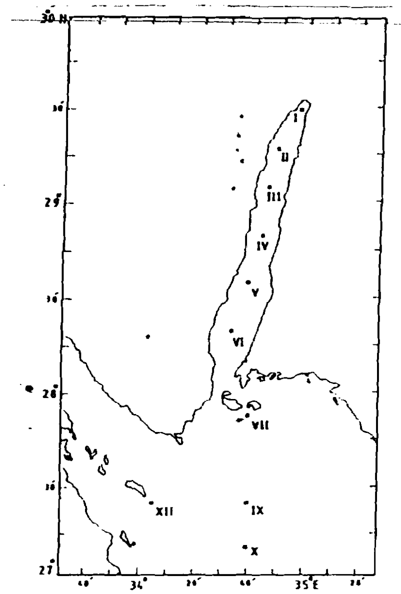

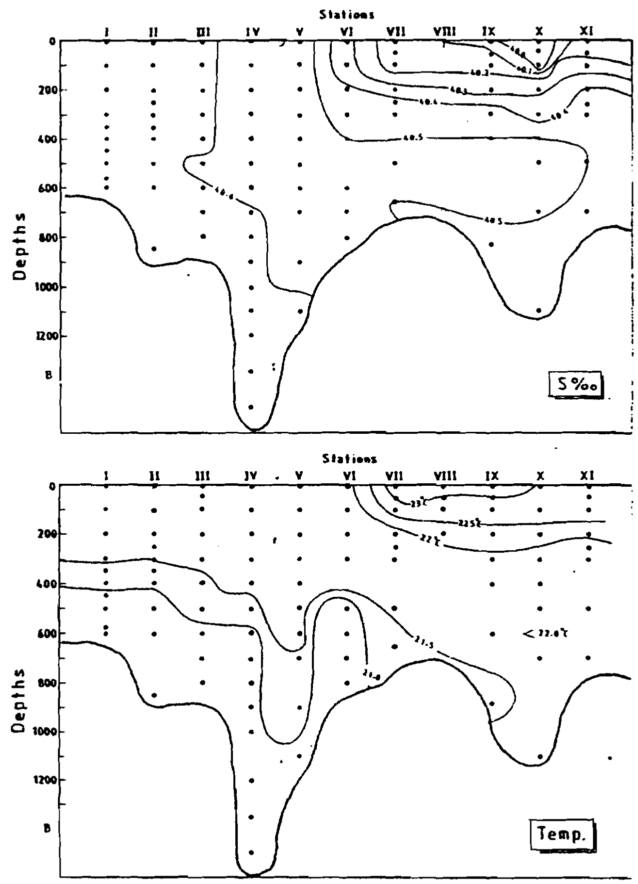

Fig. (1 a): Location of stations in the Gulf of Aqaba (I-VI) and Northern Red Sea (VII-XII).

Fig. (1 b): The vertical distribution of salinity (S ‰) and temperature (°C) in the studied area.

Salinity

Gulf of Aqaba is characterized by having more or less constant salinity values. It ranged between 40.36 and 40.65 with a very small gradient 0.19, i.e. the Gulf is homohaline with an average salinity of 40.58 ± 0.05 in the upper 500 m layer. The Northern Red Sea has a wide range of variation (39.98 – 40.53) with a salinity gradient 0.65. This area is well stratified from surface to 400 m depth. The water column from 400m depth to the bottom salinity show more or less constant with an average value of 40.26 ± 0.16 and 40.50 ± 0.01, respectively.

Figure (1b) shows the vertical distribution of salinity in the studied area. It indicates the inflow of less saline surface water of the Northern Red Sea to the Gulf of Aqaba affects its salinity (especially at stations V and VI which are located near Tiran Strait below 300 m. On the other hand, a high saline bottom water flows out the Gulf (below 400 m depth).

