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Ore-filled hydrothermal karst features in the Triassic rocks of the Cracow-Silesian region

ABSTRACT: The ore-bearing dolomite of Triassic age reveals evidence of phreatic circulation of acid solutions. This circulation gave rise to a variety of karst features such as solution cavities, residual clays, collapse breccias and related disturbances consequent upon the removal of carbonates. The karst features are ore-lined or filled with sulfide ores. It is suggested that these features were produced by hot, ore-bearing solutions and that the precipitation of ores proceeded concomitantly with the cavity-making and the formation of collapse structures. The possible age of sulfide mineralization is briefly discussed.

INTRODUCTION

Opinion today is still divided upon the question of origin of zinc and lead ores in the Cracow-Silesian region. This controversy lasting already more than hundred years reflects the two opposing trends in the interpretation of ores, namely the syngenetic (e.g. Bernhardi 1889; Gürich 1903; Keil 1956; Gruszczyk 1956, 1967; Smolarska 1968) and epigenetic (e.g. Michael 1904, Duwensee 1929, Schneiderhöhn 1930, Wernicke 1931, Zwierzycki 1950, Gałkiewicz 1956, Krajewski 1957, Harańczyk 1965).

The present paper aims to submit some new or previously unemphasized evidence, to support the hydrothermal interpretation. It is limited in scope to ore-lined structures directly or indirectly related to the removal of carbonates by the ore-bearing solutions. These structures, indicated here as „hydrothermal karst" are important for understanding the origin of ores and may help to resolve the argument between the two conflicting interpretations.

The problem of karst phenomena in connection with sulfide ores has been repeatedly raised, mostly on premises that it was the ordinary meteoric water that dissolved the disseminated sulfides and reprecipitated them in more concentrated form at greater depth (e.g. Althans 1891, Ford & King 1966).

Cavity-making by hot ore-bearing solutions has been implicitly or explicitly invoked as an important factor in the formation of „cavity-filling" deposits (e.g. Loughlin 1926, Heyl et al. 1955, Ford 1969). This factor has not been ignored in connection with the Cracow-Silesian sulfide ores, but only a little attention was given to it.

Acknowledgements: This study was made possible by the friendly cooperation of many mining geologists whose assistance and help is gratefully acknowledged.

GEOLOGIC SETTING

Zinc and lead deposits in the Triassic rocks are essentially confined to the so called „ore-bearing dolomite". Figure 1 shows the generalized relationship between the dolomite and the stratigraphic members differentiated in the Triassic sequence (for details see e.g. Assmann 1944, Siedlecki 1948, Śliwiński 1969).

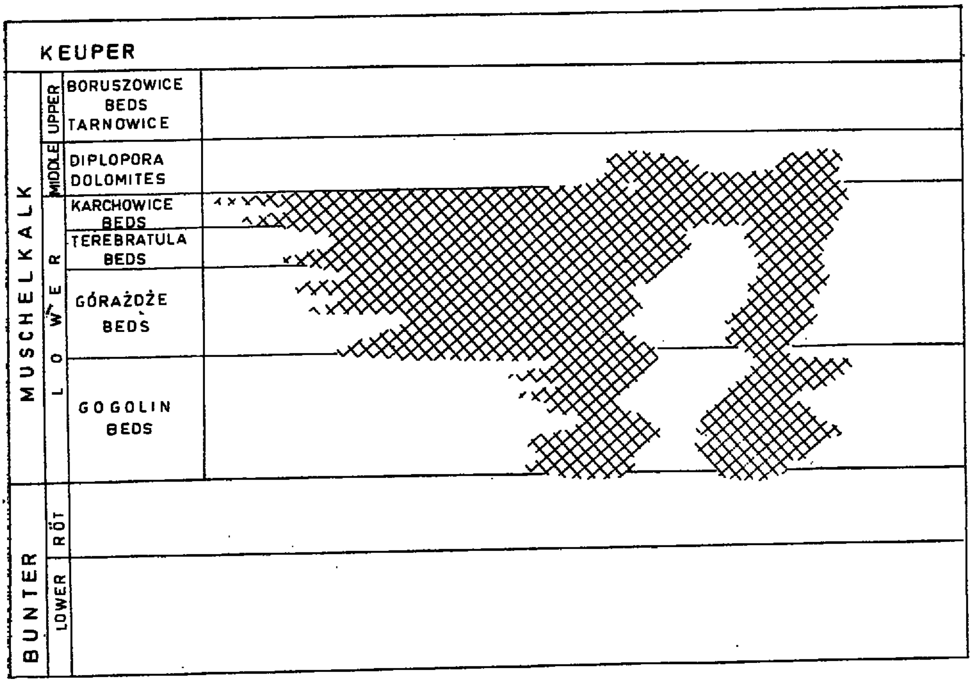

Fig. 1

Generalized picture showing the distribution of the ore-bearing dolomite within the Triassic sequence; modified after Śliwiński (1969)

The lower carbonate members of the sequence, i.e. the Röt and the Gogolin Beds contain abundant marly intercalations. With a few, but notable exceptions, these beds are devoid of any significant mineralization. The overlying Górażdże and Karchowice Beds, which stratigraphically correspond to the ore-bearing dolomite consist mainly of relatively pure limestones.

Major carbonate sedimentation ended at the close of the Muschelkalk. The Boruszowice Beds (see fig. 1) consist chiefly of argillaceous marine sediments. The Keuper is made up of non-marine clays which in places contain lenses of pure limestones (the Woźniki Limestone).

In much of the Silesian area, the Triassic overlaps the Upper Carboniferous Coal Measures, and it is here where fully developed succession of members is found, the Bunter included. Along the north-eastern margin of the Silesian Basin, the Triassic rests upon a deeply dissected surface of hard limestones and dolomites of Lower Carboniferous and Devonian age. Here, the lower members of the sequence are locally missing and the strata corresponding to the upper part of the Lower Muschelkalk and, even the Middle Muschelkalk, may rest upon the Paleozoic (Śliwiński 1969).

The overlap reflects the primary configuration of the pre-Triassic land surface, on which the resistant rocks stood relatively high in topography, and may have formed a fringe of islands in the see which at that time occupied much of the Silesian Basin (see Śliwiński 1969).

At the close of Triassic time the Cracow-Silesian area was subjected to tectonic movements related to the Early Cimmerian phase. These movements, heralded by the appearance of an unconformity between the Keuper and the Muschelkalk, resulted in broad folding of the Triassic rocks (e.g. Piekarski 1965, Bogacz 1967, Alexandrowicz 1969, Śliwiński 1969). One of the effects of the Early Cimmerian movements was also an uplift of the area situated east of the Silesian Basin. Across the uplifted area an erosion surface was produced. The sediments corresponding to the uplift and to the subsequent erosion are fluvial gravels of Lowermost Jurassic age (Znosko 1955, Unrug & Calikowski 1960).

The Middle Jurassic marine sediments rest discordantly upon a truncated surface of the Paleozoic and Triassic rocks so that various members of the Triassic sequence, the ore-bearing dolomite included, are found in contact with sandstones and gravels of the Middle Jurassic age.

At the close of the Jurassic and during Cretaceous time, the Triassic rocks and their Paleozoic substratum were again involved in tectonic movements. Significant faulting occurred at the opening of the Cenozoic (Dżułyński 1953). The recently discovered high-angle thrust-faults showing evidences of post-Jurassic zinc and lead mineralization (Harańczyk et al. 1968) belong presumably to these movements. However, the precise age of these faults has not yet been determined.

