SALINITY AND WATER MOVEMENT IN THE SUEZ CANAL.

by

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From a hydrographic point of view the Suez Canal is fundamentally distinguished from maritime straits by a series of interesting phenomena. Morphologically, the Canal can be considered with truth as a connecting link between the Mediterranean and the Red Sea. But while in straits the oceanographical conditions depend essentially on the stratification of temperature and salinity in the adjoining seas, and are characterized by two currents flowing in opposite directions (surface and subsurface currents), the salinity and temperature distribution in the Suez Canal is determined principally by the high salinity of the Great Bitter Lake in the course of the Canal. There is a strong density gradient from the interior of the Canal towards its ends, while as a rule, in junction channels, the densities between one sea and the other gradually become compensated. For this reason among others, the water movement in the Canal must differ in principle from the current systems of maritime straits.

This problem of the exchange of waters is of particular importance in maritime biology, for it plays a great part in the matter of knowing to what extent, since the Suez Canal was opened (in 1869), Indian fauna has penetrated into the Canal and the Mediterranean, and conversely to what extent Mediterranean fauna has appeared in the Indian Ocean. An investigation into this problem was undertaken in 1924 by the Cambridge Expedition to the Suez Canal, the results of which were published between 1926 and 1929 in the *Transactions of the Zoological Society*, London, No. 22. From measurements of density (density at 20°C.) and of water level made by the Suez Canal Company, H. Munro Fox concludes in this journal that for ten months of the year the salt water of the Bitter Lakes is borne northward in the Canal, while only in August and September, under the influence of the prevailing northerly winds, is it carried in the opposite direction. We now propose, taking the observations made by the Suez Canal Company and other measurements as a basis, to paint a new picture of the oceanographical conditions, and particularly of the salinity, using the symbol common in oceanography (salinity per mille instead of density at 20° C.). (*).

The length of the Canal, which lies roughly in a north and south direction, is 162 km. (100 2/3 statute miles) including the lakes which it crosses; its depth is from 10 to 12 metres (33 to 39 feet), its width at water level from 110 to 130 metres (361 to 426 feet) and its width of floor from 36 to 45 metres (118 to 148 feet). The northern section of the Canal, as far as Km. 50, is bordered on the west by Lake Mensale, very shallow (1 to 2 metres — 3.3 to 6.6 feet) and filled with brackish water, and by the Sweet Water Canal which communicates with the Suez Canal at Port Said by way of a lock. The middle section, from Km. 50 to Km. 95, includes Lake Timsah, which at Ismailia receives small quantities of fresh water from the Sweet Water Canal without, as a general rule, its central portion being affected by this fact. In the next section, (Km. 95 to Km. 133), the Canal cuts the Great and Little Bitter Lakes, on the bottom of which are salt deposits from an earlier period. DE LESSEPS in 1868 reckoned the depth of the deposit in the Great Bitter Lake as 13 metres (43 feet) in round numbers. Owing to the afflux of masses of less salty water from both sides, this deposit is steadily dissolving, which obviously results in increasing the depth of water in the Great Bitter Lake. Since 1869, when the depth of water there was 7.65 metres (25.1 ft.), it had

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(*) *The values of the density (at 20°) have been converted into salinities on the basis of the table for σ_t computed by Picotti (1927, p. 18) for high densities ; this table is an extension of Knudsen's* Tables Hydrographiques. *It has been assumed for this occasion that the values of the density at 20° given by the Canal Co. refer to distilled water at 4°. This conversion based on the ratios of the* Tables Hydrographiques *is also valid for the conditions in the Great Bitter Lake ; for general analyses in this region show that since 1872 the proportion of the different ions is about the same as in sea water.*

increased by 1921 almost linearly to 11.7 metres (38.4 ft.), and the diminution of salinity went hand in hand with it by falling from 68 ‰ in 1872 to about 52 ‰ in 1924 (*).

