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Relationship between the Composition of Raw Brines Originating from the Mining of Lorraine Salt Rock (NE France) and the Lithology of the Deposit

Alain Buffet[1], Jean Hilly[2] and Claude Marchal[2]

[1]*Compagnie des Salins du Midi et des Salines de l'Est, 54110 Varangéville, France*
[2]*Université de Nancy 1, Laboratoire de Géologie des Ensembles Sédimentaires, 54506 Vandoeuvre-lès-Nancy, France*

ABSTRACT

The Keuperian salt-bearing deposit at Lorraine-Champagne (north-eastern France), a marginal dependence of the so-called 'Germanic Basin', is operated by drilling and mining in the Nancy region. The raw brines obtained by dissolution also contain other ions (SO_4^{2-}, Ca^{2+}, K^+, ...) in addition to Cl^- and Na^+. Their absolute and relative content, more or less variable, can be essential for the operators (especially Mg^{2+}). Therefore, it is useful to discover the origin and distribution of these elements in the evaporitic formations mined which, in some places, contain a high proportion of sterile carbonated and sulphated argillaceous rocks intercalated in the salt-bearing strata.

The SO_4^{2-} and Ca^{2+} ions obviously originate from the progressive dissolution of the anhydrite contained in the salt, but are also well developed (up to 75%) in the sterile levels. In order of importance, the Mg^{2+} and K^+ ions come from: the interstitial waters trapped in the microporosity of the clays, the fluid inclusions of the halite crystals, the dissolution of polyhalite associated to the salt in the upper part of the deposit, and the dissolution of the magnesite (5–20% in the clays). Therefore, most of the Mg^{2+} and K^+ in the raw brines come from original brines preserved in the salt rock and in the clays, but more or less modified by an early and often important diagenesis.

The variations observed in the chemical composition of the raw brines during the workings result both from the relative importance of salt and clays in the worked part of the deposit and also from these diagenetic processes.

INTRODUCTION

Geographical extent and stratigraphy of the salt deposit

In the north-eastern part of the Paris basin, an important salt deposit was deposited during the Upper Triassic (Keuper) and more precisely within the 'Marnes Irisées Inférieures' formation (Fig. 1). It extends in an east–west direction for more than 200 km from the Lorraine to the Champagne, passing progressively under more than 2000 m of sedimentary cover. This salt deposit is now worked by mining and dissolving at its eastern extremity, in the Meurthe Valley near Nancy, at a shallow depth (less than 200 m).

In this area, the salt series, with a maximum thickness of 150 m, is composed of the alternation of salt beds intercalated with unproductive layers (clays with magnesite and anhydrite). Traditionally, this series is divided by the miners into five units, from 20 to 35 m thick and called '1er, 2e, ...5e faisceau' (= 1st, 2nd, ... 5th band) according to the relative importance of salt layers. Recently, they have been redefined on the basis of their well log characteristics and named from top to bottom Q, P, ...L (Marchal, 1983) (Fig. 1).

The units P + Q and N (= 1st and 3rd 'faisceaux') are the most rich in halite, with 90 and 95% of salt rock. Between these units, the O unit (= 2nd 'faisceau') contains many more clay layers which are several meters thick; the salt beds do not represent more than 43%. The M unit (= 4th 'faisceau') is composed essentially of argilo-anhydritic layers and does not contain any primary salt. The L unit, at the bottom of the salt deposit, is made of salt and unproductive layers in the same proportion.

Salt extraction industry

Since 1855, several mines have been opened at different levels of the salt series, mostly at the bottom

