TRANS 323

RASPREDELENIYE NITRATOV I NITRITOV V VODE SEVERNOY CHASTI INDIYSKOGO OKEANA

(Distribution of Nitrates and Nitrites in the Water of North Indian Ocean)

by

A. G. ROZANOV and V. S. BYKOVA

TRUDY INSTITUTA OKEANOLOGII

VOL. LXIV

Pp. 94-101

MOSCOW 1964

Translator: M. Slessers
Editor : K. Kaye

U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C.
1967

ABSTRACT

The general distribution of dissolved mineral nitrates and nitrites in the Arabian Sea, Bay of Bengal, Andaman Sea and in the open northern part of the Indian Ocean is given. Mean values of nitrates: 1 µg-at N/l in surface water, sharply increasing to 22-26 µg-at N/l with depth. After achieving these concentrations the content of nitrate changes little.

Nitrites as a thin layer were dissolved in the thermocline layer and under it in quantities depending on zooplankton (up to 2 µg-at N/l).

In the Arabian Sea the second maximum of nitrites was discovered (up to 5 µg-at N/l in 150-1500 m); it can be explained by the reduction conditions of these waters.

The author

DISTRIBUTION OF NITRATES AND NITRITES IN THE WATER OF NORTH INDIAN OCEAN

The distribution of nitrites and nitrates dissolved in sea water depends to a large degree upon hydrological, biological and physical-chemical conditions. In the layer, where the process of photosynthesis occurs, the content of dissolved forms of mineral nitrogen may decrease as a result of its consumption by phytoplankton. On the other hand, a cycle of transformations occurs as a result of mineralization of organic matter; the last phase of the metamorphosis, according to Bruyevich (1954), includes the oxidation of ammonium and nitrates with intermediate formation of nitrites. This is a spontaneous process since it is accompanied with a decrease of free energy. The formation of nitrites in lieu of reduction of nitrates requires additional use of energy or is spent in specific reducing conditions.

The following expeditions worked in the investigated area of the Indian Ocean: Mabahiss (1933-1934), Discovery II (1931-1939), Dana (1928-1930), Ob' (1955-1957), Vityaz' (1959-1961). In the Mabahiss (Thompson, Gibson, 1937) and Discovery II (Discovery Reports, 1941-1947) expeditions the nitrates were determined by the colorimetric method with strychnine, in the Ob' (Ivanenkov, Gubin, 1960) with diphenylamine, in the Vityaz' (reports on 31st and 33rd cruises) with diphenyl benzidine. In all the expeditions the nitrites were determined by the Griss-Ilosvay method.

All the water area of the Indian Ocean, which was investigated during the 33rd cruise of the Vityaz', was divided into the following regions: the Arabian Sea, open part of the Indian Ocean and the Gulf of Bengal with contiguous Andaman Sea.

The Arabian Sea (October-November). The distribution of nitrates in the Arabian Sea depends on the following factors: rather high biological activity in comparison with other areas of the Indian Ocean (the production of the Arabian Sea approaches to that of our Far Eastern Seas)*; the presence of clearly pronounced density discontinuities, the presence of a vast layer of oxygen minimum and the zone of hydrogen sulfide (Ivanenkov, Rozanov, 1961) in intermediate water.

*See the study of Nauknov and Ponomareva on p. 250 of this collection of papers.

Nitrates are, as a rule, absent from the surface layer. A sharp increase in the concentration of nitrates reaching 15-20 mkg-at/l is observed under the discontinuity layer (25-50 m. along the coast and 50-75 m. in the central part). Nitrates increase with depth to 18-24 mkg-at/l.

