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ANHYDRITES FROM GYPSUM CAP-ROCK OF ZECHSTEIN SALT DIAPIRS

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Abstract: Petrographic studies of gypsum cap-rock formations of the Wapno, Dębina, Mogilno (Poland) and Gorleben (Germany) salt domes indicate that the occurrence of anhydrite in the domes, in the form of both single grains which sometimes create an anhydritic sandstone bed in the bottom section of the cap-rocks, and massive fragments or anhydrite rocks (detached blocks), most often represent the Main Anhydrite formations.
Both types of anhydrites:

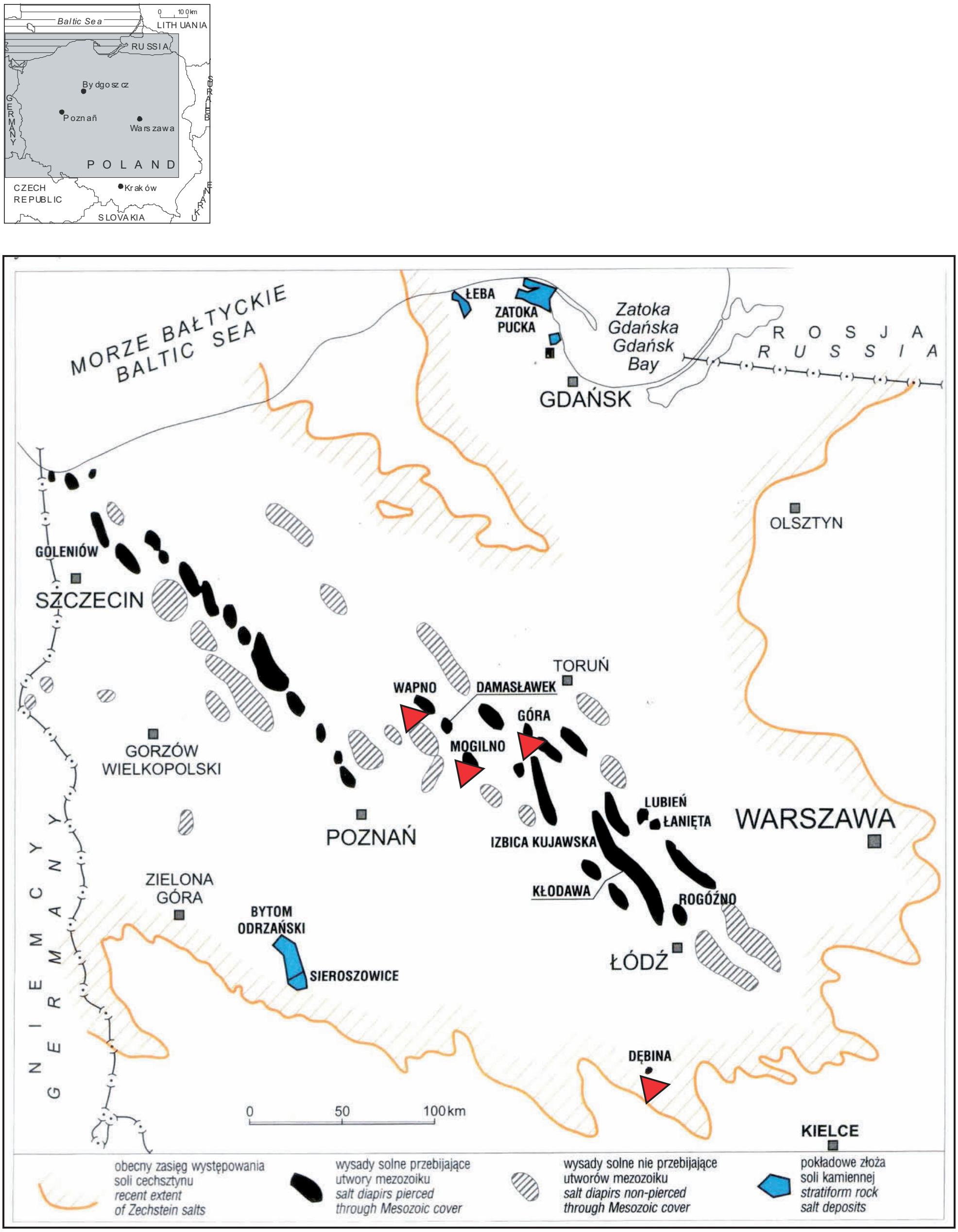
- can be distinguished owing to their different structures and textures,
- are subjected to the gypsification process, although anhydrite sand and sandstone are transformed quickly, while detached blocks of anhydrite very slowly.

Residuum anhydrites are concentrated in the cap-rock bottom and/or dispersed in coarse-crystal gypsums, while detached blocks occur irregularly.

Key words: anhydrites, diapirs, cap-rock, residuum, detached blocks, gypsification

INTRODUCTION

Most anhydrites on the Earth are of evaporate origin. They were formed in specific order as a result of the precipitation of calcium sulphate inside the gradually drying basins. During evaporation processes, the gypsum crystallizes first, than the anhydrite, but actually the only phase of calcium sulphate which crystallizes with rock salts is anhydrite. The thick rock salt deposits seldom form salt structures: pillows, swells, and diapirs. Sometimes roof surfaces of such salt structures (salt mirrors) are located close to the Earth's surface and easily undergo leaching, leaving less soluble residues, mainly anhydrite grains, forming the so-called cap-rock that constitutes the natural cover of the salt deposit.



