Exploration of anhydrite wall and klippe structures for an optimized extraction of rock salt in the K+S salt mine Bernburg (Northern Germany)

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Main Anhydrite (Hauptanhydrit) wall and klippe structures of the Leine formation (Zechstein 3) occur in the subhercynian basin. They displace the overlying rock salt and therefore separate the Liniensalz and Kristallsalz, which are the object of mining in the salt mine Bernburg. A combination of underground core drilling and radar measurements in the boreholes allow to determine the size and the occurence of these anhydrite structures. The exploration results are the basis for the selection of rock salt areas which reach the required high quality parameters.

1. Geological Setting

The K+S salt mine Bernburg is located in the southeastern part of the subhercynian basin, which is filled with palaeozoic (Zechstein), mesozoic (Bunter Sandstone, Muschelkalk) and local caenozoic (Oligocene, Holocene) sediments. The border of the basin consists of older palaeozoic rocks from the permo-carbonian period. Parts of these basement rocks crop out in the Harz mountain.

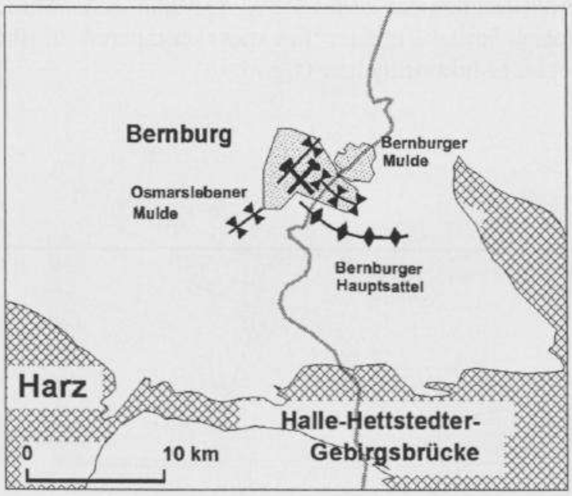

Figure 1. Structural situation in the southeastern part of the subhercynian basin

The salt deposit is tectonically characterized by anticlinal (Bernburger Sattel) and synclinal structures (Bernburger und Osmarslebener Mulde) within the subhercynian basin (fig. 1.).

2. Stratigraphy

The overlying cover of the salt deposit consists of holocene and oligocene sediments as well as the middle and lower Bunter Sandstone.

Table 1
Sequence of strata from the permian to the quaternary sediments of the salt mine Bernburg

Era	Period	Group	Thickness in Meter
Caenozoic	Quaternary	Holocene	up to 7
	Tertiary	Oligocene	up to 40
Mesozoic	Bunter Sandstone	Middle Bunter Sandstone	up to 225
		Lower Bunter Sandstone	up to 290
Palaeozoic	Permian	Zechstein	up to 1100

The Zechstein group is represented by six formations named as Werra, Staßfurt, Leine, Aller, Ohre and Bröckelschiefer (Table 2).

Table 2
Stratigraphy of Zechstein in the salt mine Bernburg

Formation	Zone / Bed	Symbol	Thickness (Meter)
Z 6 Bröckel-schiefer		zB	30-35
Z 5 Ohre	Schluffstein	T5r	4-5
Z 4 Aller	Grenzanhydrit	A5r	up to 1
	Aller-Steinsalz	Na4	up to 35
	Pegmatitanhydrit	A4	up to 2
	Roter Salzton	T4	up to12
Z 3 Leine	Tonflockensalz	Na3ι	15-25
	Schwadensalz	Na3	
	Anhydritmittelsalz	Na3η	20-35
	Bändersalz	Na3ε	6-18
	Kristallsalz	Na3γ	20-50
	Liniensalz	Na3β	15-40
	Basissalz	Na3α	0,5-3
	Hauptanhydrit	A3	15-85
	Grauer Salzton	T3	7-10
Z 2 Staßfurt	Deckanhydrit	A2r	0,7-0,8
	Decksteinsalz	Na2r	0,2-1,5
	Kaliflöz Staßfurt	K2	15-40
	Staßfurt-Steinsalz	Na2	200-700
	Basalanhydrit	A2	1,8-2,7
	Stinkschiefer	Ca2st	5,2-6,7
Z 1 Werra	Oberer Werra-Anhydrit	A1r	20-25
	Werra-Steinsalz	Na1	up to 12
	Unterer Werra-Anhydrit	A1	30-35
	Werra-Karbonat	Ca1	4-10
	Kupferschiefer	T1	0,4-0,5

Object of mining is a bed of rock salt within the Leine formation. This formation is characterized by a thickness between 100 and 200 m. The mined salt bed with the two horizons, the Liniensalz and the Kristallsalz, reach a thickness between 35 m to 90 m depending on the underlying Main Anhydrite (Hauptanhydrit, A3).

