

## GEOCHEMICAL BEHAVIOUR OF SILICA AND MAGNESIUM DURING THE EVAPORATION OF WATERS IN CHAD

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### ABSTRACT

Gac, J.Y., Droubi, A., Fritz, B. and Tardy, Y., 1977. Geochemical behaviour of silica and magnesium during the evaporation of waters in Chad. *Chem. Geol.*, 19: 215–228.

In the Lake Chad system, most of the strongly evaporated waters yield high concentrations in  $\text{HCO}_3^-$ — $\text{CO}_3$  and Na, but very low concentrations in Ca and Mg. An experimental evaporation of the diluted original water has shown a Ca depletion due to calcite precipitation and a Mg depletion due to a Mg-silicate formation. The geochemical balance of Mg in the Lake Chad system is discussed.

### INTRODUCTION

Lake Chad is located in a closed continental basin and submitted to an arid climate. This climate is characterized by a mean annual temperature of 28°C, a rainfall of 300 mm/year and a very high evaporation of 2,200 mm/year. Two main rivers, the Chari and the Logone, flowing from the south, bring diluted waters resulting from granitic rock weathering under a humid tropical climate into the lake. In the north, the lake is limited by a fossil erg, forming small depressions between the sand dune alignments, where waters concentrate by evaporation. The waters flowing into the lake contain less than 100 mg/l of dissolved material in which Ca and  $\text{HCO}_3^-$  are the dominant ions (Gac and Pinta, 1973). These waters are progressively concentrated by evaporation from the delta to the interdunal depressions where the salinities can be very high (more than 200 g/l of dissolved material). These waters are chiefly enriched in Na,  $\text{CO}_3$  and  $\text{HCO}_3^-$ ; they are strongly depleted in Ca and Mg (Cheverry, 1974; Maglione, 1974; Roche, 1974). Ca depletion is due to calcite precipitation which occurs in lake-bottom sediments as well as in soils of the edges of interdunal depressions. In the central part of these depressions, abundant salt precipitations were recognized: gaylussite, natron, trona, magadiite, kenyaite, halite, kanemite, mordenite, thenardite, mirabilite and gypsum (Cheverry, 1974;

TABLE I

Chemical composition of evaporated water at different concentration factors (mequiv./l)