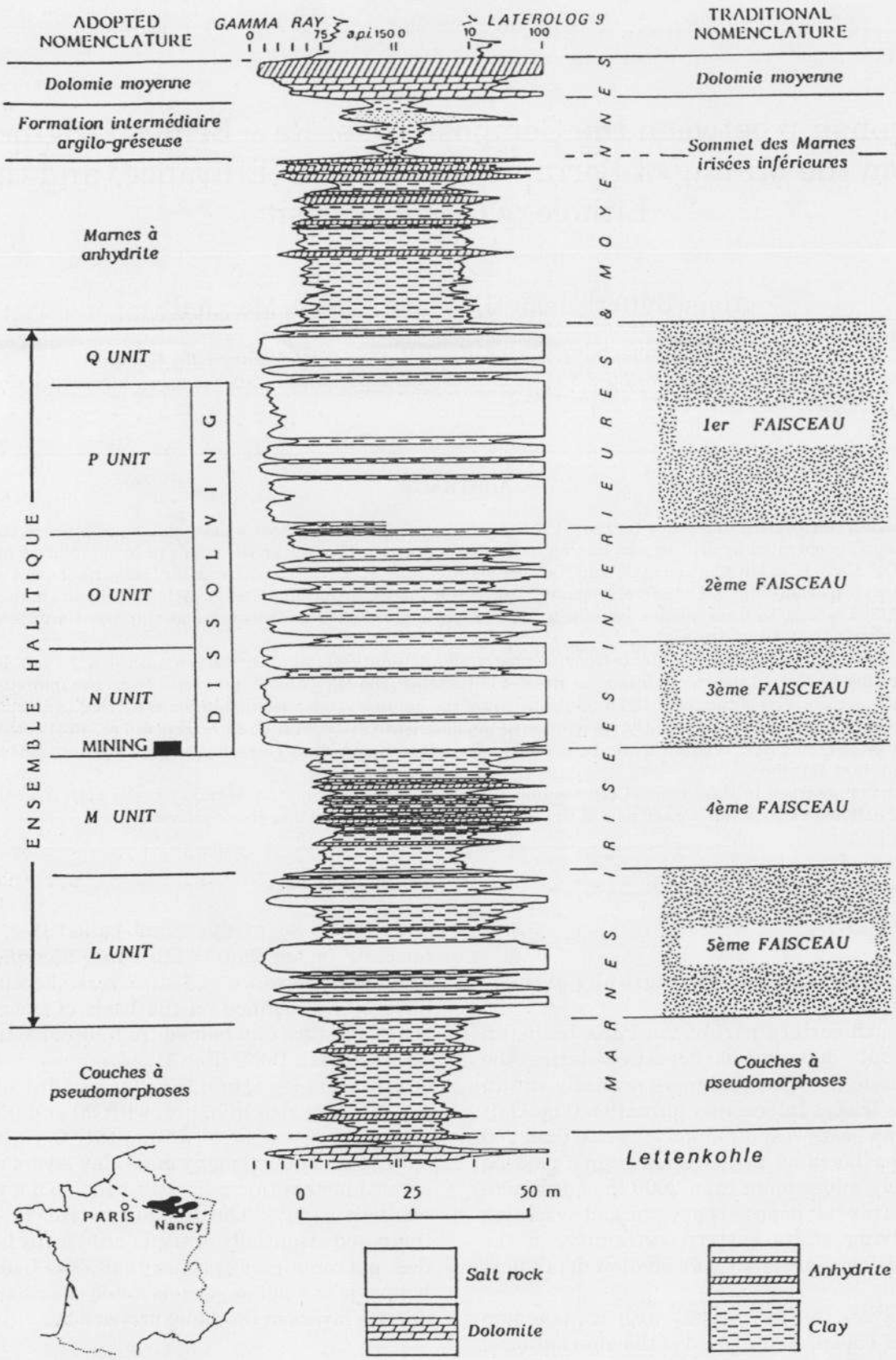

Fig. 1. Location of the salt basins of Lorraine–Champagne in France. Lithology, logs and subdivisions of the saliferous series in the area of Nancy.

of the N unit where the salt is the most pure. The only salt mine now in operation exploits this level for a thickness of 4.50 m at Varangéville (12 km east of Nancy).

In the same region, three salt companies produce brines by pumping fresh water into the salt deposit, dissolving the halite. Only the top units P, O and N are exploited. The M unit, entirely argilo-anhydritic, does not allow recovery of the salt in the underlying L unit.

One of these companies (Salins du Midi) uses two sets of wells separated by a distance of 3 km. The drill holes are interconnected at their base by hydrofracturation. The water injected in one well takes a few days, on average, before it is pumped as nearly-saturated brine in another well generally down-dip.

The analysis of these brines showed the presence, other than Na^+ and Cl^-, of HCO_3^-, SO_4^{2-}, K^+, Mg^{2+} and Ca^{2+} ions. HCO_3^- is never much abundant and is generally not analyzed. According to the annual averages, the amounts of SO_4^{2+} and Ca^{2+} are fairly constant, close to 3.4–3.8 g/l and 0.9–1.1 g/l respectively. On the other hand, the amounts of Mg^{2+} and K^+ ions show a great deal of fluctuation. For example, at the time of putting a well into production, the base of the N unit which corresponds to the level worked in the mine gives no more than 180–200 mg/l Mg. With the enlargement of the cavern, the brine then progressively starts to be enriched in magnesium up to an average of 600 mg/l when the O unit is attacked, and 800 mg/l when the dissolution reaches the upper P unit.

