Significant sedimentary structures in the Keuper salt series of Lorraine – Champagne (NE France)

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ABSTRACT

The Keuper salt series of Lorraine – Champagne is very regularly stratified on the whole. It presents however, on each level, various sedimentary structures (*e.g.* tepees, fissures, erosion surfaces, ...) giving accurate data on environmental evolution during the formation of the salt deposit. These are also useful for stratigraphic correlations. It is thus very important to locate these structures, which is easily done in the mining drifts, but in drill core their sure or likely identification is much more difficult. The illustrations presented in this paper enable comparaison of their aspect when they are cut by a drift (Varangéville mine) or by a bore hole (Gellenoncourt and Réméréville drillings).

The Keuper salt deposit of Lorraine – Champagne spreads, in the eastern part of the Paris basin, over more than 200 km from East to West and over a variable width up to a hundred km (Fig. 1). The salt series (~ 150m) has been dated back to the Carnian. Its deposit was formed in the axial part of a very remote annex of the huge German basin.

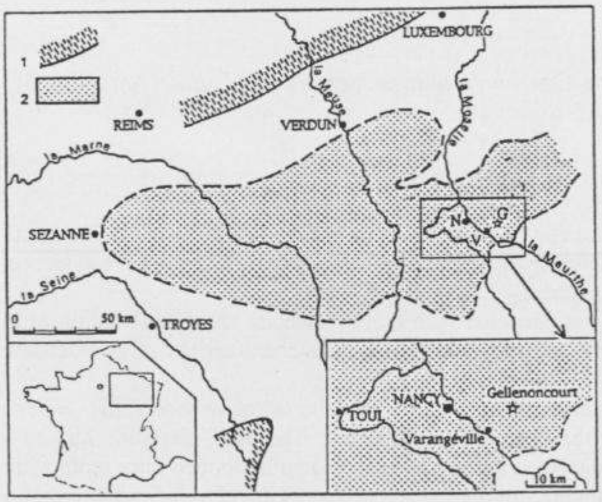


Figure 1.- The Keuperian basin of Lorraine – Champagne. 1: Limit of the sedimentary basin. 2 : Salt deposit.

In Lorraine, the deposit is subject to solution in the outcrop borderings. It gradually goes deeper westwards so that its occidental extremity is more than 2000 m below the surface in the Champagne region.

The drilling data enabled one of us [1] to consider, in this regularly stratified salt series, 8 successive units with an average thickness of 20 m. These units are easy to identify and connect to one another according to their well logs profiles. These units, in which halitic and clayed sulfated levels are associated according to variable ratios, have been referenced L to S from bottom to top. The lower units (L to Q *p.p.*) are only represented in Lorraine.

Salt activity currently concentrates in the Meurthe Basin, East of Nancy, where the salt deposit is accessible at little depth (100 to 300 m). With too low salt contents, units L and M are rejected, while units N, O and P are - either mine or solution – worked.

Based on observations of several drillings (core samples and well logs) and in former and current mine works, we proposed a genetic model for that kind of deposit [2]. Succession of periods of immersion and emersion is its main feature. Every cycle immersion/emersion is an "event sequence" which schematically divides into the following phases.

1- Emerged deposits from the previous sequence are quickly or progressively flooded by marine and/or continental waters. The first ones bring the evaporite salts (sulfates, chlorides), the others the detrital particles (clays). A subaqueous and rhythmic sedimentation associates, on average few meters, sulfated claystones and salt (fig. 2A). From bottom to top of the deposit, the progressive decrease of claystones and the increase of salt emphasize the rise of aridity. Signs of temporary emersions may exist (mud cracks, microtepees). The relative proportions between detrital and evaporite facies are most variable from one sequence to another.

PLATE I

1- Level with microtepees in the layered salt. (First event sequence of the N unit. Mining drift in the Varangéville salt mine).

This level (under small ruler = 20 cm) is characterized by fairly distorted lamines, fractured at microtepees tops. The secondary halite develops into irregular masses and fills in the cracks of tepees which have penetrated into the stratified underlying salt. This microstructure is the result of transitory emersion in salt subaqueous sedimentation. Despite its thinness, this level can be followed on a wide area in the mine. Thus, it is a reference layer, as well for both the stratigraph and the miner.

2- Same level on a drilling core (diameter : 85 mm). (Gellenoncourt drilling, depth around 289,50 m).

