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W najstarszych solach kamiennych (cyklotem PZ1) cechsztynu, z obszaru wyniesienia Łeby, występuje szczególny typ laminacji, nazwany „laminacją wewnętrzną". Tworzą ją drobne kryształy lub agregaty siarczanowe (anhydryt, polihalit) oraz ciekłe i gazowe inkluzje, rozmieszczone liniowo w obrębie wielkich, przezroczystych kryształów halitu, równolegle do granic pakietu solnego (ryc. 3–4). Warstwy wielkokrysztalicznego halitu (C) powstały z solanek chlorkowych o niskim stężeniu, o czym świadczy niższa w porównaniu do sąsiadujących pakietów solnych zawartości bromu (ryc. 5).

Powstanie „laminacji wewnętrznej" związane jest z tą fazą cyklu ewaporatowego, gdy w zbiorniku zaczyna się formować warstwa cięższych dennych solanek chlorkowych, zaś w przypowierzchniowych, rozcieńczonych partiach wód trwa jeszcze strącanie siarczanów (ryc. 6). Kryształy i agregaty krystaliczne siarczanowe opadają na dno zbiornika i włączane są w obręb powstających tu wielkich kryształów halitu tworząc laminy, rejestrujące przebieg kolejnych powierzchni depozycji.

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GROWTH OF CRYSTALS AND SEDIMENTARY STRUCTURES IN THE SABRE-LIKE GYPSUM (MIOCENE, SOUTHERN POLAND)

UKD 549.766.21:548.5:551.782.12(438.13+23)

In the Middle Miocene (Badenian) gypsum deposits of the southern Poland lithological variety called the sabre-like gypsum occurs (16). It is contained within the skeletal gypsum distinguished by Kwiatkowski (9, 10). The sabre-like gypsum is composed of the characteristic large crystals (from 15 to 90 cm in length), which have grown upward and simultaneously curved laterally (Fig. 1). In the Nida Gypsum (5, 11) cropping out near Busko, Wiślica and Pińczów on the southern margin of the Holy Cross Mountains the sabre-like gypsum forms the layers **g** and **i** (1, 2, 22). These layers, together with the layer **h** which attains maximally 0.5 m, range from 5.5 to 8.5 m in thickness (1). Sporadically the sabre-like crystals (Fig. 1) are visible also in the layers **d**, **f**, **j** and **l**.

These gypsum crystals have grown upward by advance of the prism faces 120 (Fig. 1a) or aggregates of parallel lens-shape subcrystals (Fig. 1b). In the second instance the crystals have macroscopically seen blocky (mosaic) structure (cf. 15) built of subcrystals (see also 23). The particular subcrystals are visible on the surfaces of the perfect cleavage 010 as separate blocks, each of them reflecting light at slightly different angle. The crystals trapped impurities in a different manner depending on the morphology of the growing tops. On the 010 cleavage surfaces following structures of crystal growth are distinguishable: regular growth zones of the prism faces 120 (Fig. 1a) or streaks and patches of impurities, poikilitically trapped along the boundaries between the lens-shaped subcrystals, placed conformably to elongation of the crystal (Fig. 1b). The impurities consist of the aggregates of clay and calcite. Commonly rod-like relicts of algal filaments are macroscopically noticeable in the crystals (1, 17, 21). The sabre-like crystals have grown developing from their upper sides the **curved surface** (Fig. 1 and lit. 17, 20) characteristic for many gypsum individuals. The growth of the crystals on this specific surface was drastically inhibited due to adsorption of organic compounds (18, 19). Crystallographic axes **c** of some of the crystals reach more vertical position going to the crystal tops (Fig. 1). Those crystals besides of the surfaces curving reveal distinctly the twisting of the entire crystal lattice. Sometimes the crystals split and create the bunches of the base-blent sabre-like individuals.

Gypsum crystals precisely similar to the discussed ones occur in the Miocene evaporites of the Mediterranean (3, 4, 17, 18, 19, 20) and also are found in the recent salinas (17, 18). Primary nature of the investigated crystals, i.e. their synsedimentary origin is justified by the presence of the pocket-like hollows between the crystal tops filled with a detrital material (6). The hollows of this type occur at Chwałowice and Gartatowice outcrops (1). Irregular spaces between the sabre-like crystals protruding from the top of the layer **g** are filled with a finegrained indistinctly laminated gypsum mixed with mud (Fig. 2). Infillings of the primary bottom hollows with sediments redeposited by waves or currents are very rare in the Nida Gypsum. In the other part of the evaporitic basin in the vicinity of Staszów such hollows filled with a detrital material containing gypsum ooids were found in the bore-hole (Kasprzyk and Bąbel: this volume Fig. 2).

