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THE EXCHANGE OF WATER BETWEEN THE MEDITERRANEAN AND THE RED SEA THROUGH THE SUEZ CANAL.

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ABSTRACT

Seasonal water exchange is exhibited between the Mediterranean and the Red Seas which is highly controlled with the species characteristics of the water body of the Suez Canal and the belonging lakes. Six hydrographic surveys-mostly in summer - have been conducted along the Canal between Port-Said and Port-Tawfik during the period 1982-1986. Four cruises were involved in-depth surveys and have been undertaken to investigate the current regime particularly in summer. Temperature, salinity and currents have been observed. The mean water level along the Canal was taken into considerations. It should emphasize that the last two cruises of August and September 1986 gave an evidence of peculiar patterns of the water movement in summer and winter. The southward current set on earlier than that previously experienced. Consequently, the northward current regains its original direction more earlier.

The southward current regime along Suez Canal is highly affected by the significant amount of fresh waters discharged from Lake Timsah, Lake Menzelah and the entertainment of relatively low saline water from the Mediterranean which have been prevailing before the construction of the Aswan High Dam Presently, its amount fluctuates from year to year and consequently influences the water circulation in the Canal. The prevailing north winds also play an important role in driving the water into the northern and southern parts of the Canal. The water of the central part is affected by the high saline water from the Bitter Lakes and the low saline water discharging from the Sweet Canal at Ismailia and driven by the tidal currents. A current of more than 30 cm/ sec is observed in the northern part of the Canal which could be related to the high water level recorded at El-Kantara.

The last deepening and widening of the Canal is assumed to influence the resident time of the water in the Bitter Lakes and its water salinity The resident time of the water in the Lakes expected to be about three to four months. The minimum salinity of 43.5‰ is reached in the last few years and the salt barrier is disappearing, which is revealed by the free movements of the marine organisms between the Mediterranean and the Red Seas.

INTRODUCTION

The exchange of water between the Mediterranean and the Red Seas shows seasonal variations particularly between summer and winter. Such variations are due to different characteristics of Suez Canal water, in particular a salt barrier that might exist almost at middle part. In fact it is considered as an obstacle against the migration of the marine organisms between the joined Seas. These water characteristics have been attracting many investigators, since the Canal opening in 1869, to discuss the behaviour of its water movements and to conclude a general regime for its currents.

Although many works have been carried out to examine the water characteristics in the reaches of the Canal, in the lakes belonging to it and its entrances (Fox, 1926; Wust, 1934; Ghazzawi, 1935; Fouzi, 1951; Krauss, 1958; Morcos, 1959, 1960a, 1960b, 1967, 1970 & 1975; Morcos and Messieh, 1973; Morcos and Gerges, 1974; El-Sabh, 1967,1968 & 1969; Hassan and El-Sabh, 1975; El-Sharkawy, 1969; Miller and Munns, 1974; Sharaf El-Din, 1974; El-Sharkawy and Sharaf El-Din, 1983; and Soliman et al., 1987), the exchange of water between the two seas is still controversial. The present work is carried out mainly during summer seasons to throw more light on water exchange and to trace the movement of the salt barrier in the Canal if still existing.

OBSERVATIONS

A lot of surveys had been carried out during the period 1982-1986. The first work was conducted in 9 October, 1982 on R/V "Marion Duffersne" from Suze to Port-Said during its backtrip from the Red Sea, Gulf of Aden and Antarctic on its way to France. Surface water samples were collected at stations spacing of five kilometers. Two surveys were undertaken in 2-3 October, 1983 and 21-22 September, 1984 on "ABU El-SIBAH" boat. Once more water samples were collected in April, 1985 from Port-Said to Suez on R/V "LE NOROIT" on its way to the Red Sea. Finally, two surveys were conducted during the period August 29-September 12, 1986 on "ABU EL-SIBAH" boat, between Port-Said and Suez. During the second two cruises and the last surveys, water temperature and salinity as well as currents were measured using drifters, Ekman and Direct Reading Currentmeters at different depths.

BACKGROUND

a- The Hydrographic Characteristics of the Suez Canal:

According to Morcos (1980) the survey made by Jone C. Richards, H.

M. Malabar during the period November 1871-July 1872 showed that the water salinity was about 60-64‰ in the northern part and 42-44‰ in the southern part. The maximum salinity value of 68‰ was observed in the Bitter Lakes in October, 1871. Furthermore, his comparative analysis between his collected data of 1954/55 and Malabar's data of 1871/72 shows that the corresponding curves almost matching towards the entrances of the Canal, while having major discripancies in the central part (26‰ for 1871/72 and 48‰ for 1954/55). Fox (1926); Wust (1934) Ghazzawi (1935) and Faouzi (1951) found that for ten months of the year (Oct.-July) the high density water of the Bitter Lakes was driven northwards to Port-Said as the water level at Port-Tawfik is higher than that at Port-Said and intermediate in the Bitter Lakes. Meanwhile, during August and September the low density water of the Mediterranean flowed southward to lake Timsah and the high density water of the Bitter Lakes was extended to Suez, as the mean water differences at the two entrances are equalized and the water moves southwatds under the action of the wind.

b- The Mean Sea Level Differences at Port-Said & Port-Tawfik:

In winter (October-June) the mean sea level (M.S.L.) at Port-Tawfik (P.T.) is often between 18.30 m and 18.40 m compared with a M.S.L. between 18.0 and 18.10 m at Port-Said (P.S.). This head difference which reaches a maximum value of about 0.30 m in January, gives rise to a northward residual current. In summer (July-September) and due to the prevailing north winds the M.S.L. at P.S. of 18.20m is higher than that at P.T. of 18.0 m. This head differernce gives rise to a southward residual current from P.S. to the Great Bitter Lake (G.B.L.) and from G.B.L. to P.T.