During early Tertiary time, the Cracow-Silesian region was reduced to a low relief, and the peneplained surface, was locally covered with a fine quartzitic sand and various products of chemical weathering (Alexandrowicz 1970). Later, but still prior to the Miocene transgression, numerous sink-holes were formed on the surface of the exposed carbonate rocks. The sink-holes were filled with the above mentioned sand, green clays, and with partly decalcified rock-debris (Gradziński 1962).

The Miocene transgression which came after that, and affected most of the Cracow-Silesian region, was associated with, and followed by an intensive faulting which resulted in the formation of numerous horsts and grabens (Dżułyński 1953, Alexandrowicz 1964, Bogacz 1967).

This, in brief, is the outline of geological history of the Cracow-Silesian region which will serve as a framework for the following considerations. Before entering into these considerations it may be useful to make a few statements concerning the ore-bearing dolomite and the composition of the ores.

There has been much controversial writing on the subject of the ore-bearing dolomite, and no agreement has been reached as to its origin and the processes by which the dolomitization occurred (for references see Śliwiński 1969).

It is beyond the scope of this article to enter into the question of validity of the existing arguments in favour of the secondary or primary origin of the dolomite. In the present authors' opinion, there is no evidence which would justify the tendency of some investigators to consider the ore-bearing dolomite as a primary deposit.

Although the boundary between the dolomite and limestone is usually gradational, the contacts are narrow (from a few up to several tens of meters) and go obliquely to the bedding. It is even possible, in a single bed, to see the sedimentary structures extending uninterruptedly from limestone to dolomite. The passage does not affect the outline of the structures though a marked decrease in their size is sometimes observed. Further away from the contacts, particularly in the areas of significant ore mineralization, the sedimentary structures tend to disappear, and only the primary chert nodules, if present bear the record of primary structures and fossils. The above indicated features are characteristic of emplacement and point out to a secondary origin of the ore-bearing dolomite (e.g. Michael 1913; Duwensee 1928; Wernicke 1931; Siedlecki 1948, 1952).

Short notice needs be given to the composition of the primary sulfide ores (for details see Harańczyk 1962). They consist mainly of simple sulfides of zinc, lead and iron such as sphalerite, wurtzite, brunckite, galena, boleslavite, marcasite and pyrite, with rare sulfosalts, e.g. jordanite and gratonite.

The ores occur as 1) replacements and 2) cavity-filling deposits. It is the second type of occurrences to which this paper is devoted.

ORE-LINED KARST FEATURES IN THE ORE-BEARING DOLOMITE

Various solution effects related to different karst developments are among the striking features of the ore-bearing dolomite. Karstic processes involving the action of cold meteoric waters have been repeatedly operating at different time intervals, whenever the Triassic rocks became exposed to the circulation of ground water (e.g. Michael 1913, Gilewska 1960). These processes are excluded from the following considerations which are limited to the solution features contemporaneous or penecontemporaneous with the emplacement of sulfide ores and which are thought to represent the work of hot ore-bearing fluids.

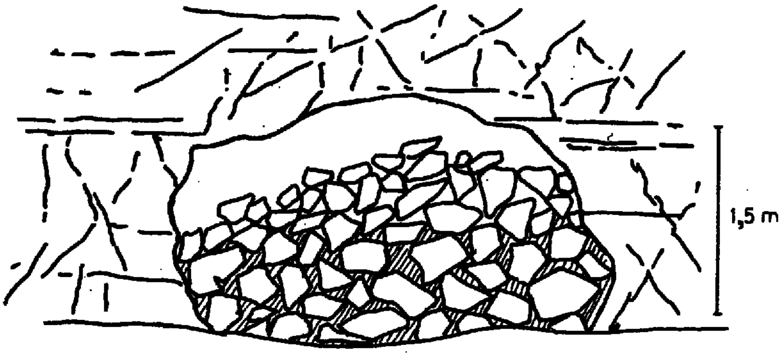

Fig. 2

Solution channel partly filled with ore-cemented rock debris; Trzebionka

Solution cavities with intact roofs

Small ore-lined conduits, evidently produced by circulation of acid solutions, are very common in the ore-bearing dolomite. They tend to appear as a network of irregular passages devoid of visible joint-control. Roofed solution cavities, large enough to admit human body, i.e. proper caves (see Curl 1964) are rare. They also tend to occur as nearly horizontal galleries or irregular chambers filled partly or entirely with tumbled rock — fragments (fig. 2) derived from the nearby collapse structures. The walls of cavities as well as the rock fragments are coated with sulfide ores.

Collapse breccias

The caves merge into a system of structures with collapsed roofs (figs. 3 and 4) and these into zones of breccias in which the collapse pro-

Fig. 3

Solution cavity with collapse roof filled with ore-cemented breccia; Bytom

cesses have so modified the original pattern of caves that their outlines are hardly recognisable. The breccias consist of randomly distributed blocks and fragments of the ore-bearing dolomite cemented with galena, sphalerite and marcasite crystals. The cement may not fill the whole space between the rock-fragments, and unfilled cavities may occur. These are coated with idiomorphic sulfide crystals.

The breccias occur widely ever different parts of the ore-bearing dolomite, and frequently are sandwiched between the undisturbed beds. They rest either on solution-made surfaces or upon residual clays (see below). Therefore their lower boundaries are usually abrupt. In contrast, sharply defined upper boudaries seldom exist, and the breccias pass upwards into a shattered and fractured dolomite.

The breccias range from a few tens of centimeters to several meters in vertical extension, and can be traced horizontally over a considerable distance which is difficult to assess. The geometrical form of the breccias bears no relation to their extension. For instance, the small breccia body depicted in fig. 4 finds many geometrical replicas among much larger accumulations of blocks.

Extensive zones of breccia occur at the contact of the ore-bearing dolomite with the underlying Gogolin Limestones. Of particular interest, here are large blocks of the dolomite or parts of the collapsed cave roof which settled into the solution pockets developed in the limestone (Du-

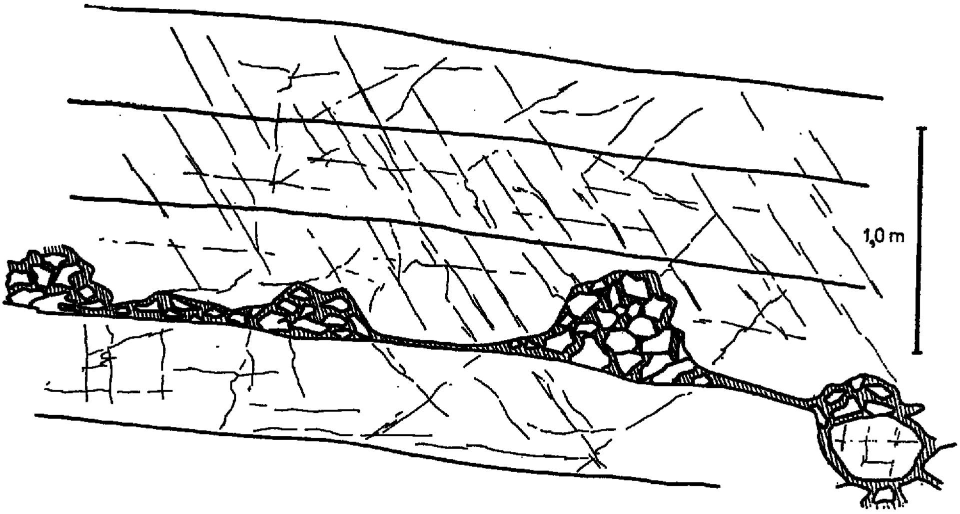

Fig. 4

Small solution channels filled with ore-cemented breccia; Bytom

wensee 1929, comp. also fig. 4 in Horzemski 1962). Local discordances that arise, may bear a remonte similarity to „diastrophic" or „sedimentary" discordances. Such discordances are easily distinguishable from the tectonic or syn-depositional contacts by 1) irregular concave solution surfaces dividing the dolomite from limestones, 2) common occurrence of residual clays, and 3) the absence of tectoglyphs.