The average thickness of 30 m of the Main Anhydrite is often extremely enlarged by klippe and wall structures of the anhydrite

3. ANHYDRITE KLIPPE AND WALL STRUCTURES

The exploration within the salt mine has shown that the Main Anhydrite is characterized by two phenotypes: the klippe and the wall structures. Both structures have the same lithological profile as the the regular layered Main Anhydrite with seven zones: A3α, A3β, A3γ, A3δ, A3ε, A3t and A3a. The structural change between these zones of the Main Anhydrite is described in [1].

3.1. Properties of klippe and wall structures

The distinction of the two main anhydrite structures is based on their length, width and thickness.

Table 3
Properties of klippe and wall structures

Property	Klippe	Wall
Thickness	35 – 85 m	70 m
Length	10 to 100 m	1000 m
Width	< 200 m	>500 m

The difference in thickness between the regular layered Main Anhydrite and its wall or klippe structures especially depends on the thickness of the three lithological zones A3γ, A3δ and A3ε. These zones have a greater thickness compared to the regular Main Anhydrite (fig.2).

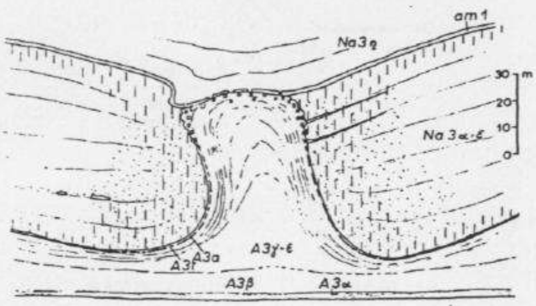

Figure 2. Section of a anhydrite klippe structure [1]

3.2. Origin and occurrence

The origin of the anhydrite structures is based on the dehydration of the primary sedimented gypsum. The process started after the sedimentation of the gypsum and continued during deposition of rock salt in the Leine formation (fig 3.).

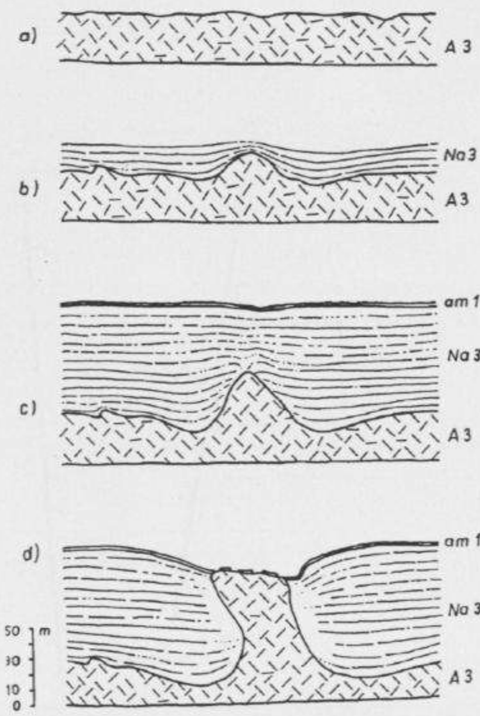

Figure 3. Example of the development of a klippe structure [1]

Wall and klippe structures all terminate in the Bändersalz (Na3 ε) level or with the first anhydrite layer within the Anhydritmittelsalz (Na3η).

The textural observations in [1] agree with the geochemical considerations from [2-6].

The mining in Bernburg has shown, that most of the wall and klippe structures have different thicknesses. Their distribution is irregular. Regular layered Main Anhydrite alternate with klippe and wall structures within a short distance (fig. 4).

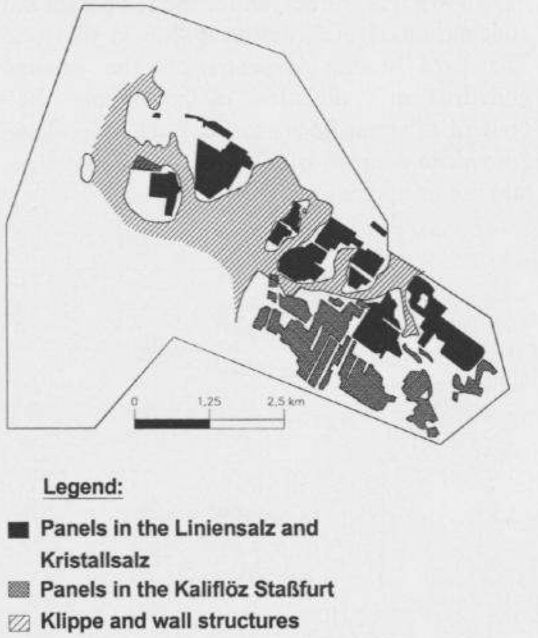

Figure 4. Occurence of wall an klippe structures of main anhydrite in the salt mine Bernburg [7]

The largest wall structure of the Main Anhydrite is located between the central field and the west field in Bernburg. It has a width of 1000 m and a thickness of 60 m.

