LAKE CHAD: A SUBDESERTIC TERMINAL BASIN WITH FRESH WATERS

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ABSTRACT: The salinity control of lake Chad is one of the most remarkable characteristics of this terminal basin. In spite of considerable dissolved salt input from rivers (ions : 42 mg/l, silica : 26 mg/l, total inflow : 3.10^6 t/year) and very high rate of evaporation, lake Chad has a low salinity (ions : 320 mg/l, silica : 50 mg/l). The removal of ions and silica by sedimentation in the lake is evaluated at more than 37% and 83% of the input, respectively. Removal of sodium, which is not evaluated, is the smallest. The salt budget provides a means for evaluating water losses by evaporation and infiltration. Evaporation consumes more than 93 to 96% of the inflow.
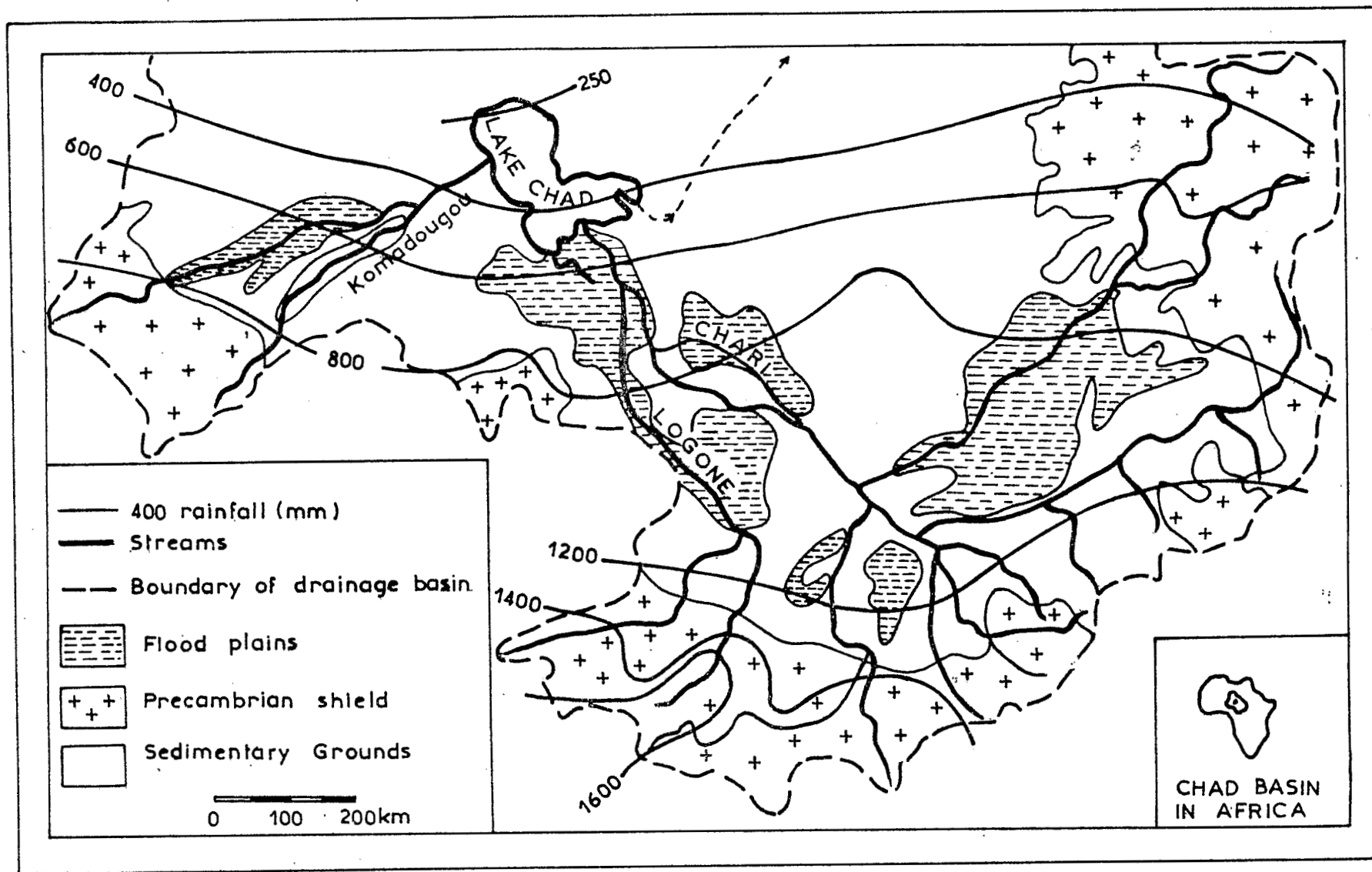
Résumé: La régulation saline du lac Tchad est la caractéristique la plus remarquable de ce bassin endoréique. Malgré un apport considérable en sels dissous par les rivières (ions : 42 mg/l, silice : 26 mg/l, apport total : 3.10^6 t/an) et une évaporation très élevée, les eaux du lac Tchad ont une salinité faible (ions : 320 mg/l, silice : 50 mg/l). Les pertes d'ions et de silice par sédimentation dan le lac sont évaluées respectivement à plus de 37% et 83% des apports. Les pertes en sodium dans le lac, non évaluées, sont les plus faibles. Le bilan salin permet d'évaluer les pertes en eau par évaporation et infiltration. L'évaporation consomme plus de 93 à 96% des apports.

