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HYDROGRAPHIC FEATURES IN THE GULF OF SUEZ AND THE ESTIMATION OF ITS WATER AND SALT BUDGETS

By

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Key Words: Gulf of Suez, water and salt budgets.

ABSTRACT

The available oceanographic data in the Gulf of Suez were used to illustrate its hydrographic features. Current observations recorded during the period June-July, 1981 were used to estimate its water budget. The results showed that the water salinity of the Gulf is usually higher than that of the Red Sea with a clear gradient from the south (40.2-40.5 ‰) to the north (42.0-42.7 ‰), with more stronger gradient in its central part. The water structure appears to compose of two layers; the warm less saline light water at the surface and the cool high saline dense water near the bottom. Instead of the unidirectional flow that directed northwards along the Gulf; eddies, meanders and transverse currents seem to occur mostly over the whole basin. After the deepening and widening of the Suez Canal and its lakes, the salinity in the Gulf and particularly in the Suez Bay showed a significant decrease which did not exceed 42.7 ‰ all the year round.

The water in the Gulf of Suez could be classified into three water masses: the Suez Bay and the northern part of the Gulf (with temperature and salinity ranges of (16.0-28.0 °C and 41.8-42.6 ‰); the central part (18.0-26.0° C and 40.8-41.4 ‰) and the southern part (20.0-28.0° C and 40.2-40.5 ‰).

The results obtained from the salt balance formula and the current observations, showed that the water exchange with the Red Sea is about

$2.3\text{-}6.0 * 10^4\ m^3.sec^{-1}$ for the different cruises. The water and salt budgets as obtained from water and salt budget equations indicate the presence of the diffusive fluxes beside the advective ones.

INTRODUCTION

The Gulf of Suez at its extreme northern part of the Red Sea was subjected in the last few decades to continuous release of waste effluents from oil fields and refineries, industries and sewage. Such pollutants affected the marine life and man.

Among the cruises had being undertaken in the Gulf for short periods are the following vessels: the Egyptian R/V MABAHISS (Dec. 1934), the Japanese R/V SHOYO MARU (March, 1959), the American R/V ATLANTIS (Feb., 1965), the Russian R/V ICHTIOLOG (Sept. 1966), the French R/V GIRAUD (14.1-11.2.1963 and 24.3-14.4.1972), the Egyptian boat Karam El-Suez (July, 1981), and the French R/V MARION DUFRESNE (June-Oct., 1982). The available data obtained from the previous cruises, which were mostly conveyed during winter and early spring seasons, have been analyzed as an attempt to understand the hydrological conditions of the Gulf, its water characteristics, its water exchange with the Red Sea, and its water and salt budgets. In addition, it may help in identifying the most seriously affected areas which need more intense studies in the next field work.

OBSERVATIONS

The observations covered water temperature and salinity measurements at stations selected along the Gulf of Suez (Table 1) as well as at a reference station outside the Gulf (Fig. 1).

Current observations have been recorded for few weeks (July, 1981) at four locations at the entrance of the Gulf in the vicinity of Ashrafi Island (Fig.2), and at Ras Shukeir (March-April, 1972).

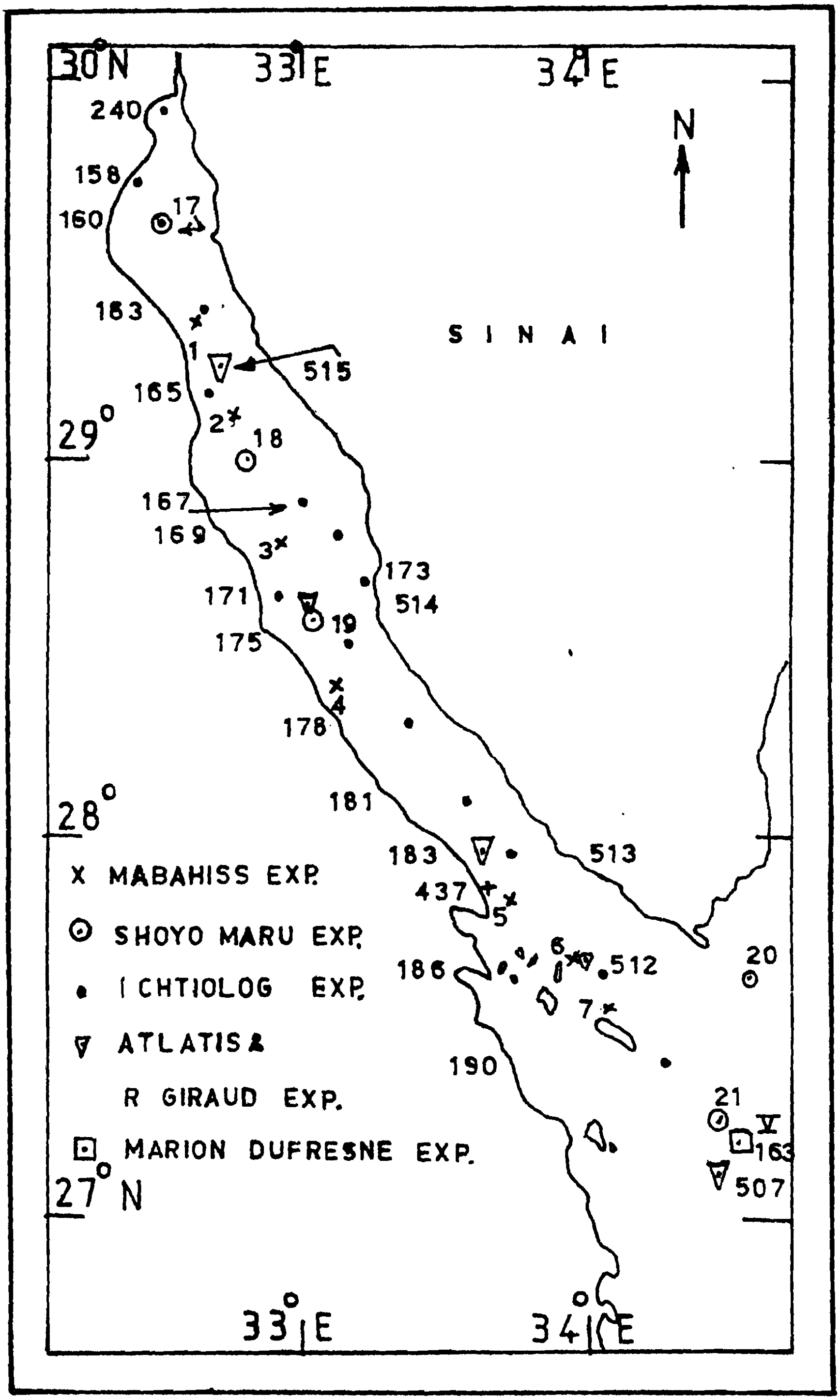

Fig. 1 The Gulf of Suez Map and the location of stations.

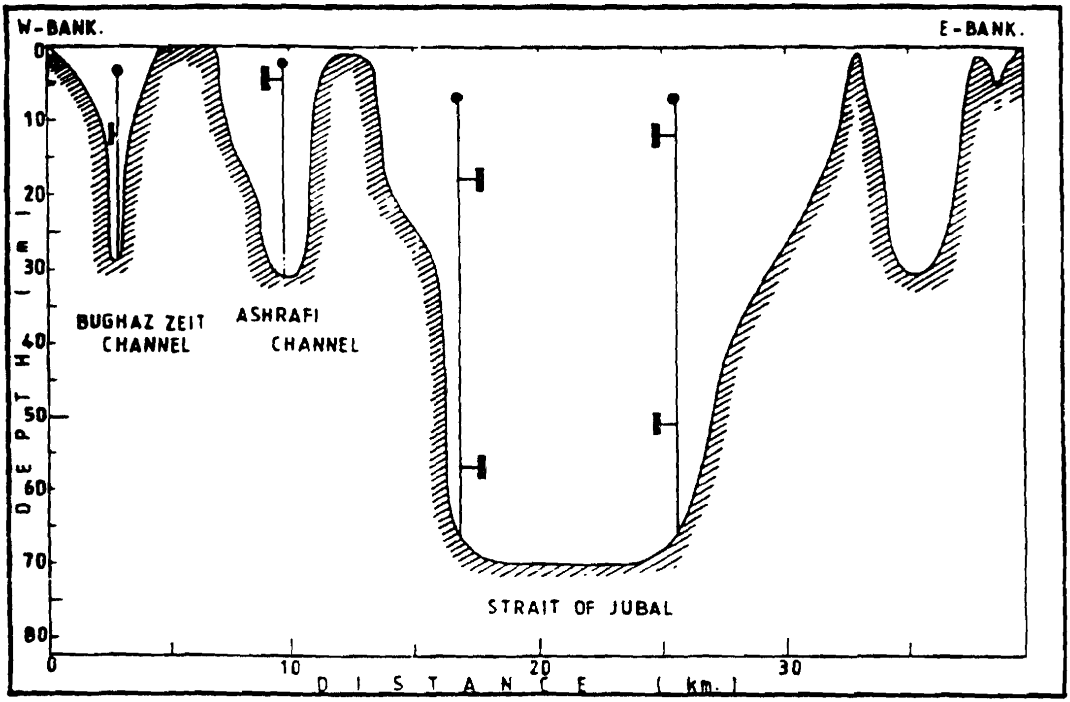

Fig. 2 Locations of current meters fixed along a section across the Strait of Jubal.

CRUISE	STATION No.	Lat.	Long.
I- MABAHISS	1 ×	29 23' 30" N	32 37' 00" E
(22-25.12.1934)	2 ×	29 08' 15" N	32 45' 30" E
Dec., 1934	3 ×	28 46' 45" N	32 57' 15" E
	4 ×	28 24' 30" N	33 07' 30" E
	5 ×	27 50' 00" N	33 43' 30" E
	6 ×	27 50' 15" N	33 55' 45" E
	7 ×	27 30' 40" N	34 03' 30" E
II- SHOYO-MARU	17 ⊙	29 38' 48" N	32 31' 18" E
(23-25.3.1959)	18 ⊙	29 00' 00" N	32 48' 06" E
March, 1959	19 ⊙	28 34' 42" N	33 02' 48" E
	20 ⊙	27 39' 24" N	34 34' 38" E
	21 ⊙	27 16' 48" N	34 34' 54" E
III- ATLANTIS	507 ∇	27 52' 00" N	33 36' 00" E
(Feb.1965)	507 ∇	270 07' 00" N	34 27' 00" E
IV- R. GIRADU	512 ∇	27 40' 00" N	34 00' 00" E
(14.1 - 11.2.1963	513 ∇	27 28' 00" N	33 38' 00" E
Jan. - Feb. 1963	514 ∇	28 38' 00" N	33 03' 00" E
	515 ∇	29 15' 00" N	32 44' 00" E
V- MARION	V ⊡	27 14' 00" N	34 32' 00" E
DUFRESNE	163 ⊡	27 14' 00"N	34 32' 00" E
(June- Oct.1982)			

Table 1. The location of stations for the different cruises.