Apparently, this is true, if we consider the Suez Canal as a simple channel connecting the Mediterranean and the Red Seas. In fact this not the case, since the M.S.L. was only available at P.S. and P.T. and sometimes at few locations along the southern part of the Canal. Such data is not enough to deduce the M.S.L. along the Canal. During the present study observations from nine locations (Fig. 1a) are used to construct the monthly M.S.L. along the canal (Fig. 1b), which seems to be a very complicated diagram and not a simple device as previously thought in relating the water level between P.S and P.T.

c- The Fresh Water Discharging into the Canal:

Miller and Munns (1974) showed that there is a significant effect of the Nile flooding on the Suez Canal through the fresh water canals entering Lake Timsah at Ismailia, and the Suez Canal from Lake Manzalah near P.S. Actually, before the construction of the Aswan High Dam, the effect of the Nile was very close to shore, which reduced the surface salinity to 37.0‰. Its influence extends to about 20 km into the Suez Canal. From that point to kilometer 70 the surface salinity varies between 41.5‰ and 42.0‰ as is abruptly lowered to 36.5‰ at Lake Timsah. Morcos (1975) mentioned that in September 1964, the mixed water of the Mediterranean and the fresh water of the Nile discharging at Damietta branch is clearly seen below the depth of 6 m outside the Canal which is then penetrating it and can be easily traced to about 18 km from P.S. While the water

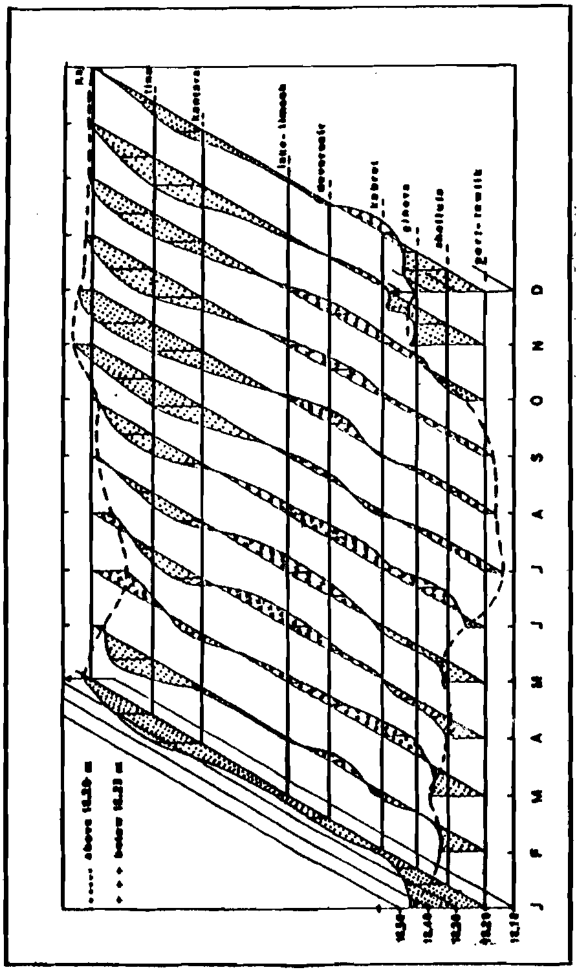

Fig. (1 b)
Monthly mean water level diagram along the Suez Canal averaged over the period 1980 - 1986.
.... Elevation above 18.20 m water level.
++++ Elevation below 18.20 m water level.

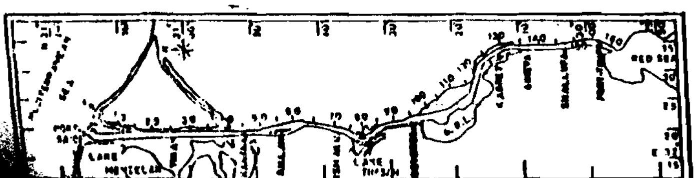

Fig. (1 a)
Suez Canal Map

discharged from Lake Menzalah (with salinity less than 20‰) into the Canal affect the water at the surface to about 5 m depth and can be traced in the northern part of the Canal to a distance of about 25 km from P.S. On going far to the south and nearby to Lake Timsah (80 km), the salinity section shows continuous increase with depth (34.0‰ at the surface, about 35.0‰ at 6 m depth and increases sharply downward). At kilometer 90, in the central part of the Canal, the vertical gradient is very strong where the salinity increases from about 35.0‰ at the surface to about 47.0‰ at 6 m depth. Below that depth the water is nearly homogenous of about 47.2‰ salinity. Morcos (1975) estimated the fresh water discharged into Lake Timsah as 16 x $10^6 m^3$/month during (May to September) and 22 x $10^6 m^3$/ month during (October to December). This water is then mixed with the high salinity water in the Lake and the central of the Canal (of about 43.0% salinity) reducing their salinities to less than 38.0‰ which is similar to the salinity of the Mediterranean water.

