GEOSTROPHIC CURRENTS IN THE SOUTH EASTERN SECTOR OF THE MEDITERRANEAN SEA

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ABSTRACT

The dynamic topography of the south eastern sector of the Mediterranean Sea is shown during the flood season before and after the Aswan High Dam and during the winter season for three depths, surface, 50 m and 100 m. Defant's principle for reference level was, applied at offshore stations, while Groen's method was used at coastal stations. One hundred and fifty hydrographic stations were used in the analysis. The level of no motion is between the 200 to 300 meter layer for the offshore stations. The T-S diagrams show the interaction between atmosphere and sea on the water masses during the winter season, and the effect of the Nile flood before and after the construction of the high dam. Comparison between observed and calculated-geostrophic current during the summer confirms that the geostrophic circulation constitutes the principal component of the total circulation. The circulation pattern for late summer (October) is noticeably distinguishable from that for the winter season.

INTRODUCTION

Direct current measurements over the continental shelf off the Nile Delta are very scarce. Only five measurements were taken from a few localities by international research vessels and by the Suez Canal Authority (Sharaf El Din, 1972 B).

The common feature of the current system along the Egyptian coast is a west-east flow. Before the construction of the Aswan High Dam, the effect of the Nile flood along the coast was noticeable to a few kilometers away from the coast and to maximum depth of 100 m (Sharaf El Din, 1972 A; Gorgy, 1965). During winter months, the current pattern is different from that in the summer. This is attributed above all to wind action. Different investigators have attempted to formulate the circulation pattern in the Mediterranean Sea (Ovchinnikov, 1966), while others investigated the current regime in the area between the Lebanese coast and Cyprus (Engel, 1967).

In this paper, the dynamic topography at the diffferent levels will be studied using the temperature, salinity and density observations over the continental shelf in the area bounded by the south and east coasts of the Mediterranean Sea to latitude 34°N and, longitude 27°E. These observations were taken during the flood period (September-October), before and after the construction of Aswan High Dam and in the winterseason (non flood season). Forty five hydrographic stations were taken (during September-October) before the construction of the High Dam and 49 stations were taken after the stoppage of the Nile flood. During the winter season only forty one stations were used in this analysis. The water characteristics and the geostrophic current will be described during these seasons.

DATA AND METHODS USED

The data used in these analyses were taken by the different research vessels as follows :

Calypso	from 22 to 23 October 1956
Vavilov	from 3 to 6 October 1959
	16 October 1964
Shoyo-Maru	from 17 to 21 March 1959
Ovcica & Golobica	from 16 to 20 October 1960
	from 4 to 11 October 1961
Chypre 04	from 19 to 20 February 1965
Ichthyolog	from 6 to 14 October 1966
	from 11 to 14 September 1970.

Figures 1, 2 & 3 show the locations of the hydrographic stations during the three seasons.

The reference level was calculated using Defant's hypothesis (1941) only at the deep stations. In the shallow parts of the investigated area, where the depths were less than the depth of the reference level computed for the deep stations, Groen's method was applied (Groen 1948). In this method the isosteres at each level in the imaginary water mass (solid part) have a constant slope equal to the slope of the isosteres at the point where it meets the bottom line. From the dynamic height computations, geopotential topography charts for the surface, 50 db and 100 db relative to the selected reference level were made. These charts represent the flood period before and after the High Dam as well as the winter season. Geostrophic velocity profiles were made for different pairs of stations and were plotted for the three periods mentioned before.

