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Contribution to mineralogy and geochemistry of *Tonmittelsalz* (z3TM) and *Tonbrockensalz* (z4TS) in the German Zechstein

Wkład do mineralogii i geochemii Tonmittelsalz (z3TM) i Tonbrockensalz (z4TS) z niemieckiego cechszytynu

Julia ONNEKEN, Michael SCHRAMM & Jörg HAMMER

Federal Institute for Geosciences and Natural Resources (BGR),
Stilleweg 2, 30163 Hannover, Germany, e-mail: julia.onneken@bgr.de

Abstract

In the German Zechstein basin, two main clay-bearing salt strata occur, in fact *Tonmittelsalz* in Z3 (Leine formation) and *Tonbrockensalz* in Z4 (Aller Formation). These units may correlate with the Brown Zuber (Na3t) and Red Zuber (Na4t) in the Polish Zechstein basin. To mark out the characteristics of *Tonmittelsalz* and *Tonbrockensalz*, BGR started detailed mineralogical-geochemical investigations. Even though these units are characterized by a similar mineral composition of mainly halite with subordinate quantities of anhydrite and clay minerals, differences were observed. Based on microscopical observations, carbonate is only existing in *Tonmittelsalz* and polyhalite is more common in *Tonbrockensalz*. Characteristic for *Tonmittelsalz* seem to be clay bands with idiomorphic halite and a breccious fabric for *Tonbrockensalz.* Similarities to the equivalent zuber beds were observed. This ongoing project will be continued with more samples from other locations.

Keywords: clay-bearing salt strata, Tonmittelsalz, Tonbrockensalz*,* Zechstein, zuber

Streszczenie

W niemieckiej części basenu cechsztyńskiego występują dwie główne warstwy soli ilastych: *Tonmittelsalz* w cyklotemie Z3 (formacja Leine) i *Tonbrockensalz* w cyklotemie Z4 (formacja Aller). Warstwy te korelują się z Brązowym Zubrem (Na3t) i Czerwonym Zubrem (Na4t) w polskiej części basenu cechsztyńskiego. BGR wykonało badania mineralogiczne i geochemiczne soli *Tonmittelsalz* i *Tonbrockensalz*, aby uzyskać ich szczegółową charakterystykę. Pomimo podobieństwa składu mineralnego, w którym głównymi minerałami są halit, anhydryt i iłowce zaobserwowano różnice. Na podstawie obserwacji mikroskopowych stwierdzono, że węglany występują tylko w *Tonmittelsalz*, natomiast polihalit jest częściej spotykany w *Tonbrockensalz*. Ponadto, w *Tonmittelsalz* iłowce tworzą pasma z idiomorficznymi kryształami halitu, a w *Tonbrockensalz* występują brekcje. Badania opisanych soli są nadal prowadzone.

Słowa kluczowe: warstwy soli ilastych, Tonmittelsalz, Tonbrockensalz*,* cechsztyński zuber

Introduction

One of the most interesting lithologies in evaporites are clay-bearing salt strata, e.g. the clay-bearing salt layers in the upper part of the Leine (Z3) and Aller (Z4) formations of the North German Zechstein basin (Permian). During the sedimentation of salt formations, frequent periods of clastic sedimentation with deposition of salt clays and clay-bearing salt layers are documented. Depending on the paleogeography of the Zechstein basin and the conditions of sedimentation, the lithological types of salt clays and clay-bearing salt layers developed differently.

BGR started detailed mineralogical and geochemical studies of the salt clay *Grauer Salzton* (z3GT) at the bottom (e.g. Kühn 1938, Lotze 1938, Niemann 1960, Gruner et al. 2003, Bornemann et al. 2008) and the clay-bearing strata *Tonmittelsalz* (z3TM) at the top of the Leine formation (e.g.

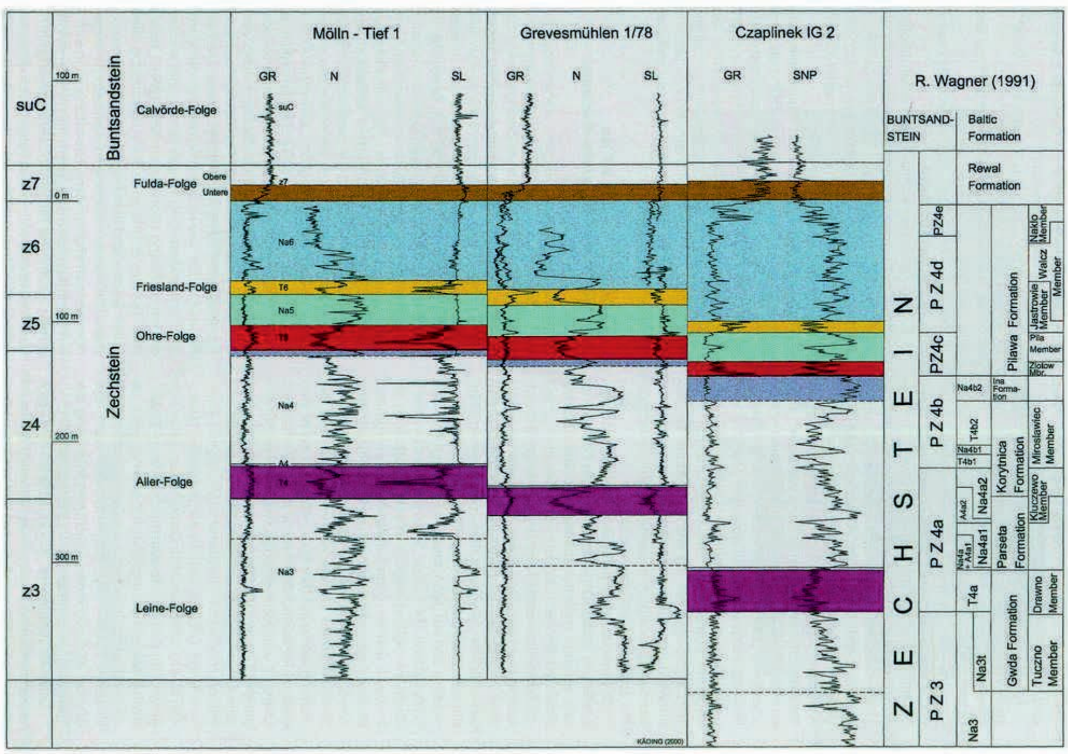

Fig. 1. Zechstein Z4 to Z7 in the Ostholstein-Westmecklenburg Basin in comparison (colored marked stratigraphic units) with the basin facies in Poland (Käding 2000).

Ryc. 1. Profil cechsztynu od cyklotemów Z4 do Z7 w basenie Ostholstein-Westmecklenburg (ogniwa stratygraficzne zaznaczone na kolorowo) w porównaniu z ogniwami basenu polskiego (Käding 2000).

Herde 1953, Bornemann et al. 2008) as well as the salt clay and clay-bearing strata of the Aller formation. The Aller formation is characterized by more detrital units. The bottom is formed by the salt clay *Roter Salzton* (z4RT) (e.g. Kühn 1938, Lotze 1938, Herde 1953, Kästner 1999, Gruner et al. 2003, Bornemann et al. 2008) and the upper parts by the clay-bearing strata of *Tonbrockensalz* (z4TS) (Bornemann et al. 2008), *Tonbanksalz* (z4TB) (Klarr, Paul 1991), and at the top by the *Oberer Aller-Ton* (z4OT) (Kästner 1999). The younger formations like the Ohre (Z5), Friesland (Z6), and Mölln formations (Z7) show salt clay strata as well (Kästner 1999). Based on well logs, the Zechstein Z4 to Z7 evaporites in the

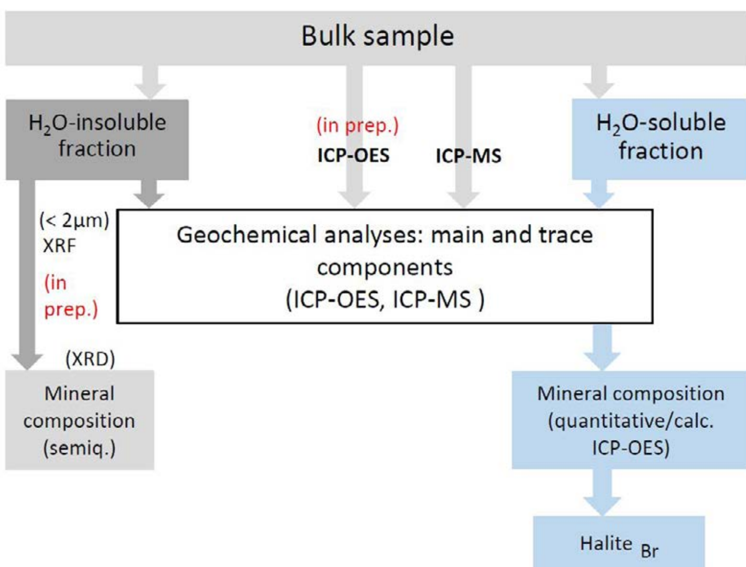

Fig. 2. Schematic chart of the geochemical and mineralogical analyses. ICP-OES – inductively coupled plasma optical emission spectrometry, ICP-MS – inductively coupled plasma mass spectrometry, XRF – x-ray fluorescence.

