

## 2. The lacustrine environment

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### 2.1 Geography of the lake

The lake is situated between 12° and 14°20 latitude north and between 13° and 15°20 longitude east. It occupies the entire part of a 25 000 km<sup>2</sup> closed basin which has an outlet towards the Chad Bahr-el-Ghazal above the altitude of 283 m (Fig. 1). Lake waters rise above this point only after several consecutive high river floods and then flow towards the lower regions in the northern part of the basin. Around this level, the lake looks like a small inland sea, as was the case during the second half of the 19th century and more recently in 1963–64. On the other hand, it can be reduced to a number of residual ponds of a few hundred square kilometers which are covered with vegetation, as in the beginning of the century (Tilho 1910) or in 1973–76.

These changes depend upon the lake water regulation, its morphology and the growth of higher aquatic plants. Water regulation, associated with the morphology of the lake basin, is such that the mean depth of the lake is 4 m (or 281.8 m a.s.l.) and the seasonal and between years variations in water level are respectively about 0.5 and 5 m. However, it should be noted that the variations in depth are in the range of about 4–5 m excluding the extreme values. Therefore, large areas are likely to be emerged or immersed with small variations in the water level. Moreover, the bottom of the basin is characterized locally by a dune system which determines three types of landscapes according to the altitude of the dune crests compared with that of the water level:

- a region of islands when the dune crests are emerged
- a region of vegetation island called reed islands when the crests are immersed in 0.50–1.50 m of water and occupied by semi-aquatic phanerogams (mainly *Cyperus papyrus* and *Phragmites*)
- a region of open waters when the crests are inundated and without emergent vegetation, generally the case when they are situated at depths greater than 1.5 m.

A fourth zone can appear in very shallow and protected regions. It is

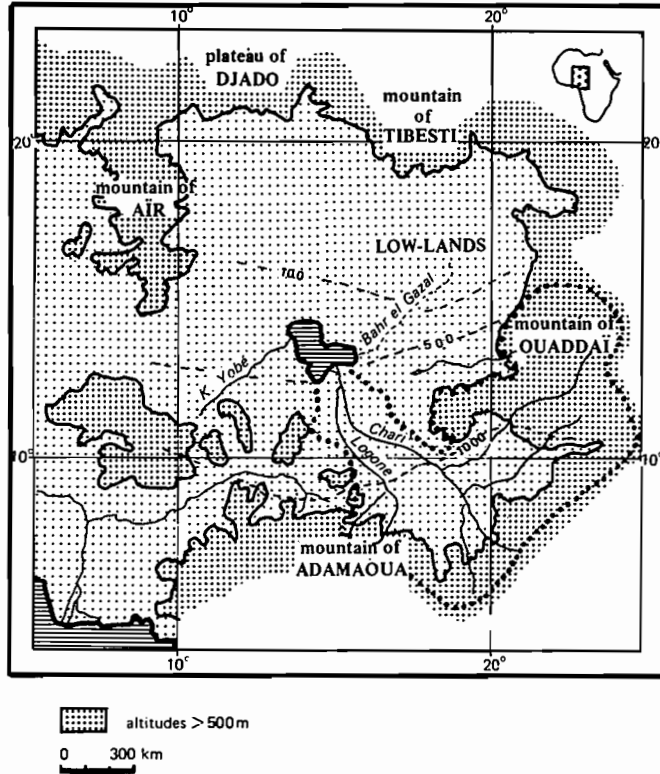


Fig. 1 The Chad basin.

composed of reed islands and swampy meadows with *Potamogeton*, *Vallisneria* and *Ceratophyllum demersum*.

In fact, aquatic and semi-aquatic phanerogams which create the landscapes of reed islands and swamps do not always settle in such a simple way, as they also depend largely upon the recent past history of the water level (Fotius and Lemoalle 1976).

On the whole, the distribution and extent of the lake regions depend upon:

- the bottom topography and dune relief
- the height of the water level
- the plant cover which is itself dependent upon the seasonal and annual changes in water level.

We shall first describe the morphology of the basin, defining the various lacustrine environments in relation to the water level during the period of our study.

### 2.1.1 *Morphology of the lake basin*

The basic maps used for the Niger, Cameroon and Chad parts of the lake are those made by the Institut Géographique National during 1950 to 1954. However, the maps used for the Nigerian part were made by the Federal Survey Department in 1957. They were set up with lake levels ranging from 280.6 to 282.2 m, corresponding to the most usual aspect of the lake.

Carmouze and Dupont in 1970 and Roche in 1971 gave respectively, a bathymetric map for the level of 282 m and a map of the bottom altitude. Aerial observations conducted during the partial drying up of the lake in 1973 were used to make a new map which showed the bottom altitude and served as an extension of the two preceding ones (Carmouze 1976). The contour of this map corresponds to the altitude of 281.9 m and the relief is described by curves showing equal bottom altitudes which were drawn from a thousand measurements taken regularly from the whole lake (Fig. 2). In fact, this kind of representation makes it possible to define properly the easily flooded zones for a given height of the water level but it does not show the bottom dune relief which largely determines the distribution of the zones. So, after the description of the bottom topography, we shall determine the dune relief.

2.1.1.1 *Bottom topography.* In its northern part, from Baga-Kawa to Daboua (Fig. 2), the lacustrine basin is bounded by a continuous dune chain whose altitude is always above 284 m; in the northeast and east, from Daboua to Kouloudia, by a fixed erg which gives a very meandering contour; finally in the south, from Kouloudia to Baga-Kawa, by a low flat plain with slight contour lines (282–283 m). Therefore, the southern limits are likely to be greatly displaced during fluctuations in the lake level.

The lake is divided into a south and a north basin by a line from Baga-Kawa to Baga-Sola because of a narrowing coastal periphery at this level, as well as a bottom shift (the bottoms of the south basin range usually from 280 to 278.5 m and those of the north basin from 277.5 to 275.5 m (Fig. 2).

The lowest region of the lake bottom, with an average altitude of 275.5 m lies in the north basin. Its area is 4000 km<sup>2</sup> and its position is slightly north of the geographical center of the basin. The slope is smoother towards the south than towards the northeast and west. In the south basin where the relief is less sharp there are three regions of higher altitudes (278.5 m on an average). The one which is near the Shari delta has an area of 1100 km<sup>2</sup>, that in the north, of 1000 km<sup>2</sup> and, finally the other one in the south is 550 km<sup>2</sup>.

Morphometric curves showing the graphical determination of the surface occupied by the lake in the north and south basins as well as the corresponding volume are given in Fig. 3 (Carmouze et al. 1972; Carmouze 1976; Lemoalle 1978). Furthermore, data from Lansat satellites in 1972–73 and 1975–76 during

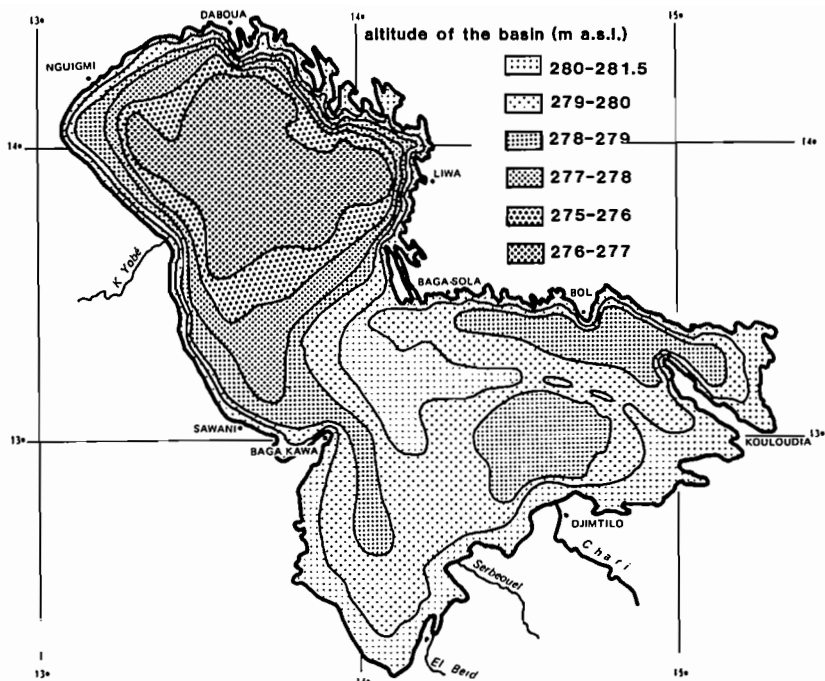


Fig. 2 The altitudes of the lacustrine basin.

the successive emergence of different regions of the lake make it possible to define precisely the relief of the major part of the lake bottom.

2.1.1.2 *Dune relief.* The erg bordering the lake in the north and the east provides the bottom of the lake basin with a very irregular relief. The orientation of the dunes is southeast–northwest. Their height as well as the altitude of their crests decreases from the shoreline towards the inner part of the lake. Therefore, areas of lake bottom furthest from the northern and eastern limits of the lake are much less influenced by the dune system.

The coastal dunes of the south basin are longer (5 to 10 km against 3 to 6 km) and higher (10 to 15 m against 7 to 9 m) than those of the north basin. On the contrary, beyond the coast, the dune relief diminishes more rapidly in the south basin than in the north basin. The wave amplitude is usually below 1.5 m in the southern part of the south basin but it is higher in threequarters of the north basin. The dune crests lower than 285 m in altitude are usually eroded, probably as a result of the erosive action of the lake floods during the periods of lacustrine transgressions.

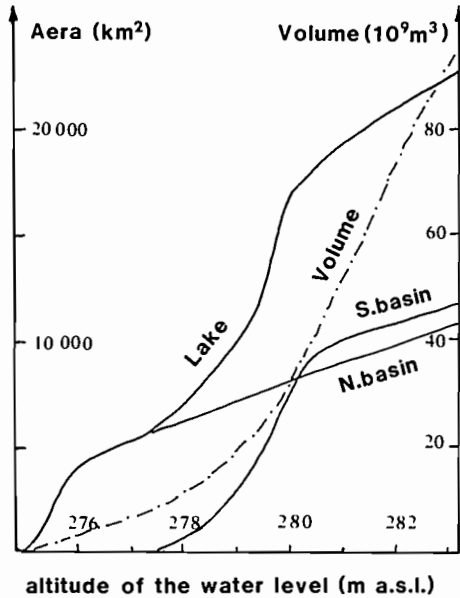


Fig. 3 The morphometric curves of the lake.

Finally, though it is shaped by a sharper dune relief, the bottom of the south basin is flatter and higher than that of the north basin. This may result from lake sedimentation, which is more important in the south than in the north (Bouchardeau and Lefèvre 1957).

### 2.1.2 Changes and development of the lake regions

From 1967 to 1975, the water level continued to decrease each year from a mean of 281.9 m to 279–279.5 m and was followed by irregular changes in the lacustrine environment. Thus, until the level of 280.5 m, there was only a slight change in the different regions from 1967 to 1971. On the contrary, profound changes have been recorded below this level from 1972.

In the first case, we are dealing with a lake under average circumstances or 'Normal Chad' and in the second case, with a lake undergoing reduction or 'Lesser Chad' (Tilho 1910).

2.1.2.1 *The 'average' lake or 'Normal Chad'* (water level 281.9 m a.s.l.). Lake waters in the north and south basins occupy, respectively, 10 000 km<sup>2</sup> and 11 000 km<sup>2</sup> (Fig. 4).

