The Muschelkalk Salt at Heilbronn, Germany

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ABSTRACT

The Muschelkalk Salt at Heilbronn, Germany, presents a three-unit sequence of halite completely unlike any deposit in North America. The middle unit, 6-10 meters of horizontally banded primary halite and anhydrite, lies between recrystallized halite units (each up to 20 m. thick) characterized by vertical striping. Contacts are sharp. Unique conical-shaped depressions of banded salt may be sufficiently deep so that the lower vertically striped salt is absent at the apex. Vertical banding and conical depressions have generally been attributed to a single process. Subaqueous slumping, solution and recrystallization in the presence of synsedimentary water, post-depositional solution and recrystallization by upward moving water liberated during the conversion of gypsum to anhydrite are processes called upon to explain these features. The author believes, however, that the development of vertical striping is not contemporaneous with the formation of the conical depressions. Vertical striping is attributed to water moving downward following the deposition of the individual unit, whereas the depressions have formed following the deposition of the entire salt sequence.

INTRODUCTION

Some of the problems of solution and recrystallization in halite sequences are brought sharply into focus in the halite sequence in the Anhydritegruppe of the Middle Triassic Muschelkalk of southwestern Germany in the vicinity of Heilbronn. Muschelkalk salt, presently distributed in a series of isolated basins roughly along a line from Basel, Switzerland to Magdeburg, Germany, was originally deposited over a much more widespread area (Borchert and Muir, 1964, p. 204) (Fig. 1) in a shelf environment in an arid climatic region adjacent to the Tethys Geosyncline. The original depositional extent was subsequently modified by solution. Muschelkalk salt was first discovered in 1816 through drilling north of Heilbronn near Jagstfeld along the north side of a small salt basin, 75 by 30 kilometers in size. It is in the salt of this basin that this study was undertaken.

In the basin under consideration the salt attains its maximum thickness and diversity of sequence at Heilbronn (Fig. 2). Here, well exposed in the mines of Heilbronn and Kochendorf, can be seen the striking relationship between the 12-20 meters of vertically striped Unteres Salz and the overlying Bändersalz which is comprised of 7-10 meters of horizontally bedded salt. The contact between the two units is sharp and relatively smooth. At Heilbronn, this unit is in turn overlain by the Oberes Salz, up to 20 meters thick, the characteristics of which are essentially identical with those of the Unteres Salz. Local depressions of the Bändersalz ("Napf") accounts for the thinning of the Unteres Salz from 20 meters to a feather edge. North from Heilbronn (Fig. 3) the Oberes Salz is absent at Kochendorf near Bad Friedrichshall and still farther north in the shaft at Jagstfeld only the Unteres Salz is present. The development of the vertical banding and its relationships with the 'normal' banded salt which it encloses is unique and has justifiably received a

