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Origin and function of a closed depression in equatorial humid zones: the Lake Télé in North Congo

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Abstract

Lake Télé has a nearly perfect ellipsoidal shape and is surrounded by swamps and barely penetrable flooded forests in the heart of the Congo–Zaïre watershed basin, and has intrigued the international scientific community for decades. In June 1992, a first Franco–Congolese multidisciplinary scientific expedition was finally able to reach the lake which is vast (23 km^2) and shallow (3 m). Its volume is estimated at 71×10^6 m^3 and is 40% filled with an organic silt layer a metre thick. Its hydrological exchanges are almost exclusively vertical with very little lateral contribution from the surrounding swamp. This leads to the observation that the waters are very slightly mineralized (< 3 mg l^{-1}), but are very rich in organic carbon (44% of suspended matter and of total dissolved matter) and are very acidic (pH < 4). In addition, a magnetic anomaly of some hundred nanoTesla from a magnetic body at shallow depth has been detected in the lake's northern half, although its origin remains unknown. Botanical and palynological observations suggest the persistence of a strongly hydromorphic forest environment for at least the last 6600 years. Identified pollen taxa, whether ancient or recent, come mainly from pioneer and colonizing taxa such as *Macaranga*, which tends to indicate that the forest is continuing to gradually fill in the lake. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Congo; Lake Télé; Limnology; Palynology; Magnetism; Meteorite

1. Introduction

When the first French military, then civilian, administrators approached the rare unflooded lands of the upper Likouala aux Herbes, near what was to become the township of Epena, the local Bomitabas and Babingas (Pygmies) populations told them of the mythical Lake Télé, whose nearly perfectly ellipsoidal shape had always excited local imaginations. Its presence, more than 70 km from the meandering

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course of the Likouala aux Herbes, is intriguing because of a strange magnetic anomaly which has been observed by pilots overflying this mirror of water along the aerial axis from Bangui to Brazzaville. This lake is also known by the legend of ''*Mokélé-Mbembé*'', a hypothetical and mysterious amphibious creature, which may resemble a sauropod of the Mesozoic (Heuvelmans, 1980). This was the origin of two international expeditions by Professor Mackal of the University of Chicago, in 1981 and 1983 (Sciences et Vie, 1981; Mackal et al., 1982; Regusters, 1982; Agnagna, 1983; I.S.C., 1986).

Some other expeditions took place over the course of the 1970s and 1980s, especially at the end of this last decade, when the question of making the region of Lake Télé an 'international biosphere reserve' was raised. Only two of these actually got as far as Lake Télé and few samples of irrefutable scientific results have come out of these, with the notable exception of a Congolese-American mission in 1976, in which ORSTOM hydrologist J. Grandin participated and carried out the first reliable bathymetric survey of the lake (Agnagna, 1983).

It is in this context that ORSTOM's Department of Inland Waters (DEC) organized a first Franco–Congolese multi-disciplinary scientific expedition in June 1992, in association with the Congolese DGRST[1] (Pouyaud, 1992). Its objective was to scientifically explore this environment and to try to answer some of the questions surrounding it. Fig. 1 shows the progress of this mission to the lake.

It was not possible to remain at the lake longer than one day, which was devoted entirely to making in situ measurements (magnetometry, bathymetry, physico-chemistry of the waters...), taking samples (water, lake and river sediments, specimens of flora, etc.) as well as making a great number of observations. Before presenting the results and first interpretations of the data gathered during this mission, we will describe the environmental context.

[1] DGRST = Direction Générale de la Recherche Scientifique et Technique.

2. Regional physiography

2.1. Geographical situation

Lake Télé (Fig. 1) is part of the upper Likouala aux Herbes watershed, and is in the north-west portion of the ''*Congolese Cuvette*'' which lies within the Congolese Basin, the second largest (3.7 million km^2) in the world. The lake (17°10′ East, 1°20′ North), is surrounded by a vast zone of swamps and flooded forest in periods of high waters, which, in the Congo, spreads 220 km from the city of Ouesso on edge of the Sangha River, to Impfondo on the right bank of the Oubangui River and yet further into Zaire. The lowest point of this depression, at approximately 350 m altitude, is at the confluence of the Congo–Zaire River with the Oubangui, the Likouala aux Herbes, the Sangha and finally the Likouala Mossaka. This ''*Cuvette*'', enclosed to the south by the sandstone ''Batékés Plateau'', constitutes the western extension of the vast central Zairean depression of which the floodable part (up to 60%), covers nearly 220 000 km^2 according to Burgis and Symoens (1987).

The surface formations of this whole region are constituted of Quaternary clayey or sandy fluvial alluvia.

The population density is approximately one inhabitant per square kilometer.

In terms of the vegetation, in addition to the marshy forests, the region is covered with floating prairies in the middle of which appear rare zones of ''firm earth'', which are only rarely flooded and which support small areas of primary forest, as for example, the sort of ''bridge'' linking the east of Lake Télé to the Likouala aux Herbes.

This lake presents an evident nutritional interest, especially for the pygmies and for the inhabitants of Boa' village who get there twice a year to fish. They mention they find a great variety of fish (*Tilapias*,...), and some big reptiles, such as aquatic turtles and crocodiles. The neighbourhood of the lake is also visited by pythons and by many mammals including numerous monkeys, gorillas and forest elephants. Many species of bird attend this lake, including many types of cormorants.

2.2. Climatology

The climate is of equatorial transition type, marked

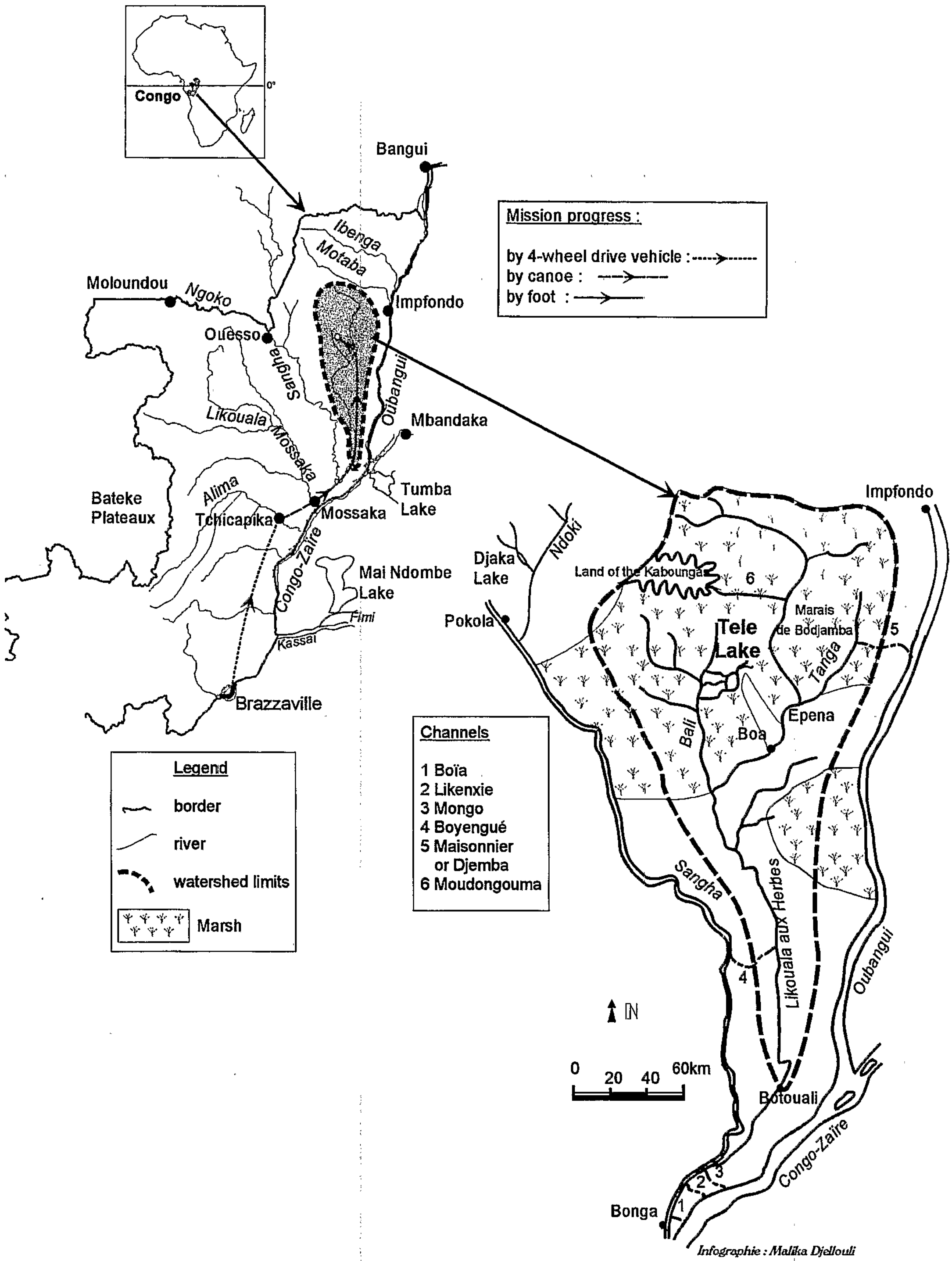

Fig. 1. Map of the situation of Lake Télé within the Likouala aux Herbes watershed basin.

