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ZINC AND LEAD MINERALIZATION IN COLLAPSE BRECCIAS OF THE OLKUSZ MINE (CRACOW-SILESIAN REGION, POLAND)

(Pl. I—X + 9 fig.)

Mineralizacja cynkowo-ołowiowa w brekcjach zawałowych kopalni Olkusz (rejon śląsko-krakowski)

(Tabl. I—X i 9 fig.)

Abstract: Commercial Zn and Pb ores in the Olkusz Mine occur exclusively in solution-collapse breccias. The ore bodies resulted from a succession of mineralization and brecciation processes. Five stages of mineralization and four stages of brecciation have been differentiated. Each stage of mineralization is characterized by a specific assemblage of minerals. As a broad generalization it appears that the processes of mineralization and brecciation occurred alternately whereby the clastic products of earlier stages are cemented and enclosed by the products of younger mineralizations. The steps of development of ore bodies in solution-collapse breccias are discussed with the aid of selected and representative sections.

INTRODUCTION

The present article is the third in the series of papers reporting the results of investigation in the Olkusz Mine, north-west of Cracow (Sass-Gustkiewicz, 1974 and 1975). It aims to discuss the sequence of mineralization in solution-collapse breccias, to investigate the steps of development of ore-bodies in breccias and to provide a three-dimentional picture of the ore body that may be regarded as representative for the Olkusz region.

The origin of breccias, geologic setting of the study area and references have been given in earlier publications and no attempt is here made to dwell on these questions any further. For the sake of clarity, however, it is advisable to recall the following facts:

The Olkusz ore body belongs to the Cracow-Silesian zinc and lead deposits. The body occurs in Middle Triassic carbonate rocks and consists chiefly of sphalerite, galena and iron sulfides. The ores are located in solution collapse breccias the origin of which has been dealt with in an earlier publication (Sass-Gustkiewicz, 1974). The breccias in question consist of angular dolomite fragments and are scattered in form of nest-like bodies through the mass of the ore-bearing dolomite. In the light of recent investigations by Bogacz et al. (1972) and the present author's own studies, the epigenetic character of this dolomite is unquestionable — the conclusion arrived at by many authors before.

STAGES OF BRECCIATION AND MINERALIZATION — GENERAL COMMENTS

A closer inspection shows that the breccias are not uniformly mineralized. They are comprised of parts where the rock fragments are cemented by sulfide ores and parts which are notably barren. Within the mineralized parts of the breccias several ore structure can be differentiated, among them those commonly termed "breccia structures". Investigation of such structures reveals the fact that the breccias, as we see them today, resulted from a succession of brecciation and mineralization processes. In other words, stages of brecciation and mineralization occurred alternately and several times. The age relationships between such stages are recorded where the succesively younger minerals cement or enclose the clastic products of earlier mineralizations and brecciations.

If we assume, that sulfides uniformly dispersed in the ore-bearing dolomite represent the first stage of mineralization (1M), then the second stage (2M) is represented by minerals that cement and enclose the fragments of the ore-bearing dolomite (Pl. I. Fig. 1 and 2). The third stage (3M) is represented by minerals that cement and enclose the products of the first and second stage (Pl. II. Fig. 1). Consequently, each successive stage of mineralization encloses the products of earlier mineralizations and bracciations. For instance, the marcasite shown in Pl. II. Fig. 1 represents the fourth stage of mineralization (4M) and encloses a breccia fragment that bears a record of all the preceding stages. The fifth stage (5M) is represented by calcite. This mineral encloses clastic fragments of the previously mentioned marcasite (Pl. II. Fig. 2).

The relationships just described enable us to differentiate in the Olkusz ore-body five stages of mineralization. These stages are here indicated by symbols 1M, 2M, 3M, 4M and 5M. The time intervals between such stages represent periods or stages of brecciation. These are indicated by symbols 1B, 2B, 3B and 4B. The succession of all the above mentioned mineralization and brecciation stages and the resulting structural patterns of ores are diagrammatically illustrated by Fig. 1.

The mineralogy of the Olkusz Mine is very simple. As noted, the ores consist chiefly of sphalerite, galena and iron sulfides. The same type of ore minerals may appear repeatedly in different stages. To mark the different generations of sulfide minerals Roman numbers will be employed. These numbers indicate the order of appearance of the particular sul-

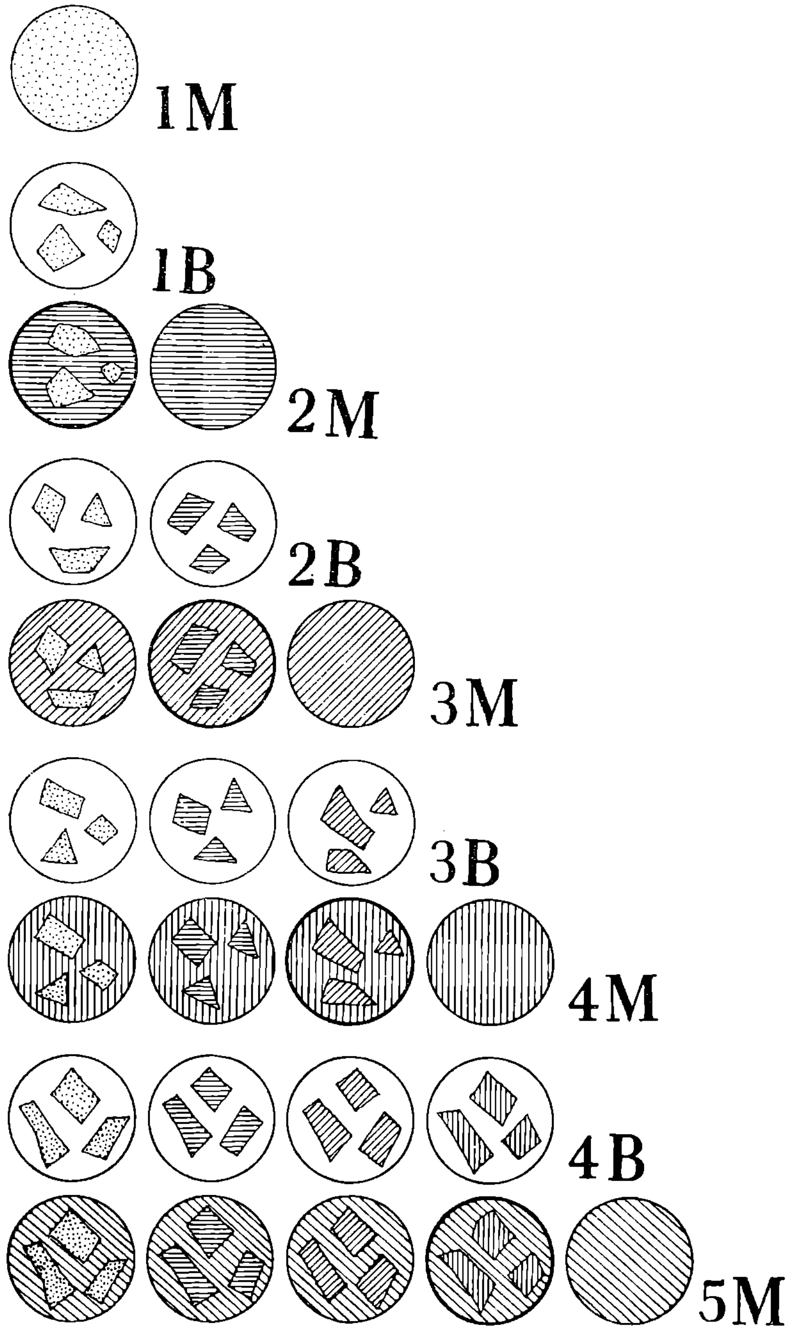

Fig. 1. Schematic diagram illustrating development of mineralized breccias. 1M, 2M, 3M, 4M and 5M — stages of mineralization; 1B, 2B, 3B and 4B — stages of brecciation. Products of earlier mineralizations are enveloped by younger minerals. Each stage of mineralization is marked by different design. Circles delineated by thick lines correspond to structures shown in Pl. I. Fig. 1, 2 and Pl. II. Fig. 1, 2

Fig. 1. Diagram ilustrujący rozwój zmineralizowanych brekcji. 1M, 2M, 3M, 4M i 5M — stadia mineralizacji; 1B, 2B, 3B i 4B — stadia brekcjowania. Produkty wcześniejszych stadiów mineralizacji są otoczone młodszymi minerałami. Każde stadium mineralizacji jest oznaczone inną szrafurą. Kółka otoczone grubą linią odpowiadają strukturom przedstawionym na Pl. I. fig. 1, 2 oraz Pl. II fig. 1, 2

fide minerals and should not be confused with the numeration of stages (Fig. 2).

It must be admitted that the diagrams (Fig. 1) depicted are fraught with uncertainties. It is, for instance, not possible to determine the length

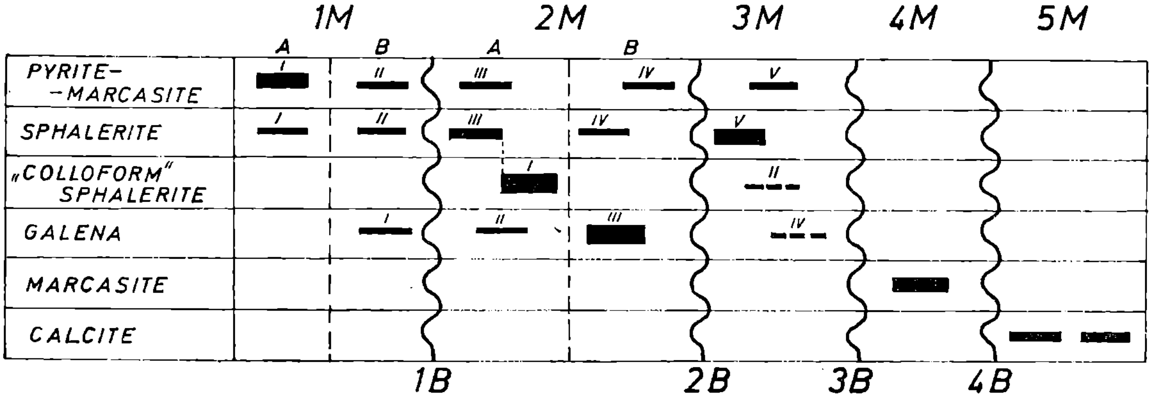

Fig. 2. Paragenetic diagram for Olkusz ores

Fig. 2. Sukcesja mineralna w złożu Olkusz

of time that may have elapsed between the successive stages of mineralization. There remains also the perplexing question concerning the age of deposits and the length of mineralization stages. It is also not known whether or not the periods of brecciation corresponded to temporary breaks in the emplacement of ores. Both processes might have overlapped in time and space.

STAGES OF MINERALIZATION

1M — first stage of mineralization. Sulfides of this stage were emplaced before the first breciation of the host rock. These sulfides are dispersed in form of small grains through much if not the whole mass of the ore-bearing dolomite.

The first stage of mineralization can be divided into two sub-stages: the older "A" and the younger "B".

The sulfides of the sub-stage "A" include: pyrite-marcasite I and sphalerite I (i.e. the first generations of these minerals). No galena has been found associated with the sub-stage "A".

The pyrite-marcasite I is uniformly distributed through the dolomite. This sulfide occurs in form of minute particles. The sphalerite I tends to appear sporadically in form of isolated grains. Inasmuch the size of the sphalerite I and pyrite-marcasite I does not exceed that of the dolomite crystals, both sulfides are regarded here as formed simultaneously with the ore-bearing dolomite (in agreement with suggestion set forth by Harańczyk 1973).

The sub-stage „B" includes irregularly distributed sulfides belonging to: 1. the second generation of pyrite-marcasite and sphalerite (i.e. pyrite-marcasite II and sphalerite II) and, 2. the first generation of galena (galena I). These sulfides tend to fill small vugs, minute fractures, intercrystalline voids and pore space. The sulfides of the sub-stage "B" may also replace the dolomite crystals as it is shown by their contact relationships with the host rock.

2M — s e c o n d s t a g e o f m i n e r a l i z a t i o n. This stage includes sulfides that were emplaced between the first and the second stage of brecciation. Also here, two distinct sub-stages "A" and "B" can be differentiated.

The sub-stage "A" is comprised of a variety of sulfide minerals. The first to be formed is here the sphalerite III. This sphalerite impregnates and replaces the walls of fractures whereby the size and the amount of sphalerite grains decrease progressively with increasing distance from the fracture (Pl. III. Fig. a-f). In principle, the sphalerite III disappears entirely 50—70 cm away from fractures.