In the north basin, dune crests above 282 m which are situated along the northern and eastern coasts create an archipelago landscape called the North-

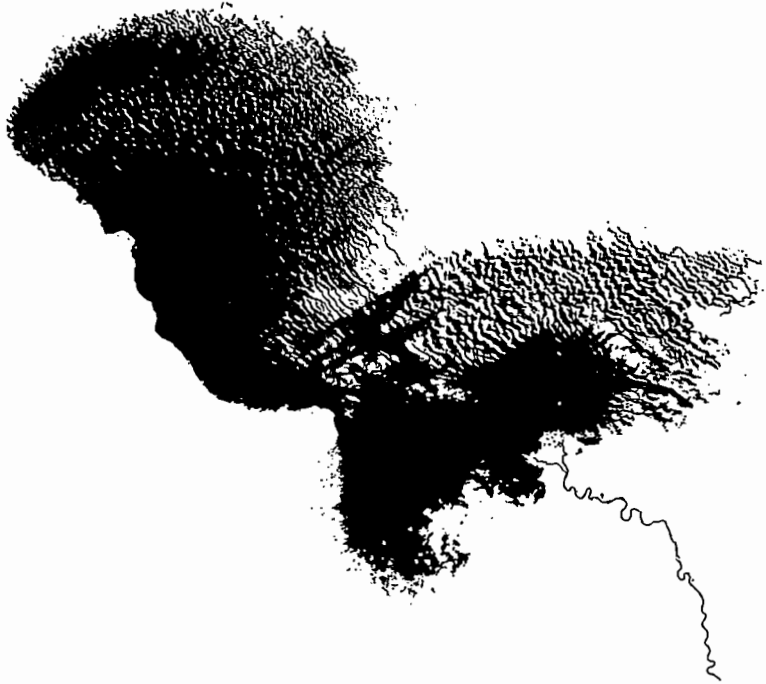


Photo 5 Water surface of Lake Chad (January 1973) from a satellite photograph.

eastern Archipelago, along a stretch of about 25 km wide (Fig. 4). About 500 flat islands occupy 40% of the total area amounting to 2400 km<sup>2</sup>, and are covered with herbaceous vegetation. They are often surrounded by a narrow stretch, a few meters wide, which is occupied by macrophytes, mainly *Phragmites* and sometimes extended by *Ceratophyllum demersum* and *Potamogeton demersum*. Depths range from 2.5 to 6.5 m.

Northwest of the archipelago, most of the dune crests whose altitudes range from 279 to 281.5 m are immersed and covered by macrophytes, mainly *Phragmites*. The archipelago zone is followed by a region of reed islands extending to the Nigerian coast. It has a total area of 3600 km<sup>2</sup>, of which 17% is occupied by reed islands with an average area of 2.5 km<sup>2</sup>. In some cases this region is divided into northern and northeastern reed islands (Fig. 4). To the east of Nguigmi, there is a small area with few reed islands forming a zone of open waters, with depths ranging from 4 to 7 m.

The southwest part of the basin with dune crests under 1.5 to 3 m of water is less influenced by the dune system. It also has a large zone of open water, the northern open waters, which is bordered to the west and the southwest by

sandy beaches of a dune chain. Their area amounts to 4200 km<sup>2</sup>, and depth increases regularly from the south to the north, ranging from 2 to 6.5 m.

The northern open waters are bordered in the southeast by a region of low dune undulations of low interdune depth that constitute a mixture of archipelago and reed islands. This shallow region with numerous sandy islands and vegetation extends to the south basin and interferes with water transfers between the two basins; it is therefore called the Great Barrier (Fig. 4).

In the south basin, a fixed erg borders the northern and eastern coasts as in the north basin, thus creating a 20 to 35 km wide archipelago. The islands can reach 10 m in height and become lower and flatter with increasing distance from the coasts. Some doom-palms (*Hyphaene tebaica*) and acacias grow here and there, while the lowest islands are covered with herbaceous vegetation. Some of them are partially lined with a narrow stretch occupied by *Phragmites*, *Cyperus papyrus* and *Typha*.

A dune chain from Kouloudia to the northwest divides this archipelago into Southeastern Archipelago and Eastern Archipelago, which occupy respectively areas of 1400 km<sup>2</sup> and 1800 km<sup>2</sup>. Islands cover 40% of the total area in the first region and 45% in the second one and depths usually range from 2 to 4 m



Fig. 4 The main natural regions of the lake.

The rather low and flat regions situated immediately to the east and north of the delta have a large open water region of 3900 km<sup>2</sup>. This is divided into Southern Open Waters and Southeastern Open Waters which are located, respectively, west and east of the shallow Great Barrier which advances towards the mouth of the El Beïd (Fig. 4).\*

The regions around this zone of open waters are higher. Dune crests are immersed under 0.5 to 1 m of water, thus contributing to the establishment of macrophytes (*Cyperus papyrus*, *Typha* and *Phragmites*). To the east of Baga-Kawa up to Kouloudia, there is a 5 to 80 km wide coastal stretch with reed islands, covering an area of 1500 km<sup>2</sup>. 20% of the area is occupied by the reed islands themselves (Southern Reed Islands) (Fig. 4). To the east of the delta where the bottoms are flat and high (280 to 281 m), there is a swampy zone with meadows occupied by *Potamogeton* and *Vallisneria*; the Southerneastern Reed Islands (1700 km<sup>2</sup>) are developing between the islands and the open waters. They continue to the southern border of the Southeastern Archipelago and join the Great Barrier which has a region of reed islands only in its eastern part.

On the whole, the open waters, archipelagos and reed islands comprise respectively 38, 23 and 39% of the total water area which is about 21 000 km<sup>2</sup>. Lake Chad belongs to the category of shallow lakes, being a unique example because of its great extent.

Table 1 shows the main hydrological features of the large natural regions of the lake at the 281.9 m level.

**2.1.2.2 The change towards 'Lesser Chad' in 1973.** Since 1973, the appearance of the lake has been profoundly modified following a very small flood in 1972-73 ( $17.3 \times 10^9$  m<sup>3</sup> against  $40 \times 10^9$  m<sup>3</sup> annual average). As it was insufficient to initiate any seasonal rise of the level, and barely succeeded in compensating for the evaporation losses over two to three months. Then, a marked lowering occurred, resulting in the emergence of the shallow zones of the lake such as the Great Barrier, the Eastern Archipelago and the Southern Reed Islands. From April 1973, the lake became split into three unequal water masses (Fig. 5). The north basin retained its water, however the shoreline was displaced towards the center of the basin from between a few hundred meters to a few kilometers according to the region. About half the south basin was exposed and only the Southeastern Open Waters, the South Open Waters which looked like an appendix to the north basin, as well as the central part of the Southeastern Archipelago retained their waters (Fig. 5).

During July 1973, in the Northern Open Waters, previously submerged dune crests appeared; the Southern Open Waters dried up and the Southeastern

\* The differences between the North and Northeastern Reed Islands and between the South and Southeastern Open Waters appear *a priori* arbitrary. However, they are very useful in studying some hydrological, hydrochemical and sedimentological aspects.

Table 1 Hydrological characteristics of the main natural regions for an average water level of 281.9 m (above sea level).

	Z (m)	S (km <sup>2</sup> )	V (10 <sup>9</sup> m <sup>3</sup> )		Z (m)	S (km <sup>2</sup> )	V (10 <sup>9</sup> m <sup>3</sup> )
Southeastern	3.60	2000	7.2	Southeastern	3.30	875	2.9
Open Waters	3.20	1975	6.3	Archipelago	2.95	850	2.5
	2.75	1925	5.3		2.55	825	2.1
Southern	2.75	2000	5.5	Eastern	3.10	1075	3.3
Open Waters	2.35	1975	4.6	Archipelago	2.70	1050	2.8
	1.95	1925	3.6		2.40	1025	2.5
Southern	2.05	1525	3.1	Great Barrier	2.10	1700	3.5
Reed Islands	1.55	1475	2.3	(southern part)	1.80	1675	3.0
	1.10	1425	1.6		1.55	1610	2.5
Southeastern	2.55	1800	4.6	Southern	2.75	10 975	30.1
Reed Islands	2.15	1750	3.7	Basin	2.35	10 750	25.3
	1.65	1700	2.8		1.95	10 435	20.4
Great Barrier	3.40	1550	5.3	Northeastern	6.00	975	5.8
(northern part)	2.95	1525	4.5	Reed Islands	5.65	950	5.3
	2.55	1455	3.7		5.15	925	4.7
Northern	4.90	3750	18.3	Northern	5.35	1475	7.9
Open Waters	4.40	3700	16.3	Archipelago	5.00	1450	7.2
	3.90	3660	14.2		4.70	1400	6.7
Northern	5.35	2700	14.5	Northern	5.00	10 325	51.8
Reed Islands	5.00	2650	13.2	Basin	4.60	10 145	46.7
	4.60	2550	11.7		4.15	9865	41.1
	3.85	21 300	82.0				
	3.45	20 900	72.0				
Lake	3.05	20 300	61.5				

Z = depth; S = area; V = volume.

For a given region and parameter, three values should be noted: the upper number corresponds to the flood level (282.4 m), the lower number to the lower water level (281.5 m) and the intermediate figure to the average level.

Archipelago was composed only of some residual ponds (Fig. 6). From August 1972 to August 1973, the water level decreased from the average level of 280.1 to 278.4 m, i.e. by 1.6 m. This resulted in the occupation by the macrophytes of some newly emerged zones, especially those of the Great Barrier, the Southeastern Reed Islands and the Southern Open Waters. While the immersed or half-immersed vegetation around the islands or along the coastal zones had

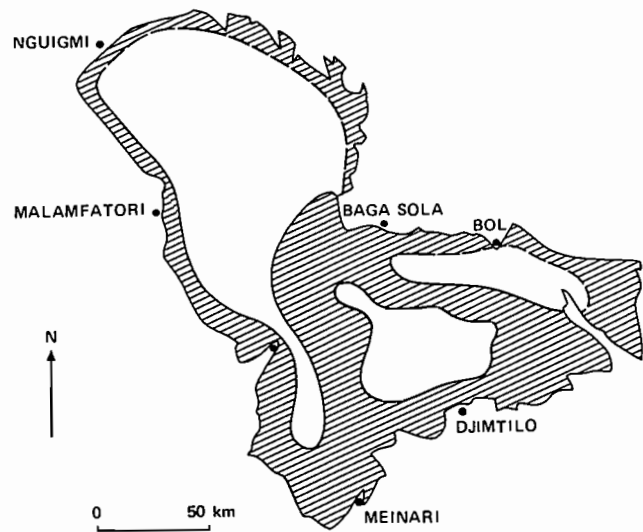


Fig. 5 The 'Lesser Chad' in April 1973.

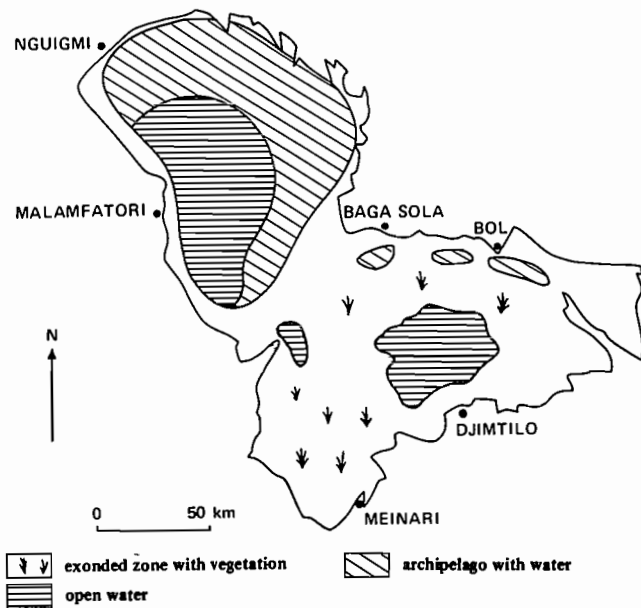


Fig. 6 The 'Lesser Chad' in July 1973.