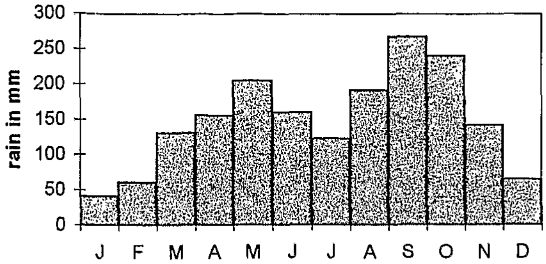

Fig. 2. Mean annual rainfall at Ouesso (1985–94).

by two seasons of rains and two dry seasons of unequal intensity (Fig. 2). Average daily minimal and maximal temperatures for the region, are respectively 20.3 and 30.2°C, while the minimal and maximal daily observed absolute temperatures over the period 1950–59 (Bultot, 1972) were 14 and 36.4°C, at the Mbandaka station (18°17′E, 0°03′N, at an altitude of 328 m). Lake Télé is situated between the 1600 and 1700 mm isohyets (Samba-Kimbata, 1991). Bultot (1971), indicates average evaporation of the order of 1300 mm per year for the central "*Cuvette*" for the period 1930–59. From the calculation of the inter-annual precipitation, for the whole of the Likouala aux Herbes watershed for the period 1953–93, the flow deficit obtained, or the difference between precipitation (1710 mm) and run-off (360 mm), is 1350 mm, while for 1992, the year of our mission, it reaches 1416 mm (1690 mm–274 mm) (Laraque and Maziezoula, 1995). But this latter higher value takes storage into account, which the prior value does not.

2.3. Hydrology of the Likouala aux Herbes watershed basin

In addition to the 700 km of meandering Likouala aux Herbes River, its entire watershed (like that of the whole of the *Congolese Cuvette*) is criss-crossed with natural or man-made channels that link it to the adjoining hydrographic basins. These channels are narrow (2 to 3 m wide), sometimes more than 2 m deep and often encumbered with snags, when they are not completely obstructed by the "grassy corks". These are made up of large floating rafts of vegetation torn from the banks by winds and currents, which change with the water levels of the adjacent rivers that they feed into. Thus the 22 km long Maisonnier Canal, dug across the forest between 1937 and 1941, established the junction between the Tanga River (tributary of the Likouala aux Herbes) and the Djemba (or Illébou) tributary of the Oubangui River. Further upstream in the basin is found the Moudongouma or "River of the Kaboungas", also cut through the flooded forest to connect the higher ground of the Land of the Kaboungas to the upper Likouala aux Herbes. At its southern end, the Likouala aux Herbes flows into the Sangha River via the man-made Boyengue canal. The lower Sangha is itself connected to the Congo River by at least three channels (Fig. 1): the Mongo, the Likenzi, and the Boïa (S.G.A.E.F., 1949, and C.E.R.G.E.C., 1990).

Because the slope of the terrain is very slight (3 cm km^{-1}), all these waterways and canals flow slowly (1.2 km h^{-1} for the Likouala aux Herbes at low water). Beyond the choking edges of narrow channels, the spreading waters probably mix with the alluvial water table which appears in many places. The totality slips at imperceptible speed downstream in a laminar manner. One could then qualify all of it as a "fluvial table". This would also ensure hydraulics continuity with neighboring basins, the imprecise contours of which are due to the absence of relief in their lower reaches. This is the case for the vast Bodjamba marsh to the north of the Likouala aux Herbes basin, which extends into the Motaba basin and the marshy areas west of Lake Télé, drained by a sub-tributary, the Bali (I.G.N., 1963a, b). With the exception of the rare small unflooded areas like the Land of the Kaboungas and the land already described between Boa and Lake Télé, the Likouala aux Herbes basin is considered to be a "flooded plain". It is certainly the most sinuous waterway of the northern Congo, the principal axis of drainage, the numerous meanders of which come and go throughout the middle of a vast flood plain covered by a prairie of tall grasses ("herbes"). During the dry season, the outflow is slowed by alluvial deposits which hold back vast quantities of water in bogs and marshes, and which maintains a certain level at low water (July to September).

The particularity of these numerous aqueous interconnections justifies the precautions presented by Pouyaud (1970) as to the validity of the flow rates of the Likouala aux Herbes, calculated at Botouali, the main hydrometric station that monitors 99.2% (24 800 km^2) of the watershed. It is thus necessary to consider the mean annual discharge of 285 $m^3 s^{-1}$ (calculated for the period 1953–93) as an order of magnitude, because it is apparent that the basin's water level is influenced by that of the Sangha River and to a lesser extent by those of the Oubangui and Congo Rivers. The coefficient of flow of this basin would be 21% and its floodpoint is in November. The month of June, chosen for our mission, is in the middle of the low water season, greatly facilitating our progress to Lake Télé.

2.4. Paleo-hydrography

During this mission to the lake, samples of alluvial deposits were collected every 10 km along the 520 km length of the Likouala aux Herbes from its confluence to the village of Boa. Censier et al. (1995) have shown a very marked variation in the mineralogical succession of the sands, suggesting that in teh recent past, the confluence of the Likouala aux Herbes and the Sangha was some 130 km upstream of the current confluence. The meandering of these waterways is, of course, favored by the relative flatness of the lower parts of the basin.

3. Techniques and methods for the study of the lake

3.1. Sampling and measurement locations

Bathymetric, magnetometric and physico-chemical profile measurements along the three transects shown

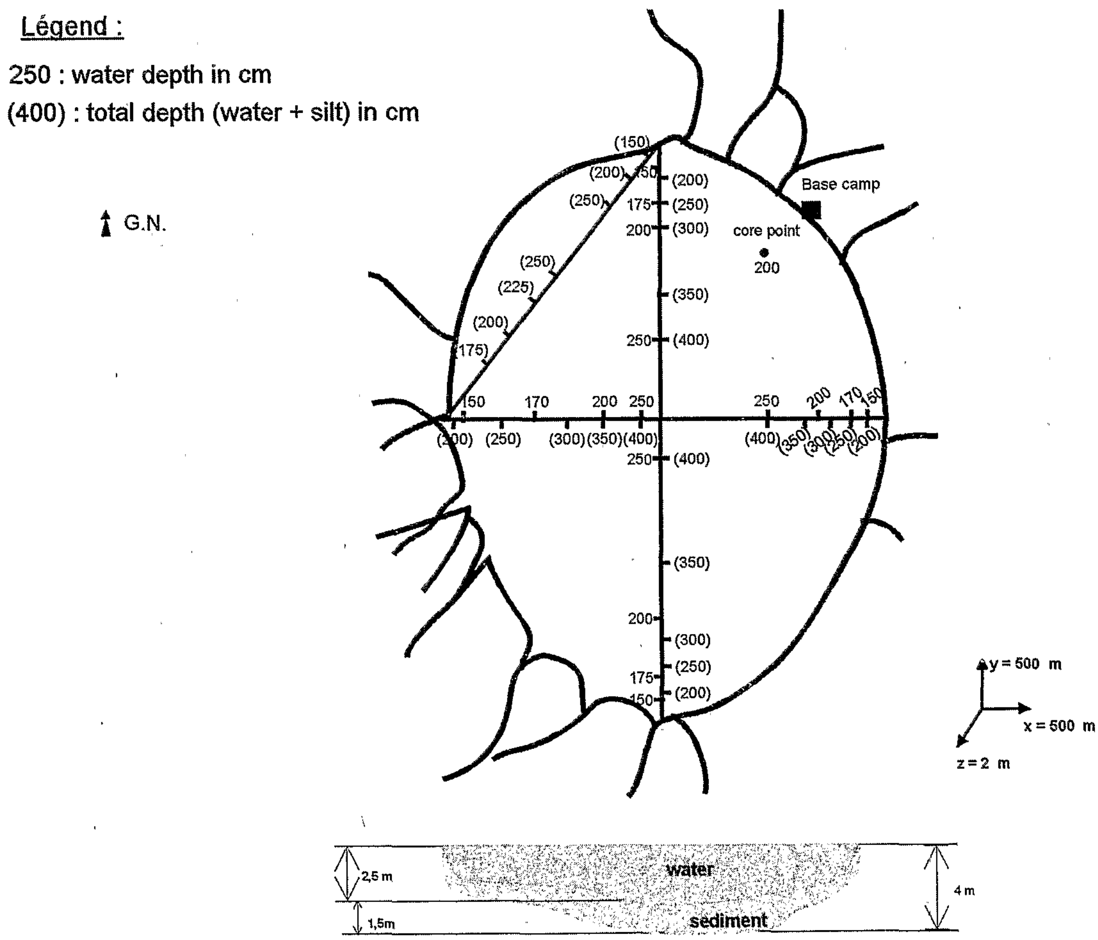

Fig. 3. Bathymetric measurements and west-east cross-section of Lake Télé.

in Fig. 3 were carried out using a Zodiac with a March Echo-probe, a proton magnetometer (Geometrics) sensitive to one nanoTesla, and using a thermometer, portable pH meter and conductivimeter. The probes of these instruments had been previously calibrated to ranges characteristic for these waters.