The exploration of the west field began after the development heading for the ventilation system and the haulage drift in 1980.

Today the mining activities are concentrated in the west field. In this panel wall and klippe structures of Main Anhydrite are similar to the structures in the east and central field.

3.3. Transition from Main Anhydrite structures to the rock salt bed

In most cases, wall and klippe structures include areas of rock salt. Among these, two stratigraphical horizons, the Liniensalz (Na3β) and Kristallsalz (Na3γ), with a total thickness of up to 90 meters and NaCl contents of 98,5 % to 99,7 % can be found. The rock salt of the two horizons is colourless and characterized by clear coarse grained halite crystals.

Aureoles of red and grey colour occur in the transition zone between the Main Anhydrite structures and the rock salt.

Microscopical examinations of this appearence has shown that the reason for the red colour are high concentrations of hematite within in the rock salt. The grey colour depends on the contents of anhydrite and polyhalite. In the aureoles the NaCl content is about 95 % to 96 % (fig. 5). The Main Anhydrite consists of 97 % to 98 % anhydrite, clay and minor magnesite.

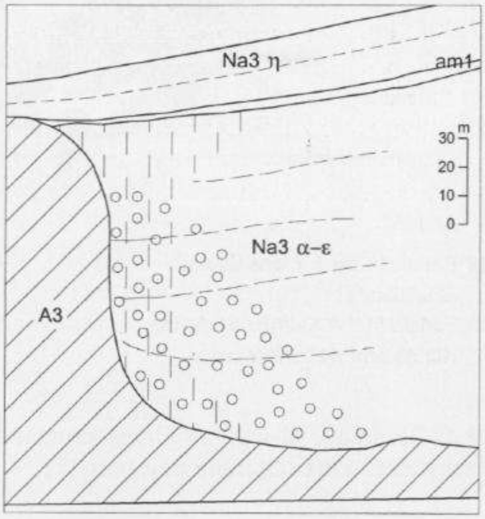

Figure 5. Transition zone from a klippe structure of Main Anhydrite to the bed of Liniensalz and Kristallsalz (Na3 β/γ)

Legend:	A3	- wall structure
	Na3α-ε	- Basissalz to Bändersalz
	Na3η	- Anhydritmittelsalz
	||	- red aureole
	°	- grey aureole

4. EXCAVATION METHOD

In the salt mine Bernburg a panel work with sub-level stoping is practised. The principle is to closely join at least four rooms with a width of 20 m, height of 40 m and a length of 400 m to one mining subpanel.

In a first step the opening-out of these subpanels is realized through a passby from four sites. It is followed by narrow workings along the stratigraphical boundary between Kristallsalz (Na3β) and Bändersalz (Na3ε). After this work the passby and the rooms become arched (fig. 6.).

The installation of conveyer belts and the crushing station follows in a second step. In the third step the extraction of the bench is started.

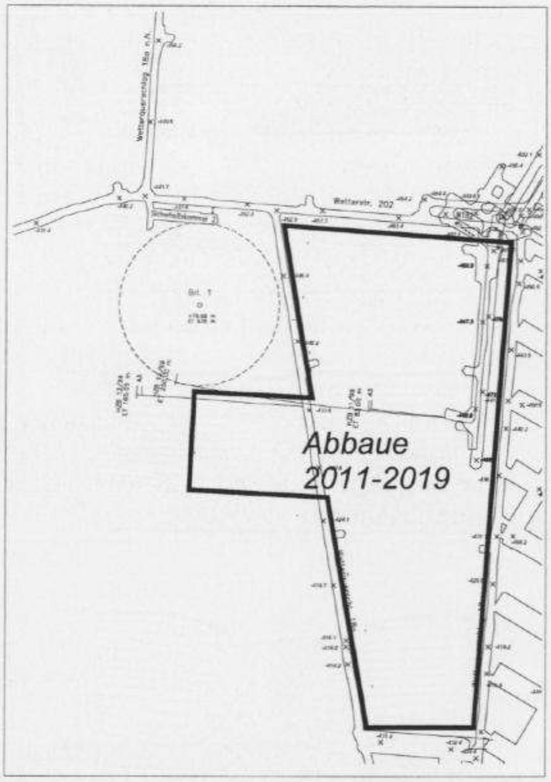

Figure 6. Example of a mining subpanel with the planning of the rooms (Abbaue) 2011-2019

5. EXPLORATION

Before these steps can be realized, it is necessary to explore the subpanel with boreholes and radar measurements.