Low salinity values at the Northern Red Sea area may be due to either the effect of less saline Red Sea water or to the effect of less saline water comes from the western coast of the Red Sea in front of Safaga and El-Ghardaqa. Mohamed (1938) and Morcos (1984) found that due to the progressive increase in surface salinity from 36.5 in the south to 40.5 in the north the vertical salinity gradient above the 40.5 isohaline decrease from south to north. In the Gulf of Aqaba, the surface and deep waters have higher salinities than the corresponding depths outside the sill in the Red Sea proper. Reiss and Hottinger (1984) found that the average surface salinity ranges between 40.56 and 40.78. Salinities of deep water are higher than 40.8 in summer and exceptionally may reach >41. The evaporative loss is compensated by inflow from the Red Sea through the Straits of Tiran Enterprise and Grafton Passages) and thereby the main circulation pattern in the Gulf of Aqaba is thermohaline (inverse estuarine).

During February 1999 warm relatively low saline upper Northern Red Sea waters enter the Gulf through the Straits of Tiran, flowing northward against the wind. An outflow at sill depth of less warm and highly saline water leaves the Gulf through the Straits of Tiran.

Nutrient salts

Nitrite

Surface distribution of nitrite indicates that area of Aqaba is characterized by higher nitrite content especially at station I (0.15 µmol l^{-1}). The Northern Red Sea surface water has very low nitrite content varied between depletion and 0.08 µmol l^{-1} at stations XII and X, respectively (Fig. 2).

Regarding vertical distribution of nitrite, Fig. (2), shows that its content in the Gulf decreases with depth from surface to 400 m depth. Nitrite is completely depleted below 400-800 m at stations I-III and from 300-500 m at stations IV and V, this water layer flow (sink) deeper from 300 to 900 m at stations IV and VI. The subsurface water of the Gulf flow out through the Straits of Tiran causing an increase in the Northern Red Sea nitrite content at depth of (200-500 m). The concentrations of nitrite in the Northern Red Sea is lower than its content in the Gulf (0.04 µmol l^{-1}). At station IV, which is the deepest one, nitrite values increase again below nitrite depleted layer (500 m depth) reaching a maximum of 0.12 µmol l^{-1} at 135 m depth. The euphotic zone (0.0–200 m) at station VII has low nitrite content below this zone its content increases again (0.34 µmol l^{-1}, at 300 m). Generally, average nitrite content at stations I and II at both surface and bottom water are equal (Table I).

Nitrate

Their values are also higher within the Gulf of Aqaba during February 1999 than in the Northern Red Sea, Surface distribution of nitrate, Fig. (2), shows that nitrate content at station V is higher (2.06 µmol l^{-1}) than at station II (0.5 µmol l^{-1}). Concentrations of nitrate in the Northern Red Sea ranged between 0.07 and 0.63 µmol l^{-1} at stations X and VII, respectively.

The vertical distribution of nitrate along the section extending along the Gulf, and in the Northern Red Sea, Fig.(2), increased with depth from surface to about 400 m depth. Its values ranged from 0.5 µmol l^{-1} (station II) to 4.16 µmol l^{-1} (station IV, 500 m depth). Outside the Gulf in the Northern Red Sea, the vertical gradient for nitrate shows an increase with depth from surface to 300 m. Below this depth nitrate values are more or less constant. Its concentrations in this area ranged from 0.07 µmol l^{-1} at station X to 3.15 µmol l^{-1} (station VII) at 650 m depth. Nitrate concentrations in the surface water (surface to 200 m depth) are lower than in the deeper water, this could be attributed to the