These transects allowed us to measure these parameters every 500 m for a total of thirty measurement points. The physico-chemical measurements were also checked at every half metre of depth from the surface to the bottom of the lake, through a vertical profile in the northeast quarter of the lake at around 400 m from the base camp. Two water samples were taken from 50 cm below the surface, for physico-chemical measurements and five others for the determination of organic carbon content.

Finally, two 1.5 m-long lake sediment core samples were also taken manually and with great difficulty in this area. The echo probe suggested that the silt went no deeper.

After drying, these core samples were reduced to a thickness of about 30 cm. One of these was used for mineralogic studies using X-ray diffraction, for pollen studies and for extraterrestrial component research, while the other was used for ^{14}C and $\delta^{13}C$ carbon-dating studies at three levels: 0–2, 14–15, and 28–29 cm.

3.2. Analytical techniques

Water samples were sieved at 50 μm for the coarse suspended matter (CSM) then filtered at 0.2 μm for the fine suspended matter (FSM). After being dried then put through a desiccator, these fractions were weighed to a precision of 0.1 mg (Sartorius scale). A litre of filtrates was heated in a steamer to 105°C to obtain the dry residue, which corresponds to the Total Dissolved Solids (TDS) and the total Dissolved Organic Matter (DOM).

The filtered FSM and the aliquots of 100 ml of corresponding filtered water served for the qualitative and quantitative analyses (granulometry, mineralogy, and chemical composition) carried out by the Laboratory of Surface Formations at ORSTOM's Centre at Bondy (France). The TDS were determined as follows:

Ca and Mg, by atomic absorption spectometry (reproducibility ±5%, and detection limit of 0.01 mg l^{-1} for both elements), and Na and K, by flame emission spectrometry (reproducibility of ±5% and a detection limit of 0.02 mg l^{-1} for both elements), using a VARIAN SPECTRAA-10 spectometer without background correction;

Cl, NO_3, and SO_4, by ionic chromatography (DIONEX 4010i model, reproducibility ±5%, detection limit of 0.05 mg l^{-1} for Cl, and 0.1 mg l^{-1} for other anions);

Si, Al, and Fe, by inductively coupled plasma atomic emission spectrometry with an ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectometry, using a VARIAN Liberty 200 spectrometer with a reproducibility of ±2%, and a detection limit of 0.01 mg l^{-1}); and finally, the DIC (Dissolved Inorganic Carbon) was determined by potentiometric titration (reproducibility ±5%, and detection limit of 0.5 mg l^{-1} of CO_2).

The five specific samples for organic carbon were placed in glass bottles after using a vacuum pump, then filtered through 0.2 μm GFF filters (pre-grilled to 400°C for 8 h) in preparation for later treatment in a high combustion oven, after decarbonatation, in order to determine the Particulate Organic Carbon (POC). Twenty millilitres of each sample of the raw water filtrate was treated by addition of $HgCl_2$, to kill any living organisms, for the measurement of the Dissolved Organic Carbon (DOC). These determinations were carried out by the Department of Geology and Oceanography (DGO) at Talence (France). A Leco CS 125 analyser was used for the POC and a Shimadzu TOC 5000 for the DOC with a precision of 5%, for each.

4. Results and discussion

4.1. Morphology

The lake has an ellipsoidal shape with a 6.4 km long axis oriented north-south, and a 4.8 km axis oriented east-west. It covers a surface of approximately 23 km^2 with a circumference of 18 km (Fig. 3).

Our bathymetric measurements agree perfectly with those of Grandin (1976). The echo-probe bands on the three transects (south-north, east-west and north-west) show an extremely regular shallow bottom that gradually slopes from less than a meter near the banks, to approximately 2.5 m of depth some 100 m from the shore, and remains perfectly uniform in the central zone of the lake. The echo-probe and samples taken 400 m from the north-east bank of the lake, near the base camp, show the presence of a layer of mud and silt at least 1.5 m thick, which is also remarkably uniform, the consistency of which becomes firmer as the depth increases to reach a certain compactness, blocking the penetration of the plastic tubes we used for taking core samples.

The total depth between the free water level and the solid substratum is thus around 4 m for a total volume estimated at 71×10^6 m^3, of which 43×10^6 m^3 is free-flowing water and 28×10^6 m^3 is mud, so respectively 60% and 40% of the global volume. Based on these bathymetric measurements, we have established a first formula to estimate the free water volume of the lake (V in m^3) for a layer of water up to 2.5 m in depth (P in m)

$$V = 8.99 \times 10^6 \times P^{1.70}$$

The results are comparable to those obtained by using the classic geometrical formula for the calculation of the half volume of an ellipsoid, that is: "2/3. π. a. b. c", where a, b, and c are the three orthogonal axes of the ellipsoid.

4.2. Limnology

Lake Télé is situated in a geographic zone of preferentially north-south drainage, as demonstrated by the direction of flow of the Likouala aux Herbes, its tributary the Bali, or again the Oubangui and Sangha Rivers. Nevertheless, a highly interlinked drainage system seems to connect the west banks of the lake to the upstream tributaries of the river Bali.

According to local testimonies, the marks left on the tree trunks, and aerial roots of taxa such as *Xylopia rubescens*, it would appear that the lake can rise a metre during the rainy season. In periods of high waters, this body of water extends into the kilometres of mudflats and swamps which surround the lake. Taking into account only the free water surface delimited by the forest belt, the maximum water reserves of the lake may thus attain a volume of nearly 55×10^6 m^3 for a water layer 3.5 m deep. Still based on this free surface, the lake is estimated to receive 38×10^6 m^3 of rain annually, for a loss by evaporation of 30×10^6 m^3, or around 88% and 70%, respectively, of the volume observed at the time of our visit. Compared to the maximum estimated volume, these water level movements would not represent more than 70% and 55%, respectively, which still guarantees a good renewal of the waters of this reservoir. We also consider that it is in hydrological equilibrium with the alluvial water table of which it constitutes the upper level. Given the lack of elevational relief and the relatively limited area of its watershed, inputs from surface flows appear negligible. Also, it may be that the laminar flow alone and the creek network westward to the Bali, are sufficient to evacuate the 8×10^6 m^3 of

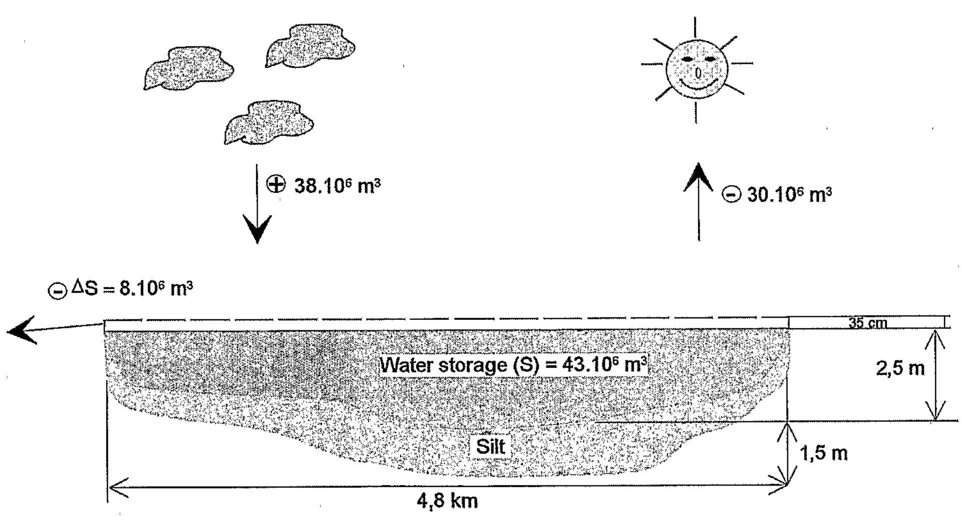

Fig. 4. Hydrologic model of Lake Télé (annual balance).