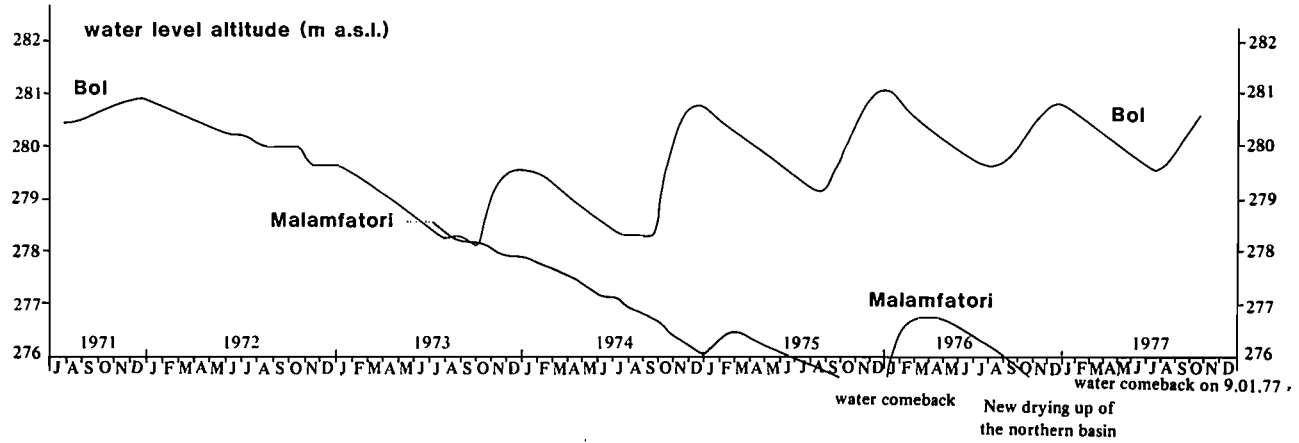


Fig. 7 Water levels of the lake in the southeastern archipelago and the northern basin from 1971 to 1977.

virtually disappeared during the 'Normal Chad' period in 1972 as a result of the rapid contraction of the lake, the exposure of the above-mentioned regions made it possible for seeds in the surface sediments to germinate (Fotius and Lemoalle 1976). This vegetation which was mainly composed of *Cyperus papyrus*, *Typha vossia*, *Ipomea* and *Ludwigia* largely persisted until the water level increased again. The 'Ambadjs' (*Aeschynomene* ssp., *Sesbania* spp.) were equally prominent. In the south basin, the areas thus occupied were equal to about 5000 km<sup>2</sup>.

In conclusion, apart from the reduction and the fragmentation of the water area, the second important phenomenon which occurred in 1973, was the development of a thick vegetation over a large part of the emergent areas in the southern basin.

2.1.2.3 *The development of the lake during the period of 'Lesser Chad' (1973-77).* (a) 1973-74: partial drying up of the south basin during the period of low water and the beginning of drying up in the north basin.

In 1973-74, the Shari flood was scarcely greater than that of 1972-73 ( $18.4 \times 10^9$  m<sup>3</sup>). Until mid-September, the Shari low waters flowed into the restricted Southeastern Open Waters that grew larger when the Shari flood occurred. From the beginning of October, the Southern Open Waters and a part of the Southeastern Archipelago, which were covered with abundant vegetation at that time, were filled up by water (Fig. 8). Although macrophytes were not entirely immersed, the rise of the water level was large and rapid (Fig. 7) amounting to about 1.30 m between early October and the end of November for the Bol region and to 1.00 m for the Baga-Kawa region.

The south basin reached its maximum water level in December (Fig. 9) and open waters of this basin occupied nearly the same area. In the Southeastern Archipelago, open water areas appeared, resulting in the total immersion of macrophytes and swampy zones were displaced southwards and northwards. At that time, water flowed through the thick vegetation of the Great Barrier towards the north basin, in a diffuse and minor way. As it received practically no water supplies, except those from the Komadougou Yobé and slight rainfall, the north basin underwent profound changes. The water level decreased by 85 cm in the central zone, dividing the open waters into two remnant large ponds separated by an archipelago of sandy islands without vegetation.

During 1974, the flood in the south basin was similar to that of the previous year with the decrease in water less marked during the first months (Fig. 7). Dune crests and shallows gradually reappeared but they were covered with vegetation before being exposed. Ambadjs developed to such an extent that in places they looked like forests. In July, the water level was nearly the same as that of the previous year at the same time, but with more abundant vegetation, especially at the level of the Great Barrier.

In the north basin, which had not been supplied with water since the

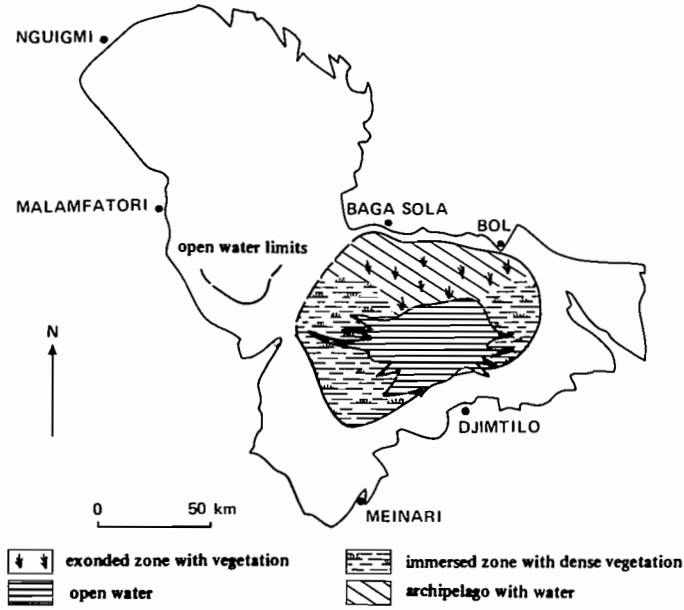


Fig. 8 The 'Lesser Chad' in October 1973.

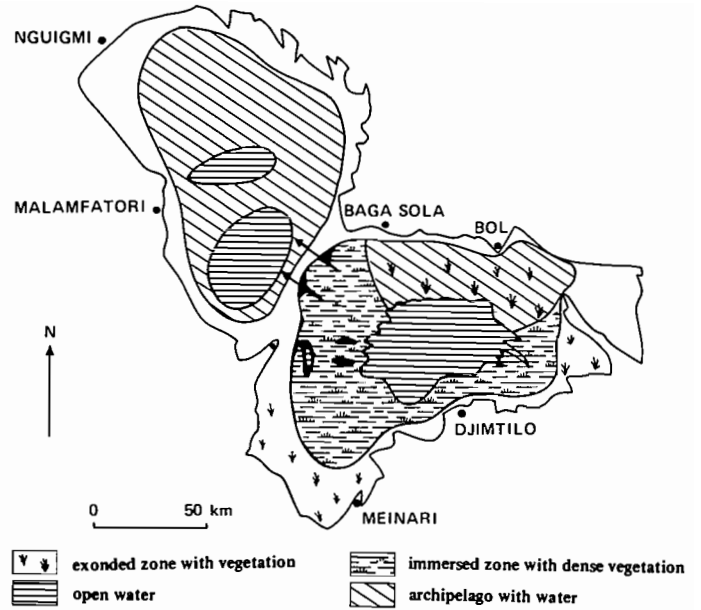


Fig. 9 The 'Lesser Chad' in December 1973.

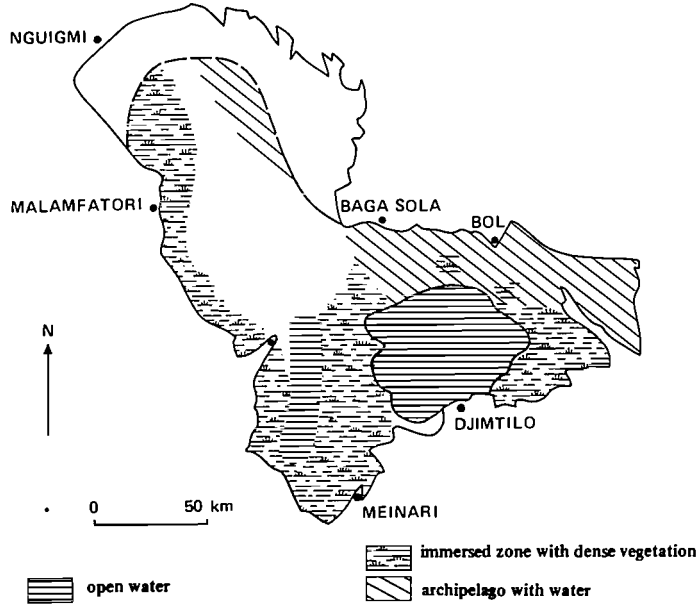


Fig. 10 The 'Lesser Chad' in January 1975.

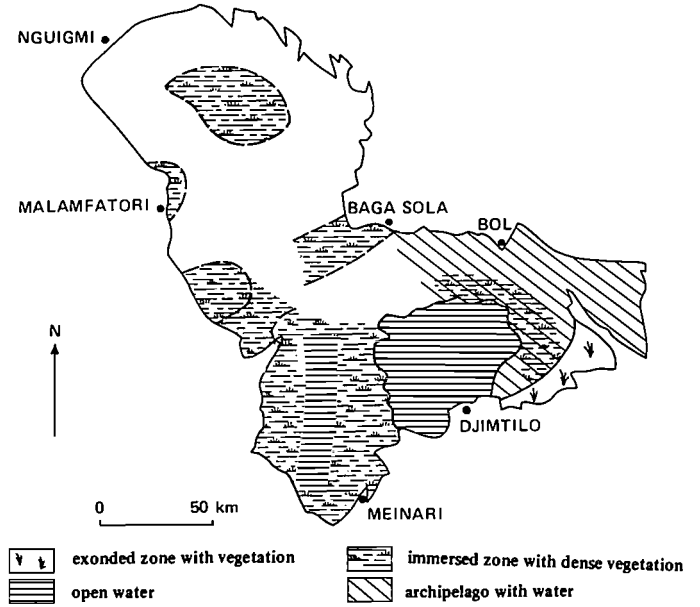


Fig. 11 The 'Lesser Chad' in July 1975.

beginning of the year, the water level decreased by 1.90 m from July 1973 to July 1974 (Fig. 7), and it turned into a large archipelago.

(b) 1974–77: return to a nearly normal situation in the south basin and almost total drying up of the north basin during the period of low water.

In 1974–75, the Shari flood was clearly that of the two previous years, while being still below the average flood ( $30.5 \times 10^9 \text{ m}^3$ ). There was an abrupt rise in the water level in the south basin in October–November (Fig. 7). At the end of 1974, the water level at Bol was similar to that recorded from the same station at the end of 1971.

The vegetative cover did not prevent waters from moving into the south basin, but it restrained their movement towards the north basin which was supplied with an insufficient amount of water to be able to compensate for the annual evaporation of 2.20 to 2.50 m. From May 1975, the water area was thus gradually reduced to a few isolated ponds around Kindjeria which were completely dried up by October 1975. The floods of the Komadougou Yobé had a limited influence since a vegetation zone existed only around its mouth.

During the period of low waters examined above, a hydrological discontinuity between the Southeastern Archipelago and the Southeastern Open Waters existed only during 1973 and 1974. The south basin later returned to a normal state, except that seasonal variations in the water level were accentuated.