For the chemical industry, the magnesium ion in particular obstructs the brine treatment. It is necessary to avoid hydrolysis of the magnesium chloride in evaporators which work according to the principle of high suspension of the calcium sulphate crystals. Magnesium chloride must be eliminated by precipitation as magnesia which is drawn together with the calcium chloride resulting from the reaction by a continuous purging.

It was of interest to determine the origin of these ions and to try to explain the identified variations in order to discover if it is possible to limit the amount of Mg in the raw brines by modifying the methods of exploitation and particularly the flow of water injection.

Petrography and mineralogy

The saliferous series is composed of well-stratified salt layers intercalated by more or less abundant argilo-anhydritic layers with a thickness of from less than one millimetre to several meters.

The white salt is the most pure, sometimes with a small amount of anhydrite $CaSO_4$, whereas the grey salt also contains argillaceous impurities. The unproductive levels, of differing colours (grey, green, purplish, reddish-brown ...), have the aspect of more or less hardened mudstones and are usually called 'clays'. In reality, the argillaceous phase does not always prevail (Haïmoud, 1988). The anhydrite content is very variable, from less than 1 to 75%. Magnesite $MgCO_3$ represents the carbonate phase with an average of 12% (from 5–20%). The clay minerals suite includes, in different proportions, illite, chlorite, regular (corrensite) and random mixed layer clays (14_C–14_M). Consequently, the term 'clays' covers a series of rocks ranging from more or less carbonated real clays with very little sulphate to slightly carbonated argillaceous anhydrites.

The salt rock and the clays in the upper part of the series contain, here and there, the glauberite ($Na_2SO_4 \cdot CaSO_4$) and above all the polyhalite ($K_2SO_4 \cdot 2CaSO_4 \cdot MgSO_4 \cdot 2H_2O$) which give the rocks their rose colour.

POSSIBLE ORIGIN OF IONS ACCOMPANYING Na^+ AND Cl^- IN THE RAW BRINES

First, it is logical to consider the dissolution or the alteration of the saliferous series minerals to explain the presence of anions and cations, other than Na^+ and Cl^-, recognized in the raw brines. The carbonate ion can come from the magnesite, SO_4^{2+} from the sulphates: glauberite, polyhalite, and notably from the ubiquist anhydrite which also gives Ca^{2+}. For Mg^{2+}, magnesite and some clay minerals (chlorite, mixed layer clays) can be considered. The potash minerals are limited to polyhalite and illite. However, these ions could also be supplied by the natural brines contained inside the rocks: the fluid inclusions of the halite crystals and the interstitial waters trapped within the microporosity of the clays.

Several laboratory experiments were carried out to test these hypotheses.

LABORATORY EXPERIMENTS: RESULTS AND INTERPRETATION

The purpose of these experiments was to put different rocks and minerals in contact with water and more or less concentrated brines. At the end of a variable time (from one hour to more than 100 days), the ions released into the liquid from the rocks and minerals were estimated.

The first experimental conditions were as close as possible to those of the salt deposit during its exploitation by dissolution:

TABLE 1

Chemical composition of clay and magnesite samples

	Samples							
	1	2	3	4	5	6	7	M
SiO_2	16.08	16.65			39.58	36.04	38.96	2.18
Al_2O_3	5.07	4.24			13.95	13.29	13.54	0.22
Fe_2O_3	0.82	1.13			6.72	6.05	6.62	1.50
FeO	0.70	0.53						
MnO	0.03	0.05			0.07	0.08	0.08	0.07
MgO	4.66	5.01			12.67	13.95	12.62	41.93
CaO	25.60	25.77	22.59	18.21	2.98	0.26	0.34	4.12
Na_2O	0.49	0.34			1.50	1.45	1.24	
K_2O	1.67	1.42			4.44	4.03	4.25	0.08
TiO_2	0.22	0.19			0.59	0.58	0.61	0.06
P_2O_5	0.09	0.09			0.11	0.10	0.13	n.d.
Loss at 110°			1.96	4.47		11.61	9.49	
LOI					16.45	12.43	12.01	49.72
H_2O_{tot}	4.01	3.72						
CO_{2tot}	2.69	3.11						
SO_3	36.66	36.48	32.95	26.25				
Cl	0.76	0.66						
O=Cl	0.17	0.15						
TOTAL	99.38	99.24			99.06	99.87	99.89	99.88

Analysts: 1 and 2 — Laboratoire de Chimie, Centre de Recherches Pétrographiques et Géochimiques (C.N. R.S), Vandoeuvre-lès-Nancy (France).
3–7, M — Laboratoire de Fluorescence X, Faculté des Sciences, Université de Nancy I (France).