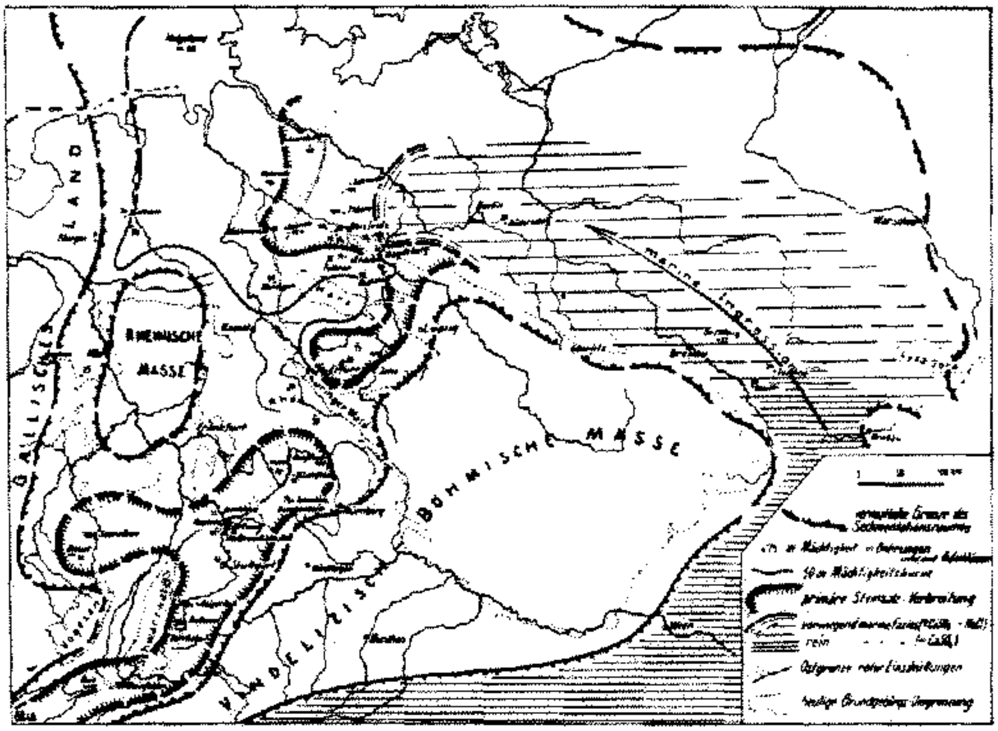


Figure 1. Middle Triassic (Middle Muschelkalk) paleogeography (Richter-Bernburg, 1955).

great deal of attention and has been subjected to a variety of interpretations. This problem, and the associated problem of "Napf" development, were the subject of this investigation.

This presentation and interpretation is based on a limited study, initiated during my residence in Göttingen, Germany, as a Fulbright Research Scholar and completed on my return to the University of Kansas. Credit for any contribution contained herein must be shared. Dr. Annarose Heydemann of the Sedimentpetrographisches Institut der Universität (Göttingen) was responsible for all contacts made with mine personnel. Mr. Hildebrand, also of the Institut, prepared thin and polished sections for laboratory study. Mr. Muthmann and his staff at Heilbronn and Mr. Keune and his staff at Kochendorf were most cordial and helpful. I am particularly indebted to Dr. Robert Kühn of Kaliforschungs-Institut in Hannover who accompanied me to these mines and who also reviewed the manuscript and offered many helpful suggestions.

THE SALT SECTION

Unteres Salz and Oberes Salz are characterized by straight, vertical banding which appears with equal clarity and similar spacings regardless of the orientation of the mine face (Fig. 2). Schachl indicated a columnar structure in cross section, but has observed it only locally. Near the shaft at Kochendorf, mining progressed upward only to just below the base of the Bändersalz and solution by moist air over a long period of time has removed the remaining thin layer of Unteres Salz leaving the contained insolubles in relief. No significant pattern is visible. The vertical banding itself is defined by: (1) the concentration of insolubles in vertical bands, (2) contrasting bands of clear inclusion-free salt and bands of dark inclusion-rich salt, and (3) large masses of clay and anhydrite (Mann-im-Salz, Anhydritsporaden) which are generally elongate in the vertical direction and which usually display an internal bedding structure which, at least in the central section, is horizontal (Fig. 4). Schachl has reported remnants of horizontally banded salt both at the base of and contained within, the Unteres Salz and the Oberes Salz.