▶ selected diapirs

Fig. 1. Salt structures in Poland (after Karnkowski & Czapowski 2007)

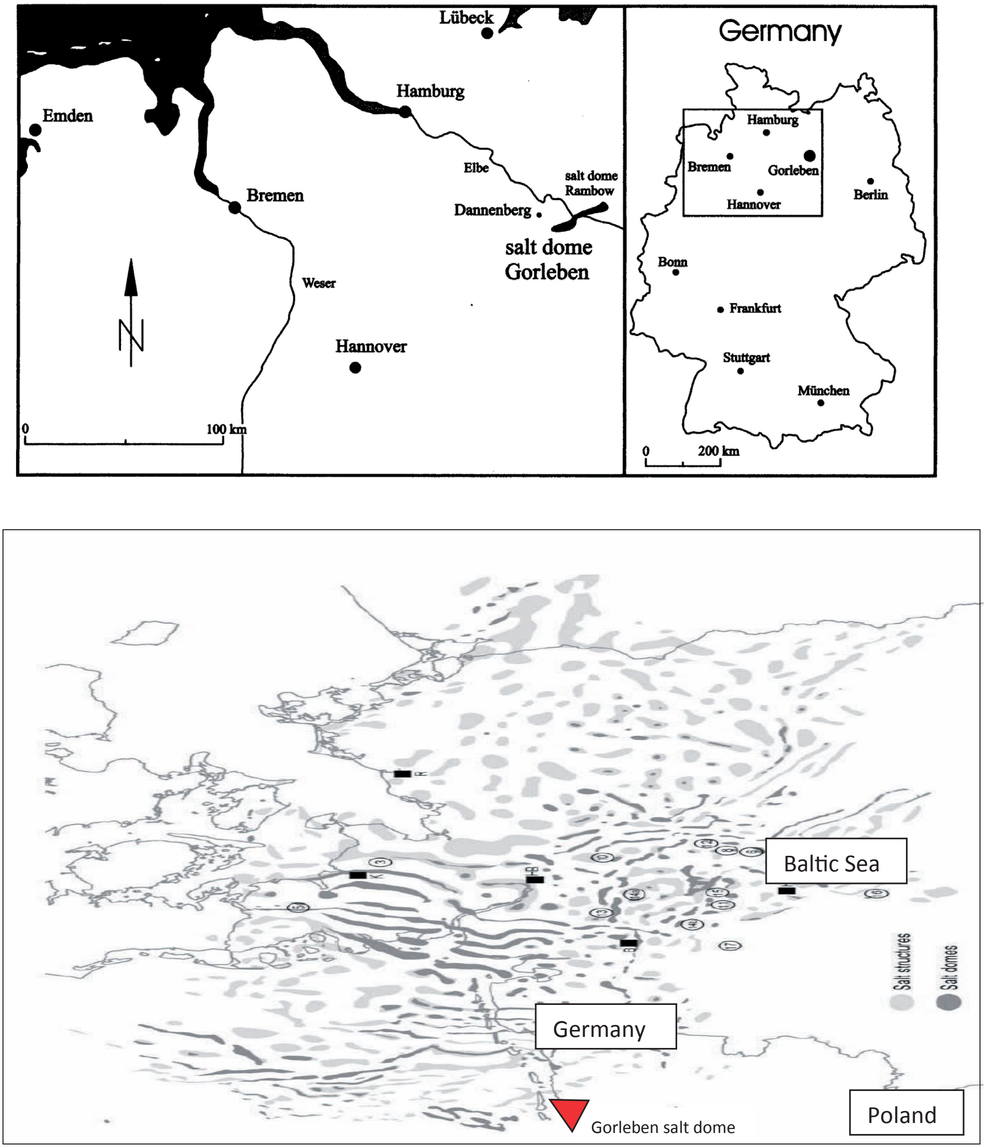


Fig. 2. Location of the Gorleben salt dome (Bäuerle et al. 2000b). The salt structures in western part of the Southern European Permian Basin. Fields: black – salt domes, grey – salt pillows (Kockel 2003)

Anhydrite grains are very easily transformed into gypsum. In fact, cap-rocks are complex objects and they consist of the material from the dissolution of the rock salt (residuum), detached blocks of the rocks surrounding the salt dome or of the accompanying rock salt, weathering waste of the cap-rock, gypsum-clay breccias, and new minerals precipitated from the solutions circulating in the cap-rock (Jaworska et al. 2010). The cap-rock stratigraphy is generally inverse: the oldest rocks are on top and the youngest sediments on the bottom, near the salt mirror.

The purpose of this study is to determine the origin and diagenetic history of anhydrites occurring within cap-rocks (usually being gypsum cap-rocks) in Wapno, Mogilno, and Dębina in Poland (the Great Poland, Kujawy, and Mazowsze Lowland regions) (Fig. 1), as well as Gorleben in Germany (near the borders of Lower Saxony, Saxony-Anhalt and Branderburg) (Fig. 2). The most important elements of this study include mineralogical and petrographic analyses of anhydrite samples collected from the boreholes of Gorleben (2 boreholes), Wapno (12 boreholes; partly incomplete), Mogilno (3 boreholes), Dębina (1 borehole; incomplete) or the rock salt samples, with anhydrite grains originating from Góra (1 borehole).

GEOLOGICAL SETTING

Salt structures: diapirs, pillows, and swells are the most characteristic elements of the Zechstein (Late Permian) deposits in the European Southern Permian Basin (ESPB). This basin, with the area of about 600,000 km^2, was divided into two epicontinental sub-basins: east basin (Polish) and west basin (from British Isles to Germany) (Ziegler 1990, Dadlez et al. 2005, García-Veigas et al. 2011).

The Kujawy and the Great Poland areas constituted the central parts of the Polish Zechstein Basin. This basin, as well the German Basin, became filled with four successive evaporate layers, including salt rocks, several hundred meters thick. The Late Permian evaporates were buried under Triassic, Jurassic, Cretaceous and Cenozoic strata. During the Mesozoic (mainly in the Late Cretaceous), salt deposits evolved simultaneously and the Zechstein basin was affected by intensive tectonic movements. The present-day salt bodies are of various sizes and they occur at a wide range of levels in the Mesozoic rocks, penetrated by brine. In effect, diaper salt deposits obtained very complex internal structures. Some salt diapirs, including those of Mogilno, Wapno, Dębina, Góra (in Poland), and Gorleben (in Germany), cut the Mesozoic surface, and penetrated the Cenozoic cover. The salt mirror in the majority of salt structures in Poland is located at depth below 1,500 m, although in some cases (i.e. Mogilno, Wapno, Dębina, and Góra) at no more then 200–300 m and close to the surface. A similar situation is noted in Germany; the salt mirror of the Gorleben salt dome is located at the depth of 310 m b.s.l. All those salt structures are protected in a natural manner by gypsum cap-rocks, covering upper parts of salt bodies. The gypsum cap-rock thickness is changing as follows: Wapno (70–160 m), Mogilno (100–190 m), Dębina (ca. 48 m), and Gorleben (ca. 111 m).