Ryc. 2. Schematyczny diagram badań geochemicznych i mineralogicznych, ICP-OES – spektrometria emisyjna ze wzbudzeniem plazmowym, ICP-MS – spektrometria mas sprzężona z plazmą wzbudzaną indukcyjnie, XRF – fluorescencja rentgenowska

German basin may correlate with the according strata in the Polish Basin (Fig. 1). Käding (2000) linked *Tonmittelsalz* and *Roter Salzton* to the Gwada formation including Brown Zuber (Na3t) in Z3 (Wachowiak et al. 2014), *Tonbrockensalz* and *Tonbanksalz* to the Korytnica formation including Red Zuber (Na4t) in Z4 (Natkaniec-Nowak et al. 2014), and the Ohre- and Friesland formations to the Pilawa formation.

Material and methods

To point out the similarities and differences of *Tonmittelsalz* and *Tonbrockensalz*, we used different methods like microscopy (polarization and scanning electron microscope – SEM), computed tomography (CT), x-ray diffraction (XRD), and chemical analyses of the soluble and insoluble components. The analysis scheme used to achieve a full mineralogical-geochemical analysis is complex (Fig. 2).

At the first stage of investigations, samples were taken from the deep borehole Go1004 in the south-eastern flank of the Gorleben salt dome. The layers in the salt dome flank lay steeply and are folded (Bornemann, Fischbeck, 1988). The Gorleben salt dome is located in the eastern part of Lower Saxony near the river Elbe. The structure strikes from NE to SW with an approximate length of 14 km and a minimum width of 4 km, continuing for another 16 km to the River Elbe as the Rambow salt dome, although with reduced width. The salt table is approximately 250 m below ground level whilst

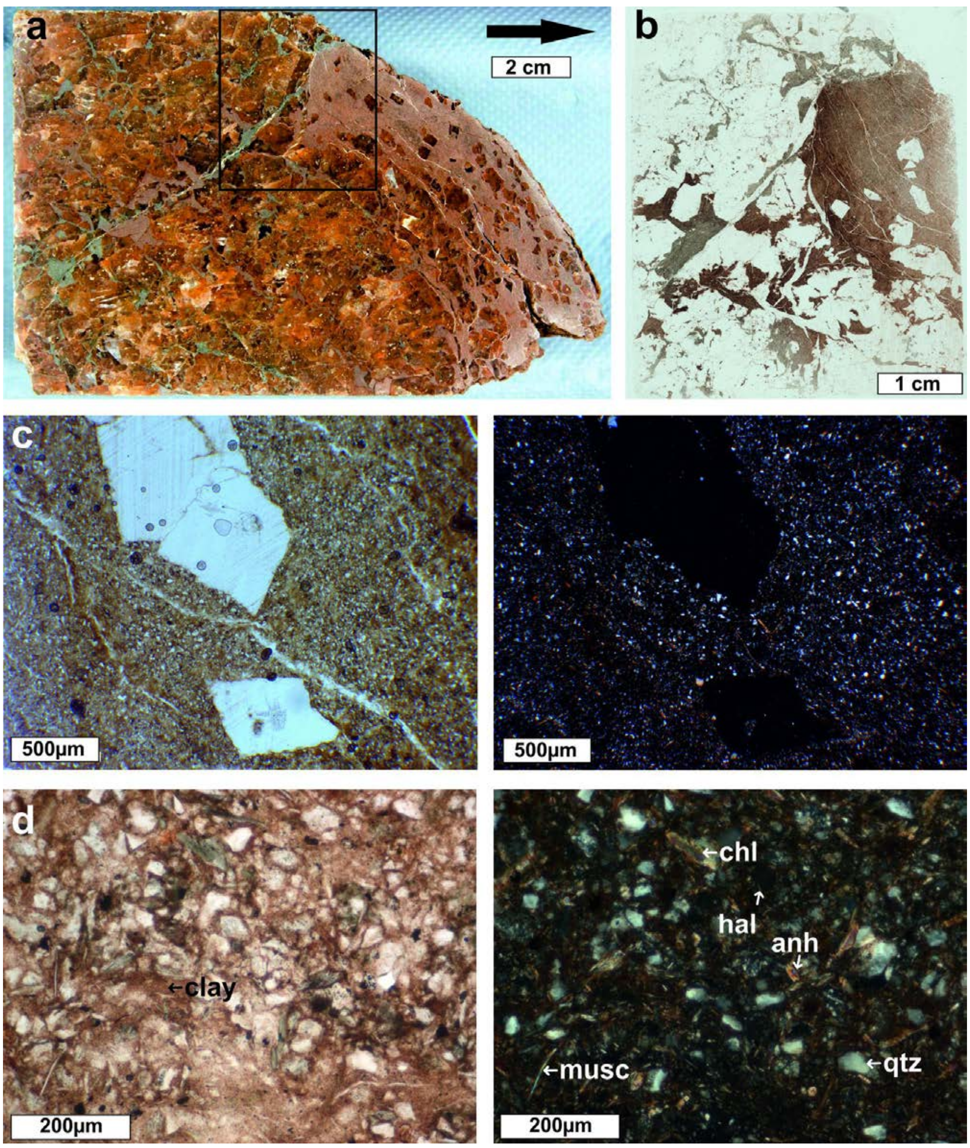

***Fig. 3**. Macro- and microphotographs of medium Tonmittelsalz (z3TM2/t), a) polished surface of a core of the Go1004 (depth: 1724.80 – 1724.90 m), arrow points in drilling direction, b) zoom of (a), thin section, c) idiomorphic halite crystals within the clay matrix with halite filled fractures, d) clay matrix with clay minerals, quartz (qtz), anhydrite (anh), halite (hal), muscovite (musc), and chlorite (chl), all microphotographs: with parallel polarizers (left), with crossed polarizers (rigsht).*

Ryc. 3. Zdjęcia w skali makro- i mikro- średnich *Tonmittelsalz* (z3TM2/t), a) wypolerowana powierzchnia rdzenia wiertniczego Go1004 (głębokość: 1724.80 – 1724.90 m), strzałka pokazuje kierunek wiercenia, b) fragment zdjęcia (a), c) idiomorficzne kryształy halitu w iłowcowym matrix oraz spękania wypełnione halitem, d) iłowcowe matrix z minerałami ilastymi, kwarcem (qtz), anhydrytem (anh), halitem (hal), muskowitem (musc) i chlorytem (chl), zdjęcia przy skrzyżowanych nikolach po prawej stronie, przy *równoległych nikolach po lewej stronie*.