RESULTS AND DISCUSSION

Most of the previous investigators postulated the same trend of the temperature and salinity distributions in the Gulf and its water exchange with the red Sea. They noticed that the temperature decreased vertically with depth and horizontally from south to north, while salinity decreased at all level from north to south (Luksch, 1908; Vercelli,1927; Gorgy and Shaheen, 1964; Morcos, 1970; Maillard, 1974; Wyrtki, 1974; and El-Sabh & Beltagy, 1983). On the other hand, the vertical distribution of salinity shows that the salinity decreases with depth in the North whereas it increases in the South (El-Sabh and Beltagy, 1983) . Moreover, they noticed that a warm less saline water flows into the Gulf from the Red Sea and a colder saline bottom water is moving in the opposite direction . They attributed the increase of salinity to evaporation and to the salt deposits in the Bitter Lakes. Morcos (1970) assumed that the salt layers below the region of the Gulf may contribute also to the increase of its salinity.

A- The Hydrographic Features and Thermo-Haline Circulation:

To follow up the changes in the parameters from one cruise to another, the vertical distributions of temperature and salinity along the Gulf have been presented for each cruise (Figs. 3-6). The resolution of the isolines was increased whenever required. The temporal changes of temperature and salinity over the year round for the outer station at the head of the Red Sea were illustrated in Fig.7. The hydrographic features and the associated circulation for the different cruises are as follows:

1. During the period 22-26 of December 1934, the Gulf of Suez was surveyed along its axis by the Egyptian R/V MABAHISS. The vertical distribution of temperature (Fig. 3a) is presented in some detail to expose the different processes that are taking place during that time of the year and the type of interaction of the different water masses within the basin or with that outside at the head of the Red Sea. During the survey, SW and SE winds prevailed at stations 3 & 4 respectively, and hence accelerated the inflowing surface warm water towards the North. On its due course, it became cooler and denser and has the ability to sink down. At stations 5,6 and 7 the NE, W & NE winds dominated in respective. Such wind system drives the upper surface layer,

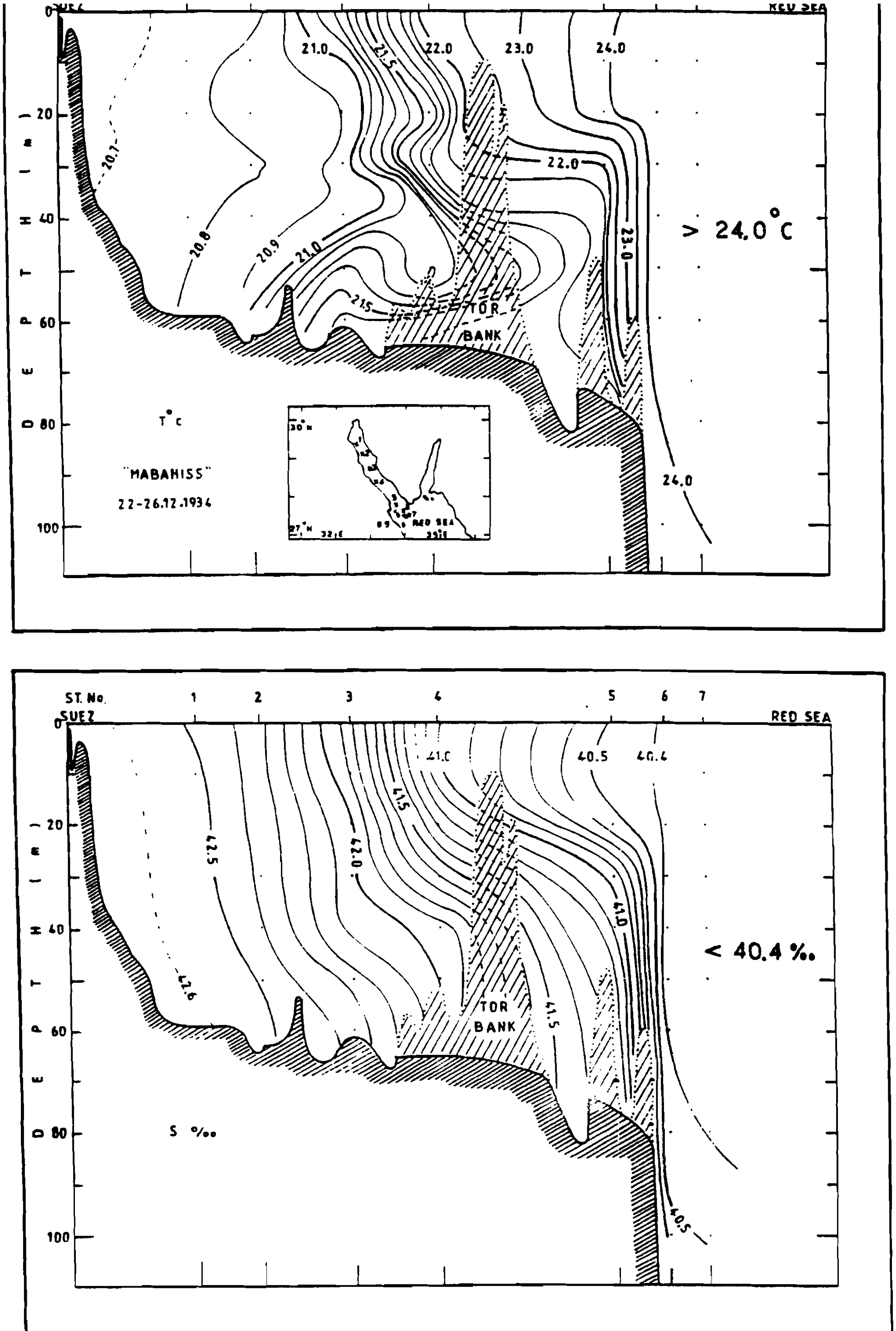

Fig. 3 Vertical distributions of temperature and salinity for MABAHISS EXPEDITION

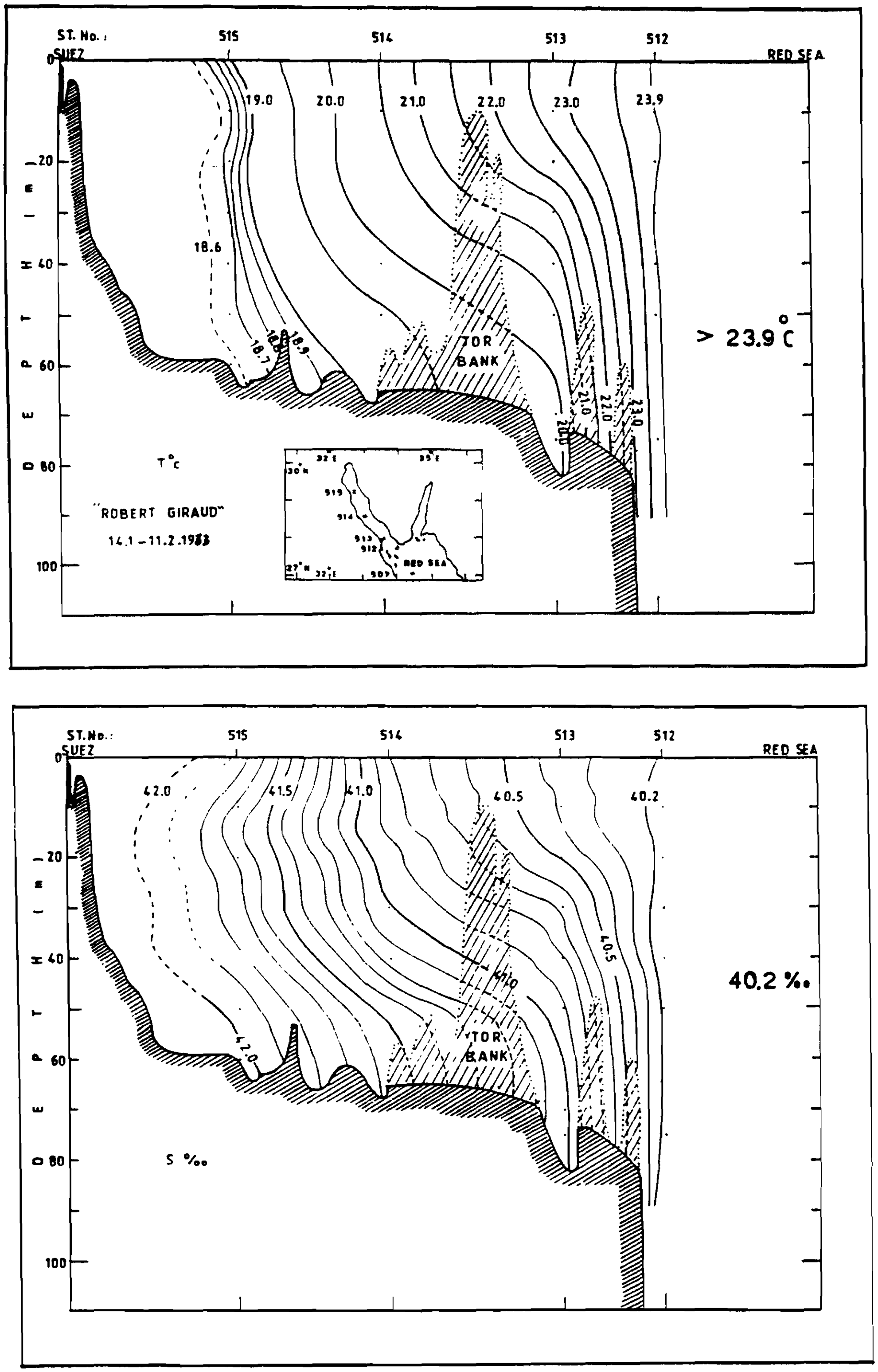

Fig. 4 Vertical distributions of temperature and salinity for R.GIRAUD EXP.