The sequence of the Zechstein evaporates is arranged in four cycles/cyclothems: PZ1 (Werra), PZ2 (Stassfurt), PZ3 (Leine), and PZ4 (Aller) (see Fig. 3 and Tab. 1). The salt diapirs presented there do not show the salt of the Werra cyclothem (PZ1/Z1). Probably, that part of the salt sequence occurs at greater depths. In the central parts of the salt bodies, analysts observed the profiles of the Stassfurt cyclothem (Z2), beginning with the Older Halite (Na2), and the sediments of the Leine (Z3) and Aller cyclothems (Z4) in peripheral sections. What is characteristic of those structures is the vertical arrangement of the layers of three Zechstein salt cycles. The internal structure of the salt body is complex and it contains folds, with vertical, steeply inclined, and overturned axes.

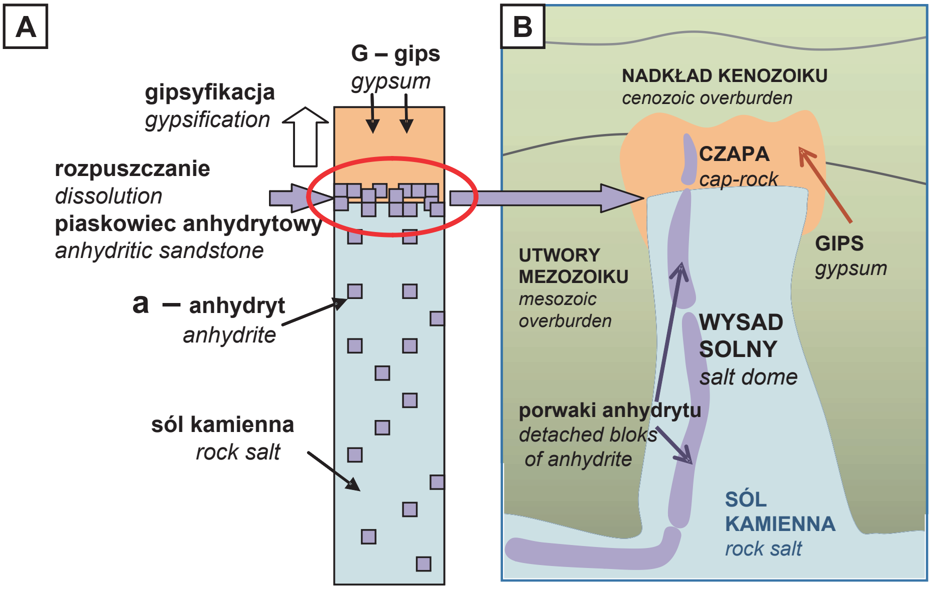


Fig. 3. Origin of anhydrites in cap-rocks of salt domes: A) anhydrites – insoluble material – residuum after salt solution; B) anhydrites – detached bloks

Table 1

Simplified Zechstein profiles in the Polish and German Basins (after Wagner 1994)

Cyclothems	Simplified main units (Polish Zechstein Basin)	Simplified main units (German Zechstein Basin)
Z4/PZ4 ALLER saline units (Na4), alternating with anhydrite (A4) and detrical unit (T4)	Upper Youngest Clay Halite (Na4a2t)	Aller Steisaltz (Na4)
	Upper Youngest Halite (Na4a2)	
	Upper Pegmatite Anhydrite (A4a2)	
	Lower Youngest Halite (Na4a1)	
	Lower Pegmatite Anhydrite (A4a1)	Pegmatitanhydrit (A4)
	Underlying Halite (Na4a0)	
	Lower Red Pelite (T4a)	Roter Saltzton (T4)

Table 1 cont.

Cyclothems	Simplified main units (Polish Zechstein Basin)	Simplified main units (German Zechstein Basin)
Z3/PZ3 LEINE	Younger Clay Halite (Na3t)	Leine Steinsaltz with Kalisalze (Na3)
	Younger Potash (K3)	
	Younger Halite (Na3)	
	Main Anhydrite (A3)	Hauptanhydrit (A3)
	Platy Dolomite (Ca3)	Plattendolomit (Ca3)
	Grey Pelite/Grey Salt Clay (T3)	Grauer Saltzton (T3)
Z2/PZ2 STASSFURT	Screening Anhydrite (A2r)	Deckanhydrit (A2r)
	Screening Older Halite (Na2r)	Decksteinsaltz (Na2r)
	Older Potash (K2).	Stassfurt Kalisaltz (K2)
	Older Halite (Na2)	Stassfurt Steinsaltz (Na2)
	Basal Anhydrite (A2)	Basalanhydrit (A2)
	Main Dolomite (Ca2)	Stassfurtkarbonat (Ca2)
Z1/PZ1 WERRA	Upper Anhydrite (A1g)	Ob. Werra-Anhydrit (A1o)
	Oldest Halite (Na1)	Werra Steinsalz (Na1)
	Lower Anhydrite (A1d)	Unt. Werra-Anhydrit (A1u)
	Zechstein Limestone (Ca1)	Werrakarbonat (Ca1)
	The Kupferschiefer/Copper Shale (T1)	Kupferschiefer (T1)

METHODS

Over 120 thin sections of cap-rock collected from 18 boreholes were studied: Gorleben (2 boreholes: 3010 and 3155), Wapno (12 boreholes: C1, C4, C6, G1, 240, 263, 267, 269, 270, 271, 272, and 278; partly incomplete), Mogilno (3 boreholes: M3, M9, and M13), Dębina (1 borehole; incomplete), as well as 10 samples of anhydrite grains originating from Góra (1 borehole). Mineralogical and petrographic analyses were carried out: binocular-loupe and scanning electron microscopy, using Hitachi S-3700N (SEM, with back scattered electron image), for anhydrite grain observation, and optical microscopy, using OLYMPUS AX70 PROVS, with a DP50 camera, for thin section observations.

RESULTS AND DISCUSSION

The petrographic analysis of the sulphate samples from:

- cap-rocks (usually gypsum cap-rocks) covering the ceiling sections of the salt diapirs of Wapno, Mogilno, Dębina, and Gorleben,
- rocky salt (water-insoluble residuum) from the Góra diapir,

indicated, that the origin of anhydrites occurring within cap-rocks could be of two types:

1) “residual” anhydrites, or
2) detached blocks of anhydrites (see Fig. 3A, B).