WATER CHARACTERISTICS

The water masses in the investigated area (Figs. 1, 2 & 3) are identified during the flood season before and after the High Dam and during the winter season. Figure 4 shows temperature versus salinity for the observations taken in the area during the flood period before the High Dam. The effect of the Nile flood is indicated in the T—S curve by surface coastal water of low salinity (26 to 36%) and high temperature (22 to 26°C). The effect of the Nile flood disappears at the offshore surface stations as shown in Fig. (5) which gives a surface water of high salinity (39 to 39.4‰) and high temperature (about 19°C to 25°C). A layer of subsurface minimum salinity (less than 39‰) and low temperature (about 16.5°C to 19°C) is observed between 50 m to 100 m depth. Below that depth the salinity slightly increases while the temperature decreases. The deep water (below 300 m) is characterised by low salinity (38.6 — 39.0‰) and low temperature (13.3 to 14.8°C).

The stratification of the water masses during the same season after the disappearance of the Nile flood due to the construction of the High Dam, is the same at the different depths except for the surface layer. The surface layer without the Nile flood shows wide range of salinity from 36‰ near the coast to about 39.5%, at the offshore stations (Fig. 6).

During the winter season (February-March) the characteristics of the water masses are shown in the T—S diagram (Fig. 7). This T—S diagram illustrates the homohaline condition in the whole water column with small range of salinity from surface to bottom layers. The surface layer (from 0 to 50 m) has an average salinity of 39‰ and temperature between 16.2°C to 18°C (Sigma-t around 28.5). The salinity shows a slight decrease in the subsurface layer (50—100 m), followed by a slight increase at the intermediate layer

(100—300 m). The deep water shows again a slight decrease in salinity. However the differences in salinity are much less than in summer and indicate a great homogeneity due to the winter convection. The Sigma-t values reflect such a small stability.

