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Aus dem Institut für Meereskunde der Universität Kiel

The Chemical Composition of Sea Water from the Suez Canal Region

Part. 1: The Major Anions

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Zusammenfassung: Die chemische Zusammensetzung von Meerwasser aus dem Gebiet des Suez-Kanals. Teil 1; Die Hauptanionen. Drei Wasserkörper werden im Gebiet des Suezkanals festgestellt. Im Bereich von Port Said wird das Mittelmeerwasser im Spätsommer von der Nilflut beeinflußt. Das Wasser vom Bittersee hat einen Salzgehalt von 44—48‰ aufgrund der Salzablagerungen am Boden des Großen Bittersees. Das Wasser im Gebiet der Bucht von Suez wird im Herbst vom Salzwasser aus den Bitterseen beeinflußt.

Die Salzablagerungen sind sehr arm an Sulfat und Bromid. Das Wasser des Großen Bittersees zeigt SO''_4/Cl' und Br'/Cl' Verhältnisse, die unter den ozeanischen und Suez-Bucht-Werten liegen. Eine jahreszeitliche Veränderung des SO_4''/Cl'-Verhältnisses wurde im Großen Bittersee festgestellt. Im September wird der höchste Salzgehalt zusammen mit einem Minimum des SO_4''/Cl'-Verhältnisses beobachtet. Das Salzminimum fällt mit dem SO_4''/Cl'-Maximum in den März.

Die empirische Beziehung $SO_4'' = 0.1118\ Cl‰ + 0.6469$ wird für das salzreiche Wasser aus dem Suez Kanal ermittelt ($S‰ > 41.5$). Das SO''_4/Cl'-Verhältnis des Port Said Wassers ist größer als das ozeanische. Dies ist auf die Verdünnung durch Nilwasser zurückzuführen, das ein 12mal größeres SO_4''/Cl'-Verhältnis als das von Meerwasser aufweist. Das Br'/Cl'-Verhältnis ist im Gebiet von Port Said niedriger als normal. Es wird angenommen, daß das Nilwasser ein relativ niedriges Br'/Cl'-Verhältnis hat.

Das F'/Cl'-Verhältnis der drei Wasserkörper ist niedriger als der für Meerwasser aus der Oberfläche angenommene Wert. Die niedrigsten Werte werden im Bittersee gefunden.

Summary: Three water masses are identified in the Suez Canal region. The Port Said region represents Mediterranean waters influenced in late summer by the nile flood. The Bitter Lake waters have salinity 44 to 48‰ due to the effect of the salt deposits in the bottom of the Great Bitter Lake. The Suez Bay water is affected in autumn by the salty water from the Bitter Lakes.

The salt deposits were found to be very poor in the sulphates and bromides. The waters of the Bitter Lakes show SO_4''/Cl' and Br'/Cl' ratios less than the oceanic values and that of the Suez Bay. A seasonal variation in the SO_4''/Cl' ratio was detected in the Great Bitter Lake. The maximum salinity together with the minimum SO_4''/Cl' ratio occur in September, while the minimum salinity is accompanied by the maximum SO_4''/Cl' ratio in March. The empirical relationship $SO_4''\ 0.1118\ Cl‰ + 0.6469$ is suggested for the highely saline water of the Suez Canal ($S‰\ 41.5$).

The SO_4''/Cl' ratio of Port Said waters is higher than the oceanic ratio due to dilution by the Nile waters which was found to have SO_4''/Cl' ratio 12 times that of the sea water. The Br'/Cl' ratio in Port Said is less than the normal ratio in sea water, since the Nile water must have a relatively low Br'/Cl' ratio.

The F/Cl ratio of the three water masses is less than the accepted value for surface sea water. The lowest values are encounterd in the Bitter Lake waters.

Introduction

Before the recent discovery of the hot salty water from the bottom of the Red Sea (Brewer et al. 1965, and Miller et al. 1965), the waters of the Great Bitter Lake in the Suez Canal represented the highest salinity ever found in free connection with the open seas. They still represent the highest surface salinities recorded. In a recent paper

Morcos and Riley (1966) have demonstrated that the relationships between chlorinity, salinity, density, and conductivity of sea water from the Suez Canal region show slight but significant deviations from those established for ocean waters. This suggested the present investigation of the chemical composition of this water. The magnitude of the difference in composition from typical sea water, if any, can explain the deviations of its physical properties.

Background and Previous Investigations:

a. The Salt Bed:

The basin of the Bitter Lakes was a dry valley, until it became part of the Suez Canal in 1869, when it was filled by water from north and south. The dry basin of the Bitter Lakes was originally a northern extension of the Gulf of Suez, and remained so in early Pharaonic times. Later, the basin was cut off from the sea by elevation of the land level at Shalloufa (km 146) (Fig. 1).