(a) The rocks were not ground to a powder, but only crushed; the fraction 2–5.8 mm was used.

(b) They were immersed in an already very concentrated brine (S1) (about 280 g/l NaCl; d = 1.173) obtained by dissolution of white salt from the mine, slightly anhydritic and almost totally free of argillaceous impurities.

(c) The agitation was very limited, no more than a few seconds each day.

Two samples of argillaceous anhydrite from the first bed of the O unit, one green and slightly purplish (sample 1), the other grey-green (2), were used. They had a similar chemical composition (Table 1: ≈62% of anhydrite, 5–6 % of magnesite). For each sample, 19 experiments which lasted from 6 h to 107 days were made with 35 g rock and 100 g brine. At the end of these experiments, Ca^{2+}, Mg^{2+}, and K^+ of the brines were analyzed. By substraction of the initial existing amounts in the S1 brine, the concentration of the ions realised by the rocks was obtained (Table 2).

Several conclusions could be drawn from these data.

Origin of calcium

The quantities of calcium liberated by samples 1 and 2 in accordance with time are shown in Fig. 2. They correspond to the anhydrite dissolution, the only calcic mineral of these rocks. Effectively, the chemical analysis of these samples (Table 1) shows that the percentage of CaO exactly fits that of SO_3 to form this sulphate. The dissolution, relatively fast during the first week, then becomes much slower; after two months and with approximately 500 mg/l, it stops or increases only imperceptibly.

Origin of magnesium and potassium

The clay minerals

The curves (Fig. 3), representing the quantity of Mg and K released by sample 1, are clearly different from those observed for the calcium: the maximum values of Mg^{2+} (≈520 mg/l) and of K^+ (275 mg/l) are obtained in less than one day and remain almost unchanged until the end of the experiments (107 days). Figure 4, which integrates data from Figs. 2 and 3 for the first week and the 107th day, gives a

good picture of the progressive liberation of Ca as opposed to the very fast and total liberation (in some hours) of Mg^{2+} and K^+.

TABLE 2

Amounts of Ca, Mg and K released by clay samples 1 and 2 immersed in S1 brine in relation to the duration of the experiment

	Sample 1				Sample 2			
	Ca	Mg	K	K/Mg	Ca	Mg	K	K/Mg
6 hours	148	459	241	0.53	96	490	273	0.56
12 hours	196	516	266	0.52	148	507	276	0.54
20 hours	204	511	258	0.50	144	540	293	0.54
34 hours	212	507	263	0.52	152	545	305	0.56
4 days	276	531	266	0.50	232	523	296	0.57
7 days	440	504	277	0.55	392	501	295	0.59
10 days	440	513	280	0.55	408	492	288	0.59
15 days	472	518	274	0.53	420	501	292	0.58
23 days	484	511	271	0.53	420	545	307	0.56
30 days	492	511	270	0.53	456	525	301	0.57
37 days	492	516	276	0.53	444	535	307	0.57
44 days	496	492	261	0.53	456	516	297	0.58
50 days	508	516	280	0.54	460	540	303	0.56
58 days	524	506	273	0.54	468	533	302	0.57
65 days	524	504	272	0.54	468	554	261	0.47
72 days	524	511	265	0.52	508	516	263	0.51
79 days	524	511	274	0.54	496	535	285	0.53
93 days	524	511	275	0.54	464	530	273	0.52
107 days	524	533	280	0.53	504	487	291	0.60

Sample 1 = green-purplish clay; sample 2 = grey-green clay. Analyst: Laboratoire de Chimie, Compagnie des Salins du Midi, Varangéville (France).

This rapidity allows us to set aside the hypothesis that attributes the origin of magnesium and potassium in brines to the clay minerals. Neither the chlorite nor the mixed-layer clays for the Mg — and the illite for K even less — could loose their cations in so short a time. It is very likely that the cause for a long period would be the same since the amounts of Mg^{2+} and K^+ do not increase significantly with time.