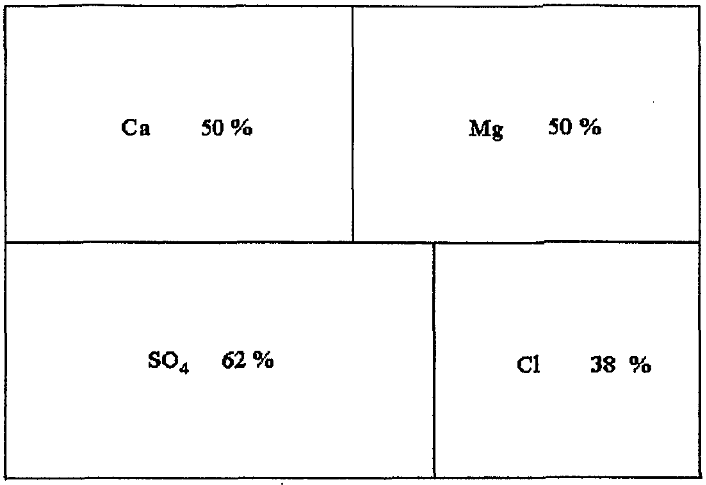

Fig. 5. Stabler's diagram of the ionic composition of the waters of Lake Télé (in meq l^{-1}) on the 06/19/92.

excess rainfall, which correspond to a layer of 35 cm of free water in the lake (Fig. 4).

The classic equation of the water balance of a lake

variation in volume = inputs − losses = [Rain + lateral contributions (surface and underground)] − [evaporation + infiltration + lateral losses (surface and underground)]

are in equilibrium and may be summarized for this lake annually by

$$\text{Rain} - \text{evaporation} - \text{lateral surface losses} \approx (38-30-8)\times 10^6\ \text{m}^3$$

These essentially vertical water displacements thus suggest exclusively meteoric contributions on the order of 1650 mm $year^{-1}$, largely compensated (up to 80%) by evaporation on the order of 1300 mm $year^{-1}$ (Fig. 4).

4.3. Bio-geochemistry of the waters

For the waters of Lake Télé, the geochemical facies is chloro-sulphated calcico-magnesium, marked by an absence of alkalines, bicarbonates and nitrates (Fig. 5). The ionic succession represented is, in decreasing order, as follows: $SO_4 > (Ca, Mg) > Cl$, expressed in μeq l^{-1}.

On the one hand, the series of spatial measurements of the physico-chemical parameters along the transects referred to above reveal that these waters do not present vertical stratifications, because of the lake's shallowness and large surface area, making it very susceptible to mixing by the wind. Well-exposed to the sun, its average temperature of 28°C is slightly higher (one to two degrees) than those of its neighboring waterways (Likouala aux Herbes, Bali).

On the other hand, we observed a slightly dissymetric zone, with lower electrical conductivity in the centre of the lake (31 μS cm^{-1} at 25°C) than on the edges, with higher maxima on the northern periphery (47 and 37 μS cm^{-1} at 25°C) than on the southern (33 μS cm^{-1} at 25°C) (Fig. 6 and Table 1).

The total matter in the water is 79.8 mg l^{-1} of which the particulates represent only 17.8% (14.2 mg l^{-1}). About half of this value is constituted by POC (6.88 mg l^{-1} or 48%) in the form of aggregates and colloids.

The total dissolved matter dominates (65.6 mg l^{-1}) with only 11.8% (7.75 mg l^{-1}) of TDS, while the DOM (57.9 mg l^{-1}) is very high, with 88.2%. This latter value is deduced from the dry residue minus the TDS and corresponds to approximately twice the DOC measured (42.5% or 27.92 mg l^{-1}), as usual.

The TDS contains very few ionics elements (2.85 mg l^{-1}), the rest (4.9 mg l^{-1}) coming essentially from alumino-ferrous or -ferric complexes, and there is very little dissolved silica (12 μmoles l^{-1}). It should

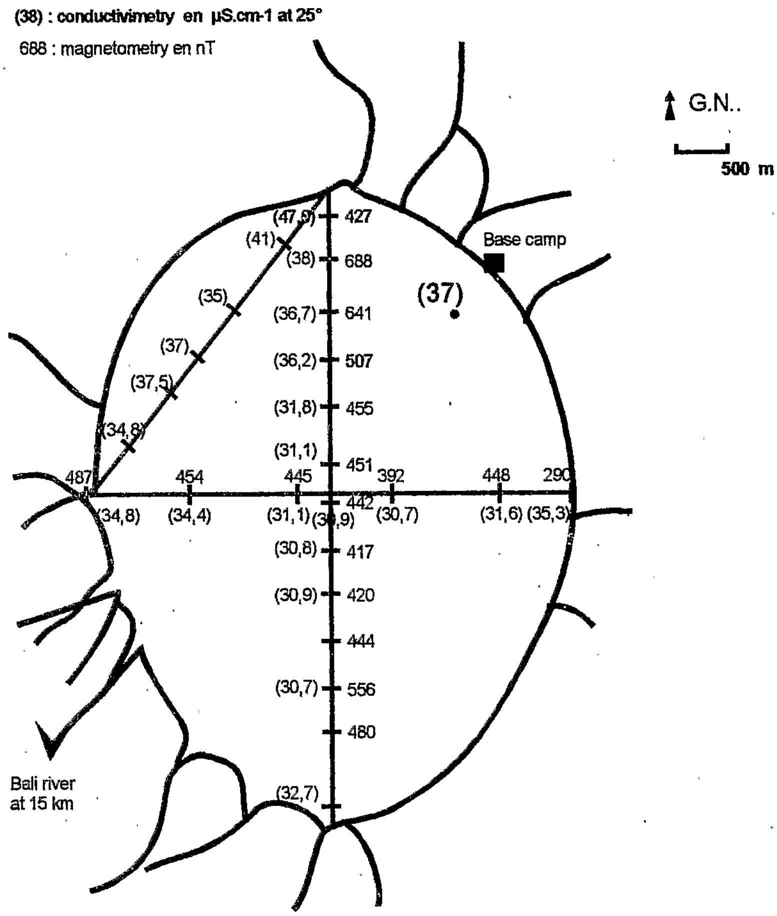

Fig. 6. Conductivimetric and magnetometric cross-sections.

be noted that the measurements for iron and aluminium are very approximate since it was not possible to acidify the water samples in situ, and they were preserved only by the inherent acidity of the water (pH 3.6–4).

The major quantities of dissolved organic matter and ionized colloidal compounds of iron and aluminium lead to very high electrical conductivity (37 $\mu S \cdot cm^{-1}$ at 25°C), despite the very low mineral load (less than 3 mg l^{-1}). This electrical conductivity is close to that found in the neighboring rivers (Likouala aux Herbes, Bali), but with the notable difference that the waters of the Lake Télé have a much lower mineral and silicate content, and are much richer in organic matter. This is what gives the dark-coloured waters of the ''*Cuvette*'', nicknamed ''*coca cola rivers*'', and explains their acidity.

4.4. Interpretation and model of the functioning of the lake

We have seen that the main flow in this region is north-south; however, within the lake, there seems to be a very slight NE to SW tendency toward the river Bali situated 15 km westward. This direction is induced, on the one hand, by the network of narrow channels at the western periphery of the lake (visible on aerial photographs) and, on the other, by a weak electrical conductivity gradient of the waters, decreasing from NE to SW (Fig. 6).

The free waters of the lake are surrounded by an uninterrupted ring of large trees, reaching 50 m high, whose roots are bathed in mud which is more or less one metre deep, depending on the time of year. Also, the run-off surface waters, loaded with organic matter

Table 1
Physico-chemistry of the waters of the Likouala aux Herbes watershed basin, and various regional lake waters and rain waters