Convincing evidence that the breccias discussed are of collapse origin is provided by the way some of the blocks fit the wall from which they were broken apart (fig. 3).

In bedded carbonate rocks, the cavity-making and breccia-making are usually contemporaneous. Thus the production of large open chambers which suffered from roof failure is not necessary for the formation of breccias showing a considerable vertical extent.

The breccias under consideration have been variously interpreted. There is a good reason to believe that they were frequently confused with tectonic breccias or mistaken for sedimentary and/or early diagenetic breccias. The possibility of their collapse origin has not been ignored, but information pertinent on this problem was, in the past, very fragmentary (e.g. Kuźniar 1928). Parenthetically it may be noted that similar collapse breccias from other ore deposits have been repeatedly mentioned by various authors (e.g. Loughlin 1926, Heyl et al. 1955, Ford 1969).

Zones of ore-lined fractures

The breccias may pass upwards and laterally into a network of ore-lined fractures and small faults cutting up the ore-bearing dolomite in all possible directions. Some of these fractures are only a few centimeters in length, others can be traced over a distance of several or several tens of meters. Only a few of them are regular, and a considerable part of these fractures appears to be oblique or roughly parallel to the bedding. They also may occur in parallel and crossing sets which do not necessarily conform to the pattern of regional jointing. The fractures are filled with sulfide ores and the longer is the fracture the thicker is the sulfide vein in it.

The problem of the fractures and veins awaits systematic measurements. The data hitherto available are still insufficient for generalization (Duwensee 1943). Some of these ore-lined fissures may be interpreted, at least partly, in terms of a solution along bedding planes and preexisting fractures (figs. 5 and 6). Other presumably resulted from stress redistribution consequent upon the collapse of caverns and the subsidence of the overlying rocks (Kuźniar 1928, Krajewski 1957).

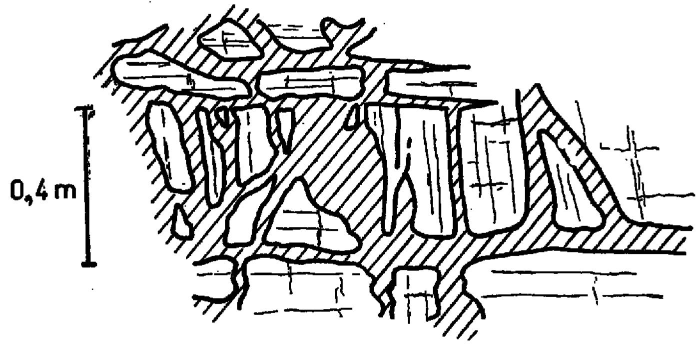

Fig. 5

Solution-made cavities filled with sulfide ores; Trzebionka

Of particular interest are horizontal fissures developed along the bedding planes and internal parting surfaces. Such fissures are of common occurrence among karst features and tend to develop preferentially above the cavernous horizons in bedded rocks. The subsidence may then serve to widen the fissures which may be filled with the material that crystallizes from the dissolving solutions or which is carried in suspension (e.g. residual clays).

It seems that the whole case of syn-sedimentary interpretation of zinc and lead ores in the Cracow-Silesian region rests on the assumption that the horizontal fractures filled with sulfides are sediment layers deposited in the same environment as the carbonate beds. However, as indicated by several authors (e.g. Gałkiewicz et al. 1960), the alleged „layers" if traced over a sufficiently long distance, branch into a system of oblique and perpendicular subordinate veins cutting across a number of beds (fig. 7). These branching veins and veinlets are in every respect identical in composition with the horizontal ones, and cannot be regarded as secondary off-springs resulting from a remobilization of sulfides, as it is claimed by the advocates of the syngenetic origin of ores (Smolarska 1968). One of the diagnostic features in this respect is the „comb structure" which results from interlocking of crystals growing from opposite walls of the fracture. The comb structures of branch-veins join those of the main ones, so that the mineral filling passes from one vein into another without break.

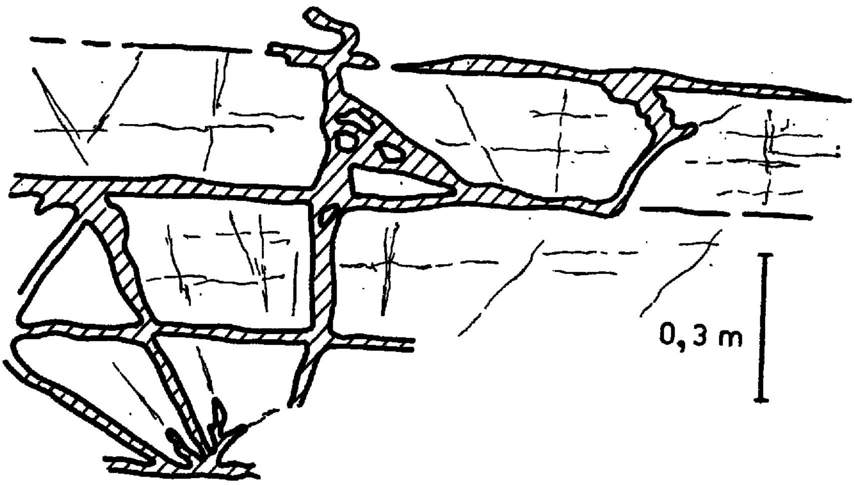

Fig. 6

Sulfide veins partly developed along bedding planes (fragment of the exposure shown in fig. 5)

The above indicated interpretation of the ore-filled fractures is substantiated by the fact that identical zones of shattered rocks from above the cavity-filling ore deposits of unquestionably epigenetic origin are of common occurrence (see e.g. Loughlin 1926). Close analogous are also found in recent karst regions where the formation of openings is due to the circulation of ordinary meteoric waters.

Residual clays

The solutional removal of carbonates leaves a residue of argillaceous matter. Such residual clays do occur in the Triassic rocks and are known as „vitriol clays". The residual character of these clays has been recognized by a number of authors (Kuźniar 1928, Stappenbeck 1928, Krajewski

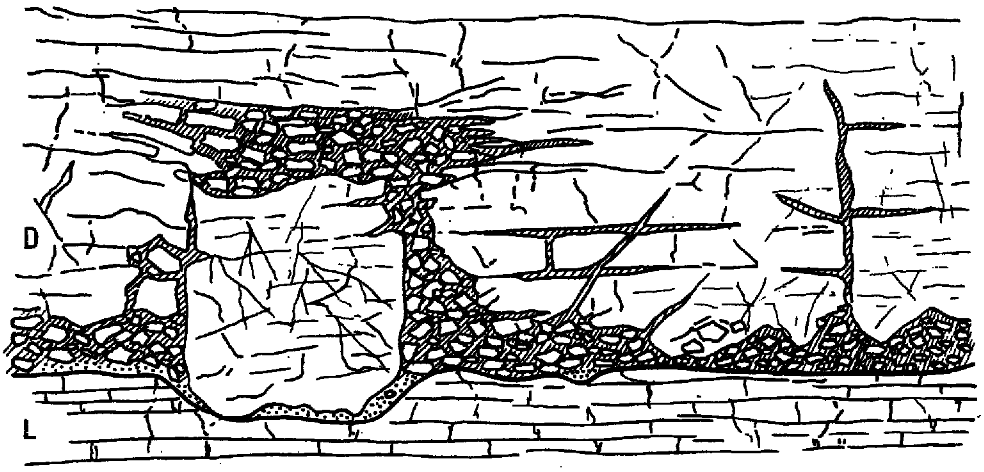

Fig. 7

Idealized and schematic picture showing ore-filled karst structures and related disturbances at the boundary between the ore-bearing dolomite (*D*) and the Gogolin Limestone (*L*). Vertical dimensions and the size of blocks greately exagerated