INTRODUCTION

The hydrological system of lake Chad is the active part of a vast continental basin situated in the heart of Africa (Fig. 1), in the climatic zone ranging from humid tropical to subdesert (M.A. ROCHE - 1973 c, 1975). Lower regions than lake Chad, called "Bas-Pays," exist in the north of the basin but, in the present time, under desertic conditions, they are not covered by surface water.

Extensive plains, flooded by the Chari and the Logone rivers, lake Chad and groundwater connected with the lake, constitute the actual active system, making up a series of sedimentary traps for dissolved and suspended components originated from upstream areas with high rainfall (1,500 mm/year) and low evaporation (1,100 mm/year) to downstream areas with weak rainfall (200 mm/year) and high evaporation (2,300 mm/year).

Therefore, in this zone, the geochemical phenomena are very evident because of intense increasing evaporation and because of the shallowness of the water. The sedimentation begins in the flat plains, where 10% of the major ions settle out but the salinity control of lake Chad, closed basin without surface outlets, appears to be the most remarkable characteristics of the system.

Legend:
- —— 400 rainfall (mm)
- ▬▬ Streams
- – – Boundary of drainage basin
- Flood plains
- +⁺+ Precambrian shield
- Sedimentary Grounds

0   100   200km

CHAD BASIN IN AFRICA

LAKE CHAD

Komadougou

CHARI

LOGONE

250
400
600
800
1200
1400
1600

During normal periods which can be several decades long, the lake water covers about 20,000 square kilometers, with maximum length and width of 200 kilometers, and depths no more than 5 to 8 meters.

It receives, on the average, 50.10^6 m^3/year, 95% of which enters the southern part (Fig. 2). **The Chari river alone assures 83% of this alimentation,** rainfall (325 mm/year) contributes 12% (P. TOUCHEBEUF -1969-, B. BILLON et al. -1974-). These inflows are essentially consumed by evaporation and a few percents by infiltration. **These losses determine an annual oscillation (0,50 to 1 m)** of the lake level and a pluriannual stabilization in normal periods.

The global losses due to evaporation plus infiltration cannot be separated by means of the hydrological budget. However, the saline budget does offer a way of making this separation, and of thus determining the amount of evaporation of a large surface of water in the sahelian zone.

The hydrological steady-state over long periods can be interrupted by droughts of the type which has raged the tropical regions from 1972 to 1974. In 1973, the lake area was the third of the area in 1970, the volume was the fourth part (Fig. 3). In 1975 the northern basin, isolated by vegetation grown up on the shallow "Grande Barrière", dried up completely (M. ROCHE -1973-, A. CHOURET -1974-, J. RODIER -1974, 1976-, J. SIRCOULON -1976).

Such a drought is not unique in the recent historical period. This is the third times in a century, after 1910-1914 and 1940-1944 that such a catastrophe has occurred. It is probable that, once the water rises again, the lake will regain a chemical steady-state few different of that which has been studied during a period of normal level.