“Residual” anhydrites

The first type of anhydrites consists of calcium sulphate, constituting a classical residuum occurring after rock salt dissolution (Fig. 3A). On the European Lowland areas, the cores, or the central sections of diapirs, are formed by the second cyclothem salts (Z2/PZ2). They are Older Halite characterized by high purity (more than 90%). The remaining several percent include “impurities” composing insoluble or hardly soluble residuum. Anhydrite is usually the main, or sometimes the only residuum component (Fig. 4), accompanied by other minerals in much smaller quantities (e.g. carbonates, sulphides, clay minerals, quartz etc.). Those diapirs that have pierced through the Mesozoic formations and penetrated the Cenozoic deposits are particularly exposed to aggressive, leaching activity of underground waters. On the top of those diapirs, anhydrite sand deposits are collected at the height of the salt mirror (Fig. 5). It quickly transforms into anhydrite sandstone, often bound by halite, with the texture called a “pile of brick.” The level of sands and anhydrite sandstone usually creates a clear layer separating in diapires the top of rock salt from the bottom of gypsum cap-rock. That level is not often found in boreholes (some boreholes from Wapno and Dębina are incomplete). However, wherever that level was recognized, its thickness was up to 10 cm (in the case of Wapno and Gorleben; Fig. 5A, C) and 3 cm (in the case of Mogilno; Fig. 5B). Such a level was not identified in the Dębina diapir.

A close microscopic observation of the anhydrites obtained from the dissolution of the rock salts of the Dębina and Góra diapirs indicated that residuum anhydrites had the form of grains/crystals of the size of 0.5–2.0 mm (see Fig. 4A, B). Sometimes, they form larger aggregates (with several integrated individuals) or several-millimetre large grains, showing the traces of corrosion (dissolution). Their particular shapes can be:

- automorphous, and then they assume the habit of prismatic/tablet crystals (the class of double rhombic pyramid (see Fig. 4C), or
- irregular, or
- thin prisms/plates, with octagonal shape (see Fig. 4D), or
- short studs, with edges finished with “crest” (see Figs. 4E, F).

Those minerals crystallized together with rock salts, which is indicated e.g. by:

- the isotopic analyses of $\delta^{18}O$ and $\delta^{34}S$ anhydrite sample (anhydrite sands) from the Mogilno diapirs: the $\delta^{18}O$ and $\delta^{34}S$ values measured in the SO_4 point at the Zechstein evaporite basin as the primary source of these sulphates (Jaworska 2012, Jaworska & Wilkosz 2012);
- a high strontium content in comparison to that of the overlying gypsum rocks (gypsum cap-rock).

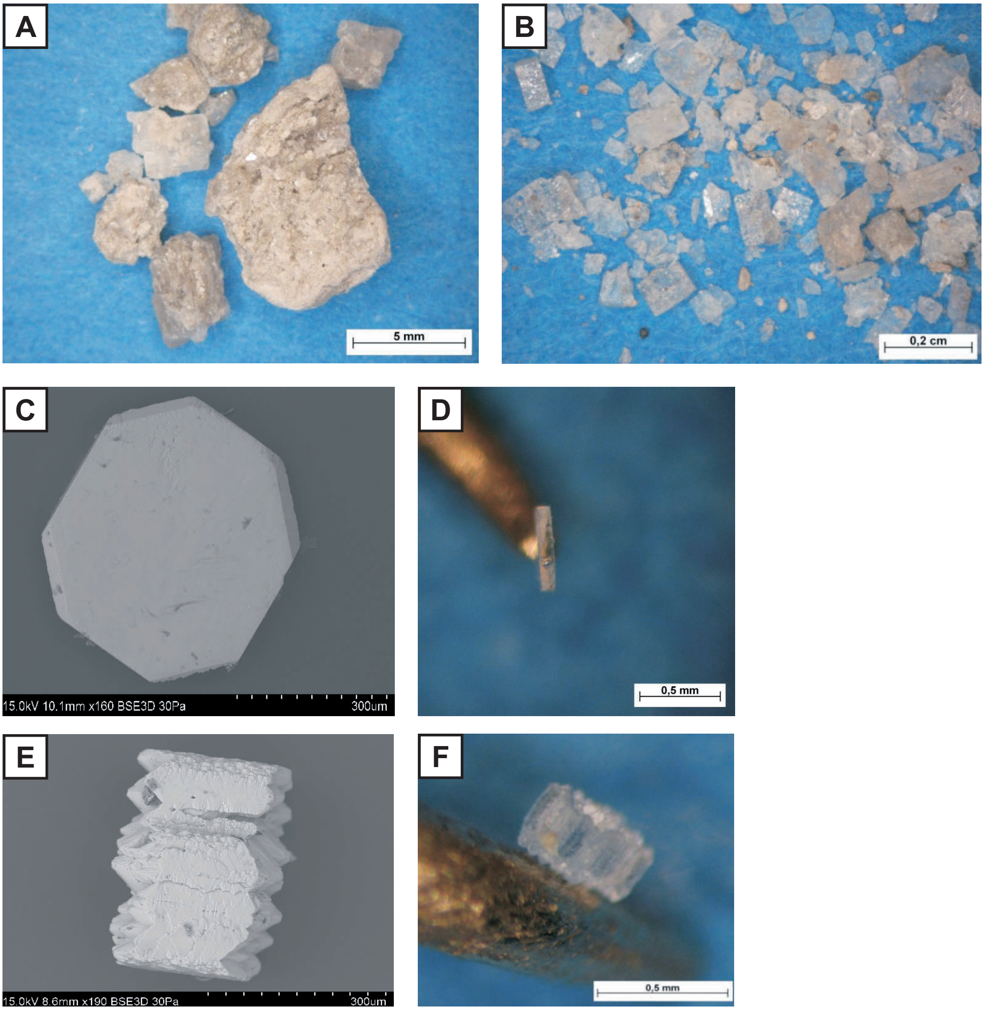


Fig. 4. Anhydrites – insoluble material – residuum after salt solution (rock salt of Dębina dome): A) and B) fraction >1 mm; C)–F) fraction <1 mm (phot. A. Kyc, J. Jaworska). Figures A, B, D, F – binocular pictures, figures C and E – SEM-BSE pictures

The strontium content analysis in the anhydrite sandstone samples collected in Wapno displayed the values of the order of 1,700 ppm and the overlying gypsums Sr content ranged between 750 ppm to 160 ppm (Jaworska & Ratajczak 2008, Jaworska 2010 abs.). The low Sr content in gypsum samples resulted from the diagenetic processes occurring in an open system (Sr is easily removed in an open system). The crystallization of anhydrites from brine started on a larger scale when the brine concentration reached the value of 5–6 times higher in comparison to that of normal sea water salinity, at the temperature of about 40°C (Warren 1999).

