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Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

Calcite or calcite-sulphur limestones pseudomorphic limestones after gypsum selenite crystals are a salient feature of the Polish sulphur deposits and associated (barren) carbonate rocks which serve as a cardinal argument for the bioepigenesis of the Polish stratiform sulphur deposits. Detailed investigations indicate that these postselenite rocks form distinct facies defined as gypsum-ghost facies. This facies is composed of empty or filled (mainly with calcite and sulphur) spaces ("pseudomorphs") after selenite gypsum. With regard to the main component,which is ghosts of variously developed original selenite gypsum crystals (fine, coarse selenite or sabre-like forms), they may be divided into fine gypsum-ghost subfacies and coarse gypsum-ghost subfacies. Petrographic characteristics of the gypsum-ghost limestones are inconsistent with the features of selenite gypsum deposits and clearly indicate no close analogies between these two lithologies. The differences between these facies with regard to components, matrix, porosity, structures and textures excludes them from being facies equivalents. Characteristics of these limestones suggest additional diagenetic factors which could play an important role in the preservation of original gypsum structures during the course of the alteration.

INTRODUCTION

Native sulphur deposits located in the Carpathian Foredeep (southern Poland) are the products of a complex sequence of physical and diagenetic processes. More precisely, during diagenesis, biochemical interactions were responsible for the formation of distinct native sulphur ores composed mainly of "secondary" sulphur-bearing and barren limestones. According to the commonly assumed model of native sulphur formation, bioepigenetic alteration of gypsum rocks occurred in geologically favourable settings and under specific structural and biochemical conditions (summarized by S. Pawłowski, 1968, 1970; S. Pawłowski *et al.*, 1965, 1979, 1985; M. Nieć, 1977, 1982, 1992; M. Pawlikowski, 1982; B. Kubica 1992, 1994). In general, as bacterial oxidation of hydrocarbons to carbon dioxide reduced sulphates, native sulphur and caleium carbonate (as a byproduct) were generated.

As the general model (supported by several lines of evidence, *op. cit.* with references therein) says, the alteration of primary solid rocks (sulphates) into secondary (carbonate) lithologies was recorded and is reflected by, for instance, various structural and textural features of the ore deposits inherited after sulphate rocks. The carbonate rocks characterized by distinct mineralogical and petrographic varieties are, in a very general way, ascribed to various gypsum lithotypes which have undergone alteration (e.g., K. Pawłowska, 1962; R. Krajewski, 1962; S. Pawłowski, 1968, 1970; S. Pawłowski *et al.*, 1965, 1979, 1985; M. Nieć, 1969, 1982, 1992, T. Osmólski, 1972; M. Pawlikowski, 1982; B. Kubica, 1992). However, no detailed reconstruction of original sulphate lithofacies which (according to the demands of the bioepigenetic model) should be preserved in the carbonate series has been developed so far. In particular, among a wide spectrum postsulphate deposits, mineralized or barren limestones with abundant preserved postselenitic gypsum macrostructures play an exceptional role and are defined in this work as the gypsum-ghost facies. These limestones, for their highly spectacular nature, serve also as one of the cardinal arguments for the bioepigenetic formation of the Polish native sulphur ores.

The preservation of original selenite fabrics in the gypsum-ghost limestones is of special importance mainly for association with the sulphur mineralization. These limestones appear as essential features of the Polish sulphur deposits and therefore provide unique possibility to (1) evaluate the current model of Polish sulphur deposit formation in the light of inheritance of original host features and (2) reconstruction of original processes and compresion of conditions of the solid sulphate alteration into carbonates and native sulphur. The aim of this work is to describe and to compare both selenite gypsum and gypsum-ghost facies based on insight from petrology. This study is also intimately connected with regional characteristics of these two main lithologies (A. Gąsiewicz, 1994). Both papers are, in turn, a part of more extensive research focussing on the gypsum-ghost limestones undertaken by the author. In particular, the researeh includes further work on both geochemical and sulphur mineralization characteristics of the facies as well as a reconstruction of both paragenetic sequence and original non-altered deposits. All these questions are in progress and will be presented in forthcoming papers.

MATERIAL AND METHODS

Detailed sedimentological analysis comprised carbonate (mainly) and sulphate series (drilled generally southeast of the Holy Cross Mts. and cropping out on the southern margin of the Holy Cross Mts. area) successively developed at various stages of the author's research. In the core material from over 60 boreholes of the Osiek – Baranów Sandomierski deposit and core material from selected boreholes of other sulphur deposits (Grzybów, Tarnobrzeg and Basznia), as well as numerous field studies in the open-pit mine at Machów were carried out. These sections were sampled and polished thin section were investigated using both standard and cathodoluminescence petrography with a Technosyn Cold Cathodo Luminescence Model 8200 Mk II. Alazarin Red staining indicates that the investigated carbonate rocks are exclusively composed of calcite.

GEOLOGICAL SETTING

The Miocene formation of the Carpathian Foredeep contains an evaporite unit (Badenian stage) widespread in the basin. It forms the Chemical Series composed mainly of gypsum and anhydrites with locally (mainly in the marginal part of the foredeep) developed so-called secondary sulphur-bearing or barren limestones. This unit is unconformably covered by a thick (up to around 3000 m) monotonous claystone series (see G. Czapowski, 1994) belonging to the Sarmatian. Stratigraphic and lithologic framework of the Carpathian Foredeep is described in detail by K. Pawłowska (1962, 1965), S. Pawłowski (1970), S. Pawłowski *et al.* (1965, 1979, 1985) and summarized up by K. Pawłowska (1994) and P. Karnkowski (1994).

Mineralized or barren limestones are the main lithology (with a subordinate content of marls and sulphates) found within native sulphur formation. This formation is composed of textural varieties of the ore deposits and were described in general way by K. Pawłowska (1962), M. Nieć (1969, 1982, 1992), S. Pawłowski (1970), S. Pawłowski *et al.* (1979, 1985). The most striking feature of these rocks is the preservation of original sulphate structures (R. Krajewski, 1962; K. Pawłowska, 1962; S. Pawłowski, 1968, 1970; M. Nieć, 1969, 1982, 1992; S. Pawłowski *et al.*, 1965, 1979, 1985; M. Pawlikowski, 1982). These original selenitic gypsum precursors form specific interbeds defined here as gypsum-ghost limestones.

CHARACTERISTICS OF GYPSUM-GHOST LIMESTONES

GENERAL FEATURES

Abundant and distinct relics of original calcium sulphate (selenite gypsum) precursors form a distinctly three-dimensionally defined variety of carbonate (limestone). The primary contents of such postselenite structures have been commonly completely removed. The structures include "ghosts" (i.e., empty spaces left after gypsum crystals) and so-called calcite and sulphur (or both) pseudomorphs (spaces remaining after removal of gypsum crystals and later fully (rarely) or partly (most commonly) filled with calcite and/or native sulphur). For all these reasons the considered limestones are defined here as "gypsum-ghost" facies. Rocks consisting entirely of pseudomorphic gypsum are rare and limited to the lower part of the carbonate series where larger gypsum-ghost structures commonly occur. The most distinctive features of the facies are porosity (Pl. I, II) and ghosts of selenite precursors (Pl. III–VII).

The porosity of the gypsum-ghost limestones is connected with the presence of less regular or irregular and numerous small caverns (commonly up to several centimetres in size) which usually mould clusters of gypsum crystals. These forms which follow particular selenite gypsum crystal are sometimes more regular and linear in shape. They usually occur in the more massive, often thicker, variety of the gypsum-ghost facies, which is typical for the altered carbonates and may be very (exceeding 20%) cavernous (J. Kowalik *et al.*, 1979). Such elongated caverns may occur chaotically or may be (usually finer forms) arranged into single, weakly marked and discontinuous horizons. Locally, extremel porosity of these limestones is manifested by the presence (Pl. I) of small (about 0.5 m in size) to large (maximally up to few metres in height) and isolated caverns (interpreted as the result of karstification — B. Nielubowicz, 1973; T. S. Piątkowski, 1974; T. Osmólski, 1976; M. Nieć, 1977). In general, for such high porosity, these rocks are sometimes very friable, especially those containing empty, abundant and larger postselenite spaces. In the extremel case, this led (after disappearance of gypsum crystals) to collapse of vuggy limestones and thus formation of crushed material locally found in the core material. This, in turn, could have been followed by strong local thickness reduction of the carbonate sequence.

The porosity of this facies varies from massive, compacted, calcite-dominated (with low or even no microporosity) limestones to very porous or even cavernous rocks. The porosity of this facies depends on the abundance, arrangements and size of altered original gypsum crystals and the presence of unfilled spaces remaining after occlusion by later diagenetic minerals. The gypsum-ghost facies is generally highly porous (Pl. III, Fig. 8), locally as high as about 40% of the rock volume. The measurements in such deposits indicate (J. Kowalik *et al.*, 1979) that the porosity commonly exceeds 30% and often reaches about 36-42%. The porosity is especially abundant in the facies originally containing abundant, larger (up to several centimetres in the length) and tightly interlocking gypsum crystals. Sometimes the vugs are connected or occur close to one another forming distinct horizons. In fine-grained gypsum-ghost facies vugs are distinctly smaller (usually below 1–2 cm in size) and generally less common. However, locally abundant vugs of various sizes form fine to coarse, porous, sponge-like rocks. Typically, more porous rocks irregularly pass laterally and vertically into more massive varieties of the facies with individual caverns often defined as the Ratyń limestones (K. Pawłowska, 1962; S. Pawłowski *et al.*, 1985). The porosity distribution often emphasizes lense-like variability of the facies. In coarse crystalline calcite rocks the porosity is also induced by the presence of intercrystalline spaces, thus leading to fragility of the rock.

Gypsum-ghost limestones composed of finer postselenite relics are thin to thick bedded, while those containing larger structures commonly do not exhibit any stratification (Pl. I). Structureless gypsum-ghost limestones preferentially occur in the lower part of the Chemical Series where the partition is usually irregular. However, stratification (Pl. II) on a local scale is reflected by thin, flat or wavy lamination or streaks (of clayey-calcite, calcite or sulphur fractions as well as of porous horizons) or by intercalation of thinner marly carbonate or massive carbonate interlayers or beds horizontally or obliquely oriented. These limestones intercalate generally massive, bedded, grey, micritic or microsparitic carbonates, are usually are light or light-grey to dark-coloured, occasionally contain fossil fragments (represented by unidentified thin shells and foraminifera tests) and contain poorly sorted, oval peloids (up to 0.25 but usually 0.05-0.10 mm in size).

The gypsum-ghost limestones may be sulphur-bearing (Pl. III, Figs. 9, 10) or barren (Pl. III, Fig. 8) and locally more marly. As far as these varieties are concerned, the main difference is connected with the presence or lack of sulphur mineralization. Small differences between these two lithologies are sometimes marked by less frequent and finer postselenite structures found in the barren limestones, which, however, seem to be rare. Both types of limestone pass one into another with a sharp or gradual boundary marked mainly by a change in sulphur content.

The gypsum-ghost limestones form (Pl. I, Figs 2, 3; Pl. II, Fig. 5) more or less elongated lense-like (usually about 0.5–2.5 m in length), isolated carbonate bodies, commonly up to 1.0–1.5 m thick and several to tens of metres long (where are connected one to other). They occur mainly in the lower part (where they are relatively thicker and laterally more widespread), and rarely in the middle and upper part of carbonate ore series where they are more discontinuous. Thus, these bodies sometimes form more distinct stratiform and thinner beds which are more laterally continuous. They are separated one to other (Pl. I, II) by thin (5–20 cm thick) interlayers of more massive or marly limestones (often laminated by clayey matter or sulphur aggregates) commonly with lower content of sulphur. Contact between the both gypsum-ghost limestones and other carbonate deposits (Pl. II, Fig. 4) as well as between particular lense-like bodies may be (usually) gradual or sharp. The gradual contact is expressed by change in: (1) both size and number of gypsum-ghost structures, (2) content and form of sulphur aggregates, and (3) content and nature (marly, micritic or sparitic) of the matrix. The sharp contact is reflected by partly cutting off original selenite crystals and emphasized by increase of clayey matter. Regional characteristics of this facies are discussed in a supplementary paper in this volume (A. Gąsiewicz, 1994).