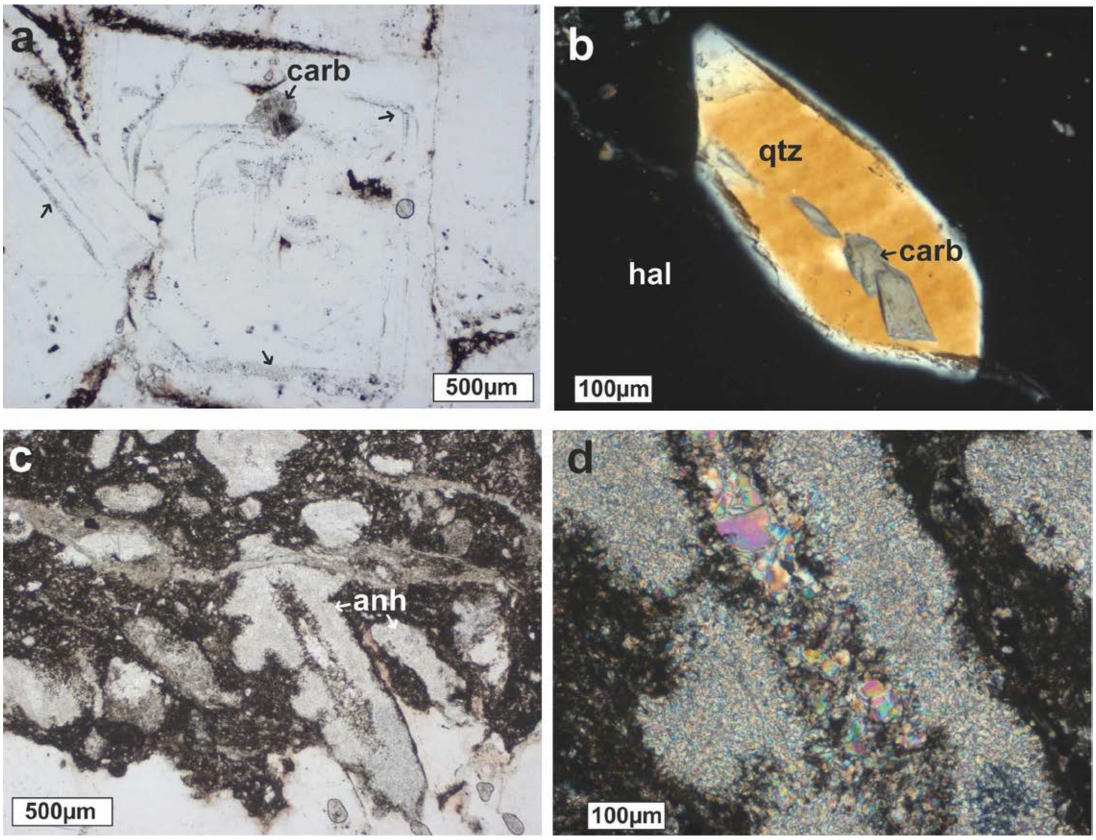

Fig. 4. *Microphotographs of lower Tonmittelsalz (z3TM1/t), a) halite crystals with fluid trails (arrows), carbonate (carb), and clay on the grain boundaries, b) quartz (qtz) crystal with carbonate (carb) crystals in halite (hal) matrix, c) anhydrite aggregates (anh) in clay matrix, d) zoom in (c), bigger anhydrite crystals and clay in the center of the anhydrite aggregate, all microphotographs: with parallel polarizers (left), with crossed polarizers (right).*

Ryc. 4. Zdjęcia mikroskopowe dolnego *Tonmittelsalz* (z3TM1/t), a) kryształy halitu ze śladami roztworów (strzałki), węglany (carb), I iłowce na granicach ziaren, b) kryształ kwarcu (qtz) z węglanami (carb) w matrix halitowym (hal), c) skupienia anhydrytu (anh) w iłowym matrix, d) powiększenie (c), większe kryształy anhydrytu i iłowca w centrum skupień anhydrytowych, zdjęcia przy skrzyżowanych nikolach po prawej stronie, przy równoległych nikolach po lewej stronie.

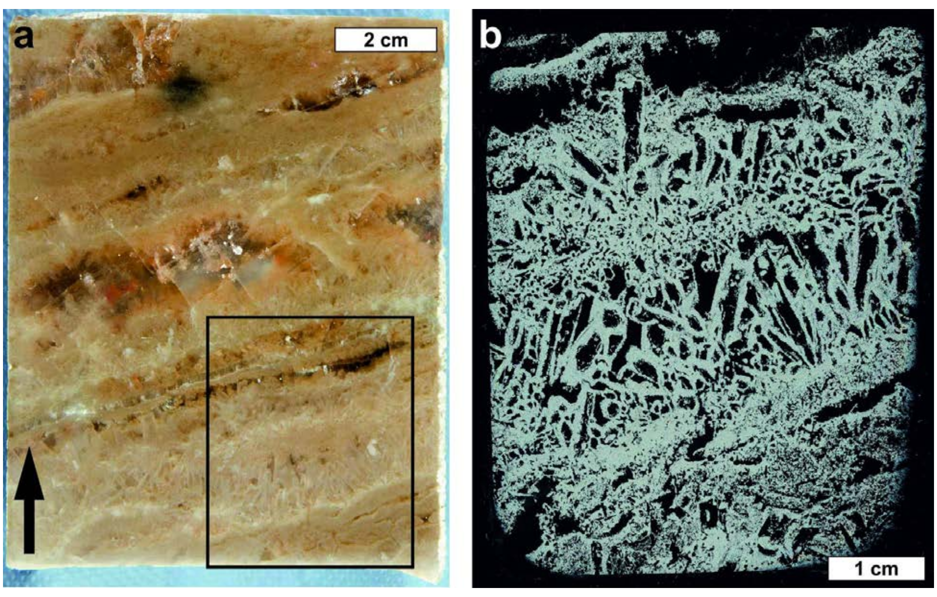

Fig. 5. *Anhydrite layer in the halitic rock salt layer of lower Tonmittelsalz (z3TM1/na): a) polished surface of a core of the Go1004 (depth: 1720.80 – 1720.96 m), arrow points in drilling direction, b) Scan of a thin section with crossed polarizers.*

Ryc. 5. Warstwa anhydrytu w warstwie halitowej soli kamiennej dolnej *Tonmittelsalz* (z3TM1/na): a) wypolerowana powierzchnia rdzenia Go1004 (głębokość: 1720.80 – 1720.96 m), strzałka wskazuje kierunek wiercenia, b) skan płytki cienkiej przy skrzyżowanych nikolach.

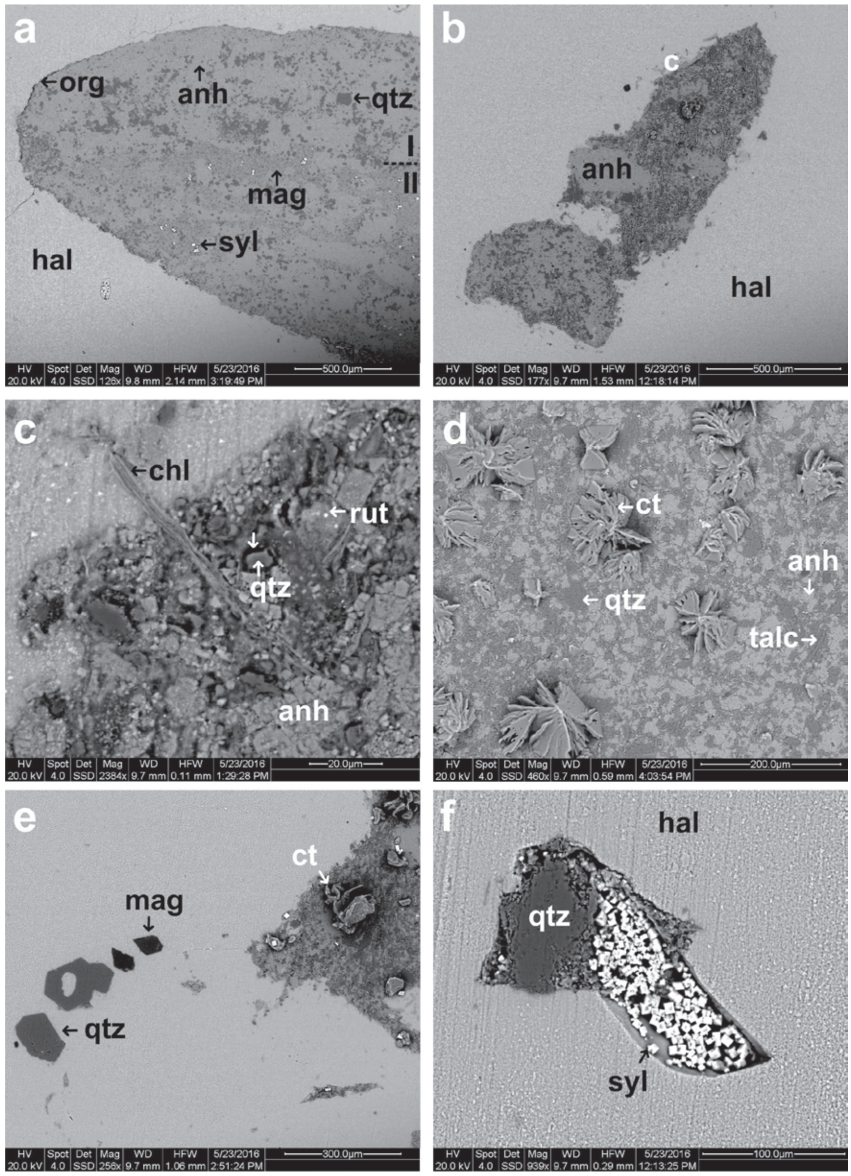

Fig. 6*. SEM images of Tonmittelsalz (z3TM), a) anhydrite aggregate with two zones (I and II), b) aggregates with anhydrite and clay matrix, c) zoom in (b), clay matrix with chlorite (chl), quartz (qtz) with a dark rim, anhydrite (anh), and rutile (rut), d) clay matrix with carnallite (ct) flakes, e) quartz and magnesite (mag) in halite (hal) matrix and carnallite flakes in clay matrix, f) pore with sylvite (syl) cubes and quartz.*

Ryc. 6. Obrazy SEM *Tonmittelsalz* (z3TM), a) skupienia anhydrytów z dwoma strefami (I i II), b) skupienia z anhydrytem i ilastym matrix, c) powiększenie (b), iłowe matrix z chlorytem (chl), kwarc (qtz) z ciemnymi pasmami, anhydryt (anh) i rutyl (rut), d) iłowe matrix z karnalitowymi (ct) płatkami, e) kwarc z magnezytem (mag) w halitowym (hal) matrix i płatkami karnalitu w iłowym matrix, f) por z Kryształy sylwinu i kwarcu w halicie.

the base of the Zechstein lies at a depth of between 3200 and 3400 m (Bornemann et al. 2008).