Water No.	Concentration factor	pH	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>2-</sup>	Alc.	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Σ <sup>-</sup>	Σ <sup>+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SiO <sub>2</sub> (mg/l)	log pCO <sub>2</sub>	Ionic strength
1	1.0	7.6	0.792	<0.01	0.792	0.025	0.014	0.831	0.842	0.177	0.050	0.340	0.275	20.2	-2.90	0.001
2	1.7	8.15	1.347	0.018	1.365	0.043	0.023	1.431	1.417	0.306	0.085	0.606	0.420	26.5	-3.21	0.002
3	1.9	8.45	1.461	0.039	1.500	0.045	0.025	1.570	1.575	0.320	0.090	0.703	0.462	38.0	-3.47	0.002
4	2	8.6	1.541	0.059	1.600	0.051	0.030	1.681	1.697	0.370	0.102	0.768	0.457	39.0	-3.59	0.0023
5	2.2	8.6	1.637	0.063	1.700	0.055	0.032	1.787	1.837	0.400	0.112	0.850	0.475	43.0	-3.57	0.0024
6	2.4	8.5	1.796	0.054	1.850	0.066	0.037	1.953	2.022	0.470	0.132	0.913	0.507	45.5	-3.43	0.0026
7	2.5	8.35	1.738	0.037	1.775	0.068	0.038	1.881	1.883	0.483	0.138	0.900	0.362	45.7	-3.29	0.0025
8	2.7	9.0	1.597	0.153	1.750	0.069	0.040	1.859	?	0.505	0.141	1.020	?	49.0	-	-
9	2.85	9.3	1.444	0.276	1.720	0.072	0.041	1.833	1.934	0.515	0.148	0.956	0.315	47.5	-4.32	0.0025
10	2.97	9.4	1.193	0.287	1.480	0.077	0.043	1.600	1.718	0.555	0.155	0.848	0.160	48.0	-4.51	0.0021
11	3.0	9.2	1.355	0.205	1.560	0.080	0.045	1.685	1.673	0.565	0.155	0.820	0.133	47.5	-4.25	0.0022
12	4.0	8.9	1.682	0.128	1.810	0.109	0.062	1.981	2.024	0.790	0.224	0.920	0.090	62.5	-3.86	0.0025
13	5.0	8.8	1.777	0.107	1.884	0.129	0.072	2.085	2.139	0.910	0.257	0.880	0.092	64.5	-3.74	0.0026
14	7.0	8.8	2.018	0.122	2.140	0.191	0.107	2.438	2.445	1.365	0.380	0.630	0.070	68.0	-3.68	0.0028
15	8.8	8.8	2.282	0.138	2.420	0.229	0.130	2.779	2.754	1.646	0.468	0.580	0.060	81.0	-3.63	0.0032
16	10.2	8.8	2.612	0.158	2.770	0.282	0.160	3.212	3.197	2.015	0.562	0.550	0.070	116.5	-3.57	0.004
17	11.8	8.95	2.930	0.250	3.180	0.316	0.174	3.670	3.588	2.224	0.631	0.678	0.055	122.5	-3.67	0.0042
18	13.6	8.8	2.848	0.172	3.020	0.338	0.191	3.54	3.549	2.418	0.676	0.455	<0.01	147.5	-3.53	0.0039
19	15.0	8.5	3.149	0.096	3.245	0.371	0.210	3.82	3.826	2.650	0.758	0.418	0.07	156.5	-3.19	0.0042
20	17.2	8.25	3.584	0.061	3.645	0.436	0.243	4.32	4.324	3.06	0.871	0.393	0.07	170.0	-2.88	0.0046
21	19.6	8.20	4.103	0.064	4.167	0.501	0.282	4.95	4.950	3.56	1.023	0.367	<0.01	187.5	-2.77	0.0053
22	22.2	8.65	4.356	0.186	4.542	0.549	0.305	5.39	5.396	3.875	1.096	0.425	<0.01	185.0	-3.20	0.0058
23	25.6	8.70	4.927	0.236	5.163	0.645	0.355	6.16	6.163	4.475	1.288	0.400	<0.01	200.0	-3.20	0.0066
24	30.0	8.90	5.803	0.441	6.244	0.776	0.436	7.45	7.456	5.537	1.549	0.370	<0.01	207.5	-3.33	0.008
25	33.7	9.10	6.158	0.742	6.900	0.832	0.468	8.200	7.943	5.885	1.698	0.360	<0.01	200.0	-3.50	0.009
26	35.5	9.10	6.515	0.785	7.300	0.891	0.501	8.692	8.399	6.285	1.819	0.295	<0.01	200.0	-3.48	0.0095
27	40.3	9.30	6.574	1.256	7.830	1.023	0.562	9.415	9.451	7.160	2.041	0.250	<0.01	210.0	-3.68	0.01

Maglione, 1974). These salts are mostly Ca- and Na-rich carbonates, sulfates and silicates. Mg-salts were not found and calcite contains only 2–4 mole% fraction of magnesite (Cheverry, 1974).

Mg-rich montmorillonite was found locally in highly saline environments, and it was supposed that montmorillonite formation controls the Mg concentration in the lake system (Tardy et al., 1974; Carmouze, 1976). This is also suggested by the results of an experimental evaporation of the diluted water of the Chari River.

#### EXPERIMENTAL EVAPORATION OF THE CHARI RIVER WATERS

An experimental evaporation of Chari River water was realized at N'Djamena (capital of Chad) as follows. During the long dry season, 7,500 l of water, including the suspended materials, were collected from the Chari and submitted to atmospheric evaporation in a series of metallic vats. The evaporation rate of about 6 mm/day on a total surface of 10 m<sup>2</sup> allowed an evaporation of about 60 l/day. During the first 85 days original diluted water was added in order to maintain the same level in the vats and to permit a continuous sampling for analyses. After that time, no more water was added and sampling was performed every 4 or 5 days, during a period of about six months. Concentration factors were calculated taking into account the addition of diluted water and sampling for analyses.