1957, Cibis & Cibis 1960) and their intimate association with karst features was clearly demonstrated by Horzemski (1962). Admittedly, opposite views are being held. The advocates of syngenetic origin of ores regard them as ordinary sedimentary intercalations within the Triassic sequence (Gürich 1903, Gruszczyk 1956). The factual basis for this view is that the vitriol clays exhibit lamination and contain pollen of Triassic age (Zawiślak 1965). It should be born in mind, however, that residual clays seldom remain in place of their leaching. They are usually carried away by the dissolving fluids and tend to settle in cavities with stagnant or slowly moving solutions. In this respect, the residual clays are sedimentary rocks, and may show all the structures which are diagnostic of sediments. They also contain all other insoluble particles, which may occur in the rock subjected to leaching, the pollen included. Moreover the „vitriol clays" do not occur as continuous layers but fill the solution pockets, cavities and crevices (see Horzemski 1962). These clays tend to appear at the base of the collapse breccias and may be squeezed upwards as small diapirs between the fallen blocks.

Considerable lateral extension of some of the „vitriol clays" in the Bytom area may find its explanation in the fact that the accumulation of residual clays does not proceed simultaneously at different places. Moreover, the clays once deposited, behave in a manner similar to that of the sand filling in mines, i.e. they prevent the closure of openings and make their further lateral extension possible.

The „vitriol clays" contain fragments of the ore-bearing dolomite and scattered idiomorphic crystals of sulfides. These latter grew up in a soft deposit as evidenced by the fact that the clay laminae are bent down and up over isolated crystals.

The „vitriol clays" are thus residual deposits and are contemporaneous with the solution of cavities and the formation of collapse breccias.

INTEGRATED AND NON-INTEGRATED CIRCULATION OF FLUIDS IN THE ORE-BEARING DOLOMITE

Solution channels, collapse breccias and residual clays testify to extensive, horizontal and integrated circulation of acid solutions. In accordance with what is known of equivalent features produced by the action of meteoric waters (see e.g. Bretz 1942), one can assume that the solution structures in the ore-bearing dolomite have been made under phreatic conditions. Stalactitic forms of sulfides, indicative of vadose conditions, are found only in the upper part of the ore bodies and, presumably post-date the main period of cave formation.

An integrated flow under phreatic conditions is preceded by a non--integrated circulation through:

1) primary openings; i.e. voids between individual crystals and detrital particles, cleavage planes of individual crystals, bedding planes etc.

2) secondary openings; i.e. joints, faults and related tectonic fractures (see Hohlt 1948).

Secondary openings offer the best routes for dissolving solutions and it seems clear that the faults provided the pathways for the solutions mineralizing the Triassic rocks. However, the relation of faults and joints to the karst features discussed has not yet been established, and little can be said on this subject.

The ore-bearing dolomite provides yet another record of nonintegrated flow which is indicative of a circulation through primary openings. This is a spongework of irregular, minute conduits devoid of joint-control.

It is known that one of the effects of a circulation through primary opening is a solutional widening of voids between individual grains which ultimately may lose their original framework and change into an incoherent aggregate of particles. The presumptive evidence pointing to the existence of non-integrated circulation through the pore-space merits particular attention. The solutional widening of such openings permits an easy ingress of fluids for replacements into the innermost parts of the host rock.

RELATION OF SULFIDE ORES TO THE KARST FEATURES

Although isolated ore bodies, show specific properties and individual variations in mineral assemblages and in the ratio of particular constituents, they also reveal significant similarities regarding their paragenesis and geochemistry.

Four principal generations of primary sulfide ores have been distinguished (see e.g. Wernicke 1931, Harańczyk 1962).

First generation consists almost exclusively of disseminated coarse crystalline sphalerite or marcasite genetically related to dolomitization and ankeritization.

Second generation is that of crustified ores in which four types have been distinguished: 1) The „Schalenblende" made up of bands of sphalerite, wurtzite and brunckite intergrown with galena, boleslavite (pl. I, fig. 1) and, rarely, with jordanite, gratonite and rathite. 2) The „Strahlenblende" which consists mostly or exclusively of wurtzite showing a radial structure and, occasionally, the intergrowths of galena (pl. II, fig. 1). 3) The „Schalenkies" made up of bands of anomalous melnikovite-pyrite and marcasite which tend to coat the types 1 and 2 (pl. I, fig. 1). 4) Galena filling, sometimes with obscured crustification and comb-structures. To this generation belong also sulfide ores (sphalerite, brunckite and „skeletal galena" showing colloform structure (pl. II, fig. 2).

Third generation consists of galena forming mainly replacement deposits. It has been given the name of „main galena" (Wernicke 1931).

Fourth generation is made up of sulfides (sphalerite, galena and marcasite) in paragenesis with barite.

The question that arises is the relation between the ore generations and the karst features described in the preceding chapters. It will be realized that a rational solution to this question requires further investigations and that the following remarks must be taken tentatively.

The first generation of ores is mainly of the replacement type and does not show visible connection with the integrated solution features and breccias. It is possible, however, that the emplacement of this generation was associated with a non-integrated circulation through primary openings combined with a partial removal of the replaced carbonates. The shrinkage consequent upon dolomitization, as it is assumed by many authors (e.g. Wernicke 1931), may have served to widen the primary openings and to develop new contraction fractures. This might have provided the supply routes for incipient integrated flow of mineralizing solutions. Indeed, the minute fractures which may be interpreted as resulting from shrinkage are crustified with the „Strahlenblende" (second generation of the ores).

Crustifications are known to characterize the cavity-filling deposits and, it is the second generation of ores that shows the closest and most intimate relation to the karst features described previously. This generation fills the cavities, coates the solution surfaces, cements the collapse breccias, and forms crustifications around the rock-fragments found in the solution cavities.

It should be added that the galena intergrowths mentioned previously (type 1 and 2) tend to concentrate on the top surfaces of the crustified rock fragments, though this applies to the innermost bands only (the so called „shadow structure" see fig. 1 in pl. II). Such a concentration is indicative of gravity settling of galena from fluids filling the voids between the rock-fragments.

Sulfides belonging to the second generation occur as euhedral crystals in residual clays. They also make up rare stalactitic forms.

Although the third generation of ores is mainly of the replacement type it may occur as the latest cavity filling, coating the crustified ores of the second generation.

Little is known about the relation of the fourth generation of sulfides to the karst features described. From the publication by Winczakiewicz (1969) one can infer that also this generation may occur in cavity-filled deposits. This problem, however, awaits further investigations. Also the question of the „nest-like" ore bodies in limestones and primary dolomites (Röt) is not yet ripe for discussion though these ore bodies have distinct karst features of their own.

A definite relation between the karst features and the primary ores is at present recognized only in connection with the first and second generation of sulfides. The karst structures are evidently younger than the first generation of ores though it is not known how long was the time span between the two phenomena.