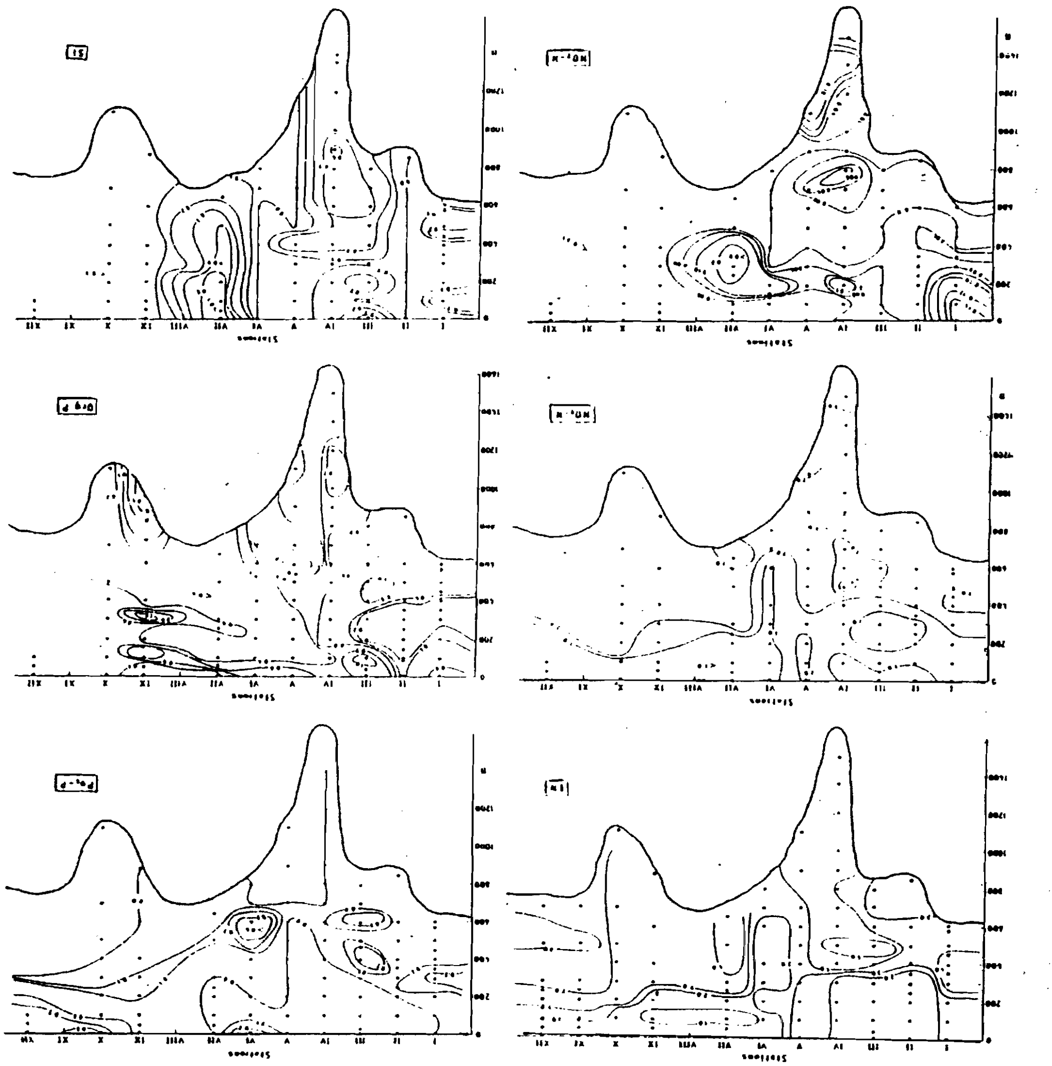

Fig. (2): The vertical distribution of total nitrogen, nitrate, nitrite, inorganic, organic phosphorus and silicates in the studied area (µ mol l^{-1}).

Table (1): Average concentrations of nitrate, nitrite, organic and inorganic phosphorus and silicates ($\mu mol\ l^{-1}$) in Gulf of Aqaba and Northern Red Sea areas.