During 1975–76, the Shari flood was similar to the average flood ( $36.6 \times 10^9 \text{ m}^3$ ) as in 1974–75. In the south basin, the water level variations were close to those of 'Normal Chad' but with a slight increase in the subsidence period. Around the pocket of the Eastern Open Waters, numerous ambadjis disappeared because of an increase in the water level. On the other hand, those from the northern side of the Great Barrier remained along with abundant macrophytes, and acted as a buffer to water penetration. Events occurred as if the communication between the two basins has been raised higher, since in 1971–72, for the same level of the south basin, the water penetration into the north basin was normal. So, the north basin was in the same situation as in the previous year, although the Shari flood was higher. In zones of temporary water, vegetation became thicker and thicker year by year.

The Shari flood of 1976–77 was again small ( $28.7 \times 10^9 \text{ m}^3$ ). However, the south basin was only slightly affected and the average water level decreased by 10–20 cm compared with the water level of the previous year. Figures 10 and 11 give an idea of the environmental modifications since 1974, respectively, during the flood and the subsidence periods.

### 2.1.3 *Sedimentological characteristics of the lake bottom*

Dupont (1967, 1970) was the first to study the surface sediment facies and their geographical distribution. The classification of sediments according to their

form, colour, degree of coherence, texture and organic matter content was reduced to four main types: mud, clay, sand and pseudo-sand, which are subdivided into varieties. In some zones of the lake, these materials are encrusted with limestone.

From 1970 to 1973, Dupont and Carmouze continued this study. A new map with surface sediments was drawn from 1500 observations that were uniformly distributed over the entire lake (Carmouze 1976) (Fig. 12).

2.1.3.1 *Materials with muddy clay facies.* Mud is a structureless material which usually appears in the form of a greyish-black, fine, homogeneous suspension and sometimes as big brownish flakes. Its water phase is always very important since it represents 250 to 500% of the dry weight. Its mineral portion, representing 80% of the average dry weight, is distributed approximately equally among three types of metric granules: clay up to 0.002 mm, silt from 0.002 to 0.050 mm and sand from 0.05 to 2 mm. Its organic fraction which is mainly composed of decaying macrophyte debris is relatively high usually ranging from 10% to 16% of the dry weight but reaching more than 30% when it is genuine peat. The average percentages of carbon and nitrogen are equal to 90% and 8% respectively of the dry weight; the C/N ratio is almost 11, indicating the leading part played by the higher plants in the accumulation of this organic matter.

The most abundant material, mud, is found particularly in the zones of reed islands and archipelagos (Fig. 12). Thus, the lake bottoms of the Southeastern Archipelago, the Southeastern Reed Islands, the Southern Reed Islands, the majority of the Great Barrier and finally the eastern and southern edges of the Northern Reed Islands and the Northern Archipelago are covered with flaky brown mud (flakes can reach 1 cm in diameter). The eastern half of the Eastern Archipelago is also covered with it. Peat like mud is found along the northern and eastern coasts of the north basin, as well as in some parts of the Southeastern and Eastern Archipelago arms.

Clay is a material with a variable consistency but always firmer than mud. It appears either in a homogeneous soft and structureless form or in a more or less structured form (cleaving into angular polyhedrons, a few centimeters in diameter and into smaller aggregates) or finally in the granular form (composed of thick particles resistant to manual weathering). Whatever the variety may be, clay is characterized by a mineral portion containing more than 50% of components less than 2 mm in diameter. It is usually composed of 10 to 40% slime and 10 to 20% sand. The water phase represents 120 to 130% of the dry weight when it is soft clay and 40 to 120% of the dry weight when it is structured clay. The organic portion is smaller in clays than in muds and does not exceed 5% of the dry weight. The average percentages of carbon and nitrogen in organic matter amount respectively to 25% and 2.5% and the C/N ratio of 10 is similar to that of muds.

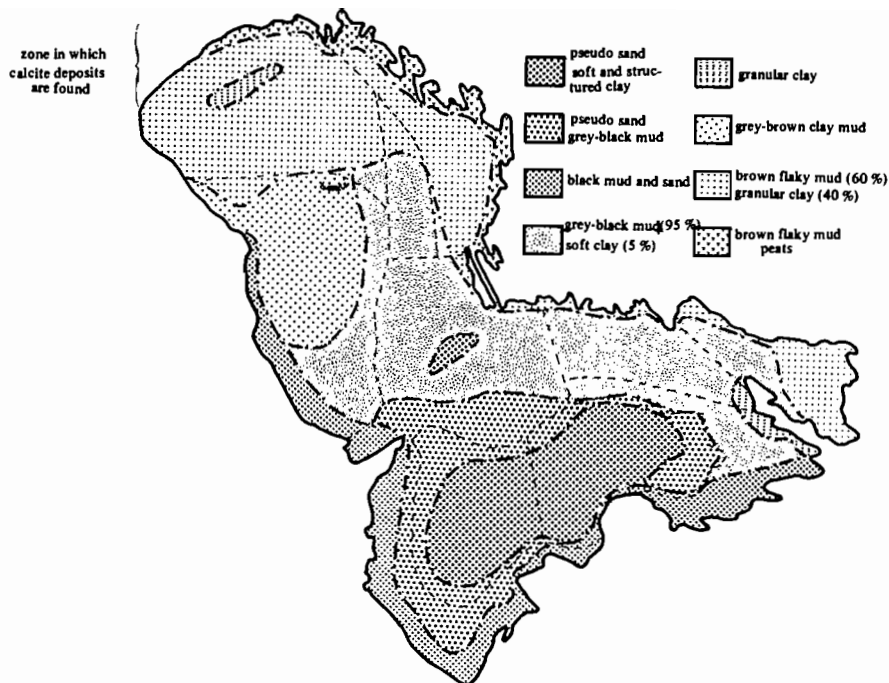


Fig. 12 The different types of sediments.

Clay appears in large amounts in open water zones such as the Southeastern, Southern and Northern Open Waters. In the first two regions, it appears in the form of soft clay and covers the depressions, while the shallows are covered with pseudo-sand as is shown further on. In the second region, it forms a slightly flaky material between soft clay and greyish-brown mud. The Northern Reed Islands and the Northern Archipelago are usually covered with 30 to 40% clay, either soft or granular (Fig. 12). Either type of clay is still found in the bottoms of the Southeastern and Eastern Archipelagos, the Great Barrier and the Southeastern Reed Islands which are swept over by currents, representing 5 to 15% of the area of these regions.

This schematic distribution of muddy and clayey materials over the entire lake whose limits are not always easy to define, leads us to make several observations.

Mud is especially found in the zones of reed islands and archipelagos, due to the large amount of macrophytes whose debris constitute the main part of this sediment. Thus, the mud layer reaches 30 to 80 cm in thickness in regions with a high macrophyte production. However, as it is a fine suspension, it is not found in places swept over by currents. Finally, the flaky mud is located

in regions where highly saline waters cause flocculation, when the pH is higher than 8.8.

Unlike mud, clay is found in large amounts only in regions with few macrophytes such as the Southeastern Open Waters, the South Open Waters and the Northern Open Waters. From a distribution study of the different varieties a general interpretation (Dupont 1970) could be suggested. This author noticed that soft clay is found in the deepest zones where vegetation could generally not settle during lake recession; on the contrary, structured clay is found in shallower zones where macrophytes could occasionally grow during temporary drying up periods. Finally, granular clay is related to emergent regions either as a result of their shallowness or because of their isolation from the Shari delta, which exposes them to temporary drying up during large decreases in the lake. Dupont inferred that soft clay would have been the original material and could undergo a structural change resulting from the development of the root system as a result of macrophyte settlement. This would result in the isolation of polyhedrons and a decrease in water content. When sediments are exposed, this process would be accentuated leading to the formation of clay granules. Desiccation which isolates polyhedrons could be increased in certain cases by fires by farmers.

2.1.3.2 *Materials with sandy facies.* Fine and well-sorted sands originate from two different stocks. The first one corresponds to the eastern and northern edges of the submerged erg and is composed of aeolian quartz sand whose average diameter is about 0.250 mm. The second one derived from river sources is mainly situated in the coastal zones of the Southern and Southeastern Reed Islands. It is micaceous and the average diameter of its grains is about 0.16 mm. Both varieties are often mixed. Their organic matter content remains low, equal to or less than 1% of the dry weight (Dupont 1970).

It should be noted that sands are more abundant than is shown in Fig. 12, for, they actually cover the submerged periphery of the islands as well as most of the lake shallows where the reed islands are.

2.1.3.3 *Materials with granular facies (pseudo-sand).* These materials are composed of small granules which are variable in size and were first described by Guichard (1957) as 'marc de café'. Their unimodal frequency curves reach a peak around 0.250 mm (Dupont 1970) and in the samples under study, the median range is from 0.205 to 0.283 mm. Moreover, cumulative curves are very straight, thus showing that it is a well-sorted material (Fig. 13). There are also pseudo-sand samples smaller in average size in which the measurement\* of granules cemented into clay or mud is difficult. They appear in different forms,

\* The phylogeny of these granules is studied in Chapter 4.

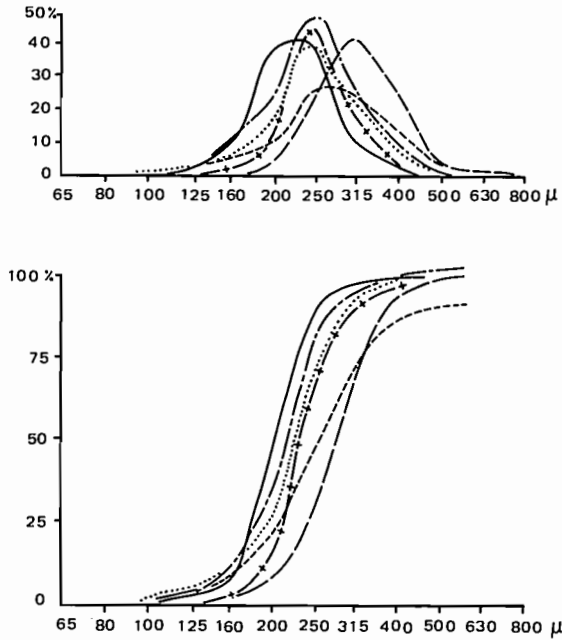


Fig. 13 The granulometry of the pseudo-sands.

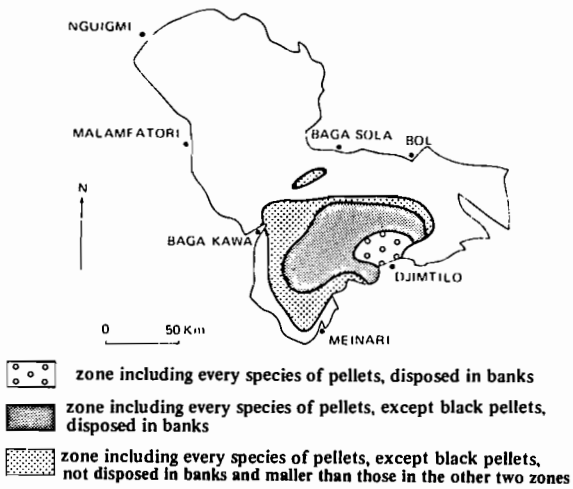


Fig. 14 The localization of the different types of pseudo-sands.

colours and hardness, ranging from the spherical, unstriped black and manually non-friable form, to the ovoid form with big superficial yellow-greenish irregularities which are easy to crumble by hand.