At that stage, anhydrites are still accompanied by gypsum. During the evaporation process, gypsum crystallizes as the first mineral (at much lower brine concentrations). Only in the case of the brine whose concentration is close to NaCl saturation (ca. 320 g/dm^3), practically, anhydrite is the only calcium sulphate phase which crystallizes at that time and accompanies rock salts, even when the temperature does not exceed 18°C (Jowett et al. 1993).

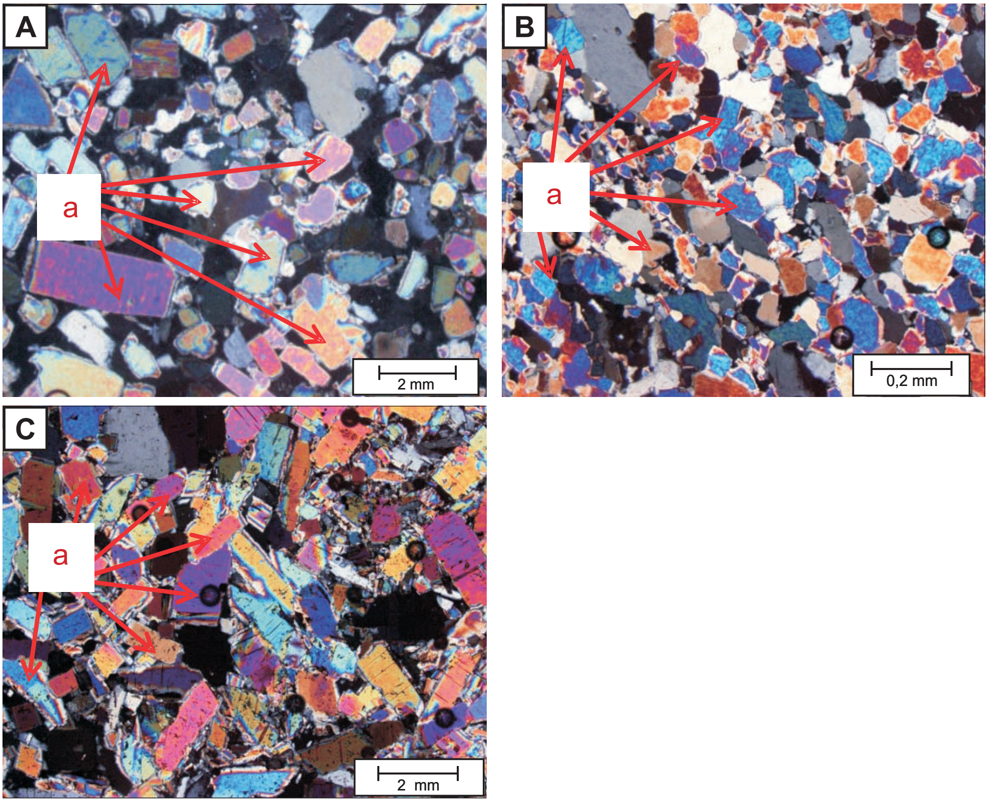


Fig. 5. Anhydrite sandstone, salt mirror. Salt diapirs: A) Wapno; B) Mogilno; C) Gorleben. XN, scale in photo; a – anhydrite (phot. J. Jaworska)

Anhydrite crystals sometimes contain ingrowths of e.g. pyrite (the Góra diapir) or they constitute small ingrowths, e.g. in euhedral quartz crystals. Euhedral quartzes with anhydrite ingrowths were recognized in the cap-rocks of the Wapno, Mogilno, and Gorleben diapirs.

Detached blocks of anhydrites

The other type of anhydrites includes the detached blocks of anhydrite layers (see Fig. 3B), occurring in Zechstein cyclothems. They primarily belong to Z3 (Main Anhydrite; Fig. 6A, B), which is lying directly above Z2. Salt diapirs are some of the largest folds, with the highest amplitude. The height of those folds reaches several kilometres, depending on the Zechstein deposit depth and the degree of its penetration through the Mesozoic and Cenozoic caps. In the case of the Gorleben diapir, the depth is 4 km (present Zechstein deposit depth), while in the cases of the Wapno, Mogilno, and Dębina diapirs, it is 6–8 km deep.

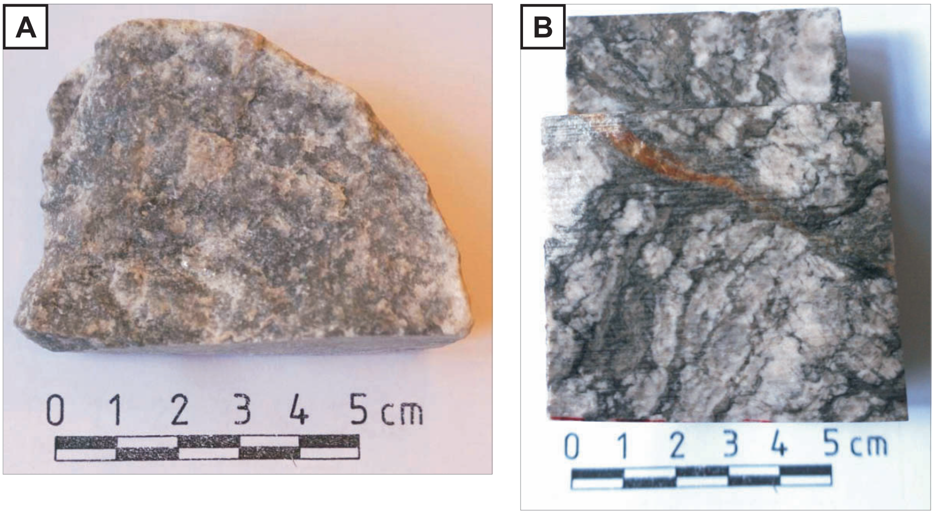


Fig. 6. Fragments of drill cores, detached blocks of Main Anhydrite Z3. Gypsum cap-rock salt dome: A) Wapno; B) Gorleben (phot. J. Jaworska)