/95

Vertical Distribution of Oxygen, Nitrates and Nitrites (mkg-at/l)

Arabian Sea								Open part of the ocean				Gulf of Bengal			
St. 4814				St. 4865				St. 4890				St. 4934			
lat. 18°41'0 N λ long. 61°59'2 E				lat. 15°19'5 N λ long. 70°57'8 E				lat. 30°00'9 N λ long. 71°22'9 E				lat. 16°58'4 N λ long. 86°59'7 E			
*Depth, m	O_2	NO_2 - N	NO_3 - N	*Depth, m	O_2	NO_2 - N	NO_3 - N	*Depth, m	O_2	NO_2 - N	NO_3 - N	*Depth, m	O_2	NO_2 - N	NO_3 - N
0	410	0,2	<0,01	0	396	0,8	<0,01	0	462	0,2	<0,01	0	413	0,6	<0,01
11	403	0,2	<0,01	10	397	—	<0,01	10	457	0,4	<0,01	12	414	0,3	<0,01
25	402	0,1	<0,01	25	394	0,2	<0,01	25	454	0,4	<0,01	27	384	0,4	<0,01
56	341	17	0,50	50	138	14	0,32	41	480	3,1	<0,01	55	409	0,4	<0,01
83	205	15	0,08	75	43	14	0,06	65	524	0,2	<0,01	82	239	3,0	0,05
110	175	16	0,01	100	17	18	<0,01	90	498	0,4	<0,01	110	94	17	0,03
138	11	—	0,28	125	8	—	0,04	114	484	—	0,03	137	36	—	0,03
166	10	17	0,44	149	6	20	0,95	139	500	3,0	<0,01	165	20	20	0,03
189	11	—	<0,01	175	6	—	3,08	162	482	—	0,23	188	13	—	0,01
215	13	17	0,62	200	7	9,2	2,79	186	475	6,2	<0,11	211	14	21	0,01
293	17	—	<0,01	250	7	19	0,08	235	473	—	<0,01	256	13	—	0,02
358	12	—	<0,01	299	6	15	0,18	284	490	10	<0,01	305	15	21	0,01
484	12	18	0,03	404	8	16	0,18	383	477	13	<0,01	407	15	21	0,01
602	15	—	<0,01	500	7	—	0,08	478	480	14	<0,01	504	24	22	<0,01
823	17	—	<0,01	592	5	19	0,08	572	476	15	<0,01	600	26	22	0,03
1093	22	17	<0,01	784	13	19	<0,01	780	461	19	<0,01	794	45	22	<0,01
1200	57	17	<0,01	981	21	18	0,08	985	414	22	<0,01	987	73	21	<0,01
1363	31	—	<0,01	1215	37	—	<0,01	1005	423	22	<0,01	1223	108	—	—
1468	73	18	<0,01	1444	65	20	<0,01	1222	369	—	<0,01	1459	125	21	—
1710	135	—	<0,01	1684	121	—	<0,01	1457	334	—	<0,01	1683	178	—	—
1977	163	18	<0,01	1925	175	21	<0,01	1662	348	21	<0,01	1899	211	21	—
2428	205	—	<0,01	2391	237	21	<0,01	2175	357	21	<0,01	2373	236	21	—
2897	229	15	<0,01					2665	368	21	<0,01				
3367	258	18	<0,01					3148	371	20	<0,01				
								3612	387	22	<0,01				

*Depth, m

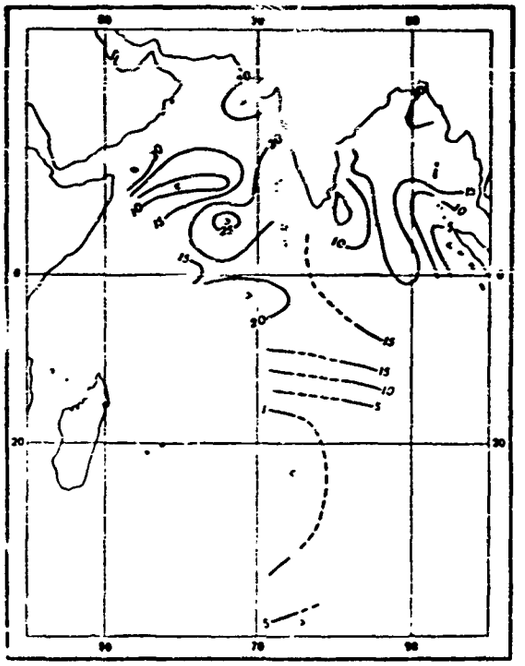

FIG. 1. Distribution of nitrates (mkg-at/l) at the depth of 100 m.