Results

Macro- and microscopical studies of *Tonmittelsalz* (z3TM) were divided into three subunits consisting of clay-bearing rock salt (z3TM1/t, z3TM2/t, z3TM3/t) with nearly halitic rock salt (z3TM1/na, z3TM2/na) in between. The normal thickness is around 36 m (Bornemann et al. 2008). The microscopically studied section is located at a depth between 1713.5 – 1755.8 m and lays upside-down.

The clay-bearing subunits of *Tonmittelsalz* consist of grey-green and slightly orange rock salt with grey or brown-red clay-rich flakes and layers (Fig. 3a). The clay amount increases to the top of the *Tonmittelsalz*. The clay appears as clay-rich flakes between halites as well as in 1 to 3 mm thick layers in z3TM1/t and in layers of up to 5 cm thickness in z3TM2/t and z3TM3/t. Halite crystals are fine to medium-grained (2 to 10 mm) with lots of fluid inclusions, which appear like chevron crystals (Fig. 4a). Idiomorphic quartz and carbonate crystals are common in the halite matrix (Fig. 4b). The clay rich matrix consists mainly of quartz, anhydrite, chlorite,

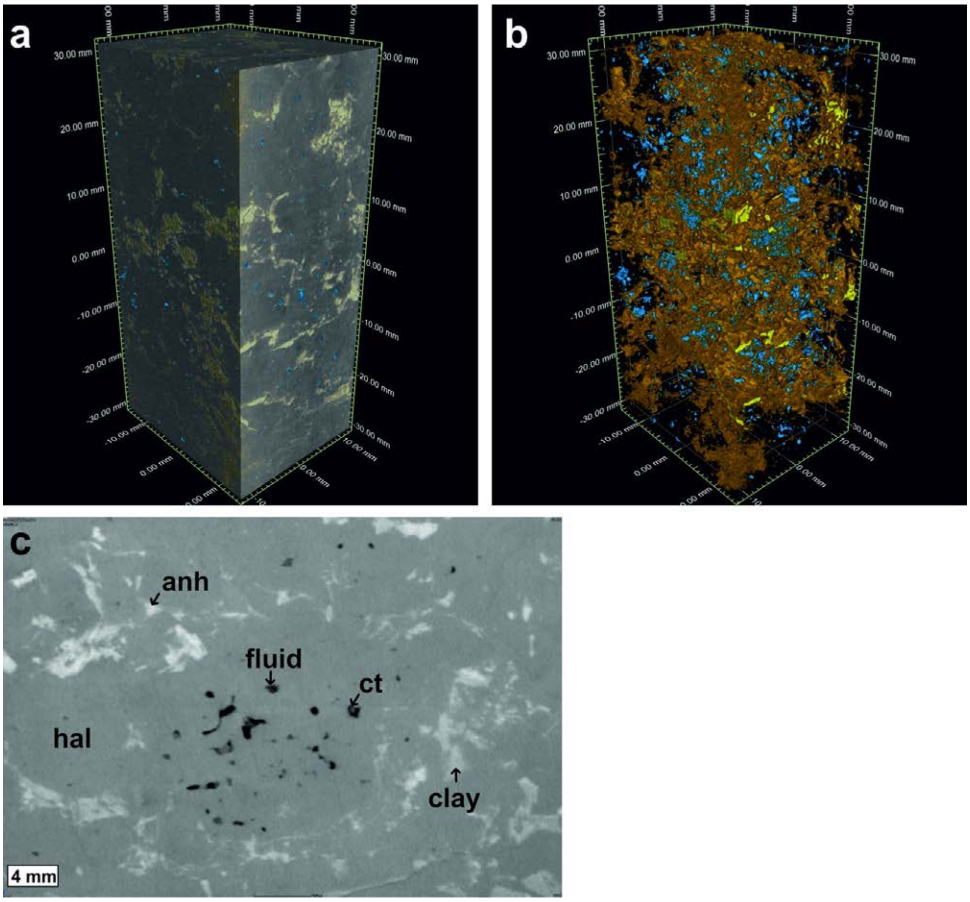

***Fig.** 7. CT images of upper Tonmittelsalz (z3TM3/t): a) volume body of the sample, b) volume body with three phases, brown: clay, yellow: anhydrite, blue: micropores, c) slice image with halite (hal), clay, anhydrite (anh), fluids, and probably carnallite (ct).*

Ryc. 7. Obraz CT górnej Tonmittelsalz (z3TM3/t): a) widok objętościowy próbki, b) widok objętościowy próbki z trzema fazami: brązową-ił, żółtą-anhydryt, niebieską-makropory, c) obraz przekroju z halitem (hal), iłem, anhydrytem (anh), fazą ciekłą, i prawdopodobnie karnalitem (ct).

muscovite, magnesite, and hematite (Fig. 3d). The grain sizes of these components are below 100 µm and most of the sheet silicates are crypto-crystalline. Unique in the z3TM1/t are anhydrite aggregates with rounded, irregular shapes in sizes up to 1.5 mm (Fig. 4c, d). Idiomorphic halite crystals with sizes up to 2 cm are often present in clay-rich layers in z3TM2/t and especially in the highest subunit, z3TM3/t (Fig. 3a, b, c). In the SEM, idiomorphic magnesite crystals were detected. Carnallite flakes on the surface of the thick sections probably grew out of filled pores after preparation (Fig. 6d). The CT analysis shows a more or less uniform, isotropic distribution of clay and anhydrite without a preferred orientation. Within the halite matrix, lobate pores with a fluid phase are associated with carnallite (Fig. 7).

The halitic rock salt subunits between the clay-rich subunits consist of orange or red colored, fine to medium grained (1 to 10 mm) halite with some clear crystals up to 5 cm in size. Some orange-red clusters of carnallite occur. In the lower subunit (z3TM1/na), a distinct anhydrite-halite layer with anhydrite needles, which grow nearly perpendicular or V-shaped to the bedding with halite lenses between them, can be observed (Fig. 5).

Geochemical results of *Tonmittelsalz*

The geochemically investigated sections of the z3TM in the Go1004 are located between 918.85 – 1027.00 m and 1719.47 – 1729.23 m. In the section 918.85 – 1027.00 m the quantitative mineralogical composition of the z3TM varies in parts obviously (Fig. 8).

The mineral assemblage is dominated by halite in all subsequences (applies also for the z3TM at 1719.47 – 1729.23 m; XRD analyses). From the z3TM1/t to the z3TM2na the halite content shifts between 93 and 99 wt. % with mean values of 97 – 98 wt. %, whereat in the youngest subsequence, the z3TM3/t, the halite concentration decreases to a mean value of 94 wt. % (85 – 99 wt. %). In contrast, the insoluble residue increases in direction to the younger unit with a maximum of 13 wt. % (Fig. 8). The insoluble residue is characterized by quartz as a minor component in the z3TM1 and z3TM3/t. Traces of silicates are common, such as chlorites, muscovite/illite or kaolinite (Fig. 8). In all subunits of the z3TM, anhydrite was observed. A mean value of about 1 wt. % anhydrite has been detected in the z3TM1 (minor component from 1719.47 – 1724.42 m depth; XRD analyses), z3TM2/t, z3TM3/t (mi-