d-The Influence of the Winds:

As the winds prevail mostly from NNE, El-Sabh (1969) showed that the main reason of the southern flow is the wind stress on the water. During summer season and under the influence of the northern winds, the Mediterranean water penetrates into the northern part of the Canal reaching Lake Timsah and is responsible for reducing the salinity of the Lake water to less than 38.0‰. Morcos (1960a) showed that the northern wind prevailing on the Suez Canal region reaches its maximum frequency in September. This helps piling of water in front of P.S. and creating southwards current in the Canal.

e- Evaporation:

Krauss (1958) and Miller and Munns (1974) stated that the salinity of the Bitter Lakes will always remain above normal sea salinity even after complete dissolution of the salt bed. El-Sharkawy and Sharaf El-Din (1983) showed that the effect of evaporation is about three times that of the salt bed, hence the Lake will always be higher than that of the inflowing Red Sea water by 1.25‰.

f- Salt Bed in the Bitter Lakes:

Fox (1926) suggested that salt at the bottom of the Bitter Lakes may be dissolved by the end of the 20^{th} Century. Wust (1934) had estimated that the salt bed would be exhausted by 1970. Miller and Munns (1974) showed that, from the samples taken in G.B.L. In 1965 by Atlantis II, the salt deposits were probably exhausted.

In 1869, the depth of the Canal was about 8.0 m. Meanwhile, after the last widening and deepening in 1976, its depth reaches about 19.5 m, and accordingly the salt bed seems to be exhausted.

DISCUSSION AND CONCLUSIONS

a-The Water Characterstics as Observed from The Data of 1924/25 and 1934/35:

The density data of 1942/25 (Fox, 1926) and the salinity data of 1934/35 (Ghazzawi, 1939) are used to furnish the classical distribution of density and salinity along the Canal (Figs. 2 & 3), whcih illustrate the water circulation in the Canal as well as the exchange of water between the joined seas and the inner regions of the Canal over the year-round. The figures show also how the highly saline water formed in the Bitter Lakes during summer is trapped by the fresh water discharged from Lake Timsah and Lake Menzalah and accordingly reduces the water salinity in the central part of the Canal. This water, as moving northwards in wintér, is diluted with the fresh water discharging from the drains existing along the northern part of the Canal as well as from Lake Menzalahh, and hence leaving the

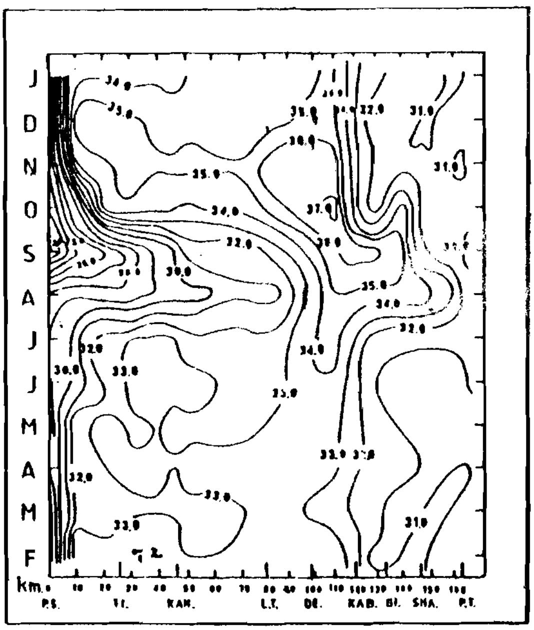

Fig. (2)
The classical density distribution diagram during 1924-1925 along the canal.

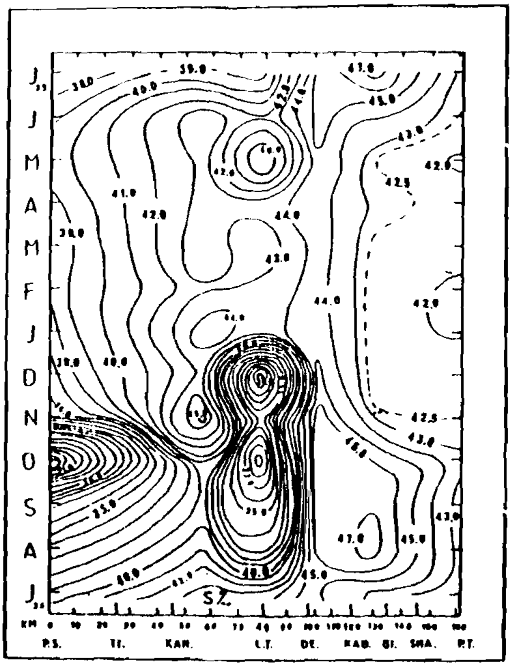

Fig. (3)
The classical salinity distribution diagram
during 1934-1935 along the Suez Canal.

Canal with salinity approaching the salinity of the Mediterranean. Dilution may take place in the northern part of the Canal, as shown in Fig. 4, which obtained during anchoring in April 1985 near Ballah. The strong tidal currents that occur in this area (Fig. 5) play a good role in mixing the water there. Accordingly, it is concluded that:

1- The formation of the high salinity water in the Little Bitter Lake is started before the reverse of the current in the northern part, which is in agreement with the data of 1954/55 (Morcos, 1960b.)