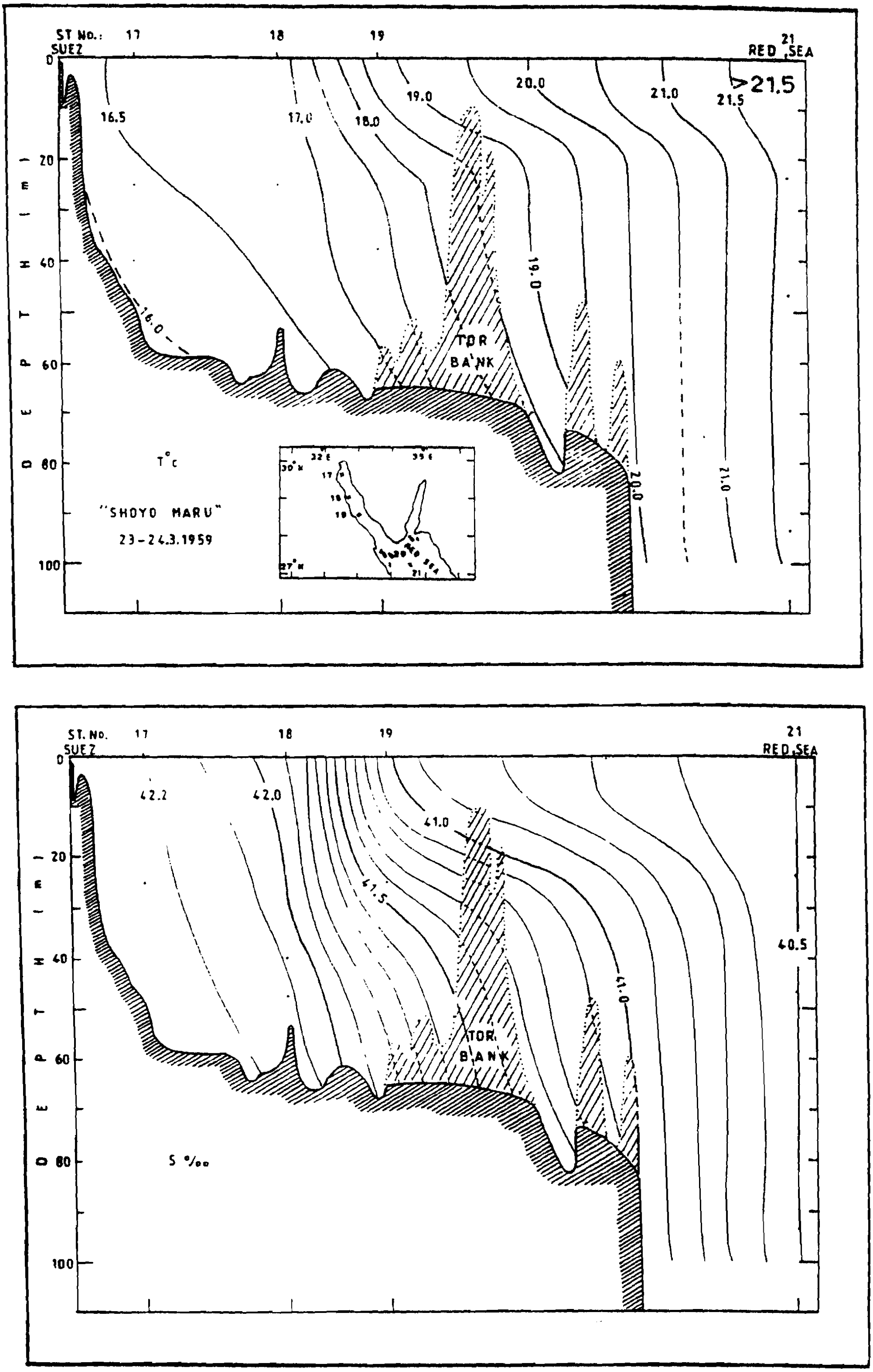

Fig. 5 Vertical distribution of temperature and salinity for SHOYO MARU EXP.

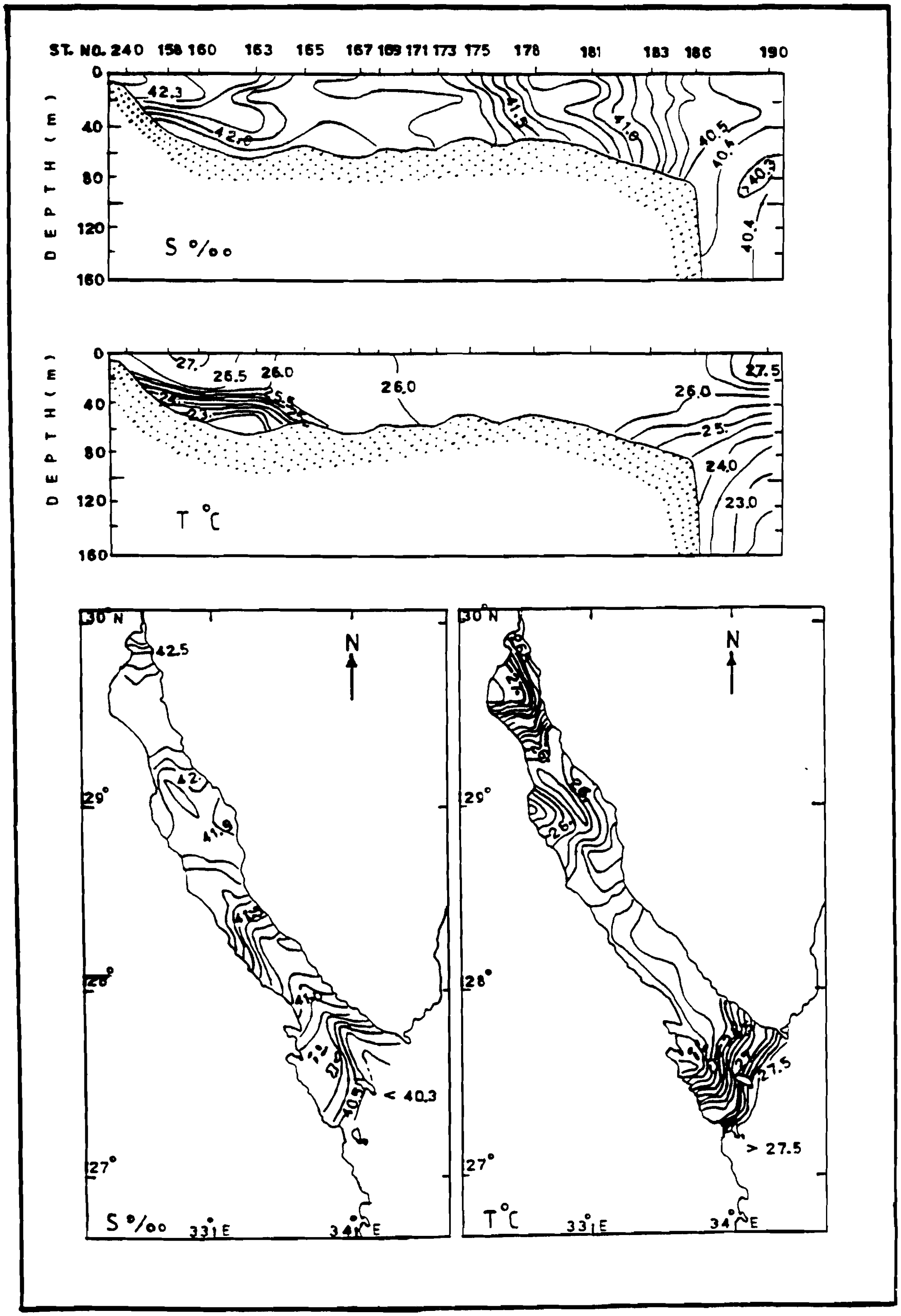

Fig. 6 Horisontal and vertical distribution of temperature and salinity for ICHTIOLOG EXP.(after El-Sabh and Beltagy).