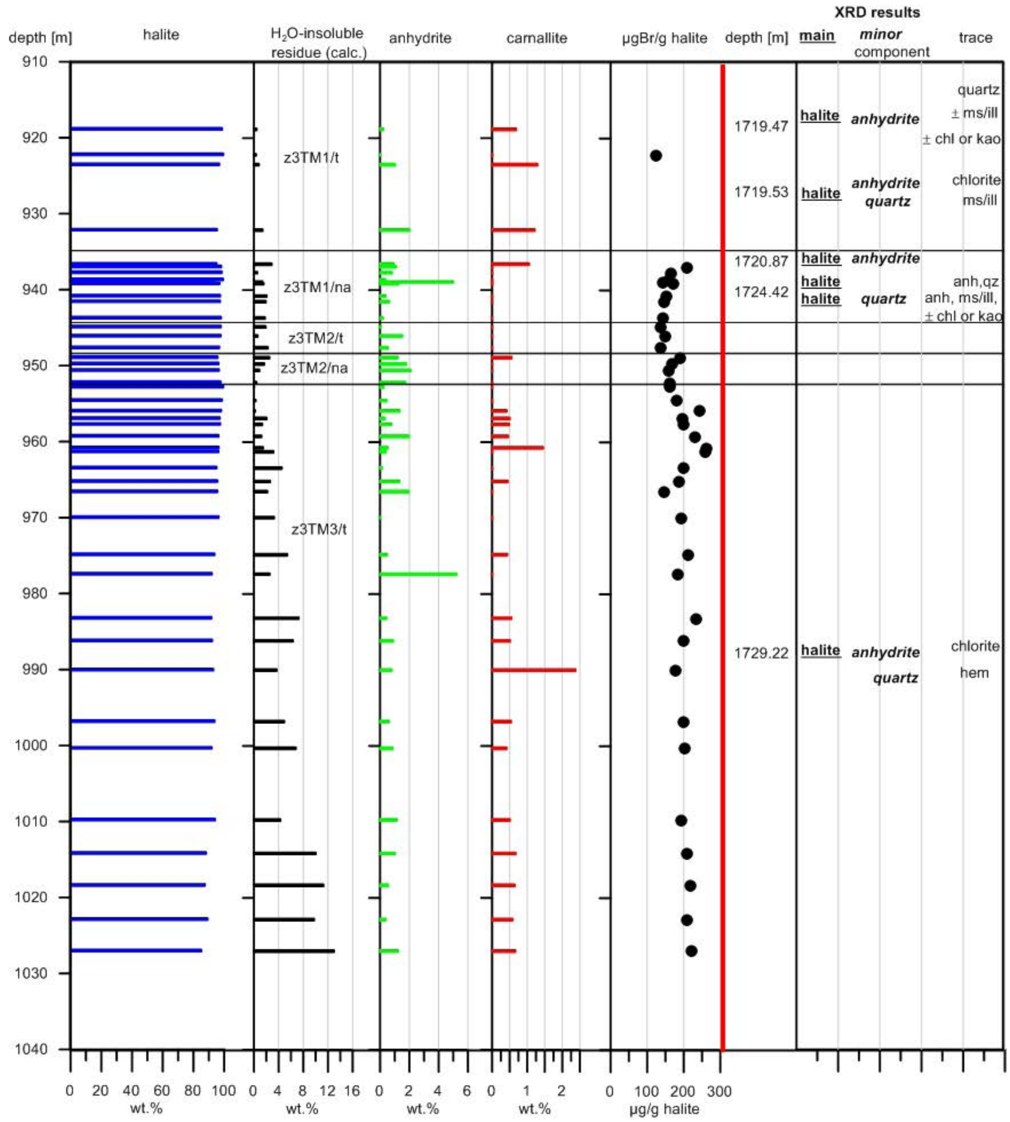

Fig. 8. Quantitative mineralogical composition and Br content of halites in the Go1004 (918 – 1028 m), based on ICP-OES analyses. On the right hand side: XRD analyses of selected samples of a deeper section of Go1004 (1719.47 – 1729.22 m).

Ryc. 8. Ilościowy skład mineralny i zawartość Br w halicie z Go1004 (918 – 1028 m), oparty na analizie ICP-OES. Na prawo: analiza XRD wybranych próbek z głębszych części Go1004 (1719.47 – 1729.22 m).

nor component in 1729.22 m; XRD analyses); and approx. 2 wt. % in the z3TM2/na. The highest anhydrite concentration of approx. 5 wt. % has been analyzed in the z3TM1/na and z3TM3/t. Carnallite was detected locally, only in small quantities, in the z3TM1 approx. 1 wt. % (max.) and in the z3TM/3t up to approx. 2 wt. % (Fig. 8).

The Br concentrations of the halites show obvious differences (Fig. 8). A Br content of 143 – 210 µg/g halite (mean = 161 µg/g halite) were detected in the stratigraphically lying section (z3TM1/t) and the highest Br concentrations of the halites in the youngest subunit (z3TM3/t) with 146 – 263 µg/g halite (mean = 204 µg/g halite).

An overview about the trace elements (left column) and the rare earth elements (REE) of the drilled z3TM (1719.47 – 1729.23 m) is displayed in Fig. 9.

The Li content mainly correlates with the Rb and Zr content, partly at a relative high level with the exception of the z3TM1/na, where both are much lower concentrated than Li. The Li content varies between 6 and 143 µg/g (Fig. 9). Rb contents of 0.14 – 82 µg/g and Zr contents of 0.12 – 162 µg/g have been detected. The Tl content in all samples is < 1 µg/g. Co (0.4 – 8.3 µg/g), Cs (0.4 – 8.7 µg/g), and Pb (0.2 – 4.4 µg/g) show comparable concentrations and trends.

The rare earth elements (REE) of z3TM show overall a comparable complimentary trend to the trace elements displayed in blue on the left hand side of Fig. 9. The samples of z3TM document increasing trace element and REE concentrations in direction to the younger section, which is characterized by a higher clay mineral content (Fig. 9).

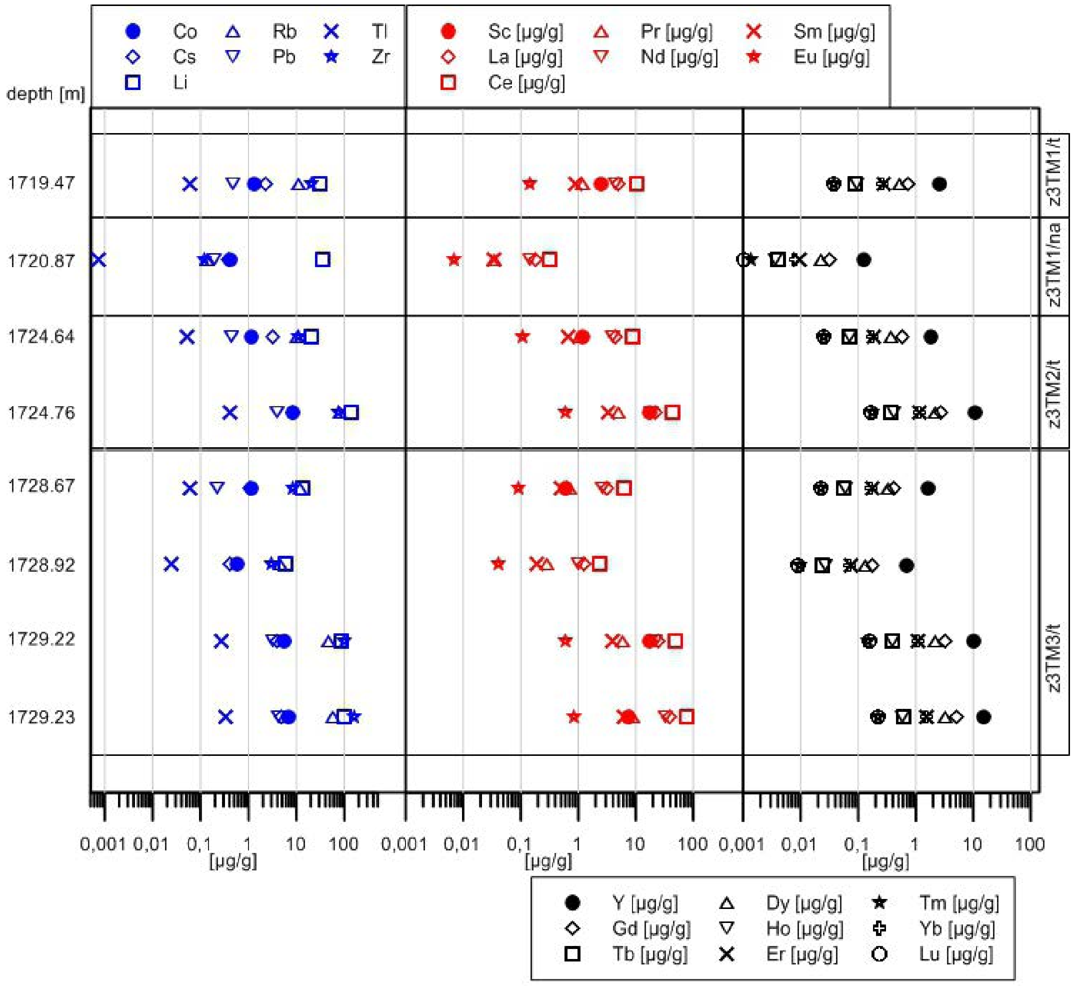

Fig. 9. *Trace (blue) and rare earth element concentrations of z3TM in the Go1004 (section: 1719.47 – 1729.23 m).*
Ryc. 9. Pierwiastki śladowe (niebieski) i pierwiastki ziem rzadkich z z3TM w Go1004 (głębokość: 1719.47 – 1729.23 m).