In general, the postselenitic gypsum structures include individual or isolated clusters of fine (straight) to large (straight to sabre-like) structures remaining after the removal of individual or groups of original gypsum crystals (Pl. II, Fig. 5; Pl. III). The individual forms range in size from millimetres up to tens of centimetres in length (maximally about 30 cm in length). They may be either tightly or loosely packed (with numerous intercrystal voids or matrix in between the forms). Large structures commonly are obliquely oriented, usually from 20 to 70°. They may be parallel to one another or chaotically arranged (especially if they are abundant), or randomly dispersed (if they are isolated). These forms may occur in micritic or microcrystalline matrix or in matrix composed of mixed micritic carbonate and gypsum mixed with small gypsum erystals. Small lenticular structures are usually isolated or interlocked randomly and only sometimes form thin and discontinuous layers or clusters. They may also be scattered in the matrix between larger forms or local twins of the gypsum-ghosts. Generally, it is possible to distinguish (Pl. II, Fig. 5; Pl. III–VII) three types of gypsum-ghost structures: (1) large (mainly up to around 20 cm in length and up to 2–3 cm in width), straight or bent; (2) smaller (below 10 cm in length and below 1–1.5 cm in width), straight or twinned; and (3) small (below 1 cm in size) lenticular or lath-shaped (small square-shaped relics occur occasionally dispersed in between larger or smaller forms). A common lack of square-shaped cross-sections preserved in the rock matrix indicates that almost all small forms are inherited from gypsum crystals and only a few from original anhydrite crystals. While the first type of structure is the most distinct (usually as interbeds or thicker complexes), the second one occurs more abundantly and is typical for Polish ores. The third type appears more rarely, commonly in between the larger structures, but often may form distinct layers or beds of higher concentrations. The smaller forms often are indistinct and poorly preserved but usually build up distinct beds or complexes.

A common feature of the gypsum-ghost limestones is their heterogeneity reflected, except for the development of gypsum relics, by the presence of variously types of carbonate clasts. These are dispersed in between the gypsum-ghost structures and sometimes form interlayers or thicker beds with distinct conglomeratic features. Most clasts are dark uniform (micritic) or heterogeneous (micrite-sparitic, containing no lenticular gypsum relics or peloids), angular or oval, elongated, and sometimes broken. The nature and especially shape of the clasts indicate that they mostly represent material originally preserved in between selenite gypsum crystals. Clasts usually are angular (sometimes slightly rounded), irregular, up to a few centimetres in size (commonly below 1 cm), heterogeneous (micrite or sparite, laminated or nonlaminated, with no sulphur or celestite), poorly sorted, occasionally broken and healed with calcite, chaotic and dark, with sharp or blurred margins. Larger grains are sometimes parallel to local stratification. The conglomeratic beds commonly have laminations of clayey-calcite and/or mainly calcite-sulphur laminae in between the clasts (in preparation).

The matrix is generally light grey or dark, massive, heterogeneous (micrite to sparite fractions with sulphur granules and local peloidal textures), less porous or macroscopically nonporous, and locally discontinuously laminated. The matrix commonly predominates the rock composition, only rarely do the other components reach extremely high concentrations and become strongly packed. Crystallinity of the facies changes from a very fine fraction (below 0.02 mm) to a relatively coarse (up to 0.8 mm in size) fraction. Usually, the more massive variety of limestones have more micritic matrix and finer, anhedral, tight calcite crystals (about 0.01 mm in size). The sparite fraction may form the whole matrix but usually occurs as irregular patches co-occuring with the micritic fraction. These fractions gradually pass into one another. Calcite crystals are transparent or light grey (with abundant impurities), are commonly very variable in size, and composed of mosaics of anhedral blocky calcite. These blocks locally border one another indistinctly and may form poikilitic texture. Impurities are more abundant in larger calcite crystals which typically show the cleavage system. Calcite crystals often are larger and better developed at the contacts with sulphur aggregates and, in general, are the main component of gypsum-ghost facies occurring in the lower part of the Chemical Series. Particularly, they build up the largest ghosts of gypsum sometimes forming distinct druses with hemi- or pyramidal ends. Highly calcite crystalline rocks are fragile.

Gypsum-ghost limestones are sometimes cross-cut by thin, straight or zig-zag micro- and macroscopic calcite or/and native sulphur, gypsum and celestite veins. The veins often are incompletely healed with centripetal growth of minerals; rock components are sometimes slightly displaced. The wider structures are sometimes filled with columnar or spherulitic calcite cement.

Various calcite and native sulphur-associated minerals often occur or co-occur in varying combinations and quantities in postselenite vugs. These minerals rarely completely occlude spaces remaining after gypsum precursors and usually a variable degree of porosity still exists. The most common minerals are late (transparent, yellowish to brownish) acicular or columnar calcite, native sulphur, dispersed pyrite and rarely milk to transparent celestite. Other minerals (like strontianite, barite, and aragonite) are distinctly subordinate and occur occasionally. Locally a multistage mineral encrustation is (especially in larger vugs or small caverns) distinctly expressed by the presence of (thinner or thicker) layered crusts composed mainly of calcite, native sulphur and rarely celestite. Typically, a whole available space remaining after removal of (larger and smaller) selenitic gypsum crystals from sulphur-bearing or barren limestones is completely filled with various minerals, especially calcite and native sulphur. Native sulphur filling up the voids usually separates euhedral faces of calcite or other mineral crusts projecting from adjoining walls and precipitated earlier.

Sulphur crystals found in such vugs usually are well developed, while those found in the matrix commonly are xenomorphic. Spotted sulphur aggregates and crystalline sulphur crusts often line vugs and thus mimic, in a general way, the original gypsum crystal fabric or occur as individual aggregates, or crystal overgrowths on other mineral crusts. In other cases, a complete infilling by native sulphur forms distinct so-called sulphur pseudomorphs after gypsum crystals. However, in most examples the space is only partly occupied by these later diagenetic minerals (generally outlining the previous selenitic gypsum crystals), often leaving empty vugs. In barren limestones, the post-gypsum voids commonly are empty and only sometimes covered by thin continuous or (mainly) discontinuous calcite crusts or fine individual calcite crystals. Finer voids commonly are completely occluded by crystalline calcite. Both standard petrography and cathodoluminescence microscopy studies revealed (in preparation) a complex paragenetic sequence developed from relatively early (when vuggy to cavernous porosity was formed) to late (when available space was successively infilled with various minerals) diagenetic stages. It also indicates that this calcite is generally developed as uniform and transparent, light blocky or equant cement. This cement varies from a fine to coarse crystalline texture and, commonly, is also developed as successive crusts or druses around void spaces. In the fine structures, calcite crystal infillings commonly exhibit a centripetal growth pattern.

Other minerals have been found in the matrix, they include: individual oval grains of fine of pyrite (or aggregates up to 0.15 mm in size) of pyrite, occasional grains of glauconite (a few millimetres), detrital quartz (usually below 0.1 mm), radial secondary gypsum aggregates, acicular aragonite (up to 0.2 mm) in small vugs, and muscovite (up to 0.4 mm), common celestite crystals (columnar or poorly developed and usually a few millimetres) and shreds of bitumens covering pore vugs or impregnating the micrite fraction. The matrix contains also fragments of coalified flora remains.

As a general rule, gypsum crystals are totally absent within the gypsum-ghost structures. Only a few exceptions, restricted to very fine individuals preserved within the carbonate matrix, are composed of both gypsum crystals and calcite infillings. However, even in such examples, it cannot be excluded that gypsum may be of secondary origin (that is formed very late, by the precipitation from circulating post-formational ore waters). This sometimes may be indicated by well developed calcite faces bordering gypsum crystals or granoblastic texture of infilling gypsum. Direct contacts between carbonate and sulphate complexes in a so-called transitional zone are irregular and embayed in both vertical and horizontal directions.

SUBFACIES

Occurrence of variously developed ghosts of gypsum preserved in the lower and the upper part of the Chemical Series, thickness of beds, sulphur mineralization and other features of the gypsum-ghost limestones presented above strongly imply the occurrence of different carbonate facies preserved within sulphur-bearing or barren sequences. In general, they mainly differ in size, abundance, orientation and aggregation of the main component, which is postselenite relics (preserved as either empty moulds or moulds partly to completely infilled with other minerals). Based upon detailed macroscopic and microscopic investigations of the carbonate rocks it is possible to distinguish the following subfacies which differ with respect to preserved relics (ghosts), sedimentary structures and mineralogical associations: (1) fine-grained, more or less loosely packed in the calcareous matrix (Pl. I, Fig. 3; Pl. II, Fig. 4) and, (2) middle to coarse crystalline which may occur individually or as intergrowths, usually in interlocking mosaics (Pl. II, Fig. 5; Pl. III–VII).

F i n e g y p s u m - g h o s t s s u b f a c i e s (Pl. IV, V). This subfacies is generally light in colour, relatively more marly, fragile and soft than the coarse one, although pure limestones were found as well. It forms relatively thin complexes or beds, commonly finely stratified that gradually pass into other carbonate rocks. Stratification is usually horizontal but locally dips up to 10°. It is often expressed by thin (usually 1–2 cm) laminae or streaks of clayey matter, vugs and irregular or rhythmical flat, wavy or streaky lamination of disseminated sulphur. Bedding is locally marked by thin calcite or celestite layers. Laminations are characterized by a variety of proportions of clay, carbonate grain contents, arrangement and crystallinity of the calcite fraction, and distribution and form of both sulphur and porosity. Parallel lamination is commonly shown by clayey or carbonate-clayey particles forming more or less distinct laminae and streaks and sometimes by flat-lying, elongated grains, or by the presence of small vugs or pyrite aggregates. Lamination may be horizontal or oblique, flat, wavy, and is usually laterally discontinuous and with indistinct margins.

Characteristically, these limestones are (Pl. IV, V) variably porous, and are composed of fine (usually 1 cm in size) individual (Pl. IV, Figs. 11, 12) or connected (Pl. IV, Fig. 13), irregular to oval and angular pores often arranged into more or less distinct laminae, streaks or layers (Pl. IV, Figs. 11, 14). As may be inferred from the shape of the vugs, most of them are of after-grain origin and strongly resemble fragments of selenite crystals. The structures may occur individually chaotically arranged (Pl. IV, Fig. 14; Pl. V, Fig. 16) or reflect the presence of original selenite clusters (Pl. V, Figs. 15, 17). The larger vugs are often less regular, obliquelly oriented (40–60°) and occasionally are parallel to general stratification. The more marly a rock is, the finer pores it has. Locally, a sponge-like rocks in carbonates where porosity is very high (Pl. IV, Figs. 13, 14).

Grain composition of this subfacies is, in general, complex, and it is possible to distinguish structures which strongly follow the shape of original selenite gypsum (commonly broken) as well as grains which strongly resemble originally carbonate particles (including carbonate clasts, peloids and occasional bioclasts). Carbonate grains vary from well-sorted (the finer, the better sorted) to (commonly) unsorted. They may be distributed irregularly throughout the facies or occur in distinct streaks, laminae, and rather thin layers and beds. The content of these grains varies from abundant (up to around 60–80%) to individual grains scattered or concentrated into irregular patches and streaks in carbonate matrix. These components are common in the fine gypsum-ghost-facies and rarely may build up separate grainy, generally fine to coarse sand sized intercalations or thicker complexes. Dispersed carbonate grains usually co-occur with postselenite structures and thus form interbeds that range from single streaks (up to a few centimetres thick), layers (below 10 cm thick) and more continuous sequences totaling a few metres in thickness. The thicker complexes usually are laminated by both calcite or clayey fractions. There is no concentration of the grains along bedding and instead of this, somewhat transitional contact at the facies boundaries is commonly observed.

