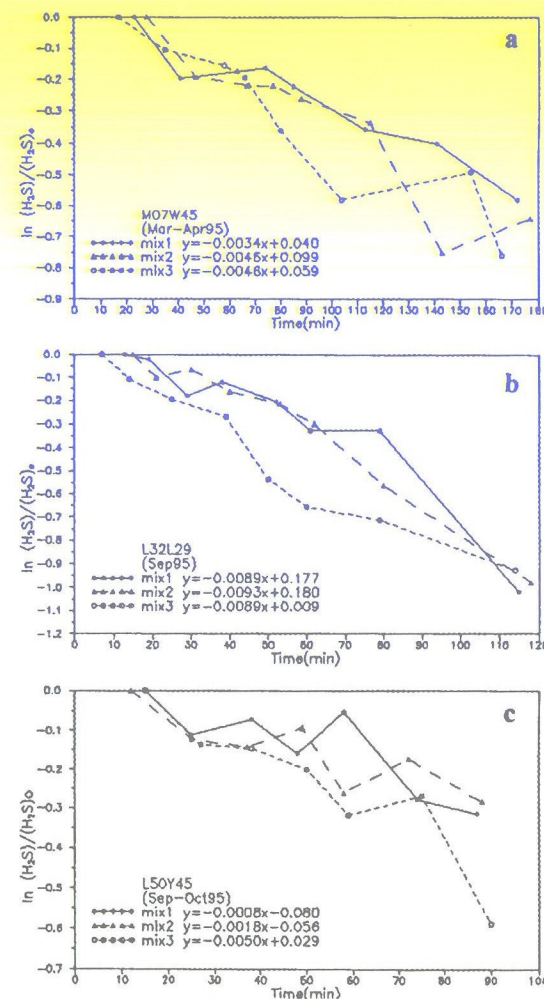


Figure 2. Change in H_2S concentration as a function of time (a) in cyclonic, (b) in rim current, (c) in anticyclonic regions of the Black Sea

Interestingly, in the interior of the Batumi anticyclonic eddy (Station L50Y45), the shortest half-life for H_2S removal processes was measured in the sea water mixture from 16.50 and 15.95 density surfaces (Mixture-III, see Table 3).

Although dissolved oxygen concentrations of water masses from 15.95, 16.00 and 16.10 σ_θ surfaces were very low and comparable (2-6 μM) (Table 4), large differences observed between the rates of three mixtures imply that DO concentration has no direct

TABLE 2. Time-dependent variations in the hydrogen sulfide concentrations in the sea water mixtures of different density surfaces (*): in March-April, 1995 (#): in September-October, 1995 cruises of R/V Bilim.

Sta. M07W45 (*)	Mixture I (16.05+16.50)		Mixture II (15.85+16.50)		Mixture III (15.70+16.50)	
	Time (min)	H ₂ S (μ M)	Time (min)	H ₂ S (μ M)	Time (min)	H ₂ S (μ M)
	23	10.0	28	9.1	17	9.0
	41	8.2	47	7.5	35	8.1
	63	8.4	67	7.3	58	7.7
	74	8.5	77	7.3	66	7.4
	85	8.0	88	7.0	80	6.3
	113	7.0	115	6.5	104	5.0
	141	6.7	143	4.3	154	5.5
	172	5.6	177	4.8	166	4.2

Sta. L32L29 (#)	Mixture I (16.10+16.50)		Mixture II (16.00+16.50)		Mixture III (15.90+16.50)	
	Time (min)	H ₂ S (μ M)	Time (min)	H ₂ S (μ M)	Time (min)	H ₂ S (μ M)
	13	9.7	15	9.3	7	10.6
	19	9.5	21	8.4	14	9.5
	29	8.1	30	8.7	25	8.7
	38	8.6	40	7.9	39	8.1
	52	7.9	53	7.5	50	6.2
	61	7.0	62	6.9	60	5.5
	79	7.0	80	5.3	79	5.2
	115	3.5	118	3.5	114	4.2