MACRO- AND MICROSCOPICAL STUDIES OF *TONBROCKENSALZ*

Tonbrockensalz (z4TS) was drilled twice in the Go1004. Mineralogical and geochemical studies were performed on samples between 1803.5 – 1825.5 m and additionally, geochemical analysis was performed on one sample from 1874.5 m. The normal thickness is approximately 15 m (Bornemann et al. 2008). The *Tonbrockensalz* is divided into a lower and an upper subunit.

The lower *Tonbrockensalz* (Fig. 10) consists of a brown clay-bearing rock salt with a clay/anhydrite content of approximately up to 10 % at the bottom and top. The layer in between is characterized by an orange halitic rock salt with impurities less than 5 %. In the clay-bearing bands, halite crystals with sizes of up to 2 cm are embedded in a vague layering. Red-brown or grey clay consist of thin bands, clasts up to 2 cm in size with anhydrite or coats of halite crystals. The halitic rock salt is characterized by halite crystals with sizes up to 5 cm within a fine-grained (0.5 – 3 mm) and often elongated halite matrix (Fig. 12a, b). Fluid inclusions decorate grain boundaries (Fig. 12a) or show rectangular patterns within halite crystals like chevrons (Fig. 11c, d). Anhydrite aggregates in the halite matrix consist of up to 300 µm (hyp)-idiomorphic crystals with lots of polyhalite and often associated with a rim of clay matrix, which was observed in the upper *Tonbrockensalz* also (Fig. 14a, b). In the clay matrix rounded quartz (50 to 100 µm) and anhydrite is very common as well as chlorite, feldspar, muscovite, celestine, and hematite (Fig. 13a, b). Some carnallite is present as well. Sheer bands appear in the clay matrix (Fig. 13b).

The upper *Tonbrockensalz* (Fig. 11) is an orange rock salt with a breccious fabric of halite and clay clasts up to 5 cm in size embedded in a fine-grained halite matrix with carnallite nests. Several fractures cross cut the rock with fibrous halite. The clay clasts show an internal breccious fabric of very fine-grained, opaque clay, coarser clay-rich clasts and anhydrite aggregates or bands in a quartz, anhydrite, and clay matrix (Fig. 14c, d).

Celestine and zircon were detected by SEM (Fig. 15). In the CT, clay mineral coating of idiomorphic halite crystals in a halite matrix and an aligned orientation of clasts associated with fractures was observed (Fig. 16).

Fig. 10. Lower Tonbrockensalz (z4TSU): Polished surface of a core of the Go1004 (depth: 1808.30 –1808.47 m)*; arrow points in drilling direction*.

Ryc. 10. Niższa *Tonbrockensalz* (z4TSU): polerowane powierzchnie rdzenia Go1004 (głębokość: 1808.30 –1808.47 m); strzałka wskazuje kierunek wiercenia.

Fig. 11.Upper Tonbrockensalz (z4TSO): Coarse-grained rock salt with fractures, fibrous halite, and clay clasts; Polished surface of a core of the Go1004 (depth: 1814.30 – 1814.44 m); arrow points in drilling direction.

Ryc. 11. Górna *Tonbrockensalz* (z4TSO): gruboziarnista sól kamienna ze spękaniami, halitem włóknistym i klastami iłowca. Polerowane powierzchnie rdzenia Go1004 (głębokość: 1814.30 – 1814.44 m); strzałka wskazuje kierunek wiercenia.

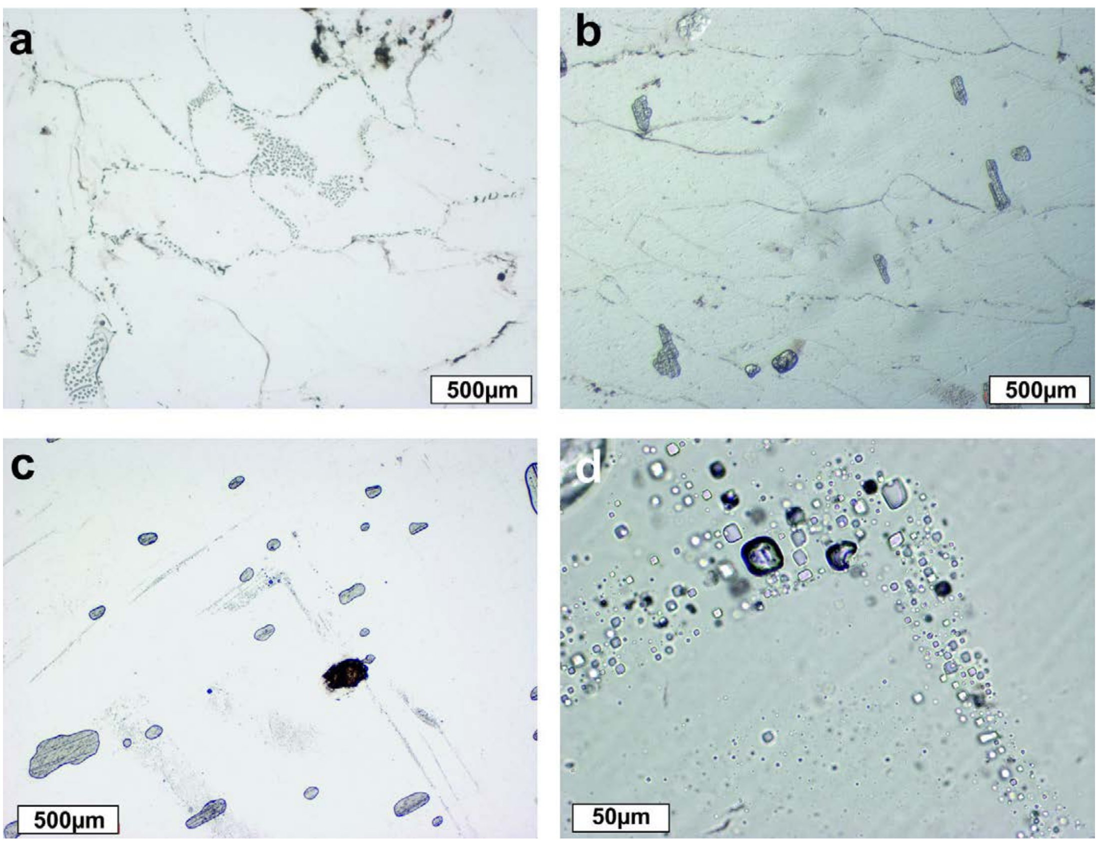

Fig. 12. Microphotographs of lower Tonbrockensalz (z4TSU): a) halite crystals with fluids on grain boundaries, b) elongated halite crystals, c) fluid trails within a halite crystal, d) zoom into (c) angular shaped fluid inclusions, all microphotographs with parallel polarizers.

Ryc. 12. Obrazy mikroskopowe dolnej *Tonbrockensalz* (z4TSU): a) kryształy halitu ze śladami cieczy na granicach ziaren, b) wydłużone kryształy halitu, c) ślady cieczy w krysztale halitu, d) zbliżenie (c) kanciaste inkluzje ciekłe, wszystkie zdjęcia przy równoległych nikolach.