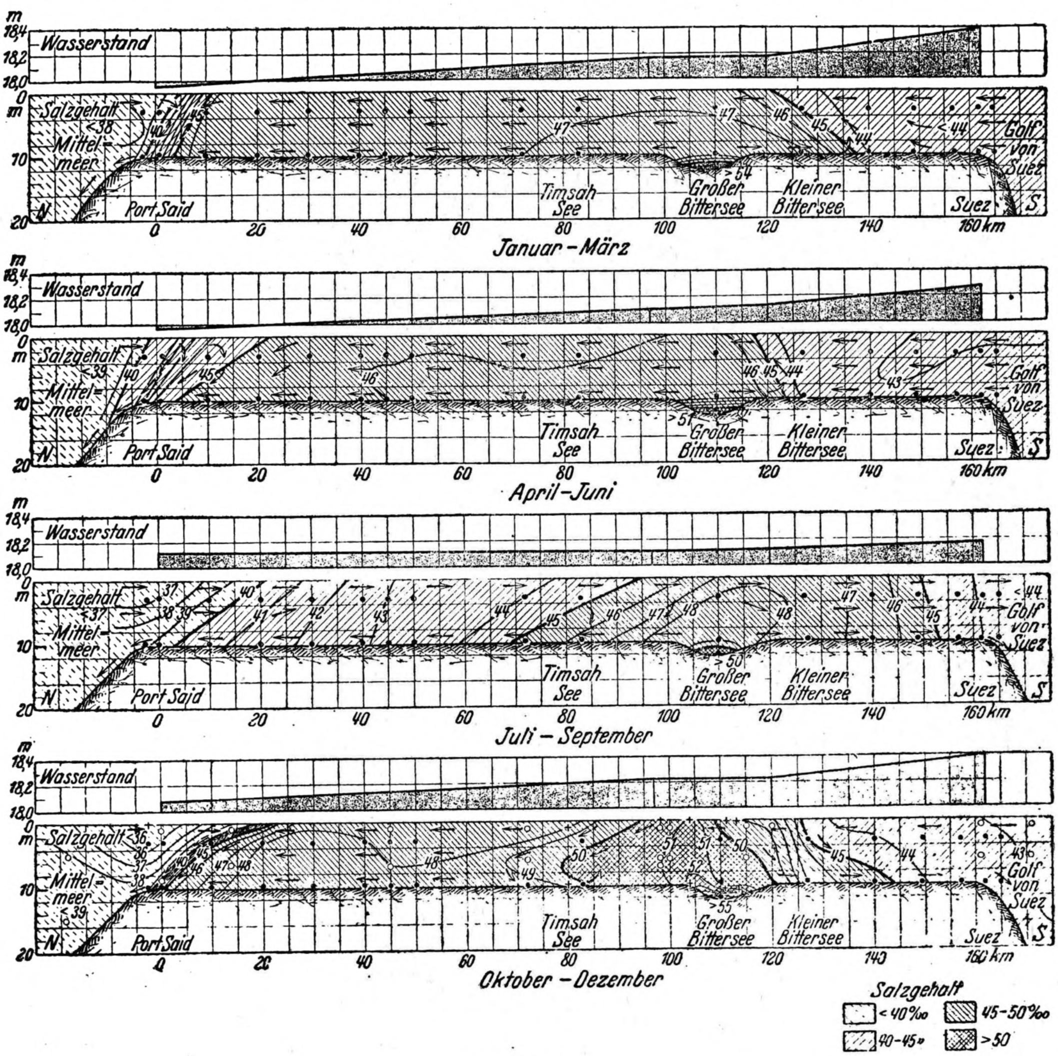

FIG. 1.

Longitudinal Section down the Suez Canal, showing water level, salinity (in ‰) and probable water movement (mean quarterly values).

Observation Stations of :-

. *Suez Canal Company (February* 1924 *to January* 1925).

\+ *Cambridge Expedition (October to December* 1924).

o *Italian Surveying Ship* Ammiraglio Magnaghi (*October* 1923).

(*) *It would be interesting to try to estimate, from this increase of depth or from the diminution of salinity, the moment at which the salt deposit will be completely dissolved and the salinity of the Great Bitter Lake will have fallen roughly to the value of that of the Red Sea water. Linear extrapolation, taking as hypothesis a depth of salt deposit of* 13 *metres* (43 *ft.*) *and working on the increase of depth of* 4 *metres* (13 *ft.*), *places this moment at about the year* 2030 ; *but if the salinity curve is produced linearly, the oceanic value of* 42 ‰ *should be attained in the year* 1970. *But such an extrapolation does not seem to be admissible, observing that on the one hand the superficial area of the salt deposit cannot be considered as constant, and on the other hand the processes of dissolution may be slowed down or, less likely, hastened by some unforeseeable circumstance (such as a new deepening, through the formation of a zone of fracture).*

The southernmost section of the Canal, 29 km. (18 ½ miles) in length, from the Little Bitter Lake to Suez, contains tidal streams of which the mean speed, according to Fox, is 0.82 m/sec. (2.69 ft/sec.) and the maximum speed 1.40 m/sec. (4.59 ft/sec.). The absence of tidal streams in the northern section is thus in direct opposition to what has been stated above. The Spring Range, according to the German Sailing Directions for Steamships is, in the port of Suez, 2.1 metres (6.9 ft.); at the southern end of the Little Bitter Lake, 0.2 metres (0.7 ft.); between Port Said and the Little Bitter Lake, imperceptible.