Area	St. No.		Depth m	Salinity	Nitrite	Nitrate	Total nitrogen	Phosphorus Organic	Phosphorus Inorganic	NO_3:PO_4 ratio	PO_4/TP %	Silicates
Gulf of Aqaba	I	S	600	40.63±0.00	0.13 ± 0.02	1.33 ± 0.11	2.59±0.27	2.59 ± 0.20	0.03 ± 0.04	48 : 1	1.14	0.09 ± 0.1
		B		40.62±0.01	0.13 ± 0.02	2.54 ± 0.61	3.99±0.46	3.52 ± 0.20	0.07 ± 0.08	38 : 1	1.95	0.09 ± 0.1
	II	S	900	40.64±0.00	0.04 ± 0.01	0.84 ± 0.24	1.80±0.14	1.72 ± 0.20	0.00	-	0.00	0.00
		B		40.64±0.01	0.04 ± 0.02	1.31 ± 0.76	2.59±0.87	3.31 ± 0.20	0.05 ± 0.03	27 : 1	1.49	0.01 ± 0.01
	III	S	800	40.63±0.00	0.06 ± 0.01	1.00 ± 0.45	1.96±1.00	0.77 ± 0.43	0.24 ± 0.33	4 : 1	24.00	0.26 ± 0.14
		B		40.62±0.02	0.01 ± 0.02	1.65 ± 1.00	3.39±1.26	0.46 ± 0.44	0.12 ± 0.15	14 : 1	20.69	0.25 ± 0.09
	IV	S	1350	40.53±0.00	0.08 ± 0.03	0.72 ± 0.39	1.57±0.10	0.61 ± 0.19	0.00	-	0.00	0.15 ± 0.02
		B		40.58±0.04	0.04 ± 0.04	2.62 ± 0.76	3.84±1.09	0.20 ± 0.20	0.04 ± 0.08	66 : 1	16.67	0.28 ± 0.09
	V	S	1100	40.51±0.00	0.03 ± 0.03	2.23 ± 0.15	3.51±0.36	0.32 ± 0.22	0.02 ± 0.03	113 : 1	5.88	0.00
		B		40.53±0.03	0.05 ± 0.07	2.14 ± 0.44	3.55±0.83	0.62 ± 0.37	0.02 ± 0.03	110 : 1	3.13	0.01 ± 0.01
	VI	S	800	40.38±0.03	0.06 ± 0.04	0.65 ± 0.24	1.635±0.46	0.40 ± 0.21	0.11 ± 0.16	6 : 1	21.57	0.00
		B		40.49±0.11	0.03 ± 0.07	1.23 ± 0.46	1.86±0.40	0.49 ± 0.28	0.13 ± 0.19	10 : 1	20.97	0.04 ± 0.05
Northern Red Sea	VII	S	650	40.19±0.08	0.04 ± 0.01	0.25 ± 0.22	1.28±0.37	0.43 ± 0.26	0.00	-	0.00	0.55 ± 0.11
		B		40.49±0.02	0.11 ± 0.13	2.34 ± 0.80	3.90±0.31	0.71 ± 0.52	0.03 ± 0.05	82 : 1	4.05	0.54 ± 0.34
	IX	S	885	40.15±0.08	0.01 ± 0.01	0.72 ± 0.42	1.48±0.38	0.41 ± 0.44	0.07 ± 0.03	10 : 1	14.58	0.05 ± 0.06
		B		40.49±0.01	0.02 ± 0.02	2.35 ± 0.31	3.55±0.22	0.62 ± 0.59	0.03 ± 0.05	79 : 1	4.62	0.09 ± 0.03
	X	S	1100	40.08±0.14	0.08 ± 0.02	0.87 ± 1.10	0.40±0.33	0.25 ± 0.20	0.15 ± 0.14	6 : 1	37.50	0.05 ± 0.03
		B		40.46±0.06	0.02 ± 0.02	2.26 ± 0.60	0.24±0.14	0.19 ± 0.16	0.05 ± 0.03	46 : 1	20.83	0.20 ± 0.21
	XII	S	700	40.26±0.09	0.02 ± 0.02	0.65 ± 0.21	2.35±0.77	0.25 ± 0.15	0.15 ± 0.11	4 : 1	37.50	0.00
		B		40.50±0.02	–	--	1.98±0.61	--	–	-	0.00	--

S = Surface. B = Bottom.

consumption of nitrate in the euphotic zone (Table 1). The data showed that nitrate contents at both surface and bottom water at station V are approximately equal, being 2.23±0.15 and 2.14±0.44 µmol l^{-1}, respectively. Grasshoff (1969) reported that a nitrate minimum of 14.5 to 19 µmol l^{-1} between 500 and 600 m in the inner part of the Gulf of Aqaba to disappear almost completely in the central part of the Gulf.