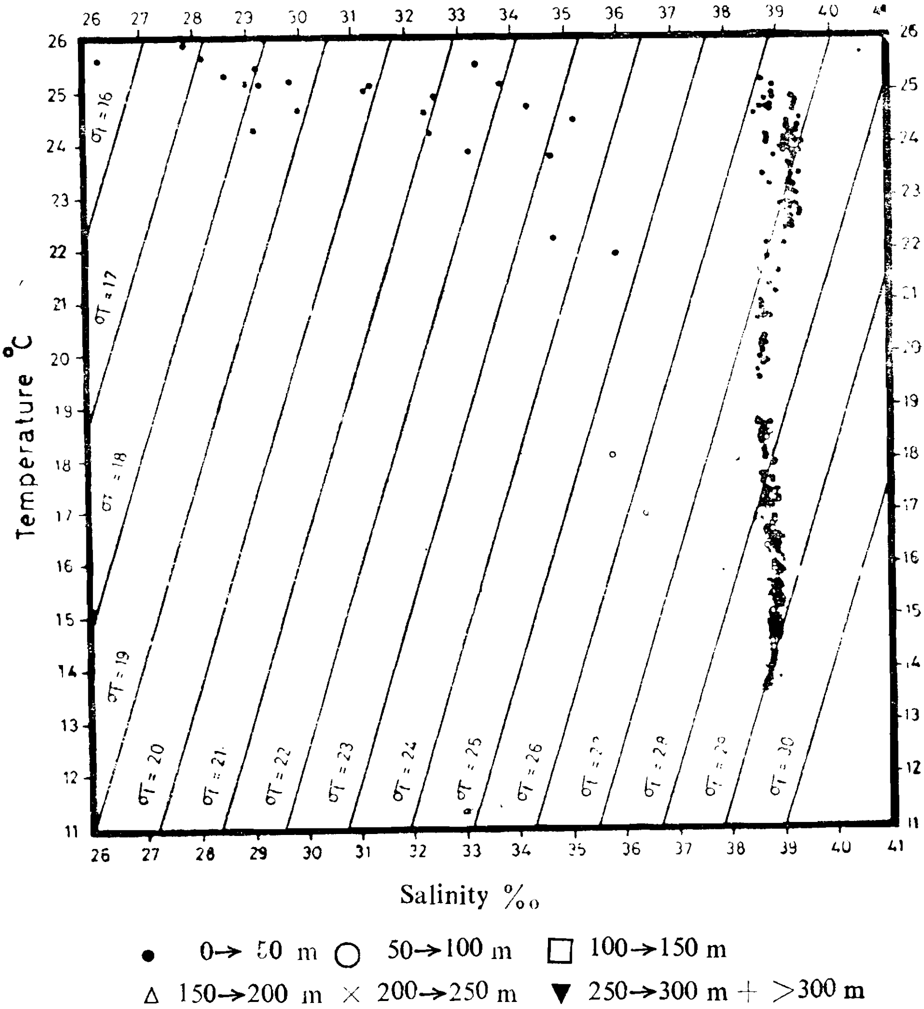

Fig. 4.—Temperature versus salinity for all observations taken in the investigated area during the flood period before High Dam.

The bottom water remains almost the same during most of the season. The bottom water (below 300 m) has a salinity of about 38.8% and temperature 13.5°C (Sigma-t = 29.2), similar to that which was observed during September and October. The bottom water masses correspond exactly to that found before by Pollak (1951) and Wust (1961) in that area.

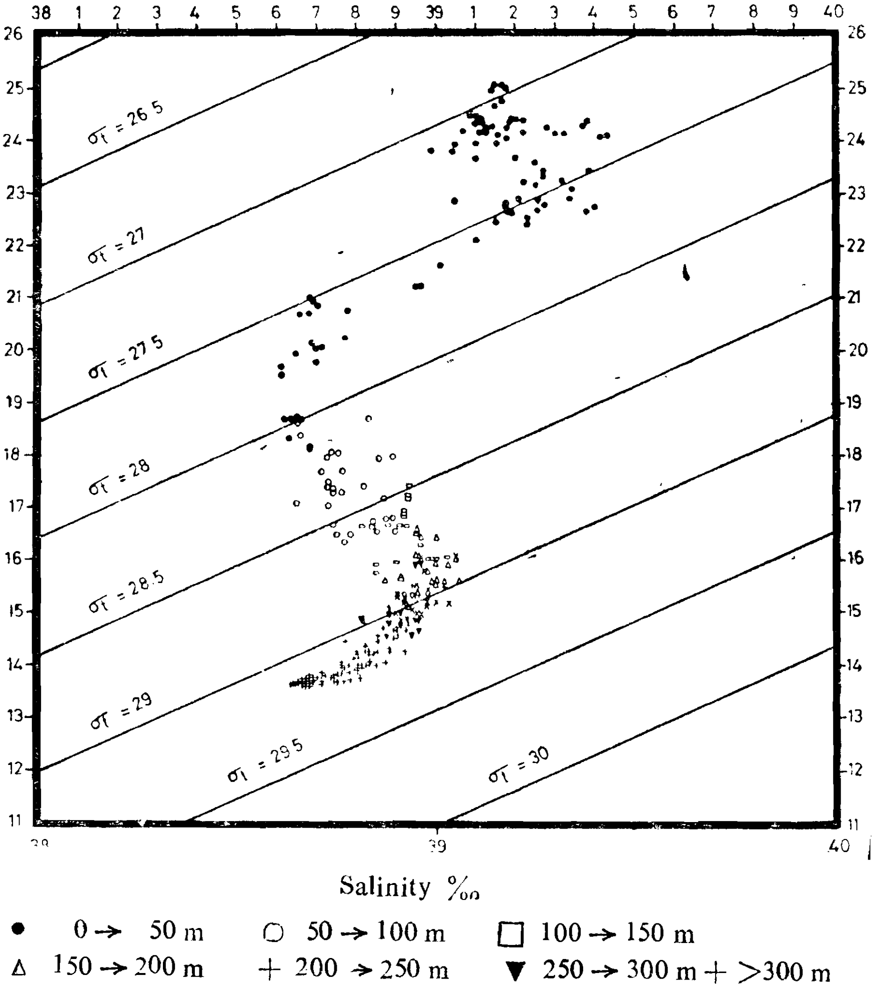

Fig. 5.—Temperature versus salinity for all observations taken in the investigated area between latitudes 32°N to 34°N, during the flood period before High Dam.