SALINITY CONTROL OF THE LAKE WATERS

The study was based on thousands of hydrological measurements, and geochemical and isotopic analysis taken for water feeling the lake, for the lake itself and for its banks (M.A. ROCHE -1973 c-). In the lake, the average concentrations and quantities of dissolved constituents were evaluated from salinity maps gotten every two months.

Salinity of the Lake Waters

The river waters flow into the lake with an average concentration of 42 mg/l of dissolved ions, 25 mg/l of dissolved silica and about 70 mg/l of suspended matter, about half of which is kaolinite. In spite of an annual discharge of about 3 million tons of dissolved components, plus the equivalent weight of suspended materials, over a period of thousands of years, the lake water has not become greatly mineralized (Fig. 4).
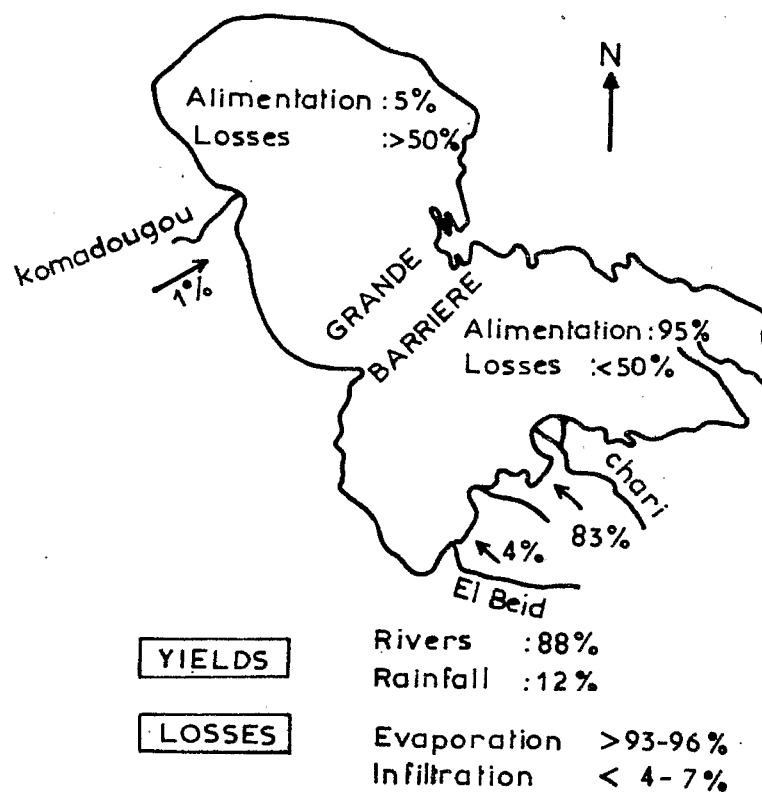
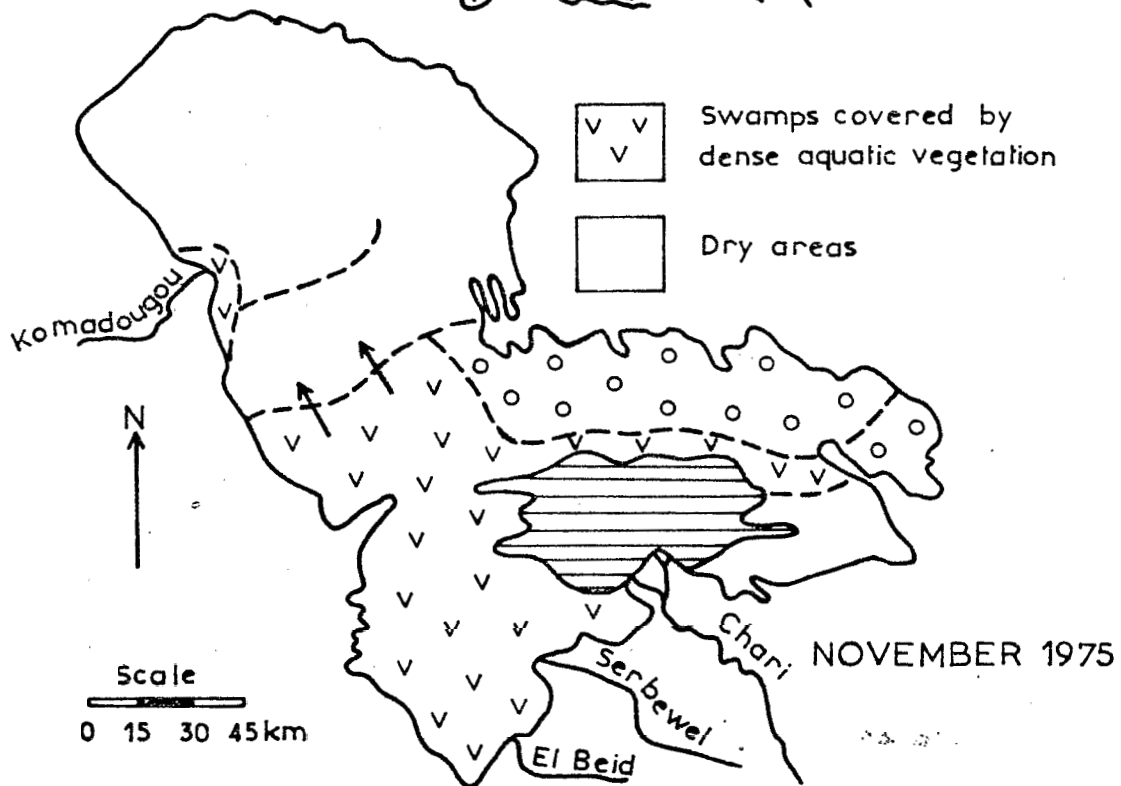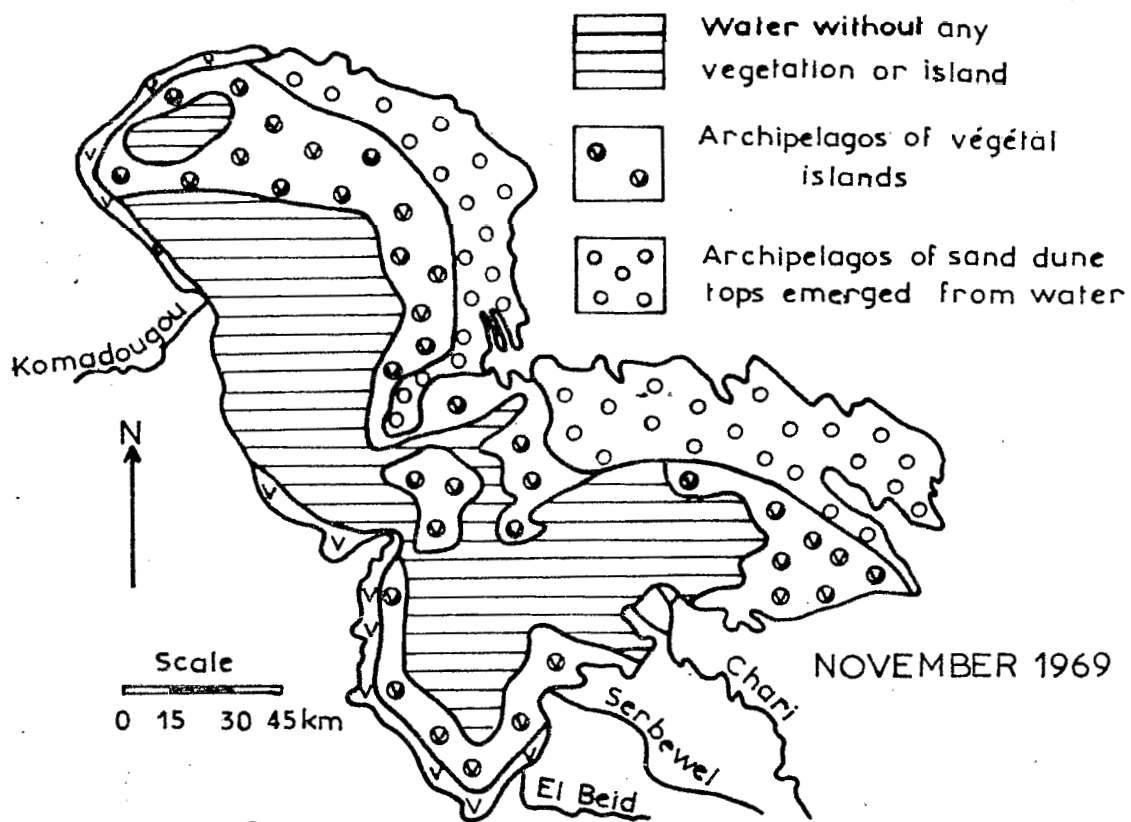Figure 2. Water budget of lake Chad in normal period (1954-1969).