The Bändersalz is typical bedded salt and is essentially undeformed. The sequence includes two finely crystalline anhydrite beds, the lower one (Unterere Anhydritebank) of which is contained within the sequence whereas the upper (Oberere Anhydritebank) bed is at the top of the unit. Grain

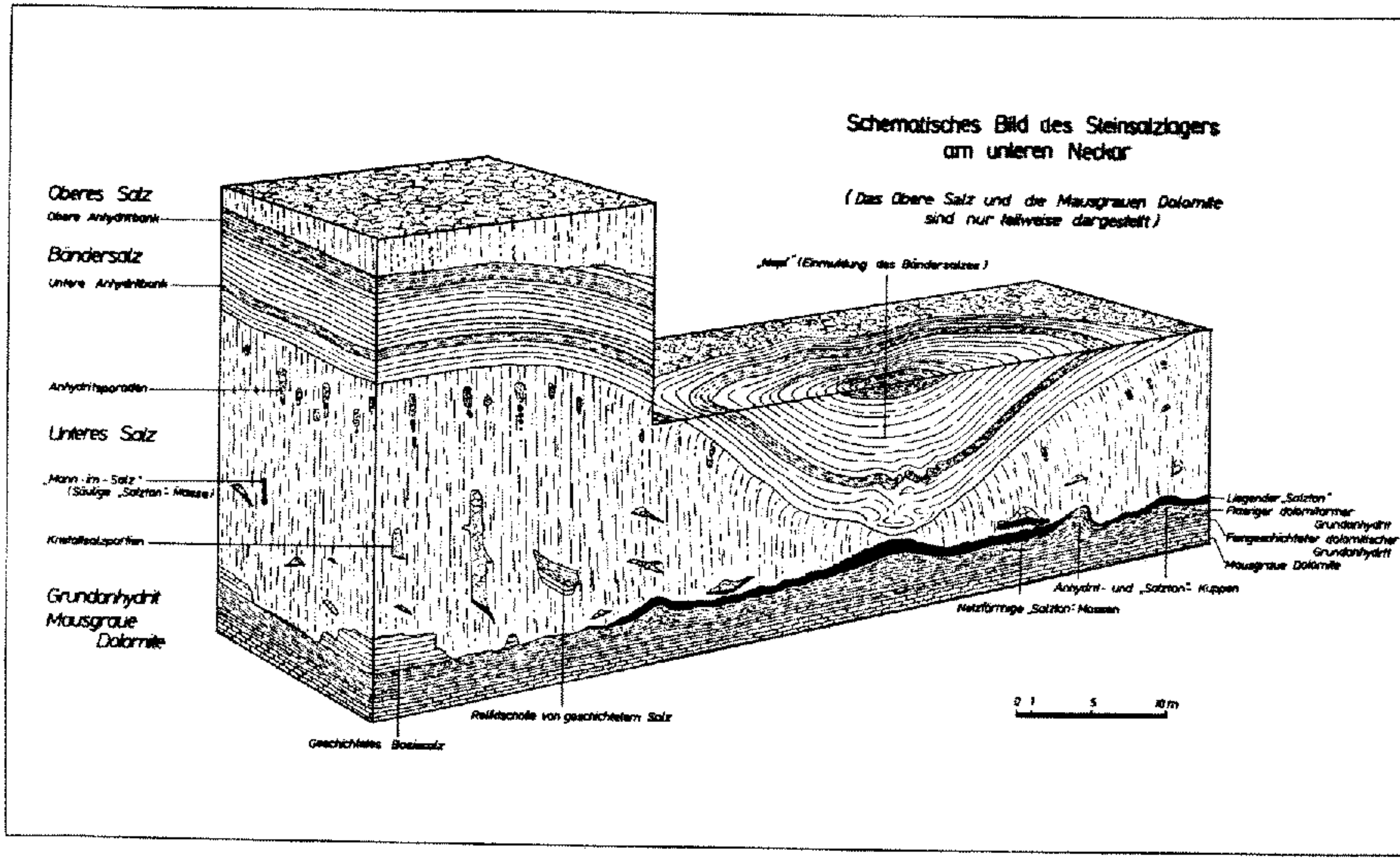


Figure 2. Schematic diagram of the halite sequence in the Middle Muschelkalk in the Lower Neckar District (Schachl, 1954).