The anhydrite rocks creating detached blocks were pressed out, together with Older Halite, towards the salt mirror and terrain surface, and, as being much less plastic in comparison to rock salts, the anhydrite rocks behave as rigid rocks and get crushed. They have the form of boudins, or otherwise they are described as breccias. For example, the occurrence of Main Anhydrite in the Wapno diapir salts, in the form of detached blocks, was described by Poborski et al. (1956); the mineral was accompanied by a polyhalite vain. Charysz (1973) described it as tectonic detached blocks (2.0–2.5 m in size) of Main Anhydrite (dark grey and streaky), with crystalline texture. Within carnallite salt, the presence of dark-grey silt salt chips, with single detached block of anhydrite, was additionally identified, which made the impression of dislocation breccias (Poborski et al. 1956). When describing the occurrences of Younger Halite in Wapno, Charysz (1973) found abnormal contacts between Older Halite and Younger one of the lower stratum where, along the dislocation joint separating the two, there were detached blocks of Main Anhydrite dispersed, with grey salt silts. In the case of the Main Anhydrite (*Hauptanhydrit* in German) of the Gorleben diapir, those formations created a clear and locally torn apart, 68 m bed which pierced through up to the very salt mirror, creating an "anhydrite cliff," distinguished by its morphology (Bäuerle et al. 2000a). Those formations are easily recognizable and they constitute a very important stratigraphic horizon. Within those formations, several characteristic types were described, e.g. those with stylolithic structures (Bäuerle et al. 2000b), turbidites, breccias etc. (Bäuerle et al. 2000a).

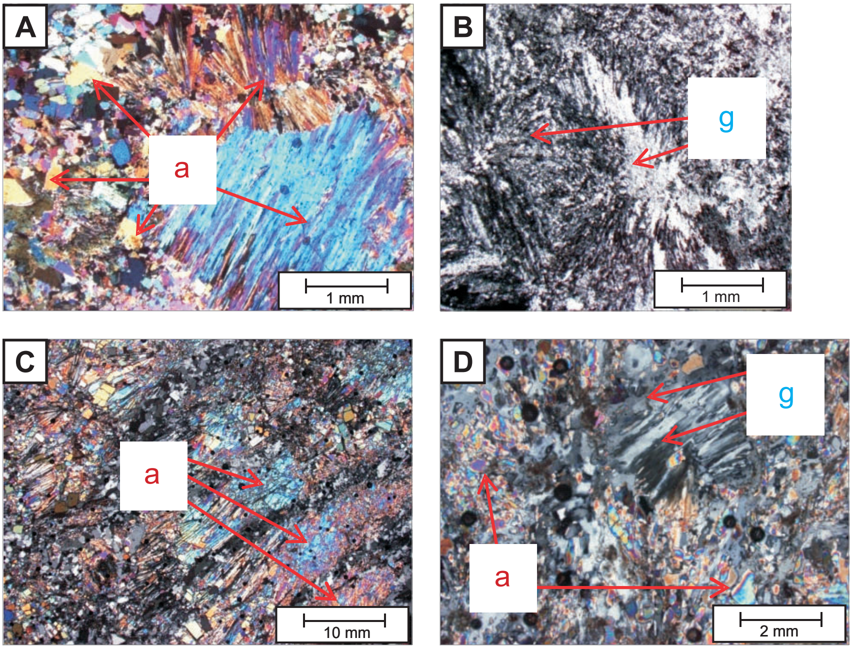


Fig. 7. Microphotographs of detached blocks of Main Anhydrite Z3, „fish-bone" structure, XN, scale in photo. Gypsum cap-rock salt dome: A) and B) Wapno; C) and D) Gorleben; a – anhydrite, g – gypsum (phot. J. Jaworska)

Moreover, anhydrites of that type are recognizable within salt (e.g. they are visible on the salt-mine corridor walls or in boreholes), or cap-rocks. Detached blocks of anhydrites occur irregularly in cap-rocks (and similarly in pressed-up salts), mostly locally, in the form of torn apart fragments (their sizes range from lumps of several centimetres to blocks of several metres), or at the sections of several dozens of metres in a single profile, at various depths and in various locations within cap-rock cross-sections (see Wilkosz 2007, Jaworska & Ratajczak 2008, Jaworska et al. 2010), falling down at various angles. For example, in the case of the gypsum cap-rock formations of Wapno: at the depth of 53.8 m b.g.l. (below the ground level) there are gypsums with anhydrite inserts, and from 120 m down, dark-grey anhydrites set at the angle of 65°. However, Chlebowski & Sztelak (1953) mentioned silt-anhydrite and anhydrite formations at the depth of 167–224 m b.g.l. whose dip reached ca. 90°. Those detached blocks of anhydrite could preserve either the original lamination (in the case of the Main Anhydrite stratum, anhydrite laminae are most often accompanied by magnesite) or spherolithic, pin- or needle-like structures of the "fish-bone" type, or grass-like formations (see Fig. 7A–D). Many indications prove that those anhydrites are in fact diagenetic anhydrites, or pseudomorphs after original primary gypsums, e.g. the fish-bone (see Bäuerle et al. 2000a) or grass-like anhydrite formations (Jaworska & Ratajczak 2008, Jaworska 2012).