According to De Lesseps (1874, 1876), the central part of the floor of the Great Bitter Lake consisted of a salt bed, 13 km long and 5 km wide. In the year 1868 its greatest thickness was estimated to be 13.2 meters. This salt bed was assumed to be formed by the evaporation of the sea water left in the arm of the Gulf of Suez after it had been isolated. It consisted of numerous layers of salt crystals, separated from one another by thin layers of a mixture of sand and crystals of calcium sulphate. These salt layers vary in thickness from 5 to 25 cm, most of them being of 10 cm (Alliaud, 1868, Bader, 1869 and Czoering, 1869).

The stratification of the salt-bed into successive layers was explained by De Lesseps (loc. cit.) in the following way; The evaporation of the Red Sea water, which once filled the basin of the Bitter Lakes, would have yielded a salt bed of only one tenth of that found before the canal was estabilished. He assumed therefore, that after the isolated arm of the Red Sea had dried up and deposited all of its salts, it must have refilled and evaporated repeatedly. Bader (1869) suggested that the sand which separated the salt layers originated from the surrounding desert.

In 1869 the dried basin of the Bitter Lakes was filled with sea water from the north and from the south. The concentrated water of the Lakes gradually mixed with the sea water entering through the Canal, with the result that its salinity steadily decreased. At the same time, the depth of water in the Great Bitter Lake over the salt bed increased continuously as a result of the gradual dissolution of salts. The process of decrease in salinity and increase in depth is very much reduced at present, but was very apparent in the first decades after the opening of the Canal. This subject has been discussed by De Lesseps (1876), Voisin Bey (1902—1904), Fox (1920), Wüst (1935, 1951), Krauss (1958) and Morcos (1959).

b. The Current Regime in the Suez Canal:

Figure 1 shows the distribution of the main water masses along the Canal during April 1964 and September 1966, when the water samples for the present investigation were collected. These two months were chosen because, as pointed out by several observes (Fox, 1926; Wüst, 1934; Faouzi, 1951; Morcos, 1960 a, b) they represent two extremes of hydrographic conditions in the Canal.

Except from July to October, the mean sea level is higher at Suez than at Port Said, the currents are mainly northward, and the waters of the Suez Bay ($S < 43‰$) occupy the southern part of the Canal and the Little Bitter Lake. The saline waters of the Bitter Lakes flow northward, thus increasing the salinity of the northern part of the Canal,

and of the Port Said Region. These conditions are well represented by the April section (Fig. 1), when the waters of the Great Bitter Lake have the lowest values of salinity ($44^0/_{00}$) of the entire year.

From July to October, the mean sea level at Port Said is higher than at Suez, and the currents are mainly southerly. The Mediterranean water, diluted by the Nile flood (from August to December with its peak in September), penetrates the Canal southward up to the northern boundaries of the Great Bitter Lakes. The saline water mass of the Bitter Lakes is also pushed southward. This effect is observed in Suez Bay, where higher values of salinity are often measured at this time of the year. In September (Fig. 1) the highest value of salinity ($S > 48^0/_{00}$) for the whole year is often observed south of the Great Bitter Lake.

The newly erected Aswan High Dam at present prevents the annual flooding of the Nile. MORCOS (1967) has observed a complete reversal of the former current regime in the Canal in September 1966. The current attained a northward direction instead of being dominantly southward as has usually been the case at that time of year.

c. Chemical Composition of the Canal Water:

ALLIAUD (1868) described the dry basing of the Bitter Lakes before they were filled with sea water. He analysed the saturated water found in the grooves of the salt bed, and also the water of Lake Timsah, which was then filled with Mediterranean water only. He also made a detailed study of the rate of solution of the salts of the salt bed.

MÜLLER (1872) published an analysis of a water sample brought to him from the Bitter Lakes. DURAND-CLAY (1874) carried out a detailed chemical analysis of 21 water samples from the Suez Canal. SCHMIDT (1878) published an analysis of a water sample from Lake Timsah in October 1875. KRUKENBERG (1888) collected samples from the Great Bitter Lake in December 1886, and from Lake Timsah in February 1887. He made a complete analysis of these samples and compared his results with the older investigations.

NATTERER (1898), the chemist of the Pola expedition, published analyses of five samples taken from the Suez Canal in October—November 1895 during the crossing to the Red Sea.