The magnesite

Although it is slightly soluble (106 mg/l in cold water, i.e. 31 mg/l Mg), the magnesite can supply Mg^{2+}. To measure its importance, it was necessary to have an idea about the solubility of this carbonate in the brines and to establish the dissolution curves as a function of time (3 h to 6 days). A sedimentary magnesite (M) from Eugi (Spanish Navarre) was used. The X-ray diffraction and the chemical analysis (Table 1) showed that the only two important components are magnesite (81.5%) and dolomite (13.5%). We have estimated that the presence of this dolomite, 3 times more soluble than the magnesite but 2.2 times less rich in Mg, does not greatly influence the results. The tests were carried out with (a) distilled water and (b) an S2 brine prepared as for S1 from a white salt from the mine (320 mg/l NaCl ; d = 1.197 ; Mg = 58 mg/l). Figure 5 shows that in both cases the dissolution, relatively fast during the first hours, slows down after one day, but is incomplete after six days (18 mg/l against 31 mg/l in water at the saturation). This solubility is much higher in the S2 brine than in water, mainly during the short experiments ($x \approx 3$); it is still twice as high after six days. It would seem that only 30–35 mg/l Mg are released by the magnesite, since the transit of the injected

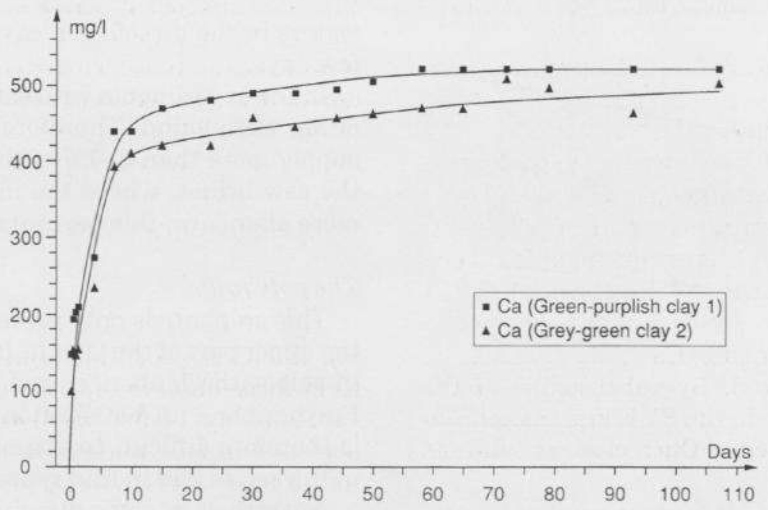

Fig. 2. Release of Ca in relation to time for the clay samples 1 and 2 immersed in S1 brine.

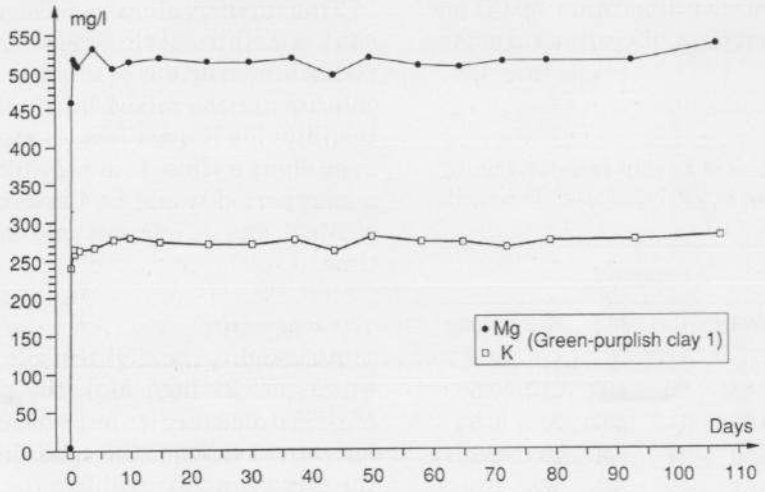

Fig. 3. Release of Mg and K in relation to time for the clay sample 1 immersed in S1 brine.