The above discussed mode of occurrence of the sphalerite III points to an epigenetic origin of this sulfide. It also indicates that the replacement and impregnation was initiated from visible fractures which guided penetrating solutions (Pl. IV. Fig. 1).

The dispersion halo of sphalerite grains around ore-veins is of common occurrence in the Trzebionka Mine (see B o g a c z et al. 1973 b). However, in the region of Olkusz such halo is surprisingly rare.

The filing of fractures shows commonly banded, fine crystalline incrustation of colloform sphalerite. This sphalerite is here indicated as "colloform" sphalerite I. There is a continuous passage between the sphalerite impregnations and replacements of the fracture walls on one side and the colloform sphalerite on the other. Such passage points to a continuous process of mineralization (Pl. IV. Fig. 2). In some instances, however, between the crystalline and colloform sphalerite there occur isolated grains of the second generation of galena (galena II) — (Pl. IV. Fig. 2). In most instances, crystals of the galena II are well developed. In Pl. I. Fig. 2 the galena II occurs directly above the first, dark band of the "colloform" sphalerite. Occasionally the crystals of the galena II may coalesce to form a more or less continuous crustification layer (Pl. V.). In this connection it should be noted that all bands of the colloform sphalerite shown in Pl. V. are interpreted as belonging to the first generation of colloform sphalerite. The laminae which make up bands in question are predominantly light-colored with the exception of those which occur in the uppermost parts of these bands. Parenthetically, it may be noted that the "colloform" sphalerite I is partly replaced by the galena III (see below).

The colloform sphalerite I and the galena II form chiefly ore structures indicative of deposition in rock openings [1]. Such structures are particularly well developed around dolomite fragments in breccias where the previously indicated sulfides fill entirely or, more commonly, partly the interfragmental voids.

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[1] It is to be noted that the colloform sphalerite I and galena II are frequently replaced by the galena III.

Sub-stage "B". Minerals of this sub-stage are: sphalerite IV, galena III and pyrite-marcasite IV. They tend to occur together, most commonly in form of vein deposits filling short fissures, 2—5 meters long and a few centimeters wide. Occasionally such ore veins may cross to produce a net-like pattern and may pass into the ore-lined breccias proper (Pl. VI. Fig. 1).

The sulfides belonging to the sub-stage "B" are characteristically associated with wall-rock alterations such as bleaching and granular disaggregation of the host dolomite ("sandification"). (Pl. VI. Fig. 1 and 2). These alterations provide the most readily available criterion for recognition of the sub-stage "B". The zone of such alterations varies from a few milimeters to a score of centimeters. The intensity of disaggregation is also variable.

Chemical analyses show that the CaO content in the disaggregated and bleached dolomite is slightly less (a few weight percent) than that of the unaltered host rock whereas the MgO content remains unchanged.

The alterations previously described are presumably analogous to those reported from other ore deposits e.g. from the Thompson ore body by Heyl et al, 1964 and from the Flat Gap ore body in East Tennessee by Hill et al, 1971.

Where minerals of the sub-stages "A" and "B" are in contact with each other the galena III commonly replaces the colloform sphalerite I and the galena II. This process is clearly visible in Pl. V. in which the galena between the first and the second band of the colloform sphalerite I is thought to be the replacing mineral [2]. Evidence for replacement is provided by metasomatic contacts between the two sulfides and by the relicts of sphalerite in the galena. In places the process of replacement is so advanced that only such relicts bear a record of it (Pl. VII. Fig. 1). It should be added that the galena III may also replace the galena II as it is shown by Pl. VII. Fig. 2.

3M — third stage of mineralization. Minerals of this stage occur chiefly in the matrix of breccias. Such matrix consits of disaggregated dolomitic grains and dolomite fragments (Pl. VIII. Fig. 1) [3]. The matrix contains a certain amount of not yet identified clay minerals. It also contains detrital fragments of minerals formed during he preceding stages of mineralization (Pl. II. Fig. 1). The matrix shows irregular distribution of components and some sort of banding indicative of plastic deformations (Pl. VIII. Fig. 2). It may inferred that originally the matrix was, to a considerable degree, a plastic dolomitic mud' saturated

[2] The present writer is wholly aware of the fact that somewhat similar occurrences may be and frequently are interpreted in different way (Rödder 1968, Kutina 1957, Harańczyk 1969).

[3] The breccias here described bear a resemblance to the so called "chemical breccias" discussed by Sawkins (1969).

with ore-bearing solutions. The presence of dolomitic grains is explained by granular disaggregation processes of the ore-bearing dolomite consequent upon and associated with the emplacement of sulfides. The accumulation of such dolomitic grains in breccias is a depositional processes analogous to that described by Bogacz et al (1973 a).

The sulfides of the third stage include: sphalerite V, colloform sphalerite II, pyrite-marcasite V and galena IV.

The sphalerite is by far the most common sulfide. It occurs in form of grains which, together with the dolomitic grains, constitute a considerable part of the matrix. However, in the absence of euhedral crystals, the origin of this sphalerite can be interpreted in two ways one of which implies a clastic derivation. In fact, it is not possible to determine with assurance how much of the sphalerite grains resulted from mechanical deposition and was derived from products of earlier mineralizations and how much was precipitated from solutions penetrating the matrix. Evidence for the second alternative (precipitation), admittedly a circumstancial one, is based upon the fact that during the replacement of ZnS by PbS, discussed in the preceding section, considerable quantities of zinc ions must have been released. Accordingly it is not unlikely that the zinc ions freed during the replacement processes went into solutions and then, under suitable conditions, were reprecipitated to form the sphalerite V.

While the origin of sphalerite in the matrix is liable to be interpreted in more then one way, there seems to be little doubt that the pyrite-marcasite V and the colloform sphalerite have grown in the matrix. Evidence for this is provided by abundant spheroidal and kidney-shaped nodules of these sulfides showing radial and concentric structures.

The colloform aggregates of the colloform sphalerite II from Pl. VIII. Fig. 2 are suspended in the matrix and could have grown only in place, in a soft medium (such a process is analogous to that described by Bogacz et al 1973 a, in connection with the galena crystals growing freely in a disaggregated mass of dolomite grains, i.e., in "sanded dolomites").

The galena IV occurs in small grains within the lower laminae of the "colloform" sphalerite II. The mutual relationships between these two sulfides indicate the essentially simultaneous crystallization of both minerals. Concluding our discussion on the third stage of mineralization it should be added that in contrast to the ubiquitous pyrite-marcasite V, the "colloform" sphalerite II and the associated galena IV are only rarely encountered in the matrix of breccias.

4M — fourth stage of mineralization. This stage is represented by one mineral only, the marcasite. This mineral incrusts the rock fragments produced by the third stage of brecciation and encloses the minerals formed during the second and third stages of mineralization (Pl. IX. Fig. 1). Finally, the colloform aggregates of this marcasite are commonly found in empty, interfragmental voids of the breccias.

5M — fifth stage of mineralization. The only mineral of this stage is calcite. It is the latest in the paragenetic succession of the ores here discussed and cements or encloses the products of all the preceding stages of mineralization and brecciation. In breccias, the calcite fills the voids which were not filled by the products of earlier mineralizations. Here the calcite is frequently associated with the marcasite of the stage IV. It fills the central parts of marcasite-lined fractures. Examination with ultraviolet lamp reveals two generations of the calcite: the milky and the red-violet one. These two generations differ presumably in trace elements. Hovever, nothing definite is known as to this question.

DEVELOPMENT OF ORE BODIES

The paragenetic order previously discussed allows to interpret properly the ore bodies from Olkusz in their three-dimentional aspects and provides the key to the intriguing question of the development of these bodies in time and in space.

The ore bodies in question may and do differ in some respects (e. g. mineral content, differences in meso- and macro-ore structures of the body) but they reveal everywhere the same paragenetic order of crystallization. In fact the observed differences between the various ore bodies are largely due to the fact that the development of the ore bodies was arrested at different stages of mineralization. This can best be considered with the aid of selected examples of ore bodies.

Fig. 3/1 exemplifies the cross-section through a typical solution-collapse breccia in the Olkusz Mine. This breccia originated during the first stage of brecciation (1B). The interfragmental voids and open fractures that extend into the unbrecciated host dolomite are filled with sulfides belonging to the second stage of mineralization (2M). Within the breccia proper, these sulfides incrust and cement the rock fragments. In fractures, the sulfides form symmetric lyering to produce typical ore veins sometimes of considerable horizontal extent. The minerals of the second stage have filled all the voids produced during the first stage of brecciation. Accordingly the resulting ore body reflects exactly the shape of the breccia body formed during the second stage of brecciation. From this one can infer that after the emplacement of sulfides belonging to the second stage (2M) no further brecciation occurred. The development of the ore body was thus arrested at the second stage of mineralization.

Fig. 3/2 exemplifies the third stage of brecciation (3B). The breccia structure depicted is entirely enclosed in the unbrecciated host dolomite. The bottom of the structure is a sharply defined solution surface representing the original cave floor. The sulfide mineralization is confined to the central part of the breccia structure and is notably absent in the left

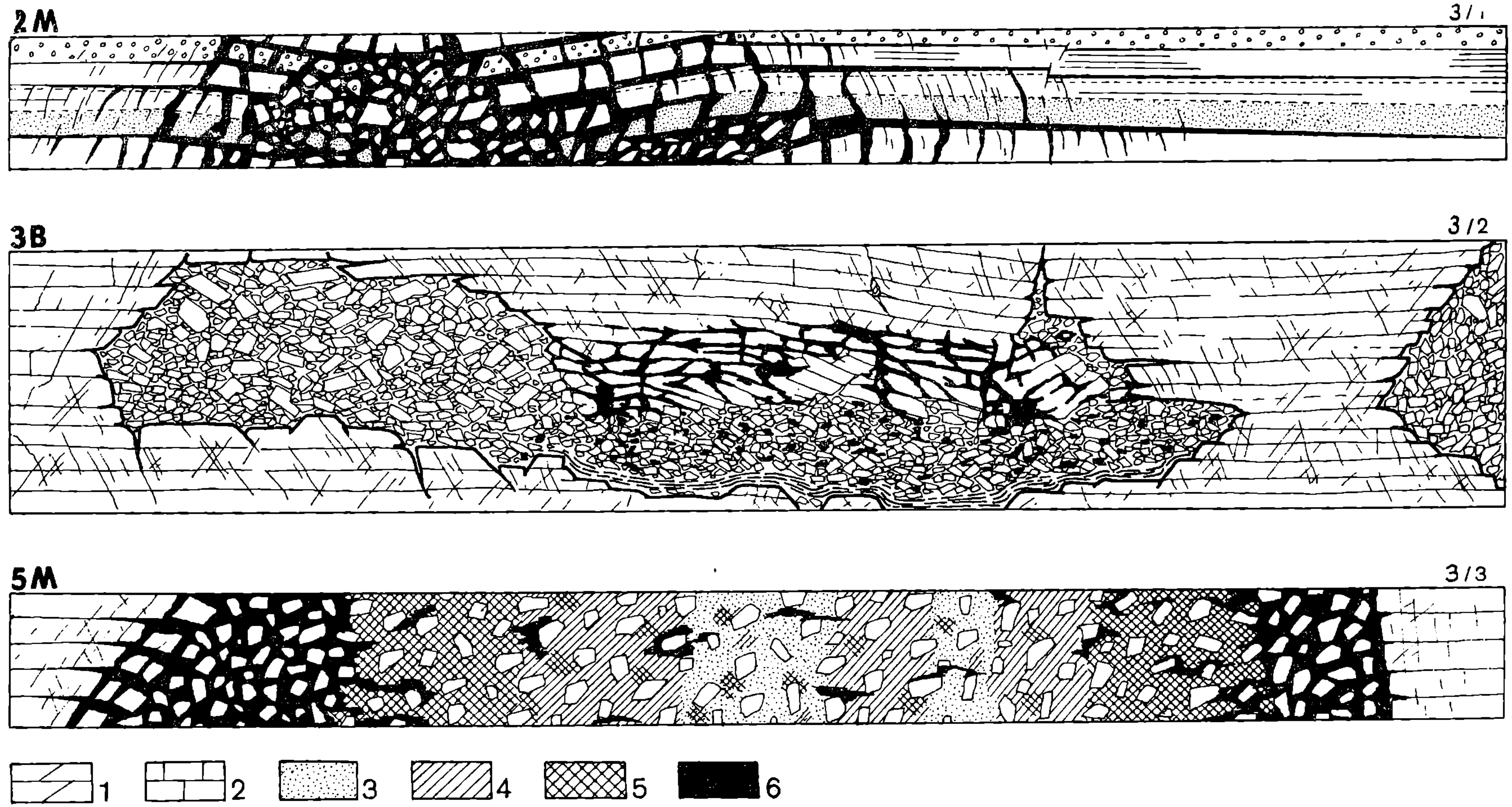

Fig. 3. Examples of ore nests representings different stages of development. 3/1 — 2M — breccia structure cemented by products of second stage of mineralization (dark shades). 3/2 — 3B — breccia formed during third stage of brecciation. It contains products of second and third stages of mineralization in form of clastics. These clastics (black) tend to concentrate within the uncemented breccias (lower centre). 3/3 — 5M — breccia structure formed during the last stage of development. Breccia contains clastic products of all earlier stages (1M, 2M, 3M, 4M)