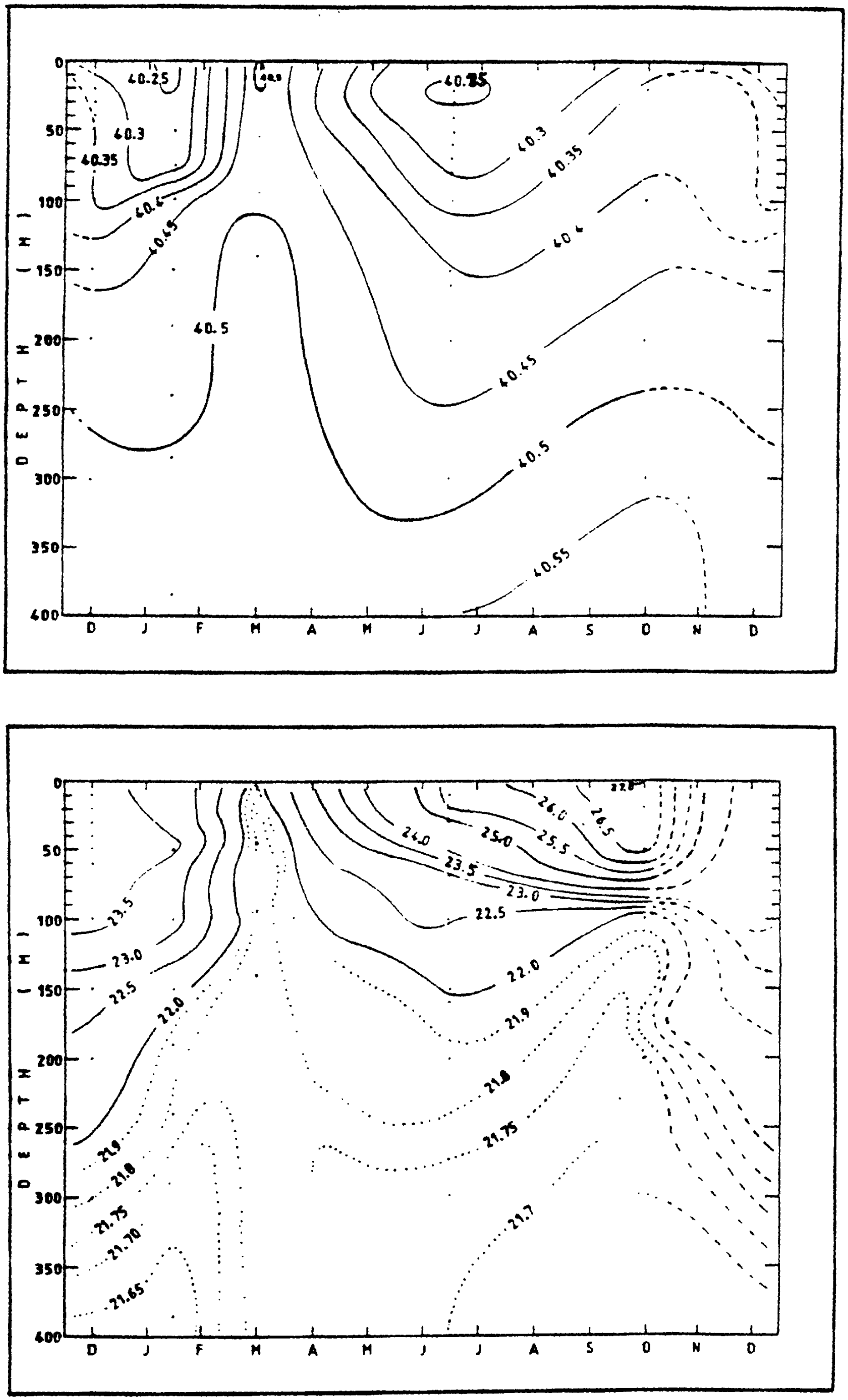

Fig. 7 The temporal changes of temperature and salinity for the outer station at the head of the Red Sea, over the year round.

within few meters thick thick southwards producing a divergence condition allowing for the intermediate Red Sea warm water to penetrate into the Gulf below the surface layer. Such oscillations in the water movements forward and backward, caused by the diversity in the wind conditions, permits the warm water near the bottom (between stations 3 & 4) to be trapped and mixed with the surrounding cold water to overcome the instability in its buoyancy. Near the continental shelf, the summer thermocline could be readily observed at depths between 20 - 40 m in the southern part of the Gulf. Therefore and according to the different circulation patterns, the Gulf could be divided into five segments:

I- A very shallow water basin in the extreme northern part of the Gulf (Suez Bay) affected by the meteorological conditions. It is rapidly cools in winter (about 16.0°C) and completely mixes under the action of the wind, while in summer its soon warms (28.0°C) as a homogenous or a stratified basin according to the wind conditions. Its hydrography was given by Meshal (1967).

II- The northern part of the Gulf which is nearly homogeneous in the vertical direction.

III- The central part of the Gulf which is located to the North of Tor Bank. The existence of the bank at the middle of the transverse section in that region permits both the formation of gyres and the rotating currents around it. The existence of such processes underway facilitates the mixing processes before reaching the end of the Gulf. It is worth to mention that such situations convert the unidirectional motion to a complicated one. Therefore, it is concluded that, in the vicinity of Tor Bank one would expect to find a complicated current pattern. This could be easily achieved when considering the current observations near Ras Shukier (Maillard, 1974).

IV- The southern part of the Gulf that located to the south of Tor Bank and to the north of continental shelf presents mostly the condition of the Gulf before starting the mixing processes in the upper surface layer and the type of water near the bottom.

V- The continental shelf area, which shows the typical type of water in the most extreme northern part of the Red Sea during that time of the year.

The vertical distribution of salinity (Fig. 3b) gives mostly the same behavior of the water masses as previously described in the temperature distribution.

2. During the period 14.1-11.2.1963, the second cruise was conducted on the French R/V Cdt. ROBERT GI. The vertical distributions of both temperature and salinity (Fig.4) were nearly similar to the previous cruise. Due to the lack of data in the vicinity of Tor Bank, the interpolation is incomplete. Generally, the temperature relatively decreased due to continuous cooling. Stratification features are nearly disappeared and was replaced by homogeneous water columns of homo-thermal and homo-haline waters. The central sector indicates the mixing between the surface and the bottom water. The pronounced feature of decreasing salinity in the northern sector of the Gulf. This reveals the insignificant influence of salt beds in the Bitter Lakes on the water of the Suez Bay.

After the reopening of the Suez Canal for navigation and the last widening and deepening projects after 1975, the salinity of the water in the Bitter Lakes did not exceed 43.5‰ (Soliman and Morcos, 1990). In addition, the salinity in the Suez Bay also did not exceed 42.7‰ all the year round particularly in autumn and winter.

3. During the period 23-24 March 1959, the third cruise was carried out on Japanese R/V SHOYO MARU. The vertical distributions of temperature and salinity (Fig. 5) showed the typical winter pattern. The temperature decreased strongly showing values of less than 17.0°C, while salinity was nearly identical as in Fig. 4.

4. The last cruise was conducted on the Russian R/V ICHTIOLOG in September 1966. It was the only cruise that sampled stations across the Gulf. The horizontal distributions of temperature and salinity (Fig. 6) approved the current pattern (Fig. 8) suggested by Soliman ***et al.*** (1995) on applying the numerical methods. El-Sabh and Beltagy (1983) showed that the surface salinity varied between a maximum of 42.85‰ at Suez Bay and a minimum

of 40.14‰ at the south of the Gulf, i.e. it decreases from north to south as well as from west to east.

Generally, the vertical distributions of temperature and salinity also illustrate the existence of the different sectors and the stratification feature both at the head of the Red Sea and the Gulf of Suez.

B- Water Characteristics

The T-S diagram (Fig. 9), relating all the considered cruises in the present work, illustrates the characteristics of the different water masses along the gulf and at the head of the Red Sea. The water at the head of the gulf fluctuates between density values of σ_t 26.5 and 28.5. In summer, the surface water is warm, less saline and hence of low density. As the air temperature starts to decrease on moving towards the winter season, surface water cools and sinks down. The water parcel at the isopycnal 26.5 starts to move vertically downward on the diagram with nearly the same salinity value. Temperature showed a continuous decrease with time, causing an increase in the rate of mixing through the convection processes until the whole column reaches the same low temperature and high salinity values ($\sigma_t = 28.5$). Thus, such water characteristics in the Suez Bay reveals that temperature is mostly the main factor influencing the water density between winter and summer. Therefore, it is concluded that evaporation is not the main factor that drives the lower layer towards the south in the Gulf. There are other factors that are taking place in each sector along the Gulf, they are mainly mean sea level, variation in temperature, wind conditions and the type of water circulation. In summer and early autumn, the temperature is nearly of the same order over the whole area (26.0-27.0° C), while salinity differs greatly from North to South (42.3-40.5 ‰). At the head of the Red Sea, water below 200m deep has nearly a constant value of temperature and salinity of about 21.6-21.8° C & 40.5 ‰ respectively. This reveals that the water of the Gulf during summer does not contribute to the deep water formation in the Red Sea, but is going to mix with the intermediate water of the sea.

As the surface Red Sea water enters the Gulf, its characteristics change until it reach the head of the Gulf. It is clear that, while the origin of these water masses is the same, yet each sector of the basin has its own water characteristics. These features enforced the aforementioned results concerning the thermohaline circulation.

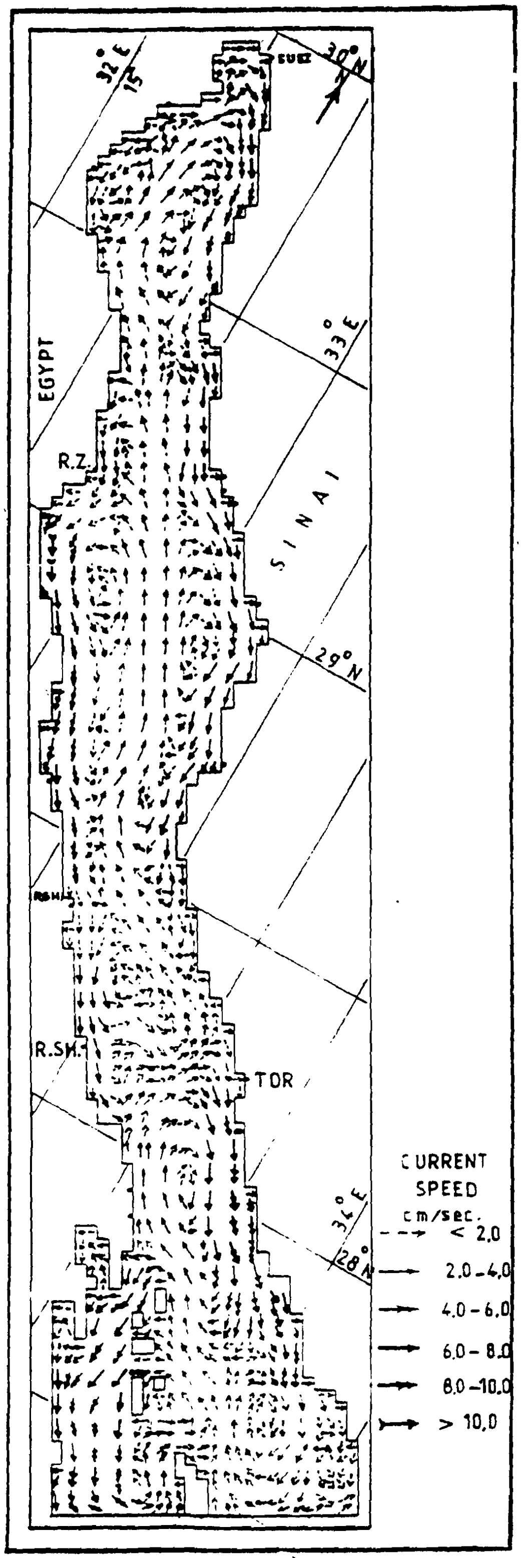

Fig. 8 Computed wind induced current velocities in the Gulf of Suez with wind strees 1 dyne/cm^2.(after Soliman et al., 1995).