The Cambridge Expedition to the Suez Canal stayed three months (from October to December 1924) in the Isthmus of Suez. FOX (1926) recalculated the analyses made by DURAND-CLAYE, SCHMIDT, KRUKENBERG and NATTERER, in order to make them comparable with the analyses of 12 samples in the Canal and the Lakes collected by the Cambridge Expedition. When the proportional composition of the Canal water in various years was studied it became evident that all the time the relative proportions of the ions were approximately the same as those in sea water. This was at first accepted by MORÄOS (1960c) who published Hydrographical Tables for high salinities to be used for the Suez Canal waters. MORCOS and RILEY (1966), however, found that the directly determined salinities and densities of these waters are lower than those computed from chlorinity using Knudsen's equation. They suggested the use of the empirical relationship $S\ ^0/_{00} = 1.802\ Cl\ ^0/_{00}$, for conversion of $Cl\ ^0/_{00}$ into $S\ ^0/_{00}$, instead of the classical Knudsen's equations $S\ ^0/_{00} = 0.03 + 1.805\ Cl\ ^0/_{00}$.

The Salt Bed

The main purpose of the following study on the salt bed in the Great Bitter Lake is to trace its influence on the chemical and physical properties of the sea water in the Great Bitter Lake and in the Suez Canal in general.

Three samples of the salt bed which is now covered by a layer of sediments, were obtained in October 1955 from 16 meters depth by the dredgers of the Suez Canal

Authority. The positions where the samples were collected are km 104, km 108, and km 112 along the navigable channel in the Great Bitter Lake. The bottom is mainly hard salt mixed with variable amounts of clay.

The weight of each sample was a few kilograms. They consist of lumps of various sizes composed of crystalline salts and amporphous material. About 500 g. of each sample were selected at random from the smaller lumps, ground to a fine powder, and thoroughly mixed. The three samples were examined in the following way: —

1. A preliminary investigation of the powdered solid was carried out. The results are summarized in Table (1.)

Table (1)

Preliminary Investigation of the Salt Bed (Powdered Samples)

Test	A km 104		B km 108		C km 112	
(1) 2 g. boiled with water + HNO_3: Cl′	57.81%		58.57%		25.08%	
calculated as Na Cl	95.29%		96.55%		41.34%	
(2) 20 g. boiled in HCl Filtrate	ion	Cl-Ratio	ion	Cl-Ratio	ion	Cl-Ratio
analysed for SO_4	1.40 %	0.02422	1.62 %	0.02766	1.03%	0.04107
Ca	0.83 %	0.01436	0.71 %	0.01212	4.04%	0.16108
Mg	0.05 %	0.00086	0.04 %	0.00068	0.06%	0.00239
K	0.005%	0.00009	0.005%	0.00008	0.04%	0.00159
(3) Insoluble Residue dried at 110° C	—		—		44.12%	
ignited	0.48%		0.06%		45.87%	
SiO_2 in residue	—		—		42.69%	
(4) CO_2 in the starting substance	1.85%		0		3.84%	
loss by ignition at 105° C	0.62%		0.55%		0.65%	
500° C	1.02%		0.85%		1.60%	
750° C	2.10%		1.50%		6.05%	
(5) Observations when boiling the substance in diluted HCl	Very turbid solution with chocolate brown flocculent solid matter floating at the surface		Only slightly turbid solution, little sand		Turbid greenish yellow solution. Considerable amounts of soil particles having dirty reddish brown colour (dirty sand). The residue attains slightly lighter colour on ignition	

2. Solutions of the powdered samples in distilled water were prepared by continuou stirring for 24 hours. The solutions were then filtered and adjusted to about 21—22‰ chlorinity. The solutions were examined in the following way: —

a. The clorinity, relative conductivity, and gravimetric salinity were measured by the following procedures:

(i) Chlorinity by potentiometric titrations (HERMANN, 1951).

(ii) Relative conductivity with an Autolab Australian Salinometer.

(iii) Gravimetric salinity according to MORRIS and RILEY (1964).

The determinations were made in quadruplicate, and gave a coefficient of variation of 0.035%, i.e., 0.01 S $^0/_{00}$.

Table (2) gives the results of the above determinations as well as the salinities computed from the chlorinity and conductivity values, assuming that the solutions have the same relative composition as sea water.

Table (2)

Sample	Position	Cl $^0/_{00}$	Rel. conduct.	Gravimetric S $^0/_{00}$	S $^0/_{00}$ from Cl $^0/_{00}$	S $^0/_{00}$ from Rel. conduct.
A	km 104	21.122	1.06141	35.679	38.155	37.428
B	km 108	21.440	1.07685	36.193	38.730	38.044
C	km 112	22.171	1.11500	37.823	40.050	39.386

b. The three samples were analysed for the major anions and cations by means of the procedures used for the 17 canal water samples as described in this paper. The results of the three samples are given and discussed together with the sea water samples in the appropriate sections.