Sta. L50Y45 (#)	Mixture I (16.10+16.50)		Mixture II (16.00+16.50)		Mixture III (15.95+16.50)	
	Time (min)	H ₂ S (μ M)	Time (min)	H ₂ S (μ M)	Time (min)	H ₂ S (μ M)
	15	11.5	12	11.3	15	11.0
	25	10.3	25	10.0	27	9.6
	38	10.7	37	9.8	38	9.5
	48	9.8	48	10.3	50	9.0
	58	10.9	58	8.7	59	8.4
	74	8.7	72	9.5	75	8.4
	87	8.4	88	8.5	90	6.1

contribution to the removal and/or oxidation rates of H₂S. This is confirmed by a simple one-dimensional vertical exchange model of Murray *et al.* [13], who suggested that the upward flux of sulfide into the suboxic zone is not oxidized by oxygen. Instead, the most probable factors for sulfide removal within the suboxic zone of the Black Sea

are the presence of particulate iron and manganese species (settling Mn and Fe oxides) and/or microbial oxidation processes (anaerobic oxidation of sulfide during phototrophic reduction of CO₂).

TABLE 3. H₂S removal rate constant (k_1) and half-life ($t_{1/2}$) for dynamically different regions of the Black Sea

STATION M07W45			
	Mixture-I ($\sigma_\theta=16.05+\sigma_\theta=16.50$)	Mixture-II ($\sigma_\theta=15.85+\sigma_\theta=16.50$)	Mixture-III ($\sigma_\theta=15.70+\sigma_\theta=16.50$)
$k_1(\text{min}^{-1})$	3.4×10^{-3}	4.6×10^{-3}	4.6×10^{-3}
$t_{1/2}(\text{h})$	3.40	2.51	2.51
Average half-life=2.80 h			

STATION L32L29			
	Mixture-I ($\sigma_\theta=16.10+\sigma_\theta=16.50$)	Mixture-II ($\sigma_\theta=16.00+\sigma_\theta=16.50$)	Mixture-III ($\sigma_\theta=15.90+\sigma_\theta=16.50$)
$k_1(\text{min}^{-1})$	8.9×10^{-3}	9.3×10^{-3}	8.9×10^{-3}
$t_{1/2}(\text{h})$	1.30	1.24	1.30
Average half-life=1.28 h			

STATION L50Y45			
	Mixture-I ($\sigma_\theta=16.10+\sigma_\theta=16.50$)	Mixture-II ($\sigma_\theta=16.00+\sigma_\theta=16.50$)	Mixture-III ($\sigma_\theta=15.95+\sigma_\theta=16.50$)
$k_1(\text{min}^{-1})$	7.5×10^{-4}	1.8×10^{-3}	5.0×10^{-3}
$t_{1/2}(\text{h})$	15.40	6.42	2.31
Average half-life=8.04 h			

As seen in Figure 3, the particulate manganese profile displaces a maximum within the suboxic/anoxic interface where the particulate iron does not show such a coherent distribution. The possibility of particulate manganese for being a potential oxidant for the hydrogen sulfide is higher than that of particulate iron since its concentration is larger than concentration of iron. Although standard electrode potentials of both particulate manganese and iron are high enough to oxidize hydrogen sulfide, manganese has priority as compared to iron (see Figure 1).

At station L32L29 located in the meandering rim current, particulate manganese concentrations were relatively low (5-30 nM) within the suboxic layer, compared to those at stations M07W45 and L50Y45 (see Table 4). Interestingly the half-life of H₂S removal was found to be shortest at this station where the particulate Mn does show a maximum in the upper anoxic zone but not within at suboxic/anoxic interface. The Mn peak was located at around 16.15 surface at the station (L50Y45) within the anticyclonic eddy (see Figures 3,4). The deep particulate manganese maximum at around 16.40 isopycnal surface at station L32L29 indicates that there exists a detectable

TABLE 4. Suspended iron and manganese concentrations at selected stations (*) Visited during March-April, 1995 (#) Visited during Sept.-Oct., 1995 cruises of R/V Bilim