Sample source	Date	pH	EC	Ca	Mg	Na	K	Cl	SO_4	DIC	NO_3	H_4SiO_4	Al	Fe	DR	TDL	TDS	CSM	FSM	DOC	Temp
unit			($uS.cm^{-1}$)	($\mu mol\ l^{-1}$)											($mg.l^{-1}$						°C
Lake Télé	06/19/ 1992	4.00	36.10	12.00	12.00	< DL	< DL	18.00	15.00	< DL	< DL	12	26	9	65.60	2.80	7.75	2.36	11.80	27.92	28.70
Lake Télé	06/19/ 1992	3.60	37.00	12.00	12.00	< DL	< DL	22.00	16.00	< DL	< DL	11	27	9	–	3.07	7.91	–	–	–	28.90
Bali kp5	06/14/ 1992	3.96	55.11	18.00	18.00	16.00	16.00	53.00	22.00	< DL	11.00	114	27	12	137.10	6.77	15.97	1.10	6.40	–	26.80
Likouala aux Herbes kp480	06/15/ 1992	4.02	46.15	15.00	15.00	10.00	18.00	43.00	17.00	< DL	10.00	120	37	23	133.20	5.68	16.58	0.90	5.90	–	26.60
Likouala aux Herbes kp45	06/24/ 1992	4.50	29.77	20.00	20.00	17.00	16.00	48.00	23.00	< DL	11.00	118	19	13	95.80	6.85	15.98	0.70	8.00	–	28.50
Mean rain water at Enyelle	1988–89	< DL	< DL	13.59	1.93	2.48	4.30	30.51	5.30	18.00	7.10	–	–	–	–	–	–	–	–	–	–
Mean rain water at Moloundou	1992	6.25	12.30	26.81	10.97	31.20	15.27	21.11	7.15	25.61	6.13	–	–	–	–	–	–	–	–	–	–
Rain water at Bonga	09/01/ 1993	6.39	27.13	31.00	5.00	< DL	7.00	11.00	7.00	45.00	13.00	< DL	–	–	–	6.21	6.21	–	–	–	–
Rain water at Bonga	09/25/ 1993	6.20	17.85	19.00	6.00	14.00	13.00	24.00	4.00	50.00	6.00	< DL	–	–	–	6.42	6.42	–	–	–	–
Rain water at Bonga	10/01/ 1993	6.06	13.56	10.00	5.00	< DL	6.00	13.00	3.00	15.00	4.00	< DL	–	–	–	2.68	2.68	–	–	–	–
Rain water at Bonga	10/09/ 1993	5.93	13.56	11.00	4.00	< DL	< DL	13.00	12.00	4.00	1.00	< DL	–	–	–	2.40	2.40	–	–	–	–
Lake Tumba	–	4.5–4.9	24–32	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	30.00	26–33
Lake Maï Ndombe	–	4.00	36.10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	29.00	28–30

Legend: kp = kilometric position. EC = Electrical conductivity in uS cm^{-1} at 25°C. DR (in mg l^{-1}) = $SiO_2 + Al_2O_3 + Fe_2O_3$ = dry residue. TDL = Total dissolved load. TDS = Total dissolved solids. CSM = Coarse suspended matter. FSM = Fine suspended matter. DOC = Dissolved organic carbon. Temp. = temperature. < DL = Below detectable limit. – = Data missing.

and acidified by passage under forest litter (presence of humic and fulvic acids) reach the lake via small north-eastern tributaries and by lateral spreading, to dilute into its liquid mass, coming essentially from meteoritic precipitations. When these waters reach the centre of the lake they are very dilute (lowest recording of electrical conductivity), then become progressively more charged as they approach the southwest bank by a rim effect, where they diffuse toward the Bali, across the flooded forest, following the tangle of small channels southwest of the lake (see Figs. 1, and 6). The natives say that here the currents always flow west (toward the Bali) and do not reverse during the course of the year as may often be observed in the channels of the ''*Cuvette*''. On the other hand, these small channels do dry up in the dry season, and their beds are then used as access paths by the Pygmies.

The important values of carbon in the Télé Lake are far higher than those noted by Seyler et al. (1995) in the forest waterways in the Central Congo Basin. These may be explained by the almost endoreic character of the lake, preventing the washing out of the organic components, which come from the slow soaking of the water in the swamps all around.

In terms of the chemistry of the rains in this part of the equatorial forest, the results of samples taken in 1988 and 1989 at Enyelle on the right bank of the Oubangui are to be found in the thesis of Lefeivre (1993), those from Moloundou near the Ngoko river taken in 1992 are in the thesis of Sigha Nkamdjou (1993), and some from Bonga at the outlet of the Sangha river were collected at the end of 1993 in the context of ORSTOM's Environment Intertropical Geosphere Program (PEGI's Program). These three localities form a triangle surrounding the region concerned in our study. The data confirm the very slight mineralization of the waters of the lake, close to that of the rainwater in the region, and the negligible quantities of H_4SiO_4 (12 μmoles l^{-1}), relative to levels ten times higher in the surface waters of the rest of the basin. This confirms the almost entirely vertical input predicted by water balance studies, with limited lateral ''oozings'', very low in dissolved minerals, since the underlying soil is ''protected'' by a blanketing layer of vegetation litter.

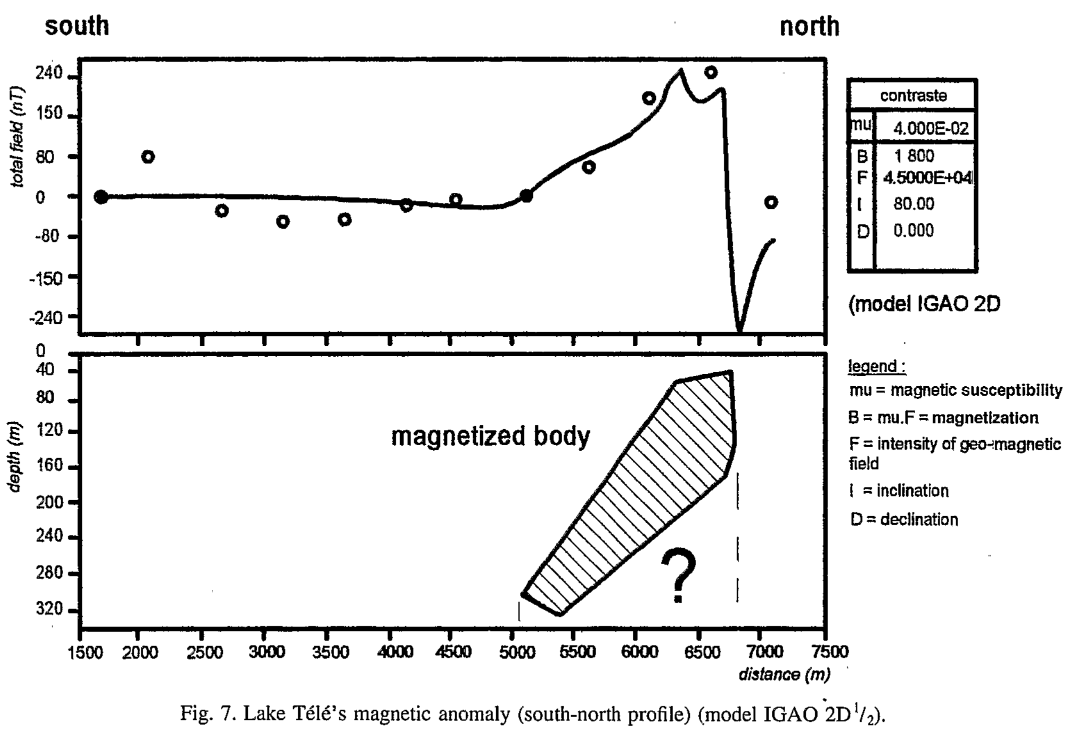

Fig. 7. Lake Télé's magnetic anomaly (south-north profile) (model IGAO 2D$^1/_2$).

4.5. Magnetometry

The west-east transect presents no notable magnetic anomaly. Thus, we will only consider the north-south transect composed of twelve points. Ten measurements were made at each point; they have been averaged, then smoothed.

The north-south transect (Fig. 7) does show an anomaly (difference between the observed values and the regional geomagnetic fields obtained at the Geophysics Observatory of the ORSTOM's Centre at Bangui) in the northern half of the lake. This can be interpreted by the presence of a magnetized body, the top of which would be less than 50 m from the surface. Note that a clearly positive anomaly, like that observed, is difficult to explain, at low latitudes, by a magnetized body in the current field (induced magnetization). The most plausible shape of this body, which may be compact or diffuse, would be within the limits of a polyhedron, as shown in Fig. 7, and proposed by the I.G.A.O $2D^1/_2$ model (Bouchard and Chouteau, 1993). This body with a magnetic susceptibility of 0.04 and a magnetic remanence of 1800 nT, was probably magnetized in a field of 45 000 nT, inclined at 80°. As a reminder, the current field is 33 200 nT and inclined at –24°. It is not possible by magnetism alone to conclude a meteoritic or intrusive origin of this lake based on the existing data. This is why one can imagine (as in Fig. 7) a body with an "infinite" downward extension and a susceptibility slightly weaker than that limited by the represented polygon, and that could just as well explain the magnetic anomaly observed. However, a volcanic origin for this magnetism seems unlikely, as there is no evidence that any such activity has ever been recorded in the sediments of the *Congolese Cuvette*. The closest volcanic mountains, in the Adamaoua Ridge in northern Cameroon extending to Mount Cameroon to the West, remain sufficiently distant that any possible influence can be ruled out. However, magnetic anomalies can be found on sedimentary geologic formations related to the placers of rivers (Schwarz and Wright, 1988). From this point of view, the Carnot formation, which underlies the Quaternary alluvial deposits of the "*Cuvette*" and which is of fluvial origin, possesses tiny quantities of magnetic materials. In addition, these are disseminated homogeneously throughout the series (Censier et al., 1992), which would argue against any localized magnetic anomaly.