The grains resembling original selenite gypsum crystals (Pl. IV, V) are composed of distinct calcite-infilled relics or vugs with characteristic shapes which allow their interpretation them as the relics of former selenitic gypsum crystals. Most of them (70%) comprise the relics below 3 cm in size and maximally reach 10 cm in length and 1 cm in width. Most distinctive grains have a shape which clearly represent fragments of twinned selenite crystals. Generally, these grains tend to be euhedral but many are blunted and sub-rounded, clearly showing that they are abraded. Small calcite "pseudomorphs" remaining after selenitic crystals may be tabular, twinned, irregular or rarely equant. A common feature of the former sulphate grains is the presence of broken, incomplete, original selenitic fragments of crystals that allow primary detrital boundaries to be recognized. Although generally no preferred grain orientation is visible among smaller, more equant grains, relatively larger ones, especially elongated ghost of gypsum crystals, often have their long axes roughly parallel to general bedding. Small equant grains are often packed between the larger postselenitic ones. These grains commonly are chaotically arranged and even thicker complexes do not exhibit noticeable decrease or increase in grain-size of the original crystals. Other grains such as sub-rounded sand-size carbonate (micritic) grains or lithoclasts, detrital quartz, glauconite or pyrite aggregates are distributed in these beds. In addition, carbonate mud chips (less than a few millimetres long) are found scattered through a relatively uniform carbonate-clayey matrix. Macroscopic features of this facies with regard to grain composition, shape, size, sorting, and orientation clearly indicate the conglomeratic nature of the fine gypsum-ghost facies (Pl. V, Fig. 18). This is also confirmed by both standard and cathodoluminescence petrographic observations.

The matrix is composed mainly of calcite (both micrite and sparite fractions), irregularly dispersed (or arranged into fine streaks or laminae) clayey or clayey-organic matter, and individual grains. Although the micrite fraction generally prevails, the intergrain space is often occupied by anhedral crystals of blocky calcite which vary in size.

In general, these limestones are predominated by calcite (micrite and sparite) and contain other minerals like sulphur, celestite, barite, pyrite, gypsum, quartz, feldspar and a relatively abundant and varied suite of clay minerals (?kaolinite, smectite, chlorite, muscovite and glauconite) as well as local irregular patches of bitumens which may be dispersed in the matrix. Calcite occurs mainly as micrite and sparite which irregularly build up carbonate matrix and a variety of calcite crystals filling up abundant vugs. Sulphur occurs mainly in the matrix where it forms individual aggregates or commonly is irregularly dispersed or forms distinct laminae or streaks. Other minerals like calcite, sulphur, celestite, barite and gypsum also locally infill also the spaces remaining after gypsum. Volumetrically, distinctive mineral phases include micrite, which predominates the matrix composition, and sulphur, which occurs as individual grains dispersed in the matrix or infilling postsulphate spaces. Relatively more abundantly, in comparison to the coarse gypsum-ghost subfacies, occur clay minerals, detrital grains and, locally, shreds of bitumens.

Coarse gypsum-ghosts subfacies (Pl. VI, VII). This subfacies includes relatively large gypsum-ghost structures, often accompanied by finer ones. These limestones may be relatively either (occasionally) gypsum-ghost-structure-supported (Pl. II, Fig. 5; Pl. III, Fig. 9; Pl. VII, Figs. 23, 24) or (mainly) matrix-supported (massive variety) (Pl. I, Fig. 3; Pl. III, Figs. 8, 10; Pl. VI). This subfacies has sharp boundaries or gradually passes into other sulphur-bearing or barren limestones.

They are light to dark grey, high porosity and high crystalline calcite varieties usually are fragile, while massive varieties are more compact and firm. The latter limestones often contain elongated, angular or oval, dark and uniform, indistinct, chaotic clasts. Coarse gypsum-ghost limestones are locally brecciated with grains cemented by calcite. The largest ghosts of gypsum usually occur in the lower part of the section and upwards usually become finer. In general, the subfacies is locally discontinuously laminated (mainly by various calcite fractions or calcite-sulphur material), especially when it occurs in the lowest part of the Chemical Series.

Larger (often exceeding 10 cm in length and up to 2–3 cm in width) ghosts usually show (Pl. VI; Pl. VII, Figs. 23, 24) distinct, relatively regular, and preferred orientation in that they grew in a vertical or subvertical (commonly between 40–80°) position. They are straight or slightly to distinctly bent (resembling sabre-like forms); they may occur individually or closely packed parallel to one another. The finer postselenite relics (usually below 10 cm in length) are straight and thin. They may occur individually, randomly dispersed in between the larger relics or as clusters consisting of randomly or preferentially (and thus more regularly) oriented ghosts of crystals. These ghosts often are obliquelly oriented at an angle lower than that typical for the larger structures. The smallest forms commonly are randomly disseminated in carbonate matrix without any preferential orientation of particular forms and only sometimes show an arrangement into streaks. In addition, smaller structures may chaotically co-occur, for example, smaller ghosts may be accompanied by the smallest; however, in general, this co-occurrence is distinctly insignificant volumetrically. It happens relatively often at the margins of the facies (at the transition to other diagenetic facies) in both vertical and lateral extent.

Matrix between the ghosts of gypsum is heterogeneous in that it is composed mainly of micrite and sparite fractions with common microsparite patches with blurred margins and individual, fine peloids. The matrix exhibits distinct bipartition into (1) a relatively uniform, massive, grey or dark-grey form, representing the matter between former gypsum crystals which irregularly interfinger with (2) lighter, typically highly crystalline with crystals very variable in size which is commonly coarse (and rarely fine) crystalline, locally laminated, and which contains peloids and often displays features of recrystallization. Thus, both petrographic and cathodoluminescence analyses of the gypsum-ghost limestones exhibit two types of matrix representing different stages of formation — the first one corresponds to synsedimentary deposition, while the second one (with peloidal texture) to a later diagenetic stage.

The fabric often exhibits additional primary textures such as numerous streaks or small and discontinuous wavy lamination composed of clayey matter or variations in crystal size and calcite-sulphur proportion (Pl. VII, Figs. 25, 26). These streaks are often variously inclined (often up to 20–30°) and sometimes the dip is associated with the presence of adjacent larger gypsum ghosts or carbonate clasts. In general, the stratification is poorly marked or absent but locally may be well expressed by either streaks and laminae (sometimes disturbed) or thin interbeds (up to about 30 cm thick) and rarely thicker lense-like complexes. Thinner layers usually dip slightly (5–10°). These bodies composed of streaky, marly limestones with gradual or sharp boundaries and containing dispersed and fine ghosts of gypsum, locally resemble rudstones composed of angular carbonate clasts which are poorly sorted, chaotically and variously packed (Pl. VII, Figs. 25, 26). They are usually below 5 cm in length, light or dark, often elongated or tabular, with sharp or blurred margins. Some clasts are impregnated by sulphur, others are laminated, but most of them are dark and uniform (micritic) usually, cemented by lighter calcite. Individual clasts are often found in between larger postselenite relics. These rudstones are commonly laminated by calcite, clayey-calcite or calcite- sulphur fractions. Lamination may be horizontal and flat but usually is wavy and oblique (20–40°).

Gypsum-ghost structures, as mentioned above, may be empty, partly or completely infilled, or impregnated with various minerals, most commonly with calcite and sulphur (Pl. VI; Pl. VII, Figs. 23, 24). This subfacies, if it is not or only slightly infilled with later diagenetic mineral phases, may be highly porous (up to around 40%) and mainly results of removal of large selenite crystals. A lack of later diagenetic mineral infillings caused sponge-like texture of the subfacies (Pl. VII, Figs. 23, 24). In the lower part of the section they usually are very cavernous. In contrast, the matrix is generally of low (and locally extremely low) porosity and sometimes coarse crystalline streaks contain fine (up to a few millimetres in size) and irregular elongated or partly angular pores. These small vugs may emphasize local stratification or may be scattered throughout the matrix. Their shape, relationships as well as the orientation, however, only sometimes indicates original sulphate crystals and most commonly they are very irregular.

Mineralogical composition of this subfacies is generally similar to the fine gypsum-ghost one, and the differences are mainly quantitative. The most distinct mineral phase is euhedral or semihedral and mostly coarse crystalline calcite that centripetally infills the vugs or occurs as anhedral sparite in the matrix where it often encloses irregular micrite patches with diffuse margins. Calcite, sulphur and celestite forms druses in moulds of gypsum crystals. Sulphur commonly infills or encrusts various vugs present in the matrix. High porosity of this carbonate vuggy facies often forms a framework for accumulation of economic amounts of native sulphur. It may be locally as high as 50-80% with thicker (maximally up to about 1 m thick) intergrowths of pure sulphur. These intergrowths represent specific, highly heterogeneous mineral deposits in the form of irregular pockets (in preparation) in comparison to typical sulphur mineralization in other ore facies (strati-form sulphur layers or regular beds with disseminated sulphur).

CHARACTERISTICS OF SELENITIC GYPSUM FACIES

GENERAL FEATURES

Gypsum deposits form a widespread unit in the Carpathian Foredeep and are composed of different lithofacies (S. Pawłowski *et al.*, 1965, 1985; M. Pawlikowski, 1982; M. Bąbel, 1986, 1987; A. Kasprzyk, 1989; B. Kubica, 1992; with references therein).

Although gypsum deposits of the Carpathian Foredeep exhibit a wide variety of lithotypes with respect to chemical composition, mineralogy, texture and sedimentary structures, the most spectacular feature of the gypsum sequence remains the presence of selenitic (i.e. composed of macroscopically visible gypsum crystals) complexes and layers. Based upon variation in texture and structure (particularly on the size, arrangements and sedimentary structures) the selenitic gypsum may be further subdivided into several varieties (A. Kasprzyk, 1989). Gypsum is the most abundant mineral in the evaporite section but small amounts of other minerals like celestite (A. Kasprzyk, 1994), anhydrite, calcite, dolomite, quartz, pyrite, feldspar and various clay minerals also occur. Calcite is a relatively common mineral, composed of very fine grained crystalline material (up to 0.25 mm). It is often scattered throughout gypsum beds, or forms local concentrations (as irregular patchy aggregates or concentrations in between gypsum crystals), or form more or less distinct layers in the gypsum matrix.

Generally, the series starts (for detailed illustrations of the vertical succession of gypsum lithofacies see also A. Kasprzyk, 1994*a* in a case study in this volume) with distinct, vertically oriented and twinned giant gypsum intergrowths forming crystals up to a few metres in height. This series is overlain by an alternation of bedded selenite gypsum and stromatolitic gypsum layers which in turn are covered by so-called skeletal and sabre-like gypsum deposits with characteristically bent crystals. This complex, sometimes with marly-clayey admixture and thinner laminated gypsum intercalations, commonly exhibits chaotic and tight overgrowth of successive gypsum crystal generations. These beds are followed by series consisting of bedded, finely crystalline and laminated gypsum complexes with selenitic clusters. Synsedimentary clastic gypsum deposits developed in the upper part of the sequence. Clastic texture with gypsum crystals and fragments of sulphate deposits may be arranged in grain or matrix supported frameworks. Such sections may be layered with gypsum clasts which have been rounded, sorted and mixed with other detrital material (quartz, lithoclasts) and subjected to reworking (abrasion of edges and corners) in transport.

In summary, the lower part of the gypsum sequence is dominated by exceptionally coarse (giant) or very coarse selenites while the upper part is dominated by massive, bedded and laminated crystalline or brecciated gypsum strata.