Fig. 3. Przykłady gniazd złożowych reprezentujących różne stadia rozwoju. 3/1 — 2M — struktura brekcjowa, w której wolne przestrzenie zostały wypełnione produktami drugiego stadium mineralizacji (czarny kolor). 3/2 — 3B — brekcja uformowana w trzecim stadium brekcjowania. Zawiera zbrekcjowane produkty drugiego i trzeciego stadium mineralizacji (czarne). Okruchy gromadzą się w obrębie nie scementowanej brekcji. 3/3 — 5M — struktura brekcjowa przedstawiająca ostatnie stadium rozwoju. Brekcja zawiera okruchy minerałów będących produktami wszystkich stadiów wcześniejszych (1M, 2M, 3M, 4M)

part although both parts appear to have been formed simultaneously. Presumptive evidence for simultaneity is provided by the fact that both, the mineralized and unmineralized portions are underlain by the same solution surface. The sulfides resident in the breccia under consideration belong exclusively to first, second and third stage. The sulfides of the second and third stage are chiefly concentrated in the upper portion of the mineralized breccia. Here the rock fragments match, to a considerable degree, their apposed surfaces and, for the most part, either retain their original horizontal position or are only slightly rotated. Significantly, in the chaotic array of tumbled blocks which underlie the above mentioned mineralized zone the sulfides of the second and third stage are already found as clastics. Inasmuch as the products of younger mineralization stages are totally absent it is concluded that the development of the breccia structure shown in Fig. 3/2 was arrested after the third stage of brecciation.

The structure exemplified in Fig. 3/3 represents the fifth stage of mineralization (5M). Among the chaotic rubble of the breccia there are ore fragments representing the four preceding mineralization stages. These ore fragments are distributed in such a way that the sulfides representing the earlier stages tend to concentrate in the central part of the breccia section while those belonging to younger stages occupy progressively more peripherial parts. Significance of such distribution will be discussed in the following section. For the purpose of the present consideration it is necessary to say that the calcite which is the product of the fifth stage of mineralization has not been affected by brecciation. The same situation exists in the remaining ore breccias in the study area. This means that the fifth stage of mineralization is, at the same time, the last one arrived at in the course of development of the mineralized breccias in the Olkusz region.

HORIZONTAL ZONALITY OF ORES

The breccia structure whose vertical section is shown in Fig. 3/3 has been selected for detailed studies on the zonal pattern of mineralization stages in a horizontal section. The results of these studies are illustrated by Fig. 4. The figure shows the horizontal distribution of minerals belonging to different stages of mineralization projected on a horizontal plan of the breccia body [4]. The most striking feature brought out in this figure is a distinct concentric zonation of mineralized areas.

The products of the second stage of mineralization (2M) occupy three isolated fields differing in size with the most extensive one located in the

[4] Not included are only the products of the first stage of mineralization which are uniformly distributed throughout the whole mass of the ore-bearing dolomite.

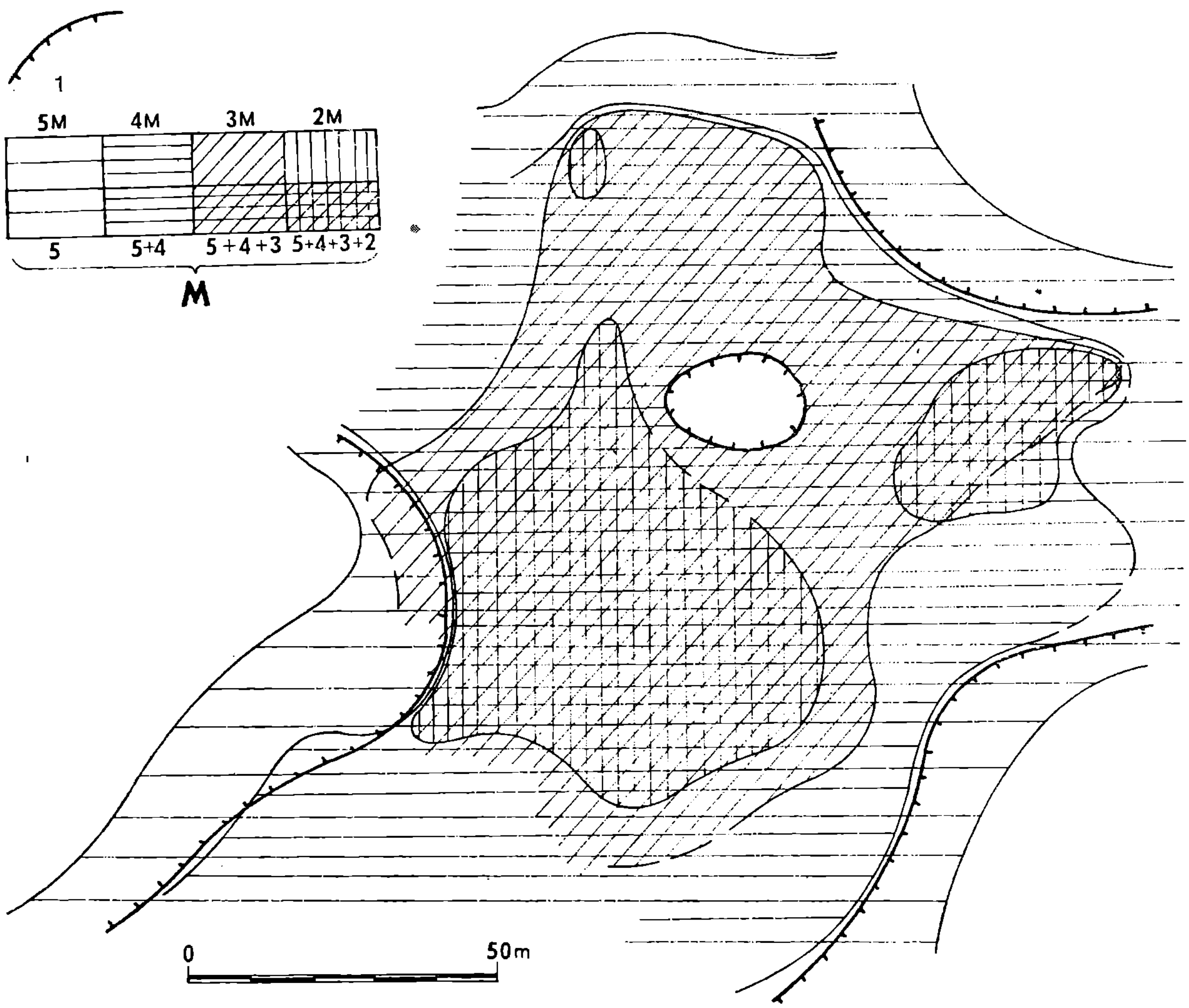

Fig. 4. Horizontal section of breccia structure showing distribution of products of various stages. 1 — breccia boundary. Design in rectangular inset (upper left) indicated by 2M, 3M, 4M, 5M correspond to different mineralization stages; numbers 5+4, 5+4+3 and 5+4+3+2 correspond to superposition of different stages

Fig. 4. Przekrój poziomy struktury brekcjowej przedstawiający rozmieszczenie produktów mineralizacji poszczególnych stadiów. 1 — granica brekcji. W ramce oznaczona przez 2M, 3M, 4M, 5M szrafura odpowiada różnym stadiom mineralizacji. Cyfry 5+4, 5+4+3, 5+4+3+2 oznaczają główne przypadki nakładania się stadiów mineralizacji

central part of the breccia structure. The area occupied by the products of the third mineralization (3M) is greater than that of the second stage and encloses all the three fields in which the mineralization occurred earlier. The area covered by the fourth mineralization is still greater and its boundaries coincide roughly with those of the breccia structure. The last mineralization (5M) is by far the most extensive and spreads beyond the actual boundaries of the breccia structure. Consequently, the areas covered by different stages of mineralization, as seen in plan view, are arranged in a genarally concentric pattern with the youngest stages covering progressively more extensive areas.

The distribution pattern of ores as revealed by investigations of horizontal cross-sections points to a close genetic relationship between the spread of mineralization and the development of solution-collapse breccias. It may well be recalled at this place that the formation of collapse breccias by roof failure is always an intermittent process, regardless whether the dissolution itself is inttermittent or not. The failure en masse occurs whenever the rock resistance is surpassed by vertical forces that tend to move the ceiling of a cavern into the opening below. Such massive breakdown may be temporarily or permanently arrested by the jamming of broken blocks. It may, however, start again whenever these blocks are removed or reduced by dissolution and a new cavern, sufficiently extensive, is restorted underneath the brecciated structure. Thus the spatial development of collapse breccias may be visualized as proceding stepwise and "in jumps" affecting progressively more and more extensive areas.

The sulfide mineralization of the breccia structures previously discussed was essentially that of cavity filling. One can envision that mineralization processes alternated with breakdown of roofs and walls of cavities. It is also conceivable that the mineralization and brecciation overlapped. Whatever was the relationship between these two processes it seems evident that the breakdown of earlier caves created new voids which then have served as receptacles for ores. Consequently, the area covered by any successive mineralization coincides with the area affected by the preceding breakdown. This, in turn, explains the observed concentric zonation of mineralization products and points to a close genetic relationship between the sulfide mineralization and brecciation.

As already noted the length of time intervals between the stages of mineralization and brecciation is not known. Given a sufficiently long time period for the whole process of formation and development of the ore breccias in the Olkusz area it is not at all unlikely that the composition of mineralizing solutions was subject to changes.

There is also a possibility that the mineralizing solutions were responsible for cavity making and solution-collapse processes. This idea has been advanced by Bogacz et al. (1970) and led them to interpret the ore-lined cavities and collapse breccias in terms of "hydrothermal karst" phenomena. It should be recalled, however, that mineralization is not uniformly distributed and that there are breccias which are notably barren [5]. Such barren breccias might have resulted from dissolution by waters differing in composition from those emplacing the ores. Admittedly, such assumption does not debar the possibility that the solutions responsible for the formation of unmineralized parts of the breccia bodies were hydrothermal.

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[5] This situation is very similar to that reported from the East Tennessee deposits where dissolution breccias are invariably features of the ore deposits, but „these features are extensively developed throughout the region without accompanying ore" (Hoagland et al. 1965, p. 708).

RANDOM DISTRIBUTION OF ORES

As it is shown in Fig. 4, within the breccia bodies there are zones in which the products of all mineralization stages may occur. A close investigation of such zones shows that the distribution of various mineralization products is highly irregular. In some places, brecciated and unbrecciated products of one specific stage are clustered together, elsewhere there is a mixture of all possible mineralization products and fragments of multiple breccias (i.e. fragments that are composed of indurated fragments of earlier brecciation). Of common occurrence is also the superposition or direct contacts between minerals which are separated in paragenetic succession. For instance the products of the fourth stage may be directly superimposed upon those of the second stage without any intermediate minerals. This as well as the lack of any visible regularity in distribution of fragments is consistent with what is known about collapse breccias and further reinforces the interpretation here presented. The collapse processes are to a considerable degree controlled by random distribution of voids that serve as routes of underground circulation. Such processes are also controlled by random distribution cavities subjected to roof failure.

THREE-DIMENSIONAL PICTURE OF THE ORE-BODY REPRESENTATIVE FOR THE OLKUSZ MINE

In the preceding chapters some representative sections through ore bodies of the Olkusz Mine have already been given (chiefly in order to examine the steps of development of the ore breccias). Examples of sections showing the same or similar character may be multiplied, but this would merely increase details without adding materially to our knowledge. The main point demanding attention will be now the three-dimensional picture of a typical ore-body which may be regarded as representative for the Olkusz region.

The three — dimensional picture here discussed has been constructed from many partial sections exposed in mine workings. It is not out of place to mention that this part of our considerations is a direct continuation of the earlier paper on breccias from the Olkusz Mine (S a s s-G u s t k i e w i c z, 1974) and leans on the observations already published.