4.6. Extraterrestrial component?

Usually, the identification of an impact crater is derived from the finding in the vicinity of the supposed crater of specific chemical or mineralogical traces characterizing the projectile material and the mechanical effects of the impact shock in the target rocks.

To test the idea of an impact origin, samples were taken at the top (1–2 cm below lake floor), in the middle (14–15 cm) and at the very bottom (24–29 cm) of one of the two core samples of lake sediment. We assumed that debris from the alleged projectile fell into the crater immediately after the collision and that material from the rim of the lake, assumed to represent the low distance ejecta, was subsequently eroded and deposites into the lake. If so, we can expect to find some extraterrestrial material, especially at the very bottom of the core which is expected to contain a fraction of the early fallout.

4.6.1. Method

Our investigation was limited to the search for iridium, an element especially abundant in meteoritic material. Analyses were carried out on bulk samples and on the magnetic fraction as most meteoritic debris, either in their original extraterrestrial configuration or after ablation and oxidation in the Earth's atmosphere, is highly magnetic. Iridium concentrations were measured by INAA.

4.6.1.1. Bulk samples. Samples about 100 mg each, housed and sealed in pure silica vials, were irradiated for 3–4 hours in the 2.10^{14} n $cm^{-2}.s^{-1}$ neutron beam of the Osiris reactor (Pierre Süe Laboratory, Saclay). Ir was counted with a γ-ray coincidence spectrometer (see Meyer (1987) and Meyer et al. (1993) for a description of the method) detecting the coincidence of 316–468 keV γ-ray lines resulting from the radioactive decay of ^{192}Ir. Two Ir standards are used: fragments ($\approx$0.050 mg) of the Negrillo iron meteorite (a very homogeneous meteorite calibrated in the CFR's laboratory[2]) and

[2] CFR = Centre des Faibles Radioactivités.

small pieces (≈0.2 mg) of an Ir–Al alloy with 5.2 ppm of Ir. The detection limit is around 20–30 pg g^{-1}.

4.6.1.2. Magnetic fraction. Meteoritic debris is strongly magnetic and can therefore be easily extracted from a liquid phase with a Frantz separator. Samples are finely ground and homogenized. Then, the organic fraction is removed using hydrogen peroxide. The residue is put in a closed-loop funnel activated by a peristaltic pump. Magnetic particles are collected in a glass tube placed in the gap of the magnetic separator. The system is run for 20–30 minutes to ensure that all magnetic particles are collected. The funnel is then rinsed with water. The magnetic separator is switched off and the particles held in the magnet gap are washed out with alcohol. They are recovered in a pure silica vial and irradiated for about 100 hours in the Osiris reactor. Ir is measured in the same way as in bulk samples.

4.6.2. Results and discussion

In the three samples analysed so far we have not found any Ir signal exceding the sensitivity limit of the instrument. The finding of a significant amount of Ir could have been considered as indicating an impact origin for the Télé lake. The absence of Ir leaves the problem open. In a sense this is not surprising if we consider the limited amount of available material. It is useful to remember that the great explosion of July 1908 in the Tunguska area left a very small amount of extraterrestrial matter. We are not even sure that the few cosmic grains found near the epicentre are relics of the 1908 explosion or from the permanent fall of micrometeorites (Jéhanno et al., 1989). Therefore, a more systematic collection of larger amounts of material is required before we can derive a reliable conclusion about the origin of this unusual circular lake.

4.7. Sedimentology

Three samples have been analysed by X-ray diffraction studies: the fine suspended matter (FSM) in the water (between 0.2 and 50 μm), and two levels (top and bottom surface) of one of the two core samples of lake sediment, which is black, relatively homogeneous, highly organic, and composed of many plant fibres, especially at the bottom of the sample.

This study shows that the suspended matter is made up essentially of kaolinite and interlayed clays that could have come from the degradation of smectites or illite. The diagrams from the two levels of the core sediments show large amounts of amorphous matter, which comes from the opal of freshwater sponges spicules. The clay-type minerals are the kaolinites, and probably the interlayed clays. At depth, one notes the more frequent presence of quartz, goethite, ilmenite and some magnetite. Magnifying glass inspection of the coarse fraction (>50 μm) of these two levels confirms the presence of numerous sponge spicules. This fraction also contains a very small amount of quartz but abundant quantities of silicified remains of vegetation, which, along with the opal of the sponge spicules could partly explain the low dissolved silica content in the water, due to biological consumption. It is difficult to explain the abundance of quartz, and the presence of goethite and titanium-containing minerals at depth in the sediments, solely on the basis of these three samples.

4.8. Present ecosystem and paleo-environment

4.8.1. Botanical observations

The hundreds of floral samples collected and observations made in situ (see Appendix A) allow us to situate the forest in the vicinity of Lake Télé within the totality of the forests of the Cameroono–Congolese sector (Moutsambote, 1992, Moutsambote et al., 1994) with typical taxa such as *Lophira alata*, *Diospyros crassiflora*, *Entandrophragma candallei* or *Uapaca heudelotti*, among many others. The current vegetation around the lake is composed of forests, some of which may be periodically flooded, and of floating prairies along waterways. The two main herbaceous taxa that dominate this characteristic prairie in its alluvial plain are *Jardinea congoensis* on flooded banks and *Hyparrhenia diplandra* on the unflooded areas. These *Gramineae* taxa can reach 2–3 m high. The floral succession identified during this mission has been classified according to the principle biotopes encountered, in Appendix A. The secondary vegetation, near the ancient and current villages of Boa, has been reconstituted naturally and rapidly after crop cultivation was abandoned.

On the periphery of the lake, the forest shows colonization dynamics and seems to be gradually "closing in" on the lake as if by a slow "healing" effect. The presence of pollens of the pioneer taxa such as *Macaranga* in the upper layers of the lake sediments, corresponds to this phenomenon.

4.8.2. Ratio carbon dating

The oldest carbon-14 (^{14}C) dating on one of the two samples is around 6650 ± 70 years BP, which suggests that this is the minimum age of this lake. Such an age, for a shallow depth of sediment would emphasize an extremely low sedimentation rate. This has been confirmed by low input of matter, especially particulate, at only one-sixth of the total contribution. This again supports the essentially vertical water inputs that we have evoked previously.

4.8.3. Study of δ^{13}c ratios

Measurements of the $\delta^{13}C$, undertaken on the three levels already mentioned (–29.34‰, –29.20‰, –28.20‰), correspond to typically forest-type C3 plants (means of –25‰, –26‰) and indicate a total absence of C4 (savanna)-type plants. This observation is strengthened by results of the palynological determinations.

4.8.4. Palynological analyses

Appendix B shows the succession of pollen taxa identified in the lake sediment core samples.

The well-preserved microflora (pollen and spores) ensures good representativity of each pollen. The pollen spectra suggest a forest environment on the site. Tree pollens (*Moraceae*, *Sapotaceae*, etc.) represent more than 90% of the total pollen. The remaining 10% is constituted by fern spores (approx. 5%) and mainly *Gramineae* (4%). Finally, the presence of the pollen of *Elaeis guineensis* (oil palm) shows human activity, visible in ancient village sites to the north-east of the lake.

It is clear that a marshy forest formation, as attested by the association of *Symphonia globulifera*, *Uapaca*, *Hallea* and *Santiria*, has always existed around and close to the site throughout the period covered by the pollen sequence. The abundance (in absolute value) of *Symphonia* pollen, which has the particularity of being very little transported, is consistent with this hypothesis. On the other hand, *Macaranga* is a pollen produced in great quantity and is well dispersed. Its abundant representation in the spectra is characteristic of a dynamics of conquest or forest recolonization. This pioneer element is usually related to the existence of man-induced or natural perturbations in the forest environment. The consistency in the presence of *Pandanus* along with *Alchornea* indicates the persistence of an aquatic, or at least strongly hydromorphic environment because these two taxa often develop on marshy or flooded banks. In terms of the *Gramineae* pollens, the savanna never developed here in the interval of time covered by this sequence, since a pollen spectrum characteristic of such an environment contains at least about 50% of *Gramineae* (Elenga, 1992).

These observations are in agreement with other known paleo-environmental data in other parts of the central African forested areas (Maley, 1996), showing the persistence of a rain forest ecosystem since the beginning of the Holocene period.

5. Comparison with other lake systems within the Congolese *Cuvette*

Two large bodies of water are found on the left bank of the Congo–Zaire River. Lake Tumba covers 765 km^2 and appears to have been created by the blocking of its outlet by sediments of the River Zaire, followed by flooding upstream. Lake Mai Ndombe (formerly Lake Leopold II) covers 2300 km^2, and outlets to the "Lukénie" to form the "Fimi" river which itself outlets to the Kassaï, a prime tributary to the Congo–Zaire river. Some information on these lakes (Dubois, 1959; Berg, 1961; Marlier, 1960) allows some interesting comparisons.