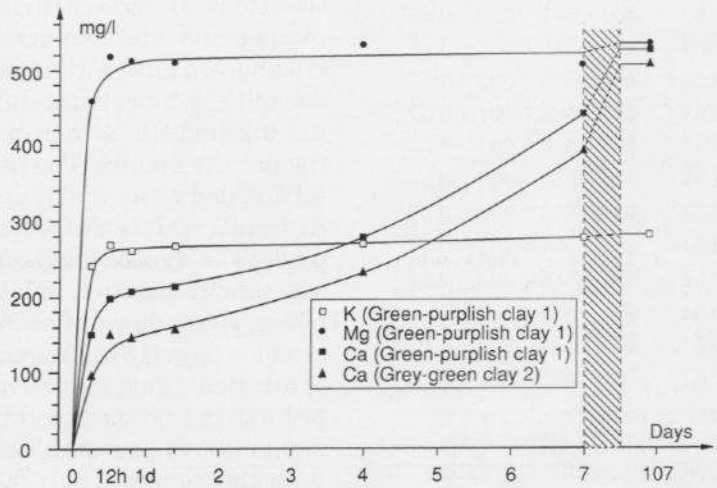

Fig. 4. Comparison between the progressive liberation of Ca and the fast liberation of Mg and K, after data taken from Figs. 2 and 3.

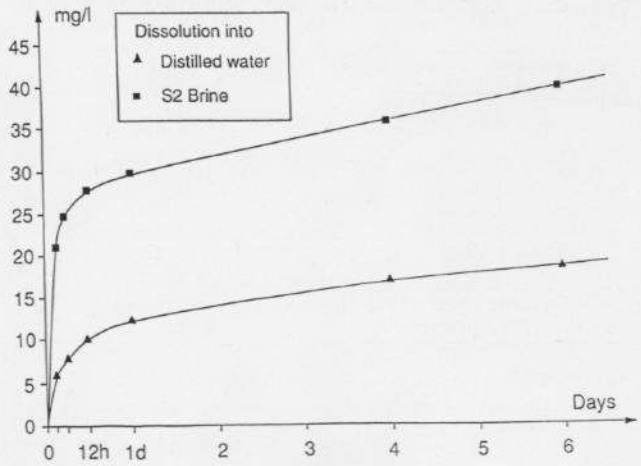

Fig. 5. Solubility curves of magnesite in distilled water and in S2 brine.

waters in the dissolution cavities does not exceed a few days.

In the experiments with samples 1 and 2, 520 mg/l of Mg were found. Therefore the magnesite cannot supply more than 6–7% of the total magnesium. In the raw brines, where the magnesium is generally more abundant, this percentage should be lower.

The polyhalite

This sulphate is only present in the P unit and in the upper part of the O unit. It is located particularly in salt with glauberite, and much less so in clays. Furthermore, its distribution is not homogeneous. It is therefore difficult to estimate its real percentage in the series and to find representative samples.

Nevertheless, some dissolution experiments were carried out. 30 g of crushed polyhalite (with a certain

amount of glauberite) prepared from isolated nodules were put into 86.8 cc of S2 brine for one day. We found a relatively high release of magnesium (3.0 g/l) and potassium (9.47 g/l). These high values, naturally more or less damped, were found again in the analysis of two brines (257 and 241 g/l NaCl) prepared with two salt samples from the P unit, the first being poor in polyhalite, the second much richer. The results are as follows: 0.194 and 2.529 g/l Mg; 0.572 and 8.800 g/l K.

For the above reasons, the real incidence of the polyhalite dissolution on the average amounts of Mg^{2+} and K^{+} within the raw brines is difficult to estimate. However, we can logically assign to it the increase of magnesium when the dissolution affects the upper part of the salt deposit.

Interstitial waters in clays

In these conditions, the interstitial waters are the last possible origin for the largest part of the magnesium and potassium released during the experiments with clays. This conclusion involves the clays having a sufficient porosity to hold a sufficient volume of connate waters. Complementary experiments were carried out with six samples of more or less anhydritic clay.

The analytical data concerning these rocks (samples 2 to 7) are given in Table 1. They were taken, as previously, at the base of unit O, except for samples 4 and 5 which came from the same bed at the top of M unit:

Sample 2 — Grey-green argillaceous anhydrite, already used in the first experiments (62% anhydrite);

Samples 3 and 4 — Grey-green clays (55% and 44% anhydrite respectively);

Sample 5 — Red-brick clay (small percentage of anhydrite);

Samples 6 and 7 — Grey-dark green slightly purplish clay and red-brick clay (less than 1% anhydrite).

In all these short-period experiments (one to several hours), 30 g of powdered rock were placed in 86.8 cc of distilled water.

The quantity of Mg and K in water as a function of the percentage of anhydrite in the clays is shown in Fig. 6. An evident negative correlation appears between this anhydrite which reduces the porosity (see below) and the liberated ions. In other words, the more the rock is argillaceous, the more it releases ions.