FACIES

For the main purpose of this work (reconstruction and comparative study of original gypsum fabrics in the postgypsum limestones) selenitic gypsum complexes are essential because they exhibit salient features which may be easily traced in the epigenetic postsulphate rocks. To facilitate the reconstruction, the selenitic gypsum complexes may be grouped into two distinct categories or subfacies: (1) giant or very coarse, and (2) crystalline or coarse to fine (including gypsum crystals a centimetre or so in size) selenitic gypsum (these deposits are described in detail in references mentioned at the beginning of this chapter and also in B. C. Schreiber, 1978 and 1988 with references therein). The selenitic gypsum strata may form thicker complexes or a few relatively thinner interbeds which intercalate other gypsum lithotypes. While the former are more frequent in the lower part, the latter usually form interbeds in the middle part of the gypsum sequence.

Giant or very coarse selenite gypsum subfacies (Pl. VIII, Figs. 27, 28). Giant or very coarse selenite gypsum builds up thicker complexes with no discernible bedding composed of giant (up to about 3.5 m in height) grey or honey-coloured crystals. They are composed of massive vertically arranged, twinned intergrowths which grew upward. This lithotype, being of very low porosity, is only locally more fractured or cavernous (with a porosity below 5% — J. Kowalik *et al.*, 1979). Giant selenite commonly occur at the base of the gypsum sequence and is characterized both by irregular thickness (up to several metres) and occurrence.

Crystalline gypsum subfacies. Crystalline gypsum rocks are distinctly more bedded and composed of smaller (up to 30 cm but commonly below 10 cm in length) grey and light-grey or brown crystals (Pl. VIII, Fig. 29). Based upon size they may be further differentiated into fine or coarse crystalline deposits, or poorly sorted selenitic crystals. These deposits include other selenitic sublithotypes like previously described sabre-like (Pl. VIII, Figs. 30, 31), skeletal (Pl. VIII, Fig. 32) and bedded selenitic gypsum.

Larger crystals commonly are suh- to vertically oriented, most of them are twinned with the twin-plane perpendicular to bedding. Sabre-like crystals (up to 90 cm in length) occur individually or form rows and usually are parallel or radially oriented. The larger individuals, commonly well formed, may be tightly interlocked or may be separated from one another. In the latter case they are often overgrown by finer crystals and the remaining space is filled with a matrix composed of micritic gypsum or gypsum-carbonate material (as much as 15% of the mass volume). Where selenitic crystals are less crowded they display bushes or a group-spherulite pattern or occur as large poikilotopic crystals; where they are more crowded, they form contiguous clusters (grass-like selenites) or rows of oriented crystals. Where the space in between larger crystals was not infilled, low porosity defined by walls of crystals usually remained. As selenite grain-size decreases, bedding is better developed. Thus, they may be banded or form covers of grass-like selenites, however, commonly they are chaotically arranged with tight intergrowths to form massive interlocking mosaics or skeletal fabric.

Selenitic gypsum beds may contain (in between the larger crystals or may be intercalated by) subordinary thin interbeds or layers of laminated gypsum-carbonate, clayey or clayey-carbonate partings or fine-grained selenite-micritic gypsum. Irregular or semi-regular intercalations, sometimes wavy laminated, may separate layers, beds or complexes of crystalline gypsum. This material may also intercalate rows of sabre-like crystals. The deposits may be compact or slightly compact, often locally fine to coarse porous or fractured, with a varying porosity maximally up to 15%. Porosity is connected with the presence of large or fine intracrystalline vugs or pores developed between selenitic crystals.

DISCUSSION

According to the demands of the bioepigenetic hypothesis of Polish sulphur deposit formation, the postsulphate rocks should be closely correlated with appropriate primary gypsum deposits having the same characteristics. As the model says, the structural and textural features of gypsum facies are inherited in the carbonate (released as postsulphate rocks) series. Based on this general reason, most workers strongly implied lithological compatibility between sulphate and carbonate series and invoked the presence of a range of transitional lithologies (with partly preserved original sulphate structures, e.g., calcite pseudomorphs after selenite gypsum) between pure sulphates and pure carbonates. In this light, the presence of distinct postselenite relics found in sulphur-bearing and barren limestones play a special role because there is evident proof of the presence of original gypsum crystals (and thus gypsum deposits) before the alteration of sulphate series into carbonates and native sulphur. A lack of adequate original gypsum structures in sulphur-bearing or barren carbonates is commonly interpreted as the effect of alteration of other (i.e., non-selenitic) gypsum lithotypes or varying intensity and selectivity of metasomatic processes (K. Pawłowska, 1962; S. Pawłowski *et al.*, 1965; 1979, 1985; B. M. Nieć, 1982; Kubica 1992, 1994), obliteration by the transformation processes (S. Pawłowski *et al.*, 1979, 1985; B. Kubica, 1992), influence of late ore-forming processes like recrystallization (M. Nieć, 1982, 1986), or dependence on the pathways of the alterating fluids (A. Bolewski, 1935; S. Kwiatkowski, 1962; M. Pawlikowski, 1982).

The gypsum-ghost facies have commonly been believed to be an equivalent of selenitic gypsum facies commonly found in surrounding areas (e.g. K. Pawłowska, 1962; R. Krajewski, 1962; S. Pawłowski, 1965, 1968, 1970; S. Pawłowski *et al.*, 1965, 1979, 1985; M. Nieć, 1982, T. Osmólski, 1972; M. Pawlikowski, 1982; B. Kubica, 1992, 1994b). Unfortunately, this view is based only on a rough comparison of various selenite gypsum lithotypes with the structures found in the carbonate series. Thus, the authors identified the carbonate analogs of sabre-like and selenite gypsum (K. Pawłowska, 1962; S. Pawłowski, 1968; S. Pawłowski *et al.*, 1965, 1979, 1985), coarse selenite gypsum (R. Krajewski, 1962; M. Nieć, 1982, 1992), very coarse selenite gypsum (M. Pawlikowski, 1982), and crystalline (selenite) gypsum (T. Osmólski, 1972). This ambiguity in the reconstruction of gypsum facies analogs in carbonate series as well as the often emphasized impossibility of the correlation of adequate sulphate and carbonate (postsulphate) facies imply that there is no transition between these two lithologies.

Generally similar (the differences are essentially quantitative) mineralogical composition and overall structural similarity of the fine and coarse gypsum-ghost subfacies argues for genetic unity of these subfacies. However, structural variations between gypsum-ghost limestones and selenitic gypsum facies argues for a genetic diversity.

There is no doubt that the gypsum-ghost structures follow gypsum crystals and represent original variously developed selenitic gypsum individuals. However, with regard to the both gypsum-ghost (sulphur-bearing or barren) and selenitic gypsum facies, detailed petrologic comparison of these litholigies exhibits distinct differences in their textural and structural development which exclude any correlation.

There is general agreement that the giant or exceptionally coarse selenite gypsum facies has no analog in the postsulphate carbonate series. This is especially striking because of the fact that this gypsum lithotype has a relatively stable stratigraphic position (commonly in the lower or lowermost part of the sulphate sequence) and is widespread in the Carpathian Foredeep (B. Kubica, 1992; A. Kasprzyk, 1994*b*) and should be preserved in the carbonate series, at least locally. This is not the case, however, although a very rough analogy still exists: this lithostratigraphic position usually is occupied by the very coarse gypsum-ghost subfacies. However, the differences connected with the size, arrangement of selenitic crystals, as well as features of both grain composition and matrix clearly exclude any correlation between these two lithofacies.

In general, both gypsum-ghost subfacies are for the most part distinctly matrix-supported (from about 30–40 up to 80–90 and usually 40–80%) which significantly exceeds the percentage of the sulphate (or carbonate-sulphate) matrix commonly found in the mentioned gypsum lithotypes. Thus, gypsum-ghost structures are too scarce to be correlatable to adequate selenitic gypsum facies. Note also the conglomeratic nature of the fine gypsum-ghost subfacies and common of admixture of heterogeneous clasts in the coarse subfacies.

Relatively large gypsum-ghost structures, straight or slightly to distinctly bent and subvertically to vertically oriented, and often accompanied by finer relics, seem to resemble sabre-like gypsum facies. However, common stratification by laminae or streaks and their composition, orientation and abundance as well as nature of both porosity (shapes, occurrence, abundance and arrangement) and matrix (two distinct phases with common admixture of other carbonate grains like clasts, peloids) indicate that they cannot represent typical sabre-like gypsum lithofacies. Occasional, gypsum-ghost limestones predominated by densely and parallel packed larger (10 cm in the length) relics, do not resemble typical sabre-like gypsum in that they do not contain a common admixture of smaller individuals and thus rather form a separate facies.

Finer, straight and thin, individual postselenite relics (1 centimetre in length), are randomly dispersed in between the larger relics or form clusters or separate beds consisting of randomly or preferentially oriented ghosts of crystals. They may resemble so-called skeletal selenite beds. However, a high content of the carbonate matrix, carbonate grain composition, structure and textures again do not allow correlation of these rocks to a corresponding selenite facies.

In addition, other features allow elimination of the gypsum-ghost facies described here as an analog of adequate selenite subfacies. They include: (1) irregular association of the smaller ghosts which are randomly dispersed or often arranged into distinct streaks; (2) a usually lower angle of obliquely oriented ghosts than that typical for the larger selenite individuals; (3) commonly low (volumetrically insignificant compared to corresponding selenitic facies) percentage of smallest gypsum ghost as well as their arrangement into common and distinct streaks which are often strongly wavy or dip more than in selenitic facies; (4) vugs not associated with the gypsum ghost were formed in the matrix in between the relics (as may be indicated by the growth pattern of calcite crystal mosaics) and were not limited by the original gypsum crystal walls as is often found in skeletal or very coarse selenitic gypsum rocks; (5) heterogeneity of the matrix (reflected by micrite, microsparite and sparite fractions with blurred margins, and individual, fine peloids as well as the presence of two types of the matrix) which suggests various stages of formation after the synsedimentary stage; (6) the presence of distinct and numerous primary textures sucb as small and discontinuous wavy lamination, streaks or lamination often steeper (20–30°) than in selenitic facies; (7) more or less expressed but common lamination or streaks induced by alternation of clayey-calcite and especially various calcite fractions; (8) relatively uniform nature of larger sparite areas without any preservation of original small gypsum individuals; (9) in general, relatively high matrix percentage, low or locally extremely low porosity of the matrix and arrangement of small vugs into horizons or layers emphasizing local stratification.

Characteristics of the gypsum-ghosts facies allow conclusion that so-called pseudomorphic limestones only at first glance seem to resemble some varieties of selenitic gypsum lithotypes found in the Chemical Series of the Carpathian Foredcep. All features of the gypsum-ghost limestones mentioned above lead to the conclusion that they distinctly differ structurally from the selenite gypsum deposits and therefore cannot be simply correlated with selenitic gypsum complexes. In addition, although a regional lateral continuity between gypsum-ghost ore and barren limestones is observed, there is no transition zone between these limestones and selenite gypsum beds. Instead of this, there is a sudden shift in the structural characteristics at the contacts of these two lithologies which exclude simple lateral continuity or lithologic zonation.

The presence of relics after selenite gypsum beds and common diagenetic features found in the gypsum-ghost limestones suggest that they are connected with as yet unrecognized alteration processes of original gypsum beds.

SUMMARY

Investigation of both sulphur-bearing and barren limestones, from various native sulphur ores preserved in the northern part of the Carpathian Foredeep, exhibit distinct features of original selenite gypsum precursors which allow their definition as gypsum-ghost limestones. There is no doubt that gypsum relics preserved in so-called postsulphate carbonates strictly reflect selenite gypsum individuals like fine or coarse selenitic or sabre-like gypsum crystal forms.