Sea Water from the Suez Canal

Seventeen samples were collected from the Suez Canal in two expeditions in April 1964 and September 1964. The sampling positions are indicated in Fig. 1 and in Table 3. These are the same samples which were investigated for their physical properties by MORCOS and RILEY (1966). In order to insure the continuity of the investigation, aliquots of the samples were sealed in small glass tubes. The chlorinities of the samples were determined by potentiometric titration (HERMANN, 1951). The results were found to be slightly higher than the published chlorinities. The values for the chlorinity ratios in the present paper are calculated from the newly determined chlorinities, but concentrations of the various ions are given after being reduced to correspond to the original (i.e., published) chlorinity values.

A. Anions

1. Sulphates

The determinations were made gravimetrically by precipitation as barium sulphate, following the experimental procedure of BATHER and RILEY (1954). Most of the samples were analysed in triplicate, and a few in duplicate or in quadruplicate. They gave an average coefficient of variation of 0.12%, i.e., 0.0002 SO_4/Cl ratio. Nile water samples were analysed, after being concentrated by evaporation, following the special procedure described by BATHER and RILEY (1954) for River waters.

THOMPSON, JOHNSTON and WIRTH (1931) determined the sulphate/chlorinity ratio of sea water to be 0.1395. The low salinity samples of the Baltic Sea were exceptional, having a mean ratio of 0.1414. MORRIS and RILEY (1966) found an average ratio 0 1400.

GREFFARD (1965) compared the sulphate content of the Red Sea waters with that of the Mediterranean and Copenhagen normal water.

CULKIN (1965) has summarized the principal determinations of sulphate in sea water, and has pointed out that, although the sulphate/chlorinity ratio of open sea water may be regarded as constant, certain factors tend to cause regional variation.

Regional Variation:

Table (3) shows clearly an example of regional variation in the sulphate/chlorinity ratio in the Suez Canal waters. This is demonstrated by the following observations: —

1. The salt bed has a very low sulphate content. The three samples have an average sulphate/chlorinity ratio of 0.0293, i.e., about one fifth that of sea water.

2. The Nile water has a sulphate/chlorinity ratio of 1.6878, i.e., more than 12 times that of sea water. This is in accordance with the well established fact that the sulphate/chlorinity ratio of river water is much higher than that of sea water. The sulphate/chlorinity ratio of river water in the U.S.A., ranges between 9.62 and 1.23 (THOMPSON and ROBINSON, 1932). The sulphate/chlorinity ratio of rivers flowing into the eastern Irish Sea was found to range between 11.51 and 1.32 (BATHER and RILEY, 1954). An increase in the sulphate/chlorinity ratio might be expected in regions where sea water is diluted by river waters. However, such increases are usually very small, because of the small quantities of dissolved solids in river waters (CULKIN, 1965).

3. In the Suez Canal waters, the sulphate/chlorinity ratio decreases as the chlorinity increases. The smallest values of the sulphate/chlorinity ratio are observed in the highly saline water mass of the Great Bitter Lake. In September, when the Nile flood is at its maximum, the highest values are observed at Port Said and in Lake Timsah at the surface. The value of Lake Timsah is remarkably high. This may be due to fresh water brought by drainage to the Lake from the surrounding agricultural lands.

The high salinity of the Bitter Lakes is caused partly by the high rate of evaporation in this region, especially in summer, and partly by the dissolving of evaporite deposits at the bottom of the Lake. Since the salt bed has a very low sulphate/chlorinity ratio these waters have a low sulphate/chlorinity ratio.

The water of the Suez Bay are mixed continuously with the water mass in the Bitter Lakes, because of the reversible semi-diurnal tidal currents which dominate the southern part of the Canal (MORCOS, 1960 b). The results of this effect can be observed in the analyses of the Suez Bay waters (samples 5 to 10), which have an average sulphate/chlorinit ratio of 0.1394. This value is slightly less than that accepted for ocean waters, but higher than the average value 0.1374 for the water mass of the Bitter Lakes (samples 11 to 17).

The results of analyses of DURAND-CLAYE (1874) and FOX (1926) cover the entire length of the Canal. They include determinations of the chlorides and sulphates. The

Table (4)

Year	Author	No. of samples	Position		S $^0/_{00}$	Cl $^0/_{00}$	SO_4 g./kg.	SO_4/Cl
1872	DURAND-CLAYE, L. (1874)	21	Min. S $^0/_{00}$	Port Said	22.9*)	12.7*)	1.89	**0.1448**
			Max. S $^0/_{00}$	km 76	**69.3**	**38.4**	4.93	0.1284*)
1924	FOX, M. M. (1926)	12	Min. S $^0/_{00}$	Port Said	35.53*)	19.67*)	2.77	**0.1408***)
			Max. S $^0/_{00}$	km 119	**53.55**	**29**.65	3.89	0.1312

NB: Values in block letters (underlined) are the maximum values, those marked by (*) are the minimum values among every set of analysis.