These pseudo-sand sediments are mainly situated in the Southeastern and Southern Open Waters (Fig. 14). They are scattered on banks and lie almost always on clay, either of a soft or, often, structured type. Sometimes, they are covered with a layer of soft clay or mud, 5 to 20 cm in thickness (up to 50 cm in the Great Barrier). The pseudo-sand layer is usually 5 to 15 cm thick and reaches 50 cm in certain places. In the depressions, it is not very abundant and is largely related to clay. Outside the Southeastern and Eastern Open Waters, there are pseudo-sands in the South and Southeastern Reed Islands and the Great Barrier. However, in these regions they are not very abundant and are closely mixed with mud, except in the open water zone situated southeast of the Great Barrier where they appear in greater amounts.

2.1.3.4 *Materials with calcareous facies.* Materials situated along the northern and eastern coasts of the north basin can consist of up to 10% carbonates. In this zone, numerous clay blocks and granules are encrusted with calcium carbonate which is no more than calcite. In the wadis and the former arms of the lake which are now dried up, these encrustations are much more numerous\* (Dupont 1970; Roche 1973; Carmouze 1976).

## 2.2 The lake climate

The Chad basin is situated between the anticyclones of Libya and Saint Helena which result, respectively, in the continental tropical masses of dry air and maritime equatorial masses of humid air. These two air masses converge in the Intertropical Convergence Zone (ITCZ) which moves along a south–north axis over the year\*\*. A humid climate prevails south of the ITCZ and dry climate north of it. Continental winds, or harmattan, blow over the whole basin during winter and lead to drought, while marine winds or monsoons are associated with rainfall.

So, the position of the ITCZ in relation to the lake determines the climatic features of the latter (winds, air temperatures, rainfall, humidity, insolation and evaporation); and its movements (an example of which is given in Fig 15) determine the seasonal variations.

\* The formation of these calcareous deposits is specified in Chapter 4.

\*\* This zone covers the whole Sahel; its movement is dependent upon the general circulation whose interannual irregularities can result in droughts that were catastrophic for agriculture and stock farming in 1972–73.

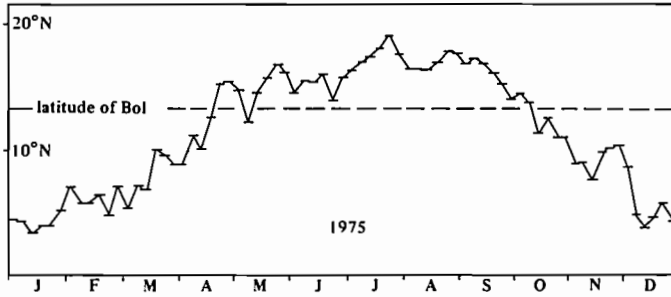


Fig. 15 The displacements of the intertropical convergence zone.

### 2.2.1 Winds

The harmattan is a dry northeast wind that blows from October to April, while the monsoon is a humid southwest wind that blows from May to September. These rather strong winds blow mainly in the morning from 0600 to 1200 hours. The daily average at Bol (Southeastern Archipelago) was measured over the period 1965 to 1970. The frequency curve for velocity which is shown in Fig. 16 (after Billon et al. 1968) indicates that the average wind velocity is above 5 m/s for 6 hours a day. The two main winds are associated with local winds that result from anabatic winds and therefore blow from the land towards the sea in the night and in the other direction during the day.

Figure 17 summarizes the directions and average velocities of winds over ten days at Bol in 1969 and 1970 (after Roche 1973).

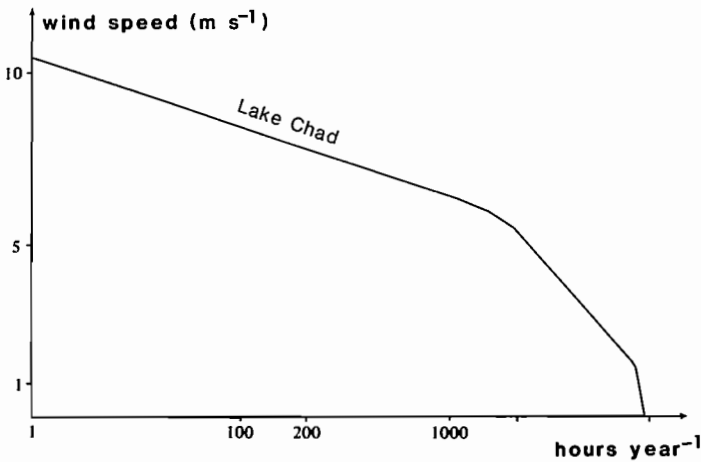


Fig. 16 Wind speed frequencies at the Bol station.

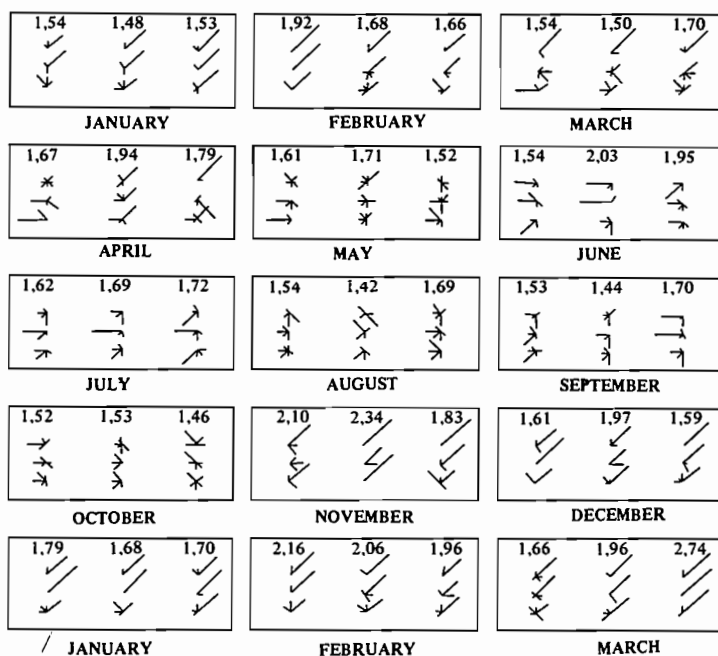


Fig. 17 The winds: mean speeds and directions at Bol (calculated upon 10 years).

### 2.2.2 Rainfall

The rainy season begins in May–June and ends in October with maximum rainfall in August when the lake receives half the rainfall. The annual rainfall decreases considerably from the south to the north. The lake, situated between the isohyets 550 and 240 mm (Fig. 18), had an average rainfall of 315 mm at Bol from 1954 to 1972 with large between years variations (the extremes recorded were 125 and 565 mm)\*.

### 2.2.3 Air temperature

The average annual air temperature is about 28°C. From 1936 to 1970, it was 28.7°C at N'Djamena and 28°9 at Bol from 1957 to 1970 (Toucheboeuf de Lussigny 1969; ORSTOM 1974a, 1974b). During the warm season, the average monthly temperatures vary from 29 to 32°C from March to October with a slight decrease in August (27.5°C). During the cool season, they range from 22

\* Brunet-Moret (1968) undertook a detailed study on the frequency of rainfall intensity.

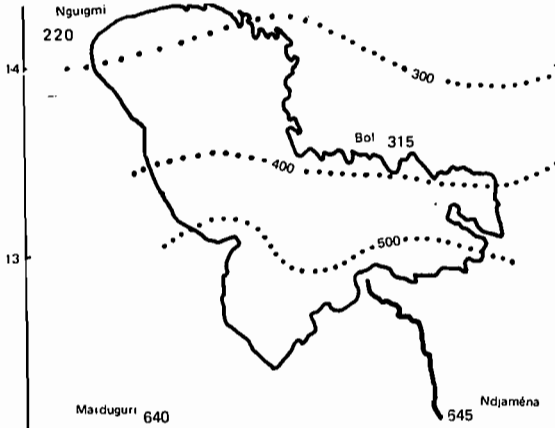


Fig. 18 The rainfall repartition on the lake (isohyets in  $\text{mm year}^{-1}$ ).

to  $24^{\circ}\text{C}$  from December to February with a minimum of  $21$  to  $23^{\circ}\text{C}$  in January when diurnal variations are in the order of  $16$  to  $17^{\circ}\text{C}$  compared with  $7$  to  $9^{\circ}\text{C}$  in August\* (Fig. 19).

#### 2.2.4 Air humidity

The air humidity recorded at the peripheral stations of the lake (N'Djamena-Bol-Nguigmi) is maximum at night and minimum at about 1200 hr. The seasonal maximum, ranging from  $72$  to  $81\%$  occurs in August and the minimum, ranging from  $23$  to  $31\%$  occurs in February–March. In fact these values are not the exact representation of those calculated for the lake. Roche (1973) showed the influence of the water mass on this parameter through a comparison of measurements made in March–April 1967 over the whole lake, with those recorded at the same time at the Bol station. He pointed out that air masses moving from the northeast at that time become saturated with water when passing over the lake. A gradient is established according to the size of the water areas that were previously swept through and this represents an average absolute variation of  $50\%$  between the northern and southern regions. Therefore, during the dry season of the lake, the average humidity is higher than that measured at the Bol station. The opposite phenomenon must occur during the humid season.

\* This temperature range was thoroughly analyzed according to the global radiation when entering the atmosphere and according to rainfall (Riou 1972).

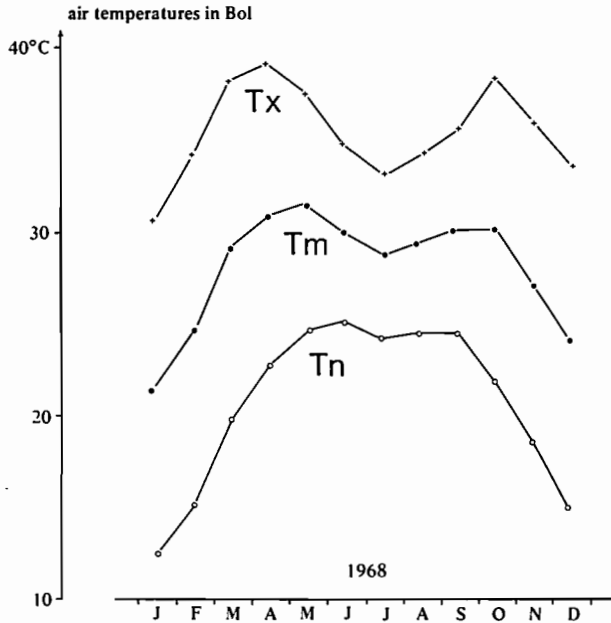


Fig. 19 Air temperatures at Bol; Tx, Tm and Tn are respectively maximum, mean and minimum temperatures.

### 2.2.5 The total incident radiation

The annual average, the daily total incident radiation at the ground amounted to  $2308 \times 10^4 \text{ Jm}^{-2\text{d}^{-1}}$  at N'Djamena from 1968 to 1973. It varies only slightly from one year to the other, and its seasonal variations are low in amplitude with a minimum of  $2140 \times 10^4 \text{ Jm}^{-2\text{d}^{-1}}$  in January and a maximum of  $2580 \times 10^4 \text{ Jm}^{-2\text{d}^{-1}}$  in March. Therefore, Lake Chad receives a relatively high irradiance with little variation in comparison with temperature zones (Fig. 20).

### 2.2.6 Evaporation

The different climatic parameters just examined lead to considerable evaporation through their characteristics of high wind frequency and intensity, high temperatures, low humidities and high insolation.