#### *Evolution of the chemical composition of the solution*

Chemical analyses were performed for alkalinity, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, SiO<sub>2</sub>, pH and conductivity. They are reported in Table I and in Fig. 1,

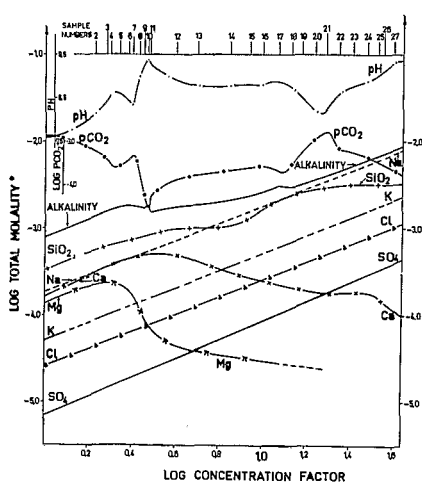


Fig. 1. Experimental evaporation of Chari River water.

as a function of calculated concentration factor.  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  were not analyzed but calculated from the direct measurement of alkalinity and pH, taking into account the ionic strength and complex ions according to the procedure described below. From the results it can be shown that, at the beginning of the experiment, all of the concentrations increase linearly with the concentration factor. For a concentration factor of about 3, Mg concentration decreases, and the shape of the silica line changes. For a concentration factor of about 5 or 6, Ca concentration decreases and alkalinity and pH are affected. The decreasing of Ca is interpreted as calcite precipitation, and Mg depletion as a Mg-silicate formation.

#### *Mineralogical and chemical data on solid phases*

X-ray diffraction analyses were performed for different size fractions of solid materials involved in this experiment. Fig. 2 shows the results for the  $< 2 \mu\text{m}$  fraction. The suspended material originally carried with Chari River waters yields quartz, kaolinite, illite and small amounts of goethite and montmorillonite. Probable dust contamination, in spite of precautions taken for avoiding it, may have influenced the mineralogical composition of the analyzed material. Dust contains essentially quartz, kaolinite feldspars, illite and occasionally small amounts of montmorillonite. After the evaporation experiment

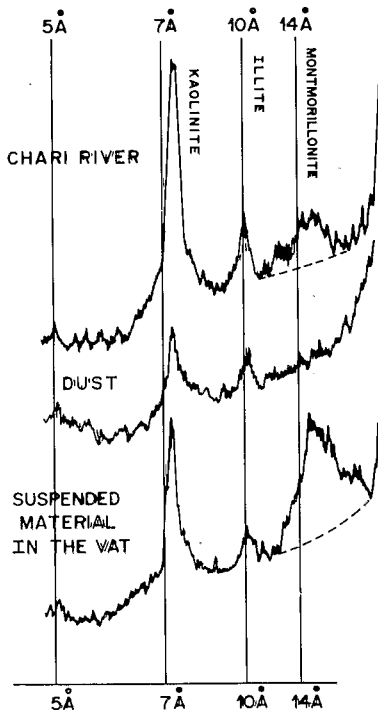


Fig. 2. X-ray diagrams of  $< 2 \mu\text{m}$  fraction of the material involved.

the final calcite, montmorillonite and amorphous silica (detected by a broad reflection at 4 Å) values were measured in addition to quartz, kaolinite and illite. Thus, montmorillonite seems more abundant (Fig. 2) in the  $< 2 \mu\text{m}$  fraction of the final suspended material in experimental vats than it is in the Chari River or in the fine fraction of the dust. Therefore, mineralogical analyses are not quantitative and the formation of montmorillonite cannot be proved definitely.

Separation between the original suspended material and that precipitated during the experiment was attempted. In the precipitates, calcite was perfectly recognized but no magnesian mineral was found. Therefore a chemical analysis of this precipitated material has shown qualitatively that Mg and silica are present in about the same proportions. Furthermore, no sepiolite, dolomite, magnesite, hydromagnesite or nesquehonite were found. The X-ray pattern of calcite shows that the mole fraction of  $\text{MgCO}_3$  does not exceed 3% (peaks at 3.03, 2.49, 2.28, 1.91 and 1.87 Å). It seems that Mg is not trapped in a carbonate phase. It may be included in montmorillonite or in some amorphous silicate as suggested by the results discussed in the next paragraph.

#### *Mass balances for magnesium and silica*

During the progressive evaporation of water, Na increases proportionally with the concentration factor. The molar ratio Na/Ca remains at a constant value and increases beyond a concentration factor of 2.9 (water 9) which corresponds to calcite precipitation. The ratios Na/Mg and Na/Si increase progressively beyond a concentration factor of about 1.9 (water 3). The beginning of Mg depletion corresponds to a variation of the slope of silica and pH curves. This suggests the precipitation of a magnesian silicate (Table II).