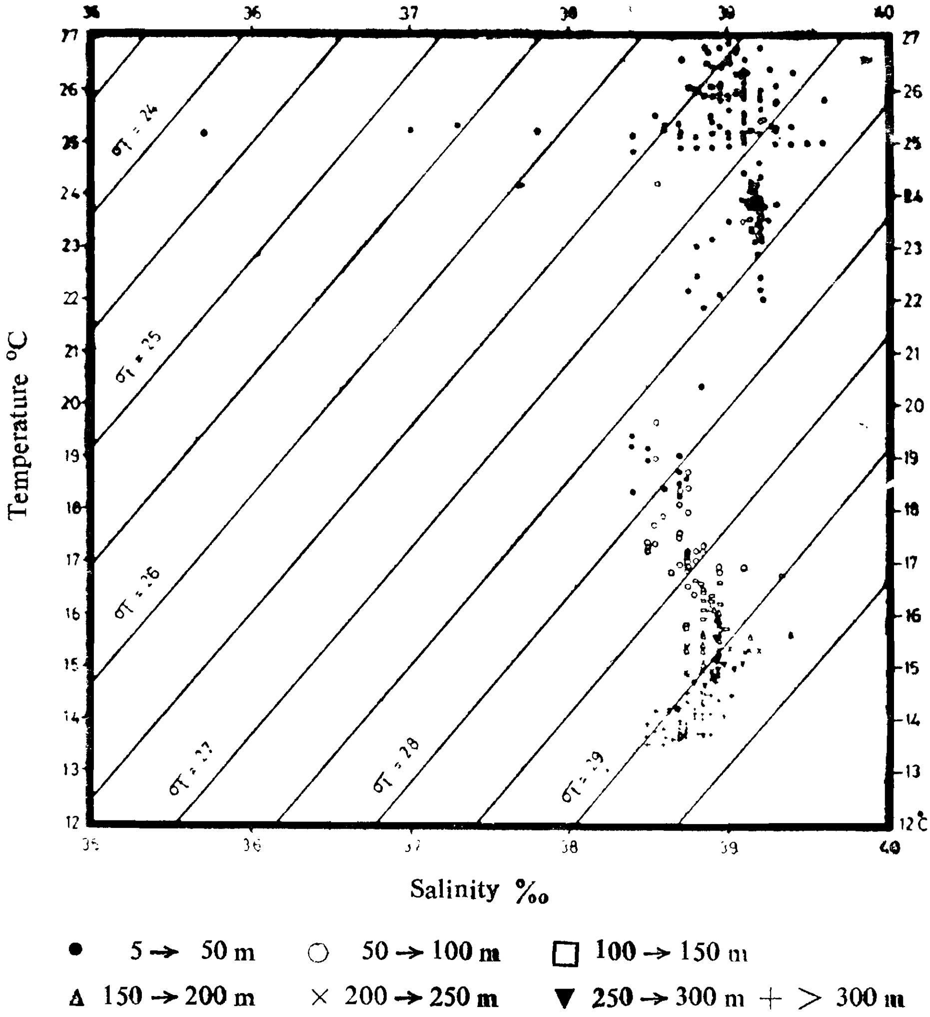

Fig. 6.—Temperature versus salinity for all observations taken in the investigated area during the non-flood season after the High Dam (September-October).