Petrologic features of these limestones allow differentiation of them into two different rock types or subfacies with distinct characteristics, mainly with regard to the main component (i.e., ghosts of selenite gypsum crystals).

Petrographic characteristics of the gypsum-ghost limestones are inconsistent with the features of selenite gypsum deposits, clearly indicating no close analogies between the facies. The differences are too significant to assume they are facies equivalents. This study indicates a common conglomeratic nature of the fine gypsum-ghost subfacies and *in situ* formation of the coarse facies with relatively high content of carbonate clasts and other grains. A comparative study of both facies indicates that, in general, there is no gypsum-ghost analog of the giant or very coarse selenite gypsum lithotype and that other crystalline gypsum facies are essentially not reflected in the carbonate series. Consequently, it attests that the characteristics of selenitic gypsum facies and gypsum-ghost sulphur-bearing limestones cannot be simply correlated to one another as has been previously assumed .

The present study does not allow exclusion of additional factors which could play important roles in the preservation of original gypsum structures in the gypsum-ghost limestones during the course of the alteration. Thus, it implies more complex conditions responsible for formation of the Polish native sulphur ores and, in the author's opinion, this problem deserves more attention and requires further study.

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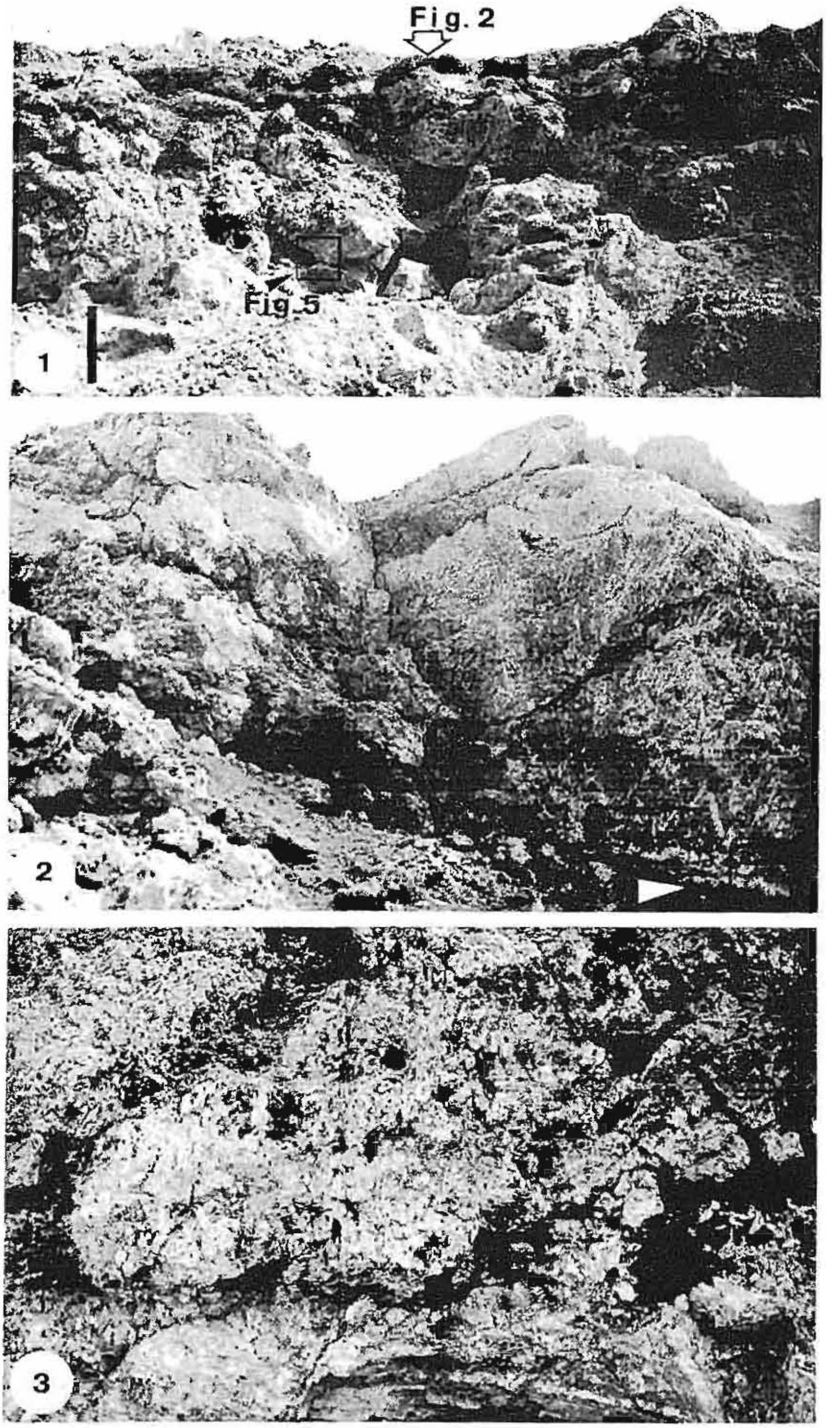
FACJE WAPIENI „POSELENITOWYCH" POLSKICH ZŁÓŻ SIARKI RODZIMEJ: ANALOG GIPSÓW SELENITOWYCH?

Streszczenie

Omówiono wapienie siarkonośne z zachowanymi reliktami po kryształach gipsów selenitowych, określone jako wapienie poselenitowe, będące charakterystycznym składnikiem płonnych i osiarkowanych utworów występujących w zapadlisku porzedkarpackim. Cechy makroskopowe i mikroskopowe tych wapieni, a w szczególności cechy ich głównego składnika, którym są relikty po niewątpliwych kryształach różnie wykształconych selenitów, pozwalają na wydzielenie dwóch subfacji złożonych z (1) drobnych i (2) dużych struktur po selenitach.

Cechy strukturalne i teksturalne tych subfacji, jak również w ogólności całej facji poselenitowej, nie wykazują analogii do odpowiednich (bardzo ogólnie zarysowanych) facji selenitowych, opisywanych wielokrotnie z obszaru zapadliska. W ogólności nie ma odpowiednika facjalnego gipsów gigantokrystalicznych lub bardzo grubokrystalicznych. Wapienie poselenitowe nie mogą być porównywane również z gipsami szablastymi, jak i szkieletowymi. Główne różnice między nimi sprowadzają się do dużego udziału tła węglanowego w wapieniach w porównaniu do tła w selenitach, a wyraźnie mniejszego udziału samych struktur poselenitowych. Ponadto zaznaczają się różnice między wymienionymi skałami w odniesieniu do struktur sedymentacyjnych, tła, składu ziarnistego i porowatości. Zwraca uwagę wyraźnie zlepieńcowaty charakter subfacji drobnoposelenitowej, a także duży udział klastów węglanowych w subfacji gruboposelenitowej, charakteryzującej się powstawaniem *in situ* pierwotnych form selenitowych. W efekcie wapienie poselenitowe nie mogą być utożsamiane z odpowiednimi litofacjami gipsów selenitowych jak to dotychczas przyjmowano.

Powszechnie obserwowane cechy zmian diagenetycznych w wapieniach poselenitowych wskazują, że zachowanie pierwotnych struktur selenitowych mogło zależeć także od nierozpoznanej dotychczas natury samych procesów przemian.



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

PLATE I

Fig. 1. Gypsum-ghost limestones complex with numerous and various in size caverns preserved in the upper part of the Chemical Series. Machów open-pit mine; scale bar is 1 m

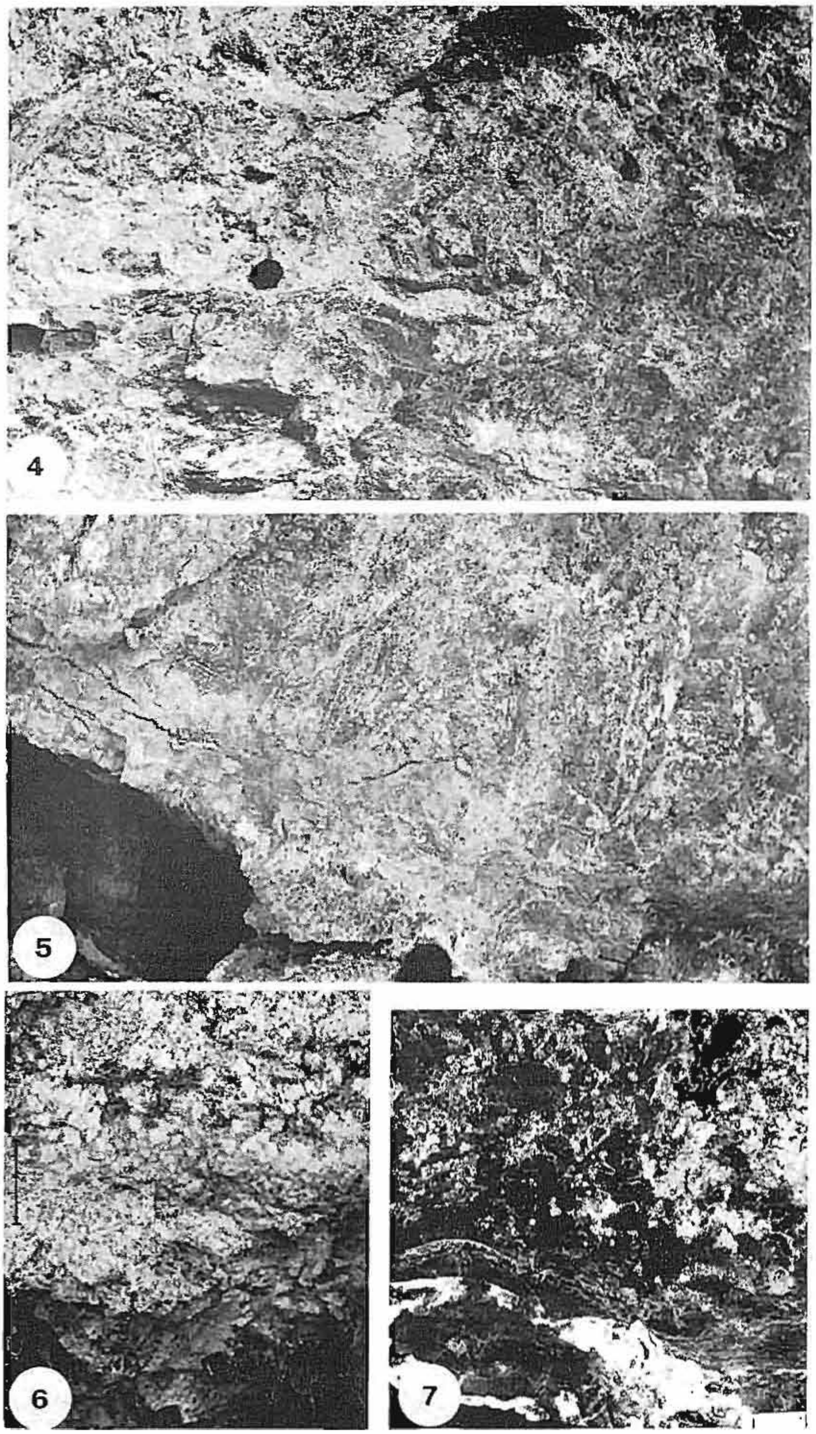
Kompleks wapieni poselenitowych z licznymi kawernami o zmiennej wielkości występujący w górnej części serii chemicznej. Kopalnia Machów; skala = 1 m

Fig. 2. Close up of Fig. 1. Porous, sulphur-bearing and large lense-like gypsum-ghost limestone body. Machów open-pit mine

Fragment fig. 1. Duża soczewa porowatych osiarkowanych wapieni poselenitowych. Kopalnia Machów

Fig. 3. Small lense-like gypsum-ghost limestones with empty vugs after individual selenite precursors and pores infilled with sulphur (white). Machów open-pit mine; lense cap is 6 cm in diameter