5.1. Exploration drilling

The boreholes are carried out using counterflush core drilling. With this drilling method, it is possible to explore the Main Anhydrite structures and the mineable bed with the drilling machine Wirth ECO–1 up to a distance of 1300 m.

The drilling fluid consists of a high concentrated brine and the tracer of zinc sulphate. With this method, it is possible to gain informations about natural brines within the rock salt or wall and klippe structures. In the past five brine occurences with a density of 1,3 g/cm^3 were discovered. The volumes were limited and the chemical analyses indicated, that the brines can be characterized as an intrasalinar type with $MgCl_2$ content of more than 320 g/l. In some cases smaller amounts of gas were observed in addition to the salt brine.

The gas is basically composed of nitrogen (60 to 70 %) and methane (30 to 40 %). In all cases of brine occurences, the boreholes were plugged with magnesia slurry.

After completing the borehole and carrying out the survey the core has to be examined and described by the geologist. The result is a geological profile, wich describes the bedding, the thickness and the colour of the rock salt bed.

Afterwards the bore cores of the rock salt bed are sent to the laboratory for chemical analyses. In the laboratory especially the contents of NaCl and $MgSO_4$ are determined.

5.2. Radar measurement

In the early 1970's K+S developed a radar system particular adapted to exploration work in salt and potash mines. A special feature is the capability to survey (sub-) horizontal boreholes more than 1800 m long.

The radar system works with frequencies of 30 to 250 MHz and can be used in boreholes with diameters of more than 42 mm. During the survey, the radar probes are pushed by special tubings. Every 5 m a measurement is recorded. After data processing and spatial migration the reflector horizons are interpreted.

In the Bernburg mine the radar system is used for exploration of the surface of the Main Anhydrite including wall and klippe structures. Another object for radar measurements is the salt cover above the mining level with the Bändersalz (Na3ε) and the Anhydritmittelsalz (Na3η).

The exploration allows an exact placement of the mining panels (fig .8).

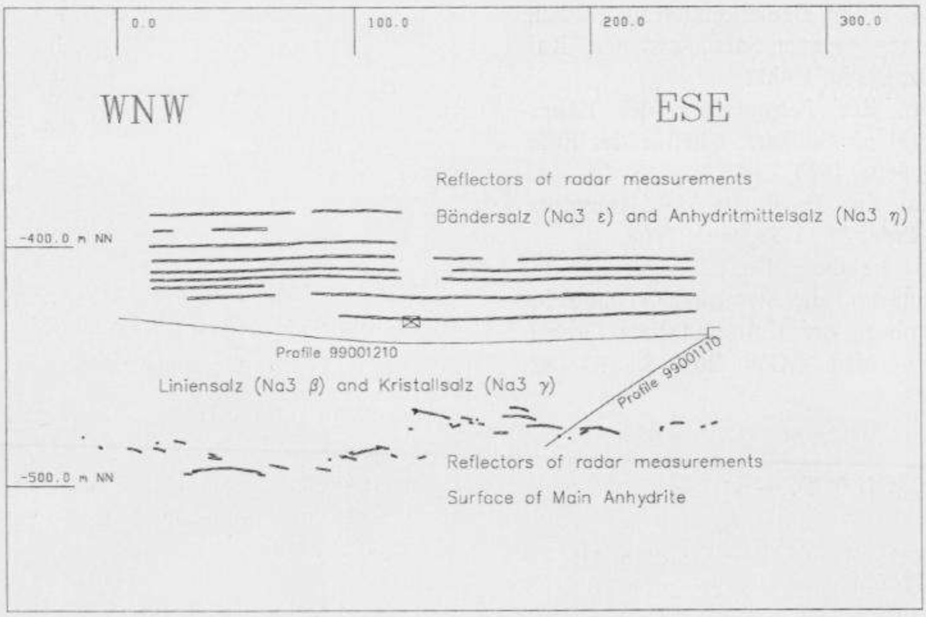

Figure 8. Exploration results by drilling and radar measurements

6. CONCLUSIONS

For the exploration and the opening up of the seam the knowledge of the occurence and size of the Main Anhydrite klippe and wall structures is of fundamental importance for mining.

Through a combination of borehole exploration and radar measurements it is possible to locate areas of rock salt with high quality parameters. This finally allows to obtain a panel work with sub-level stoping and extraction rates of 40 %.

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