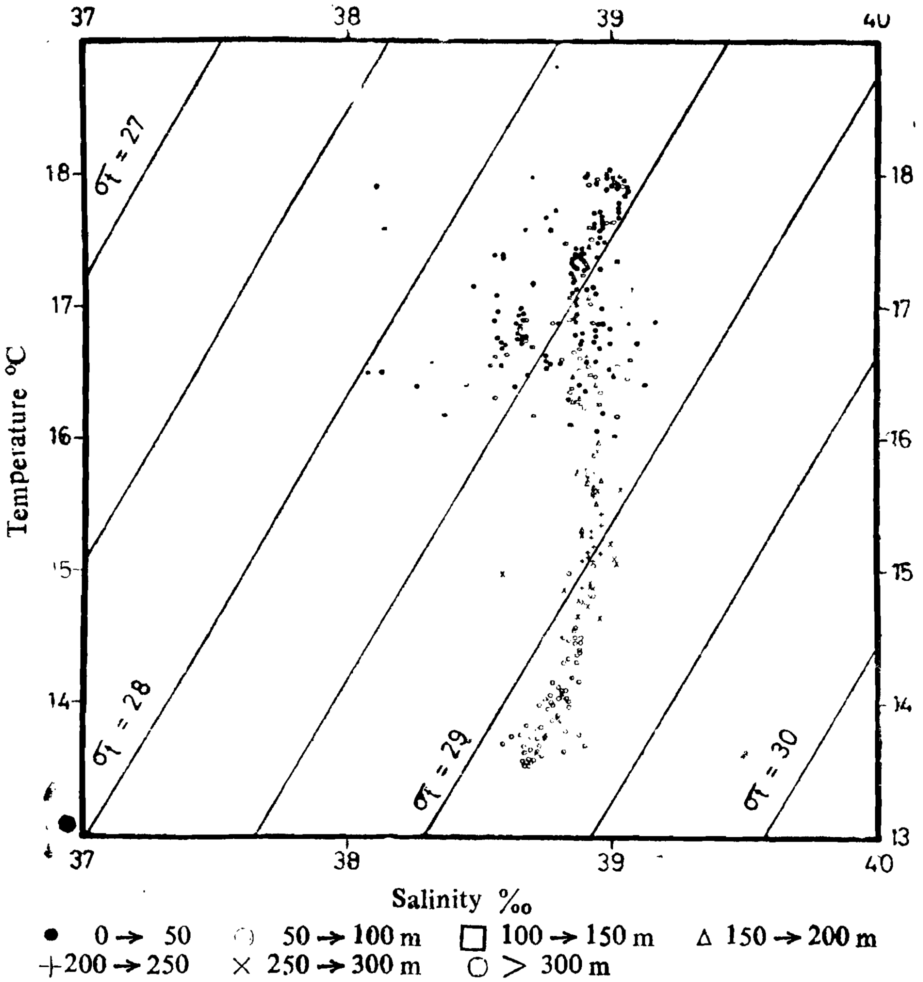

Fig. 7.—Temperature versus salinity for all observations taken in the investigated area during the winter season (February-March).

GEOPOTENTIAL TOPOGRAPHY OF THE SOUTH EASTERN SECTOR OF THE MEDITERRANEAN SEA

a) *During the flood period before the High Dam :*

The reference level is a necessary paramenter to convert the geopotential anomalies into geopotential topography. In the coastal stations, the level of no motion was calculated using the interpolation method by Groen (Groen 1948). At the offshore stations the level of no motion was found to be between 200 and 300 m below the surface. Before the construction of the Aswan High

Dam the data used in the calculation were taken from different stations, during October of different years (Fig. 1).

The geopotential topography for the surface, 50 m, 100 m below the surface relative to the selected reference level of the pair of the stations are plotted in figure 8.

The geopotential topography and associated circulation pattern near the coast follow the general trend of the flow in the Mediterranean Sea from west to east. At the surface the effect of the Nile flood is indicated by the strong concentration of the isobars in front of the Delta. This flow slightly diminishes in intensity eastwards. The general flow near the eastern Mediterranean coast off the Palestinian and Lebanese coast is northward. Away from the coast at a distance of 10 to 20 km, the flow turns to south westerly direction. The origin of this reversal could not be traced from this study but it originates somewhere near Cyprus. This trend was predicted from the current measurements taken during the Calypso-Expedittion in 1956 (Lacombe & Tchernia 1959) and was also noted by Emery and George (1963).