Work in progress includes direct measurements of the total porosity of the clays. Two indirect approaches, nevertheless, give an approximate idea of their value. First, it is possible to obtain from the mine (unfortunately at too few places) fresh samples, unpolluted by the ventilation of galleries, which still at least partially conserve their natural humidity. After drying at 110°C, the weight lost (Table 1, loss at 110°) allows minimal porosity values to be proposed, for instance: 4.3%, 9.8%, 23% and 19% for samples 3, 4, 6 and 7 (by taking a density of 2.2 for the anhydrite clays and 2 for the others). The real porosity values are perhaps higher, because these samples were taken at only a few decimeters from the top or the bottom of very ancient galleries; the connate waters in consequence could undergo a certain evaporation. In this case, part of the dissolved salts will precipitate inside the pores, but will be redissolved when the rock is immersed in water during the experiments. Nevertheless, it clearly appears that the porosity varies inversely with the percentage of anhydrite.

The second approach is supported by the works undertaken on Triassic evaporite clays. Lucas (1962, 1974), among others, has stressed the particularities of these clays, as far as their mineralogical composition or chemical characteristics (very magnesian) are concerned. He also pointed out the great uniformity and monotony of these clays throughout the whole area of the so-called 'faciès germanique' of the Triassic, from the Sahara to Germany. These last findings allow us to extrapolate to our clay samples the results published by Kulke (1979) concerning the porosity of Triassic clays in the Maghreb (Marocco, Algeria, Tunisia). He has shown that the sub-parallel ultrastructure generally acquired by clay crystals under the effect of compaction during burial is not present in the evaporite clays. In contrast, the impermeability of the salt layers oppose the evacuation of interstitial fluids and the clay minerals retain the same non-oriented ultrastructure ("house of cards") as at the time of their deposition. Consequently, "the intercalated clays in the saline facies kept an abnormally high porosity". This can reach up to 30% for

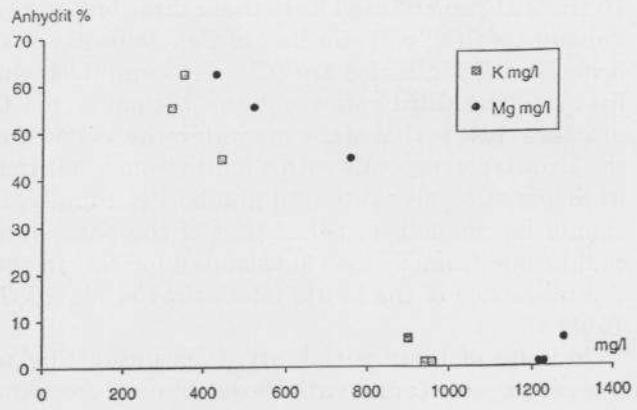

Fig. 6. Amounts of K and Mg released in distilled water in function of anhydrite percentage in clays.

clays submitted to a burial of 4–5 km and even brought to the surface by diapirism. In these conditions, the numbers proposed above for a minimal porosity (4.3–23%) are not surprising, none the least because the burial of the saliferous series of the Lorraine was smaller (less than 1500 m) and was unaffected by halokinesis.

The evaluation of the porosity necessary to justify the quantity of magnesium and potassium released by the clays during the experiments necessitates ascertaining the salinity and composition of the connate waters. A sample taken inside a brine pocket encountered during the mining works at Varangéville had a salinity of 329 g/l with an amount of 1940 mMol/l Mg (= 47.150 g/l) (Fabriol, 1989, p. 14, P). For such brine, porosities of 6% (very anhydritic rocks) and 17% (low- or non-anhydritic clays) are sufficient. The values proposed above — which are more or less underestimated values — are in the same range of magnitude.

Fluid inclusions in the halite

The quantity of ions brought in by the fluid inclusions of the halite first depends on their highly-variable percentage, even inside the same bed. Their primary or secondary origin also plays a role in their chemical composition which is, in the first case, generally close to that of more or less concentrated seawater whereas, in the second case, it could be notably modified by an early diagenesis.

This variability is illustrated by the results of two brines (295 g/l NaCl) made with pure halite taken from the O and P units. They contain 1670 and 690 mg/l Ca; 38 and 110 mg/l Mg; 12 and 163 mg/l K, respectively. These samples, very punctual, are less representative than the crushed salt industrially-produced by grinding the raw salt extracted from the mine and sifting at 0.620 mm. The brine (317 g/l NaCl) obtained with this salt contains 1479 mg/l Ca, 163 mg/l Mg and 53 mg/l K. In these three brines, the amounts of SO_4^{2-} will join that of Ca^{2+} to form anhydrite. The K/Mg ratios are 0.31, 1.48 and 0.34; the first and the third ratios (for the bottom of the O unit) are close to that of the sea water; the second (for the P unit) corresponds with a halite from a salt rich in diagenetic polyhalite and glauberite. Finally, it should be remembered that part of the potassium could come from K^+ ions substituted for Na^+ in the crystal lattice of the halite (McCaffrey et al., 1987, Table 4).