The molar ratio of the total silica to the total Mg precipitated varies significantly (column 4, Table II). At the beginning, for a concentration factor of 2.5, this ratio is about equal to 0.5 (water 7). It increases progressively and reaches the value of 1.3 for a concentration of 20 (water 21). Incidentally the ratio of 1.3 is approximately equal to 4/3 as it is in talc:  $\text{Si}_4\text{Mg}_3\text{O}_{10}(\text{OH})_2$ .

#### THERMODYNAMIC MODEL AND CALCULATIONS

##### *Saturation tests*

Saturation points of solution with respect to minerals were tested. The aqueous species distribution in the different waters was calculated with a computer program DISSOL, which is a transformed version of Helgeson's PATH CALC (Helgeson, 1968; Helgeson et al., 1969) and similar to WATEQ described by Truesdell and Jones (1974).

Ionic strengths, activity coefficients, ion activities, distribution of complex species and equivalent  $p\text{CO}_2$  were calculated for all the waters analyzed (Table I). The dissociation constants are these of Helgeson (1969), Kharaka and Barnes

TABLE II

Molar ratios of sodium to calcium, magnesium and silica in waters

Water No.	Molar ratio			
	Na <sup>+</sup> /Ca <sup>2+</sup>	Na <sup>+</sup> /Mg <sup>2+</sup>	Na <sup>+</sup> /SiO <sub>2</sub>	SiO <sub>2</sub> /Mg <sup>2+</sup> *
1	1.04	1.29	0.52	—
2	1.01	1.45	0.69	—
3	0.91	1.39	0.51	—
4	0.96	1.62	0.57	0.40
5	0.94	1.68	0.56	0.40
6	1.03	1.86	0.62	0.6
7	1.07	2.66	0.64	0.49
9	1.08	3.27	0.65	0.72
10	1.31	6.94	0.70	0.61
11	1.38	8.56	0.74	0.63
12	1.72	17.56	0.76	0.60
13	2.07	19.78	0.85	0.95
14	4.33	39.00	1.21	1.33
15	5.67	54.86	1.22	1.36
16	7.46	57.57	1.04	1.10
17	6.56	82.37	1.10	1.21
19	6.35	67.95	1.02	1.18
20	7.80	82.70	1.08	1.25
21	9.98	237.33	1.14	1.29

\* Silica and magnesium consumed by precipitation.

(1973), and Truesdell and Jones (1974). As an example, results of calculation are given in Table III, for water 15.

Solution saturations with respect to talc, magnesite, hydromagnesite, nesquehonite and calcite were tested and points representing different waters are plotted on activity diagrams (Figs. 3 and 4). At 25°C, the constants used are:

talc:	$\log K_{sp} = 4 \log [H_4SiO_4] + 3 \log [Mg^{2+}]/[H^+]^2$ = + 22.12 (Bricker et al., 1973)
magnesite:	$\log K_{sp} = \log [Mg^{2+}]/[H^+]^2 + \log pCO_2$ = + 10.09 (Helgeson, 1969)
calcite:	$\log K_{sp} = \log [Ca^{2+}]/[H^+]^2 + \log pCO_2$ = + 9.76 (Helgeson, 1969)
nesquehonite:	$\log K_{sp} = \log [Mg^{2+}]/[H^+]^2 + \log pCO_2$ = + 13.14 (Truesdell and Jones, 1974)
hydromagnesite:	$\log K_{sp} = 5 \log [Mg^{2+}]/[H^+]^2 + 4 \log pCO_2$ = + 63.76 (Truesdell and Jones, 1974)