2- Water dilution to the influx of fresh Lake Timsah is synchronized with the increase of salinity in the Bitter Lakes.

3- The outflow of high salinity water from the southern part of the Canal into Suez Bay may reach in August.

4- During the period between February and June, the northern part shows a type of instability in the water movements to the north and to the south. Meanwhile, in November and December the highly saline water of the Bitter Lakes is driven northwards into Mediterranean which is in agreement with the results of the mean water level along the Canal.

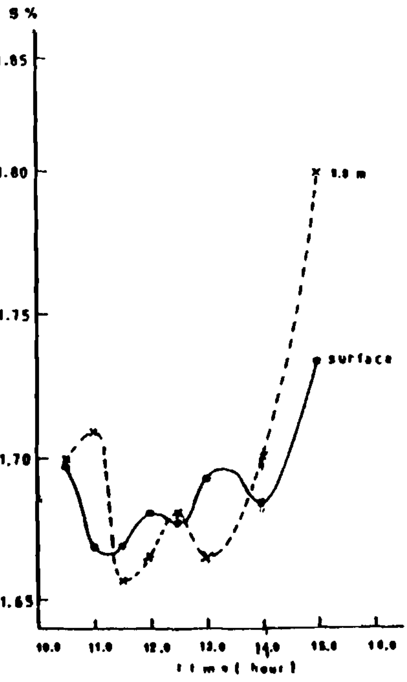

Fig. (4)
Observations of salinity at an anchor station (km 54.5) on April 14, 1985.

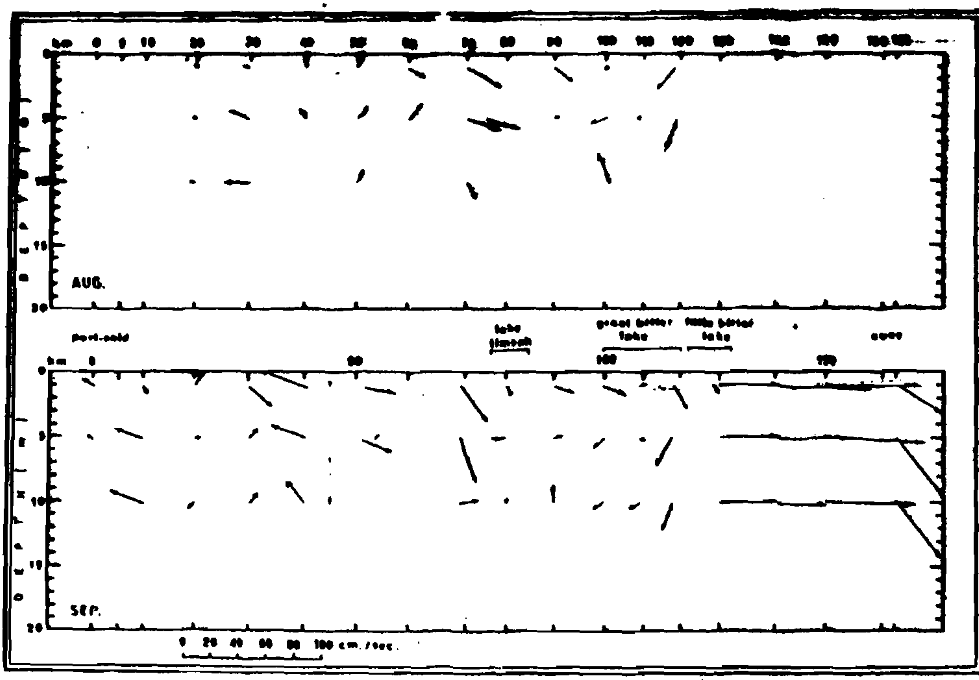

Fig. (5)
Tidal currents measured along the canal during August and September, 1986 at surface, 5 m and 10 m depth.

b- The Water Characteristics as Observed Over The Period 1982-1986:

Surface salinity distribution:

Figures 6 and 7 show surface salinity variations observed in winter and summer. In winter (April, 1985), the surface salinity is fluctuated between 41.5‰ and 42.3‰, i.e. within a range of only 0.8‰. The pattern characterizes three water masses:

1-The southern part with salinity 42.0‰.

2- The Bitter Lakes and the central part with salinity 42.3‰.

3- The northern part with salinity 41.0‰.

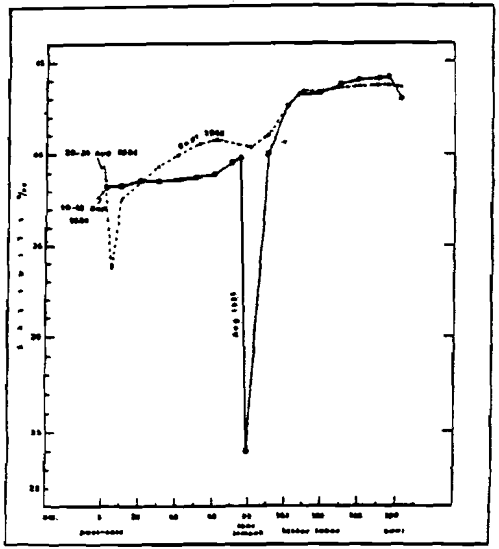

Fig. (7)
Surface salinity along the canal
during Aug. and Sept. 1986.