The sabre-like crystals have commonly crosswise fractures and breaks (Fig. 4) of a compactional nature (1). Particular fragments of the broken crystal are always in touch. Dislocation of the crystal parts took place in a vertical direction. Dronkert (3, 4, p. 192) described

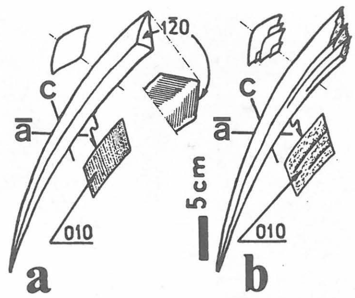

Fig. 1. Sabre-like gypsum crystals growing by advance of: **a** *– the prism faces 120,* **b** *– parallel lens-shape subcrystals or their aggregates. Note different growth structures visible on the 010 surfaces of the perfect cleavage. Crystallografic orientation of gypsum according Palache et al. (14).*

Ryc. 1. Szablaste kryształy gipsu rosnące przez rozprzestrzenianie się: **a** *– ścian słupa 120,* **b** *– równoległych, soczewkowatych subkryształów lub ich agregatów. Zauważ różne struktury przyrostów na powierzchniach doskonałej łupliwości 010. Orientacja krystalograficzna gipsu według Palache i in. (14).*

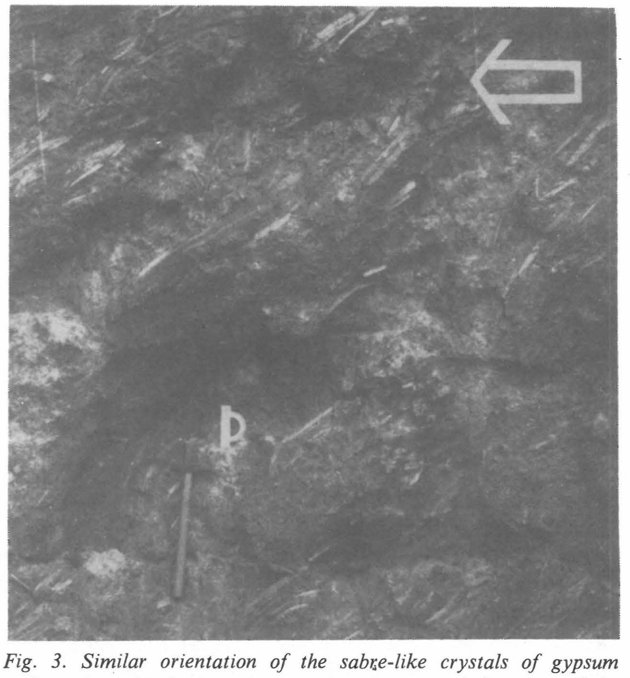

Fig. 3. Similar orientation of the sabre-like crystals of gypsum in layer **i** *at Siesławice. Arrow points interpreted direction of the brine current causing favourable growth of the crystals. in the same direction.*

Ryc. 3. Zgodna orientacja szablastych kryształów gipsu w warstwie **i** *w Siesławicach. Strzałka wskazuje interpretowany kierunek prądu nasyconej wody powodujący uprzywilejowany wzrost kryształów w jedną stronę.*

compactional breaks in similar long gypsum crystals. He stated that such breaks indicate the primary origin of the crystals.

In majority of outcrops the most of or even all of the sabre-like crystals are inclined and curved in the same direction (Fig. 3). Similar orientation of the crystal is observable on the distances of several kilometers. According to Rozen (see 8) this orientation is caused by slumps. However curvings of the crystals, being obviously an effect of their growth, indicate that the gypsum individuals were similarily oriented from the earliest stages of their development. Similar inclination of the crystals may be explained by the assumption that they grew more favourably in the direction from which the current of saturated