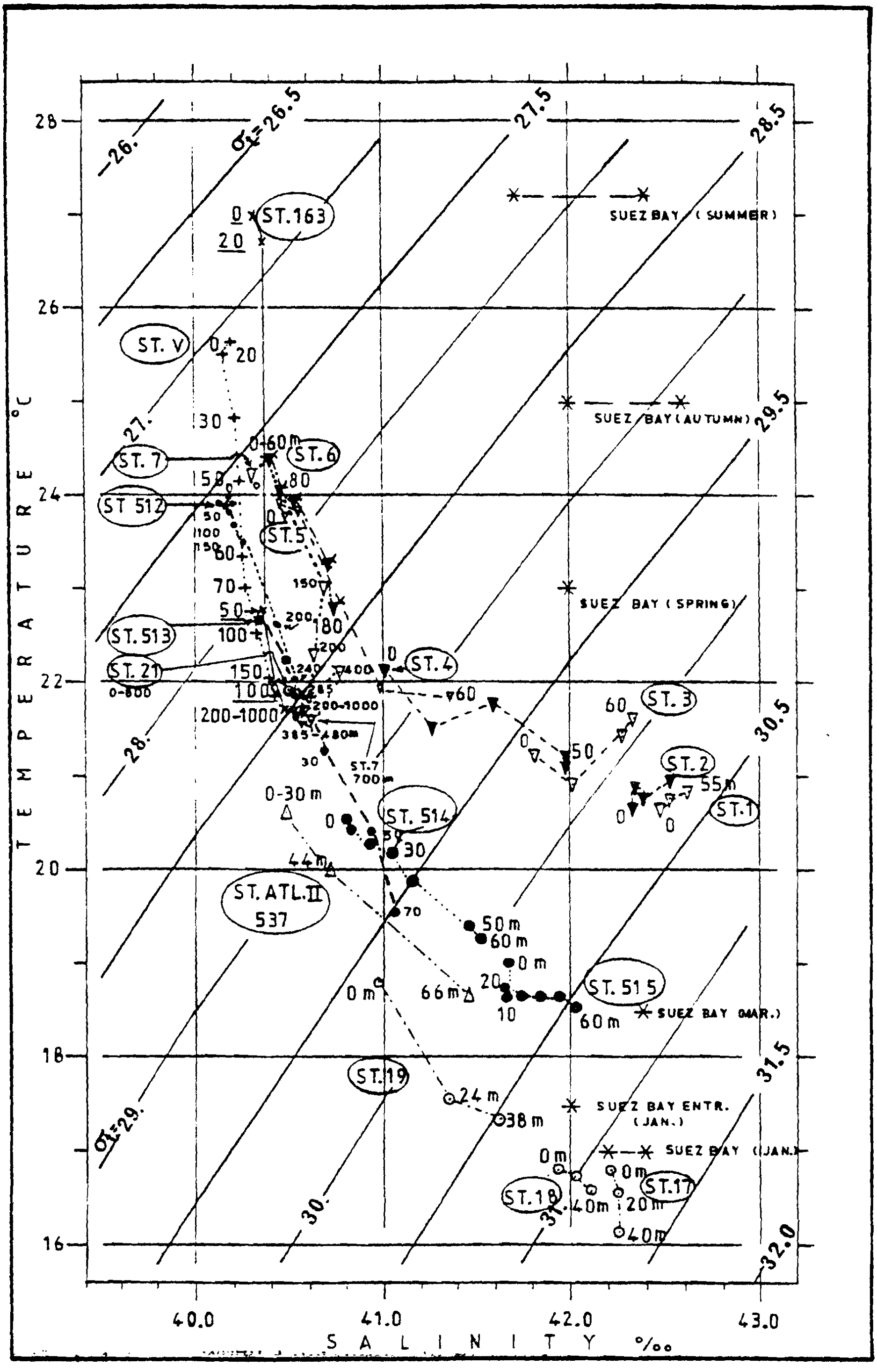

Fig. 9 T-S diagram including all stations of the different cruises.

From Fig. 10, it is also clear that the salinity values have been decreased particularly in the northern sector of the Gulf. Therefore, it can be assumed that after the completion of the Aswan High Dam and the continuous deepening of the Suez Canal, the salt deposit in the Bitter Lakes (Soliman and Morcos, 1990) has insignificant influence on the water salinity of the Gulf.

Generally, the area extending between the head of the Red Sea and the head of the Gulf of Suez could be divided into three water masses:

1- The water in the Suez Bay and the northern sector of the Gulf have temperatures between 16.0 and 28.0°C and salinities between 41.8 and 42.6‰.

2- The water in the central sector has temperature varying between 18.0-26.0° C and salinity between 40.8-41.4 ‰..

3- The water at the entrance of the Gulf and at the head of the Red Sea which has temperature between 20.0-28.0°C and salinity between 40.2-40.5 ‰..

These water masses could be readily distinguished if the spatial changes of salinity be (at surface, 20, 40 & 60m deep) considered for each cruise (Fig. 10). The obtained pattern indicates the followings:

a- The salinity of the northern sectors (1-3) are almost constant for each cruise. Similar feature is found in the southern sectors (6-8).

b- The central part of the Gulf, which involves the sectors (3-6), shows a distinct variation in salinity between the surface and the bottom.

c- The salinity increases horizontally towards the north at the surface, while it decreases southward near the bottom.

d- The changes are almost insensible in the northern and southern sectors, while abrupt changes occur in the central part.

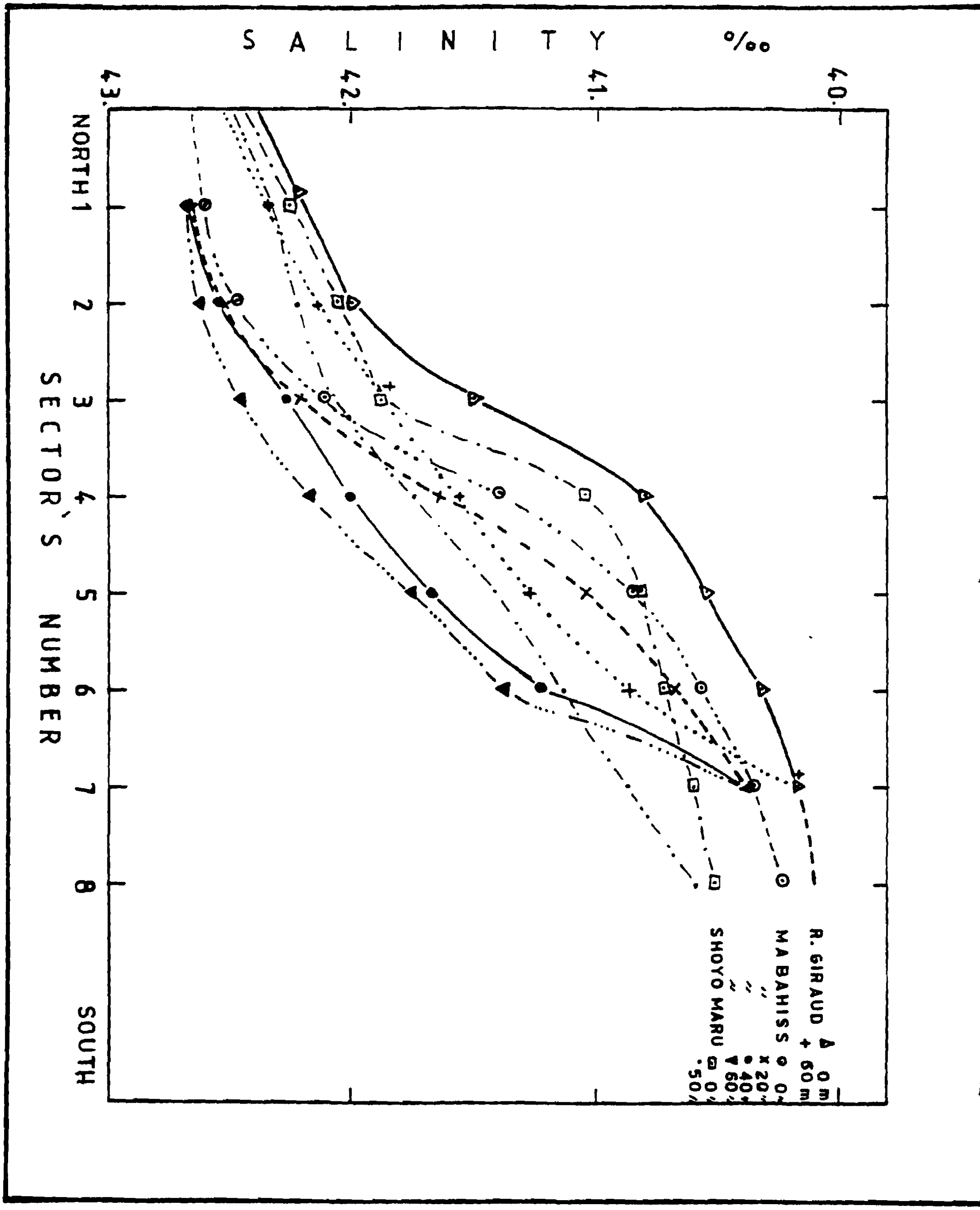

Fig. 10 The spatial changes of salinity along the Gulf for the different cruises.

Such patterns reveal that evaporation is not the main reason that causes the increase or decrease of salinity in the central part. Other processes as diffusive fluxes may act on to produce these changes , which will be regarded later when considering the water and salt fluxes along the Gulf.

C- The Successive Changes of Temperature and Salinity With Time

In order to follow up the exchange of water between the Red Sea and the Gulf of Suez, the successive changes of temperature and salinity with time at a station located at the extreme northern part of the Red Sea near the entrance of the Suez Gulf was constructed (Fig. 7).