There is a presumptive evidence that the cavities in the ore-bearing dolomite were made by the ore-bearing solutions. The relation of idiomorphic sulfide crystals (second generation of ores) to residual clays indicates that these crystals grew up in a soft unlithified sediment i.e., the crystallization was contemporaneous or penecontemporaneous with the deposition of clays (pl. II, fig. 1). Such a deposition, however, proceeded concomitantly with the formation of solution cavities. Moreover the karst features discussed, could not have been inherited from an earlier and different solutional processes antedating the emplacement of ores (as it is the case with the deposits described by Fersman & Scerbakov 1925, fide Kunsky 1956) since the loose framework of collapse structures and open fissures could not have stand intact and empty over any considerable time interval.

The conclusion is that the ore-lined karst features in the ore-bearing dolomite resulted from the action of acid ore-bearing solutions and that the emplacement of the second generation of ores took place concomitantly with the development of these karst features. This question touches upon the character of the ore-bearing solutions which could not have ascended as cold meteoric waters. The investigations of liquid inclusions found in the sulfide minerals and presented in the publication by Gałkiewicz (1967) indicate that these minerals were deposited within the range of temperatures between 50° and 150°C. It may be added, however, that the temperatures close to, or slightly above the lower limit are sufficient to explain the precipitation in karst cavities and fit with the general picture of the geological conditions attending the deposition of sulfide ores in the Triassic rocks.

AGE OF SULFIDE MINERALIZATION IN THE TRIASSIC ROCKS

Evidence is accumulating that the sulfide ores in the Triassic rocks must be older than Miocene. The Miocene faults which cut up the ore-bearing dolomite are devoid of any traces of syn-tectonic mineralization, and apparently post-date the emplacement of the ores.

Conclusive evidence in this respect comes from one of the pre-Miocene sink-holes which developed at the bottom of a Lower Tertiary river valley (exposure in the Matylda mine). Here, the fragments of galena crustifications occur in a pocket of white quartzitic sand. One side of these fragments is the cast of a solution surface developed in the dolomite, while the other consists of idiomorphic crystal faces projecting outwards. This indicates that the fragments were broken free from ore-lined solution cavities exposed on the wall of the sink-hole by the time of its filling with clays and sands.

The conclusion drawn from the foregoing is that the sulfide ores were already formed before the end of Lower Tertiary time. This renders the hypotheses of the Miocene and/or Pliocene origin of the ores (e.g. Seidl 1957, Gałkiewicz 1967) untenable.

The discovery of high-angle thrust faults which provided the access for mineralizing solutions, and consequently gave rise to the emplacement of zinc and lead sulfides into the Upper Jurassic limestones, shows that some ore mineralization occurred after Jurassic time.

Here the direct evidence so far collected ends. There is, however, a certain amount of indirect evidence, admittedly of varying degree of persuasiveness, that the extensive sulfide mineralization of the Triassic rocks may belong to an earlier stage, corresponding to the Early Cimmerian phase of tectonic movements.

The faults mentioned above post-date the formation of the ore-bearing dolomite which is displaced by them. Furthermore the transgressive sands and gravels of Middle Jurassic age which are entirely barren, rest upon a truncated surface of the ore-bearing dolomite. This relation shows that the ore-bearing dolomite was formed before the transgression of the Jurassic sea. Unfortunately the Jurassic marine sediments in known exposures are nowhere directly truncating the ore--bodies.

The fact that the ore-bearing dolomite is truncated by the transgressive sediments of the Middle Jurassic, indicates, however, that at least the first generation of sulfide ores which appears to be directly and genetically related to dolomitization occurred prior to the Jurassic time. The age of the second generation of ores, and that of the corresponding karst features, is still open to discussion. It may be younger than Jurassic (see also Bobrowski 1950) but only on the premises that the emplacement of the first and second generation of ores occurred coincidently in the same place in widely separated time intervals. It is not yet possible to present unquestionable evidence that the dolomitization and the emplacement of the first generation of ores was forerunning the emplacement of the second generation, without appreciable time lapse. Such a possibility, however, is logically defensible and has been implicitly or explicitly indicated by the authors regarding the sulfide ores as emplaced between the Triassic and Jurassic (Petrascheck 1918, Kuźniar 1928, Duwensee 1929, Krajewski 1957). It also has been taken for granted by those who expressed the view that the sulfide ores in the Triassic rocks had been already subjected to weathering and oxidation during Lower Jurassic time (e.g. Piekarski 1965).

Although it is not of immediate consequence for the subject discussed, it is to be noted that by assuming pre-Jurassic age of the sulfide ores a new light may be shed upon the Woźniki Limestones (Upper Keuper). These pure limestones which contain insignificant amount of zinc and lead sulfides are best explained in terms of lake deposits receiving large quantities of calcium carbonate from springs. The latter might have been the surficial effect of a subterranean circulation, which at greater depth brought about the dolomitization and the emplacement of the first generation of ores.

It also may be added that by relating the zinc and lead ores to the Early Cimmerian phase of movements, the apparent lack of obvious genetic relation between the numerous faults and the sulfide mineralization (the criticism levelled against the hydrothermal concept by the protagonist of the sedimentary interpretation) is more comprehensible. A great number of the faults cutting the Triassic rocks, are post-ore displacements. The discovery of faults related to the mineralizing solutions awaits further investigations and may be a matter of time only.

PROVENANCE AND POSSIBLE SUPPLY ROUTES OF MINERALIZING SOLUTIONS

The source of mineralizing solutions still remains in the realm of speculation. With sedimentary hypotheses this problem also remains unsolved. The oxidizing conditions attending the deposition of most of the Triassic carbonates, and the high energy environment manifested, for instance, in the Górażdże Beds, by the presence of large scale cross-stratification is incompatible with any significant sulfide deposition. It is also not easy to explain how the ascending meteoric waters could concentrate the sulfides disseminated in the overlying rocks (see e.g. Althans 1891) as neither the Upper Triassic carbonates nor the overlying formations contain enough of the dispersed sulfides to account for the formation of zinc and lead deposits in the ore-bearing dolomite.

It also seems unlikely that the crustified ores have been derived from leaching and redeposition of sulfides of the first generation of ores. No evidence of such a leaching exists in the rocks surrounding of the ore-filled cavities.

The only plausible explanation is that both, the first and the second generation of ores, have been emplaced by mineralizing solutions which came from an unknown deep-seated source.

The problem of "feeding channels" and supply routes of these solutions represents another area of ignorance and only speculative attempts can be set forth. It is sometimes implicitly or explicitly stated that the mineralizing solutions have passed through the Upper Carboniferous Coal Measures, though there is only a scanty and localized mineralization (e.g. Krusch 1929, Zwierzycki 1950). Another alternative is that the solutions passed through the Lower Carboniferous and Devonian carbonates where they could find the easiest way upwards along numerous tectonic dislocations and fractures. From recent publications (e.g. Harańczyk 1964, 1970; Ekiert 1968) it is known that these Paleozoic carbonate rocks show conspicuous sulfide mineralization.

The solutions which rose to the top of the Paleozoic rocks could gain the access into the Triassic sediments (corresponding to the Górażdże Beds), through the overlap mentioned previously. Then they could spread horizontally along the upper boundary of the Gogolin Beds giving rise to the karst features in the ore-bearing dolomite and to the emplacement of the sulfide ores.

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REFERENCES

ALEXANDROWICZ S. W. 1964. Przejawy tektoniki mioceńskiej w Zagłębiu Górnośląskim (Miocene tectonics in the Upper Silesian basin). — Acta Geol. Pol., vol. 14, no. 2. Warszawa.

— 1969. Utwory triasowe i jurajskie w Spytkowicach koło Oświęcimia. — Spraw. Pos. Komis. PAN Oddz. w Krakowie. Kraków.