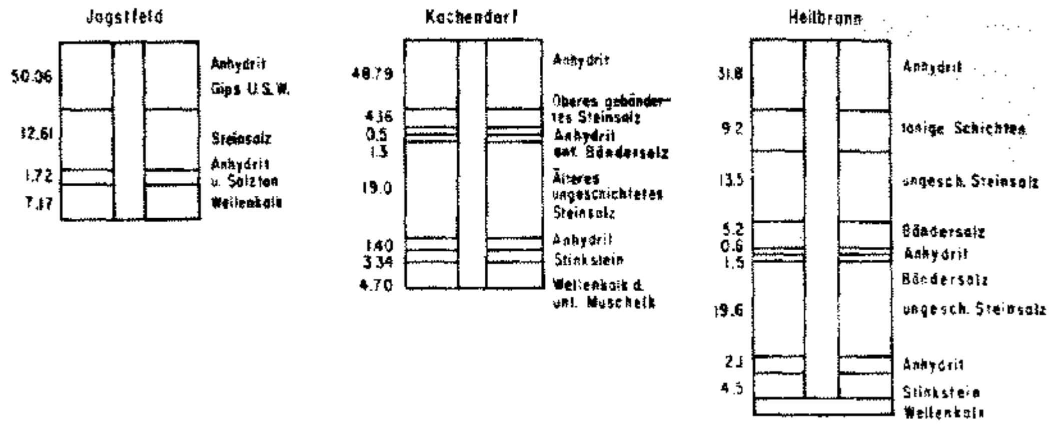


Figure 3. Portion of shaft profiles showing salt sequence at Heilbronn, Kochendorf, and Jagsfeld. (Adapted from mine data supplied by Keune, Friedrichshall-Kochendorf.)

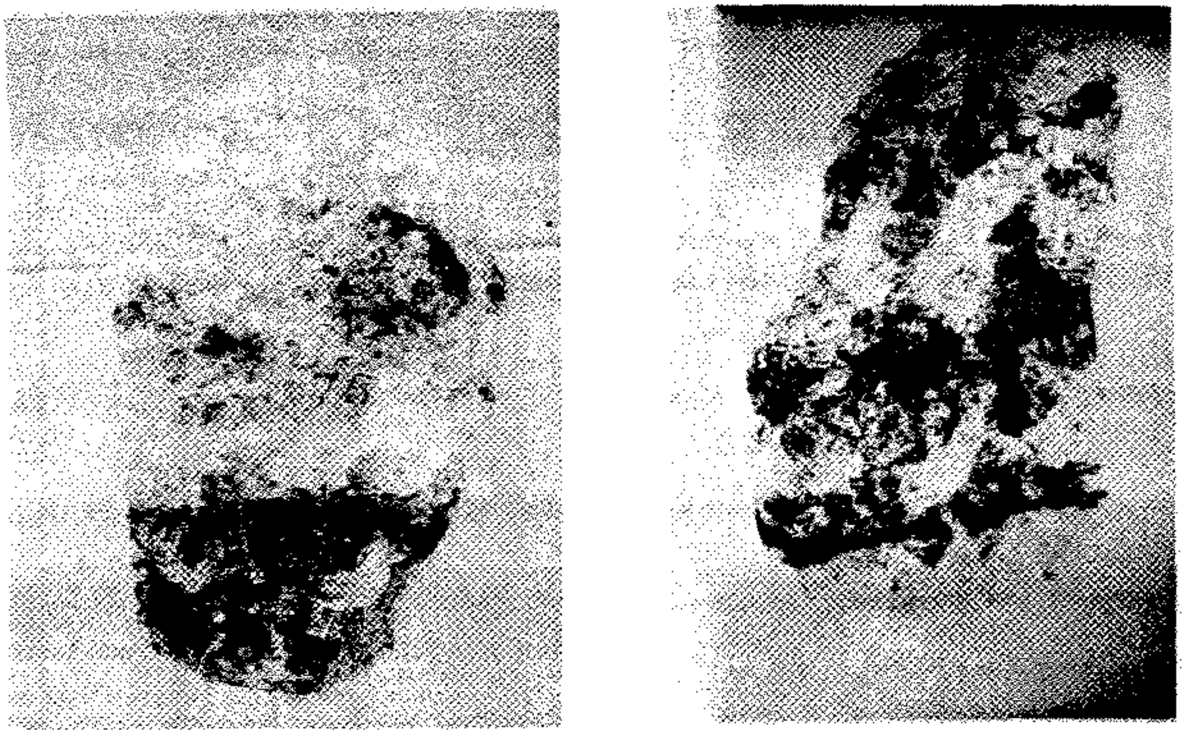
Figure 4. Typical Anhydritsporaden internal structure. Bedding in center is horizontal, progressively increasing in dip toward margin of structure. Specimen is approximately 12 centimeters high and only a part of the structure. Heilbronn.