Station	Depth (m)	σ_θ	Fe (nM)	Mn (nM)	DOW (μM)	H ₂ S (μM)
M07W45*	87	15.60	75.83	10.35	44.40	<0.5
	91	15.70	67.91	57.48	23.72	<0.5
	100	15.85	64.61	65.15	16.56	<0.5
	115	16.05	80.36	62.23	3.93	<0.5
	160	16.50	129.99	37.62	0.00	18.3
L32L29#	109	15.40	12.32	14.68	67.52	-
	121	15.60	60.71	24.46	36.04	<0.5
	129	15.80	40.77	37.16	13.79	<0.5
	159	16.10	56.45	5.35	9.38	<0.5
	167	16.20	99.88	439.28	0.00	<0.5
	176	16.30	115.14	479.33	0.00	1.2
	188	16.40	129.48	882.81	0.00	1.2
	208	16.50	104.24	7.58	-	17.7
L50Y45#	151	15.60	22.53	33.28	36.12	-
	156	15.70	49.91	26.94	26.05	-
	166	15.85	23.86	24.57	9.21	<0.5
	167	15.95	22.85	55.29	5.70	<0.5
	172	16.00	4.85	34.81	2.01	<0.5
	177	16.10	30.02	136.06	2.00	<0.5
	187	16.20	24.64	133.79	0.00	<0.5
	202	16.30	45.52	49.69	0.00	4.2
	224	16.40	69.80	61.79	0.00	11.5
	242	16.50	59.92	18.88	0.00	21.1

input of particulate Mn from sedimentary environment, which probably advected through rim current system into the interiors of the basin. Since DO concentration was proved to be ineffective in the sulfide removal processes, at least, not a direct oxidant for H₂S as stated before, and particulate manganese concentrations were lower than those of other stations, it can be speculated that microbiologically catalyzed processes dominate H₂S removal in the suboxic zone of the rim current regions. This effective removal rates can also be visualized by comparing the gradients of H₂S between 16.10 and 16.50 density surfaces. Gökmen [14] showed that H₂S gradients between the 16.10 and 16.50 density surfaces within the cyclonic and anticyclonic regions were very similar (0.40 and 0.39 $\mu\text{mol.m}^{-4}$, respectively), whereas it was lower in the rim current region (0.20 $\mu\text{mol.m}^{-4}$).

Half-life estimates for the rim current system (Sta. L32L29) suggest that H₂S diffused from the anoxic to the suboxic zone is removed as fast as it was introduced. Disappearance of the deep phosphate minimum in the suboxic zone of the rim current [15] supports the idea that the injection of H₂S together with other reduced species

through diffusion and horizontal advection processes were rapidly counterbalanced by removal processes.

3.2. VERTICAL DISTRIBUTIONS OF PARTICULATE IRON AND MANGANESE

In most marine environments, the suspended fractions of the trace metals comprise only a minor fraction of the total metal concentrations in the water column [16]. On the other hand, in anoxic environments, the suspended fraction is a major part of the total concentration [17,18], which makes the particles most important for the distribution of the trace metals in the Black Sea. The presence of hydrogen sulfide affects the distributions of transition metals [19] since sulfide is oxidized by settling particulate MnO₂ and possibly by FeOOH formed by bacterial processes [8].

Kempe *et al.* [20] have suggested that the light transmission minimum, defined as FPL, observed near the Turkish coast at the density interval of 16.00-16.20 is due to Mn-containing particles which supports our findings (Figures 3-5).

The fine particles layer (FPL), a feature of the chemocline, was determined by using the light transmission profiles. The turbidity peak representing the FPL was observed in all the light transmission profiles (see Figure 3-5), even though it was very weak at offshore station M07W45, located in the cyclonic region (Figure 5).