In winter, from November to March, mixing processes take place in the upper surface layer (about 100m thick). The temperature decreases rapidly from 26.0°C to less than 24.0°C at the surface. With the beginning of December, the upper surface layer increases in its thickness (more than 200 m) due to the intense mixing showing a homothermal structure with temperature 23.66°C and salinity 40.30 ‰.. In February, the temperature shows a continuous fall reaching the minimum value in March below 22.0°C, while salinity increases approaching the proper salinity value of the deep water in the Red Sea. The whole column from the surface to depths more than 400 m appears to be homo-thermohaline with temperature less than 21.9°C and salinity of about 40.5 ‰.. Therefore, convection appears to be the most pronounced mechanism during winter which helps in the formation of the deep water in the Red Sea. Such process is clearly observed in March (Fig. 7), during which the SHOYO MARU cruise has been undertaken. The flow seems to be diverging with the upwelling of the intermediate water to the surface. The flushing of the low saline water into the Gulf is expected to be reduced. This feature has been noticed in the current observations taken during that time of the year. In April, water starts to stratify and the thermocline is completely developed during August and September.

In summer, strong wind dominates the extnorthern part of the Red Sea, and hence mixing processes take place in the upper layer (40-80 m), which act on deepening the thermocline . In addition, during that time of the year cool water is appeared to rise to the subsurface water, which is either uplifting from the deep water of the Red Sea or streaming into the sea during the upwelling of the cold water from the Aden G. The entrainment of these cold waters suppress the rise in temperature gained through absorption of heat at the surface during summer, and hence the temperature falls rapidly to about 23.5°C.

D- Water Currents

Morcos (1970) and El-Sabh & Beltagy (1983) showed that the currents in the Gulf of Suez (tidal and non-tidal) run parallel to its axis. In vicinity of the coasts and shoals the current has a gyratory character (Morcos, 1970), or a less regular movement pattern (El-Sabh and Beltagy, 1983). In the upper strata, the non-tidal currents are very sensitive to the effect of local winds and decrease considerably with depth. Morocs (1970) also added that with persistent southeast winds the currents attain high velocities (30-35 cm/sec) comparable with those of tidal current but remain feeble in the presence of northwest winds. With southeast winds, the northward surface current decreases with depth until it becomes inverted, going southeast as a bottom current and flowing out in the Strait of Jubal. During neap tide, the non-tidal currents may exceed the tidal currents and the resulting appears in one direction.

During the period 24/3-14/4,1972, current observations were taken in the vicinity of Ras Shukier by the French R/V ROBERT GIRAUD. The current is frequently varied showing a great diversity at the surface. The surface current is directed to the North (320.0°) with a mean speed of 12.5 cm/sec, while the lower layer is directed towards the south (180.0°) with a mean speed of 18.1 cm/sec (Maillard, 1974).

In 1981 (June-July) current meters were fixed at the entrance of the Gulf in the vicinity of Ashrafi Island (Fig. 2). The observations indicated a great variety in the speed and direction from east to west and with depth. The tidal currents are strong in the vicinity of Jubal Strait.

Along the eastern side of the strait and the Asharfi Channel, a southward flow is driven in the upper 10 m layer by the persistent north winds which indicates the existence of three-layer structure for short duration .

E- Water and Salt Budgets

The water and salt budgets of the Gulf of Suez have been estimated by applying the principle of continuity on the conservative parameters as volume of water transport and salt content. Since no rivers enter the region and rainfall is practically absent, evaporation will be considered as 1 cm/day in winter, 1.75 cm/day during summer at the entrance of the Gulf, while at Suez evaporation is given as 0.6-0.8 cm/day in winter & 1.2 cm/day in summer (Egyptian Meteorological Department).

If it is assumed that evaporation is the solely factor that causes an increase of salinity as the water flows northward into the Gulf ignoring the influence of the suez canal; then the salinity will increase with a constant rate in proportion to the rate of evaporation. Therefore, if the inflowing water has a salinity of 40.69 ‰ at the entrance, it will reach the head of the Gulf with a salinity 41.31 ‰ (assuming a mean evaporation value of 0.9 cm/day in winter). If this water sinks there and flowing in the reverse direction to the south, it well arrive at the entrance without a significant change in its salinity (Fig. 11 i-b).

Hence, in order to get a gradual increase in salinity from 40.69 ‰ at the entrance to about 42.6 ‰ at the head of the Gulf, diffusive fluxes must proceed between the two layers. Such processes are very slow in the order of $4.0 * 10^{-4}$ cm/sec.

Assuming that no mixing is taking place along the Gulf and the mean sea level is constant, then the principle of conservation of volume gives:

$$T_i - (T_o + E) = 0 \quad \text{.......................(1)}$$

where:

T_i : the volume transport by inflowing currents,
T_o: the volume transport by outflowing currents,
E : the water lost by evaporation.

If the total salt is assumed to be constant in the Gulf and ignoring the influence of density, then on applying again the principle of conservation of salt, therefore:

$$T_i * S_i = T_o * S_o \quad \text{.........................(2)}$$

If equations 1 & 2 are solved together, then,

$$(T_o + E) * S_i = T_o * S_o$$

or $$T_o / E = S_i / (S_o - S_i) \quad \text{.........................(3)}$$

When equation 3 is substituted in equation 1, the value of T_i is given by the following equation:

$$T_i / E = S_o T_o / (E * S_i) = S_o / (S_o - S_i) \ldots\ldots (4)$$

If the density of the upper (ρ_i) and lower (ρ_o) layers are taking into consideration, the principle of conservation of volume and salt are given by :

$$T_i * \rho_i * S_i = T_o * \rho_o * S_o \ldots\ldots (5)$$

$$T_o / E = \rho_i S_i / (\rho_o S_o - \rho_i S_i) \ldots\ldots (6)$$

$$T_i / E = \rho_o S_o / (\rho_o S_o - \rho_i S_i) \ldots\ldots (7)$$

As the above relationships were applied to the Gulf of Suez using salinities deduced from the vertical salinity sections and T-S diagram, the water and salt fluxes were determined. The Gulf was divided into six eqally distant sectors, excluding Suez Bay. These sectors have different evaporative water loss according to their surface areas. Evaporation rate is 0.6 cm/day at Suez and 1.2 cm/day at the entrance of the Gulf with a mean value of 0.9 cm/day in winter. The Gulf was assumed to consist of two layers as indicated by the current observations (Fig. 10). The surface layer has a thickness of 40.0m, while the lower one is 20.0m.

The schematic representation of water circulation and the corresponding water and salt budgets in the Gulf of Suez for the different cruises are presented in Fig. 11. The diagram gives an estimate for the water exchange ($2.3\text{-}6.0 * 10^4 m^3/sec$) between the Gulf and the Red Sea as well as the diffusive fluxes beside the advective ones.

In addition, the diagram indicates the followings :

1- The water transport into the Gulf in the upper layer varies from moth to month and generally increases from December to March, a trend which confirms the monthly mean sea level in the Red Sea and Gulf of Suez that rises in winter and falls in summer (Morcos, 1970).

2- The flow of the surface water along the Gulf shows beside the advection fluxes clear diffusive ones.

3- Whenever the surface water transport into the Gulf varies from one month to another, the sinking water at the entrance will show the same tendency but not in the same ratio.

4- The sinking processes may continue along the Gulf as in the case of R. GIRAUD Expedition (Fig. 11ii-c), which help in reducing the salinity of the lower layer before leaving the Gulf to the deep layers in the Red Sea. This behavior may explain the absense of the abrupt changes in the salinity values at the entrance of the Gulf.

This feature may focus the light on the important role of the extreme northern part of the Red Sea as well the northern region to the entrance of the Gulf in the formation of the deep water of the Red Sea.

5- A common characteristic has been indicated by the considered Expeditions. The amount of water transport through the third sector from the entrance in the upper and lower layers showed a constant value of about $2.0*10^4$ m^3/sec. This sector coincides with the location of Tor Bank. Whatever is the amount of water that transports into the Gulf at its southern entrance, the northward or southward water flux is limited to the above mentioned value. From the oceanographic point of view the entrance of the Gulf should be located in the vicinity of Tor Bank. A fact which confirms the results obtained in previous works by Soliman & Anwar (1994) and Soliman ***et al.*** (1994), which indicate a presence of a nodal point for M2-tide at that location.

6- The vertical diffusive fluxes occurring to the north of Tor Bank could be related to the limited amount of the water flux in the lower layer at Tor Bank, where a counter clockwise motion in the vertical direction is taking place. Therefore, in addition to the rotational motions in the horizontal direction, there are other rotational motions in the vertical direction as diffusive fluxes along the Gulf.

It is worth to emphasise that not only the numerical model (Soliman ***et al.*** 1995) could investigate the rotational motion as well as sinking and upwelling processes but also the salinity gradient and salt balances can give a brief

Fig.11a A schematic representation of water circulation and the corresponding water and salt budgets in the Gulf of Suez for the different cruises, using salt balance equation.

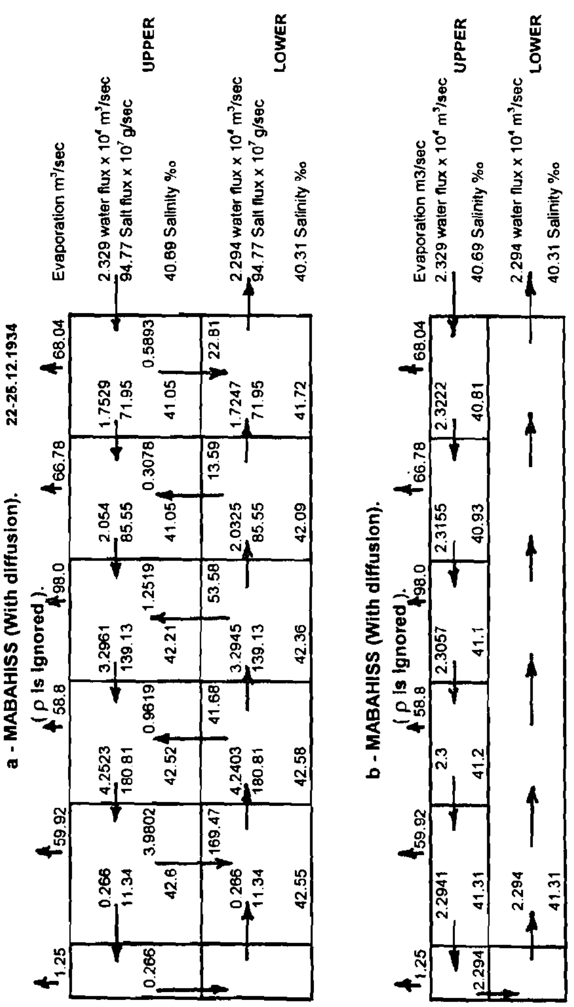

Fig. 11I.