The cyclonic eddy found in the surface layer at 33°N and 28°E disappears at depths 50 m and 100 m. The anticyclonic eddy in front of the Lebanese coast is strongly developed at the 50 m and 100 m depth. In general, the flow pattern at 50 m and 100 m resembles very closely that at the surface with various eddies at different spots. After the construction of the Aswan High Dam, the data are very insufficient to make any reliable analysis. This is due to the fact that most of the sampling stations were concentrated in the area infront of the Egyptian coast.

b) *During the winter season :*

The hydrographic stations used in these computations are those of February-March of the years 1959, 1965 and 1971 (Fig. 3). The dynamic topography of the area under investigation at the surface, 50 m and 100 m below surface is shown in Figure (9). The topography of the sea surface relative to the selected reference level agrees with the general flow in the Mediteranean Sea. The geostrophic flow goes almost parallel to the North Africa coast and then is deflected to the north easterly direction along the Lebanese coast.

At latitude 32°N in front of the Suez Canal a cyclonic eddy is developed at the surface and is strengthened at depths 50 m and 100 m below surface. Another cyclonic eddy exists at the surface at latitude 33°N and longitude 28° to 29° E. This cyclonic eddy also persists at other depths (Fig. 9). The surface eddy may be attributed to the prevailing north-west wind during that season. At depths of 50 m and 100 m below the surface, the flow pattern resembles very closely that at the surface.

GEOSTROPHIC CIRCULATION

a) *Before the High Dam :*

In this section the vertical distribution of the geostrophic flow is investigated during the flood period (September-October). The geostrophic velocity was calculated from the dynamic topography using the standard procedure. During the flood before the High Dam, the velocity of the water flow near the nile's branches reach 300 cm/sec. During the flood period in summer the atmospheric condition is fairly stable. In this case the geostrophic circulation constitutes the principal component of the total circulation.

Using the dynamic computations, six stations (No. 39, 40, 41, 42, 44, 45, Fig. 1) were taken in the shallow area in front of the Nile Delta affected by the flood. Six other stations were taken (No. 78, 79,80,81,85 and 86, Fig. 1), in the deeper areas away from the effect of the Nile flood. The geostrophic currents were calculated between each set of two stations taken over the investigated area. Each two stations were taken in direction perpendicular to coast to get the current parallel to it as the main current is from west to east. Figure (10) shows the geostrophic velocity profile at the onshore stations where the effect of the Nile flood flow is clear. The velocity of the flow deduced from the dynamical computations at these stations ranges from about 200 cm/sec. at the mouth of the two branches of Nile to 120 cm/sec. in front of Lake Burollos as can be expected, directed to the east at the different depths. The calculated geostrophic current agrees with the measurement taken by the Yougoslavian vessel during October 1960 (Gorgy). The surface velocity measurred by the Ekman current meter during October 1960 were 4 to 6 knots (Gorgy 1965) over the continental shelf in front of the Nile Delta. This velocity drops to a minimum of 6 cm/sec. off the Lebanese coast sometimes reaching a maximum of about 25 cm/sec. (Emery and George 1963). At the offshore stations, figure 11 shows the geostrophic velocity profile between the pair of stations 78—79, 80—81, and 85—86 respectively. At the surface layer the flow is directed to the west with maximum velocity of 8 cm/sec. The velocity profile between stations 79 and 78 (Fig. 11) gives three levels of zero motion, at 230, 300 and 700 m respectively. In Fig. (11 b), the velocity profile gives two levels of no motion at depths 130 m and 250 m below surface with a velocity direction to the east at the bottom layers. Between staions 85 and 86 the geostrophic velocily profile from surface to bottom is in the west direction at all depths.