Like on the previous photograph, the core shows the special character of this level within a perfectly layered salt (see location on Pl. II-1). The presence of such a level in that drilling, 6 km from the mine, and in other nearby drillings, proves the importance of it as a local reference layer and gives an idea of the minimum extension of the area once affected by emersion.

3- Unusual dips in a salt core (diameter : 85 mm). (Gellenoncourt drilling, depth around 245 m).

These abnormal dips, seen over one meter within a horizontally stratified series, certainly belong to upturned layers on a tepee side.

4- Sedimentary structures in the passage area between the first two event sequences of N unit (Aerage drift, Varangéville salt mine).

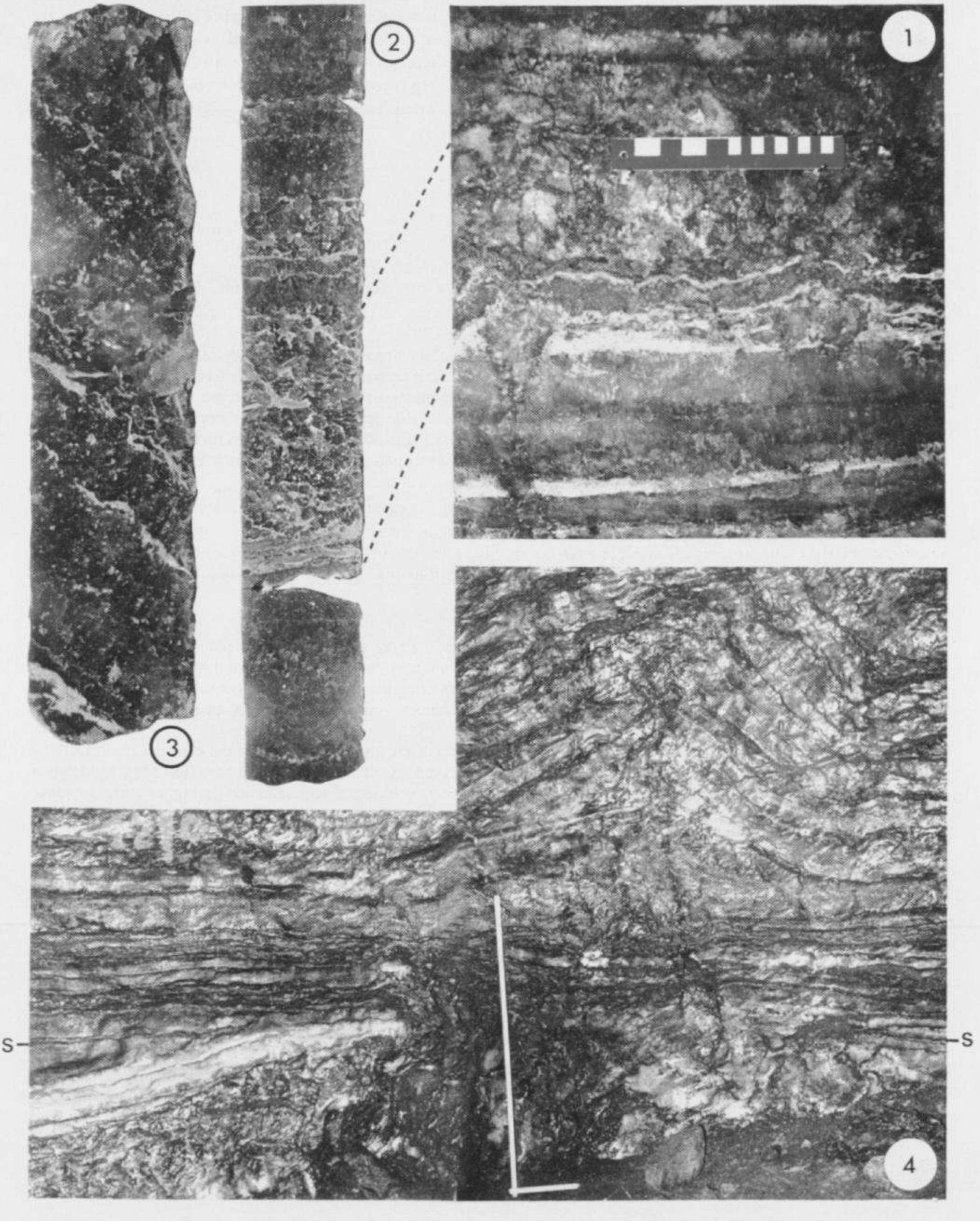
It can be noticed on this driftwall that on only a few meters the total sedimentary structures from which we have developped our halitic sedimentation model [2] coexist.