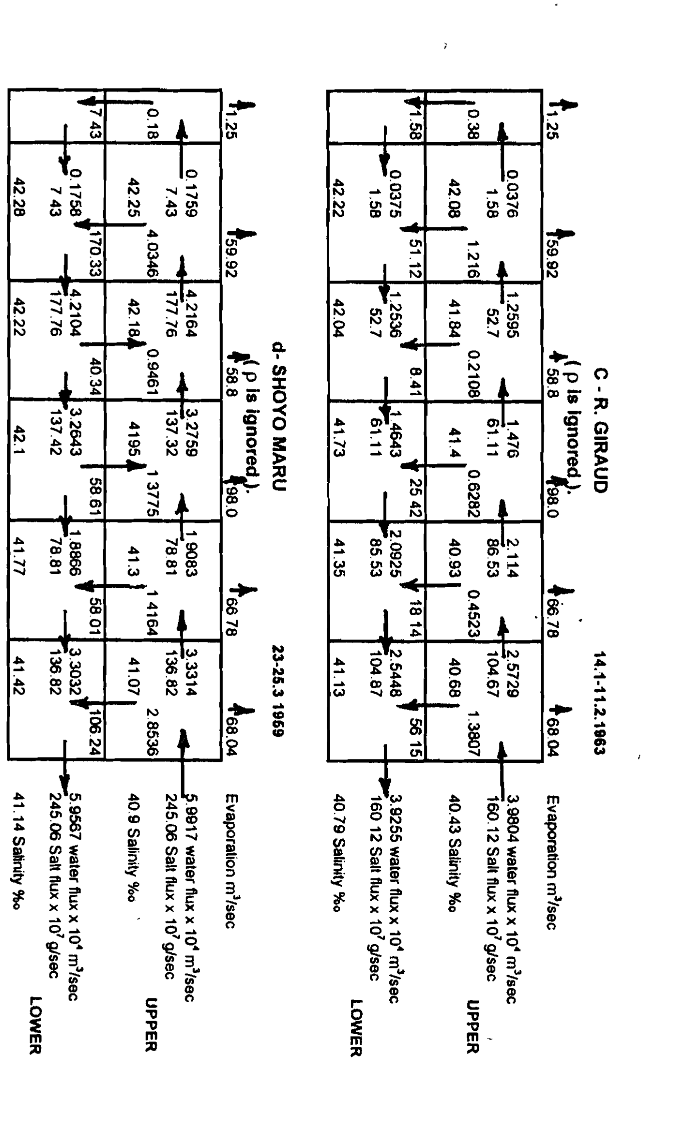
C - R. GIRAUD
(ρ is ignored).
14.1-11.2.1963
Evaporation m³/sec
3.9804 water flux x 10⁴ m³/sec
160.12 Salt flux x 10⁷ g/sec
40.43 Salinity ‰
UPPER
3.9255 water flux x 10⁴ m³/sec
160.12 Salt flux x 10⁷ g/sec
40.79 Salinity ‰
LOWER
d- SHOYO MARU
(ρ is ignored).
23-25.3 1969
Evaporation m³/sec
5.9917 water flux x 10⁴ m³/sec
245.06 Salt flux x 10⁷ g/sec
40.9 Salinity ‰
UPPER
5.9567 water flux x 10⁴ m³/sec
245.06 Salt flux x 10⁷ g/sec
41.14 Salinity ‰
LOWER

Fig. 11II.

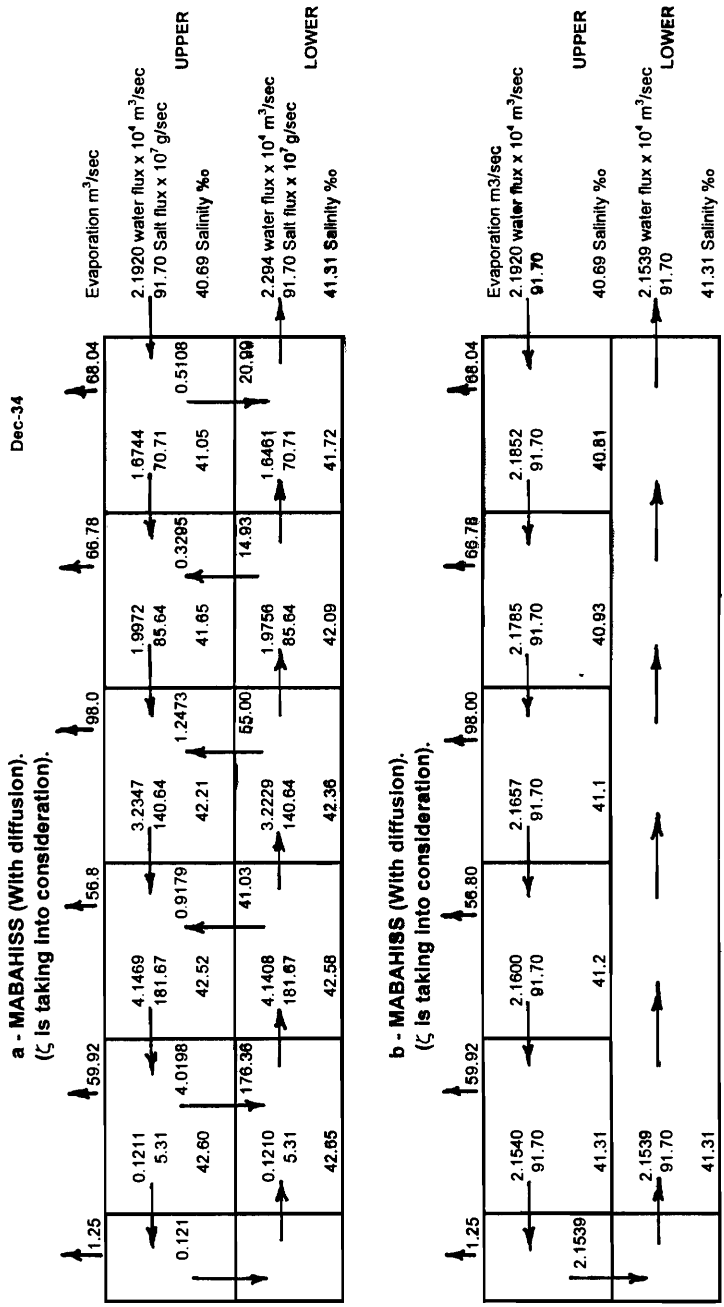
Dec-34
a - MABAHISS (With diffusion).
(ζ is taking into consideration).
Evaporation m³/sec
2.1920 water flux x 10⁴ m³/sec
91.70 Salt flux x 10⁷ g/sec
40.69 Salinity ‰
UPPER
2.294 water flux x 10⁴ m³/sec
91.70 Salt flux x 10⁷ g/sec
41.31 Salinity ‰
LOWER
b - MABAHISS (With diffusion).
(ζ is taking into consideration).
Evaporation m3/sec
2.1920 water flux x 10⁴ m³/sec
91.70
40.69 Salinity ‰
UPPER
2.1539 water flux x 10⁴ m³/sec
91.70
LOWER
41.31 Salinity ‰

Fig. 11 III

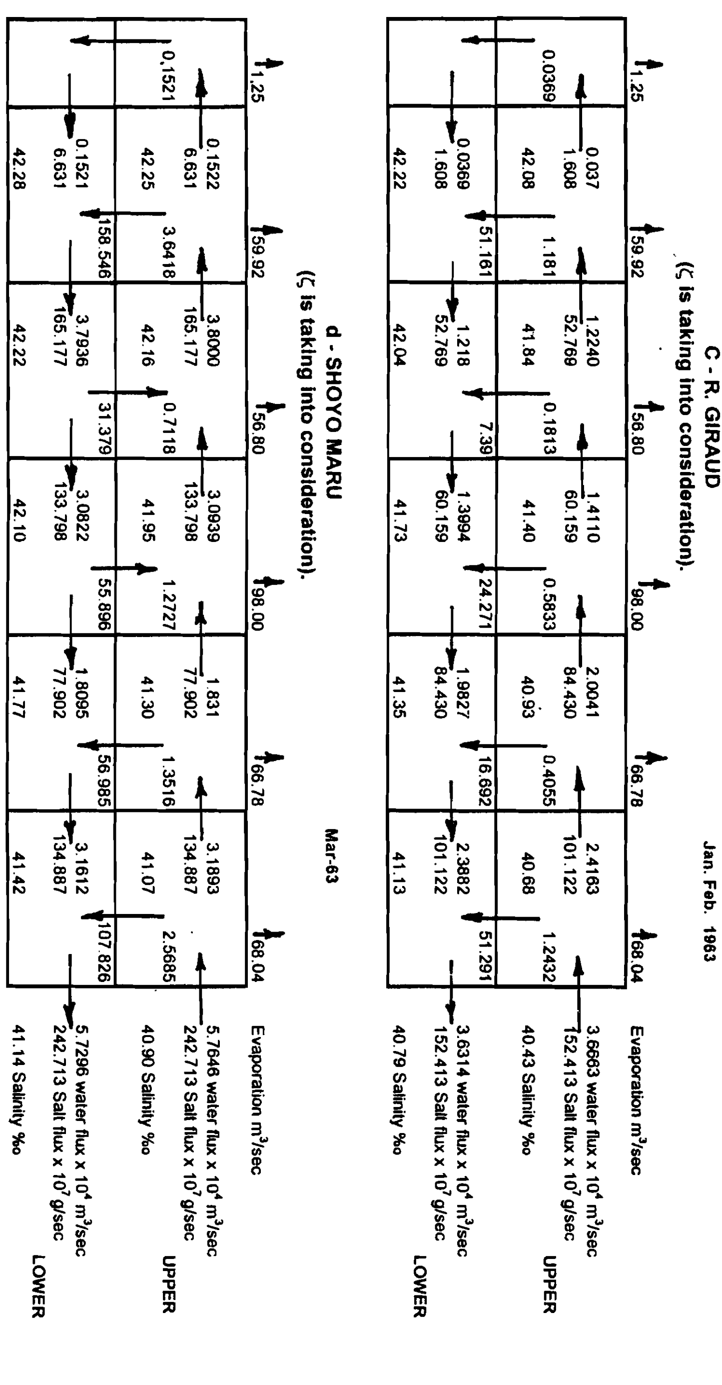
C - R. GIRAUD
(ζ is taking into consideration).
Jan. Feb. 1963
Evaporation m³/sec
UPPER
LOWER
water flux x 10⁴ m³/sec
Salt flux x 10⁷ g/sec
Salinity ‰
d - SHOYO MARU
(ζ is taking into consideration).
Mar-63

Fig. 11 IV.