Let us begin with a general picture of the distribution of mineralized breccias in the study area. Fig. 5-I shows a plan view of the ore breccias and Fig. 5-II the position of some selected vertical cross-sections exposed along an arbitrarily drawn line A—A. Attention is focused on the fact that the bottom of the breccia structures in three different sections does not lie on the same level although the bedding in the host dolomite is almost horizontal.

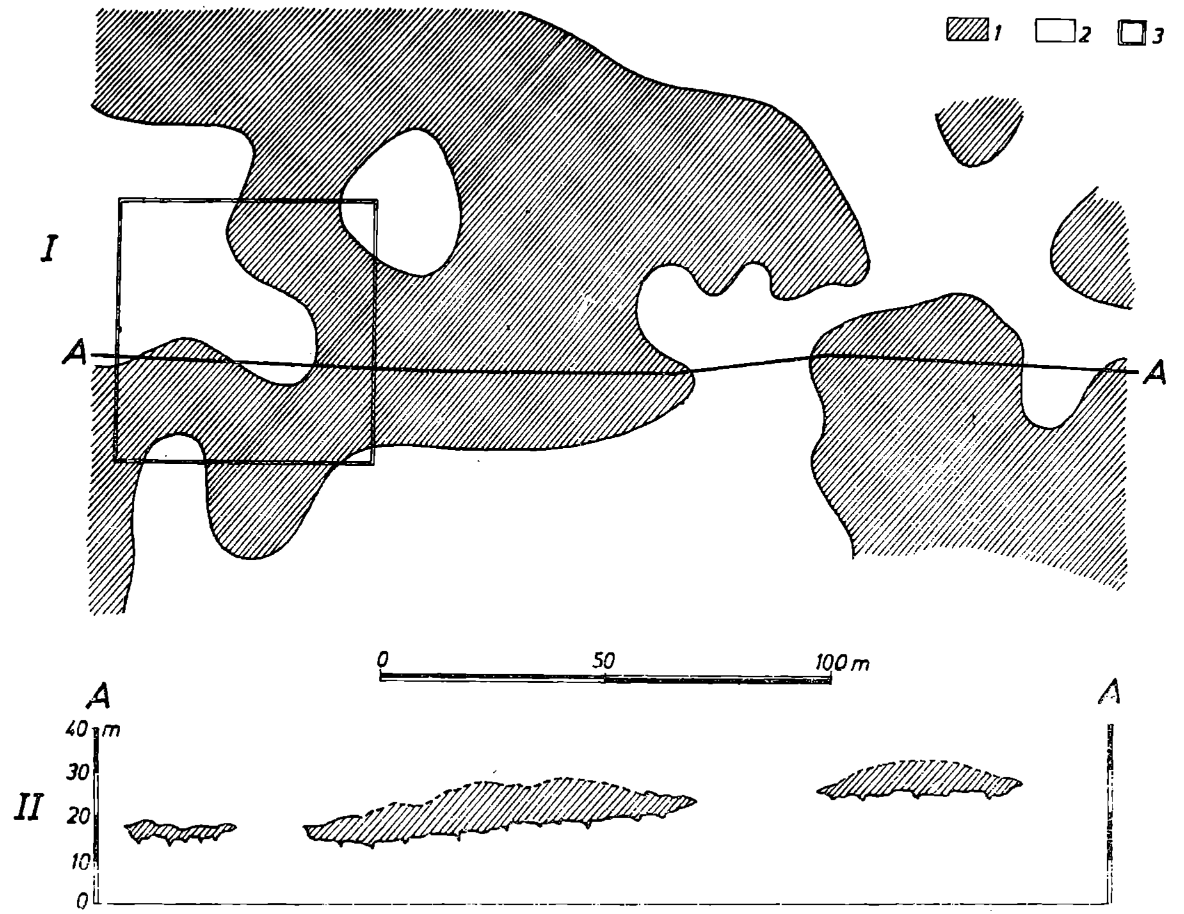

Fig. 5. Horizontal plan view of ore nests (I). Vertical section along line A—A (II). 1 — breccia; 2 — undisturbed ore-bearing dolomite; 3 — area ilustrated by cross-section — fig. 6

Fig. 5. Kontury gniazd brekcjowych w rzucie poziomym (I). Przekrój pionowy wzdłuż linii A—A (II). 1 — brekcja; 2 — nie zaburzone dolomity kruszconośne; 3 — obszar przedstawiony na przekrojach — fig. 6

The area delineated by a square inset in Fig. 5—I (left) has been selected for construction of the three-dimensional picture shown in Fig. 6 (compare also 3/2). The partial sections illustrated by this figure are largely self-explanatory and need only few comments.

The sections presented exhibit certain diversity in details, but the general character of the ore body is very much like in all the profiles depicted. Attention is again directed to the fact that the sulfide ores in breccias are by no means uniformly distributed and certain parts of the breccias are barren.

Fig. 6/B shows a generalized representative vertical section through the ore body. In this section the following zones may be differentiated:

I — zone of undisturbed ore-bearing dolomite,

II — zone in which galena is replacing the dolomite,

III — zone in which galena and "colloform" sphalerite are deposited in fractures,

IV — zone of breccias containing fragments of ore minerals. At the base of this zone there are stratified ores (see below),

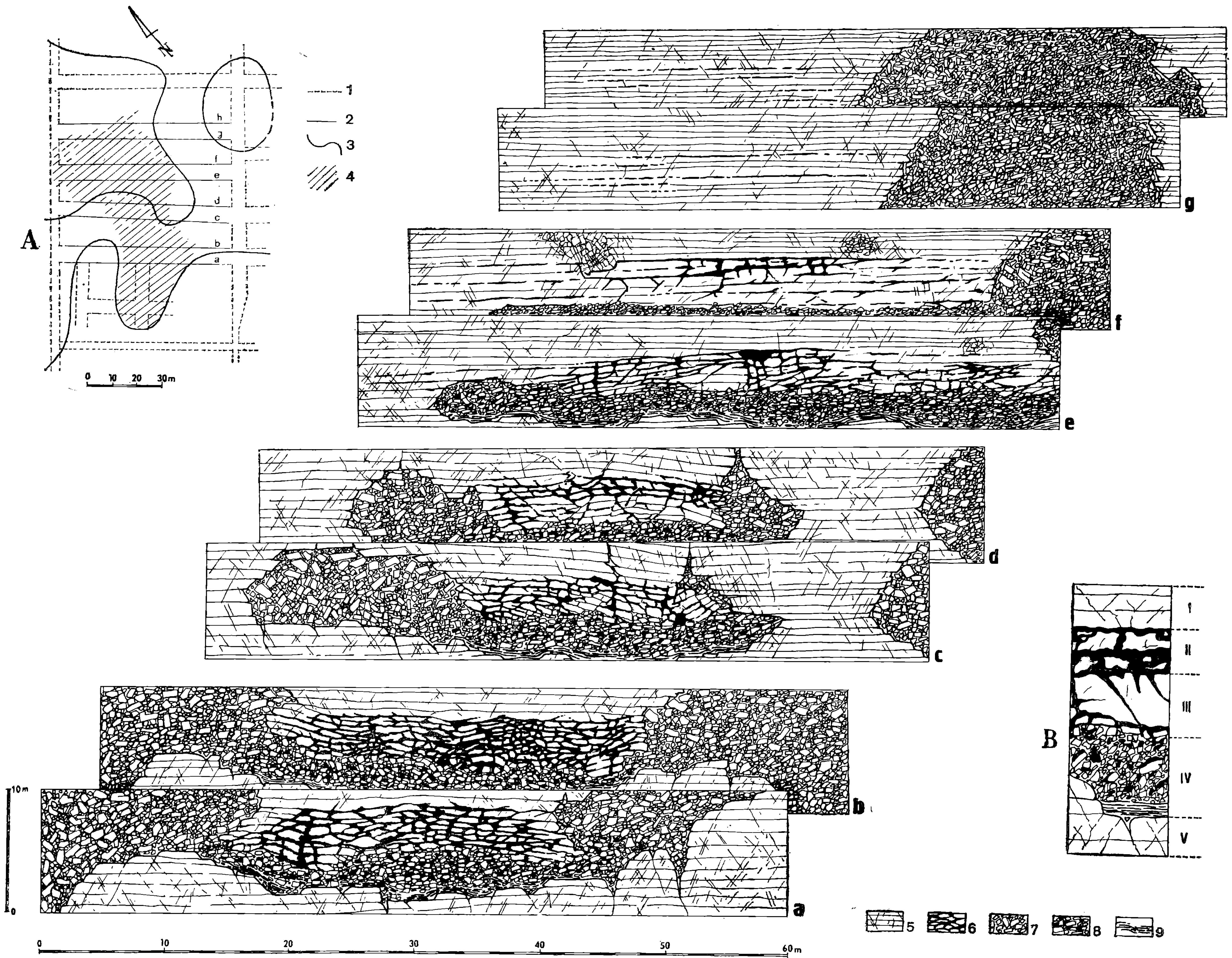

Fig. 6. Partial cross-sections of ore body in breccias. A — plan view showing localization of sections a, b, ... h and contours of breccia bodies; B — generalized vertical sections of ore body (explanations in text); 1 — mine workings; 2 — mine workings corresponding to sections (a, b, ... h) shown in figure; 3 — contours of breccia bodies; 4 — mineralized areas; 5 — ore-bearing dolomite; 6 — accumulations of ores; 7 — uncemented barren breccias; 8 — uncemented breccias containing ores as clastics; 9 — stratified ores

Fig. 6. Przekroje przez gniazdo złożowe w brekcji. A — sytuacja przekrojów a, b, ... h oraz kontur brekcji na planie; B — zgeneralizowany profil złoża (wyjaśnienia w tekście); 1 — wyrobiska górnicze; 2 — wyrobiska przedstawione na przekrojach a, b, ... h; 3 — granica brekcji; 4 — zasięg mineralizacji; 5 — dolomity kruszconośne; 6 — skupienia rud; 7 — niescementowane płone brekcje; 8 — niescementowane brekcje zawierające okruchy rud; 9 — rudy laminowane

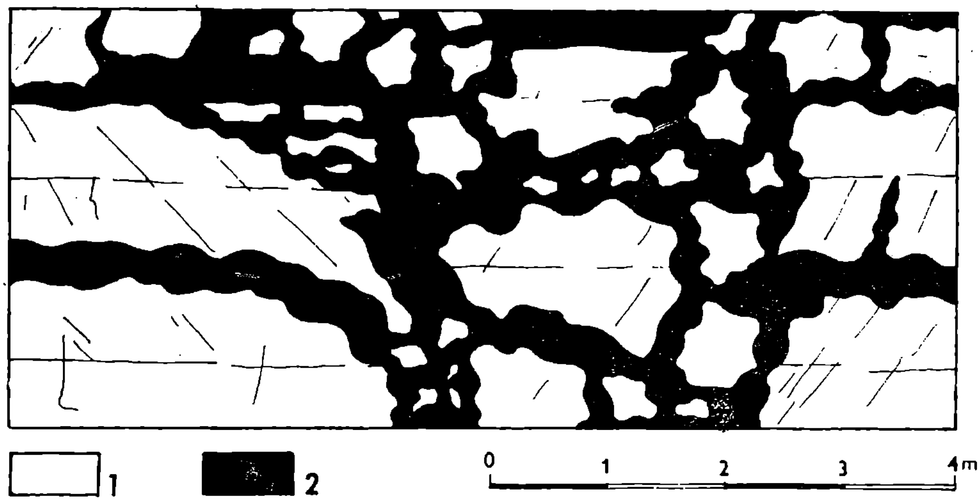

Fig. 7. Replacement structures observed in II zone of generalized profile shown in fig. 6 B. 1 — ore-bearing dolomite; 2 — galena III

Fig. 7. Struktury zastępowania obserwowane w II strefie (porównaj profil — fig. 6 B). 1 — dolomit kruszconośny; 2 — galena III generacji