The lower third of the photograph shows salt with a very sparse clayed laminae. These are the last deposits of first event sequence. They are upturned in the wide structure of a tepee, the left side of which can be easily seen. They are the evidence of a progressive emersion succeeding the subaqueous sedimentation phase.

The tepee heart (dark area, behind lower half of the meter), is occupied with the argilaceous and halitic filling of a fissure (see Pl. II-1 another fissure belonging to the same polygonal network). This structure is characteristic of an extended emergence period with a strong desiccation of halitic deposits.

Salt of the tepee and filling materials of the fissure are intersected by a fairly plane erosion surface (S-S). A few decimeters of salt down to the base of the clear halitic layer have locally disappeared. The first claystone and salt interstratified beds of the second sequence lie with angular discordance on this surface. The basin is flooded once more with sedimentation starting again. One of the many sedimentary discontinuities of the salt series is at the level of S-S surface.

Flat stratification of the deposits remains for about forty cm , beyond which it has been affected by the formation of a new tepee. This is evidence of a trend towards a subaerial environment. The shorter duration of this emersion and/or the presence of claystone intercalations prevent the strong desiccation to which the salt was subjected in the first sequence. As a result, there is no open fracture in the heart of this tepee.


1
2
3
4
S
S

2- A progressive emersion puts an end to the phase of sedimentation. Large tepee structures develop into the upper part (up to 1 – 2 m) of the sediments. They draw an irregular network of giant polygons which usually range in width from 10 to 25 m. Their morphology differs according to lithology. In massive salt, the deformation of beds is regular and symmetrical. The voids between the upturned beds are filled with secondary halite wedges (Fig. 2B). In salt interstratified with argilaceous layers, the deformation is often more irregular and strong.

PLATE II

1- V-shaped fissure intersecting the bedded salt. (First event sequence of N unit. Mining drift in the Varangéville salt mine).

Salt is mined 4,50 m in thickness. It belongs to the upper part of the deposits of this specially halite-rich sequence. The very regular stratification is flat except for the drift upper part where salt layers go up a tepee side (see on Pl. I-4 the top of a tepee of the same network). The V-shaped fissure settled at the beginning in the heart of the tepee and then grew deeper down unto the most clayed levels lying under the drift floor. It is 80 cm wide opened at its top and more than 4 m in height.

Fissure filling (small clayed and halitic alternate beds, secondary halite pockets) is layered vertically and symmetrically towards the median plane. This layout which is very distinct in the upper part gets blurred downwards where structure turns rather chaotic.

Note a light shifting of salt layers on either side of the fissure. •[: Location of the microtepees level (Pl. I-1).

2- Drilling cores (diameter : 85 mm) intersecting fissure filling (2a, 2b and 2d : Gellenoncourt drilling. 2c : Réméréville drilling, 3 km North from Gellenoncourt).

2a. *P unit, at about 222,70m.* Under the horizontal clayed layer, the core shows a vertical bedding outlined by broken layers of claystone in the salt. It is a fissure filling. From this it may be deduced that : - at this level exists a network of cracks in the deposit of the *n* event sequence ; - the surface intersecting the filling is an erosion surface (S) on which the base clays of the *n+1* next sequence lie with an angular discordance ; - this surface marks an important sedimentary discontinuity in that salt series.