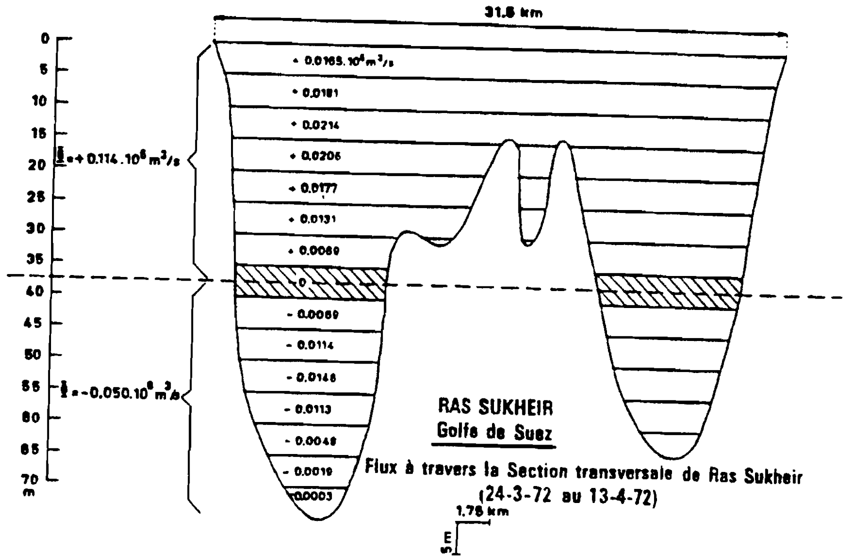

Fig.12 Water transport through a cross-section near Ras Shukeir using current observations. (after Maillard, 1974).

Table 2. Mean water current speed and direction and water transport in 10^{10} cm^3./sec at different levels at Ras Shkeir, Gulf of Suez, during the period 24.3 - 13.4. 1972 (after Maillard, 1974).

Depth (m)	5	10	15	20	25	30	35	40	45	50	55	60	65	70
Width (Km)	28.95	25.14	27.09	26.75	26.03	26.2	20	0	11.13	11.29	12.92	13.06	8.07	5
Current Speed cm./ sec	11.4	14.4	15.8	15.4	13.6	10	6.9	7.9	12.4	20.2	22.6	17.3	11.9	7.6
Current direction	340	341	320	325	320	306	302	220	189	182	180	184	189	187
Water transport * 10^{10} cm^3/ sec	1.65	1.81	2.14	2.06	1.77	1.31	0.69	0	-0.69	-1.14	-1.46	-1.13	-0.48	-0.19
water transport * 10^{10} cm^3./sec	11.4							5						

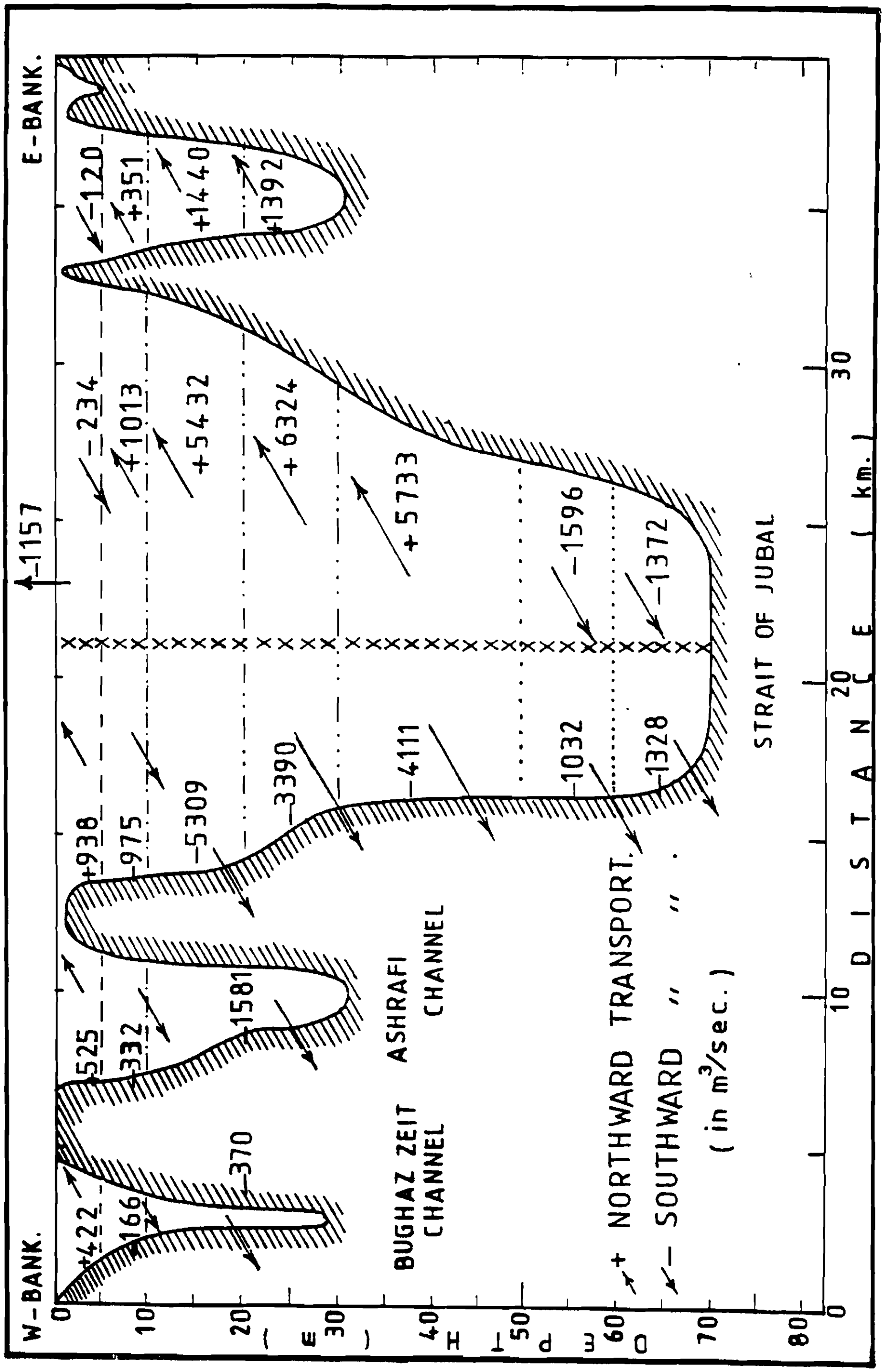

Fig.13 Water transport through a cross-section in the vicinity of Ashrafi Island.

demonstration for such processes. The diagram indicates the existence of sub-basins, each of which has its own circulation, which contributes to the general circulation in the Gulf. Moreover, the existence of Tor Bank as a submerged obstacle in the main channel has a significant influence on its water circulation. Maillard (1974) has used the recorded currents values in the Gulf to estimate the intensity of inflowing- and outflowing-water through a cross-section at the observation's site (Table 2). She divided the depth into eleven layers and hence calculated the amount of water transport at each (Fig. 12). She obtained a value of $11.6 * 10^4 m^3/sec$ for the inflowing water towards the north and $5.0 * 10^4 m^3/sec$ for the outflowing water towards the south. Such values are too high in compare with the values obtained by Wyrtki (1974) of about $2.6 * 10^4 m^3/sec$ or that already estimated in the present study using salt balance (Fig. 11).

The same current observations have been used in the present study taking into account the current pattern (Fig .8) as obtained by Soliman ***et al.*** (1995). The results obtained are in good agreement with that based on the salt balance.

In 1981 (June-July), current meters were deployed at the entrance of the Gulf in the vicinity of Ashrafi Island (Fig. 2). The observed values were used in the present study to estimate the water budget of the Gulf of Suez. The inflowing-and outflowing-water transports were estimated at the different regions of the cross-section. A schematic diagram for such values is given in Fig. 13, which is in good agreement with that obtained from the water and salt fluxes.

CONCLUSIONS

1- The Gulf of Suez was assumed as consisting of two layers structure, a warm less saline light water at the surface flowing into the Gulf from the Red Sea and a cool more saline dense water in the lower layer directed to the south towards the sea. In summer, a high possibility of existing three layers structure at its entrance due to the persisting winds.

2- The water movement in the Gulf is not simple, as believed before, a unidirectional flow; one at the surface to the north and the other near the bottom to the south. It is a complicated pattern in the horizontal and vertical directions. The accurate investigation of such processes needs an intensive net of observations all the year round which is expected to be carried out the near future.

3- Salinity values are usually higher in the Gulf than in the sea, while the temperature is mostly lower .

4- After the completion of the Aswan High Dam and the continuous deepening of the Suez Canal, the salt deposit in the Bitter Lakes has insignificant influence on the water of the Gulf.

5- The Gulf could be divided in terms of hydrographic conditions into five segments, each of which has its own water movement beside the general pattern.

6- Evaporation may not be considered the main factor that drives the water movements in the Gulf. There are other factors that are taking place in each sector along the Gulf, they are mainly sea level variation, temperature, wind conditions and water circulation.

7- The current system showed a great diversity at the entrance of the Gulf .

8- Diffusion processes are produced between the two layers which participate in increasing the salinity of the inflowing water at the surface.

9- The current observations recorded at the entrance of the Gulf in the vicinity of Ashrafi Island as well as near Ras Shukier have been used to estimate the water exchange with the Red Sea giving a mean inflowing water transport of about $2.3568 * 10^4 m^3 sec^{-1}$ and outflowing transport of $2.3672 * 10^4 m^3 sec^{-1}$. Moreover, the Knudsen's formula of the salt balance was used to determine the water and salt budgets, at its entrance and along the Gulf. The results obtained revealed the existence of rotating motions and diffusion processes.

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