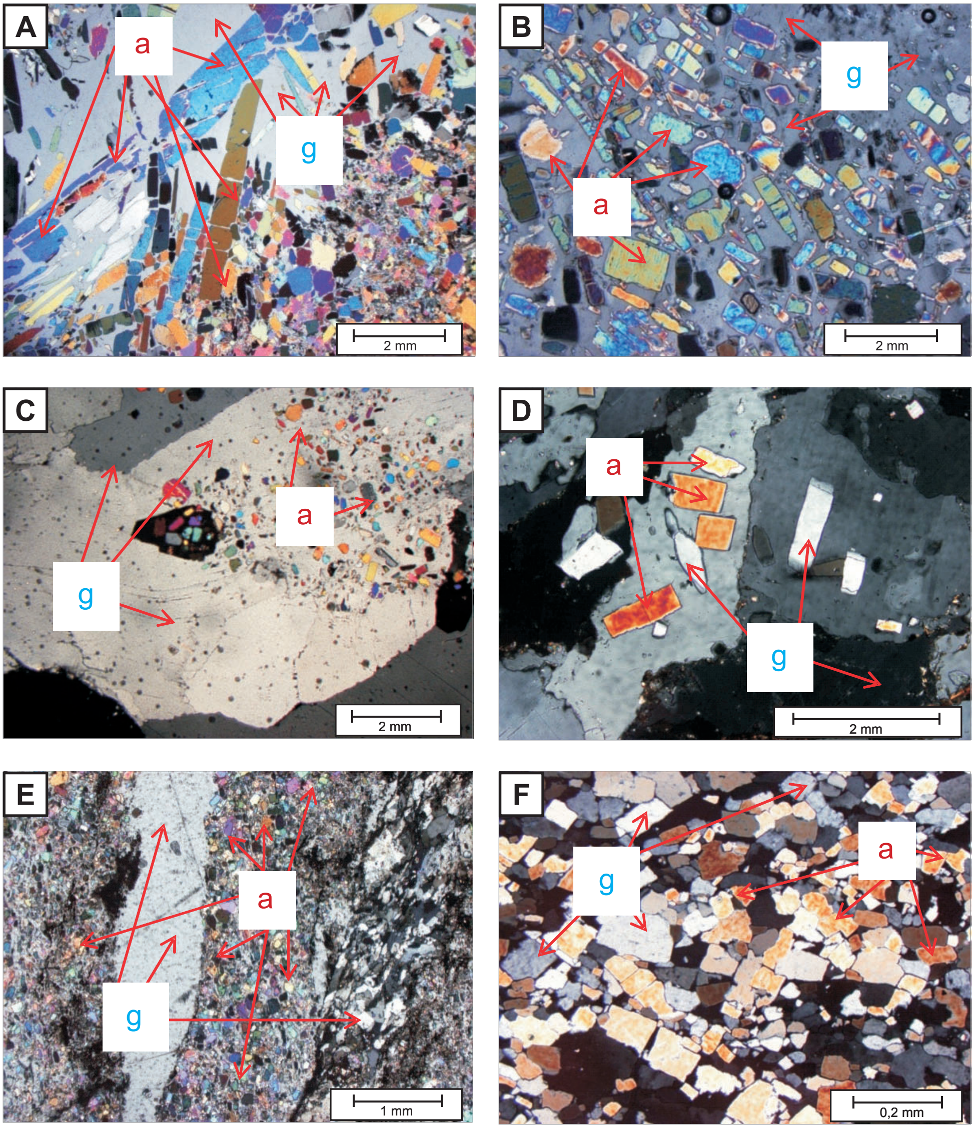


Fig. 8. Microphotographs, gypsification of anhydrite, XN, scale in photo. Gypsum cap-rock salt dome: A) and E) Wapno; B) and F) Mogilno; C) Dębina; D) Gorleben. Figures C and E – fine-crystalline anhydrites in lenticular gypsum crystals, figure F – gypsification of anhydrite sandstone; a – anhydrite, g – gypsum (figures A, B, D, E, F – phot. J. Jaworska, figure C – phot. A. Demidowicz)

The process of anhydritization of the original gypsum sediment in Zechstein basin could probably occur even during Zechstein sedimentation: (a) very early, as a result of intense heating of the primary gypsums by strong sunshine, in the conditions of hot and dry climate, where temperature exceeded 50°C (at surface or near surface): the synsedimentary model of alternation, or (b) later in comparison to the synsedimentary model (but in fact also quite early, e.g. during the sedimentation of overlying halite units), in the case of buried gypsum deposits: the burial model of alternation. The transformation process could theoretically start at the depth of 450–500 m (Murray 1964, Hardie 1967, Jowett et al. 1993). At such depths, temperature reached up to 20°C, with compensation by the properly high overburden pressure (Kubica 1972). Actually both models mentioned above could operate in the Zechstein basin. For peripheral parts of this basin, or on local elevations, transformation of gypsum into anhydrite could proceeded according to the first model but in the case of the deposits near the central part of Zechstein basin, rather according to the second model.

The area occupied by the salt diapirs (presently) constituted the axial part of the Zechstein sea. In the case of the above-mentioned salt diapirs, the transformation of gypsums into anhydrites occurred during the burial stage.

Both "residual" anhydrites and some anhydrite of detached blocks undergo the gypsification process (see Fig. 8). The process usually occurs during anhydrite exhumation at the depth of 100–150 m (Murray 1964, Klimchouk & Andrejchuk 1996). The process starts either when anhydrites enter the zone affected by underground waters or at the time of exposition to rain water. In fact, almost the whole gypsum cap-rock owes its existence to anhydrite because sulphate and calcium ions, belonging to cap-rock gypsum, originate from anhydrites.

The transformation of anhydrites into gypsum occurs in two ways:

1) pseudomorphism: replacement of anhydrite by gypsum,
2) dissolution of a larger amount of anhydrite grains/crystals (anhydrite sand).

Re. 1)

Gypsum is the pseudomorphic result of anhydrite, preserving the size and the prismatic/tablet habit after the primary mineral: anhydrite (Jaworska 2012) (Fig. 8E). That happens in the case of anhydrite sand: the anhydrites constituting classical residuum resulting from rock salt dissolution. Small thickness and sporadic occurrence of those formations indicate that the respective processes developed very quickly: the top of salt diapirs (the salt mirror being cracked) had contact with fresh water. The isotope composition ($\delta^{18}O$ values) of the crystallization water of gypsums from the cap-rocks of the Wapno and Mogilno diapirs probably indicates Pleistocene or post-Pleistocene diagenetic processes, because the hydration water is in equilibrium with water enriched with the light oxygen isotope (–10.8‰ and –11.3‰), or probably postglacial water (Jaworska 2010, 2012, Jaworska & Wilkosz 2012).