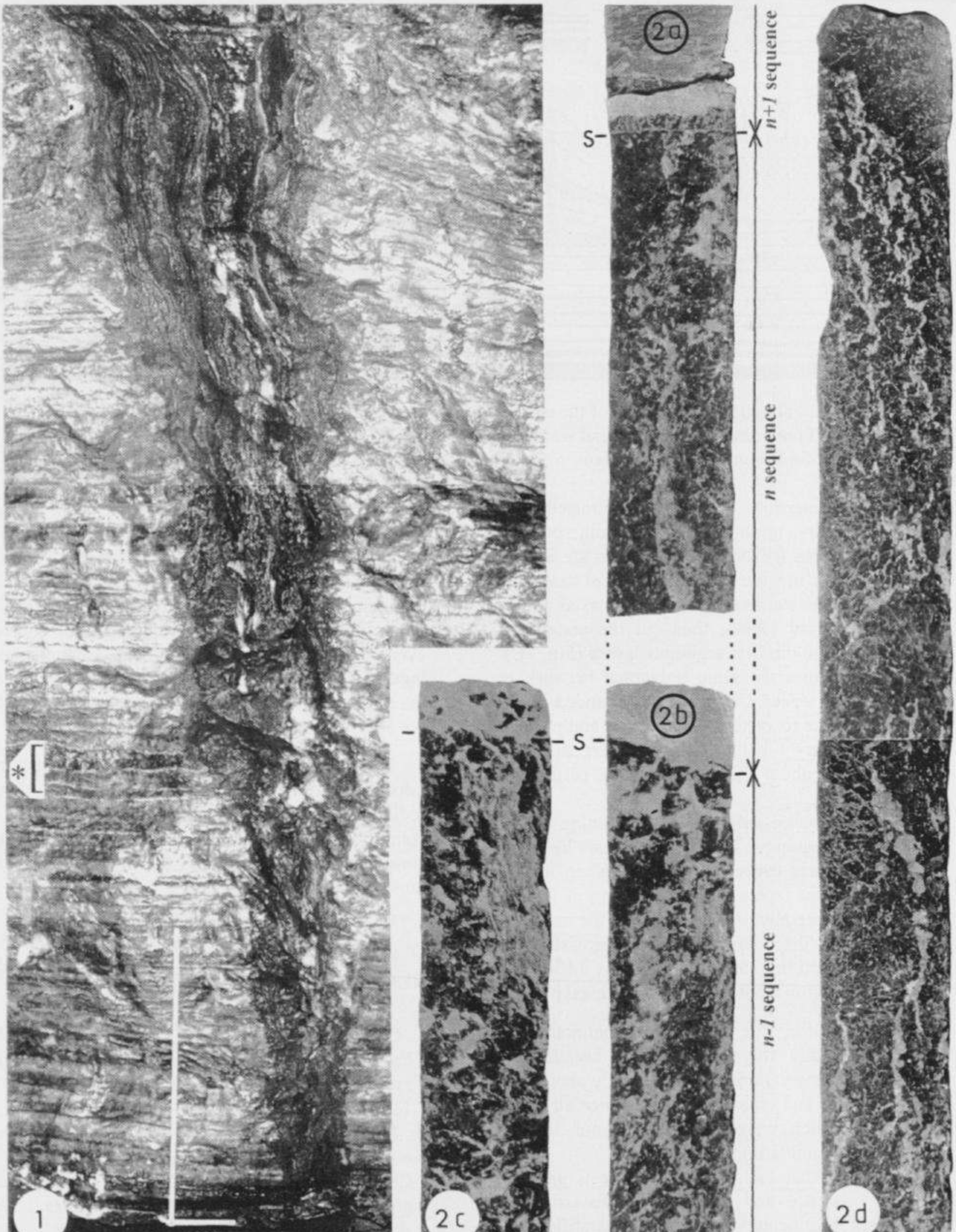
Such an interpretation is confirmed by the lithological evolution of the underlying levels of the *n* sequence. In fact, the drilling intersects the filling for 1,80 m at first, then the salt with clayed intercalations about the base (for 2 m), and lastly a big claystone layer (0,90 m). This is the normal (detrital → chimical) evolution of sedimentation during an event sequence and the sedimentary discontinuity is logically located at the top of the deposit.

2b. *P unit, at about 227,50 m.* The core shows the same aspect as the previous one and gets to the same interpretation. Claystones correspond to the base of the *n* sequence, and the fissure thus belongs to the network of the *n-1* sequence. In that favorable case in which the drilling intersects the fissures of two superposed networks, the interval between both erosion surfaces gives the thickness of deposits during an event sequence (4,70 m for the *n* sequence).

2c. *N unit, at about 271,50 m.* This core has in common with the previous ones the clayed level surmounting a fissure filling. But the latter can only be seen at the top of the core and in the right half of it. The drilling might have only grazed the fissure the importance of which remains unknow. The other part of this core shows a confused structure due to strong halite recrystallization, which frequently occurs on fissures edges in the enclosing levels.

Conclusions drawn from an examination of 2a and 2b cores can only be considered for this one with the upper caution. In that case, it looks however possible to do so. In fact, a comparison of the detailed lithologic sections of N unit 9 km apart in that drilling and in the Varangéville mine enables very close correlations between clayed and halitic layers, even when they have little thickness. And there is also a tepees and cracks network in the mine at the exact level of this core.