In spite of their variability, it is interesting to compare these results with those obtained from the clays. In the brine of crushed salt (317 g/l NaCl), there is ≈ 85 g of water for each 30 g of salt, in proportions similar to that used in our experiments with the argillaceous samples 2–7. These results can then be compared directly: for Mg^{2+}, 163 against 430–1330 mg/l; for K^+: 53 against 320–960 mg/l. The average density of these clays being nearly the same as that of the salt, it is obvious that at equal volume the salt delivers much less magnesium and potassium than the clays. In relation to the importance of the argillaceous phase and therefore to their porosity, the clays provide by means of their interstitial waters 2.8–8.7 times more magnesium and 6.2–18.5 times more potassium than the fluid inclusions of the halite. The difference that appears in these numbers for the magnesium and potassium can be explained by the increase of the K/Mg ratio in the interstitial waters after diagenesis (see below).

These results must be balanced by considering the relative percentage of salt and clay in the zone under dissolution. For example, for the base of the N unit (93% halite), the calculation gives an amount of Mg^{2+} in the range 190–280 mg/l according to the percentage of clays in anhydrite. The richness in salt in this unit implies a strongly evaporitic environment; the associated clays very likely have a sufficiently high percentage of anhydrite, which leads to a Mg value closer to 190 than to 280 mg/l. Effectively, the value given above for the raw brines at the moment of the dissolution of this level are, on average, 200 mg/l.

The same calculation for the O unit (33% halite, with rare polyhalite) yields 340–940 g/l Mg. The repeated and significant arrivals of clays point out frequent falls in salinity by continental waters; the anhydrite is certainly less abundant in the clays, which should give an amount of magnesium nearer to the middle range. This conclusion is in good agreement with the 600 mg/l found in the raw brines.

CONCLUSIONS

Part of the raw-brine ions, other than sodium and chlorine, is derived from the partial dissolution of certain salt and clay minerals. These are mainly SO_4^{2-} and Ca^{2+} from anhydrite and, in lower quantities, from polyhalite and glauberite. The incongruent dissolution of these latter sulphates also provides Mg^{2+} and K^+. The magnesite contributes slightly to the Mg^{2+} supply, but the principal origin of the magnesium and potassium is the natural brines trapped in the fluid inclusions of the halite and, even more, the interstitial waters in the pore spaces of the clay.

It has been seen that the inclusions in halite are more or less abundant, with a changing chemical composition. This is the same for the brines of clay samples 2–7 (Fig. 6); their K/Mg ratios range from 0.5 to 1. These numbers are high when compared with the value maintained by seawater during its

evaporation until the end of the halite precipitation (around 0.3). They are chiefly accounted for by a loss of ion Mg^{2+} during the diagenetic transformations: formation of the magnesite and polyhalite from the pre-existing calcium carbonate and sulphate; aggradation and neoformation of magnesian clay minerals. To a lesser extent, K^+ is also used for polyhalite and illite.

Other phenomena, such as changes in environmental conditions, can also modify these interstitial brines. For example, in this Lorraine–Champagne basin we have pointed out the repeated emersions of evaporitic sediments just deposited (Marchal et al., 1991); they can increase the concentration of the interstitial brines by evaporation or, on the other hand, favour their dilution by fresh waters.

Briefly, these brines show important variation in quantity and quality (composition and concentration), often from one bed to the next. Such variability reflects the extreme complexity of the evaporitic environment. However, the general tendency of this diagenetic evolution leads to a transfer of Mg^{2+} and K^+ from the brines into new specific minerals (see, e.g. Lucas, 1962, 1974; Stein and Krumhansl, 1988).

This geochemical trend of Mg^{2+} is favourable to those industries who work the salt deposits using dissolution, except if the mineral in which the magnesium is trapped is soluble and gives this element back to the raw brines: this is the case for polyhalite which is then a penalizing mineral. It is, however, preferable to avoid as far as possible the exploitation of levels which are too rich in clays — principal bearers of Mg^{2+} by means of their interstitial brines. The higher the percentage of salt, the smaller is the rate of magnesium.

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