Mała soczewka osiarkowanych wapieni poselenitowych z pojedynczymi próżniami po kryształach selenitów i próżniami wypełnionymi siarką rodzimą (biała). Kopalnia Machów; średnica denka obiektywu 6 cm



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

PLATE II

Fig. 4. The contact between porous lense-like gypsum-ghost limestones bodies (right side) and wavy bedded sulphur-bearing limestones (left side). Machów open-pit mine; lense cap is 6 cm in diameter

Kontakt między soczewkowatymi wapieniami poselenitowymi (prawa strona) a faliście warstwowanymi wapieniami osiarkowanymi (lewa strona). Kopalnia Machów; średnica denka obiektywu 6 cm

Fig. 5. Close up of Fig. 1. Lense-like gypsum-ghost limestones with large ghosts of selenite gypsum crystals separated by thin interlayer of limestones with no relics of selenite gypsum. Note a gradual transition into gypsum-ghost bodies. Machów open-pit mine; lense cap is 6 cm in diameter

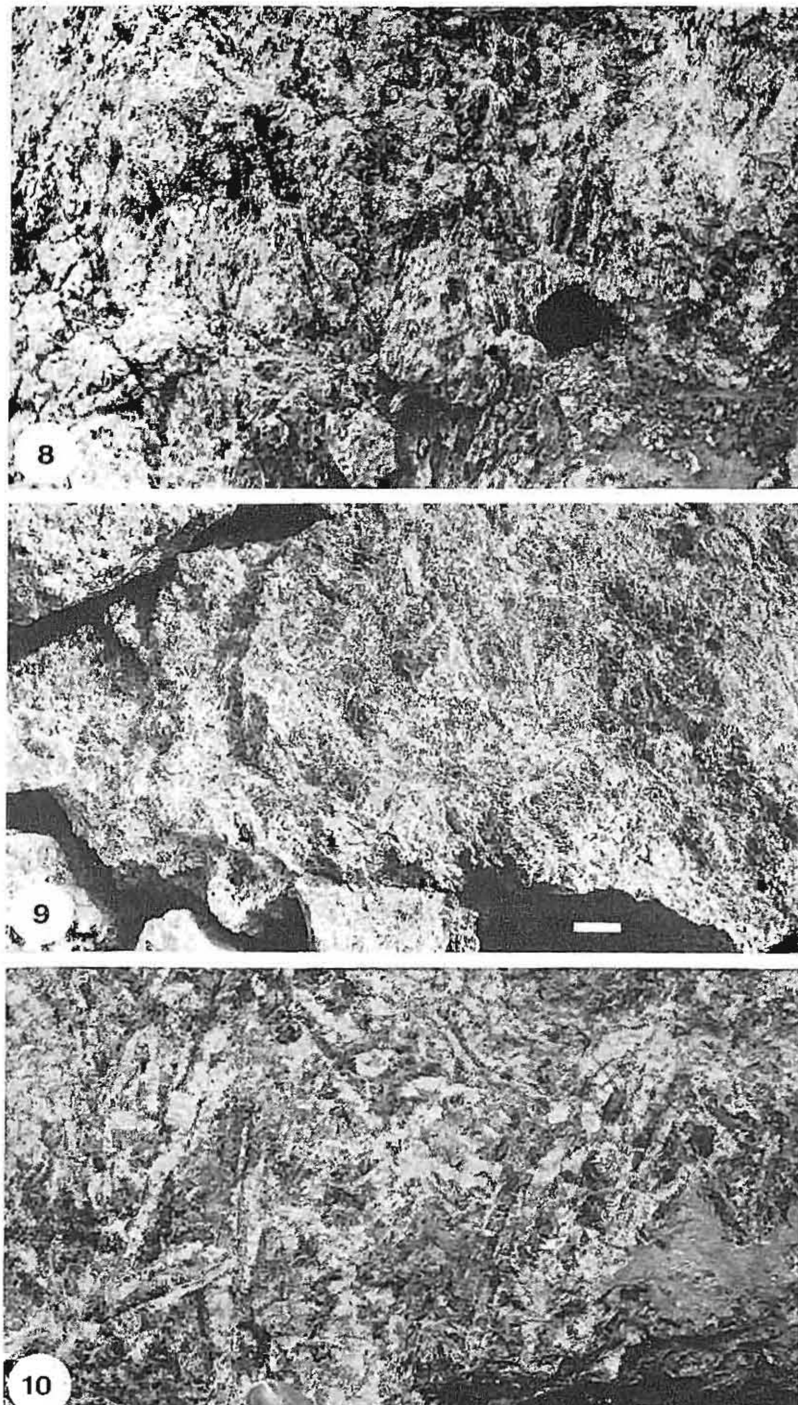
Fragment fig. 1. Soczewkowate wapienie poselenitowe złożone z dużych reliktów po dużych kryształach selenitów rozdzielone przez cienką warstwę wapieni nie zawierających struktur poselenitowych. Zwraca uwagę stopniowe przejście w wapienie poselenitowe. Kopalnia Machów; średnica denka obiektywu 6 cm

Fig. 6. Close up of Fig. 2. Gradual transition between gypsum-ghost lense-like bodies reflected by limestone interlayer with numerous sulphur granules and nodules (whitish spots). Machów open-pit mine; scale bar is 5 cm

Fragment fig. 2. Stopniowe przejście między soczewkami wapieni poselenitowych odzwierciedlone przez wapienną warstewkę z licznymi granulami i nodulami siarki rodzimej (białawe). Kopalnia Machów; skala = 5 cm

Fig. 7. Gradual transition of porous sulphur-bearing (whitish spots) gypsum-ghost limestone (upper part) into laminated interlayer (lower part). Buda Stalowska 166 borehole; depth 233.0 m; scale bar in centimetre

Stopniowe przejście porowatych wapieni poselenitowych osiarkowanych (górna część) w laminowaną warstewkę wapienną (dolna część). Otwór wiertniczy Buda Stalowska 166, głęb.233,0 m; skala w centymetrach



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

PLATE III

Fig. 8. Barren, strongly porous gypsum-ghost limestones composed of large gypsum-ghost structures. Machów open-pit mine; lense cap is 6 cm in diameter

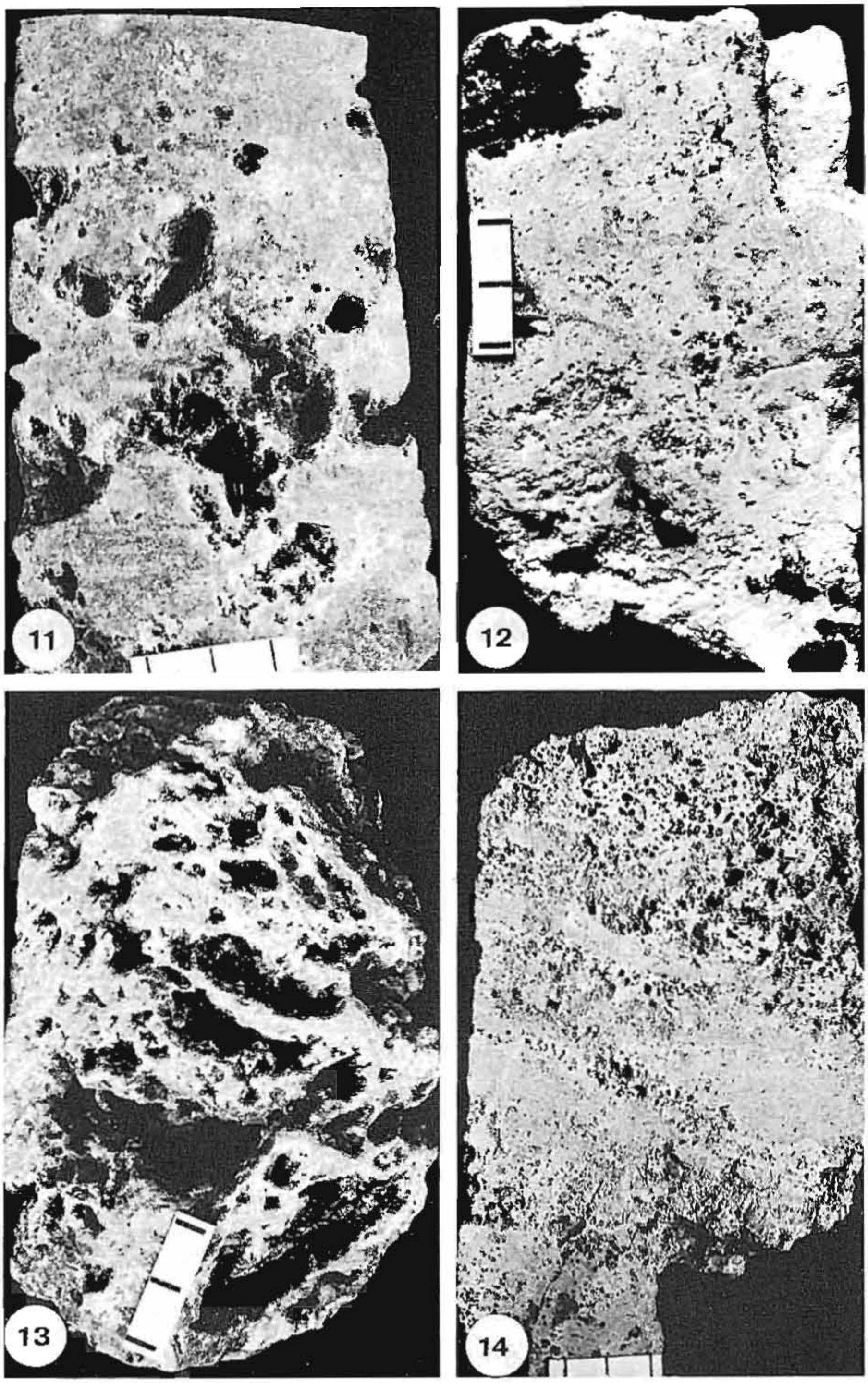
Płonne, silnie porowate wapienie poselenitowe zawierające duże struktury po dużych kryształach selenitów. Kopalnia Machów; średnica denka obiektywu 6 cm

Fig. 9. Lense of sulphur-bearing gypsum-ghost limestones composed of numerous and haevily packed ghosts of selenite gypsum crystals infilled with native sulphur. Machów open-pit mine; scale bar is 5 cm

Soczewa wapieni poselenitowych osiarkowanych zawierająca liczne i silnie upakowane relikty po selenitach wypełnionych siarką rodzimą. Kopalnia Machów; skala = 5 cm

Fig. 10. Fragment of lense-like gypsum-ghost limestones presented in Fig. 9. Numerous spaces after selenite gypsum crystals are infilled with native sulphur. Darker elongated forms represent carbonate matrix preserved in between the structures. Note individual sulphur granules and nodules preserved in the matrix as well as larger irregular carbonate accumulates (right lower corner). Machów open-pit mine; scale bar is 2 cm

Fragment soczewy wapieni poselenitowych przedstawionych na fig. 9. Liczne przestrzenie po kryształach selenitów są wypełnione siarką rodzimą. Ciemniejsze wydłużone formy przedstawiają fragmenty tła węglanowego zachowanego między strukturami poselenitowymi. W tle węglanowym występują pojedyncze granule i nodule siarki rodzimej oraz większe nieregularne skupienia węglanów (prawa dolna część). Kopalnia Machów; skala = 2 cm



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

PLATE IV

Figs. 11, 12. Massive fine gypsum-ghost limestones with indistinct porous horizons composed of elongated or irregular vugs: Fig. 11 — Jeziórko E-13 borehole, depth 172.0 m, Fig. 12 — Krzyżowe Mosty P1 borehole, depth 237.50 m; scale bar in centimetre