Figure 3. Lake Chad at a normal level of 281.5 m in 1969 (after M.A. ROCHE -1971-)
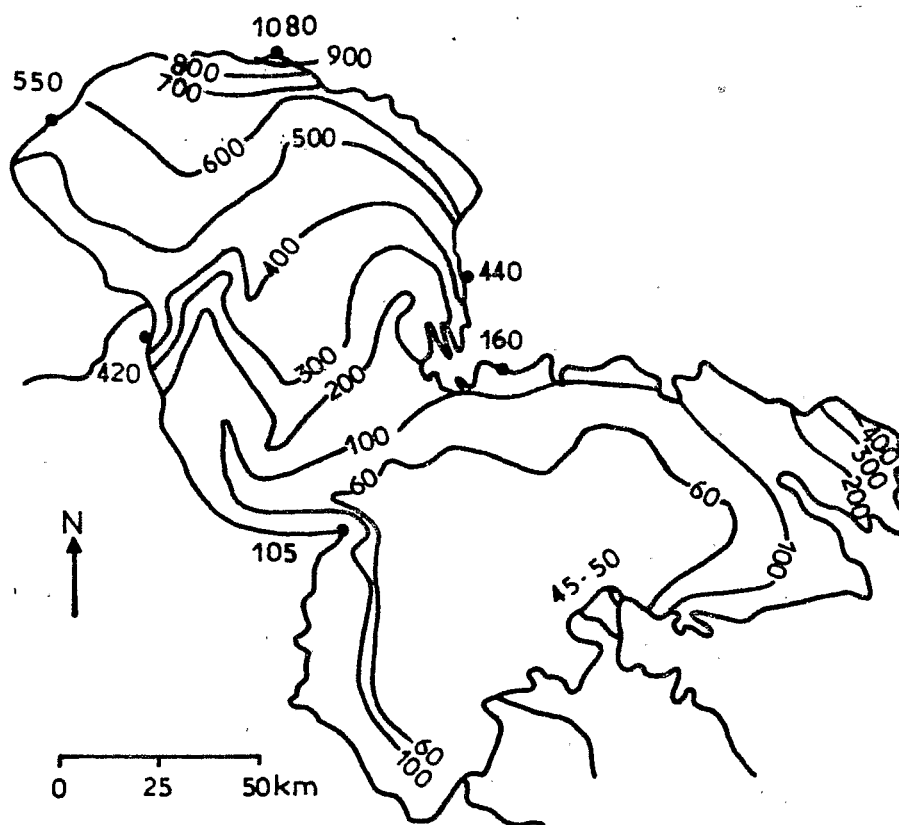and at a low level of 279,5 m in 1975 (after A. CHOURET -1975-).

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Figure 4. Global ionic content (mg/1) in the water of lake Chad (example taken in December 1969).

Once the river water arrives in the lake, it is directed progressively toward the banks. Under the effect of evaporation, the salinity increases from the Chari delta to the shore line. However, the maximum global ionic content is only 3 to 40 times more than that in the river water. The silica content is only 2 to 6 times more. The average ionic concentration for the total lake volume remains slight, at 320 mg/l. The average dissolved silica content is 50 mg/l.

Like the water which feeds the lake, the lake water itself continues to be bicarbonated. Chloride represents no more than 1%. Sulphate concentrations are even slighter.