Table (3)

Sample No.	Station	Position		Month (1964)	Depth (m)	S ‰ Computed from Cl ‰	Cl ‰
1	1 A′	N. of Port Said	km 110	September	0	27.085	14.989
2	11	Lake Timsah	km 82	September	0	32.646	18.070
3	1 A′	N. of Port Said	km 110	September	13	38.910	21.540
4	1 A′		km 110	April	6	39.244	21.725
5	25' a		km 170	April	0	42.274	23.404
6	25 a		km 164.8	April	0	42.325	23.432
7	25 b	Suez Bay	km 164.8	April	0	42.419	23.484
8	25′b		km 170	April	0	42.472	23.514
9	25′		km 170	September	0	42.896	23.749
10	25		km 164.8	September	0	43.020	23.817
11	Ka	Great Bitter Lake and	km 116.3	April	12	43.576	24.125
12	K b	Southern Canal	km 116.3	April	12	43.836	24.269
13	13 a		km 103.4	April	12	44.192	24.466
14	13 b		km 103.4	April	12	44.256	24.502
15	K		km 116.3	September	13	46.697	25.854
16	19		km 125	September	13	47.727	26.425
17	22		km 146.1	September	14	47.834	26.484
A	Salt Bed of the Great Bitter Lake		km 104	October 1955	16	38.155	21.121
B			km 108		16	38.730	21.440
C			km 112		16	40.050	22.171
N	Nile Water, Kafr El-Zayat			October 1964	0		0.044

data were examined by the author, and the sulphate/chlorinity ratios were calculated. The minimum and maximum values of salinity and the corresponding sulphate/chlorinity ratio are given in Table (4).

The data of DURAND-CLAYE (1874) and FOX (1926) show that the minimum salinity and the maximum sulphate/chlorinity ratio in the Canal were found near Port Said in both cases. The maximum salinity was found at km 76 in 1874, and at km 119 in 1926, associated in both cases with the minimum chlorinity ratio along the Canal.

In spite of the limitations of the analytical procedures used in both 1874 and 1926, Table (4) illustrates very clearly the regional distribution of the sulphate/chlorinity ratio in the Canal. The explanation of this phenomenon lies again, in the two main factors changing the salinity in the Canal, i.e., the fresh water inflow and the dissolving of the salt bed.

Seasonal Variation:

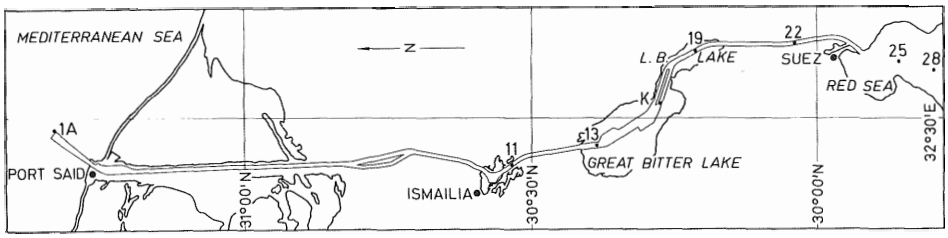
Since the Suez Canal undergoes a very pronounced monthly change in salinity, a seasonal variation in the sulphate/chlorinity ratio might be expected. A preliminary conclusion can be obtained by comparing the Bitter Lake samples of September 1964 with those of April 1964. The three samples taken in September (No. 15 to 17) have an

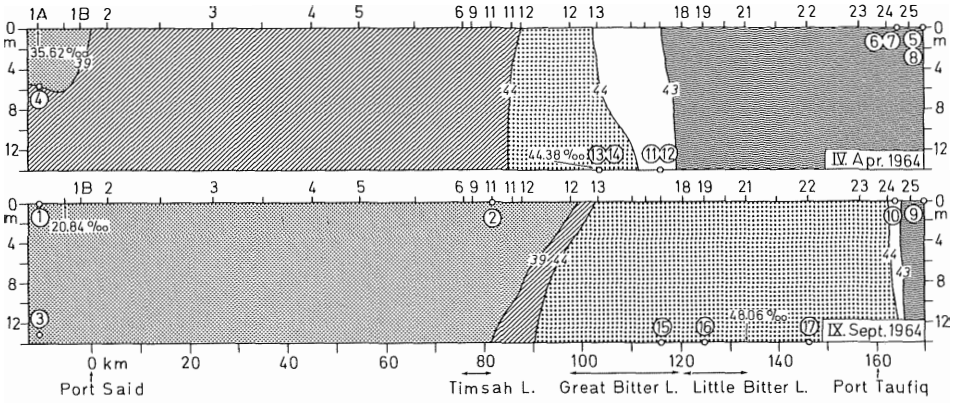
Plate (1): Position of the stations in the Suez Canal region

1) Distribution of salinity in April and September 1964.