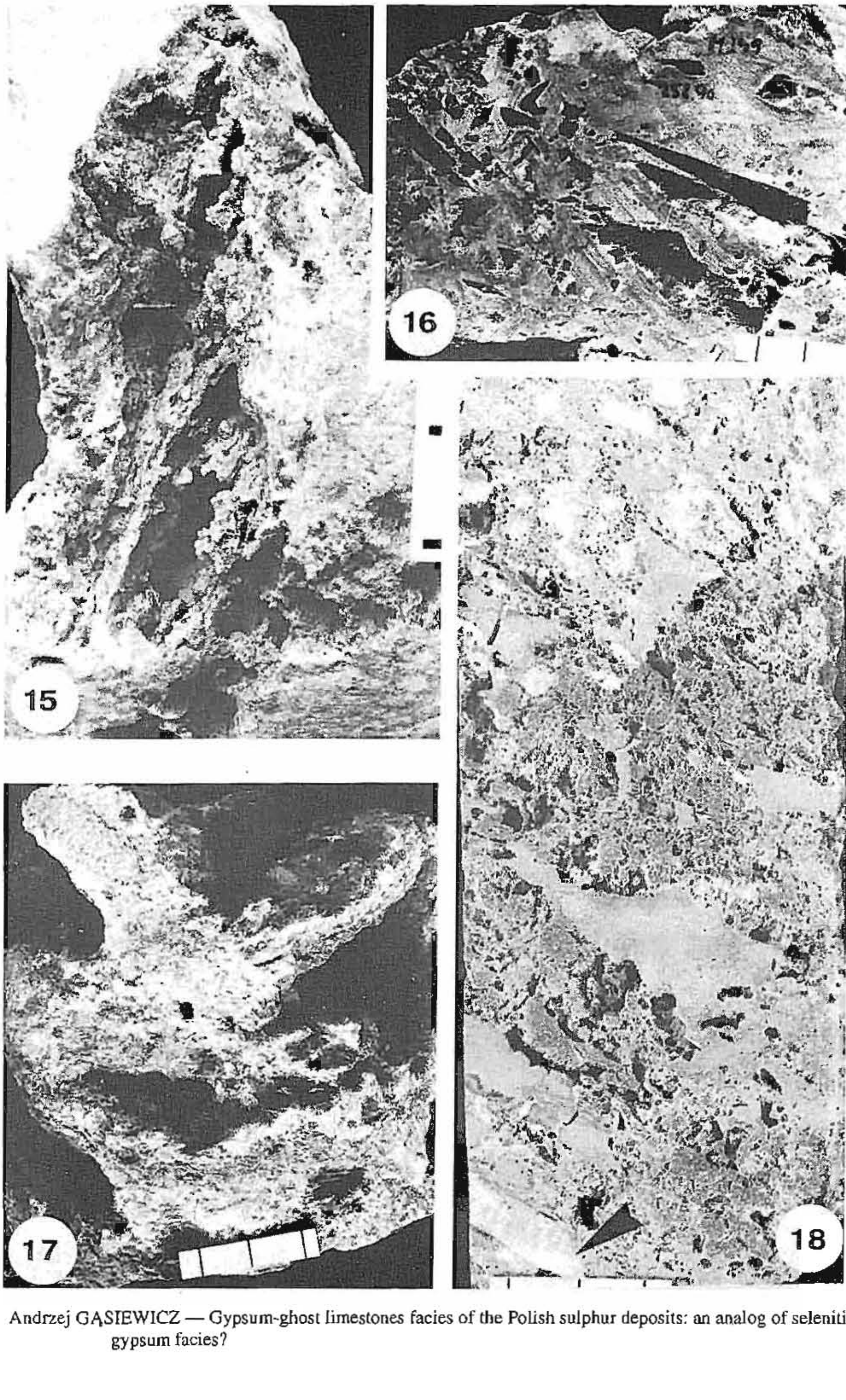
Masywne wapienie poselenitowe z wydłużonymi i nieregularnymi próżniami układającymi się w słabo zaznaczone poziomy: fig. 11 — otwór wiertniczy Jeziórko E-13, głęb. 172,0 m, fig. 12 — otwór wiertniczy Krzyżowe Mosty P1, głęb. 237,50 m; skala w centymetrach

Figs. 13, 14. Fine gypsum-ghost limestones composed of abundant vugs forming sponge-like textures. Pores may be relatively larger and connected one to other vugs (Fig. 13) or small disconnected but forming distinct porous streaks (Fig. 14) alternating with massive and subtely laminated limestones. Fig. 13 — Jeziórko E-17 borehole, depth 167.50 m, Fig. 14 — Czajków 83 borehole, depth 28.60–28.80 m; scale bar in centimetre

Wapienie poselenitowe zawierające bardzo liczne próżnie po małych kryształach selenitów tworzące gąbczastą teksturę wapieni. Próżnie mogą być względnie większe i połączone ze sobą (fig. 13) lub bardzo drobne, grupując się w wyraźne smugi przedzielone smugami masywnych i delikatnie laminowanych wapieni (fig. 14). Fig. 13 — otwór wiertniczy Jeziórko E-17, głęb. 167,50 m, fig. 14 — otwór wiertniczy Czajków 83, głęb. 28,60–28,80 m; skala w centymetrach

Hand specimens in Figs. 11 and 13 coll. by K. Pawłowska

Okazy przedstawione na fig. 11 i 13 pochodzą z kolekcji K. Pawłowskiej



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

PLATE V

Figs. 15, 17. Fine gypsum-ghost limestones with relics of selenite gypsum clusters: Fig. 15 — Machów open-pit mine, Fig. 17 — borehole Skopanie 134; depth 260.20–260.30 m; scale bar in centimetre

Wapienie poselenitowe z reliktami po wiązkach małych selenitów: fig. 15 — kopalnia Machów, fig. 17 — otwór wiertniczy Skopanie 134; głęb. 260,20–260,30 m; skala w centymetrach

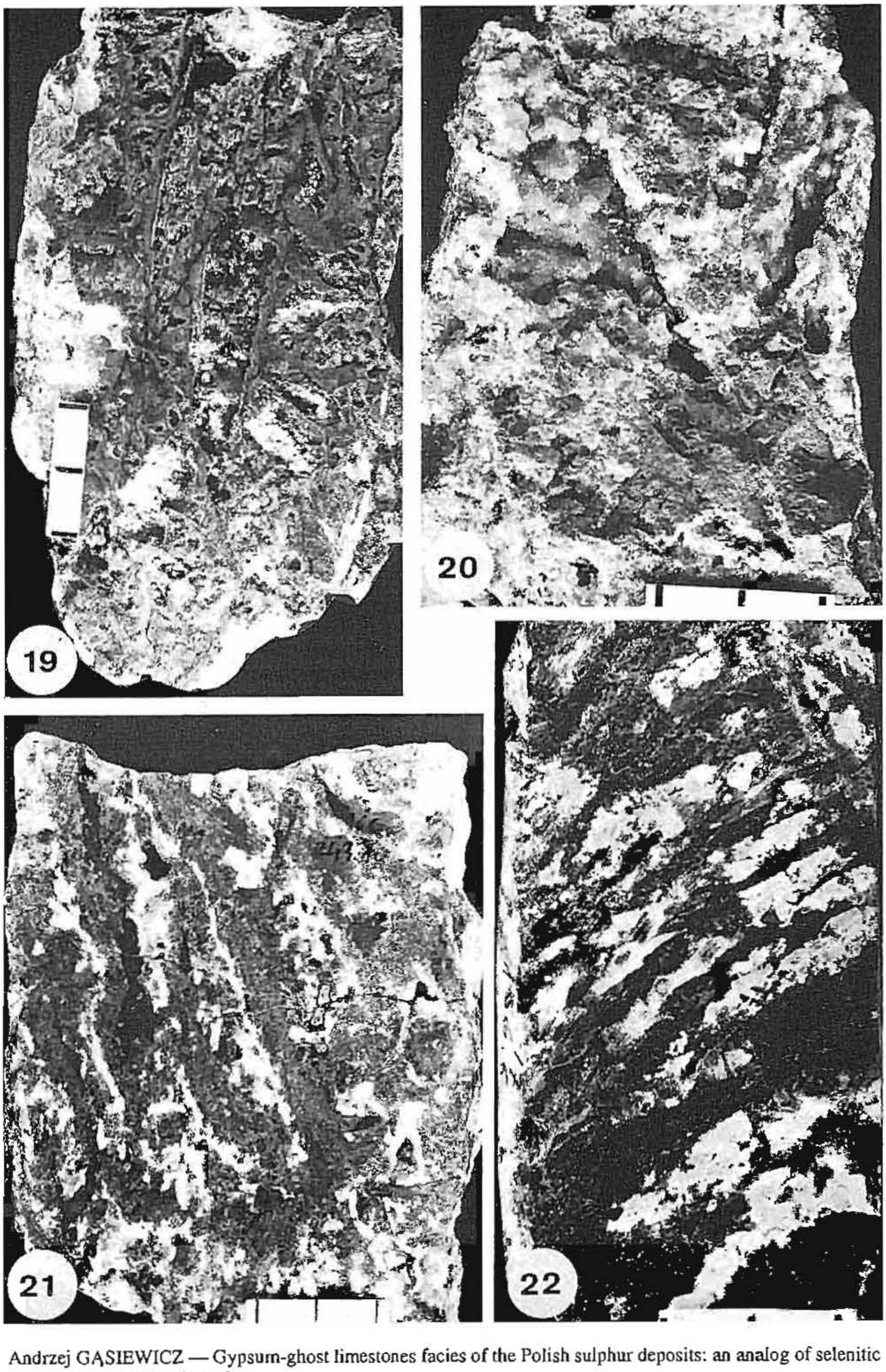
Fig. 16. Fine gypsum-ghost limestones with chaotically arranged empty voids following fragments of selenites. Borehole Międzywodzie 149; depth 252.90 m; scale bar in centimetre

Wapienie poselenitowe z chaotycznie rozmieszczonymi próżniami po fragmentach małych selenitów. Otwór wiertniczy Międzywodzie 149; głęb. 252,90 m; skala w centymetrach

Fig. 18. Porous fine gypsum-ghost limestones with distinct irregular or angular fragments of massive carbonates and selenite fragment (arrow). In the upper part of the photo intergrain spaces are infilled with sulphur (white spots). Borehole Ruda 18; depth 206.0 m; scale bar in centimetre; coll. K. Pawłowska

Wapienie poselenitowe z próżniami po małych selenitach z wyraźnymi nieregularnymi lub kanciastymi fragmentami masywnych węglanów i fragmentem selenitu (strzałka). W górnej części fotografii przestrzenie międzyziarnowe są wypełnione siarką rodzimą (białe skupienia). Otwór wiertniczy Ruda 18; głęb. 206,0 m; skala w centymetrach; kolekcja K. Pawłowskiej