With the increase of the salinity, there is a marked change in the cationic spectrum (Fig. 5), which from being calcic, becomes progressively sodic, evolving from Ca. Mg. Na.K. to Na. Mg. K. Ca through five successive stages as function of the global salinity, the elapsed time and the areas. Such a cationic chromatography is often observed in groundwater of arid or subarid zones, but rarely in surface water. It provides evidence of a specific salinity controle of each chemical component.

This selective salinity control is more evident if the residence time for each component is considered (Table I). It varies from 16 years for the sodium to 3 years for the silica. The global quantity of dissolved ions in the lake water is equivalent to only a ten year input.

Mechanisms of Salinity Control

The salinity control in the lake water is explained by two mean mechanisms.

(1) Removals by sedimentation in the lake

Interactions with the mineral and organic environment lead to a chemical and biochemical sedimentation, in the lake itself, which varies depending upon

Table I. Chemical budget of lake Chad (period 1954-1969).

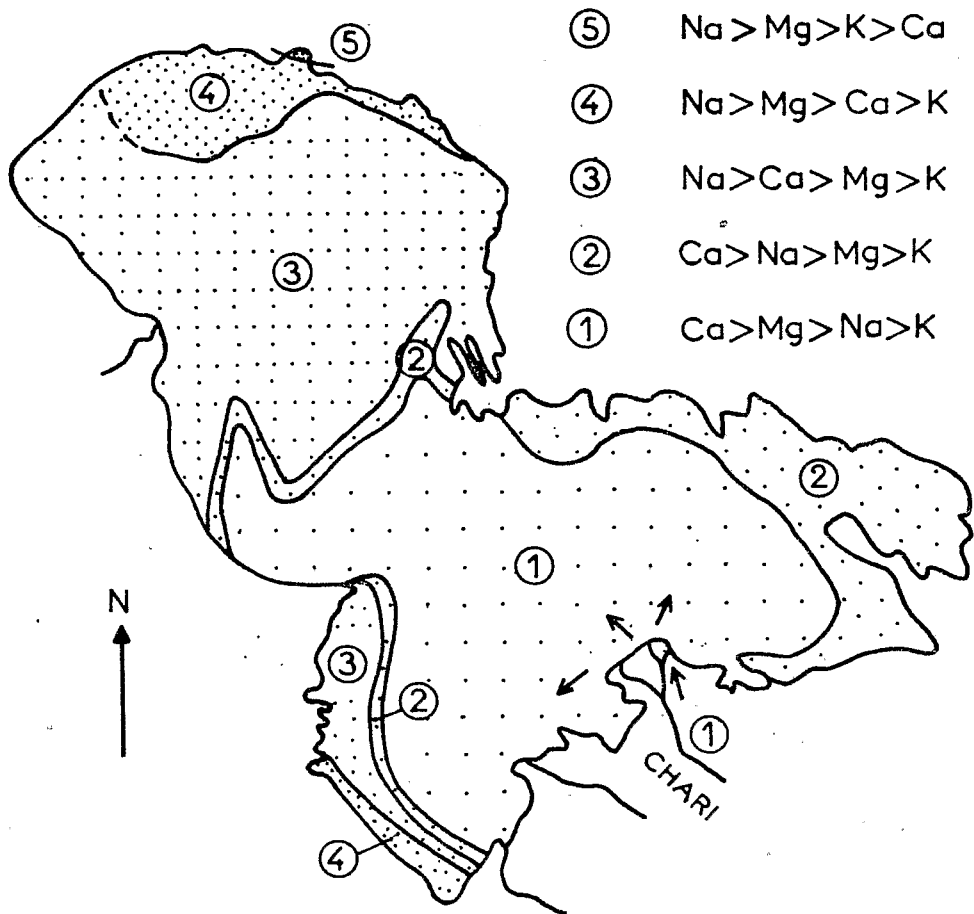|	Ca^{++}	Mg^{++}	Na^+	K^+	total cations $CO_3H^- + CO_3^{--}$	SiO_2 (mg/l)
Mean dissolved contents of river yields (mequiv/l)	0.200	0.141	0.131	0.043	0.515	25
Mean dissolved contents in lake water (mequiv/l)	1.03	0.96	1.60	0.41	3.95	53
Residence time (years)	7	9	16	12	10	3
Removal by sedimentation(%)	>58	>45	>0	>23	>37	13

Figure 5. Variations of the cationic composition of the water of lake Chad (example of December 1969). The cations are classified in decreasing order of content (in mequiv/l).

the components. From various considerations (M.A. ROCHE - 1973-), sodium ion appears the less reactive with the lake environment. Considering that sodium does not sediment in the lake and that a steady-state exists, with the aid of a simple model based on the saline budget, it is possible to estimate minimum values for the sedimentation of the components and maximum values for the water and salt losses by infiltration.