2) Seasonal variations of salinity and SO_4''/Cl' ratios at station 13.

3) SO_4''/Cl' ratios at various chlorinities and the best fit equations.





①

S‰(43‰ – 44‰)

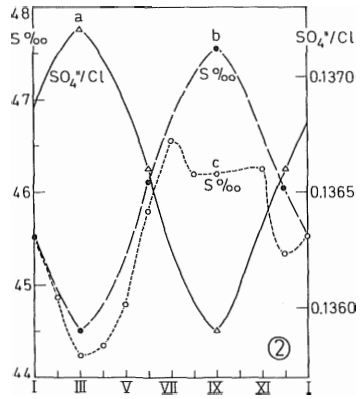
diluted Mediterranean water S‰<39‰)

suez bay water (S‰<43‰)

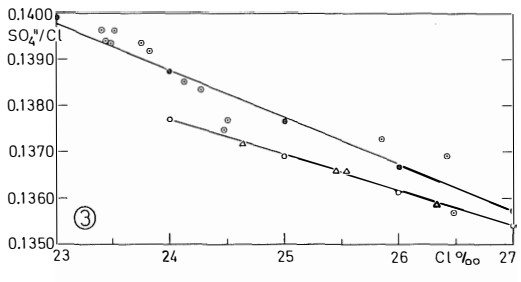
S ‰(39 ‰– 44‰)

① to ⑰ position of samples

Great Bitter Lake water (S‰ 44‰)



a = SO_4 /Cl ratio: seasonal observation in st. 13+13B
b = salinity: seasonal observation in st. 13+13B
c = salinity monthly observation in st. 13, 12m



= SO_4 /Cl ratio for 13 samples (1964)
● = SO_4 /Cl ratio computed from equation (1)
△ = SO_4 /Cl ratio for 4 samples (1954–1955)
○ = SO_4 /Cl ratio computed from equation (3)

Tafel 1 (zu S. A. Morcos)

	Sulphate			Bromide			Fluoride		
SO_4 g./kg.	SO_4/Cl	Average SO_4/Cl	Br g./kg.	Br/Cl	Average Br/Cl	F mg./kg.	F/Cl x 10^5	Average F/Cl
2.106	0.1405		0.0514	0.00338		1.215	**8.11**	
2.593	**0.1435**	**0.1408**	0.0575	0.00318*)	0.00334	1.160	6.42	6.639
3.007	0.1396		0.0731	0.00338		1.311	6.09	**6.150**
3.031	0.1394		0.0732	0.00337		1.291	5.94	
3.268	0.1396		0.0796	0.00338		—	—	
3.266	0.1394		0.0792	0.00338		1.346	5.75	
3.273	0.1394	0.1394	—	—	**0.00339**	1.342	5.71	5.758
3.283	0.1396		0.0804	**0.00342**		1.374	5.84	
3.309	0.1394		0.0805	0.00339		1.360	5.73	
3.315	0.1392		—	—		—	—	
3.341	0.1385		0.0816	0.00338		1.377	5.71	
3.358	0.1384	0.1380	0.0790	0.00325	0.00336	1.324	5.46	5.660
3.364	0.1375		0.0824	0.00337		1.399	5.72	
3.374	0.1377	0.1374	0.0838	0.00342	0.00334	1.411	5.76	5.634
3.549	0.1373		0.0861	0.00333		1.492	5.77	
3.618	0.1369	0.1366*)	0.0895	0.00339	0.00333*)	1.460	5.52	5.599*)
3.594	0.1357*)		0.0865	0.00326		1.457	5.50*)	
0.479	0.0227		0.0022	0.00011				
0.570	0.0266	0.0293	0.0038	0.00018	0.00016			
0.861	0.0388		0.0039	0.00018				
0.074	1.6878							

N.B. (1) The positions are given in hectometers north of Port Said Light House and in kilometers south of this point
(2) Samples 25'a, 25a, K a and 13a were stored in glass, the rest of samples were stored in polyethylene bottles.
(3) The samples are tabulated according to the order of the increasing salinities.
(4) Values in block letters (underlines) are the maximum values, those marked by (*) are the minimum values among the 17 water samples.

average sulphate/chlorinity ratio of 0.1366, which is lower than 0.1380, the average value for the four April samples (Nos. 11 to 14).