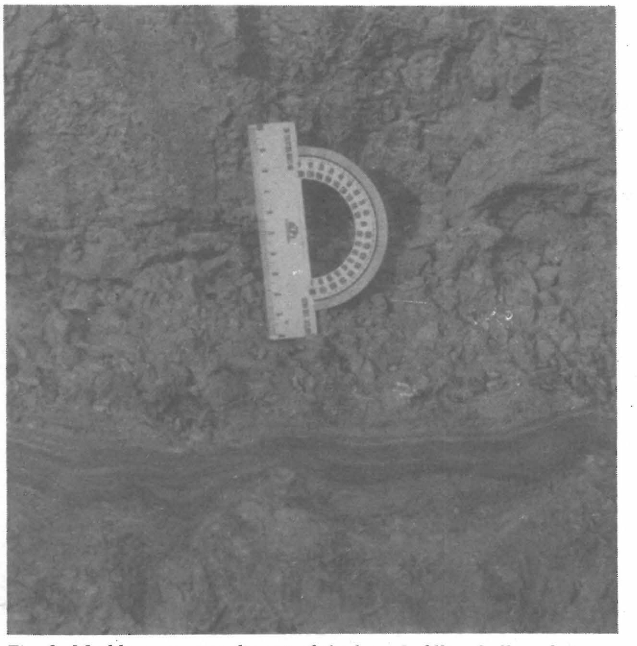

Fig. 2. Muddy-gypsum sediment of the layer **h** *filling hollows between the sabre-like crystals protruding form the top of the layer* **g**. *Gartatowice.*

Ryc. 2. Osad mułowo-gipsowy warstwy **h** *wypełniających zagłębienia pomiędzy szablastymi kryształami gipsu wystającymi ze stropu warstwy* **g**. *Gartatowice.*

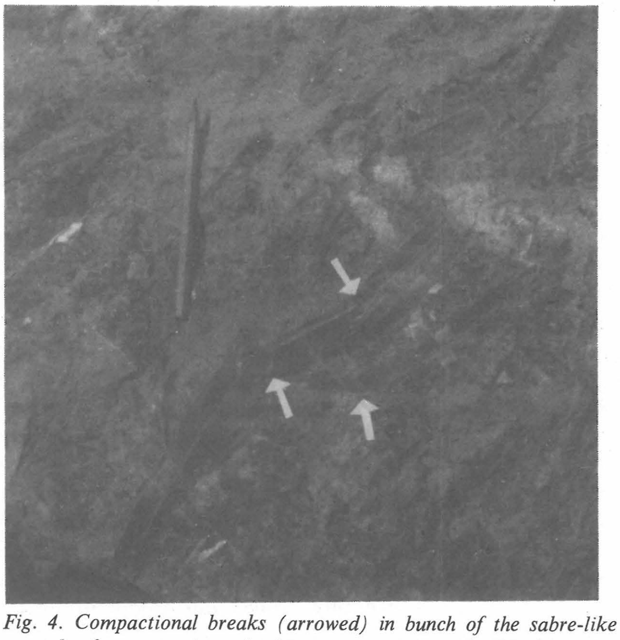

Fig. 4. Compactional breaks (arrowed) in bunch of the sabre-like crystals of gypsum. Around: thinner gypsum crystals (black) within finegrained gypsum. The layer **i**, *Gacki.*

Ryc. 4. Kompakcyjne złamania (wskazane strzałkami) w agregacie szablastych kryształów gipsu. Wokół: masa drobniejszych kryształów (ciemne) w drobnoziarnistym osadzie gipsowym. Warstwa **i**, *Gacki.*

brine supplied components necessary for their growth (Fig. 3 and lit. 1, 14 and 4 p. 205).

Kwiatkowski (10) believes that there were compensation currents in the Miocene evaporitic basin of the southern Poland. The bottom one, denser and more saturated, has flow from the coastal shoals in the north to the open sea in the south. In the Nida Gypsum the sabre-like crystals inclined to north-east and to north prevail (1). Hence

Fig. 5. Deformation of laminated gypsum around aggregates of the sabre-like gypsum crystals (black) seen in section crosswise to their slongation. Note oversteepening of the laminae above the crystal (arrowed). The layer **i**, *Staszów.*

Ryc. 5. Deformacje warstwowania laminowanego osadu gipsowego wokół agregatów szablastych kryształów gipsu (ciemne), widocznych w przekroju poprzecznym do ich wydłużenia. Zauważ zestramianie się lamin ponad kryształem wskazanym strzałką. Warstwa **i**, *Staszów.*