— 1970. Utwory paleogenu południowej części Wyżyny Krakowskiej (Couches du Paléogène de la partie méridionale du Plateau de Cracovie). — Rocz. P. T. Geol. (Ann. Soc. Géol. Pol.), t. 39, z. 4 (1969). Kraków.

ALTHANS R. 1891. Die Erzformation des Muschelkalks in Oberschlesien. — Jb. Königl. Preuss. Geol. L.-A., Bd. 12. Berlin.

ASSMANN P. 1944. Die Stratigraphie der oberschlesischen Trias. 2. Der Muschelkalk. — Abh. Reichsamt Bodenforsch., N. F., H. 208. Berlin.

BERNHARDI F. 1899. Über die Bildung der Erzlagerstätten im oberschlesischen Muschelkalk. — Z. Oberschles. Berg. u. Hüttenm. Ver., 37. Katowice.

BOBROWSKI W. 1950. Próba określenia wieku wtórnej dolomityzacji i mineralizacji skał triasowych w południowo-zachodniej Polsce. — Biul. Państw. Inst. Geol. Warszawa.

BOGACZ K. 1967. Budowa geologiczna północnego obrzeżenia rowu krzeszowickiego (The geological structure of the northern border of the Krzeszowice Graben). — Prace Geol. PAN Oddz. w Krakowie (Geol. Transact.), nr 41. Warszawa.

BRETZ J. H. 1942. Vadose and phreatic features of limestone caverns. — J. Geol., vol. 50, no. 6. Chicago.

CIBIS J. & CIBIS J. 1960. Uwagi o iłach witriolowych. — Rudy i Met. Nieżel., t. 5, nr 8. Katowice.

CURL R. L. 1964. On the definition of a cave. — Bull. Nat. Speleological Soc., vol. 26, no. 1. Arlington.

DUWENSEE F. 1928. Über die erzführenden Dolomite im östlichen Oberschlesien, insbesondere im östlichen Teile des Südflügels der Beuthener Bleizinkerzmulde. — Z. prakt. Geol., Bd. 36, H. 6. Berlin.

— 1929. Die oberschlesische Bleizinklagerstätte auf Grund der Ergebnisse der geologischen Untersuchung der Deutsch-Bleischarley-Grube. — Metall u. Erz, Jg. 26, H. 19. Halle.

— 1943. Klüftung und Vererzung in Oberschlesien. — Z. prakt. Geol., Bd. 51, H. 9/10. Berlin.

DŻUŁYŃSKI S. 1953. Tektonika południowej części Wyżyny Krakowskiej (Tectonics of the southern part of the Cracovian Upland). — Acta Geol. Pol., vol. 3, no. 3. Warszawa.

EKIERT F. 1968. Late Hercynian mineralization in the northern part of the Upper Silesian area. — Intern. Geol. Congr. Report XXIII Sess., Abstr. p. 185. Prague.

FORD T. D. 1969. The stratiform ore deposits of Derbyshire. — Proc. 15 Intern. Univ. Geol. Congr. 1967. Leicester.

FORD T. D. & KING R. J. 1966. The Golconda caverns, Brassington, Derbyshire. — Trans. Cave Research Group Great Britain, vol. 7, no. 2.

GAŁKIEWICZ T. 1956. Geneza śląsko-krakowskich złóż cynkowo-ołowianych. — Rudy i Met. Nieżel., t. 1, nr 1. Katowice.

— 1967. Genesis of Silesian-Cracovian zinc-lead deposits. — Econ. Geol. Monography, 3. New York.

GAŁKIEWICZ T., HARAŃCZYK C. & SZOSTEK L. 1960. Pojurajskie okruszcowanie utworów w zasięgu dewon-jura rejonu Olkusz-Klucze. — Rudy i Met. Nieżel., t. 5, nr 4. Katowice.

GILEWSKA S. 1960. Przyczynek do poznania rozwoju krasu w środkowotriasowym dolomicie kruszconośnym na Górnym Śląsku (Contribution to the recognition of karst development in Middle Triassic metalliferous dolomite in Upper Silesia). — Przegląd Geogr. (Pol. Geogr. Rev.), t. 32, z. 1/2. Warszawa.

GRADZIŃSKI R. 1962. Rozwój podziemnych form krasowych w południowej części Wyżyny Krakowskiej (Origin and development of subterranean karst in the southern part of the Cracow Upland). — Rocz. P. T. Geol. (Ann. Soc. Géol. Pol.), t. 32, z. 4. Kraków.

GRUSZCZYK H. 1956. Uwagi w sprawie wykształcenia morskich utworów triasu śląsko-krakowskiego (Notes on the development of marine deposits of the Cracow-Silesian Trias). — Biul. Inst. Geol. 107. Warszawa.

— 1967. The genesis of the Silesian-Cracow deposits of lead-zinc ores. — Econ. Geol. Monograph, 3. New York.

GÜRICH G. 1903. Zur Genese der oberschlesischen Erzlagerstätten. — Z. prakt. Geol., Bd. 11, H. 5. Berlin.

HARAŃCZYK C. 1962. Mineralogia kruszców śląsko-krakowskich złóż cynku i ołowiu (Ore minerals of Silesia-Cracow zinc and lead deposits). — Prace Geol. PAN Oddz. w Krakowie (Geol. Transact.), nr 8. Warszawa.

— 1964. Vertical ore zoning in the zone of faulting, observed in Klucze near Olkusz. — Symp. Problems of Postmagmatic ore deposition, vol. 1. Prague.

— 1965. Złoża Zn-Pb typu śląsko-krakowskiego i ich związek komagmowy ze skałami alkalicznymi. — Rudy i Met. Nieżel., t. 10, nr 3, 4. Katowice.

— 1970. Ore-bearing dolomite of the root-zone of Silesian-Cracovian Pb-Zn ore-deposits. IAGOD-Symp., Wall-Rock Alterations of Deposits in Carbonates. Stuttgart.

HARAŃCZYK C., SZOSTEK L. & FILIPOWICZ-LESLAK W. 1968. Pojurajskie okruszcowanie Zn-Pb w rowie kompresyjnym Klucze-Jaroszowiec. — Rudy i Met. Nieżel., t. 13, nr 7. Katowice.

HEYL A. V., LYONS E. J., AGNEV A. F. & BEHERE CH. H. 1955. Zinc-lead-copper resources and general geology of the Upper Mississippi Valley district. — Geol. Surv. Bull., 1015-G. Washington.

HOHLT R. B. 1948. The nature and origin of limestone porosity. — Quart. Colorado School of Mines, vol. 43, no. 4. Golden.

HORZEMSKI J. 1962. On the relation of the so-called vitriol clays to the ore-bearing limestones and dolomites of the Middle Triassic in Upper Silesia. — Bull. Acad. Pol. Sci., Sér. Sci. Géol. Géogr., vol. 10, no. 4. Varsovie.

KEIL K. 1956. Die Genesis der Blei-Zinkerzlagerstätten von Oberschlesien (Górny Śląsk — Polen). — Beih. Geol. 15. Berlin.

KRAJEWSKI R. 1957. Uwagi na temat genezy górnośląskich złóż cynkowo-ołowiowych (Remarks about the origin of the Lower Silesian zinc and lead deposits). — Przegląd Geol., R. 5, nr 7. Warszawa.

KUŹNIAR C. 1928. O gniazdach blendy w północno-wschodnim polu kopalni „Ulisses" (Sur les amas de blende dans la mine „Ulisses"). — Pos. Nauk. P. I. G. (C.-R. Séanc. Serv. Géol. Pol.), nr 19/20. Warszawa.