Table (5) shows the results of an unpublished investigation made by the author in 1957 with the purpose of studying the seasonal variation in the sulphate/chlorinity ratio in the Great Bitter Lake. Samples IX, XII, III and VI are mixtures of waters from stations 13 (km 103.4) and 13 B (km 118.9) in the Great Bitter Lake, collected during September 1954, December 1954, March 1955 and June 1955 respectively. Sample M is a composite sample of the Lake waters collected during July, August and November 1955.

The salt samples A', B' and C' were taken from the salt bed at km 104, km 108 and km 112. They were selected from the original samples obtained by the dredgers of the Suez Canal Authority. Solutions of the salt samples were prepared as described above, except that the salt was not ground to powder before being dissolved, and that the solutions were adjusted to a higher chlorinity value of $26^0/_{00}$, the approximate value of the Great Bitter Lake.

Since the seasonal variation of the sulphate/chlorinity ratio is very small, determinations were made in quadruplicate and gave a coefficient of variation of 0.15 (average of 4 samples), i.e., 0.0002 sulphate/chlorinity ratio.

Table (5)

Seasonal Variation in the SO_4/Cl Ratio in the Great Bitter Lake

Sample	Position	Month	S ‰	Cl ‰	Sulphate (g./kg.)	SO_4''/Cl'	Average	Coef. of variation %	Average
			a. *Water Samples:*						
IX	Great	Sept. 1954	47.547	**26.325**	3.5766	0.1359*)		0.1180	
XII	Bitter	Dec. 1954	46.039	25.450	3.4762	0.1366		0.1936	
III	Lake[1])	March 1955	44.500	24.637*)	3.3793	**0.1372**	0.1366	0.1127	0.1540
VI	St. 13								
	(km 103.4)	June 1955	46.122	25.536	3.4879	0.1366		0.1915	
M	St. 13B (km 118.9)	July, Aug., Nov. 1955	46.978	26.010	3.5564	0.1367		—	
S	Suez Bay	Nov. 1955	43.097	23.860	3.3000	0.1383		—	
			b. *Salt Bed:*						
A′	km 104	October	48.007	26.580	0.3471	0.0131			
B′	km 108	1955	47.601	26.355	0.7362	0.0279	0.0244		
C′	km 112		47.047	26.048	0.8401	0.0323			

N.B.: Values in block letters (underlined) are the maximum values, those marked by *) are the minimum values.

Table (5) and Fig. 2 illustrate a seasonal variation in the sulphate/chlorinity ratio in the Lake. The ratio has a minimum in September and a maximum in March, contrary to the trend in the salinity. The salinity in the Lake undergoes very regular seasonal variation, (MORCOS, 1960 a) and decreases from a maximum in summer to a minimum in winter. The salinity therefore attains an intermediate value in June and December. If the increase of salinity in the Lake in summer is caused by evaporation only, the sulphate/chlorinity ratio would be expected to remain constant. But if the increase in salinity of the Lake is caused, to a certain extent, by the dissolving of salts from the salt bed, a seasonal change in the sulphate/chlorinity ratio would be expected. In September, the current becomes southward and its velocity is much less than that of the northward current in winter. The water mass of the Bitter Lakes increases in salinity and in volume and is pushed southward to occupy the Little Bitter Lake and the southern part of the Canal. When the current is sluggish in September, there is more time for the water to come into contact with the salt bed, thus increasing its salinity. As a result more salts go into solution, and consequently, the sulphate/chlorinity ratio drops. Hence, there is a reciprocal relation between the salinity and the sulphate/chlorinity ratio of the Lake water.

Relationship of Sulphate to Chlorinity:

That the sulphate/chlorinity ratio has virtually a constant value in the open sea, is an accepted fact. This is not the case in the Suez Canal waters which show a regional and seasonal variation in the sulphate/chlorinity ratio. Empirical formulae were calculated from the data in Table (3) and Table (5) by the method of least squares, and are shown in Table (6). Equation (4) has been computed by LYMAN and FLEMING (1940) from data published by THOMPSON *et al.* (1936) for the Baltic Sea in July 1929 and is given in Table (6) for the purpose of comparison. The conditions in the Baltic Sea are almost opposite to those in the Great Bitter Lake.