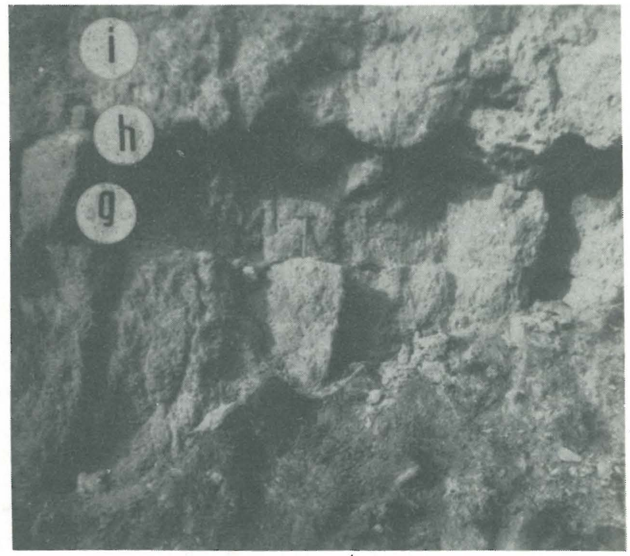

Fig. 6. Knobby load structures on the base of the layer **i** *at Gacki. The knobs are formed in places of sinking of the single sabre-like crystals of gypsum into underlying sediment of the layer* **h** *(see Fig. 7). A hammer as a scale.*

Ryc. 6. Guzowaty wygląd spągu warstwy **i** *w Gackach. Guzy tworzą się w miejscach pogrzęzania pojedynczych szablastych kryształów gipsu w niżej leżący osad warstwy* **h**. *Zob. ryc. 7. Młotek jako skala.*

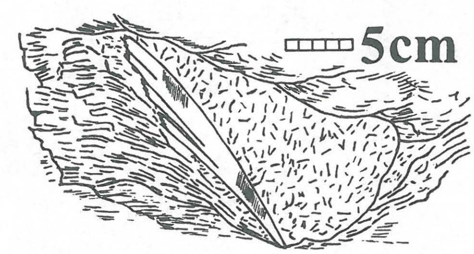

Fig. 7. Knobby convexity on the base of the layer **i** *(see Fig. 6). containing the sabre-like gypsum crystal. On the 010 surface of the perfect cleavage growth zones of the prism facies 120 are murked (compare Fig. 1). On the right from the crystal: mass of smaller gypsum crystals, on the left: bent clay-gypsum laminae of the layer* **h** *indicating that the crystal was sinking (load-casting) in time of its growth.*

Ryc. 7. Guzowata wypukłość w spągu warstwy **i** *w Gackach (zob. ryc. 6.) zawierająca szablasty kryształ gipsu. Na powierzchni doskonałej łupliwości 010 zaznaczono strefy przyrostów ścian słupa 120 (zob. ryc. 1). Na prawo od kryształu – masa drobniejszych kryształów gipsu, na lewo – zestramiające się gipsowo-iłowe laminy warstwy* **h** *wskazujące na pogrzęzanie kryształu w czasie jego wzrostu.*

the crystals are oriented favourably towards the current suggested by Kwiatkowski reflecting its paleodirection.

The sabre-like crystals occur in rows forming beds 15–40 cm in thickness, which are intercalated with finegrained gypsum or clay (particularly in the layer **g**). The crystals appear also as singles being scattered within finegrained laminated gypsum (especially in the layer **i**). Usually on the sabre-like crystals surfaces the smaller individuals have grown. In the layer **i** within the laminated gypsum apart from the sabre-like crystals secondary recrystallized aggregates of crystals are found described by Kwiatkowski (10) as the "arc and elliptical forms".

In the layer **i** the laminated gypsum sediment around the sabre-like crystals very often is deformed (Fig. 5). Bending of the laminae occurs beneath the crystals. It indicates that the gypsum individuals began to grow directly on the bottom surface and have sunk into the soft underlying sediments due to their increasing weight (1, 3, 4, 12, 17). Knobby convexities frequently occur on the base of the layer **i** (Fig. 6). Each of them contains the single sabre-like crystal, which sunk into the more loamy sediment of the layer **h** (Fig. 7). Above and around the sabre-like crystal many smaller gypsum individuals have grown. Similar load structures noticeable as knobs on the bases of the beds occur frequently in the Miocene gypsum of the Mediterranean and they have various names: **nucleation cones** (3, 4, 12), **stellate gypsum clusters** (17), **mamelloni** (21).