As no current measurements for the Canal are available, an idea of the probable circulation must be deduced from the salinity distribution. Fig. 1 shows the mean conditions along the longitudinal axis of the Canal for the four quarters of 1924, based principally on the density measurements made every month regularly by the Suez Canal Company at depths of 3 and 10 metres (10 and 33 ft.), besides at 12 metres (39 ft.) in the Great Bitter Lake, from February 1924 till January 1925. For the October-December quarter, we have also taken into account the observations (12 in number) of the 1924 Cambridge Expedition and 10 stations (24 observations) of the 1923 *Ammiraglio Magnaghi* Expedition, which agree well, in general, with the values computed by the Suez Canal Company and thus confirm the correctness of these measurements and the accuracy of our conversion (from density to salinity).

The four sections first give a clear picture of the seasonal displacements of the zone rich in salt (salinity over 45 ‰) within the Canal. While in the first, second and fourth quarters it reaches along the bottom of the Canal as far as Port Said in the north, in the third quarter, on the contrary, it only extends as far as Km. 70. Conversely, during this quarter, the water rich in salt extends particularly far towards the south. As we have already said, the maximum salinity at a given moment occurs on the bottom of the Great Bitter Lake with 51 to 56 ‰; and the two minima at a given moment occur at the two extremities of the Canal (35 to 39 ‰ at the Mediterranean and 42 to 44 ‰ at the Gulf of Suez.) The great extension of the highly saline zone (salinities over 50 ‰) in the region of the Great Bitter Lake during the months of October to December (and not, as might have been expected, during the summer months when great heat and a total drought prevail), is striking.

As the temperature differences in the Canal are very small, these enormous differences of salinity and density (*) must result in a relatively high internal field of forces, which nevertheless, on account of the comparative shallowness and narrowness of the Canal, is masked by exterior influences, as we shall see. Fig. 2 shows at once the annual variation of a few meteorological factors, of the salinity and the monthly water-level, for three stations in the Canal (Port Said, Ismailia or Great Bitter Lake, and Suez). It is evident from the curves that in the months of July to September there are exceptional conditions — maximum air temperature, maximum percentage frequency of northerly winds (above 80 or 90 %), absence of rain, and finally also absence of the comparatively large differences of water level between Suez and Port Said which exist in the other months. During the three other quarters, the sea-level at Suez is on the average 29 to 40 cm. (0.95 to 1.31 ft.) higher than at Port Said, a phenomenon which in the ultimate analysis must be laid to the charge of the circulation of masses of water in the Indian Ocean with the resulting stand in the Red Sea. During the months October to March, the drift of the north-east monsoon, blowing to the westward in the Indian Ocean, causes a north-westerly current in the Red Sea (in opposition, here, to the prevailing north winds) and a rise in the Gulf of Suez. Further, in April-June, in spite of the reversal of the currents in the Indian Ocean where, roughly from April, the south-west monsoon drives the water masses to the eastward, no greater transport of Red Sea water takes place but only a gradual diminution, so that during this quarter also a comparatively high water level is to be found at Suez. It is only in July-September that there is established in the Red Sea, under the influence of the strong regular north winds and of the Indian south west monsoon, a general flow towards the south-east resulting in the disappearance of the high water-level at Suez. This surface gradient of the Canal has been shown in Fig. 1 also, varying from season to season, according to the observations of the four existing tide-gauge stations (Port Said, Km. 97, Kabret, and port of Suez).

Taking all these factors into account, the salinity distribution gives the following representation of the currents shown by arrows in Fig. 1.