Despite their gigantic sizes, compared with that of Lake Télé, they deserve to be mentioned here because of their numerous common characteristics. Found in the same environment of forests and humid or dry grassy plains, locally called "ésobes", both lakes are very shallow (the first, 3 to 8 m and the second, 3 m deep) relative to their surface areas. To better appreciate these measurements on a "more human scale", Lake Mai Ndombe could be compared to a "film" of water 3 mm thick over a surface of 2.3 km^2!

Situated in the lowest zones of the Congolese Basin, the annual level of these giant "puddles", varies from 2 to 4 m probably closely interconnected to that of the alluvial water table, and always in direct relation to the major waterways that they feed into. Thus it may be observed that the two annual periods of high water of Lake Tumba are concurrent with those of the Congo–Zaire, and that the flood of the Lukénie engenders the high waters of Lake Mai Ndombe. However, it is not yet clear whether these lake high waters are caused by a "water dam" effect from the rivers in flood, thus preventing the outflow of the lakes' waters (Nicolaï, 1972), or a reverse flow into these lakes (Devroey, 1939), or some combination of both of these phenomena.

Exposed to the same vertical exchanges as Lake Télé (annual rainfall of 1600–1800 mm for an evaporation of 1300 mm), their waters are also brown and acidic (pH 4 to 5), little mineralized (24–32 $\mu S\ cm^{-1}$ to 25°C) and very rich in dissolved organic carbon (30 $mg\ l^{-1}$) (Burgis and Symoens, 1987) with temperatures always slightly higher (by 1 to 4°C) than those of neighboring waterways (Table 1).

All these lakes trap organic matter. The forest cover which predominates in the region and the slight topography limit the lateral contributions of matter essentially to the dissolved fraction and almost exclusively to the organic portion, which explains their common bio-geochemical characteristics (see Table 1).

6. Conclusion

Thanks to this first scientific information, this project to explore Lake Télé and its vicinity was able to establish a preliminary "scientific map" of this unusual ecosystem, which helps us to understand its functioning.

This immense elliptical body of water (3 m deep for a surface of 23 km^2 and a maximum water storage evaluated to $55.10^6\ m^3$) is situated in the heart of the dense Congolese equatorial forest. It is a humic ecosystem, acid (pH < 4), oligotrophic, extraordinarily rich in organic matter (44%) and very poorly mineralized (< 3 $mg\ l^{-1}$). These particularities are undoubtedly due to very flat regional surroundings (with little erosion) and an essentially vertical hydrological functioning, which give to the lake an almost endoreic character.

It is clear that such a highly hydromorphic environment has always existed in this region throughout the period covered by the sedimentary sequence studied, which concerns a good part of the Holocene period, when the lake probably appeared. This is suggested by the abundance of pollen of pioneer taxa such as *Symphonia* and *Pandanus*. The strong representation of *Macaranga* in the spectra, a species which pollenizes widely, emphasizes the dynamics of conquest and forest recolonization. This is also confirmed by the floral succession at the periphery of the lake and by the pollens identified in the present-day muddy deposits.

Lake Télé could simply represent the gradual filling of a somewhat deeper part of the immense marshy zone of the *Congolese Cuvette*, but the mystery of its paleo-magnetization remains undiminished. Therefore, to explain this magnetic anomaly, this study presents two possibilities for the origin of the Lake Télé. A magmatic intrusion or a meteoritic impact. This second hypothesis would need to be validated by the detection of some cosmic matter (iridium) in the lake's sediments. This is the direction we think future researchers should take in this region as soon as access by scientific expeditions again become possible.

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Appendix A. Plants identified in the Likouala aux Herbes watershed basin

Ecosystem	Vegetation
Gallery forest	*Uapaca heudelotti, Parinari congensis, Syzygium giorgii, Xylopia rubescens*
Forest islands	*Lophira alata, Piptadeniastrum africanum, Pycnanthus mechowianus, Ceiba pentandra.*
Marshy forests	*Mitragyna stipulosa, Alstonia boonei, Nauclea pobeguinii, Uapaca guineensis, Uapaca heudelotii, Macaranga schweinfurthii, Xylopia rubescens, Coelocaryon botryoides*
Flooded gallery forests	*Gilbertiodendron dewevrei, Klainedoxa gabonensis, Lophira alata, Diospyros dendo, Diospyros* sp., *Thomandersia laurifolia, Pericopsis elata*
Heterogenous land forests	*Entandrophragma* sp., *Terminalia superba, Pterocarpus soyauxii, Piptadeniastra africanum, Pycananthus mechowianus, Lophira alata, Staudtia gabonensis, Autranella congolensis, Klainedoxa gabonensis, Irvingia gabonensis, Dacryodes pubescens, Manilkara* sp.
Periodically flooded savannas	*Hyparrhenia diplandra, Panicum maximum* and *Loudetia restioidea, Clappertonia ficicolia, Stipularia africana*
Aquatic floating prairies	*Jardinea congoensis, Nymphaea lotus*

Appendix B. Palynological study of the sedimentary core sample from Lake Télé

Absolute values and percentages of pollen taxa identified and classified by ecosystem.

Ecosystems	Taxons polliniques (Family, genus, species)	Level A (0–1 cm)	%	Level B (14–15 cm)	%	Level C (28–29 cm)	%
Flooded forests	*Burseraceae Santiria*	12	4.78	2	0.79	0	0.00
	Euphorbiaceae Plagiostyles	0	0.00	1	0.40	0	0.00
	Euphorbiaceae Uapaca	19	7.57	4	1.59	21	7.81
	Guttiferae Symphonia globulifera	37	14.74	5	1.98	14	5.20
	Rubiaceae Hallea	18	7.17	2	0.79	6	2.23
	total	86	34.26	14	5.56	41	15.24
Open marshy areas	*Euphorbiaceae Alchornea*	6	2.39	5	1.98	13	4.83
	Cyperaceae	0	0.00	5	1.98	0	0.00
	Pandanaceae Pandanus	7	2.79	30	11.90	10	3.72
	Pteridophytae	12	4.78	3	1.19	3	1.12
	total	25	9.96	43	17.06	26	9.67
Forest areas	*Agavaceae Dracaena*	1	0.40	0	0.00	2	0.74
	Apocynaceae	1	0.40	0	0.00	0	0.00
	Balanitaceae Balanites	0	0.00	0	0.00	4	1.49
	Caesalpiniaceae Dialium	4	1.59	0	0.00	2	0.74
	Caesalpiniaceae Guibourtia	7	2.79	0	0.00	3	1.12
	Combretaceae	21	8.37	2	0.79	10	3.72
	Dilleniaceae Tetracera	0	0.00	14	5.56	1	0.37
	Ebenaceae Diospyros	0	0.00	0	0.00	1	0.37
	Euphorbiaceae Antidesma	0	0.00	0	0.00	3	1.12
	Euphorbiaceae Cleistanthus	2	0.80	1	0.40	0	0.00
	Euphorbiaceae Croton	0	0.00	2	0.79	4	1.49
	Euphorbiaceae Martretia	2	0.80	0	0.00	0	0.00
	Euphorbiaceae Tetrorchidium congolense	1	0.40	0	0.00	0	0.00
	Loranthaceae Tapinanthus	0	0.00	1	0.40	0	0.00
	Meliaceae Carapa procera	5	1.99	15	5.95	8	2.97
	Moraceae	2	0.80	0	0.00	0	0.00
	Myristicaceae Pycnanthus angolense	5	1.99	2	0.79	1	0.37
	Olacaceae Heisterial Strombosia	4	1.59	0	0.00	1	0.37
	Rubiaceae Canthium	1	0.40	0	0.00	0	0.00
	Rubiaceae Pausynistalia	0	0.00	1	0.40	2	0.74

Ecosystems	Taxons polliniques (Family, genus, species)	Level A		Level B		Level C	
		(0–1 cm)	%	(14–15 cm)	%	(28–29 cm)	%
	Rubicaeae Aidia	1	0.40	0	0.00	3	1.12
	Rutaceae Fagara	2	0.80	14	5.56	1	0.37
	Sapindaceae Allophylus	1	0.40	2	0.79	1	0.37
	Sapotaceae	6	2.39	9	3.57	5	1.86
	Tiliaceae Grewia	1	0.40	3	1.19	0	0.00
	Ulmaceae Celtis	3	1.20	1	0.40	1	0.37
	total	70	27.89	67	26.59	53	19.70
Pioneers taxa	*Euphorbiaceae Alchornea*	6	2.39	5	1.98	13	4.83
	Euphorbiaceae Macaranga	42	16.73	119	47.22	126	46.84
	total	48	19.12	124	49.21	139	51.67
Anthropogenic taxa	*Arecaceae Elaeis guineensis*	10	3.98	0	0.00	0	0.00
	Arecaceae Raphia	0	0.00	2	0.79	2	0.74
	total	10	3.98	2	0.79	2	0.74
Herbaceous lowland	*Alismataceae*	0	0.00	2	0.79	2	0.74
	Gramineae	10	3.98	0	0.00	5	1.86
	Urticaeae	2	0.80	0	0.00	1	0.37
	total	12	4.78	2	0.79	8	2.97
total		251	100.00	252	100.00	269	100.00

References

Agnagna, M. (1983). Results of the first Congolese Mokélé-Mbembé expedition, Field Report. Interdisciplinary Journal of the International Society of Cryptology 2, 103–112.