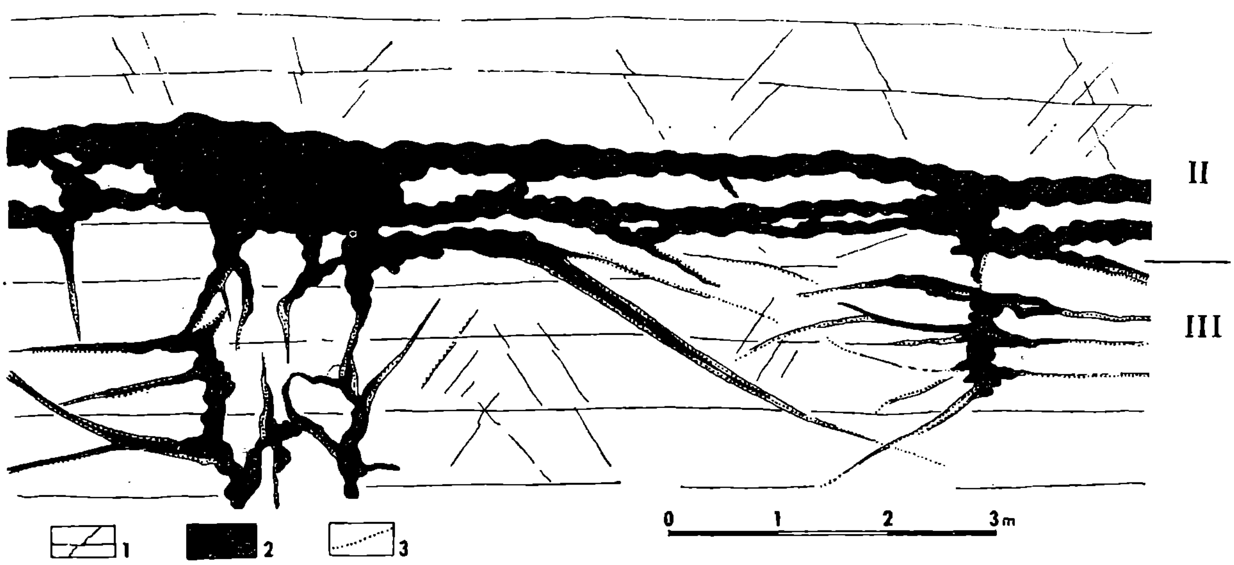

Fig. 8. Replacement structures in zone II and cavity-filling structures in zone III (compare fig. 6 B). 1 — ore-bearing dolomite; 2 — galena II and III; 3 — colloform sphalerite I

Fig. 8. Przykład struktur zastępowania w II strefie oraz wypełnienia wolnych przestrzeni w strefie III (patrz profil B na fig. 6). 1 — dolomit kruszconośny; 2 — galena II i III generacji; 3 — blenda I

V — zone of undisturbed dolomite with a distinct karst solution surface at the top.

The zones differentiated occur repeatedly in various section and tend to appear in the same order although not everywhere is the complete succession recognizable. Only three of the zones listed require additional comments.

Zone II is characterized by structures indicative of replacement of the ore-bearing dolomite by sulfides. Fig. 7 may be regarded as representative of the zone II. It shows the galena III replacing the ore-bearing dolomite to form a pattern of irregular replacements vein and relics of the dolomite enclosed in the guest mineral. Enclosed in the galena are also relics of „colloform" sphalerite. The sphalerite is locally present along the metasomatic contacts between the dolomite and galena. It should be added that the replacement galena may form accumulations of considerable dimensions.

Essential feature of the zone III as well as its relationship to the overlying zone II are shown in Fig. 8. The sulfides of the zone III tend to occur as fracture-filling ore veins. Such veins consist of the galena II and III contain also the colloform sphalerite I (Pl. IX. Fig. 2). Proceeding upwards, the amounts of the colloform sphalerite in veins decreases progresively and in the uppermost part of the zone III only insignificant relics of this sulfide are present.

Typically, the zone IV consist of uncemented breccias composed of dolomite and ore fragments. This zone contains also certain amounts of not yet identified clay minerals (such minerals tend to occur in the upper part of the zone) and abundant sulfides showing skeletal structure (Pl. X. Fig. 1). Such structure consist of the colloform sphalerite I and the galena II. In places these sulfides are replaced by the galena III (Pl. VII. Fig. 2).

In the lower parts of the zone under consideration there are accumulations of brunckite and immediately above the solution surface, the accumulations of stratified ores. These latter vary in thickness from a few centimeters to about 1,5 m. The ores in question consist of very fine dolomite particles and sphalerite grains. The stratified ores contain also spherical aggregates of pyrite and marcasite which apparently have grown in soft not yet consolidated mass of the stratified ores.

The stratified ores represent typical internal cave deposit and have been more comprehensively dealt with in an earlier paper (Sass-Gustkiewicz, 1975).

DISPERSION AUREOLE OF SULFIDES AROUND ORES

In the Olkusz Mine the dispersion aureole of sulfides around the ore-filled voids is rarely encountered. In most instances the boundary between the ore and the host dolomite is sharp. Such relationship is shown by veins illustrated in Fig. 3/1. These veins belong to the second stage of mineralization and trend parallel to the bedding. Microscopic examination of the adjacent dolomite shows everywhere the same picture of uniformly disseminated grains of pyrite, marcasite and sphalerite. The density of such grains does not change, irrespectively of distance from ore veins. There seems to be no obvious relationship between these sulfides and the order of deposition in the veins. The same holds true for small discontinuous concentrations of Zn, Pb and Fe sulfides set in pores, vugs and minute fractures. Such discontinuous concentrations are similar to those discussed in connection with the first stage of mineralization and appear to be uniformly distributed throughout the whole mass of the ore-bearing dolomite. In summary, the ore veins containing products of the second stage of mineralization are not surrounded by an aureole of sulfides showing any direct relationship to the content of these veins.

ORE STRUCTURES

Fig. 9 shows the list of ore structures recognized in the Olkusz ore body. The arrangement of ore structures into groups or classes has been partly based upon the classification suggested by Y o u s h k o (1966). The structures differentiated fall into two principal classes: "syngenetic" and "epigenetic" whereby the term syngenetic is applied to indicate an essen-

MORFOLOGIC TYPE	„SYNGENETIC" SIMULTANEOUSLY WITH DOLOMITIZATION	E P I G E N E T I C		
		CAVITY--FILLING	METASOMATIC REPLACEMENT	DISAGGREGATION SEDIMENTATION LEACHING
SHAPELESS	DISSEMINATED	DISSEMINATED	DISSEMINATED IMPREGNATED MASSIVE	
LAMINAE BAND		CRUSTIFIED BANDED	LAMINATED	LAMINAE
FRAGMENT		BRECCIATED		FRAGMENTAL
CEMENT		BRECCIATED		CONGLOMERATIC
VEINS		VEINED	VEINED	
DRIPSTONES		COLLOFORM		
DENDRITE		SKELETAL		
BOXWORK STRUCTURE				CAVERNOUS

Fig. 9. Types of ore-structures

Fig. 9. Rodzaje struktur rudnych w złożu

tial simulataneity of ores with the formation of the ore-bearing dolomite. This dolomite is, however, regarded as epigenetic with respect to the adjacent strata. Consequently, the term "syngenetic" in our classification should not be confused with the same denomination currently used to indicate ores that are syn-sedimentary with respect to the host rock.

The "epigenetic" structures include: 1. cavity-filling ores, 2. replacement ores and 3. ores that have resulted from a variety of processes such as granular disaggregation, leaching, solutional and mechanical removal of carbonates and internal sedimentation (granular disaggregation and leaching are the predominant processes). Other terms are used in the meaning generally accepted in ore geology and need no additional comments.

Emphasis is laid on the fact that the ore-structures under consideration correspond to primary sulfide ores. Not included are the structures consequent upon weathering and subsequent transformation of such primary ores.

CONCLUDING REMARKS

Summation of evidence derived from the study of the Olkusz ores leads to the following conclusions:

1. the ores occur exclusively in the ore-bearing dolomite,
2. the ore-bearing dolomite is of epigenetic origin,
3. the dolomite contains finely dispersed sulfides (sub-stage A, 1M) and these are essentially simultaneous with the formation the dolomite,
4. the commercial ores are confined to dolomitic braccias. However the sulfide mineralization is not uniformly distributed throughout the brecciated zones,
5. the breccias are of solution-collapse origin and the overall character of these breccias clearly excludes tectonic origin,
6. the formation of breccias was consequent upon the solutional removal of carbonates, whereby the solution processes were concentrated along the lower metasomatic boundary of the ore-bearing dolomite,
7. the Olkusz ore body was formed in 5 successive stages of mineralization alternating and overlapping with four stages of brecciation,
8. the same sequence of mineralization and brecciation processes is recognized in all ore-nests of the study area. The differences between such nests result from the fact that the development of various ore nests might have been arrested at different stages of brecciation and mineralization,
9. there is a distinct zonal arrangement of mineralization products in horizontal sections through the breccia bodies. Such arrangement reflects the outward spread of brecciation and mineralization processes,
10. mineralogical composition of ores is very simple and the order of deposition is such as shown in Fig. 2,
11. the chief ore-forming processes were: 1. cavity-filling, 2. replacement and 3. leaching, desaggregation and internal sedimentation,
12. the emplacement of ores was associated with wall-rock alteration such as "sandification" and bleaching of the dolomite,
13. the Olkusz ores occur in form of various ore structures listed in Fig. 9,
14. the overall character of the ore bodies clearly shows that the development of these bodies was intimately linked with karstic processes.

From the foregoing considerations it appears that any acceptable interpretation of ore bodies in the Olkusz Mine must assume significant dissolution of the dolomite and formation of underground karst cavities. The formation of such cavities initiated solution-collapse processes proceeding alternately and concurrently with deposition of sulfides in voids. The deposition of sulfides was brought about by precipitation from supersaturated solutions, replacement and by mechanical deposition (stratified ores). The most important factor in the formation of the ore-bodies was the process of repeated brecciation. Such brecciation resulted in the formation of voids which then have served as receptacles for ores. The newly formed voids contributed to the further spread of mineralization by creating new gangways and routes for ore-bearing solutions.

Acknowledgement

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STRESZCZENIE

Praca niniejsza jest trzecią z serii artykułów przedstawiających wyniki badań złoża cynku i ołowiu kopalni Olkusz i stanowi z nimi zamkniętą całość (poprzednie 1974, 1975). Jej celem jest dyskusja sukcesji mineralnej w obrębie brekcji zawałowych, rozpoznanie stopnia rozwoju poszczególnych ciał rudnych oraz przedstawienie trójwymiarowego obrazu części złoża, która jest reprezentatywna dla Olkusza. Sytuacja geologiczna i jej bibliografia została przedstawiona we wcześniejszych pracach, z których jedna dostarcza dowody na zawałowy, wywołany rozwojem krasu w jej spągu, nietektoniczny charakter brekcji. W brekcjach lub w najbliższych otaczających ją skałach występuje cała mineralizacja o charakterze ekonomicznym, jednakże obok brekcji zmineralizowanych występują w złożu również brekcje całkowicie pozbawione, makroskopowo widocznej, mineralizacji. W obrębie brekcji zmineralizowanych obserwować można cały szereg różnorodnych struktur rudnych (fig. 9). Najliczniejsze z nich to struktury brekcjowe, różniące się składem mineralnym okruchów i spoiwa (fig. 1). Na podstawie grupy struktur, w których minerały młodsze spajają i otaczają okruchy minerałów starszych (Pl. I i II), wyróżniono pięć kolejnych stadiów mineralizacji występujących na przemian z czterema stadiami brekcjowania. Poszczególne stadia mineralizacji cechuje odmienny skład zespołów mineralnych i charakterystyczny zespół struktur rudnych. Ilość minerałów kruszcowych w złożu jest niewielka, a kolejność ich pojawiania się w różnych generacjach została przedstawiona na fig. 2. Występowaniu pewnych grup minerałów towarzyszą zmiany w otaczających dolomitach, przejawiające się jego „spiaszczeniem" i wybieleniem. Ustalenie sukcesji mineralnej stało się kluczem do