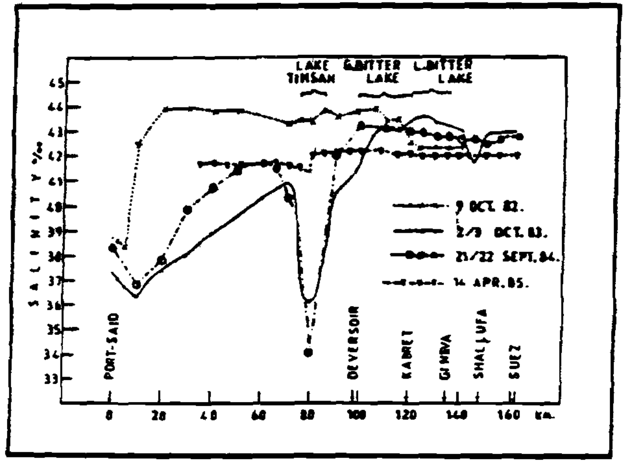

Fig. (6)
Surface salinity along the canal
during 1982, 1983, 1984 and 1985.

The summer season is described by five curves, each shows a certain pattern which differs from the other curves. The curve of October 9, 1982 characterizes the pattern of the winter regime, i.e. the onset of the northward current. The stopping of the fresh water at Lake Timsah may have accelerated the occurrence of the reversing conditions. Meanwhile, the other four curves represent different conditions of the summer regime. The most pronounced ones are that of 29-31 August and 10-12 September, 1986. Although the two curves are nearly similar but each one belongs to a certain stage of the current regime. This is well represented in the vertical distributions of temperature, salinity and density along the Canal (Figs. 8-13). The influence of the fresh water discharged from the sweet Canal into Lake Timsah in August 1986 appears to be a huge amount which reduces salinity of the Lake itself to less than 24.0%o and accordingly affects greatly the water salinity in the northern and central parts as well as the G.B.L. The slope of the M.S.L. at Kabret due to the north winds and the southward flow of the fresh water (from Lake Timsah, Lake Menzalah and the low saline water from the Mediterranean) acts togethetr to drive the saline water of the Bitter Lakes of more than 44.0%o southwards in the southern part of the Canal. Within a period of less than two weeks (directly after the cessation of the fresh water from Lake Timsah) the salinity in the central and the northern parts of the Canal starts to increase, whilst the influx of the fresh water near P.S. still acting to reduce the salinity in the extreme northern part of the canal.

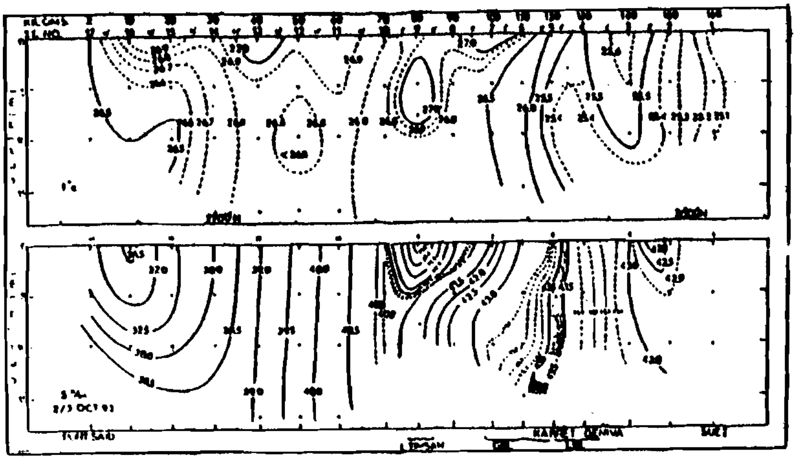

Fig. (8)
Vertical distribution of temperature and salinity
along the canal during October 2-3, 1983.

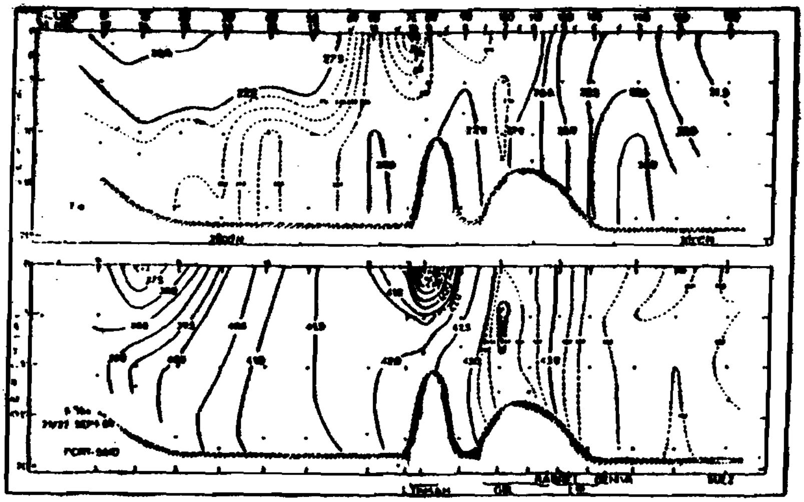

Fig. (9)
Vertical distribution of temperature and salinity along the canal during September 21-22, 1984.