Berg, A., 1961. Rôle écologique des eaux de la Cuvette congolaise sur la croissance de la jacinthe d'eau, Eichhornia crassipes (Mart.) Solms. Mém. Acad. Roy. Sc. Outre-mer, Cl. Sc. Nat. Med., Coll. in octavo n.s. 12(3), 120 p.

Bouchard, K., Chouteau, M., 1993. Modélisation et interprétation gravimétrique et magnétométrique-manuel de l'utilisateur. Dépt. de Génie Minéral et Géophysique, Institut Polytechnique de Montréal, 44 pp.

Bultot, F., 1971. Atlas climatique du bassin congolais-les composantes du bilan de l'eau-t.2-I.N.E.A.C., Brussels.

Bultot, F., 1972. Atlas climatique du bassin congolais-Température et humidité de l'air, rosée, température du sol-t.3-I.N.E.A.C., Brussels.

Burgis, M.J., Symoens, J.J., 1987. African wetlands and shallow water bodies-Zones humides et lacs peu profonds d'Afrique, Ed ORSTOM, Paris, 650 pp.

Censier, C., Boukeke, D., Perichon, P., Albouy, Y., 1992. Mise en évidence de corps d'origine cosmique probable au sein de la formation de Carnot (République Centrafricaine). Journal of African Earth Sciences 15(1), 91–102.

Censier, C., Pouyaud, B., Laraque, A., Maziezoula, B., 1995. Dynamique actuelle des sables de la Likouala aux herbes: implications sur la paléohydrographie du bassin inférieur de la Sangha (République du Congo). Actues du Colloque PEGI: Grands Bassins Fluviaux Péri-Atlantique: Congo, Niger, Amazone-(INSU-CNRS-ORSTOM), Paris, France, du 24 au 24 novembre, pp. 239–248.

C.E.R.G.E.C., 1990. République populaire du Congo-carte au 1/1 000 000. C.E.R.G.E.C., Brazzaville, IGN, Paris.

Devroey, E., 1939. Le Kassaï et son bassin hydrographique. Goemaere, Brussels, 334 pp.

Dubois, J.T., 1959. Note sur la chimie des eaux du lac Tumba. Bull. Séances Acad. Roy. Sc. Outre-mer, n.s 5(6), 1321–1334.

Elenga, H., 1992. Végétation et climat du Congo depuis 24 000 ans BP. Analyse palynologique de séquences sédimentaires du pays Batéké et du littoral. Thèse, Univ. Aix Marseille III, 237 pp.

Grandin, J., 1976. Carte bathymétrique du lac Télé au 1/40 000. Laboratoire d'Hydrologie-Centre ORSTOM de Brazzaville, Congo.

Heuvelmans, B., 1980. Les derniers dragons d'Afrique, Plon, Paris, 512 pp.

I.G.N., 1963a. Carte d'Afrique Centrale au 1/200 000, Impfondo-République du Congo, feuille NA-33 XII-34-VII, Ins. Géog. Nat. Paris (Annexe de Brazzaville).

I.G.N., 1963b. Carte d'Afrique Centrale au 1/200 000, Ouesso-République du Congo, feuille NA-33 XI, Ins. Géog. Nat. Paris (Annexe de Brazzaville).

I.S.C., 1986. Mokélé-Mbembé: new searches, new claims. The International Society of Cryptozoology Newsletter 5(3) 7.

Jéhanno, C., Boclet, D., Danon, J., Robin, E., Rocchia, R., 1989. Etude analytique de sphérules provenant du site de l'explosion de la Toungouska. C.R. Acad. Sci. Paris 308(II), 1589–1595.

Laraque, A., Maziezoula, B., 1995. Banque de données hydrologiques des affluents congolais du fleuve Congo-Zaïre et informations physiographiques. Programme PEGI/GBF, volet Congo-UR22/DEC, lab. Hydrologie, ORSTOM, Montpellier, 150 p.

Lefeivre, B., 1993. Etude expérimentale et par modélisation des caractéristiques physiques et chimiques des précipitations collectées en forêt équatoriale Africaine. Thèse de doctorat, Université de Paul Sabatier, Toulouse, France, 308 p.

Mackal, R.P., Greenwell, J.R., Wilkinson, M.J., 1982. The search for evidence of Mokélé-Mbembé in the People's Republic of the Congo. Cryptozoology 1, 62–72.

Maley, J., 1996. Le cadre paléoenvironnemental des refuges forestiers africains: quelques données et hypothèses. In: van der Maesen J.J.G. (Ed.), The biodiversity of African plants. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 519–535.

Marlier, G., 1960. Rapport sur le lac Tumba. In: Third symposium on hydrobiology and inland fisheries. Problems of major lakes, Publ. C.S.A. 63, Lusaka, pp. 75–80.

Meyer, G., 1987. Multiparameter coincidence spectrometry applied to the instrumental neutron activation analysis of rocks and minerals. J. Radioanal. Nucl. Chem. 114, 223–230.
Meyer, G., Piccot, D., Rocchia, R., Toutain, J.P., 1993. Simultaneous determination of Ir and Se in K-T boundary clays and volcanic sublimates. J. Radioanal. Nucl. Chem. 168, 125–131.
Moutsambote, J.M., 1992. Rapport de mission botanique effectuée au lac Télé (district d'Epéna, Likouala) 08–27 juin 1992. Laboratoire de Botanique, CERVE, Brazzaville, Congo, 6 pp.
Moutsambote, J.M., Yumoto, T., Mitani, M., Nishihara, T., Suzuki, S., Kuroda, S., 1994. Vegetation and list of Plants Species Identified in the Nouabalé-Ndoki Forest, Congo. In: Floral Lists from Five Study Sites of Apes in the African Tropical Forests. Tropics, vol. 3, No. 3/4), Kagoshima, Japan, The Japan Society of Tropical Ecology, pp. 277–293.
Nicolaï, H., 1972. Les destinées d'un pays équatorial. Le lac Léopold II. In: Etudes de géographie tropicale offertes à Pierre Gourou, Mouton, Paris, pp. 357–370.
Pouyaud, B., 1970. La Likouala aux Herbes à Epéna et à Boutouali. ORSTOM Centre de Brazzaville, 37 pp.
Pouyaud, B., 1992. Rapport de mission d'accès au lac Télé (nord Congo) en juin 1992. Rapport interne-ORSTOM-DEC-Paris, 5 p.
Regusters, H.A., 1982. Mokélé-Mbembé-An Investigation into Rumors Concerning a Strange Animal in the Republic of the Congo, 1981. Munger African Library Notes 12(64), 1–27.
Samba-Kimbata, M.J., 1991. Précipitations et bilans de l'eau dans le bassin forestier du Congo et ses marges. Thèse de doctorat, Univ. de Bourgogne, 241 pp.
Schwarz, E.J., Wright, N., 1988. The detection of buried placer deposits by ground magnetic survey. Geophysical Prospecting 36, 319–932.
Sciences et Vie, 1981. La chasse au Mokélé Mbembé du Congo... et le diplodocus du lac Champlain. rub. paléontologie 768, 54.
S.G.A.E.F., 1949. Croquis provisoire de l'A.E.F. Cameroun au 1/1 000 000, Ouesso-feuille No. 906a, Cameroun.
Seyler, P., Hetcheber, H., Orange, D., Laraque, A., Sigha-Nkamdjou, L., Olivry, J.C., 1995. Concentrations, fluctuations saisonniéres et flux de carbone dans le bassin du Congo. Actes du Colloque PEGI: Grands Bassins Fluviaux Péri-Atlantique: Congo, Niger, Amazone-(INSU-CNRS-ORSTOM), Paris, France, du 24 au 24 novembre, pp. 217–228.
Sigha Nkamdjou, L., 1993. Caractérisation et fonctionnement hydrochimique d'un bassin en milieu forestier équatorial humide, l'exemple de la Ngoko à Moloundou (sud est du Cameroun). Thèse de doctorat, Univ. Paris Sud. ORSTOM/MINREST, Montpellier/Yaoundé, 378 pp.

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