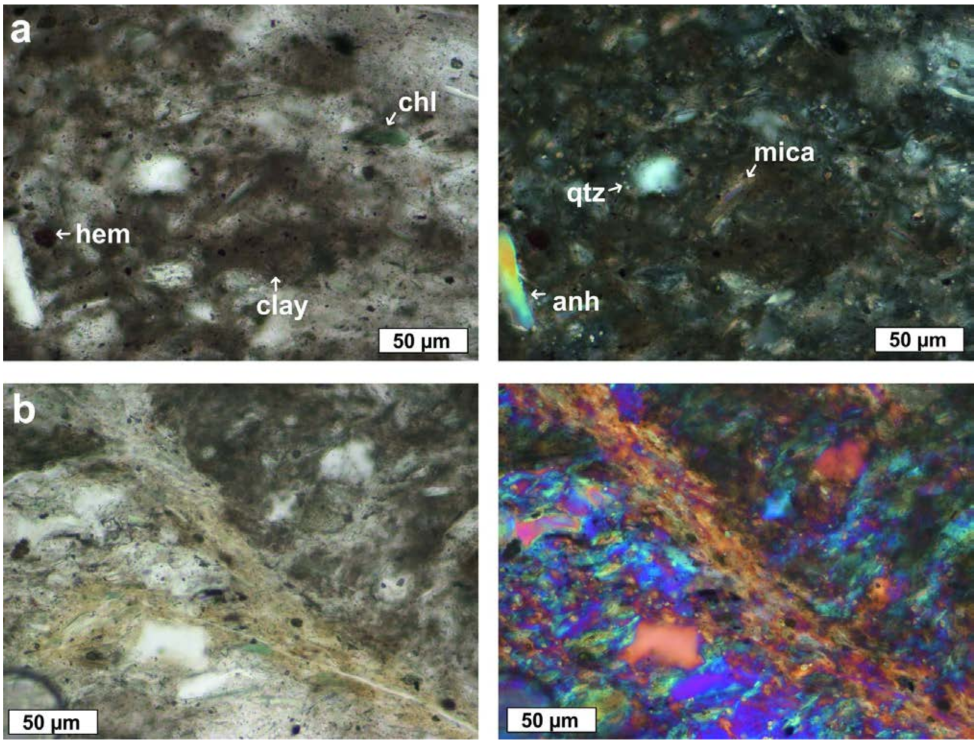

Fig. 13*. Microphotographs of Lower Tonbrockensalz (z4TSU): a) clay matrix with chlorite (chl), anhydrite (anh), mica, quartz (qtz), and hematite (hem), b) clay matrix with a quartz-rich sheer band (right: with lambda plate), all microphotographs: with parallel polarizers (left), with crossed polarizers (right).*

Ryc. 13. Obrazy mikroskopowe Tonbrockensalz (z4TSU): a) iłowe matrix z chlorytem (chl), anhydryt (anh), mica, kwarc (qtz), hematyt (hem), b) iłowe matrix z bogatym w kwarc pasmem ścinania, zdjęcia przy skrzyżowanych nikolach po prawej stronie, przy równoległych nikolach po lewej stronie.

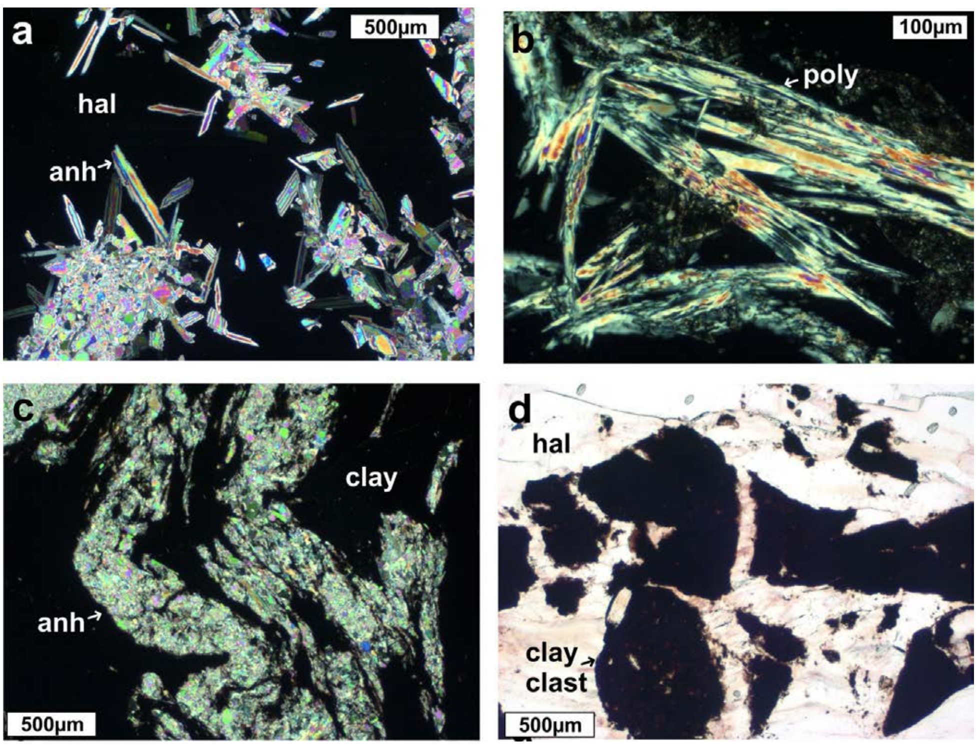

Fig. 14*. Microphotographs of the Tonbrockensalz (z4TS) a) anhydrite crystals in halite matrix (crossed polarizers), b) polyhalite (poly) crystals (crossed polarizers), c) folded anhydrite layer in clay matrix (crossed polarizers), d) clay clasts in fibrous halite matrix (parallel polarizers).*

Ryc. 14. Obrazy mikroskopowe Tonbrockensalz (z4TS) a) kryształy anhydrytu w halitowym matrix (skrzyżowane nikole), b) kryształy polihalitu (poly) (skrzyżowane nikole), c) zafałdowane warstwy anhydrytu w ilastym matrix (skrzyżowane nikole), d) klasty iłowca w halicie włóknistym (nikole równoległe).

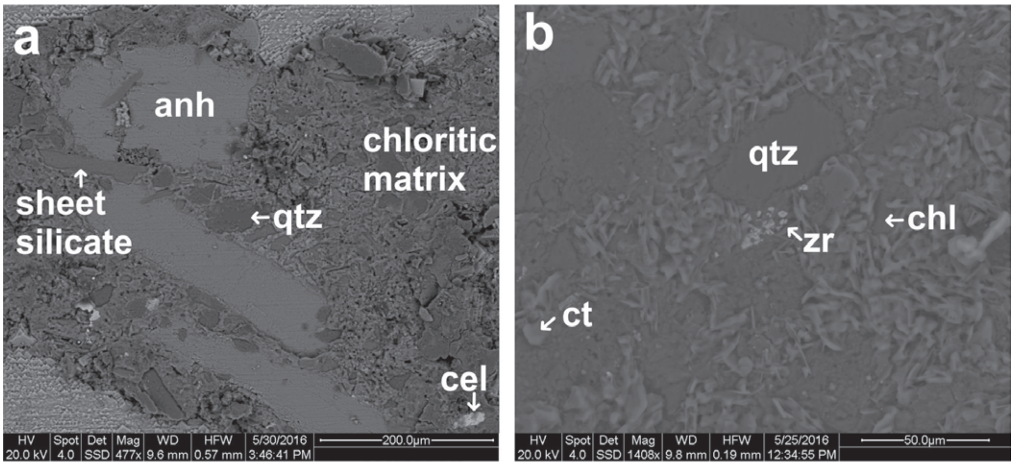

Fig. 15. *SEM images of a) chloritic matrix with anhydrite (anh), quartz (qtz), sheet silicates, and celestine (cel), b) matrix with quartz (qtz), chlorite (chl), carnallite (ct), and zircon (zr).*

Ryc. 15. Obraz SEM Tonbrockensalz (z4TS), a) chlorytowe matrix z anhydrytem (anh), kwarcem (qtz), pakietowymi krzemianami, celestynem (cel), b) matrix z kwarcem (qtz), chlorytem (chl), karnalitem (ct) i cyrkonem (zr).

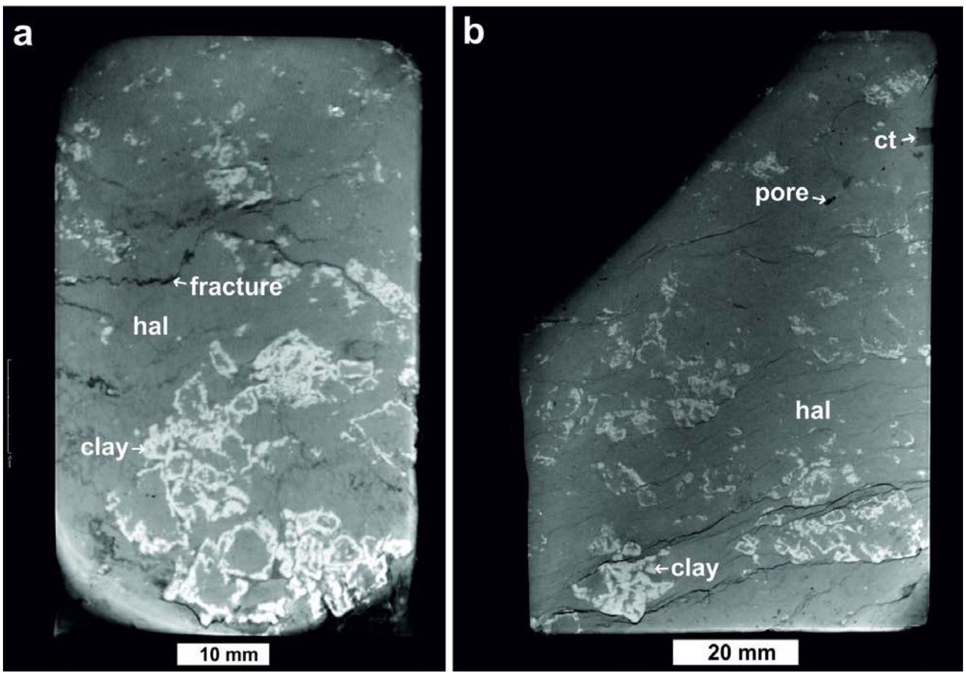

Fig. 16. *CT images of lower Tonbrockensalz (z4TSU): a) slice image with clay mineral coating of idiomorphic halite crystals in halite matrix, fractures crosscut the sample, b) slice image with clay and probably carnallite (ct) in halite (hal) matrix, with fractures and pores.*

Ryc. 16. Obraz CT dolnej *Tonbrockensalz* (z4TSU): a) przekrój z minerałami ilastymi otaczjącami idiomorficzne kryształy halitu w halitowym matrix, spękania przebiegające przez próbkę, b) przekrój z iłowcem i prawdopodobnie karnalitem (ct) w halitowym matrix (hal) ze spękaniami i porami.