However, in the case of detached blocks of anhydrite, the matter is more complex because also here pseudomorphism occurred, although in some cases it was pseudomorphism following primary gypsums (Jaworska 2012), and the respective transformation path could look like that:

	Primary gypsum ⇨	**diagenetic anhydrite**	⇨ **gypsified diagenetic anhydrite/ secondary gypsum**
Processes:	crystallization	dehydratation/anhydritization	hydratation/gypsification
Time scale:	Zechstein	Zechstein	Cenozoic

In the case of anhydrite of detached blocks, the process of transformation into gypsum was much slower; most probably, it was caused by the compactness of the rocks and scarce porosity which prevented the penetration of water and solutions inside the rock and into the inter-grain space. Therefore, in the very gypsum cap-rocks, detached blocks mostly have remained as anhydrite rocks, although not always, e.g. in the case of the Wapno or Gorleben diapir cap-rocks, both anhydrite of detached blocks and secondarily gypsified anhydrite of detached blocks occurred there.

Consequently, such rocks were originally crystallized as gypsums, they were quickly turned into anhydrites and, as such, they were incorporated in the cap-rock formations, followed by gypsification. We should point out that, despite passing two stages of diagenesis (anhydritization and gypsification), they managed to preserve their original sedimentation structures and textures (Fig. 7B, D).

Re. 2)

Dissolution of a larger amount of anhydrite grains/crystals (anhydrite sand), followed by crystallization of large, sometimes several centimetre large, lenticular /lens-shaped automorphic gypsum crystals (Fig. 8A–E). Quite often crystallization developed so quickly that it trapped anhydrite grains/crystals in lenticular gypsums, which grains created types of inclusions in gypsums. Such anhydrite remains were subjected to gypsification or calcitization with time: calcite preserved the anhydrite shape sometimes, while gypsum quickly obliterated the anhydrite features.

The courses of the gypsification or anhydritization processes were affected by the following:

a) The solutions (and their pressure) from which the minerals crystallized or which accompanied the processes. A special role was played by the NaCl solution, which was present in pore liquids; the solution modified the temperature of the transformation of the gypsum-anhydrite phase. If the composition of the pore liquids corresponds to that of sea water, the water activity (αH_2O) amounts to 0.93 and the transformation of gypsum into anhydrite occurs at the temperature of 52°C. However, when the pore liquids are saturated with NaCl, the water activity amounts to 0.75 and the transformation occurs already at 18°C (Jowett et al. 1993).

b) Alkali metal ions (Conley & Bundy 1958) and the $CaSO_4$ solution (Posnjak 1940).

c) The liquid pressure system in pores; if hydrostatic, the temperature of gypsum transformation is dropping with depth: from 52°C close to the surface to 40°C at the depth of 2 km, and in the case of lithostatic conditions, the temperature increases up to 58°C per 2 km (Jowett et al. 1993).
d) Burial depth.
e) Temperature of the fluids (hydrothermal circulation, meteoric waters, ...).
f) The anhydritization and gypsification (dehydration and hydration) processes can occur very quickly in natural conditions: within several years (Farnsworth 1925) or even one year (Moiola & Glover 1965). Experimental studies demonstrated that they developed even within about a dozen or several dozens of days (e.g. Sievert et al. 2005).

CONCLUSIONS

Anhydrites from gypsum cap-rock have a dual origin:

1) anhydrite as part of an insoluble (or rather less soluble) material – residuum after dissolution of salt rock – this material is concentrated on top of salt diapirs (salt mirror level) as anhydritic sand and sandstone;
2) anhydrite of detached blocks of Zechstein anhydrites levels – mainly Main Anhydrite (Z3); fragments of this massive anhydritic rocks, in the form of xenoliths or bigger rock bodies, were uplifted with salt and incorporated into the gypsum cap-rock.

Anhydrites of the first type are represented by the grain size of 1 mm and they crystallized together with halite (salt rock). Their shapes are automorphic-prismatic. The anhydrite sandstone level usually creates a distinct layer thickness of several-dozen centimeters, separating rock salt (upper part of salt body) and the bottom of gypsum cap-rock.

The second type of anhydrites have irregular forms (the size of a few centimeters to a few meter lumps or larger blocks) situated at different depths in different parts of the gypsum cap-rock cross-section. Detached blocks of anhydrite can preserve the original structure and texture (lamination, spherulitic structure, and the “fish-bone” or grass-like forms). Both types of anhydrite – “residual” and detached blocks – were and have been gypsified.

The transformation of anhydrite into gypsum occurred in two ways:

1) anhydrite replacement: gypsum is pseudomorphic after anhydrite and maintains the size and habit of the primary mineral (anhydrite);
2) anhydrite grain dissolution, followed by the crystallization of large, lenticular (automorphous) gypsum crystals; the evidence of this processes is preserved in the relicts of anhydritic inclusions found in large gypsum crystals.

Petrographical anhydrite studies and especially those concerning recognition of the presenc of anhydrite in the detached blocks of the diapir cap-rocks, can provide important information on the structure, stratigraphy and tectonic disorders of rock salts located below the salt mirror. Most often, anhydrite of detached blocks creates broken strata, set almost vertically (at the angle of 60–90°) in respect of the ground level, and stretching hundreds or thousands of metres from the Zechstein top up to the salt mirror and the cap-rock. The occurrence of detached blocks of anhydrite in the cap-rocks suggests that such bodies (small lumps or beds, several or about a dozen, or several dozen metres thick) may be located below the mirror as well. Such information should be an essential indication for the selection for the placement of large caverns in salt domes, e.g. those designed for underground fuel or hazardous waste (including radioactive waste) storage facilities. For that reason, possibly the most uniform and thicker salt beds are selected to guarantee structural stability, avoiding the locations which contain stratifications that differ in resistance to solubility, in respect of that of rock salts. Those kinds of "disorders" essentially affect the final shapes of caverns, and that is of key importance for the future storage operations.

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Streszczenie

Badania petrograficzne utworów czap gipsowych wysadów solnych Wapna, Dębiny, Mogilna i Gorleben (Niemcy) wskazują, że występujące w ich obrębie anhydryty to zarówno pojedyncze ziarna, które niekiedy tworzą w spągowej części czapy poziom piaskowca anhydrytowego, jak i masywne fragmenty, bloki skał anhydrytowych (porwaki) reprezentujące najczęściej utwory anhydrytu głównego.

Oba typy anhydrytów:

- można rozróżnić, mają odmienne struktury i tekstury,
- ulegają procesowi gipsyfikacji, przy czym piasek i piaskowiec anhydrytowy szybko, natomiast porwaki anhydrytowe dużo wolniej.

Anhydryty rezydualne są skupione w spągu czapy i/lub rozproszone w gipsach grubokrystalicznych, a porwaki występują nieregularnie.