rozwiązania problemu rozwoju złoża w czasie i przestrzeni. Poszczególne gniazda złożowe (struktury brekcjowe) różnią się między sobą składem mineralnym i rodzajem mezo- i makrostruktur rudnych, ale ujawniają to samo następstwo mineralizacji. Różnice w ich wykształceniu wynikają z faktu, że rozwój poszczególnych gniazd zatrzymał się w innym stadium mineralizacji lub brekcjowania. Fakt ten został zilustrowany na wybranych przykładach gniazd złożowych przedstawionych na przekrojach pionowych, fig. 3. W pojedynczych gniazdach złożowych, które stanowią równocześnie odrębne struktury brekcjowe, istnieje wyraźna pozioma strefowość mineralizacji, polegająca na koncentrycznym rozkładzie produktów poszczególnych stadiów (fig. 4). Odzwierciedla ona stopniowe rozprzestrzenianie się brekcji zawałowej synchroniczne z rozwojem procesu mineralizacji, który deponował swoje, coraz to inne produkty, w pustych przestrzeniach otwieranych przez postępujący zawał. Przedstawiony na kolejnych przekrojach (fig. 6) fragment złoża oddaje jego trójwymiarowy obraz. Szczególnie godny podkreślenia jest fakt nierównomiernego rozkładu mineralizacji w obrębie brekcji (partie pozbawione mineralizacji). Na wszystkich przekrojach powtarzają się te same elementy profilu pionowego (fig. 6 B). Spąg złoża stanowią nie zaburzone dolomity, których górną powierzchnię cechuje morfologia kresowa. Bezpośrednio na niej spoczywają rudy laminowane i nie scementowane brekcje złożone z okruchów rud i dolomitów. Powyżej znajduje się strefa, w której minerały kruszcowe wypełniają wolne przestrzenie w szczelinach dolomitów, a nad nią strefa, w której galena tworzy charakterystyczne struktury zastępowania dolomitu. Strop stanowią nie zaburzone dolomity. Z obrazu tego można wnioskować, że główne procesy, które doprowadziły do takiego właśnie wykształcenia złoża, to: 1 — wypełnienie wolnych przestrzeni, 2 — metasomatyczne zastępowanie oraz 3 — rozpuszczanie, rozdrabnianie i wewnętrzna sedymentacja. Obserwacje mikroskopowe w dolomitach kruszconośnych otaczających złoże (fig. 3/1) wskazują na brak aureoli rozproszenia mineralizacji wokół ciał rudnych. Podobnie jak w całej masie dolomitów kruszconośnych, wokół żył spotyka się jedynie rozproszoną mineralizację pierwszego stadium, która nie pozostaje w żadnym związku genetycznym z siarczkami budującymi żyły. Z rozważań zawartych w pracy wynika, że każda z interpretacji genetycznych złoża Olkusz musi uwzględnić fakt rozpuszczania dolomitów i tworzenie się pustek krasowych. Powstanie takich pustek inicjuje procesy zawału (brekcjowania) występujące na przemian lub równocześnie z depozycją siarczków w wolnych przestrzeniach. Najważniejszym czynnikiem w formowaniu się złoża był proces powtarzającego się brekcjowania. Nowo utworzone pustki przyczyniały się do rozprzestrzeniania się mineralizacji jako kanały i drogi dla roztworów kruszconośnych. Ogólny charakter złoża jasno wskazuje więc, że jego rozwój jest ściśle związany z procesami krasowymi. Z obecności brekcji nie zmineralizowanych w złożu wnioskować można, że roztwory niosące mineralizację miały inny charakter niż roztwory powodujące rozpuszczanie dolomitów, przy czym te ostatnie mogły być termalne.

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EXPLANATION OF PLATES
OBJAŚNIENIA TABLIC

Plate — Tablica I

Fig. 1. Breccia composed of dolomite fragments (d) cemented by minerals of second stage (2M)
Fig. 1. Brekcja złożona z okruchów dolomitów kruszconośnych (d) spojonych minerałami drugiego stadium (2M)
Fig. 2. Detail of breccia from fig. 1. Minerals of second stage (2M) incrust fragment of dolomite (d)
Fig. 2. Fragment brekcji (fig. 1). Minerały drugiego stadium (2M) tworzą naskorupienia na dolomicie (d)

Plate — Tablica II

Fig. 1. Breccia composed of dolomite fragments (d) and clastic derivates of second stage of mineralization (2M) cemented by minerals of third stage (3M). Stippled line indicated incrustations of marcasite representing fourth stage of mineralization (4M)
Fig. 1. Brekcja złożona z okruchów dolomitów kruszconośnych (d) i minerałów drugiego stadium (2M) spojonych minerałami trzeciego stadium mineralizacji (3M). Kropkami podkreślono naskorupienia markasytu powstałego w czwartym stadium mineralizacji (4M)
Fig. 2. Breccia in which marcasite fragment (4M) are cemented by calcite (5M)
Fig. 2. Brekcja, w której okruchy markasytu (4M) spojone są kalcytem reprezentującym piąte stadium mineralizacji (5M)

Plate — Tablica III

Impregnation and replacement of dolomite by sphalerite III. Figures a—f illustrate progressive decrease in amount grain-size of sphalerite with increasing distance from fracture. Light colored crystals — sphalerite, dark colored — dolomite
Impregnacje sfalerytu III w dolomicie kruszconośnym, występujące w otoczeniu okruszcowanej szczeliny. Na kolejnych fotografiach widać, jak w miarę oddalania się od szczeliny „a" do „f" maleje ilość i wielkość ziarn sfalerytu (jasnoszary) w dolomicie (ciemnoszary)

Plate — Tablica IV

Fig. 1. Sphalerite bands (dark) alternating with dolomite layers (light shades) close to ore-lined francture (top). Fracture filled with colloform sphalerite I (cs) containing galena II (g)

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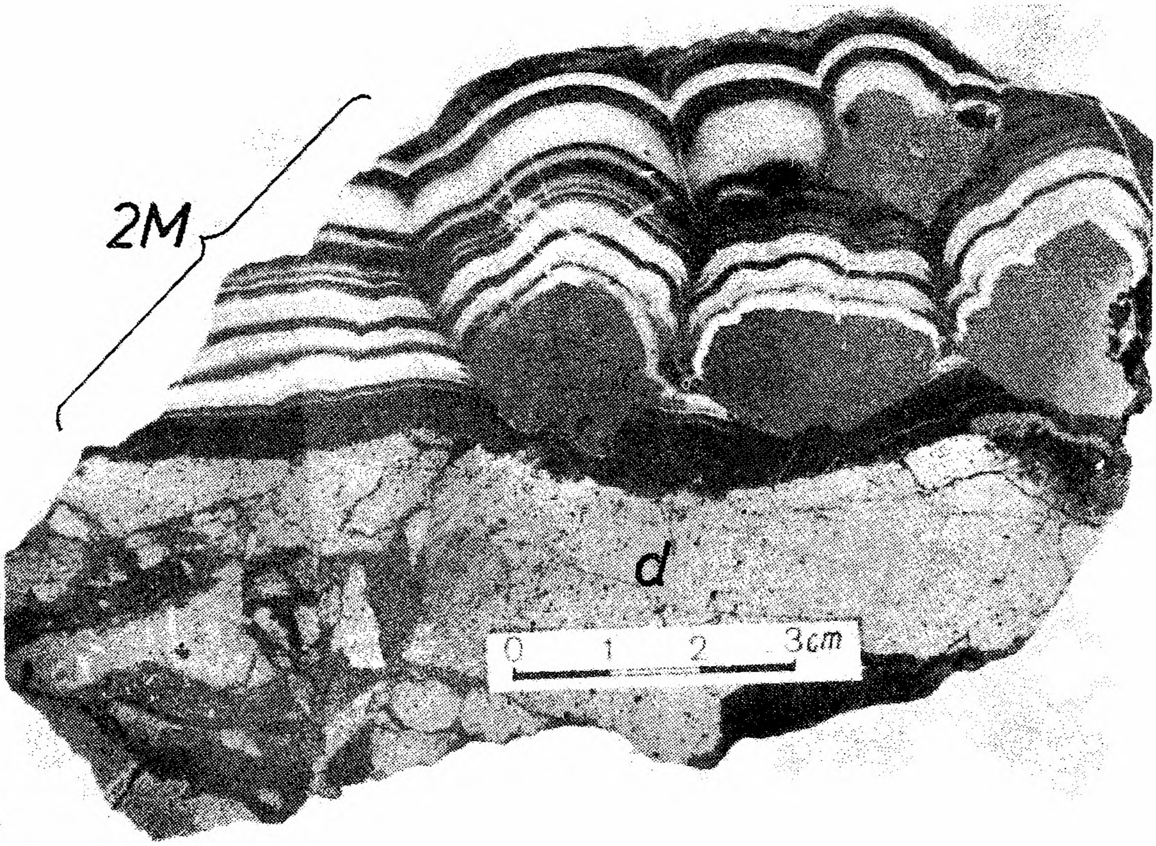

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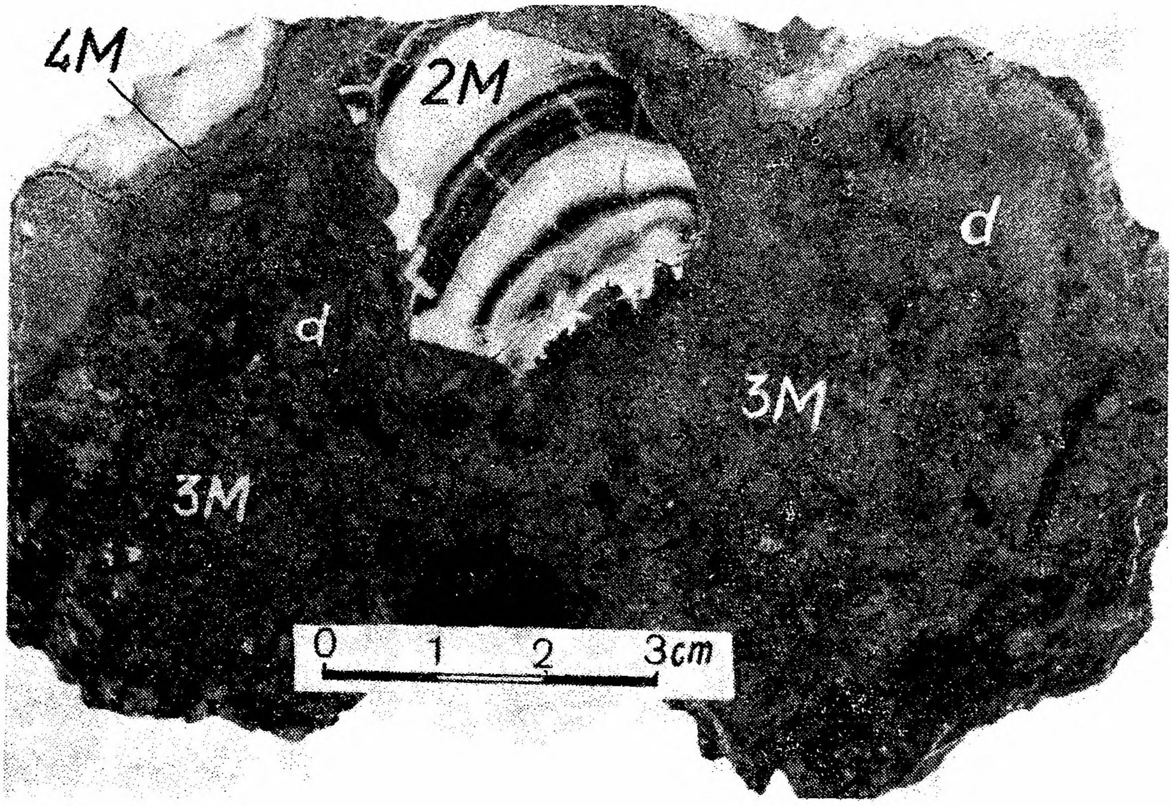

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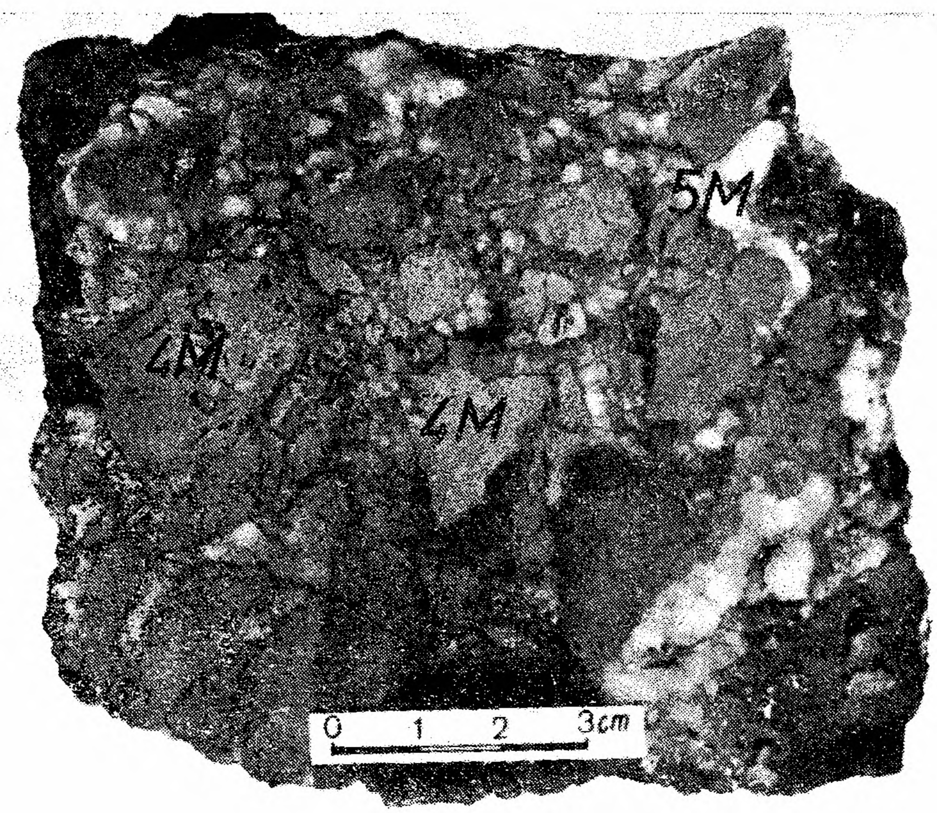