At least 37% of the ions and 83% of the silica entering the lake sediment therein (Table I). The relative removals in Ca^{++}, Mg^{++}, K^+ and CO_3H^- are at least 58, 45, 23 and 37%, respectively (M.A. ROCHE -1973 c-). For example, assuming a 50% sodium removal, the ions removals would be 68% and that of silica 92%. All the suspended matter remains in the lake.

For the most part, the sedimentation of the ions and of the silica corresponds essentially to diagenesis of clay minerals of the montmorillonite group. These diagenesis as well as the organic matter create a large adsorption capacity which contributes to the salinity control.

(2) Removals by infiltration and superficial abandonments

A non-selective removal of water and of dissolved salts is caused by infiltration through the lake banks and by superficial abandonments in the litoral basins which act as natural brine pits with the fluctuation of the lake level.

The relative removals by these processes correspond to the differences between the input and losses in the lake. That is to say that less than 63% of the ionic input and less than 17% of the silica input leave the lake with the infiltrating water. From the same model, the water outflow from the lake has been estimated at a maximum between 4 and 7% of the water inflow, less than 0,5% of which is assured by surface to the first littoral basins. Evaporation from the surface lake water therefore consumes more than 93 to 96% of the water inflow. Assuming, for example, a possible 50% sodium removal in the lake, infiltration would be only 2 to 3% and then evaporation 97 to 98% of the water yields. Therefore, evaporation is more than 220 to 230 cm/year.

The lake overlies a phreatic aquifer, 70 meters thick, within quaternary grounds : sand dunes or sandy-clay deposits. It is surrounded by depressions of the water-table in the center of which the level of the groundwater is 5 to 50 meters lower than the surface water. Though hydraulic slopes and lithology seem to allow infiltration, the volume of the lake water infiltration, estimated previously to be a few percents of the inflow, appears to be too high with regard to the origins and distribution of waters in the shore, as is shown by the isotopic composition (FONTES et al. -1970-, M.A. ROCHE -1970-). This implies that some lake water is evaporated from the aquifer quite near the bank, shortly after infiltration. This evaporating fringe correspondes principally to the area which emerges during the seasonal variation in the lake level.

The lake water then has a permanent tendency to lose its chemical components shortly after infiltration. These are picked up again by rainwater which falls at the time of the low level.

The long-term oscillations in the lake level over hundreds or thousands of years resulted in a subsurface and surface migration of salts from the lake to the surrounding country where, in the north-eastern dune region, they lie in the interdunes depressions giving rise to evaporite parageneses with predominant trona. Relationships between these salts, which age varies from present days to Quaternary, and phreatic groundwaters is function of interdune morphology and of the water-table evolution in time.

On an annual scale, such a pattern of salt migration is very limited, because it implies large variations in lake level.

CONCLUSION

Though evaporation of surface water represents more than 93% to 97% of the losses, the lake water are few mineralized, with concentrations between 40 and 1000 mg/l. Unusual deposits, often resulting from interactions between water, dissolved and suspended material, silicates, plant and animal life, are responsible for the removal of dissolved constituents from the water. These processes are favored by the bicarbonated type of the water but completed by a complex pattern of infiltration and evaporation through the banks. The superficial abandonments overall assure a long-term evacuation of salts.

In the hydrological system of lake Chad, evolution in space and time can be deduced one from the other. Over several hundreds of kilometers, large variations occur in climate, hydrology and hydrochemical processes. Similar variations, but in time in stead of space, took place during the large climatic changes during the Quaternary and on a smaller scale during climatic oscillations with a period of a decade or so. This idea helps to understand and evaluate the Quaternary heritage in the tropical and desert regions and allow to forecast certain geochemical and hydrological consequences of the main low-water periods.

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