size in the Bändersalz is small relative to the enclosing Oberes Salz and Unteres Salz. Indications of other than local recrystallization are lacking.

The contact between the Unteres Salz and the Bändersalz is, however, generally sharp and regular, with or without a concentration of insolubles along the surface of separation (Fig. 5). Recrystallization is common along the lower few centimeters of the Bändersalz. The separation is occasionally marked by a layer of clay or anhydrite but not of abnormal thickness as might result from concentration of insolubles below a recrystallized salt layer. The contact between the Bändersalz and the overlying Oberes Salz is limited in exposure. Generally the Oberes Salz lies directly above the Obere Anhydritebank of the Bändersalz although locally Schachl recognized masses of Bändersalz between the Obere Anhydritebank and the Oberes Salz.

"NAPF" STRUCTURES

Complicating the picture are the "Napf" structures (Fig. 2) the development of which have been closely allied by some workers with the development of the vertical banding in the Unteres Salz and Oberes Salz. These structures occur at both Heilbronn and Kochendorf. The depression of Bändersalz into the Unteres Salz may be sufficiently deep so that the Unteres Salz is completely absent at the apex. In Heilbronn, for example, the dip is such in one structure that the normal thickness of 16 meters of Unteres Salz feathers out toward the center of the depression over a lateral distance of 32 meters. In a similar structure at Kochendorf, approximately 11 meters of salt feather out in 40 meters laterally. In the Kochendorf structure, Bändersalz shows some thickening toward the center, and the underlying Grundanhydrit and Mausgraue Dolomite show an elevation slightly above normal. In the center of all such structures there is generally a concentration of Salzton (salt clay) above the Grundanhydrit. In the Unteres Salz immediately below a "Napf," Schachl indicated an inclining of the vertical bands toward the center of the structure. In the "Napf," thin laminae



(a) (b)

Figure 5. Contact between Unteres Salz and Bändersalz; (a) without concentration of insolubles along contact; and (b) with concentration of insolubles along contact. Specimens are approximately 22 centimeters high. Heilbronn.

in Bändersalz below the lower anhydrite are polished and striated, the striations pointing toward the center of the structure. Tension is indicated within the Bändersalz by the stretching and fracturing of bands of insolubles, some fractures in clays having been subsequently filled with red salt. Some folding has also been observed in the center of the structure, thus suggesting at least local compressive forces. However, the general character of Unteres and Bändersalz shows no significant change from areas of normal thickness to areas of "Napf" structure.

PREVIOUS INTERPRETATIONS

Numerous explanations have been offered for the development of the existing structure in Unteres Salz and Oberes Salz. Richter-Bernburg (1955, pp. 634, 635) proposed that the vertical striping represents original bedding planes which have achieved their present orientation through subaqueous slumping (Fig. 6). Slumping of the Unteres Salz was followed by planation and deposition of the Bändersalz, this followed by the deposition of the Oberes Salz and subsequent slumping. However, the near perfect parallelism of the bands; the complete absence of anticlinal crests or synclinal troughs; and the lack of any indication of linearity in plan view which should have resulted from the folding of bedded salt, regardless of the mechanism of deformation; demonstrate the improbability of the development of these structures in this manner.