TABLE III

Simple and complex aqueous species in water 15

Aqueous species	$K^+$	$KCl^0$	$KSO_4^-$	$Na^+$	$NaCl^0$	$NaSO_4^-$	$NaCO_3^-$	$Ca^{2+}$	$CaCO_3^0$	$CaHCO_3^+$	$CaSO_4^0$
Molality	$0.46 \cdot 10^{-3}$	$0.94 \cdot 10^{-9}$	$0.16 \cdot 10^{-6}$	$0.17 \cdot 10^{-2}$	$0.49 \cdot 10^{-7}$	$0.96 \cdot 10^{-6}$	$0.22 \cdot 10^{-5}$	$0.26 \cdot 10^{-2}$	$0.22 \cdot 10^{-4}$	$0.89 \cdot 10^{-5}$	$0.2 \cdot 10^{-5}$
Activity	$0.44 \cdot 10^{-3}$	$0.95 \cdot 10^{-9}$	$0.15 \cdot 10^{-6}$	$0.16 \cdot 10^{-2}$	$0.5 \cdot 10^{-7}$	$0.91 \cdot 10^{-6}$	$0.21 \cdot 10^{-5}$	$0.20 \cdot 10^{-3}$	$0.22 \cdot 10^{-4}$	$0.84 \cdot 10^{-5}$	$0.2 \cdot 10^{-5}$
Activity coefficient	0.93	1.00	0.93	0.94	1.00	0.94	0.94	0.78	1.00	0.94	1.00
Aqueous species	$Mg^{2+}$	$MgCO_3^0$	$MgSO_4^0$	$MgHCO_3^+$	$HCO_3^-$	$CO_3^{2-}$	$H_2CO_3$	$SO_4^{2-}$	$Cl^-$	$H_4SiO_4$	$H_3SiO_4^-$
Molality	$0.25 \cdot 10^{-4}$	$0.36 \cdot 10^{-5}$	$0.2 \cdot 10^{-6}$	$0.4 \cdot 10^{-6}$	$0.21 \cdot 10^{-2}$	$0.76 \cdot 10^{-4}$	$0.81 \cdot 10^{-5}$	$0.62 \cdot 10^{-4}$	$0.23 \cdot 10^{-3}$	$0.12 \cdot 10^{-2}$	$0.2 \cdot 10^{-3}$
Activity	$0.20 \cdot 10^{-4}$	$0.36 \cdot 10^{-5}$	$0.17 \cdot 10^{-6}$	$0.37 \cdot 10^{-6}$	$0.19 \cdot 10^{-2}$	$0.6 \cdot 10^{-4}$	$0.81 \cdot 10^{-5}$	$0.48 \cdot 10^{-4}$	$0.22 \cdot 10^{-3}$	$0.12 \cdot 10^{-2}$	$0.16 \cdot 10^{-3}$
Activity coefficient	0.79	1.00	1.00	0.94	0.94	0.78	1.00	0.78	0.93	1.00	0.94

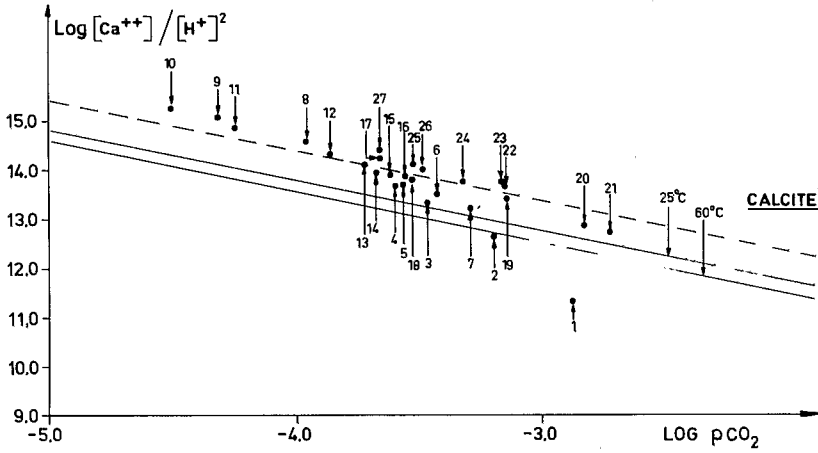


Fig. 3. Saturation with respect to calcite.