2d. *P unit, at about 240 m.* Fissure filling with obvious vertical bedding, outlined by the clayed-sulfated layers with polyhalite nodules.


1
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2a
2b
2c
2d
S
S
n+1 sequence
n sequence
n-1 sequence

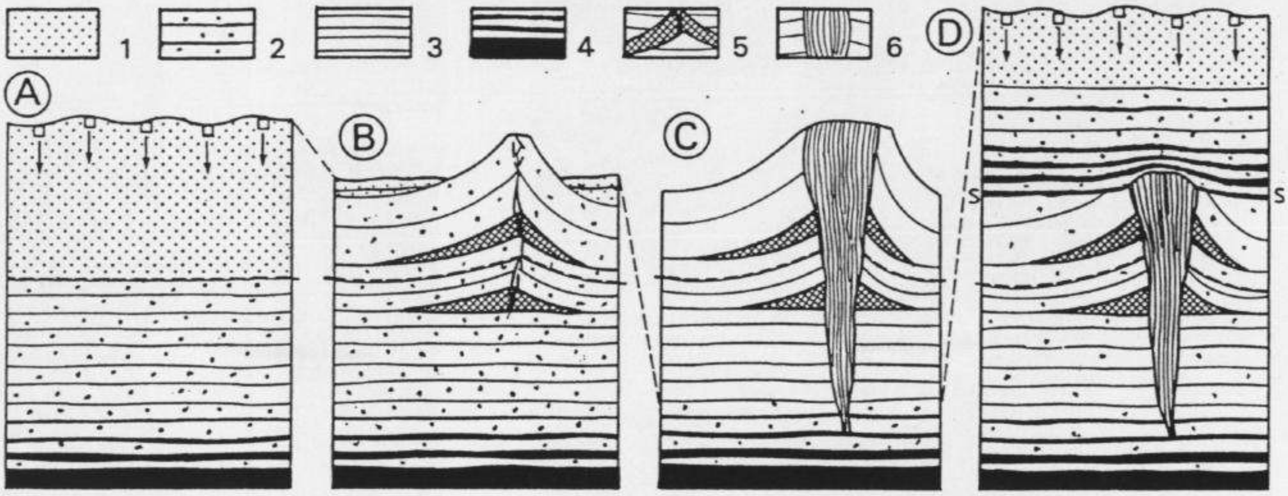

Figure 2.- The successive stages of the event sequence (after Hilly *et al.* [2]). For explanation, see text.
1 : Free brine. 2 : Brine ground water. 3 : Bedded halite. 4 : Halite with clay intercalations.
5 : Secondary halite wedges. 6 : Internal filling of fissures. S -S : Erosional surface.

3- If the emersion period is protracted, the sediments dry up in depth and numerous V-shaped fissures are formed. The largest are up to 4 m deep and 1 m wide at the top. In most cases, the fissures at the start superpose fragile axial planes of massive salt tepees, then cut the underlying deposits up to the first argileous layers (Fig. 2C). Thus they form the same polygonal network as massive salt tepees. Commonly, the banded filling of the fissures (claystone, impure salt and pockets of secondary halite) is subvertical and symmetrical about the median plane, particulary in the upper part.

4- A new flooding indicates the beginning of the next event sequence. The first sediments lie on an erosion surface especially obvious when it cuts the bedding of tepees and the layering of fillings (Fig. 2D). Laterally, in the meshes of the network, the angular discordance rapidly decreases and disappears and this stratigraphic gap is difficult to distinguish from a common stratigraphical plane.

In conclusion, the apparently continous salt series is actually very discontinuous because the period of sedimentation is interrupted by another of nondeposition and erosion during each of all event sequences which were numerous (about 10, for instance, in N unit around 22 m thick).

It is clear that each event sequence is justified by the existence and the logical succession of significant sedimentary structures : stratification, microtepees, polygonal networks of large tepees and fissures and erosion surfaces. Therefore, their recognition and location in salt series is very important. All these figures can be easily noticed in three dimensions in mining works. They are much more difficult to detect in drill cores and, of course, even more difficult to find in the common well logs. It is nevertheless in these latter conditions that the researchers are obliged, in most cases, to study the evaporite deposits.

That is why we thought it suitable to present, for information, a few photographs of these sedimentary structures from mines and, as a comparison, the particular aspects of some drilling cores which let suspect and sometimes assert the presence of such structures (Pl. I and II).

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