The fine particle layer was better pronounced in the anticyclonic system than in the cyclone (Figure 3). The particulate manganese profile at station L50Y45 displayed a coherent maximum with a peak value of 140 nM at the lower boundary of FPL (Figure 3). However, there was no detectable particulate iron peak at this station. It can be speculated that the FPL observed at this station was due to the particulate manganese i.e., this layer is a Manganese Particle Layer (MPL) as previously stated by Kempe *et al.* [20]. At station L32L29 located in northern exit region of Bosphorus, the light transmission profile displayed a wavy structure (Figure 4), being less consistent with that of station L50Y45. An unexpected maximum between 16.10 and 16.20 density surfaces and a minimum at 16.50 density surface appeared in the light transmission profile were due to as yet undefined factors. According to Lewis and Landing [21], the transmission minimum observed throughout the Black Sea within the sulfidic water interface is not predominantly due to the resuspended particulate Mn. Horizontal spreading of water carrying dissolved oxygen and dissolved Mn along isopycnal surfaces would result in greater bacterial abundances near the margins and this could account for the spatial variability in the magnitude of light scattering at these depths.

Even though there are some exceptions, particulate manganese concentrations began to increase at the density surface of 15.80, whereas particulate iron concentrations started to increase at greater density surface ($\sigma_\theta=16.10$). In literature, it is stated that the concentrations of dissolved Mn and Fe begin to increase at $\sigma_\theta=15.80$ and $\sigma_\theta=16.10$, respectively [13,21]. The effect of Mn on the sulfide oxidation is probably more pronounced than that of Fe. Tebo [22] argued that the Mn cycle may be the key process for maintaining the broad suboxic zone; oxidized Mn may oxidize both

reduced sulfur and iron as well as serve the electron acceptor for H_2 and for organic matter oxidation

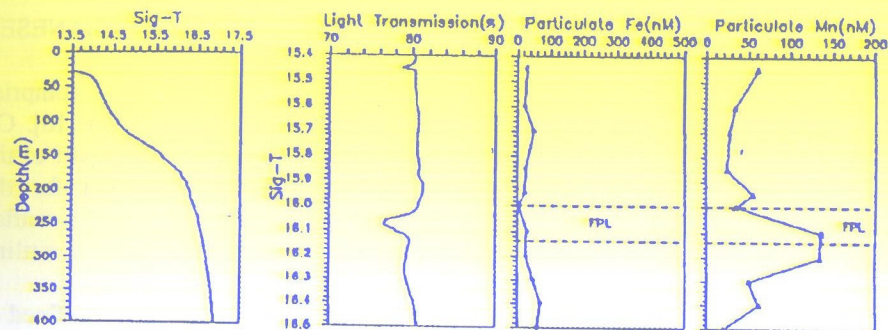


Figure 3. Vertical distributions of light transmission, particulate iron and manganese relative to potential density at station L50Y45 in September-October 1995

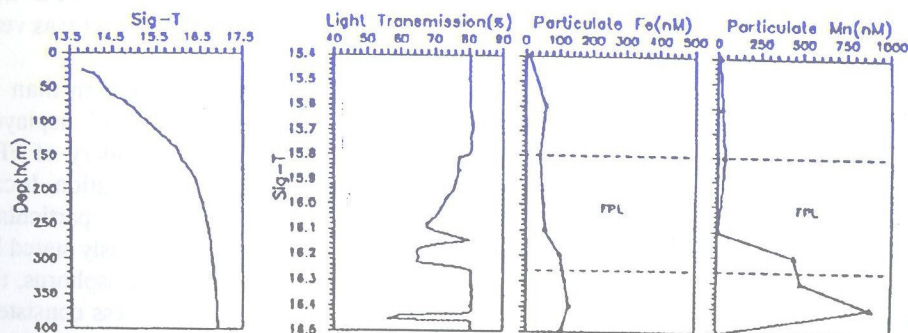


Figure 4. Vertical distributions of light transmission, particulate iron and manganese relative to potential density at station L32L29 in September-October 1995