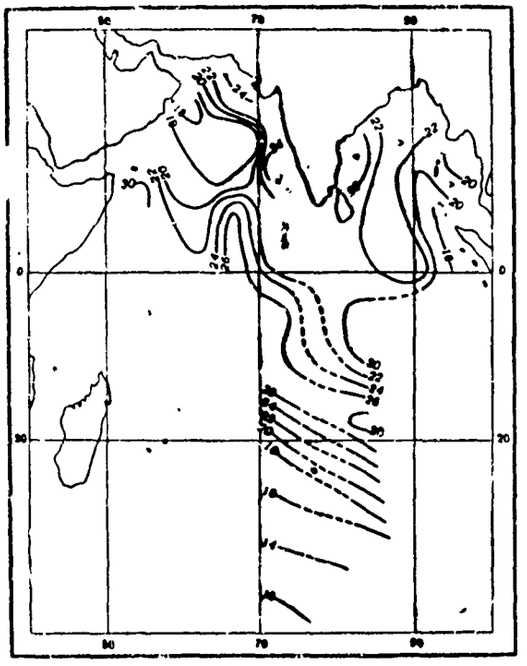

FIG. 2. Distribution of nitrates (mkg-at/l) at the depth of 600 m.

The distribution of nitrates with depth is different in the zone of hydrogen sulfide, or near it, and in the zone where the effect of hydrogen sulfide is not felt. The water contaminated with hydrogen sulfide or lying near the hydrogen sulfide zone contains somewhat less nitrates in the layer of 200-500 m.; here nitrites begin to appear (see table, St. 4865). In zones not contaminated with hydrogen sulfide the nitrates reach maximum concentration at a certain depth; lower, the concentration remains almost unchanged (see table, St. 4814).

The distribution of nitrates over the water area of the Arabian Sea is shown for water levels 0, 100 and 600 m., which makes it possible to evaluate their content in the layer of greatest biological activity (0 m.), under the first density discontinuity layer (100 m.) and in the zone of their maximum contration (600 m.). At the surface and in the upper layer of 25-50 m. the quantity of nitrates over the greater part of water area is practically zero. Only in the areas of maximum vertical intermixing does the quantity of nitrates reach 0.5-1.5 mkg-at/l in the layer of 0-50 m. (see Fig. 3 in paper by Kabanova, on page 90 of this publication).

At the depth of 100 m. (Fig. 1), the following quantities of nitrates /97
were observed: 16-18 mkg-at/l in the central part of the Arabian Sea, 20-22 mkg-at/l off the coast of India and in the Gulf of Aden, 5-15 mkg-at/l in the Somali Current area.

The intermixing caused by the Somali Current increases somewhat the quantity of nitrates in the overlaying layers (50-100 m.) and decreases in the underlying layers (100-150 m.).

At the depth of 600 m. (Fig. 2) the concentration of nitrates off the Somali coast increases to 22-24 mkg-at/l (at St. 4997 the value was 32 mkg-at/l). In the remaining part of the Arabian Sea the quantity of nitrates tends to increase at this depth level in west-east direction from 18 mkg-at/l in the western and central part to 24 mkg-at/l off the coast of India. It need be noted that the distribution of phosphates is similar in this area.*

Below the depth of 600 m. the quantity of nitrates is practically stable.

The vertical distribution of nitrites in the Arabian Sea has the

*See study by Rozanova on p. 102 in this issue.

following characteristics. At the surface in layer, 0-25 m., the nitrites are absent, in the density discontinuity layer, 25-75 m., the first intermediate maximum of nitrites appears, which was not established at the depth of 100-150 m. In the zone of hydrogen sulfide and in adjacen areas at the depths of 150 to 1500 m. the second intermediate maximum of nitrites was observed.