PLATE VI



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

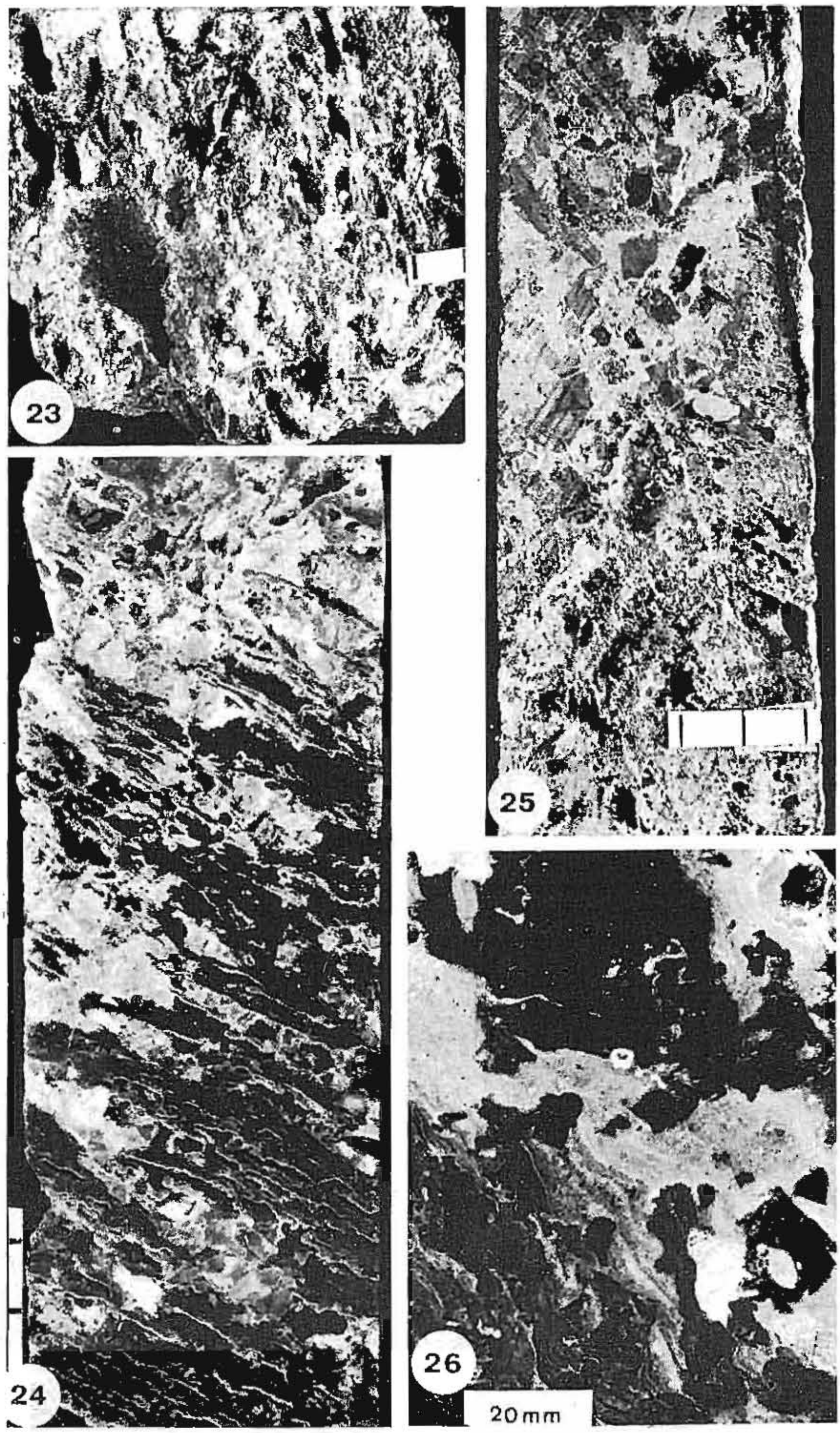
PLATE VI

Figs. 19, 20. Coarse, matrix-supported gypsum-ghost limestones composed of individual large and steeply oriented ghosts of selenites. The structures are irregularly infilled with calcite (Fig. 19) and encrusted by calcite and sulphur (Fig. 20). Machów open-pit mine; scale bar in centimetre

Wapienie poselenitowe złożone z pojedynczych struktur po dużych kryształach gipsu zorientowanych stromo. Relikty selenitów są nieregularnie wypełnione kalcytem (fig. 19) i inkrustowane kalcytem i siarką (fig. 20). Kopalnia Machów; skala w centymetrach

Figs. 21, 22. Gypsum-ghost-supported limestones composed of coarse structures obliquely oriented. These structures may be infilled with calcite (light grey) and sulphur (white) — Fig. 21, and with sulphur (white) — Fig. 22. Darker, distinct and elongated areas represent massive or finely porous carbonate matrix developed in between original selenite crystals. Fig. 21 — Buda Stalowska 166 borehole, depth 243.80 m; Fig. 22 — Jeziórko E-17 borehole, depth 156.60 m, coll. K. Pawłowska; scale bar in centimetre

Wapienie poselenitowe złożone z licznych struktur po dużych kryształach gipsu zorientowanych skośnie. Struktury te są wypełnione kalcytem (jasnoszary) i siarką (biała) — fig. 21, oraz tylko siarką (biała) — fig. 22. Ciemne, wyraźne i wydłużone listwy przedstawiają masywne lub bardzo drobnoporowate tło węglanowe rozwinięte między pierwotnymi kryształami selenitów. Fig. 21 — otwór wiertniczy Buda Stalowska 166, głęb. 243,80 m; fig. 22 — otwór wiertniczy Jeziórko E-17, głęb. 156,60 m, kolekcja K. Pawłowskiej; skala w centymetrach



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

PLATE VII

Figs. 23, 24. Sponge-like coarse gypsum-ghost limestones. Abundant, strongly packed, and thin and elongated ghosts of selenites are empty or partly infilled with sulphur (white or white-grey spots). Fig. 23 — Machów open-pit mine, Fig. 24 — Łęg 58 borehole; depth 160.10–160.30 m; scale bar in centimetre

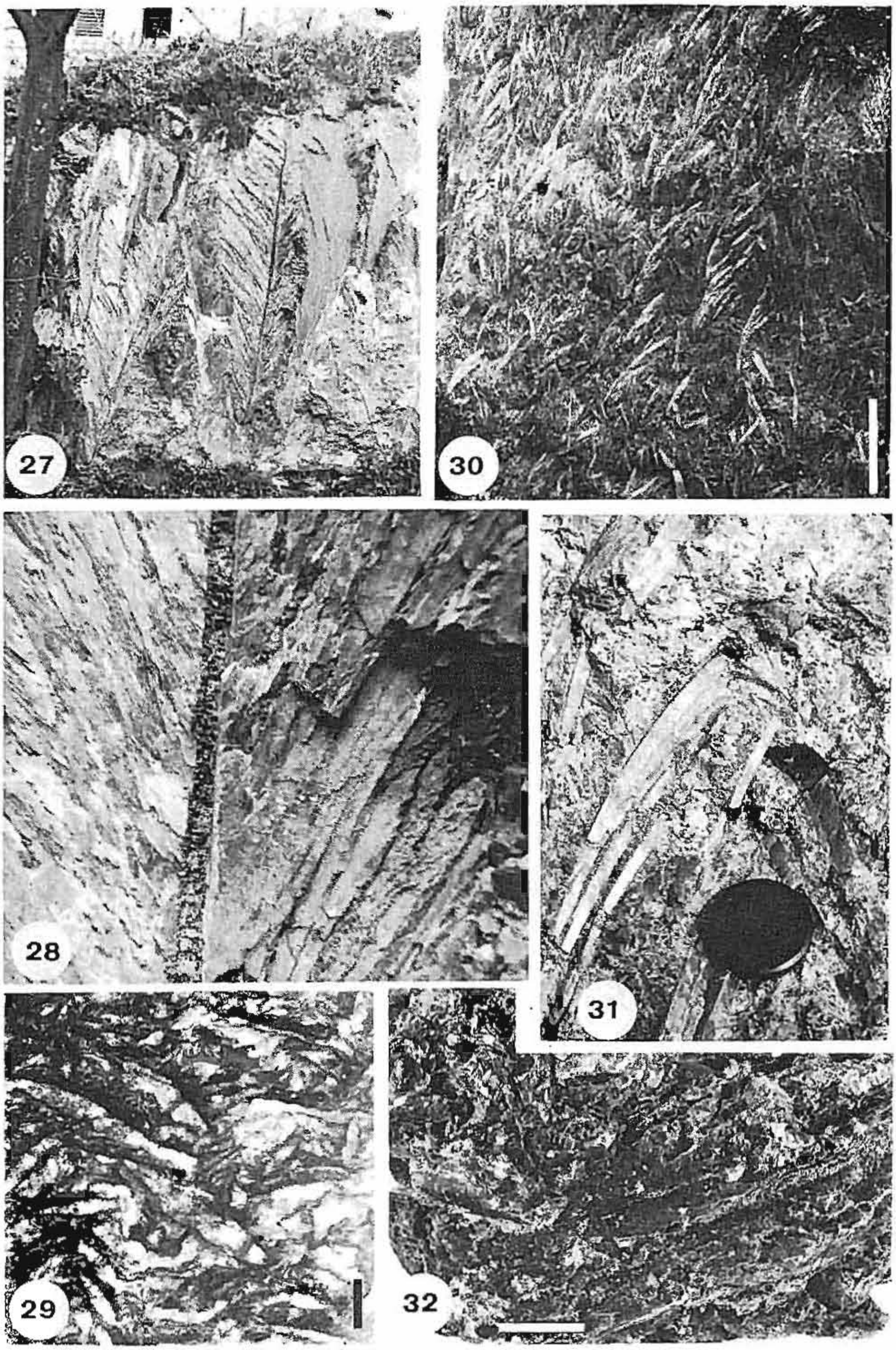
Wapienie poselenitowe o teksturze gąbczastej. Liczne, silnie upakowane i cienkie, wydłużone relikty po dużych kryształach selenitów są puste lub częściowo wypełnione siarką (białe lub biało-szare skupienia). Fig. 23 — kopalnia Machów, fig. 24 — otwór wiertniczy Łęg 58; głęb. 160,10–160,30 m; skala w centymetrach

Fig. 25. Fragment of core material with coarse gypsum-ghost limestones exhibiting carbonate clasts cemented by calcite-sulphur material (central part). Mikołajów 145 borehole; depth 161.60–161.80 m; scale in centimetre

Fragment rdzenia wiertniczego z wapieniami poselenitowymi zawierającymi relikty po dużych selenitach i pokazujący węglanowe klasty scementowane kalcytem i siarką rodzimą (część środkowa). Otwór wiertniczy Mikołajów 145; głęb. 161,60–161,80 m; skala w centymetrach

Fig. 26. Carbonate clasts cemented by laminated calcite-sulphur fractions preserved in coarse gypsum-ghost limestones. Machów open-pit mine

Klasty węglanowe zachowane między dużymi strukturami poselenitowymi scementowane laminowanym materiałem kalcytowo-siarkowym. Kopalnia Machów



Andrzej GĄSIEWICZ — Gypsum-ghost limestones facies of the Polish sulphur deposits: an analog of selenitic gypsum facies?

PLATE VIII

Figs. 27, 28. Giant selenite gypsum: Fig. 27 — large (up to about 2 m in length) crystals, Fig. 28 — close up of Fig. 27. Chotelek Czerwony

Gipsy gigantokrystaliczne: fig. 27 — duże (do ok. 2 m długości) kryształy, fig. 28 — fragment fig. 27. Chotelek Czerwony

Fig. 29. Anhydrites with fine selenite gypsum pseudomorphs well preserved. Gwoździec P10 borehole; depth 552.20 m; scale bar is 1 cm

Pseudomorfozy gipsów drobnoselenitowych zachowanych w anhydrytach. Otwór wiertniczy Gwoździec P10; głęb. 552,20 m; skala w centymetrach

Figs. 30, 31. Sabre-like gypsum: Fig 30 — Piaseczno open-pit mine, scale bar is 20 cm, Fig. 31 — Skorocice, lense cap is 6 cm in diameter

Gipsy szablaste: fig. 30 — kopalnia Piaseczno, skala = 20 cm, fig. 31 — Skorocice, średnica denka obiektywu 6 cm

Fig. 32. Skeletal gypsum. Solec D-2 borehole; depth about 22.0 m; scale bar is 2 cm

Gipsy szkieletowe. Otwór wiertniczy Solec D-2; głęb. ok. 22,0 m; skala = 2 cm

Figs. 30 and 32 courtesy by B. Kubica

Fig. 30 i 32 dzięki uprzejmości B. Kubicy