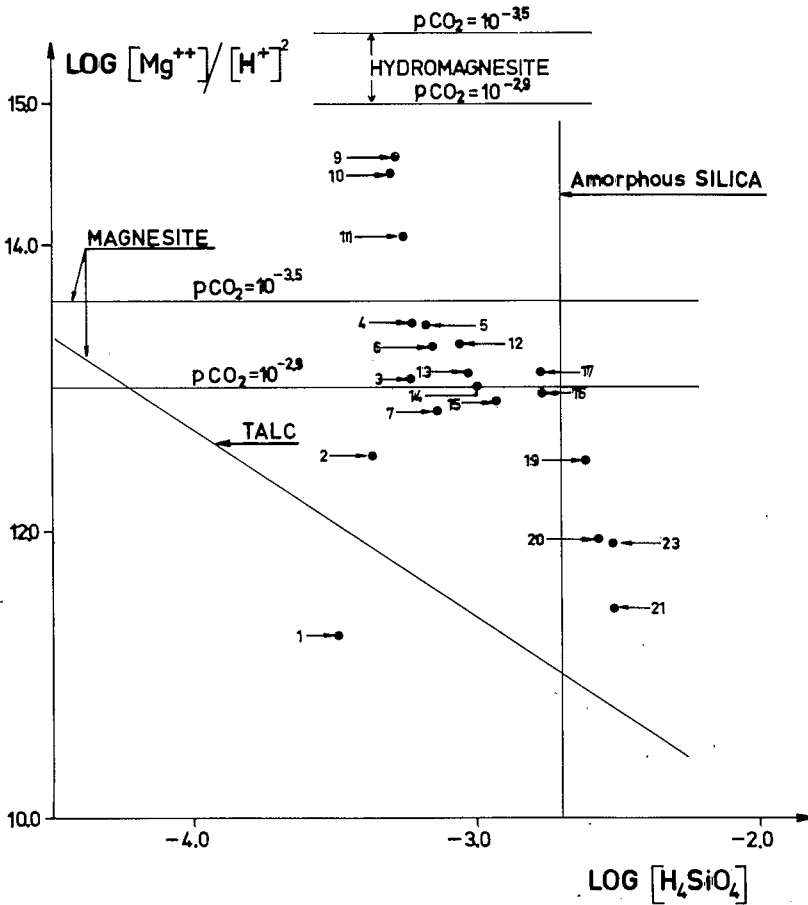


Fig. 4. Saturation with respect to magnesite, hydromagnesite, talc and amorphous silica at 25°C.



In Fig. 3, the points representing the waters (except 1 and 2) fit quite well the saturation straight line of a highly soluble calcite ( $\log K_{sp} = -7.78$  at  $25^\circ\text{C}$ ). Fig. 4 does not show any good trend. The waters all appear oversaturated with respect to talc and undersaturated with respect to hydromagnesite and nesquehonite. Most of them are almost at saturation with respect to magnesite for  $p\text{CO}_2 = 10^{-2.9}$  or  $10^{-3.5}$  atm. Furthermore, waters 19–21 and 23 are oversaturated with respect to amorphous silica.

The calculated  $p\text{CO}_2$  are plotted in Fig. 1. The data show that the initial Chari water is equilibrated with  $p\text{CO}_2 = 10^{-2.9}$  atm. and that the evaporated waters become equilibrated with atmosphere ( $p\text{CO}_2 = 10^{-3.5}$  atm.) after about two months for a concentration factor of about 3.3 (water 4).

### *Simulation of evaporation*

Another computer program, called EVAPOR, simulates, on the model described by Garrels and Mackenzie (1967), the evolution of the chemical composition of a water submitted to evaporation. Starting from a chemical composition of an initial solution, the soluble species are concentrated by successive increments. At each step the program computes the ionic strength, the activity coefficients, the activities of the free and complex aqueous species and tests the state of the solution saturation with respect to minerals included in a bank. As soon as a saturation point is reached, the mineral involved precipitates, the number of moles precipitated is calculated, and the changes of chemical composition of the solution are computed. The simulation can be made in open or closed system for salts or for gases. Here it was carried out in a closed system for salts and in an open system for  $\text{CO}_2$ . Carbonic acid gas is considered as being fictively in communication with an infinite reserve of gas at constant partial pressure during all of the evaporation run. The  $p\text{CO}_2$  chosen is that of water 1 ( $p\text{CO}_2 = 10^{-2.9}$  atm.). Starting from initial composition of water 1, given in Table I, the results of simulation are reported in Fig. 5. The first mineral able to precipitate is talc for a concentration factor of about 2, followed by calcite for a concentration factor of about 3.2 and by amorphous silica for a factor of about 16. Furthermore, except for small differences in some values of Mg, Ca and silica. The model gives a result fitting quite well the experimental data patterned in Fig. 1. Simulated precipitation of talc occurs a little before the observed depletion of Mg and silica, calculated and observed precipitation of calcite occur for a quite similar concentration factor.