KRUSCH P. 1929. Über kalloidale Vorgange bei der Entstehung der oberschlesischen Zink-Bleilagerstätten. — Z. Oberschles. Berg. u. Huttenm. Ver., 68. Katowice.

KUNSKY J. 1956. Zjawiska krasowe. Warszawa.

LOUGHLIN G. F. 1926. Guides to ore in the Leadville district, Colorado. — U. S. Geol. Surv. Bull., 779. Washington.

MICHAEL R. 1904. Über die oberschlesischen Erzlagerstätten. — Z. Deutsch. Geol. Ges., Bd. 56. Berlin — Stuttgart — Hannover.

— 1913. Die Geologie des oberschlesischen Steinkohlenbezierkes. — Abh. Königl. Preuss. Geol. L.-A., N. F., H. 71. Berlin.

PETRASCHECK W. 1918. Das Alter der polnischen Erze. — Verh. K. K. Geol. R.-A., 11. Wien.

PIEKARSKI K. 1965. Wpływ wietrzenia dolnojurajskiego na złoża rud Zn i Pb w triasie śląsko-krakowskim (Influence of Lower Jurassic weathering upon Zn and Pb ore deposits in the Silesian-Cracow Triassic). — Przegląd Geol., R. 13, nr 2. Warszawa.

SCHNEIDERHÖHN H. 1930. Mineralchemische und mikroskopische Beobachtungen an Blei- Zink- und Kieserzen der Deutsch-Bleischarley-Grube in Oberschlesien. — Chem. d. Erde, Bd. 5. Jena.

SEIDL K. 1957. Das Problem d. sogenannten Gorazdzer Kalke im erzfuhrende Dolomit Oberschlesiens u. seine Lösung. — N. Jb. Miner. Mh., H. 10/11. Stuttgart.

SIEDLECKI S. 1948. Zagadnienia stratygrafii morskich osadów triasu krakowskiego (Problems of stratigraphy of marine Triassic in the Cracow area). — Rocz. P. T. Geol. (Ann. Soc. Géol. Pol.), t. 18. Kraków.

— 1952. Utwory geologiczne obszaru pomiędzy Chrzanowem a Kwaczałą (Geologičeskie obrazovanija učastka meždu Chšanovom i Kvačaloj). — Biul. Państw. Inst. Geol. 60. Warszawa.

SMOLARSKA I. 1968. Charakterystyka złoża rud cynku i ołowiu kopalni Trzebionka (Characteristic of the zinc and lead ore deposits of the Trzebionka mine). — Prace Geol. PAN Oddz. w Krakowie (Geol. Transact.), nr 47. Warszawa.

STAPPENBECK R. 1928. Ausbildung und Ursprung der oberschlesischen Bleizinkerzlagerstätten. — Arch. Lagerst.-Forsch., Bd. 41. Berlin.

ŚLIWIŃSKI S. 1969. Rozwój dolomitów kruszconośnych w obszarze krakowsko-śląskim (The development of ore-bearing dolomites in the Cracow-Silesian area). — Prace Geol. PAN Oddz. w Krakowie (Geol. Transact.), nr 57. Warszawa.

UNRUG R. & CALIKOWSKI A. 1960. Sedymentacja i petrografia warstw połomskich (Sedimentation and petrology of the Połomia Beds). — Rocz. P. T. Geol. (Ann. Soc. Géol. Pol.), t. 30, z. 2. Kraków.

WERNICKE F. 1931. Die primaren Erzmineralien der Deutsch-Bleischarley-Grube bei Beuthen. — O. S. Arch. Lagerst.-Forsch., H. 53. Berlin.

WINCZAKIEWICZ J. 1969. Schemat budowy geologicznej złoża „Trzebionka". — Rudy i Met. Nieżel., t. 14, nr 5. Katowice.

ZAWISLAK L. 1965. Mineralogia i geneza iłów witriolowych niecki bytomskiej (Mineralogie und Genesis der Vitriolletten der Bytom-Becken). — Prace Geol. PAN Oddz. w Krakowie (Geol. Transact.), nr 32. Warszawa.

ZNOSKO J. 1955. Retyk i lias między Krakowem a Wieluniem (Rhaetic and Lias between Cracow and Wieluń). — Prace Inst. Geol., t. 14. Warszawa.

ZWIERZYCKI J. 1950. Lead and zinc ores in Poland. — Intern. Geol. Congress XVIII Sess. Great Britain 1948, Pt. 7, pp. 314—324. London.

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UTWORY KRASU HYDROTERMALNEGO W DOLOMITACH KRUSZCONOŚNYCH

(Streszczenie)

W dolomitach kruszconośnych obszaru śląsko-krakowskiego (fig. 1) występują podziemne utwory krasowe wykształcone w postaci kanałów (fig. 2—4), rozszerzonych krasowo szczelin lub fug międzywarstwowych (fig. 5—7) oraz iłów rezydualnych. Utworom tym towarzyszą rozległe strefy brekcji powstałych w następstwie zawalania się komór krasowych, a także spękania, których pochodzenie wiąże się z nierównomiernym osiadaniem skał nad walącymi się komorami. Wszystkie te formy są okruszcowane siarczkami cynku, ołowiu i żelaza, należącymi do tzw. drugiej generacji kruszców (pl. I i III). Obecnością tych kruszców, które wypełniają rozwarte spękania, puste przestrzenie po wyługowanych węglanach i które spajają okruchy brekcji zawaliskowych, omawiane formy różnią się od zwyczajnych utworów krasowych. Autorowie wykazują, że okruszcowane formy krasu podziemnego utworzyły się w następstwie przepływu roztworów, które niosły ze sobą siarczki metali. W skałach triasowych przepływ ten był zasadniczo poziomy, a przepływy wstępujące i zstępujące miały znaczenie podrzędne. Rozpuszczanie skał węglanowych i powstawanie w nich podziemnych form krasowych, wskazujących na warunki freatyczne, postępowało równocześnie lub prawie równocześnie z wypełnianiem wolnych przestrzeni przez siarczki metali. Te ostatnie nie zostały jednak wymyte ze skał podlegających krasowemu rozpuszczaniu, jak to przyjmują niektóre hipotezy krasowego pochodzenia złóż, ale zostały doprowadzone z głębi ziemi przez roztwory hydrotermalne.

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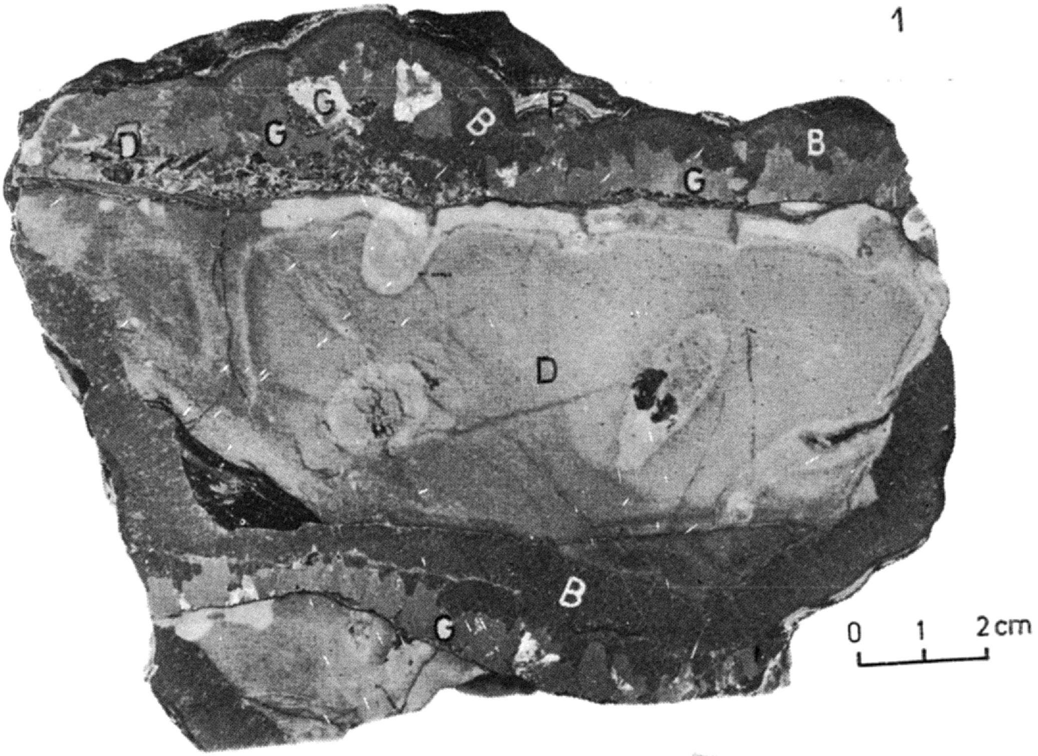
DESCRIPTION OF PLATES I—III