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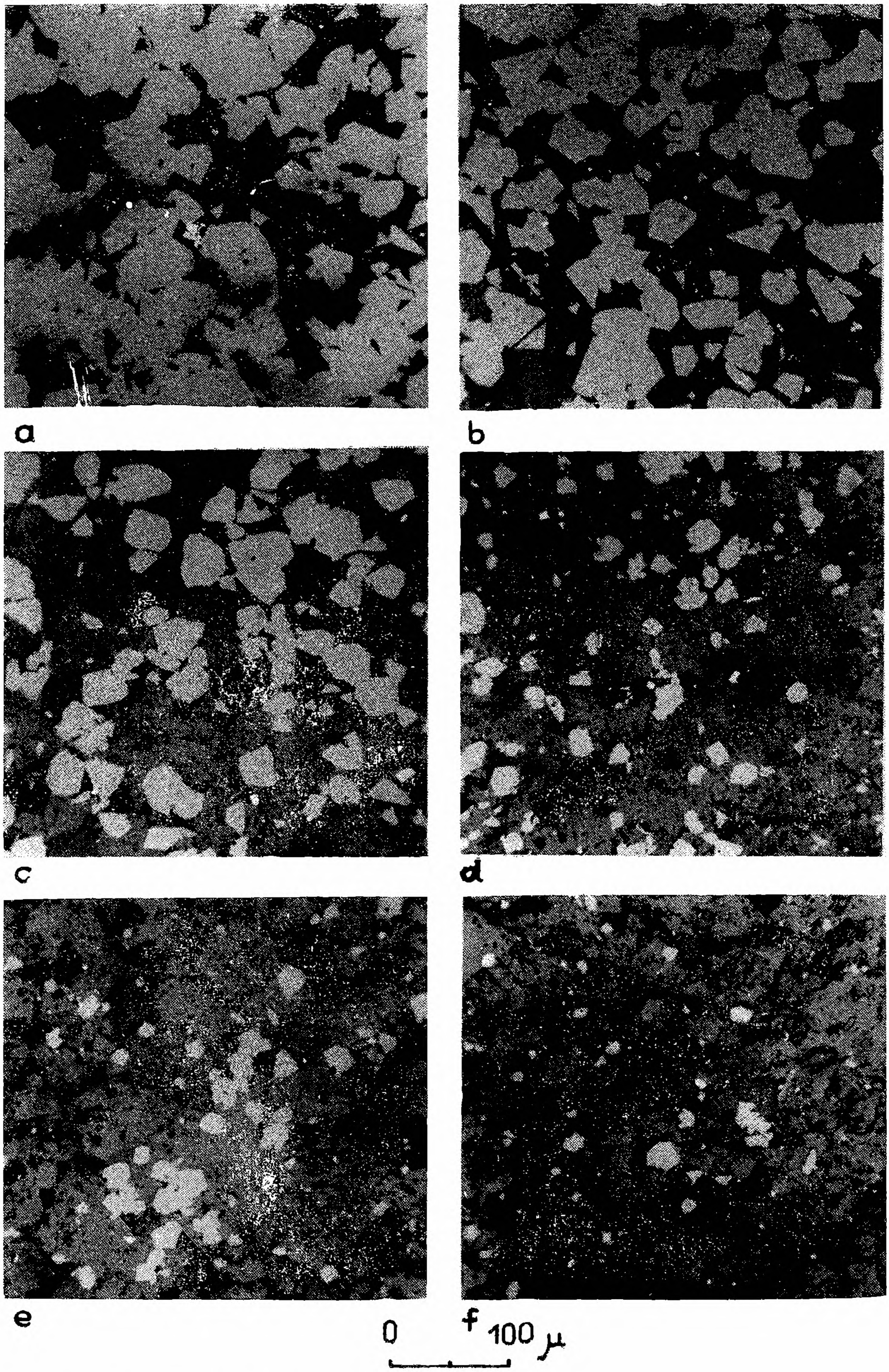
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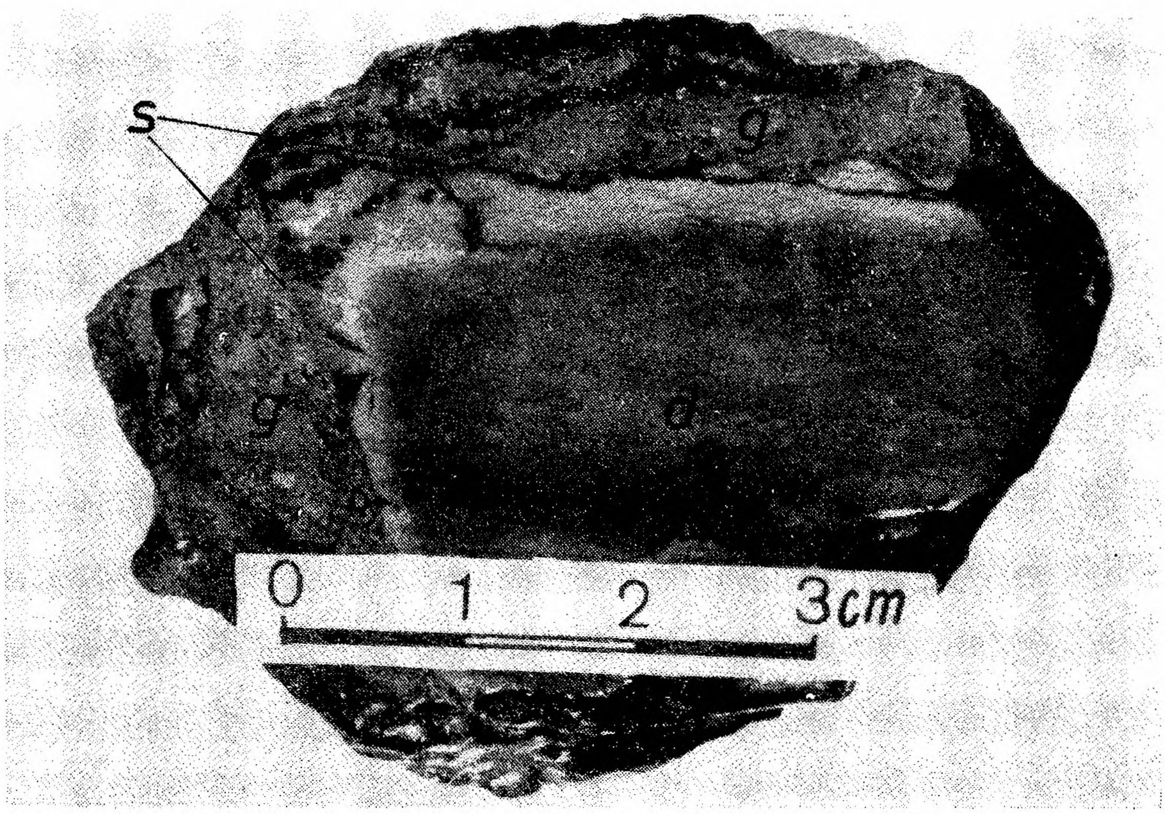

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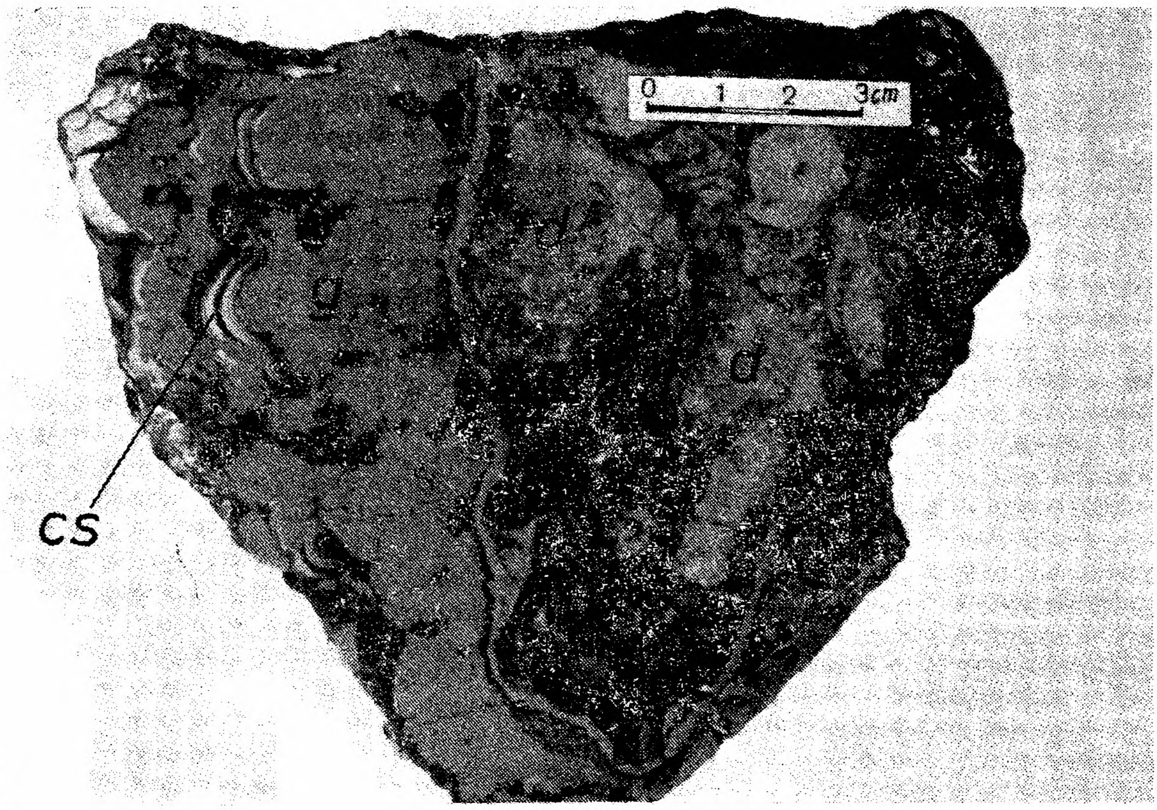

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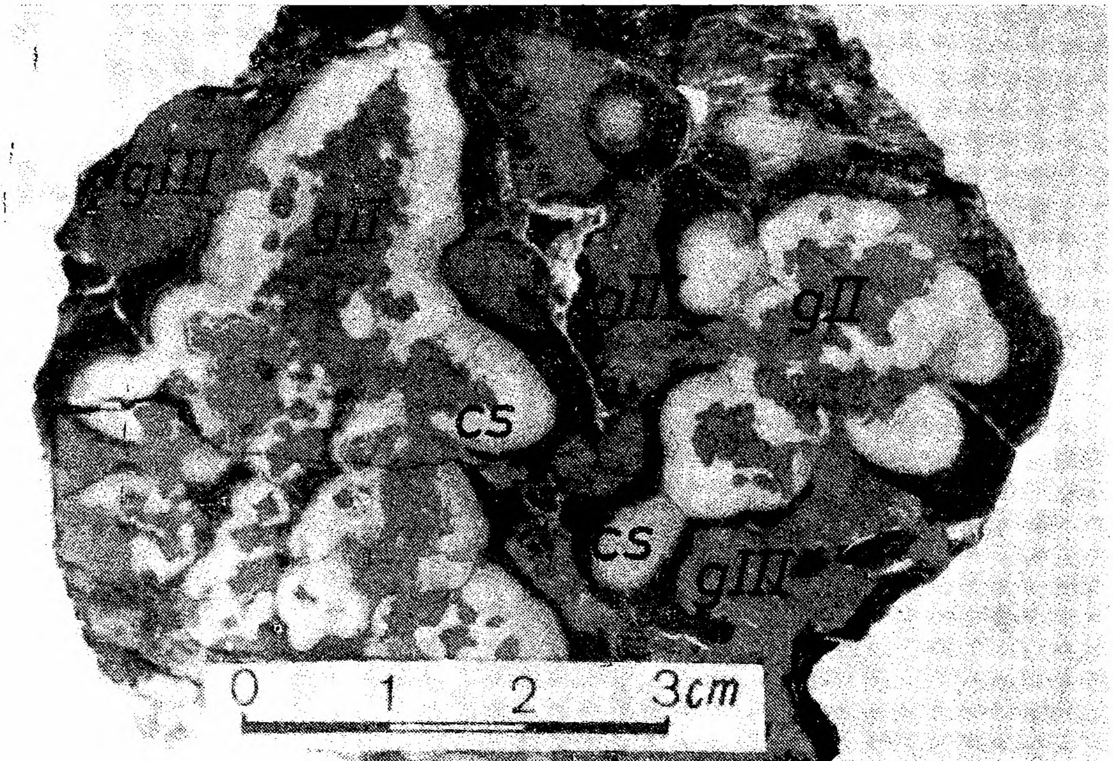