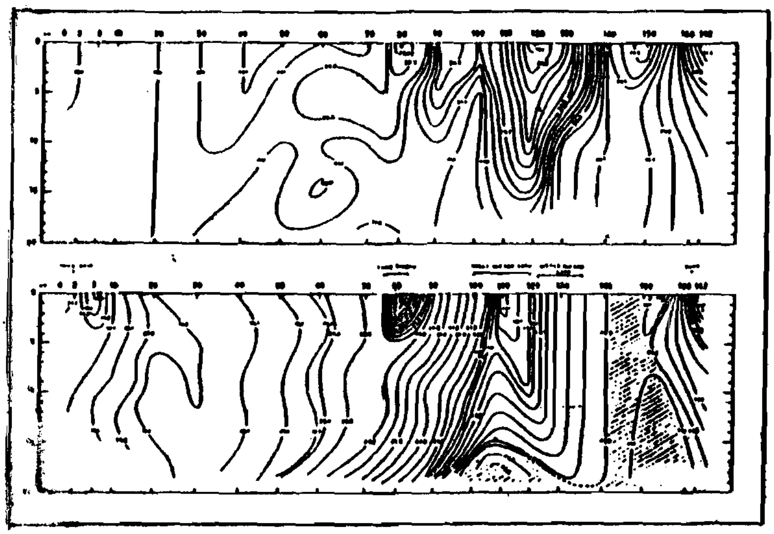

Fig. (10)
Vertical distribution of temperature and salinity along the canal during August 29-31, 1986.

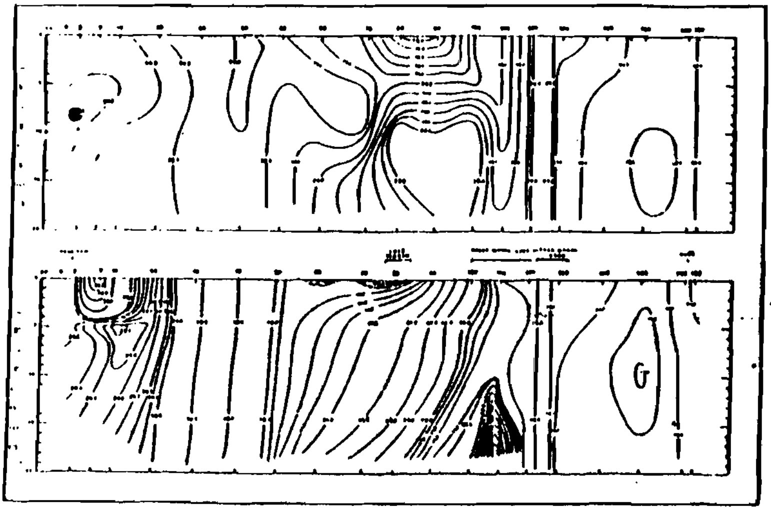

Fig. (11)
Verytcal distribution of temperature and salinity along the canal during September 10-12, 1986

Morcos (1975) threw the light on the influence of the fresh water poured into Lake Timsah on the salinity of the surrounding areas. He reported that the fresh water discharged into Lake Timsah amounted to 16 x $10^6 m^3$/ month before the construction of the Aswan High Dam. As this water moves southward, it reduces the water salinity in the Canal (of about 43.0%o) to values less than 38.0%o which is nearly similar to the salinity of the Mediterranean water. In fact, this amount of water is transported completely to the inner part of the Canal. The fresh water influx to the Lake per month during summer is enough to dilute the water existed in the Lake and the central part of the Canal from salinity 43.0%o to 38.0 %o, and to displace the water mass in the Canal over a distant of about 7.0 km. If we assume that an equal amount of fresh water is discharged into the Canal the from Lake Manzalah, then the fresh water will extend to about 14.0 km in the Canal per month. This means that, within two months a distance of 28.0 km (which is nearly equal in length to the southern part of the Canal) will be filled with the fresh water outflowing from Lake Manzalah and Lake Timsah.

Generally speaking, a great similarity is found between the present figures in comparison with the previous works of El- Sabh (1969) in September 4-17, 1966 and of Morcos (1975) in September 29, 1966. Accordingly, it is concluded that:

1- The southward motion may occur more earlier after the construction of the Aswan High Dam.

2- The strength of the southward current depends on:

a- The amount of fresh water dischargimg into Lake Timsah and that from Lake Manzalah.

b- The wind stresses acting along the Canal, which piles the water at the northern coast near P.S. and the southern part of the G.B.L. This phenomenon increases the level at Kabret and then accordingly it will be higher than at Gineva and Deversoir.