The finding of the first intermediate maximum of nitrites at the depth of 25-75 m. is not a peculiarity of the Arabian Sea; and is associated with the oxidation of organic matter of decomposing plankton organisms. The presence of the second intermediate maximum of nitrites is a phenomena typical only of the Arabian Sea (and areas similar to it) and is associated with peculiar reducing conditions in the intermediate layers of this sea. These layers have a negligible quantity of oxygen (less than 15 mkg-at/l) and are characterized by a decrease of the oxidation-reduction potential (Mokiyevskaya, 1961) and the appearance of hydrogen sulfide (Ivanenkov, Rozanov, 1961). The layer of the second intermediate maximum of nitrites is at the same time a layer of somewhat diminished quantity of nitrates, which can be explained by their partial reduction to nitrites.

The first intermediate maximum of nitrites (Fig. 3) in the form of a thin layer appears in density discontinuity layer and underneath. In the northern part of the Arabian Sea, the concentration of nitrites reaches 0.10-0.20 mkg-at/l, in central part 0.020-0.50 mkg-at/l, off the coast of India it exceeds 0.50 mkg-at/l, and in the western part of the sea, off the Arabian coast, the value exceeds 1.00 mkg-at/l. In the Somali Current area, the concentration of nitrites in the layer of first intermediate maximum reaches 2.00 mkg-at/l. A good correlation between the quantity of nitrites and zooplankton biomass (not phytoplankton, because the animal albumin liberates a large quantity of nitrogen when being decomposed) was noted in this layer. The autumn season is the Arabian Sea is characterized by a very large plankton biomass (exceeding 1 g/m3 in wet weight)*; as in other areas of the World Ocean, the richest layer is 0-100 m.

The largest plankton biomass was observed in the Gulf of Aden and in the western part of the sea, i.e. in places with maximum concentration of nitrites. A similar connection was noted earlier (Bruyevich, 1954) in other areas of the World Ocean.

*See study by Naumov and Ponomareva on p. 249 in this issue.

Below the layer of first intermediate maximum the nitrites disappear or their quantity decreases to less than 0.10 mkg-at/l. In layer, 150-1500 m. nitrites appear again, sometimes with breaks, the quantities ranging from 0.20 to 0.50 mkg-at/l. In the hydrogen sulfide zone the second maximum of nitrites fluctuates around 1.00-5.00 mkg-at/l (Fig. 4). /98

In the central part of the Arabian Sea the second maximum of nitrates is observed at a depth of 150-200 m. Off the Arabian coast and in the northern part of the sea it lies at a depth of 400-500 m.

The presence of second intermediate maximum of nitrites indicates the water distribution of the Arabian Sea in southern, eastern and open sectors. The same character of distribution of Arabian waters was noted by K. D. Sabinin* when studying the maximums of s. linity.

In the open northern sector of the Indian Ocean (December-January) a slightly different pattern in the distribution of dissolved mineral forms of nitrogen was observed. Poor production of the open water of the Indian Ocean, as well as smaller vertical density gradients, slow down the increase in the concentration of nitrates with depth in comparison with the Arabian Sea; thus the absolute values of nitrates are here smaller (see table, St. 4890).

Negligibly small quantities of nitrates (less than 0.5 mkg-at/l) are observed in the surface layer, except for several spots in the areas of upwelling. In the surface layer of the eastern part of equatorial zone of the Indian Ocean the quantity of nitrates reached 1-2 mkg-at/l.

At a depth of 100 m. (see Fig. 1) of the western sector of equatorial zone one can distinguish a subzone with small concentrations of nitrates in the area of Somali Current (10-15 mkg-at/l), a subzone with upwelling water west of Maldine Islands (20-25 mkg-at/l) and a subzone of upwelling on lat. 5°S north of Chagos Archipelago (20 mkg-at/l). In the eastern part of equatorial zone, the concentration of nitrates at the same depth is somewhat smaller than in the western part. The largest quantities of nitrates (15 mkg-at/l) are observed SW of Ceylon and in area adjacent to the Gulf of Bengal. South of the zone of equatorial divergence one can observe a gradual decrease in the quantity of nitrates, diminishing to negligible quantities (less than 1 mkg-at/l) south of lat. 16-17°S, which is associated

*In this article p. 51.

with the deepening of density discontinuity layer in this area. At the depth of 600 m. in the open part of the Indian Ocean, the concentration of nitrates reaches maximum and is, as a rule, preserved to the bottom. In Fig. 2 one can clearly see the location of upwelling in the south equatorial divergence zone where the quantity of nitrates exceeds 26 mkg-at/l; southward the quantity decreases.