PL. I

1 — Breccia structure. Fragment of the ore-bearing dolomite (*D*) coated with „Schalenblende" (*B*), galena (*G*) and melnikovite — pyrite (*P*). Note the presence of galena crystals on the top surface of large fragments (*D*) i.e. the „shadow

1



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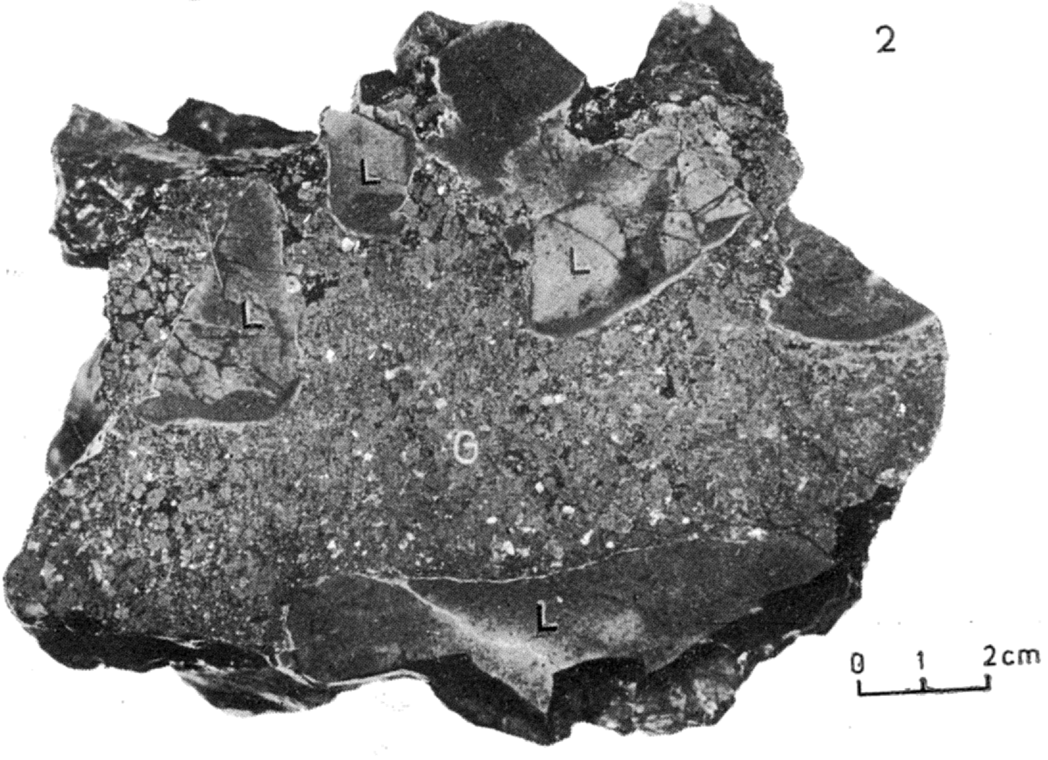

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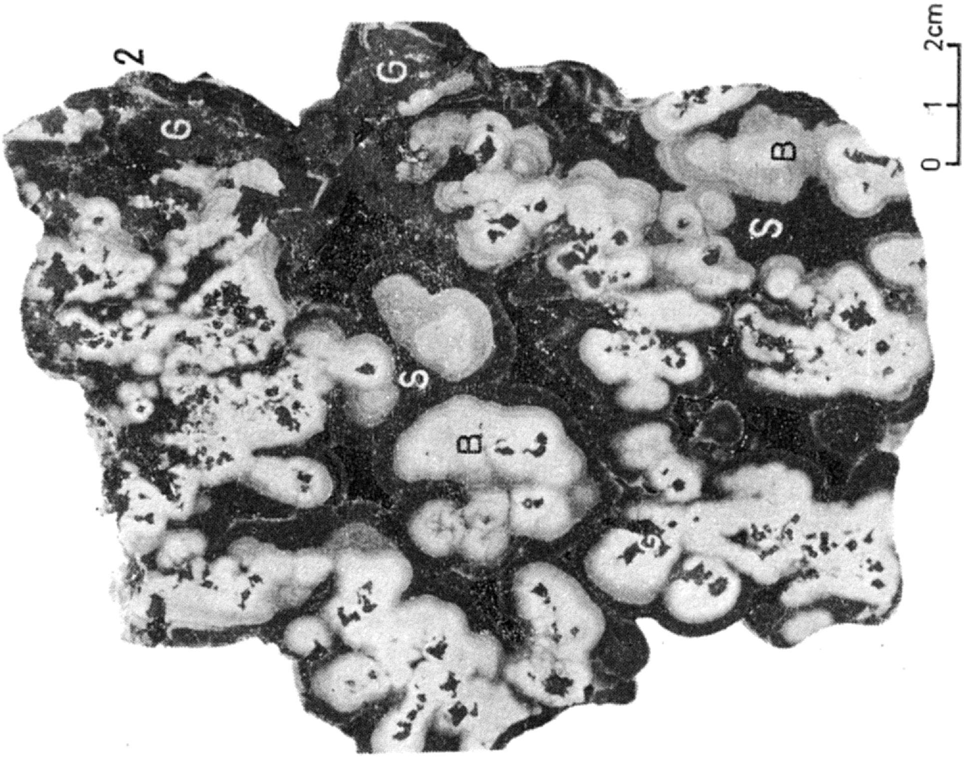

1

structure" and small fragments of the ore-bearing dolomite (*D*) within the ore crust. Locality Bolesław.

2 — Breccia from a nest-like ore body cemented by colloform aggregate of galena (*G*). Note solutional roundening of limestone fragments (*L*). Locality Bolesław.

PL. II

1 — Breccia structure. Fragments of the ore-bearing dolomite (*D*) impregnated with, and partly replaced by zinc sulfides. The fragments coated with „Strahlenblende" (*B*) and galena (*G*) which tends to appear on the top surfaces of dolomite fragments. Empty space between the dolomite fragments is partly filled with residual clay (*C*). Flat upper surface of the partial filling marks the horizontal plane at the time of filling. Locality Trzebionka.

2 — Cavity filling made up of colloform brown sphalerite (*S*), white brunckite (*B*) and „skeletal" galena (*G*). Note the framboidal and pisolitic structure of the ore. Locality Olkusz.