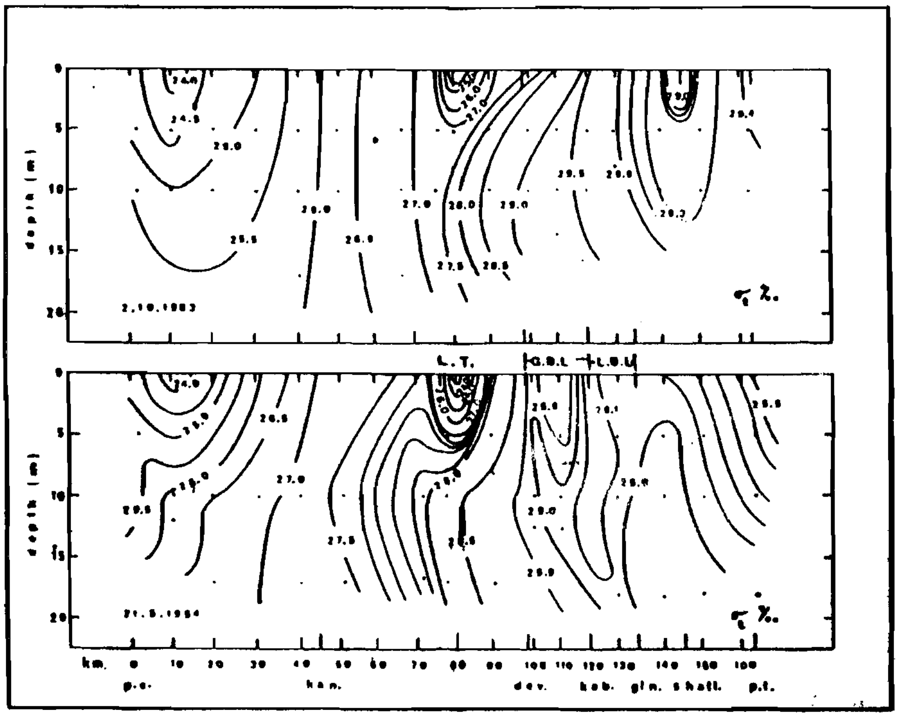

Fig. (12)
Vertical distribution of sp. density (σ_t) along the canal during October 2-3, 1983 and Sept. 21-22, 1984.

3- The increase of salinity due to the excessive evaporation in summer is subsidized by the fresh water influx from Lake Timsah and Lake Manzalah. This means that, in case of drought or of reduction in the fresh water influx, the horizontal water displacement to the south will be retarded and instead of getting a southward current in the southern part of the Canal, a transition stage may be developed and then the current starts to move northwards. This implies that, in addition to the influence of the wind at the surface, the Nile flood is also of a prime importance in driving the southward current in the southern part in summer.

4- The maximum salinity that previously confined to the upper surface layer, either in the Bitter Lakes or in the southern part of the Canal during summer of values more than 47.0 - 48.0‰, doees not exist more and is replaced by water of salinity less than 44.5‰.

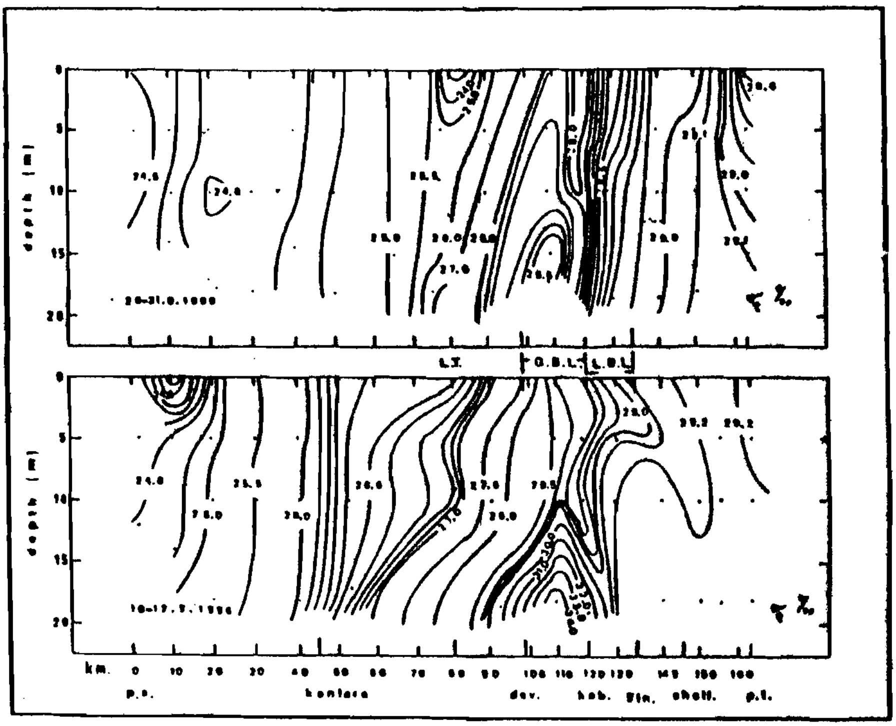

Fig. (13)
Vertical distribution of sp. (σ_t) along the canal during Aug. 29-31 and Sept. 10-12, 1986.

Vertical Temperaturre, Salinity and Density Distributions:

The isothermal pattern of October 2, 1983 (Fig. 8) indicates the stopping of the fresh water discharging into the Canal from more than one point along it, particularly in its central part in the vicinity of Lake Timsah, causing an increase in its specific volume and a decrease in its volume. These conditions are convenient for the accumulated high salinity water in the G.B.L. to move back to the north. The motion is accelerated by the reverse inclination of the water level, as the M.S.L. at P.T. becomes higher than that at kabret. The salinity as well as the density sections show the shift of the high density water from Bitter Lakes into the central and the northern parts of the Canal (Figs. 8 and 12).

Although the cruise of September, 1984 was conducted about 10 days earlier than that of October 1983, the current is more developed in 1984 towards the north (Fig. 9). The maximum salinity is already observed at the northern part of the G.B.L. and the northern part of the Canal is nearly filled with relatively high salinity water of about 41.0%°. The water temperature during this curise is more warmer, but generally decreases from north to south with maximum of about 28.0°C at P.S. and minimim of about 24.0°C at P.T.