Total nitrogen

Their concentrations in the surface water of the Gulf are higher than its content in the Northern Red Sea. Their values in the Gulf of Aqaba ranged from 3.94 µmol l^{-1} at station V and 1.25 µmol l^{-1} at station III, while at the Northern Red Sea it varied between 1.31 µmol l^{-1} (station XII) and 1.84 µmol l^{-1} (station VII).

Vertical distribution of total nitrogen indicates that its concentrations increase with depth from surface to 300 m then decrease again to the bottom. In the Northern Red Sea, its concentrations increase with depth from surface to bottom. Fig. (2) illustrated that, at station I, the water column is divided into 3 water layers. The first one from surface to 200 m with an average concentration of 2.59±0.27 µmol l^{-1}, the second layer from 300 m to 450 m with an average concentration of 4.34±0.1 µmol l^{-1}, in the third layer total nitrogen values decreased, with an average of 3.52±0.33 µmol l^{-1}. Station IV, which is the deepest one, is characterized by having 2 layers; the first one from surface to 400 m with an average of 1.72±0.28 µmol l^{-1} and the second one with an average value of 4.26±0.68 µmol l^{-1} from 500 m to bottom.

Phosphate

Inorganic phosphorus concentration in the surface water, Fig. (2), of stations I, II, III and IV is completely depleted, while at stations V and VI has high phosphate content, especially station VI located near Tiran Straits (0.34 µmol l^{-1}). The Northern Red Sea area has higher surface phosphate content, ranged from 0.0 to 0.34 µmol l^{-1}.

The vertical distribution of phosphates in the Gulf of Aqaba, Fig.(2). From the figure, it is observed that there is a water layer in which phosphate is completely depleted from surface, through the water column down to 700 m (at stations I (200 m), II (300 m), station III (400 m), station IV (700 m). The depth of this water layer decreases again when it becomes nearer to Tiran Straits, reaching a depth of 200 m at station VI and 300 m at station VII. The depleted water layer flows out from the Gulf is replaced by the inflow of a water layer with a high phosphates content at depths from 400 m to 700 m. The vertical distribution of phosphate in the Northern Red Sea indicates that its values from surface to 400 m decrease with depth, below this depth phosphate is completely depleted. At station I, phosphate values in the euphotec zone is depleted due to its consumption by plankton, increasing with depth up to 400 m. Morcos (1984) found that in the Gulf of Aqaba below the poor surface layer (0-5 mg P m^{-3}), phosphate increased slowly to the depth of 700 m, below which a constant concentration of 23 mg P m^{-3} was observed. In the Red Sea, the phosphate poor layer (<5 mg P m^{-3}) extended to a depth of about 60 m at the northern station, and 200 m at the southern, below that the phosphate rapidly increased to an intermediate maximum of 64-69 mg P m^{-3} at depths of 400-600 m. This was initially followed by a decline in phosphate concentrations with increasing depth to 800 m, below which concentrations were constant (34-39 mg P m^{-3}). Phosphate contents were, generally, higher in the Red Sea proper than in the Gulf of Aqaba. Reiss and Hottinger (1984) found that phosphate content in the Gulf is, generally, low. In the northern sector, the upper 200 m water mass is similar with regard to phosphate content both in summer and winter. In the southern sector, higher values of phosphate are present in winter. The central deep water in the northern sector in summer is richer in phosphate than in winter. Extremely high phosphate values > 2.5 µmol l^{-1} through the column down to 600 m depth are definitely attributable to air borne particulate matter brought into the sea from the phosphate fertilizer loading facilities in the Aqaba and Elate. However, average phosphate content at both surface and bottom water of station V are equall (Table I).