Most investigators, however, recognize recrystallization as the process responsible for the structure of the Unteres Salz and the Oberes Salz and also for the development of the "Napf" structures. Schachl (1954) attributed the development of vertical banding to synsedimentary solutions whereas Borchert (Borchert and Muir, 1964), p. 208) related the changes to the dehydration of underlying $CaSO_4$ after the deposition of the overlying Muschelkalk sediments, the released water of crystallization moving upward through the Unteres Salz and then migrating laterally along the base of the overlying Bändersalz. The upward migration of water was also responsible for the carrying of basal saltiferous clay blocks, blocks of banded salt, and the clay forming the vertical bands, into their present positions. He rightfully acknowledged the need for large volumes of

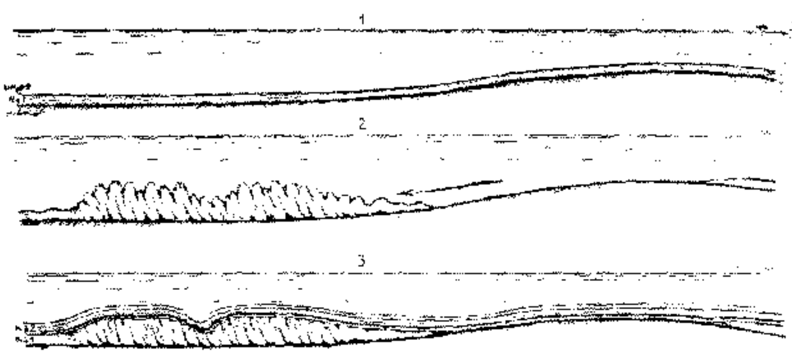


Figure 6. Development of vertical banding in Unteres Salz through subaqueous slumping. (1) Deposition of Unteres Salz, (2) subaqueous slumping, and (3) deposition of overlying Bändersalz (Richter-Bernburg, 1955).

water. Kühn (1964 and personal communication, 1964) based his interpretation primarily on geochemical evidence (Fig. 7), proposing that the Unteres Salz and the Oberes Salz were transported by turbid water as clastic material to the local of deposition and deposited without stratification or vertical structure. With this mechanism of transport Schachl now concurs. Kühn further proposed that solutions moving upward, subsequent to the deposition of all three salt units, were responsible for recrystallization and coincident concentration of insolubles along vertical channels. Where solutions were locally more active, Unteres Salz was removed in large quantity and the collapse of the overlying Bändersalz was effected. Bromine analyses by Haltenhof and Kühn indicate that the Bändersalz consists of primary halite deposited from normal sea water, whereas the Unteres Salz has either been deposited from a brine derived from an earlier deposited salt or has been recrystallized subsequent to deposition. Petrological evidence supports the latter. The chemical documentation of the origin of the present texture and structure of Unteres Salz cannot be ignored but the mechanism and timing of solution and recrystallization leave several points in need of clarification.