Table (6)

Region	Date	Samples	Relation of sulphate to chlorinity
(i) Bitter Lakes and Suez Bay	April and Sept. 1964	N = 13 (Nos. 5—17)	$SO_4 = 0.1118\ Cl\ ^0/_{00} + 0.6469$ (1)
(ii) Great Bitter Lake	April and Sept. 1964	N = 7 (Nos. 11—17)	$SO_4 = 0.1173\ Cl\ ^0/_{00} + 0.5043$ (2)
(iii) Great Bitter Lake	Sept., Dec., 1954 March, June, 1955	N = 4 IX, XII, III, VI	$SO_4 = 0.1169\ Cl\ ^0/_{00} + 0.4998$ (3)
(iv) Baltic Sea	July 1929	N = 5	$SO_4 = 0.1391\ Cl\ ^0/_{00} + 0.0061$ (4) (After THOMPSON et al, 1951 and LYMAN and FLEMING, 1940)

The SO_4/Cl-ratio versus Cl $^0/_{00}$ is plotted in Fig. 3. The two straight lines are computed from equations (1) and (3). The values of the Bitter Lakes in 1954 are systematically less than those for 1964. It is suggested that equation (1) which respresents the Bitter Lakes and the Suez Bay should be used for sea water from the Suez Canal (S $^0/_{00}$ = 41.5 $^0/_{00}$).

2. Bromides

Bromine exists in sea water as bromides. BORCHERT (1959, 1965) has pointed out the importance of bromine determinations in studying the conditions of oceanic salt depositions. The analytical procedure as described by MORRIS and RILEY (1966) was applied in the present investigation. The bromide is oxidised by hypochlorite to bromate, which is then determined iodometrically. Triplicate determinations were made. They gave a coefficient of variation of 0.82%, i.e., 0.00003 Br/Cl ratio. The results are given in Table (3).

THOMPSON and KORPI (1942) found that the bromide/chlorinity ratio is constant (0.00347) for all depths of the Bering Sea, the Pacific and the Antarctic Oceans. MORRIS and RILEY (1966) obtained a mean value of 0.00348 for all oceans. The results in Table (3) show that the bromine/chlorinity ratio in the Suez Canal is systematically less by about 0.0001 than the oceanic ratio. The individual results are less homogenous than those of the sulphates. However, the average values in Table (3) show that waters of Suez Bay have a higher bromide/chlorinity ratio than the low salinity water in Port Said and Lake Timsah, and the Bitter Lake waters.

Dilution by river waters, which presumably have low bromide/chlorinity ratios, results in a decrease in the bromide content. The minimum bromide/chlorinity ratio is found in sample No. 2 from Lake Timsah, which has also the highest sulphate/chlorinity ratio.

On the other hand, the salt bed is very poor in bromides. Sea water has a bromide/chlorinity ratio 30 times larger than the average ratio for the salt bed. The Br/Cl ratio of the Bitter Lakes is lower than that of the Suez Bay.

3. Fluorides

Fluoride was determined by a modification of the lanthanum alizarin complexon method of GREENHALGH and RILEY (1963) in which a Technicon autoanalyser is employed (GRASSHOFF, 1965).

According to GREENHALGH and RILEY (1963), the fluoride/chlorinity ratio is fairly constant for surface sea water (6.7×10^{-5}). However, anomalously high fluoride concentrations up to 9.0×10^{-5} occur in the bottom waters of certain regions of the oceans, notably the North Atlantic (GREENHALGH and RILEY, 1963 and RILEY, 1964). It may

be concluded, therefore, that fluoride is not, as has long been thought, a conservative constituent of sea water. The fluoride/chlorinity ratio varies significantly in different water masses. It may be a valuable tracer for the indication of currents and water transport (GRASSHOFF, 1965).

Table (7)

Sample No.	Station	Month	Position	Depth.
1	I A′	September	km 110	0
2	II	September	km 82	0
3	I A′	September	km 110	13
4	I A′	April	km 110	6
5	25’	April	km 170	0
6	25	April	km 164,8	0
7	25	April	km 164.8	0
8	25′	April	km 170	0
9	25′	September	km 170	0
10	25	September	km 164.8	0
11	K	April	km 116.3	12
12	K	April	km 116.3	12
13	13	April	km 103.4	12
14	13	April	km 103.4	12
15	K	September	km 116.3	13
16	19	September	km 125.0	13
17	22	September	km 146.1	14

The results given in Table (3) show that with exception of sample (1), all the fluoride/chlorinity ratios are lower than the accepted value for surface sea water. The average value of the Port Said region is higher than that for the Suez Bay, which is in turn higher than that of the Bitter Lakes. Unfortunately the fluoride content of the salt bed has not been determined, but it seems that it is poor in the fluorides, since it shows the same influence on the composition of the Bitter Lake water, as that observed with the sulphates and bromides.

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