The distribution of phosphate given by Grasshoff (1969) along a section from the southern part of the Red Sea to the inner part of the Gulf of Aqaba, where similar stratification in the inner part of the Gulf of Aqaba is reported. Below the phosphate-poor upper layer, the concentration of phosphate increases rapidly to a maximum value of 2.78 µmol l^{-1} at 150 m. A stable and strong discontinuity layer hinders the exchange of phosphate between the upper and deep waters. The phosphate content at 500 m depth decreases to values between 1.5 to 1.9 µmol l^{-1} due to the outflowing Red Sea water. Such intermediayte low values of nutrient salts at mid depths are not known in the open ocean. From Table (I), it is observed that phosphate constitute about 1% to 24% of the total phosphorus content in the Gulf and fluctuated between not detected to 37% in the Northern Red Sea.

Nitrate : Phosphate ratios

The average nitrate (NO_3+NO_2) : phosphate ratios for the Gulf of Aqaba and Northern Red Sea are illustrated in Table I. It is observed that the ratio ranged from 4:1 to 113:1 at surface water (stations I and V)in Aqaba Gulf and fluctuated between 4:1 and 79:1 in the Northern Red Sea (stations XII and IX). These high ratios attributed to a decrease in phosphate content, i.e. it is the lower content of phosphate which related in higher values for the ratio. Phosphate is a limiting factor for the growth of phytoplankton in this areas.

Organic phosphorus

Surface distribution of organic phosphorus in the Gulf ranged from 0.52 to 0.86 µmol l^{-1}. Fig. (2) shows that station I had high organic phosphorus content decreasing southward till station III then increases again. This high values attributed to the presence of station I close to Elat and El-Aqaba Harbours and to the effect of human activity in this area. Organic phosphorus in the Northern Red Sea is lower than inside the Gulf ranging from 0.29 to 0.52 µmol l^{-1}.

Regarding vertical distribution of organic phosphorus, Fig.(2), indicates that the highest organic phosphorus is encountered in the euphatic zone (0-200 m). Below this depth to 400 m its content decreases to less than 0.2 µmol l^{-1}., then increases again (400-800 m). This may be attributed to the outflow of surface water (high organic phosphorus content) and inflow of low concentrated organic phosphorus to the Gulf.

Silicates

Surface values of silicates in the Gulf of Aqaba are lower than in the Northern Red Sea up to 0.42 µmol l^{-1} in the Gulf area and not detected to 0.72 µmol l^{-1} in the Northern Red Sea. Stations II, III and IV have higher surface concentrations than the other one. Silicates contents decreased northward till station VI (Fig.2).

Vertical distribution of silicates, Fig. (2), indicates that its values in the Gulf area decreased with depth from surface to 200 m (euphotic zone) then increased again to more than 4 µmol l^{-1} 1000m, station III. Silicate is completely depleted at stations II and VI from surface to bottom and at station V from surface to 300 m. Surface silicate concentrations in the two areas are usually lower than subsurface values due to the consumption of silicates at the euphotic zone. Silicate is completely depleted from the water of station V. At station VII, which is too near to Tiran Straits, silicate concentrations greatly increased at the surface and decreased with depth till 800 m depth affecting the area that surrounds this station (0.72-0.16 μmol l^{-1}). Reiss and Hotinger (1984) found that the upper 100 m in the Northern area have a similar silicates content in summer like the upper waters in the north, while the deeper (100-400 m) waters of the southern sector are richer in silicates. In winter the whole water column down to 400 m in the southern sector is appreciably changed in silicates content that occur in the deep water, except during the diatom bloom in March. The relatively high silicates in the deep water of the Gulf immediately inside the sill during summer is probably connected with the apparently transient deep inflow of Red Sea water at sill depth. Table (1) illustrates that average silicates content in Northern Red Sea is higher than in the Gulf of Aqaba. Its content at surface and bottom water of station VII are equal (0.55 $\pm$ 0.11 and 0.54 $\pm$ 0.34 μmol l^{-1}). Grasshoff (1969) found that silicate values of 6-7 μmol l^{-1}, the water of the Red Sea flows over the sill of Bab El-Mandab and cascades over the southern side. This water is identified by the relatively small silicate values as it spreads under the silicate rich intermediate water of the Gulf of Aden.

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