(*) *There are differences in the true density in the Canal of up to* 18 *units in the* 4*th decimal place.*

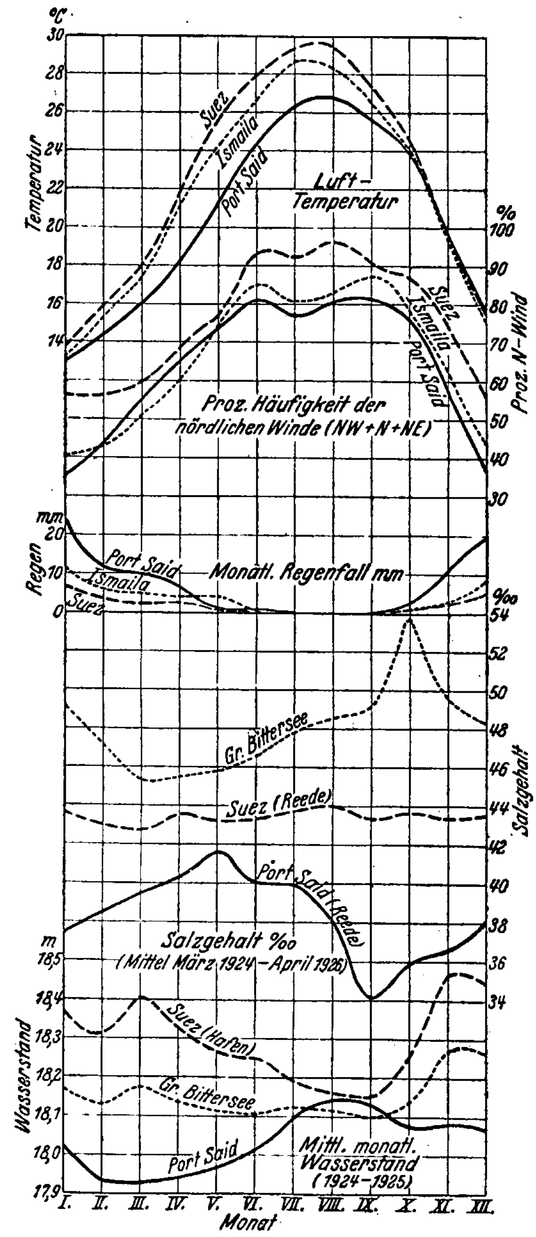

FIG. 2.

Annual variation of meteorological factors, salinity and water-level in the region of the Suez Canal.

(1) In January-March and April-June, under the influence of the big differences of level, the Red Sea water is carried northward as far as the Little Bitter Lake, where the highly saline bottom water of the Great Bitter Lake runs out along the bottom in the opposite direction as a counter-current. In spite of the frequent return of the north winds, the mixture of the two waters is transported by the surface gradient as far as Port Said, where it dives sharply beneath the Mediterranean water, unless it mixes with the latter.

(2) In July-September, with the differences of level nearly compensated and under the influence of the strong and regular north winds, a general southerly current is set up in the surface layer of the Canal. North of the Great Bitter Lake, a weak bottom current probably trickles towards the north, the highly saline water of which mixes with

the less salty water entering from the Mediterranean. South of the Bitter Lakes it seems that in the whole column of water a southerly current predominates.

(3) In October-December, it seems that in the central parts of the Canal a certain stagnation of the water masses occurs, causing a considerable increase in their salt content (salinities over 50 ‰) between 80 and 120 km. (50 and 75 miles) after they leave the bottom of the Great Bitter Lake. As a result of the formation of a new gradient, a northerly current predominates afresh, especially at the surface, while on the bottom, south of the Great Bitter Lake, it seems that the water of high salt content drifts southward towards the Gulf of Suez. The very marked zone of cleavage should be noted at the northern extremity, between Port Said and Km. 20, where the salinity increases roughly by 5 ‰ for each metre (3.3 ft.) of depth.

Thus in the Suez Canal, during the nine months October to June, as a result of the long-range influence of the surface circulation of the Indian Ocean, there is a predominating movement of water towards the north from the Gulf of Suez to the Mediterranean; at the bottom of the Canal there are, as a matter of fact, more or less retrograde movements, determined by the increased salt content of the Great Bitter Lake. During the July-September quarter, on account of the state of compensation of the water conditions, the influence of the prevailing north winds takes command and sets up a south-running current, which nevertheless, in the northern part of the Canal, does not affect the whole column of water, the latter manifestly resting upon a bottom layer having a northerly direction of movement.

In spite of a series of new details, these indirectly deduced representations of the current can of course only be schematic. Current measurements taken in an experimental man-made canal would enable the combined action of the different current-producing forces to be clearly observed and checked; in conjunction with temperature, salinity and water-level observations, they would provide extremely interesting information, and would lead, without a doubt, to more complicated representations of the current.

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