b) *After the High Dam :*

After the High Dam twelve other stations were taken, six inshore (No. 15, 16, 9, 10, 3, 4) and six offshore (No. 13, 14, 11, 12, 5 and 6), only the profiles of the geostrophic flow of the offshore stations will be discussed in details. Figure 12 shows the geostrophic velocity profile between the pair of the station, 14—13, 11—12, and 5—6 respectively. The magnitude of the calculated velocity at different depth are fairly similar to the observed one by the ship Carsamba at a station 33° 52' N and 30° 34' E during October 1968 (Guibout 1972).

The velocity profile between the stations 14 and 13 (Fig. 12). gives an easterly flow at the surface and down to a depth of 200 m and then westerly flow in the rest of the layers. Between stations 11-12, the velocity profile (Fig. 12), gives a westerly flow in the surface layer, then easterly flow below 250 m depth. A westerly flow was shown between stations 5 and 6 at all depths. The maximum velocity reaches about 18 cm/sec. at the surface layer and 12 cm/sec. in the deep layers. This indicates the same pattern observed before the High Dam, which can be expected.

c—*During the winter season :*

During the winter season, where the intermediate water of high salinity is observed in the Levantine Basin, the geostrophic velocity profile at the offshore stations is different from one station

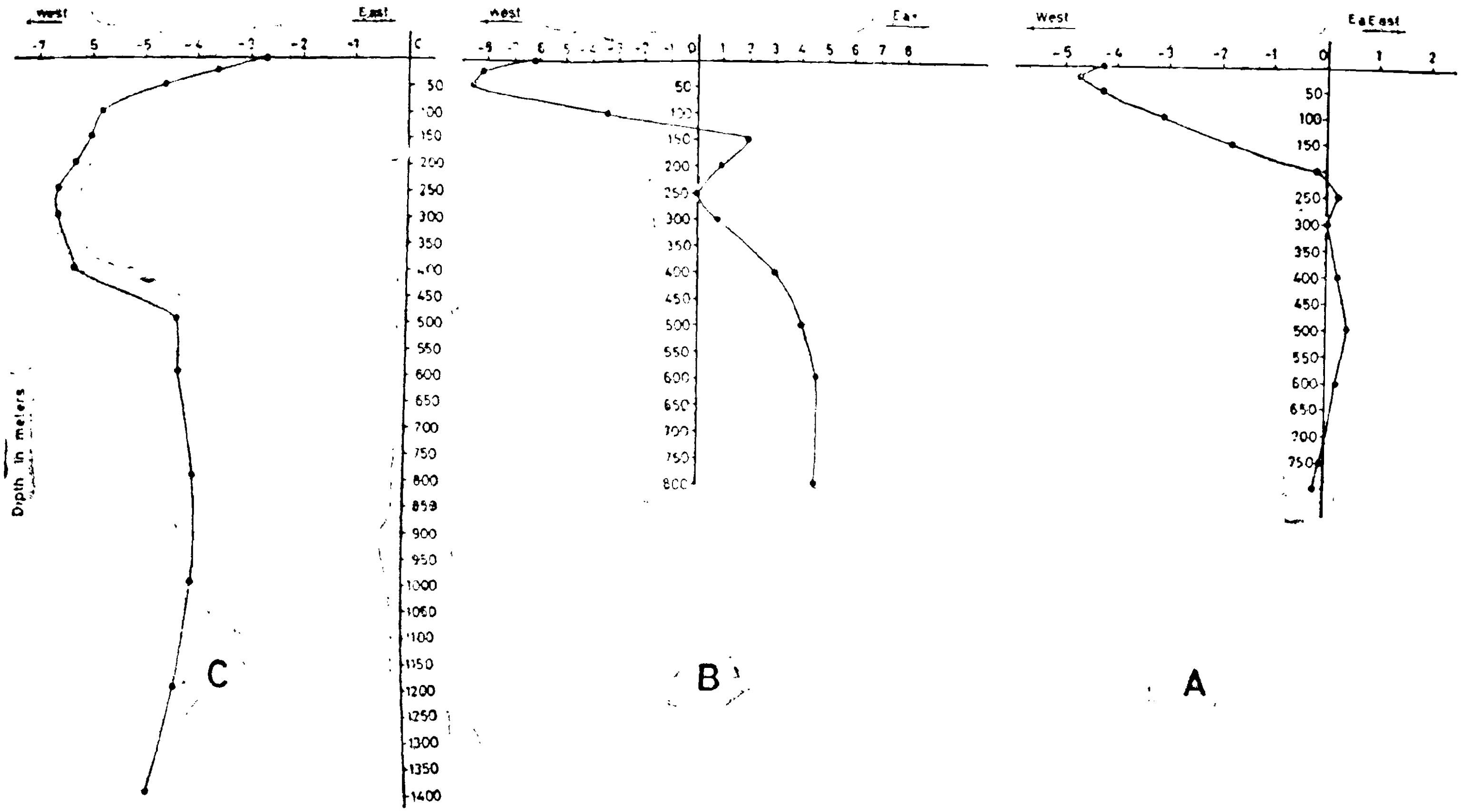

Fig. 11—Geostrophic velocity profiles between selected pairs of offshore stations during October before the completion of High Dam.

A—Flow between stations 78 and 79. *B*—Flow between stations 78 and 79. *C*—Flow between stations 85 and 86.

to another. Between stations 17 and 18 (Fig. 13), the velocity profile gives an easterly flow in the surface layer with a maximum velocity of 18 cm/sec. and a westerly flow below 200 m depth The flow between 7 and 8 (Fig. 13), is directed to the east at all depths with maximum velocity of 22 cm/sec. at 300 m depth. Again the geostrophic velocity profile between stations 5 and 6 gives an easterly flow down to depth of 250 m and westerly flow below that level. This variation in the velocity profile from one station to another can be attributed to the effect of the cyclonic eddys which exist in that area.

DISCUSSION AND CONCLUSIONS