The sections of August 1986 concerning the vertical distributions of temperature, salinity and density along the Canal (Figs. 10 and 13) may be considered as the most significant patterns recently obtained. These sections illustrate well the main features of the summer conditions, which can be summarized as follows:

1- The influence of the prevailing northern winds on piling the water at P.S. and the southern part of the G.B.L. by increasing the M.S.L. at both locations (Fig. 14).

2- The vertical rotary motion in the Bitter Lakes which is well represented by the isolines in the three vertical sections.

3- Due to piling the surface water at the southern boundary of the G.B.L., it is partially driven to the Little Bitter Lake as a southward high salinity current and partially sinking downward then returning back to the north. This water, on moving northwards, remaining in contact for a long time with the salt bed accordingly acquires more salt and hence increasing in its salinity. On repeating this cycle process, the whole volume of the Lake will be occupied by high salinity water, which is then shifted to the Little Bitter Lake and then to the southern part of the Canal as water of maximum salinity when the fresh waters from Lake Timsah and Lake Manzalah are driven southwards. The influence of the fresh water is clearly observed in the salinity distribution in the G.B.L. causing a substantial decrease in its salinity to less than 43.0%o. In the past, the reduction in the salinity of the G.B.L. was not radically inferred, inspite of the intrusion of the fresh water into the Lake, due to its high salinity.

4 The existence of the maximum salinity of more than 44.0‰ is obvious in the southern part of the Canal.

5- The appearance of the low saline water from the Gulf of Suez at the southern entrance of the Canal infers that the southward current regime during summer season is terminated while the northward of the winter season is forthcoming.

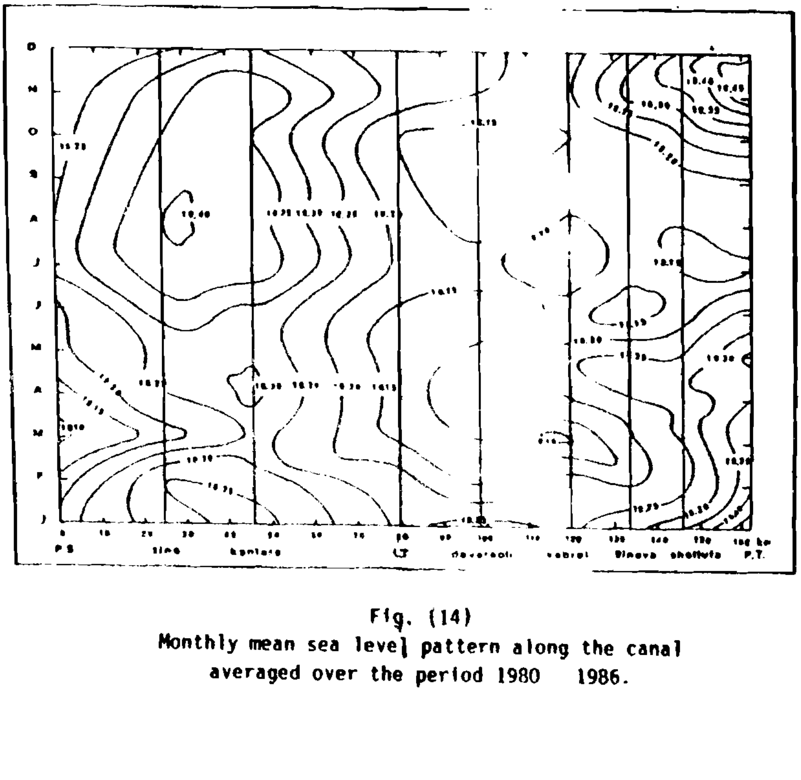

Fig. (14)
Monthly mean sea level pattern along the canal averaged over the period 1980 1986.

During the last cruise of September 10-12, 1986. the temperature, salinity and density distributions along the Canal (Figs. 11 and 13) show stratified water structure. The maximum temperature observed was in the vicinity of Lake Timsah and the central part of the Canal. The most significant feature during this is the stopping of the fresh water at Lake Timsah and its influence on the redistribution of the water masses along the Canal, which is simply clarified as the highly saline water from the G.B.L. is rushly streamed into the northern part. The isohaline of 40.0‰ was found at kilometer 80 during August 30, while after 12 days the same location was found to be occupied by the isohaline 41 5‰ and the isohaline 40.0 ‰ is shifted to the north to occupy a new location at kilometer 40 The isopycnals show similar trends. The water mass is then moved about 40 km. Within 12 days, it is transported northwards with a mean speed of about 4.0 cm/sec as a residual current. Accordingly, after the last widening and deepening of the Suez Canal in 1976, a net water transport of about 3350 x $10^6 m^3$ is moved annually into the Mediterranean in winter and of about 150 x 10^6 m^3 into the Red Sea in summer.

Moreover, the salt bed is nearly exhausted except at some locations in the Great Bitter Lake, e.g. at kilometer 110 as shown in Fig. 11 where salinity of more than 50‰ is still observed near the bottom. Accordingly, we can safely say that the salt barrier in the Suze Canal is now nearly disappearing, and there is no obstacle more against marine organisms to migrate between the joined seas.

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