Evaporation, one of the main constituents of the hydrological balance was evaluated in numerous ways, according to different approaches. Annual estimations ranging from 2.10 to 2.20 m were made by Riquier (1963), Turc (1968) and Riou (1972) from theoretical formulae. Calculations from direct

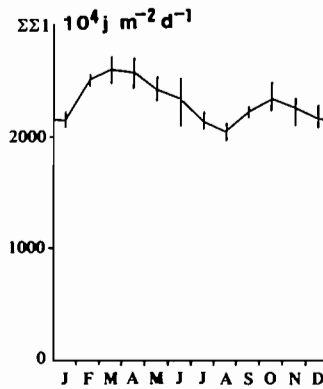


Fig. 20 Mean monthly irradiance on the lake surface.

measurements on an evaporation tank are based on data collected by the ORSTOM hydroclimatologists since 1964 along the Southeastern Archipelago at Matafo station situated near Bol. Of these data, the measurements of evapotranspiration give the best values of potential evaporation.

### 2.3 General circulation of waters

Large water movements in the lake result mainly from the regimens of river supplies and winds. Their direction and amplitude depend upon the morphology of the basin.

The Shari is related to a transition tropical regime which is characterized by a period of rising water level from the end of July to September, a period of high waters from October to November, a period of subsidence from December to early February and a period of low waters from February to July. Therefore, the seasonal distribution of water supplies is such that the lake is necessarily fed irregularly, receiving nearly 50% of the annual river supplies from October to November and 75% from September to December. Therefore, the deltaic zone is under a very high hydraulic gradient over this period with a maximum at the end of October–early November. The considerable kinetic energy from flood waters also leads to large water movements starting in September which are repeated and dampen in the whole lake until January.

From mid-October to March, the harmattan rises regularly in the middle of the night and dies down at the end of the morning. It pushes waters towards the western and southern coasts. From May to mid-October, the phenomenon is reversed and the monsoon winds tend to accumulate water on the eastern and northern coasts. It should be noted that the action of wind is reduced in the archipelagos and reed islands since they blow at right angles to the islands.

Furthermore, the winds never lead to mixing of waters between the south and north basins.

The shape of the lacustrine basin, the arrangement of islands and shallows facilitate some movements and prevent others. Thus, the Great Barrier which is a shallow region covered with islands and reed islands acts against exchanges between the Southeastern and Eastern Open Waters and the Northern Open Waters. Similarly, in all the zones of archipelagos and reed islands, the islands and shallows which are generally aligned southeastwards and northwestwards act as a brake on water movements to the northeast.

Finally, the distribution of forces exerted on the major water movements (wind regime and river supplies) is practically the same from one year to another: the period of wind reversal occurs at the same time with a difference of 15–20 days and the period of the maximum Shari flood with a difference of 10 days. The occurrence of large water movements in the lake does not vary much from year to year but the sizes of the movements are variable and depend upon the strength of the Shari flood and the lake volume\*.

These movements were shown by the study of distribution in space and time of sodium concentration in waters (Carmouze 1971, 1976) as well as that of the water conductivity (Roche 1973).

We will describe these movements over an annual cycle by taking as a starting point the period of June–July which is just before the abrupt occurrence of the Shari flood waters (Fig. 21).

### 2.3.1 *Water movements from mid-June to mid-August*

River supplies which are very low during this period (8% of the annual supplies) cannot cause water movements of great amplitude but their influence does become considerable at the end of July or at the beginning of August. The Shari waters enter the Southeastern Open Waters, however, without resulting in a major water renewal in the regions close to the delta.

However, water moves from the Great Barrier towards the Northeastern Reed Islands and Northeastern Archipelago. This water is pushed back by the water of the Southern Reed Islands and the Southern Open Waters which is driven by the southwest monsoon winds.

The other regions of the lake are not affected by large-scale water movements. In the Southeastern Archipelago, water penetration into the Southeastern Open Waters remains low. In the Northern Open Waters and the Northern Reed Islands, water movements are low in amplitude.

\* During the period of 'Lesser Chad', the water circulation is totally modified as a result of the exudation of the shallows.

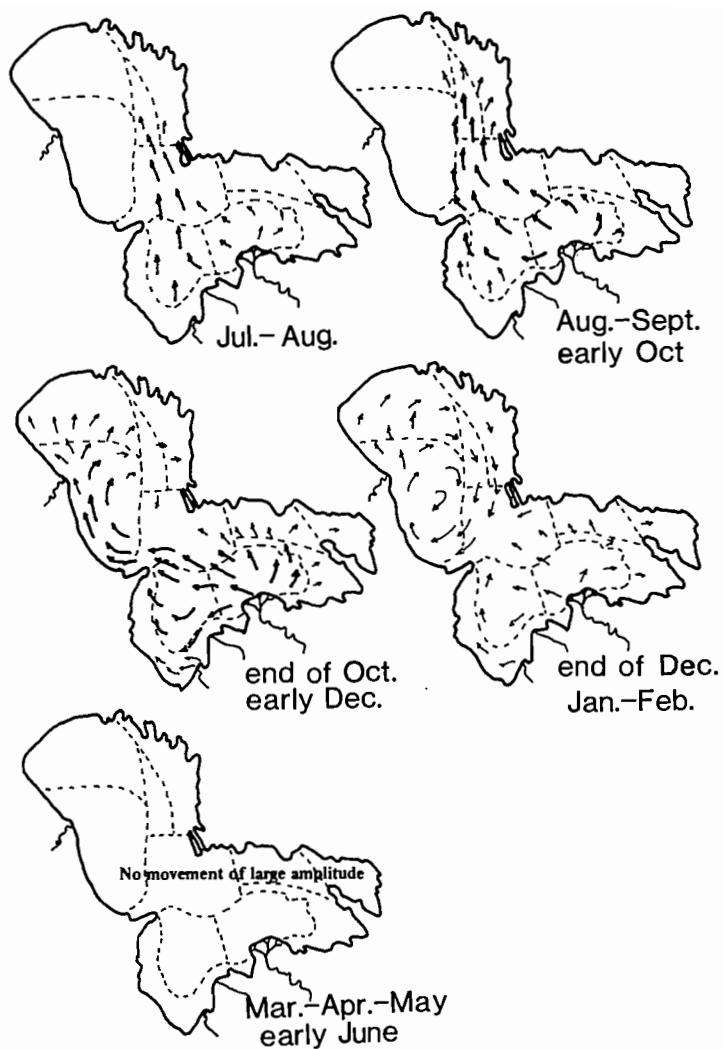


Fig. 21 Water movements in the lake.

### 2.3.2 Water movements from mid-August to early October

During this period, the Shari water supplies, representing 15 to 20% of the annual river supplies, initiate a rise in the lake water level. The waters from the Southeastern Open Water pushed back towards the periphery without mixing new water with old one.

The main flow always moves towards the Northeastern Archipelago and the Northeastern Reed Islands. However, during this period now, it results not only from the monsoon winds but also from the great upsurge of the Shari flood waters. The extent of this water movement is such that water from the Northeastern Reed Islands and the Northeastern Archipelago is also moved towards the Northern Reed Islands.

Water which occupied the Southeastern Open Waters in August begins to move to the Southeastern Archipelago and the Southern Open Waters. In the Northern Open Waters and the Northern Reed Islands, a few large water movements can be noted.

### 2.3.3 *Water movements from mid-October to December*

During October–November, the lake receives 50% of the river supplies raising the lake level by 25 to 30 cm. The upsurge of flood waters is then maximal and this water abruptly stems the flow from the Southeastern Open Waters with no mixing turning the region into a genuine extension of the Shari. Water no longer reaches the Northeastern Archipelago but now flows directly into the Northern Open Waters. This change results from the reversal in the wind regime, for the northeast harmattan blows from mid-October.

Residual water from the Northern Open Waters is pushed back towards the Northern Reed Islands and the Northeastern Archipelago. Nevertheless, a large part is quickly mixed with flood waters. In November the center of the Northern Open Waters is occupied by mixing waters, an important water supply that results in a general water movement northwards. Therefore, the water from the Northern Reed Islands is held back.

In the Northeastern Archipelago, water is also restrained and pushed back towards the coast under the upsurge of water from the Northern Open Waters along with partial mixing of water in this region as well as in the region of the Northeastern Reed Islands. Finally, the flood waters move further into the Southern Open Waters and the Eastern Archipelago.

### 2.3.4 *Water movements from mid-December to February*

Over this period, the lake receives 8 to 10% of the annual supplies and its level begins to decrease. Water no longer flows into the north basin but on the contrary, new water moves towards the Southern Open Waters and the Southern Reed Islands. In the Southeastern Archipelago, there is still a considerable water influx.

In the Northern Open Waters, incoming water mixes with residual water and in the heart of this region mixing is complete. On the other hand, the northern



*Photo 6* General view of a saline lake in Kanem (northeast of Lake Chad).

water mass from the Northern Open Waters is pushed back towards the Northern Reed Islands, while water from the Northeastern Reed Islands mixes with newer water pushed the same way to the south of the Northern Open Waters.

So, in the Northern Open Waters, new waters take a circular course, while mixing with residual waters. This is favoured by environmental topography of the Island Barrier and Reed Islands of the Northern and Northeastern Reed Islands and the Great Barrier and by the influence of the harmattan.

### *2.3.5 Water movements from March to early June*

At this time, water supplies become very low, representing 4 to 5% of the annual supplies, water movements are very reduced and the wind regime is unstable. This is a transitional period since the harmattan is gradually replaced by the monsoon.

Partial mixtures of waters from contiguous regions are caused by the Northern Reed Islands waters mixing with those from the Northern Open Waters, the Northeastern Reed Islands waters with those of the Northeastern Archipelago, the Southeastern Open Waters with those from the Southeastern

Archipelago and finally the Southern Reed Islands waters with those from the Southern Open Waters.

In summary, during June, at the end of the low water period, the monsoon winds contribute to the general water movement from the south to the north. This small water discharge into the north basin is followed at the end of July by the upsurge of the first flood waters of the Shari which flow in the same direction. It continues up to the beginning of October and contributes to the movement of the residual waters from the Northeastern Reed Islands and the Northern Archipelago further towards the north. At this time, the monsoon which favours water flow in the northeastern part of the Great Barrier is replaced by the harmattan which, on the contrary, contributes to a movement of the water discharge zone towards the south of the Great Barrier. The maximum Shari flood waters then penetrate directly into the Northern Open Waters during October, November and December. Initially they go along the Nigerian coast, then they take a circular course in the Northern Open Waters, while pushing back part of the residual waters towards the Northeastern Archipelago. In the midst of the south basin, they penetrate gradually into the Southern Open Waters and to a lesser extent, the Southern Reed Islands and the Southeastern Archipelago.

At the end of January, no water discharge is observed in the north basin. In the Northern Open Waters, the flood waters that took a curved course in November and December is followed by waters from north of the Great Barrier which is pushed back towards the western coast. Then, from February to March, the small water supply from the Shari spread into the Southeastern and Eastern Open Waters and the Eastern Archipelago, thus resulting in a general water movement towards the periphery of the basin. Finally, from April to June, there is no longer any marked movement. On the other hand, it should be noted that the irregular supply of the lake raises the water level from the end of August to the end of December and lowers the water level from the beginning of January to the end of July.

## **2.4 The river system and its tributaries**

Billon et al. (1968) and Durand (1978) described the river system in detail, and we will deal with the essential part of it.

### **2.4.1 *The Shari***

The Shari whose lower course is 25 km has a very shallow gradient of 5 to 7 m km<sup>-1</sup>, and a meandering course obstructed downstream by sandbanks. In the most intricate meanders, there are troughs up to 27 m in depth downstream from N'Djamena.

The Shari receives the Bahr Erguig on its right and its main tributary, the Logone, on its left. Several distributaries flow away from the latter and include the Loumia which flows into the Shari and the Logone during the period of high waters and then downstream from N'Djamena. Two others, the Sebbewel and the Taf-taf flow into the south bank of Lake Chad only during the period of high waters (Fig. 22).