Direct current measurements in the south-eastern sector of the Mediterranean Sea are very scarce. For that reason the current pattern computed from the oceanographic data is a solution to give the general circulation off the Egyptian Mediterranean coast. The dynamic computation for determining the geostrophic current depends to a great extent on the choice of the reference level. At deep stations there are no problems, while at the shallow stations the uncertainty in the choice makes it difficult to rely upon the result.

The effect of the Nile flood is clearly indicated in the chart of the geopotential topography of the surface. The effect is diminished towards the east and to towards the bottom. Also this effect was indicated on the T-S diagrams during the period September-October before the erection of the High Dam, and was absent after the Dam's erection.

The coincidence of high temperature (22°C to 26°C) and low salinity (26 % to 36 %), shown in the T - S diagram clearly characterise the effect of the Nile flood. This body of water disappeared after damming the River Nile. The water circulation off the eastern coast of Mediterranean Sea turns to a south westerly direction as observed before by lacombe and Tchernia (1959) and Emery and George (1963).

The geopotential topography at different depths referred to the selected reference level represents the condition clearly at these depths during the period of investigation. A good indicatoin of that representation is the agreement between the calculated and observed velocities at some locations in the investigated area. The water masses in the south eastern sector of the Mediterranean Sea vary from one season to another. In winter the Levantine water of high salinity and high temperature exists in the layer 100-300 m depth. The surface waters on the other hand are exposed to seasonal variations mainly due to the meteorological conditions. The bottom water remains almost the same during the different seasons of the year.

To establish the circulation patterns in the south-eastern sector of the Mediterranean Sea, Oceanographic data must be associated with current measurements. This will throw more light on the validity of the application of the circulation theorem involving the relationship between the field of sea water density and the current velocity field.

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