The observed pH variations do not strictly fit the calculated ones. The pH rises progressively with the degree of evaporation but the observed slope is steeper than the calculated one. This is easy to understand if one realizes that the  $p\text{CO}_2$  of water during the experiment decreases with time from  $10^{-2.9}$  to an average value of  $10^{-3.5}$  atm. Furthermore, the observed increase of pH is less regular than the calculated one. Calculated  $p\text{CO}_2$  fluctuates around the average values of  $10^{-3.5}$  atm. as well as diurnal temperature around an average value of  $39^\circ\text{C}$ . The irregular pH variations may be related to temperature and

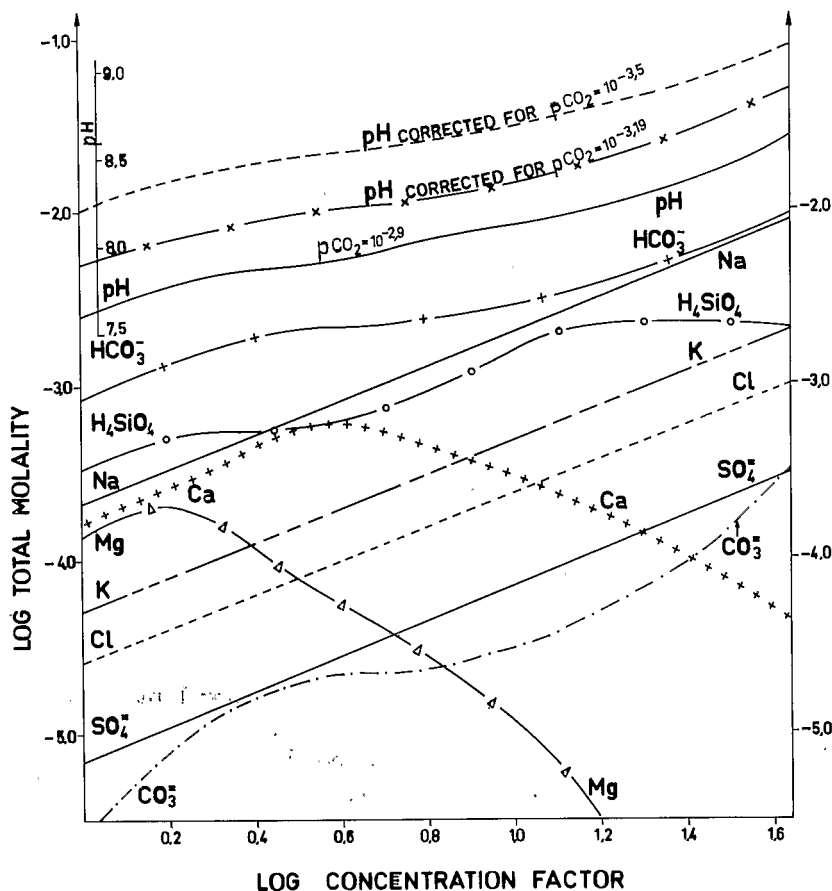


Fig. 5. Simulated evaporation of Chari River water.

$p\text{CO}_2$  fluctuations. Nevertheless, one can only remark that the two first irregularities correspond to the beginning of Mg-silicate or calcite precipitation.

Except for these small variations in pH and in the solubility products of minerals, the simulation shows an excellent agreement with the experiments: Na, K,  $\text{SO}_4$  and Cl in solution increase linearly; Mg and Ca increase and then decrease; silica and alkalinity show an inflexion corresponding to Mg and Ca maxima; Mg-silicate, calcite and amorphous silica are precipitated.

#### DISCUSSIONS AND INTERPRETATIONS

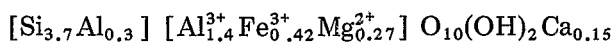
The behaviour of Mg and silica during the evaporation of the Chari River water has to be discussed in comparing experimental data, calculated models, and field observations.