The hydrological regime of the Shari is related to the tropical type, and characterized by annual flood and minimum flow. However, the variations in flow are less abrupt than in the purely tropical type as shown in Fig. 23.

The average annual flow of the lower Shari amounted to  $1270 \text{ m}^3 \text{ s}^{-1}$  from 1953 to 1976. The between year variations were considerable since the values ranged from  $537 \text{ m}^3 \text{ s}^{-1}$  in 1972-73 to  $1720 \text{ m}^3 \text{ s}^{-1}$  in 1955-56.

The average annual flow of the Shari upstream from the Logone amounted to  $815 \text{ m}^3 \text{ s}^{-1}$  from 1953 to 1976. In fact, this value covers a very high variability since during this period, the annual flow varied from  $306 \text{ m}^3 \text{ s}^{-1}$  to  $1290 \text{ m}^3 \text{ s}^{-1}$ , that is, they were quadrupled (Durand 1978).

Although the Shari floods are large, the river waters do not overflow the high water bed because the banks are high. Therefore, there is no flooding zone *sensu stricto* but a high water bed approaching 6 km in width.

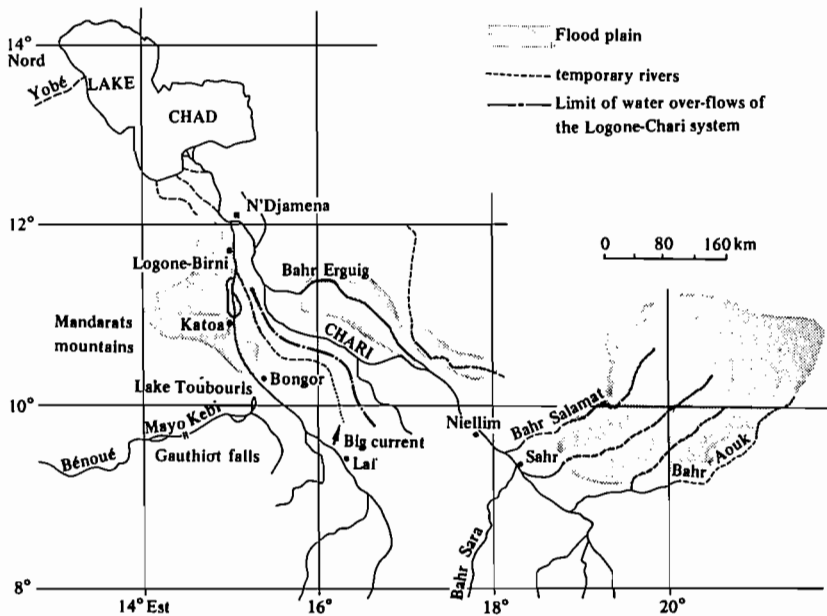


Fig. 22 The hydrographic system of the Shari.

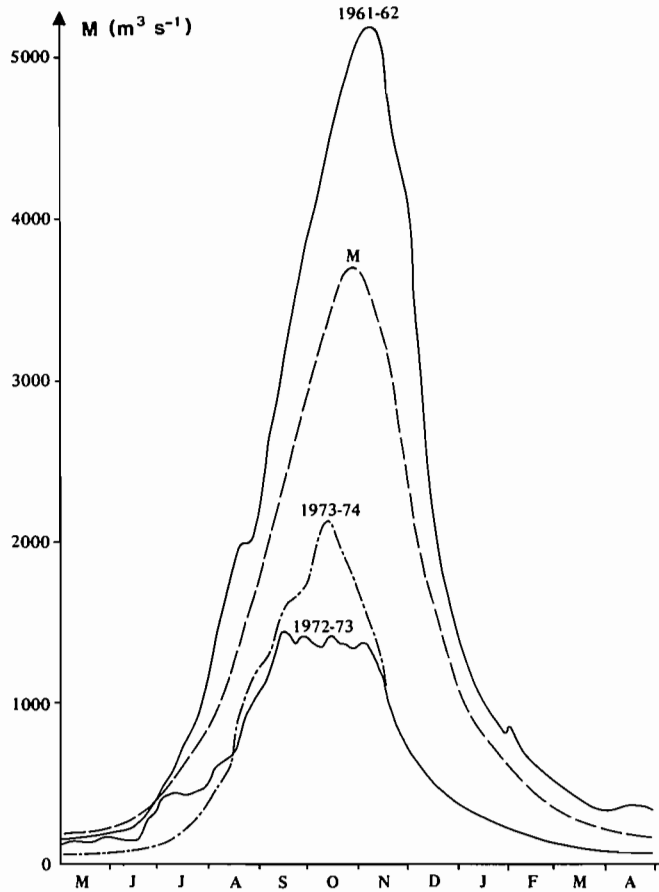


Fig. 23 The Shari floods in N'Djamena.

#### 2.4.2 The Logone

The hydrological regime of the Logone is different from that of the Shari, for the degradation of its bed in its lower course allows side discharges and distributary emissions on both banks during the flood period. On the right bank, there is a considerable discharge only upstream from Bongor, contributing to inundation of the plain between the Logone and the Shari mainly through the 'Grand Courant' which has its source downstream of Lai. Part of the water returns towards the high water bed slightly upstream of Logone Gana. During the period of high water, the Logone and the Shari are connected through the Loumia.

On the left bank, there are considerable discharges: the Logomatia brings back only a small part of the discharged water to the Logone forty kilometers further.

Thus, profound changes occur in the regime of the Logone because of the large losses along its course, resulting in a decrease in flow from upstream to downstream and a corresponding decrease in the peak of the flood is recorded (Fig. 24). The average flow of  $578 \text{ m}^3 \text{ s}^{-1}$  at Bongor decreases by  $125 \text{ m}^3 \text{ s}^{-1}$  at Kaboa and by  $103 \text{ m}^3 \text{ s}^{-1}$  from Kaboa to Logone Birni in an average hydrological year. It is obvious that in the case of low floods, these differences are less while they are increased in the case of high floods.

The result is an extraordinary stability at the junction of N'Djamena where the Logone flow varied from 47 to  $360 \text{ m}^3 \text{ s}^{-1}$  between 1953 and 1971 with an average of  $387 \text{ m}^3 \text{ s}^{-1}$ , half that of the Shari.

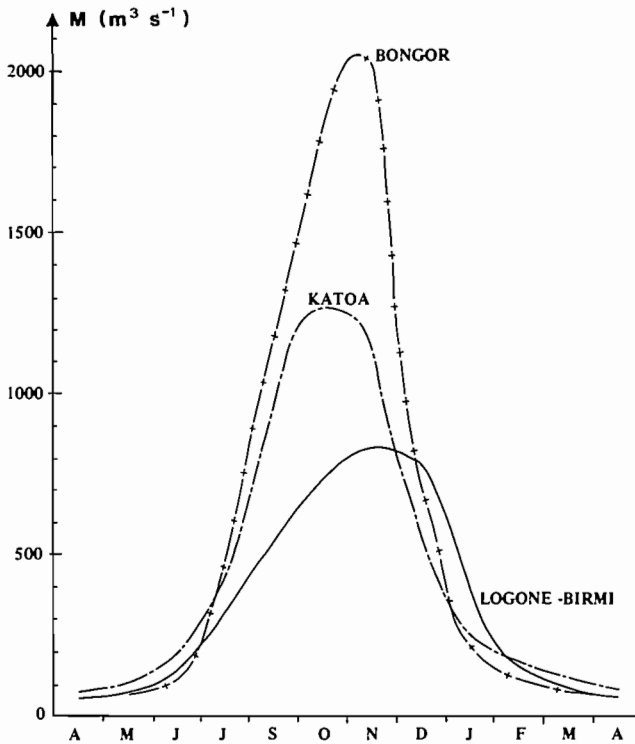


Fig. 24 The Logone floods in Bongor, Katoa and Logone-Birni.

### 2.4.3 *Temporary environments*

(a) *The great flood plain in the North Cameroons.* A very large flooding zone or 'Yaéré' extends over about 5000 km<sup>2</sup> from the Logone and the Shari on the east to the Mandaras Mountains in the west and south and runs into Lake Chad on the north (Fig. 22). This plain is very vast, covered in places with hillocks that are usually artificial and occupied by Kotokos villages where the vegetation is mainly herbaceous. During the period of the river floods, it is immersed under 0.70 to 1 m of water. By mid-July on the average, the flooding regime begins with rainfall which, a month later, increases the water level by about 30 cm. Generally, the Logone inundation appears only in September. In December, waters subside and are collected by the El Beïd which flows into the southernmost region of Lake Chad.

(b) *The El Beïd and Yobé rivers.* Although the water supplies of these two intermittent rivers to Lake Chad represent only 5% of the total, they are important, especially the El Beïd, for the migrations of numerous species (Durand 1970, 1971, 1978; J. Hopson 1969, 1972) (Fig. 22).

The El Beïd flows only five to eight months in a year and is supplied by water from the plain in the North Cameroons. Its bed is 40 to 60 m in width and is composed of only a string of muddy ponds during the period of low waters from April to July. The first runoff from the Yaéré occurs during August and September and the flood reaches its maximum in December, when the El Beïd overflows its bed. It then subsides until the end of March. From 1953 to 1976, the average flow was 46 m<sup>3</sup> s<sup>-1</sup>. The annual variations of 87.5 m<sup>3</sup> s<sup>-1</sup> in 1954–55 and 19.5 in 1955–56 and 1965–66 were great.

Throughout the periods of flood and subsidence, the transparency and the conductivity vary to a great extent according to the mixture ratio of two water masses of different origin. On the one hand, water from the first flood corresponds to the rainfall in July and August. This water is highly mineralized, resulting mainly from the dissolution of salts accumulated during the dry season. On the other hand, the Logone water has a lower conductivity of about 60 μS cm<sup>-1</sup> (Roche 1973).

The first ones prevail at the beginning of the humid season, the second ones at the end of the humid season. Transparency measured with Sacchi disc is never high and ranges from 65 cm at the beginning of the flood to 10 cm in February and 3 cm in May. This abrupt change corresponds to the arrival in the El Beïd of the last drainage water from the flood plain which is very rich in clayey materials.

The Yobé river whose flood occurs generally at the end of July and ends in April–May (Hopson 1972) also has an intermittent regime. The annual flow, very variable, is of about  $0.6 \times 10^9$  m<sup>3</sup> (Toucheboeuf de Lussigny 1969).

## 2.5 Conclusion

On consideration of its morphological, climatic and hydrological features, Lake Chad appears very unstable in time and very heterogeneous in space.

The lacustrine basin occupies temporarily a large region of 25 000 km<sup>2</sup> with few depressions. The hydraulic regulation plus the morphology of this basin is such that the mean depth of the lake amounts to 4 m. This depth is modified by: 1) seasonal variations reaching amplitudes of  $\pm 0.5$  m, resulting from the irregular feeding of the lake by the Shari which has a regime related to the tropical type (the lake receives 50% of its water supplies in October and November) and from the lack of surface effluent likely to allow an adequate regulation of the seasonal and irregular supplies. On the contrary, evaporation is responsible for 20% of the losses and infiltration for 10%, their distribution is fairly regular throughout the year; 2) considerable annual variations reaching about 5 m. These result from the fluctuations of river supplies which can be trebled from one year to the other. They become more pronounced when there is a series of 'humid' or 'dry' years.