The first intermediate maximum of nitrites in the open portion of the ocean, which is associated with the first density discontinuity equals 0.25-0.50 mkg-at/l (see Fig. 3). An increase in the concentration of nitrites in the areas of Maldive Islands, Ceylon and Chagos can be explained by the large biomass of plankton in these areas. In western part of equatorial zone the first intermediate maximum of nitrites lies at a depth of 50-80 m., in eastern part it lies at a depth of 80-100 m. South of equator, the upper boundary of this layer rises to 30 m. in the south equatorial divergence zone; on lat. 20-25°S it gradually deepens to 150 m.

The second intermediate maximum of nitrites, which is associated with the water of Arabian origin, is far less clearly pronounced in the open part of the ocean than in the Arabian Sea (see Fig. 4). Southward it is traced approximately to lat. 10°S; in the eastern part of equatorial zone this maximum is observed in layer 200-500 m. deep extending a narrow band south of Ceylon toward Sumatra (0.10-0.16 mkg-at/l).

Gulf of Bengal and Andaman Sea (February-March). The distribution /100
pattern of nitrates and nitrites in the Gulf of Bengal and Andaman Sea is much like the pattern in the Arabian Sea (See table, St. 4934). There are, however, substantial differences: the presence of considerable quantities of nitrates in surface layers, the absence of second intermediate maximum of nitrites, etc. The mean magnitudes of nitrates and nitrites in the Gulf of Bengal are smaller than in the Arabian Sea.

The quantity of nitrates in the surface water of the greater part of the Gulf of Bengal is about 1-1.5 mkg-at/l. In the eastern part of the Gulf of Bengal and in the Andaman Sea the quantity is somewhat greater--namely, 2.0 mkg-at/l (see Fig. 3 in the paper by Kananova printed on p. 90 of this issue).

At the depth of 100 m. in the central part of the Gulf of Bengal the quantity of nitrates equals 15 mkg-at/l, toward the coast of India it decreases to 10-13 mkg-at/l (see Fig. 1).

At the depth of 600 m. in the central part of the gulf the quantity of nitrates equals 22 mkg-at/l, but off the coast of India it is less

FIG. 3. Distribution of magnitudes of the upper intermediate maximum of nitrites (mkg-at/l).

FIG. 4. Distribution of magnitudes of the second intermediate maximum of nitrites (mkg-at/l).

than 20 mkg-at/l (see Fig. 2). In the northern part of the Gulf of Bengal and in the central part of the Andaman Sea the concentration of nitrates reaches 23 mkg-at/l.

The upper intermediate maximum of nitrites in the central part of the Gulf of Bengal does not exceed 0.25 mkg-at/l; it reaches 0.50 mkg-at/l in the southern part and 1.00 mkg-at/l in the northern part of the gulf. The quantity of nitrites in the layer of first intermediate maximum of the Andaman Sea fluctuates from 0.25 to 0.50 mkg-at/l (see Fig. 3).

The second intermediate maximum of nitrites was observed by us only in one area of the Gulf of Bengal near the coast of India at a depth of 200-500 m. (0.10-0.20 mkg-at/l). In this area small quantities of hydrogen sulfide (0.05 ml/l) were found (Ivanenkov, Rozanov, 1961). In the Andaman Sea the second intermediate maximum of nitrites was absent.

CONCLUSIONS

1. The general character of the distribution of nitrogen in the northern part of the Indian Ocean is as follows: very small quantities on the surface (usually less than 1 mkg-at/l, a sharp increase beneath the density discontinuity layer (to 20 mkg-at/l and insignificant increase with depth (to 24-26 mkg-at/l). When reaching this concentration, which can be considered a maximum in the quantity of nitrates, the fluctuations are very small indeed. Such a pattern of the distribution of nitrates can be explained as a result of their consumption by phytoplankton in the surface layer. However, the influx of nitrates into the photosynthetic layer from deeper strata is impeded due to a sharply pronounced stratification of water. The presence of high concentration of nitrates immediately beneath the density discontinuity layer is created by the mineralization of the unstable organic matter of dead organisms which are readily oxidized in the surface layer. Similar data on the distribution of nitrates were also obtained on other expeditions, notably on the Mabahiss, Discovery II and Ob'.