Bending and oversteepening of laminae also appear above the crystal tops (Fig. 5). They could be caused by compaction or by force of crystallisation of gypsum as well. The growing crystal, if covered by finegrained gypsum laminae, was able to push them upward. Similar deformations of sediments overlying the gypsum crystals, due to their growth, often occur in ancient and recent evaporites (see 6: Fig. 22).

Laminated finegrained gypsum of the layer **i** remained unconsolidated for a long time being easily disturbed (see 10). Some of the sabre-like crystals found in this layer were moved together with a surrounding material (1). Sometimes deformations visible as foldings of lamination involve the entire layer **i**. The folds are overthrown in direction of the crystals inclination. The crystals were evidently lain down in direction of their inclination due to the small-scale gravitational movement of the sediment and later compaction and in many places they reach nearly horizontal position. Sporadically the crystals were overthrown at opposite side and they have lain on their curved surfaces. Translocation of the sediment with disruption of the laminae continuity was not observed.

In the sabre-like gypsum, namely within the layers from **e** to **i**, large domal structures reaching a dozen or so meters in diameter occur in the vicinity of Skorocice, Aleksandrów and Wiślica. They were described long ago by Kontkiewicz (7). They consist of several concentric beds built of rod-like and the sabre-like crystals. In the core parts of the domes the karst caves are developed having unusual bell-like shapes (e.g. at Skorocice). Malicki (13) believes that the domes originated by swelling of the hydratizated anhydrite. His view was criticized by Flis (5) who described these structures as forms of pingo. The different opinions also exist. Tokarski (see 5 p. 21) stated that the domes were created by an unequal growth of the primary gypsum crystals. Wytrwalski (24) suggested that succesive layers of the discussed structures have crystallized parallely with the convex shape of the basement. However the primary nature of the domes was not proved.

One of the gypsum domes crop out very well at Zamczysko hill at Wiślica (Fig. 8). There are some features which indicate its primary origin (1). There is no cave in this structure (5) so the core part of the dome can be investigated. The preserved core is filled by a mass of chaotically arranged gypsum individuals maximum several centimeters in size. The upper part of the dome is layered but in the side parts of it the layering disappeared being obliterated by numerous sabre-like crystals up to 70 cm in length. They have grown outside from the core reaching radial orientation. Such an orientation of the crystals is exceptional in the sabre-like gypsum and evidences the primary nature of the discussed structures.

Similar gypsum domes form in the recent salina lakes of the southern Australia (23). They reach 2 m in height over the bottom level. The cores of the domes are built of the chaotically arranged gypsum crystals while in the upper parts of these structures the layering is visible and the large gypsum crystals growing upward occur. Similar domes numerously appear in the Miocenian gypsum of the Mediterranean (6, 18).

Thus the domes from the Nida Gypsum were formed on the bottom of the evaporitic basin. Their core parts were created as initial convexities on the sea floor. They were composed of many small crystals weakly bound or loosely placed in clay. These parts of the domes were more affected by a karstic corrosion than compact beds of the sabre-like gypsum above. Hence in many domes the karst caves have developed.

Sedimentary structures connected with the growth of gypsum crystals, briefly presented above, prove the primary nature of the sabre-like gypsum and can be useful for sedimentary analysis of the other similar deposits.

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W pracy przedstawiono struktury sedymentacyjne związane ze wzrostem kryształów gipsu, występujące w tzw. gipsach szablastych, w środkowomioceńskich (badeńskich) ewaporatach południowej Polski. Gipsy szablaste odsłaniają się w okolicach Buska, Wiślicy i Pińczowa na południowym obrzeżeniu Gór Świętokrzyskich. Niektóre z opisanych struktur, takie jak: kieszeniowe zagłębienia pomiędzy wierzchołkami kryształów wypełnione detrytycznym materiałem, kompakcyjne złamania kryształów lub struktury obciążeniowe spowodowane pogrzęzaniem kryształów ros-

nących na powierzchni miękkiego nie skonsolidowanego osadu – świadczą o pierwotności osobników gipsu. Podobna orientacja kryształów, tzn. takie samo ich nachylenie jest zinterpretowana jako wynik działania dennego prądu nasyconych wód, który powodował uprzywilejowany wzrost kryształów w stronę, z której prąd napływał. Wielkie kopuły obejmujące kilka warstw gipsu są przedstawione jako pierwotne struktury tworzące się na dnie morza.