Consequently, if a comparison between the amplitude of these variations in the water level and the mean depth of the environment is made, it is obvious that *large areas are likely to emerge or be immersed from one period to the other*. So in 1964, the lake occupied an area of 25 000 km<sup>2</sup>, while ten years later, it was reduced to an area of 9000 km<sup>2</sup> as a result of the drying up of the northern part of the basin. Only the region bordering the Shari delta is almost permanently occupied by water.

These variations in the water area are accompanied by profound changes in the natural lake regions. The lake is composed of three predominant zones which are related to the presence of an erg bordering the lake on the north and the east. These are: a region of islands when the crests are emerged, a region of islands occupied by macrophytes (*Cyperus Papyrus* and especially *Phragmites*) or reed islands when crests are immersed under 0.5–1.5 m of water, a favourable condition for the development of these plants; and a region of open water when crests are inundated and without emergent vegetation, generally the case when they are situated at depths above 1.50 m.

The fluctuations of the water level are such that, even if the type of colonization or decolonization of the regions is not as simple as mentioned previously, *profound changes in lacustrine zones must be expected both in time and space*. So, after a lake subsidence, a region of open water can be turned into a region of reed islands, a region of archipelago and a dry region within a few years. During 1973–75, numerous shallows appeared in the northern open waters and became an archipelago before drying up in 1975. During the period of flood, the opposite situation can occur.

The hydrological regime determines not only the water area and the distribution of lake zones the renewal of water in the different regions. The

general water circulation is such that the renewal of water is increased by proximity to the Shari delta and by the river going through a period of flood from September to January. The first flood waters move towards the archipelago under the influence of the southwest winds up to mid-October. At that time, the harmattan, a northeast wind, takes over and changes the movement of the Shari flood waters towards the zones of open water. This change in direction allows a more thorough mixing of 'new' and 'residual' waters.

According to the rate of renewal of waters, it can be said that *the northern basin has a proper lacustrine appearance while the southern basin or at least its central zone has a more riverine appearance*. From this point of view the northern basin is more stable than the southern basin as long as the lake is not divided. This is not true during a severe contraction of the lake when the Shari no longer supplies the northern basin. It can then dry up either partially or totally over a short period of time, while the region connected to the Shari delta is always occupied by water.

The nature of the lake bottom varies considerably from one zone of the lake to the other. It is dependent mainly upon the distribution of solid suspensions from the Shari, which is itself dependent upon the general water circulation as well as the distribution among the macrophytic vegetation. Generally, the deposited materials are a clay facies in the zones of open water, a muddy facies in the zones of reed islands, and a clay-muddy facies in the archipelago zones. These three main types are subdivided into varieties. *Therefore, the nature of sediments is far from being regular and it leads to a strengthening of the spatial heterogeneity of the environment.*

In short, before dealing with the physical as well as chemical features of the waters, it is observed that Lake Chad is composed of a mosaic of biotopes, each of them likely to undergo profound modifications in time, even disappearing and reappearing according to the lake floods and recessions. Only the open waters of the southern basin do not disappear during the drying up periods.

All these environments are subject to the influence of a tropical climate. Rainfall, winds, air temperature, air humidity and evaporation are determined by the Intertropical Convergence Zone (ITCZ) which moves along a south-north line throughout the year. South of the ITCZ, a humid climate prevails and north of it, a dry climate. Continental winds such as the northeast harmattan blow over the entire lake in winter leading to the occurrence of drought from October to February-March, while the marine winds such as the southwest monsoons blow from June to September and are associated with rainfall. The lake is situated between the isohyets 550 mm in the south and 240 mm in the north and receives 50% of its rainfall in August. At that time, evaporation falls to a minimum of 16-17 cm per month, while in October-November, it increases up to 21-23 cm per month. The mean monthly air temperatures range from 29 to 32°C from March to October (with a minimum of 27°C in August) and from 22 to 24°C from December to February. Diurnal

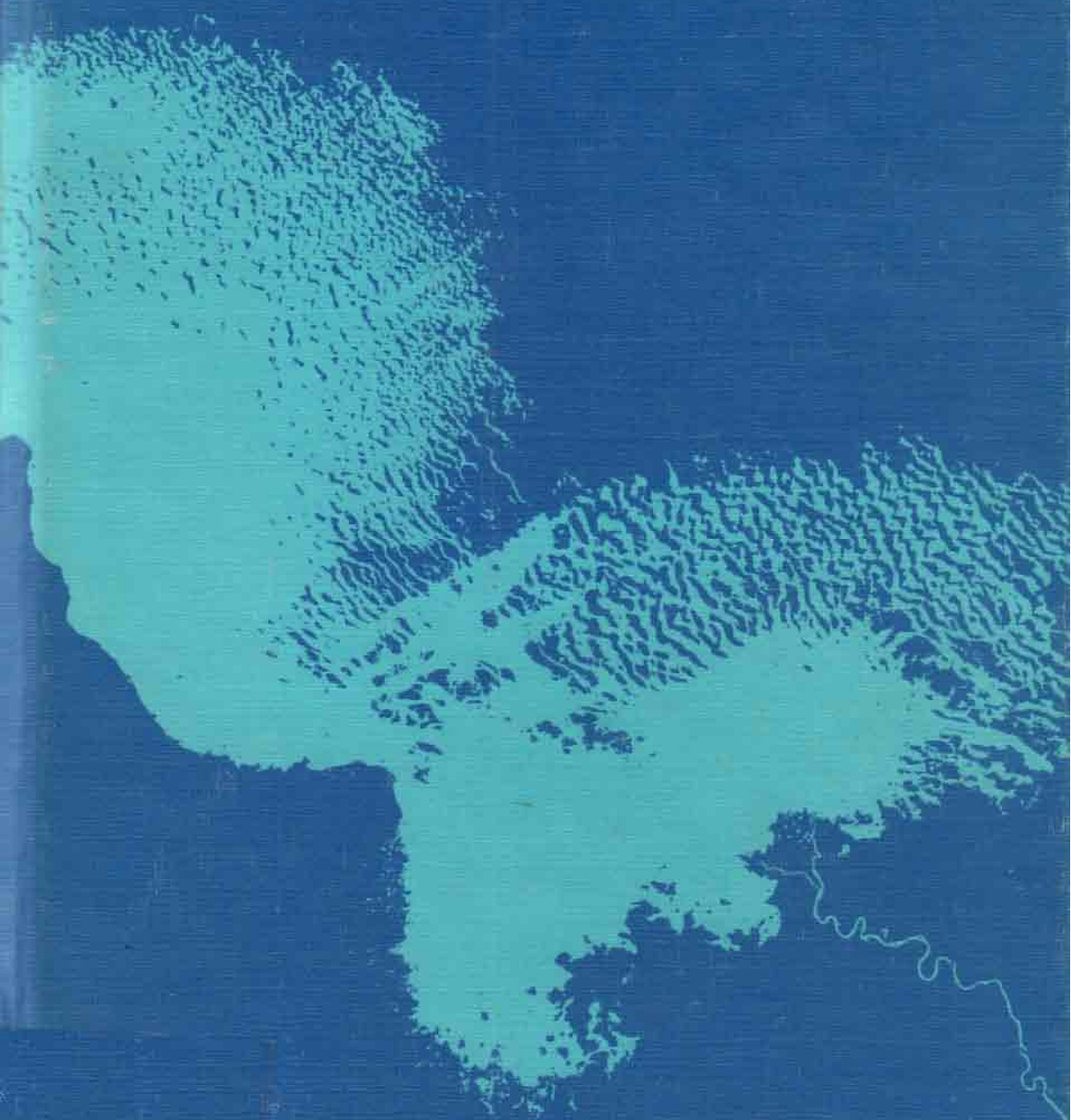
variations are considerable in winter, up to 16 to 17°C compared with 7 to 9°C in August. Air humidity reaches maximum values in August (70–80%) with minimum values in February–March (23–31%). The incident radiation amounts to  $2310 \times 10^4 \text{ J m}^{-2} \text{ d}^{-1}$  on average with low seasonal variations. These seasonal fluctuations are more pronounced than in equatorial regions, but less so than in temperate ones.

## References

- Billon, B. et al. 1968. Monographie hydrologique du Chari. ORSTOM Paris, 5 parts in 6 vols., 610 pp., mimeo.
- Bouchardeau, A. and Lefèvre, R., 1957. Monographie du Lac Tchad. C.I.E.H. Paris, 114 pp., mimeo.
- Carmouze, J. P., 1971. Circulation générale des eaux dans de lac Tchad. Cah. ORSTOM Sér. Hydrobiol. 5: 191–212.
- Carmouze, J. P., Dejoux, C., Durand, J. R., Gras, R., Iltis, A., Lauzanne, L., Lemoalle, J., Lévêque, C., Loubens, G. and Saint-Jean, L., 1972. Grandes zones écologiques du lac Tchad. Cah. ORSTOM Sér. Hydrobiol. 6: 103–169.
- Carmouze, J. P., 1976. La régulation hydrogéochimique du lac Tchad. Contribution à l'analyse biogéodynamique d'un système lacustre endoréique en milieu continental cristallin. Trav. Doc. ORSTOM No. 58 Paris, 418 pp.
- Dupont, B., 1967. Nature des fonds dans la zone est du lac Tchad. ORSTOM Fort-Lamy, 8 pp., mimeo.
- Dupont, B., 1970. Distribution et nature des fonds du lac Tchad. Cah. ORSTOM Sér. Géol. 2: 9–42.
- Durand, J. R., 1970. Les peuplements ichtyologiques de l'El Beïd. Première note. Présentation du milieu et résultats généraux. Cah. ORSTOM Sér. Hydrobiol. 4: 3–26.
- Durand, J. R., 1971. Les peuplements ichtyologiques de l'El Beïd. 2 ème note. Variations inter et intraspécifiques. Cah. ORSTOM Sér. Hydrobiol. 5: 147–159.
- Durand, J. R., 1978. Biologie et dynamisme des populations d'*Alestes baremoze* (Pisces, characidae) du bassin Tchadien. Trav. Doc. ORSTOM, No. 98 Paris, 332 pp.
- Fotius, G. and Lemoalle, J., 1976. Reconnaissance de l'évolution de la végétation du lac Tchad entre janvier 1974 et juin 1976. ORSTOM N'Djaména, 13 pp., mimeo.
- Guichard, E., 1957. Eaux du lac Tchad et mares permanentes au nord d'Ira. ORSTOM Fort-Lamy, 26 pp., mimeo.
- Hopson, A. J., 1968. The gill net fisheries of Lake Chad. Federal Fisheries Service Maiduguri, 64 pp.
- Hopson, J., 1972. Breeding and growth in two populations of *Alestes baremoze* (Joannis) (Pisces, Characidae) from the northern basin of Lake Chad. Overseas Res. Publ. 20, 50 pp.
- Lemoalle, J., 1978. Application des images Landsat à la courbe bathymétrique du lac Tchad. Cah. ORSTOM Sér. Hydrobiol. 12: 83–87.
- Riou, Ch., 1972. Etude de l'évaporation en Afrique Centrale (Tchad, R.C.A., Congo). Contribution à la connaissance des climats. Thèse Univ. Paris VII.
- Riquier, J., 1963. Formules d'évapotranspiration. Cah. ORSTOM Sér. Pédol. 1: 33–50.
- Roche, M. A., 1973. Traçage naturel salin et isotopique des eaux du système hydrologique du lac Tchad. Thèse d'Etat Univ. Paris VI, ORSTOM Paris, 398 pp., mimeo.
- Tilho, J., 1910. Documents scientifiques de la Mission Tilho (1906–1908). Imp. Nat., Paris, vol. 1, 412 pp., vol. 2, 568 pp.
- Toucheboeuf de Lussigny, P., 1969. Monographie hydrologique du lac Tchad. ORSTOM Paris, 169 pp., mimeo.

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