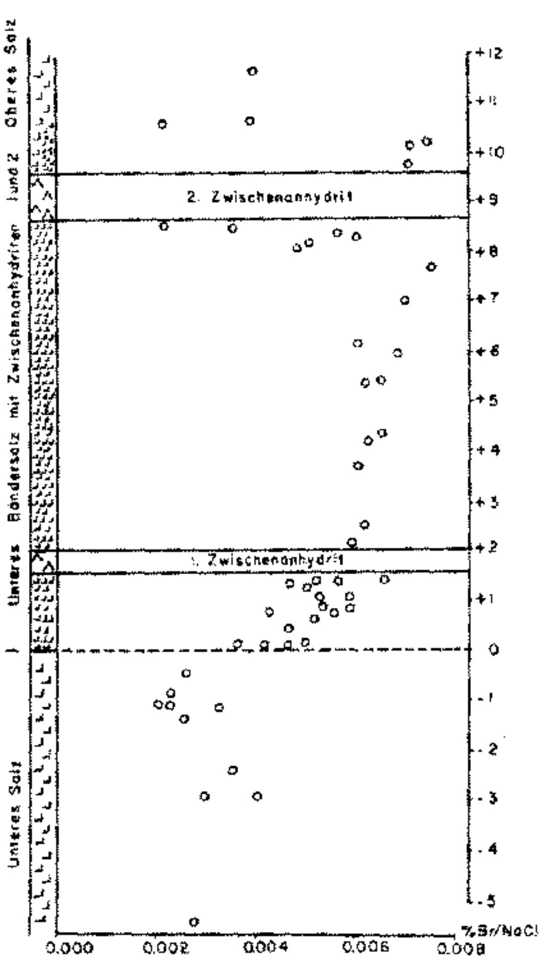


Figure 7. Bromine profile through Unteres Salz and Bändersalz at Kochendorf. (Modified after Kühn, 1964.)

Geologically the problem is somewhat more complex. Bändersalz between the Unteres Salz and the Oberes Salz poses problems relative to the upward or downward movement of the quantities of water proposed by some investigators. It is difficult to visualize recrystallization by upward moving solutions terminating along such a sharp boundary as that between the Unteres and Bändersalz. It is even difficult to visualize upward moving waters are responsible for development of the vertical banding. The transportation by recrystallizing solutions of blocks of Salzston and Basissalz upward through a mass of salt which has attained at least a degree of lithification (Borchert and Muir, 1964, pp. 205-207) is difficult to accept. Utilization of the waters of dehydration from the Grundanhydrit offers a problem in explaining its effectiveness in the Unteres

Salz, for no similar or even detectable alteration has taken place in the Bändersalz as the result of the liberation of water of crystallization from the Untere Anhydritebank. In Anhydritsporaden, horizontal bedding in the center turns upward along the margins of the structure and is more indicative of downward than of upward transport of calcium sulfate.

CONCLUSIONS

Initially I must agree with many investigators who state that the characteristics of the Unteres Salz and the Oberes Salz, when primary deposits, must have differed from the normal bedded halite of the Bändersalz. Recrystallization may, and often does, destroy bedding, but complete removal of evidence of bedding is unlikely, and to propose initial similarity of all three units would make all the more incomprehensible the intense contrast which we see today. The proposal by Kühn, that Unteres Salz and Oberes Salz were transported into their present position as clastic salt by turbulent waters, finds support in the included blocks of basal bedded salt, in some of which the bedding is not horizontal. This mechanism is now supported by Schachl. (Personal communication from Kühn.) That recrystallization occurred cannot be denied, but in the light of much evidence, downward movement of water seems preferable. The aridity of the area in Middle Triassic time, the shifting of connecting channels to the Alpine Geosyncline and the shallowness of the seas, do not preclude, and in fact support, intermittent desiccation of the basin and subsequent development, through expansion and contraction during periods of subareal exposure, of vertical channels for solution movement. The vertical structure then developed through recrystallization prior to the deposition of the overlying unit. The Oberere Anhydritebank served as a barrier to downward moving waters responsible for the recrystallization of the Oberes Salz so that the Bändersalz was not altered. "Napf" structures have formed after the deposition and least partial lithification of the Bändersalz as is indicated in the rupturing of the Untere Anhydritebank, the extensive slickensiding of the shale layers and the maintenance of relatively uniform thickness of the Bändersalz across the structures. Finding a solution to effect the removal of large quantities of salt from beneath the "Napf" and to permit collapse is admittedly difficult. I propose solutions circulating below, and perhaps within, the salt section, dissolving from the bottom up, but not moving through it. I can see no need for, in fact only evidence against, a genetic relationship between "Napf" structures and Unteres Salz and Oberes Salz textures.

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