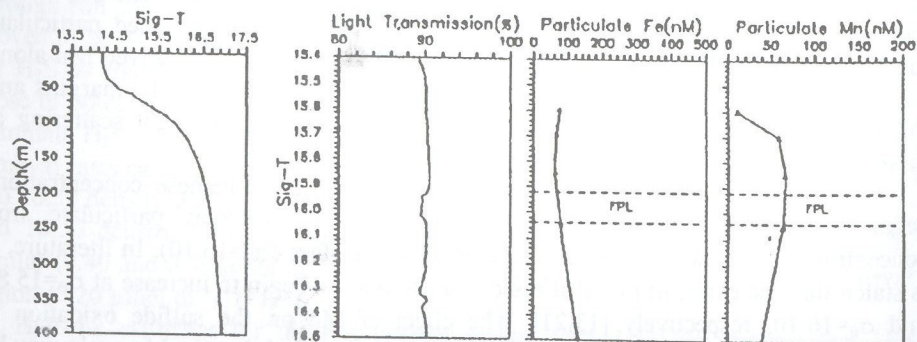


Figure 5. Vertical distributions of light transmission, particulate iron and manganese relative to potential density at station M07W45 in March-April 1995

(Mn reduction) and in turn the reduced Mn(II) may contribute to oxygen consumption (Mn oxidation).

As it is seen from the Figures 3-5, in general, there is no significant particulate Fe maximum above the sulfide interface. Lewis and Landing [21] suggested that Fe oxidation occurs above the interface, and the iron-oxhydroxides produced must have a very short residence time before settling down to reducing waters.

4. Conclusions

In the present study, we tried to determine the gross removal rate of H_2S , including the removals through precipitation, oxidation and bacterial processes. Hydrogen sulfide removal rate through biochemical processes in the anticyclonic eddy is slower than that within the interior of the cyclonic gyre and the rim current region. The shortest half-lives were observed in the meandering rim current close to the Bosphorus northern exit. On the basis of concentration measurements, dissolved oxygen has no direct contribution to the removal and/or oxidation rate of H_2S . The most probable factors responsible for sulfide removal within the suboxic zone of the Black Sea are the presence of particulate iron and manganese species and other chemical processes (e.g. NO_3 reduction catalysed by microbial processes). In the present study, the effect of Mn & Fe oxides on sulfide removal was studied in terms of concentration measurements. From the vertical distributions and concentrations of particulate forms of these metals, it seems that particulate Mn is more effective on the H_2S removal processes than that of particulate iron. However, to reach reliable conclusions on the relative effect of these two metals on the H_2S oxidation rate, one must have some knowledge of the speciation of these metals and their fluxes in addition to their concentrations. Sulfur speciation studies coupled to kinetic experiments can give insights into the possible modes (abiotic or biotic) of sulfide oxidation and sulfur cycling in the environment. In addition, sulfur speciation studies are necessary to help to discern the chemical speciation of metals (Fe, Cu, Mn, etc.) in the sulfidic and oxic waters. The effects of microbiological processes and nitrate and/or nitrite should also be studied for a complete understanding of the mechanisms responsible for the formation of the suboxic zone and its chemistry.

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6. References

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REDOX NEPHELOID COMPOSITION AND

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Abstract. Deep turbidity maximum in the Black Sea has a thickness of 10-15 m, located at depth from 100 to 150 m. It is close to the coast the scattering coefficients), being known that there

Redox reactions take place in the deep nepheloid layer (denitrification, Mn(II)-oxidation, sulfate reduction, and sulfide oxidation), between these reactions (NO₃⁻, MnO₂, S⁰) whose products are on these surfaces, concentrated. At $\sigma_t = 16, 18 \pm 0, 04$ with gradients of Mn²⁺ and in this layer and chaotic interfaces.

Because the position of the deep nepheloid layer (nephelometer) and composition of the Nepheloid Layer (RNL) is an average contribution of 2-3%. In some cases suspended matter (95%, minimum) is composed of microorganisms. Electrical conductivity of the particulate matter from origin.

1. Introduction

The deep nepheloid layer has a maximum at or just above