Geochemical results of *Tonbrockensalz*

The mineralogical composition of the z4TSU at 1808.30 – 1808.36 m depth based on XRD analysis is dominated by halite accompanied by the minor component anhydrite and traces of quartz as well as ±muscovite/illite. The trace element concentrations increase to deeper drilling depth at 1874.50 m (Fig. 17). In the middle part of the z4TSU at 1806.35 m are the lowest concentrations, which correlates with the halitic rock salt layer. The Li content varies from 0.8 – 115 µg/g and correlates well with Rb (0.5 – 123.5 µg/g) and Zr (0.6 – 143.8 µg/g). Lower concentrations have been detected for Co (0.09 – 13.0 µg/g), Cs (0.03 – 9.66 µg/g), Pb (<0.38 ng/g– 8.7 µg/g), and Tl (0.002 – 0.6 µg/g), following almost the same trend as observed for Li, Rb and Zr. The rare earth elements detected in the samples of the z4TS show a comparable complimentary trend to the trace elements (Fig. 17) in direction to deeper drilling sections.

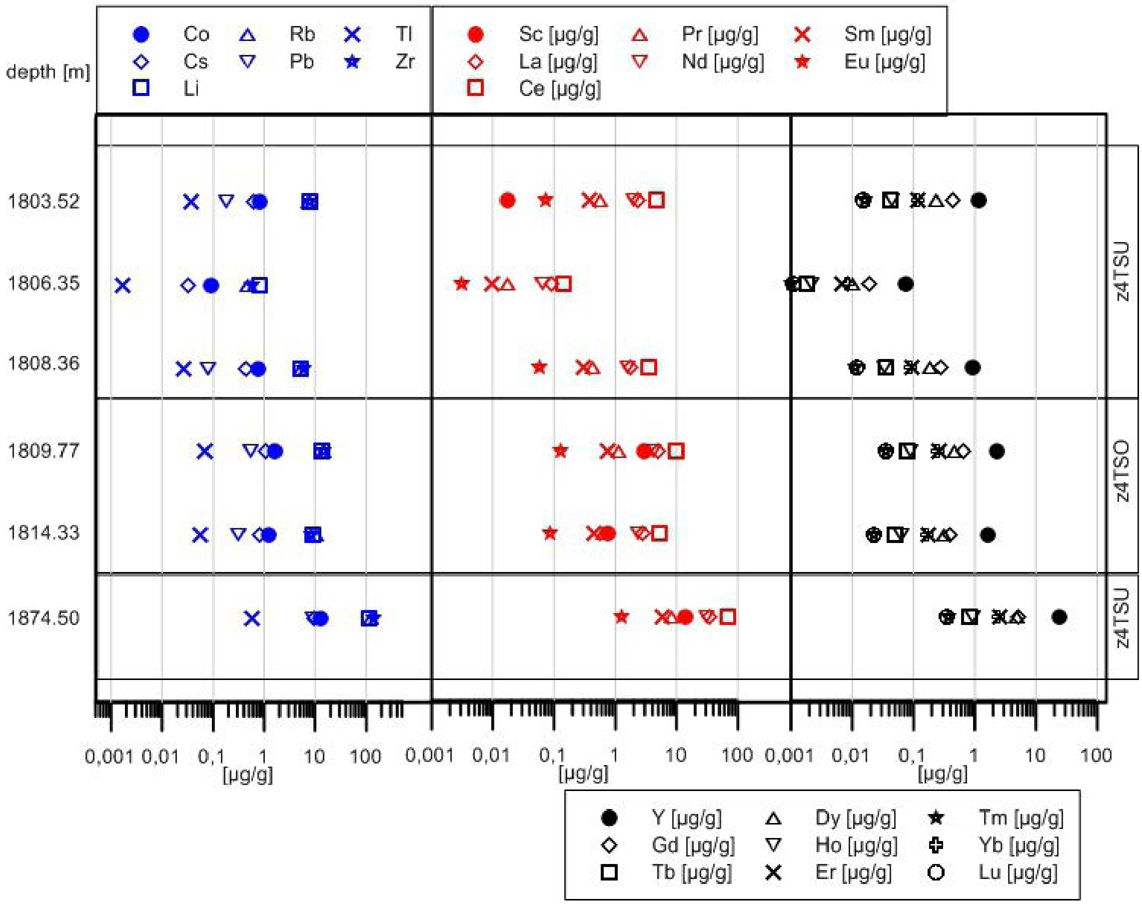

Fig. 17. Trace (blue) and rare earth element concentrations of z4TS in the Go1004 (section: 1803.52 – 1874.50 m).
Ryc. 17. Pierwiastki śladowe i pierwiastki ziem rzadkich z z4TS w Go1004 (sekcja: 1803.52 – 1874.50 m)

Preliminary conclusions

Tonmittelsalz and *Tonbrockensalz* are characterized by a similar mineral composition of mainly halite and subordinated anhydrite and clay. However, in detail some differences were observed. According to microscopical studies, carbonate is only existing in the *Tonmittelsalz* and polyhalite is more common in the *Tonbrockensalz*. Clay bands with idiomorphic halite were only detected in the *Tonmittelsalz* and a breccious fabric is significant feature of the *Tonbrockensalz*.

Based on the descriptions of Brown Zuber by Wachowiak et al. (2014) and Red Zuber by Natkaniec-Nowak et al. (2014), *Tonmittelsalz* and *Tonbrockensalz* show some similarities to the equivalent zuber beds. *Tonmittelsalz* and Brown Zuber show a very similar mineral composition and fabrics, like idiomorphic halite crystals up to several cm in a clay-bearing matrix or idiomorphic quartz and carbonate (magnesite and rarely dolomite) crystals. A similar mineralogical composition was observed for *Tonbrockensalz* and Red Zuber as well. A disordered, respectively, breccious fabric of halite blasts and clasts of clay substance in a fine-grained halitic matrix were documented in both units.

Outlook

Quantitative mineralogical composition and Br content of halites based on ICP-OES analyses for *Tonbrockensalz* is in process as well as ICP-OES analyses for bulk samples of *Tonmittelsalz* and *Tonbrockensalz*. To enhance the data density for trace and rare earth elements, additional samples will be analyzed. Additionally, the water content in the samples will be measured. Samples are already prepared to analyze the fraction <2µm with XRD and Rietveld method to get qualitative and quantitative data according to the clay minerals. Sulphur isotope studies were started and further isotope systems (oxygen, carbon) will follow. The microstructures and grain size distributions will be analyzed in order to receive additional data for characterizing the sedimentation settings. More samples of other locations (Morsleben and Asse) will be studied. Gorleben represents a central position in the Zechstein basin, Morsleben a transition from central to marginal position, and Asse a marginal position.

Summary

In the German Zechstein basin, two main clay-bearing salt strata occur, in fact *Tonmittelsalz* in Z3 (Leine formation) and *Tonbrockensalz* in Z4 (Aller Formation). These units may correlate with the Brown Zuber (Na3t) and Red Zuber (Na4t) in the Polish Zechstein basin. To mark out the characteristics of *Tonmittelsalz* and *Tonbrockensalz*, BGR started detailed mineralogical-geochemical investigations. Even though these units are characterized by a similar mineral composition of mainly halite with subordinate quantities of anhydrite and clay minerals, differences were observed. Based on microscopical observations, carbonate is only existing in *Tonmittelsalz* and polyhalite is more common in *Tonbrockensalz*. Characteristic for *Tonmittelsalz* seem to be clay bands with idiomorphic halite and a breccious fabric for *Tonbrockensalz.* Similarities to the equivalent zuber beds were observed. This ongoing project will be continued with more samples from other locations.

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