(1) In the initial water, Mg is less concentrated than Ca, but it is depleted before the formation of calcite. Calcite does not contain more than 3 mole%

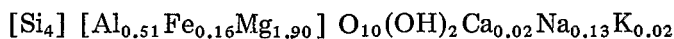
fraction of  $\text{MgCO}_3$  and magnesian carbonates, more soluble than calcite, were not found. All waters are undersaturated with respect to nesquehonite and hydromagnesite but are oversaturated with respect to talc. Furthermore, silica depletion begins at the same concentration factor as that for Mg. On the other hand, the simulation model based on the precipitation of talc gives approximately the same pattern as the evaporation experiment. Such arguments indicate an early coprecipitation of silica and Mg.

(2) The information obtained on the suspended and precipitated materials was not sufficient for characterizing the nature of the silicates formed. It is possible that the first phases obtained were amorphous. Therefore the formation of montmorillonite has to be considered by direct precipitation of Mg-montmorillonite  $[\text{Si}_4\text{Mg}_3\text{O}_{10}(\text{OH})_2]$  or by transformation of initial clays.

(3) In the Lake Chad system, montmorillonites are the dominant minerals in the clay fraction of vertisols (Paquet, 1970; Bocquier, 1971) and sediments (Dupont, 1970; Cheverry, 1974). The chemical composition of these montmorillonites are variable. In vertisols and probably in the common sediments of the middle part of the lake, in which calcite is present as concretions or deposits, montmorillonite is aluminous, ferric and magnesian (Paquet, 1970):



In the delta, the composition of the montmorillonite associated with goethite in oolites is largely an Fe-rich nontronite (Lemoalle and Dupont, 1973). In the interdunal depressions and salines the composition of montmorillonite, associated with free amorphous silica and sodium carbonate salts, approaches that of Mg-rich saponite (Tardy et al., 1974):

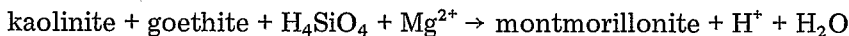


The chemical composition of such montmorillonites varies from one environment to another, but none of them has strictly the chemical composition of talc, and talc was never encountered in the Lake Chad system.

(4) In natural and superficial environments some Mg-rich clays such as saponite, stevensite, hectorite and ghassoulite, classified in the mineralogical series of talc are found frequently (Caillère and Henin, 1956; Faust et al., 1959; Millot, 1964; Trauth, 1974). Such smectites were synthesized in the laboratory by Grandquist and Pollack (1959); Harder (1972) and Baird et al. (1973); various chemical compositions were obtained. For Trauth (1974), the sedimentary phyllosilicates are formed in a continuous series from the Al-Fe-rich in diluted conditions to Si-Mg-rich in evaporites. Si and Mg are progressively incorporated in the structures as a function of concentration of the solutions. Probably such a model can be applied to the formation of montmorillonite in the Lake Chad system.

(5) The montmorillonite origin in Lake Chad has been discussed by Roche (1973) and Carmouze (1976). For the lake-bottom sediments the hypothesis of a detrital origin of this mineral was not retained above all because kaolinite (and not montmorillonite) is the dominant mineral in the suspended material

brought into the lake by the rivers Chari and Logone (Carré, 1972; Gac and Pinta, 1973). Comparison between the mineralogical composition of suspended and sedimented materials yields the validity of a reaction mechanism destroying kaolinite and goethite and forming montmorillonite during or after deposition. According to the reaction:



montmorillonite will have a variable chemical composition depending on the weight of kaolinite and goethite involved. During the progressive changes of chemistry of waters, the initial montmorillonite may be able to react with solution and give another montmorillonite, etc. Then montmorillonite could be considered as a solid solution of a great number of poles, with a chemical composition varying continuously.

## CONCLUSION

(1) The mechanism of silica and Mg coprecipitation is approached via an experimental evaporation of Chari River water. These two compounds contribute to the formation of magnesian silicates which are chemically not well determined. Even if these silicates are not crystallized in the first stages of depositions, they must be transformed later into montmorillonite.

(2) At any rate, the geochemical cycle and the mass balance of Mg in the Lake Chad system are now fairly well understood. Furthermore, calcite precipitation is confirmed and the silica budget is refined. The chemistry of waters is finally controlled by montmorillonite, calcite and amorphous silica precipitation.

(3) These results may be extended to the world-wide silica and Mg budget at the surface of the earth. Clays react with their environment; montmorillonite formation or re-equilibration can play an important geochemical rôle, but is often not observable due to the common presence and wide compositional range of clay minerals.

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