2. Nitrites appear in the form of a thin layer under the first density discontinuity layer; their quantity increases with a increase in the production of zooplankton in the surface layer.

3. The second intermediate maximum of nitrites is created by specific reducing conditions in the intermediate water of the Arabian Sea.

BIBLIOGRAPHY

1. BRUYEVICH, S. V. NITRITY I NITRITIFIKATSIYA (Nitrites and Nitrification). TRUDY IN-TA OKEANOL. AN SSSR, Vol. 8, 1954.

2. IVANENKOV, V. N., GUBIN, F. A. VODNYYE MASSY I GIDROKHIMIYA ZOPADNOY I YUZHNOY CHASTEY INDIYSKOGO OKEANA (Water masses and Hydrochemistry of the Western and Southern Parts of the Indian Ocean). TRUDY MORSKOGO GIDROFIZ. IN-TA AN SSSR, Vol. 22, 1960.

3. _____, ROZANOV, A. G. SEROVODORODNOYE ZARAZHENIYE PROMEZHUTOCHNYKH SLOYEV ARAVIYSKOGO MORYA I BENGAL'SKOGO ZALIVA (Contamination with Hydrogen Sulfide in the Intermediate Layers of the Arabian Sea and Gulf of Bengal). OKEANOLOGIYA, Vol. 1, No. 3, 1961.

4. MOKIYEVSKAYA, N. V. OTCHET O RABOTE KHIMICHESKOGO OTRYADA V 31 REYSE e/s VITYAZ' (Review of Work of the Chemistry Division in the 31st Cruise of Vityaz'). OTCHET 31 REYSA e/s VITYAZ', Vol. 2, 1960.

5. _____, NEKOTORYYE GODROKHIMICHESKIYE CHERTY INDIYSKOGO OKEANA (Some Hydrochemical Features of the Indian Ocean). OKEANOL. ISSLEDOVANIYA, No. 4, 1961.

6. PONOMAREVA, L. A., NAUMOV, A. G. OTCHET PLANKTONNOGO OTRYADE V 33 REYCE e/s VITYAZ', Vol. 2, 1961.

7. ANNONYMOUS. OTCHET 33 REYSA e/s VITYAZ', Vol. 3, 1961. BIBLIOTEKA IN-TA OKEANOLOGII AN SSSR.

8. ANNONYMOUS. "Dana"--REPORT HYDROGRAPHY OBSERVATIONS MADE DURING THE DANA 2 EXPEDITION 1928-30, 2, N 12. Copenhagen 1937.

9. Discovery Investigations. Station list 1931-33. Discovery Reports, No. 21, 1-196. Cambridge, 1941.

10. Discovery Investigations. Station list 1933-35. Discovery Reports, No. 21, 1-196. Cambridge, 1942.

BIBLIOGRAPHY continued

11. Discovery Investigations. Station list 1935-37. Discovery Reports, No. 24, 1-196. Cambridge, 1944.

12. Discovery Investigations. Station list 1937-39. Discovery Reports, No. 24, 197-422. Cambridge, 1947.

13. THOMPSON, E. F., GIBSON, H. C. CHEMICAL AND PHYSICAL INVESTIGATIONS. Science Report John Murray Expedition 1933-34, 2, No. 2. London, 1937.

/

ooOoo

BIBLIOGRAPHY continued

11. Discovery Investigations. Station list 1935-37. Discovery Reports, No. 24, 1-196. Cambridge, 1944.

12. Discovery Investigations. Station list 1937-39. Discovery Reports, No. 24, 197-422. Cambridge, 1947.

13. THOMPSON, E. F., GIBSON, H. C. CHEMICAL AND PHYSICAL INVESTIGATIONS. Science Report John Murray Expedition 1933-34, 2, No. 2. London, 1937.

/

ooOoo