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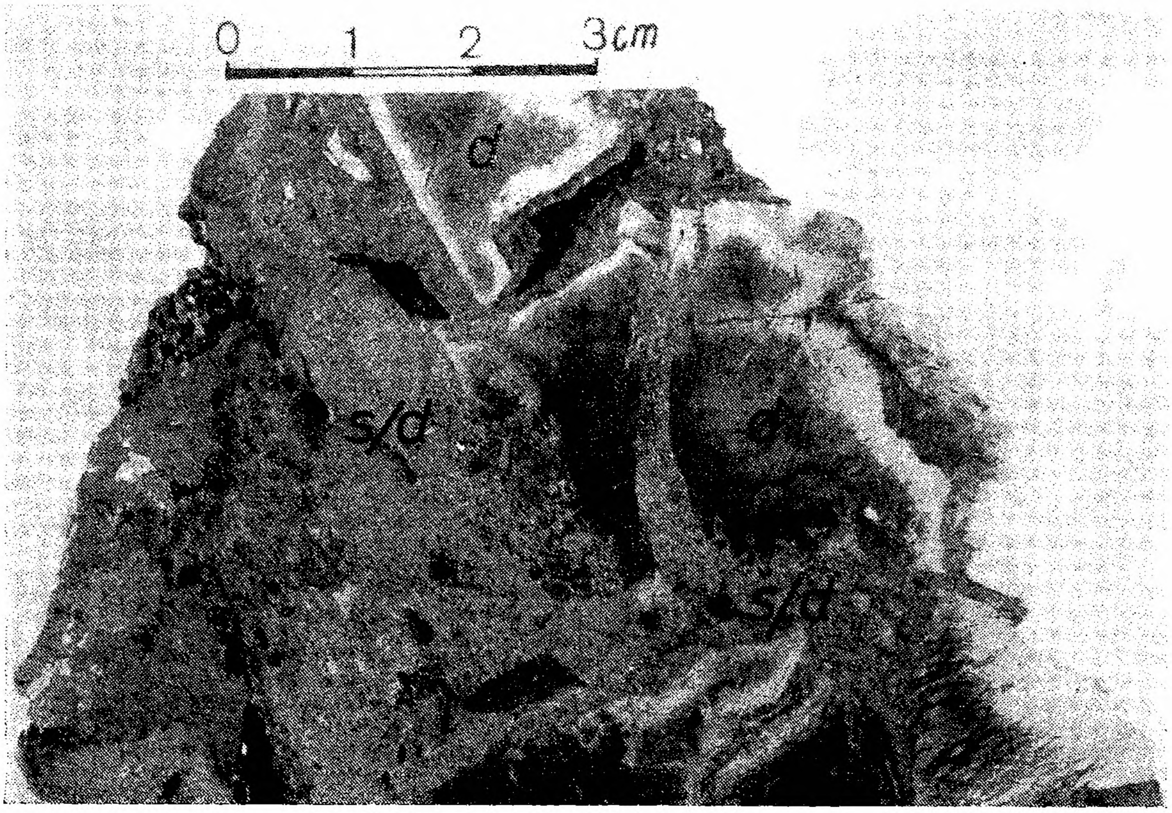

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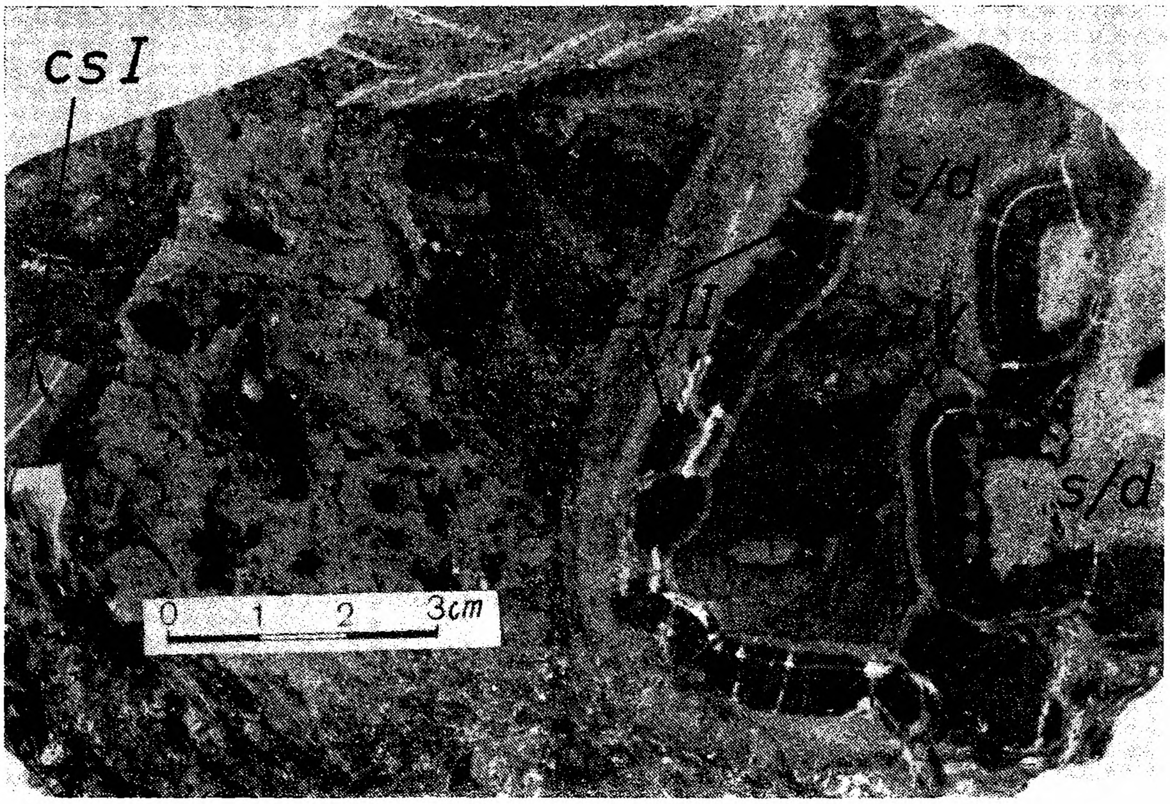

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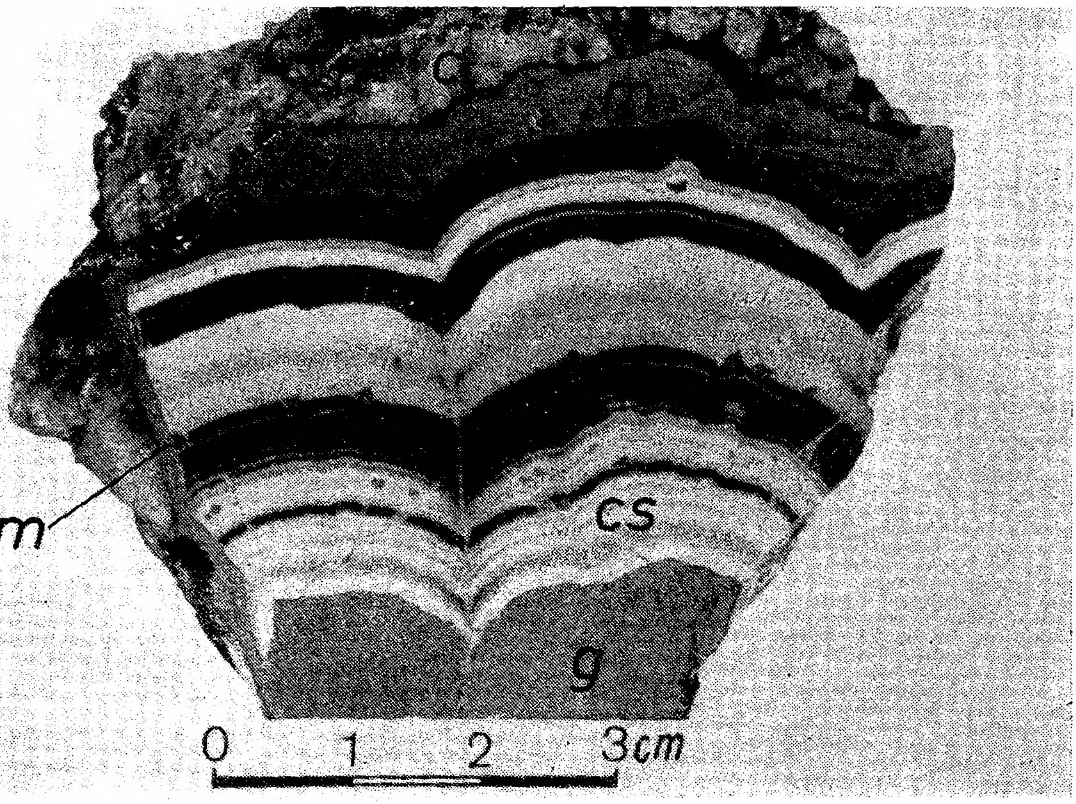

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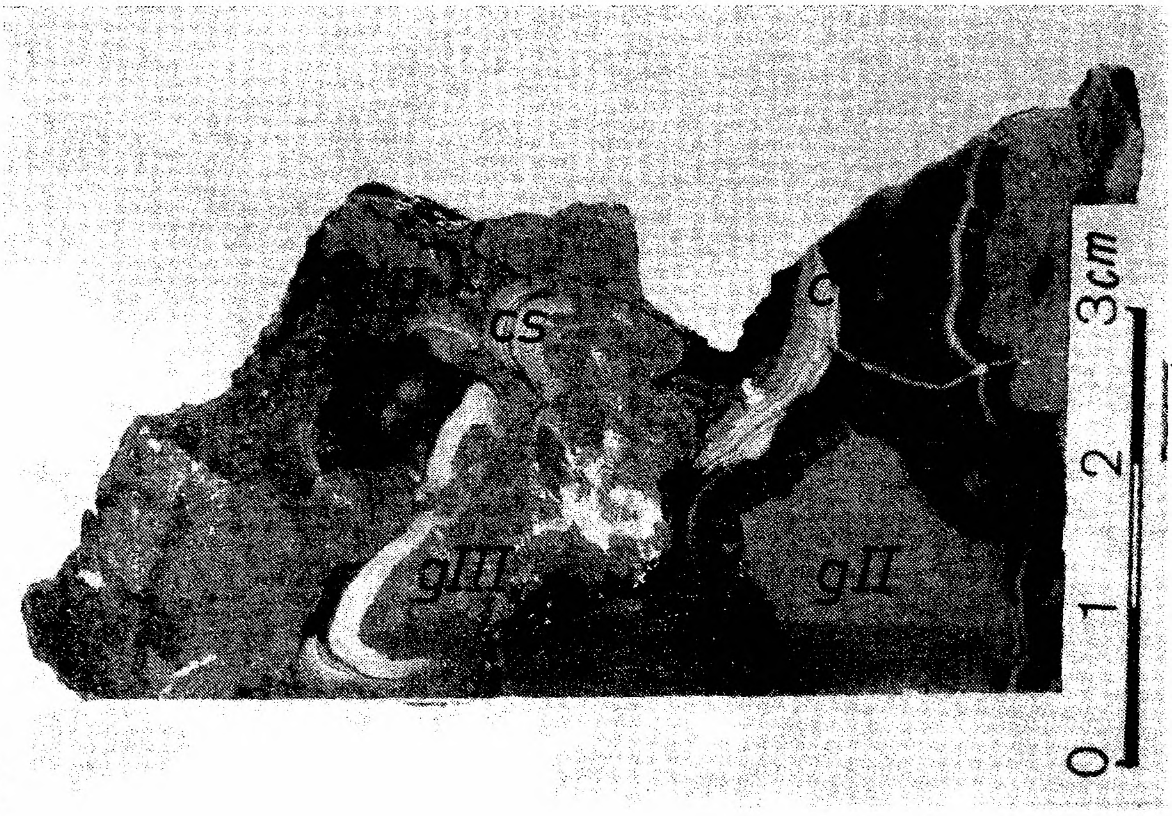

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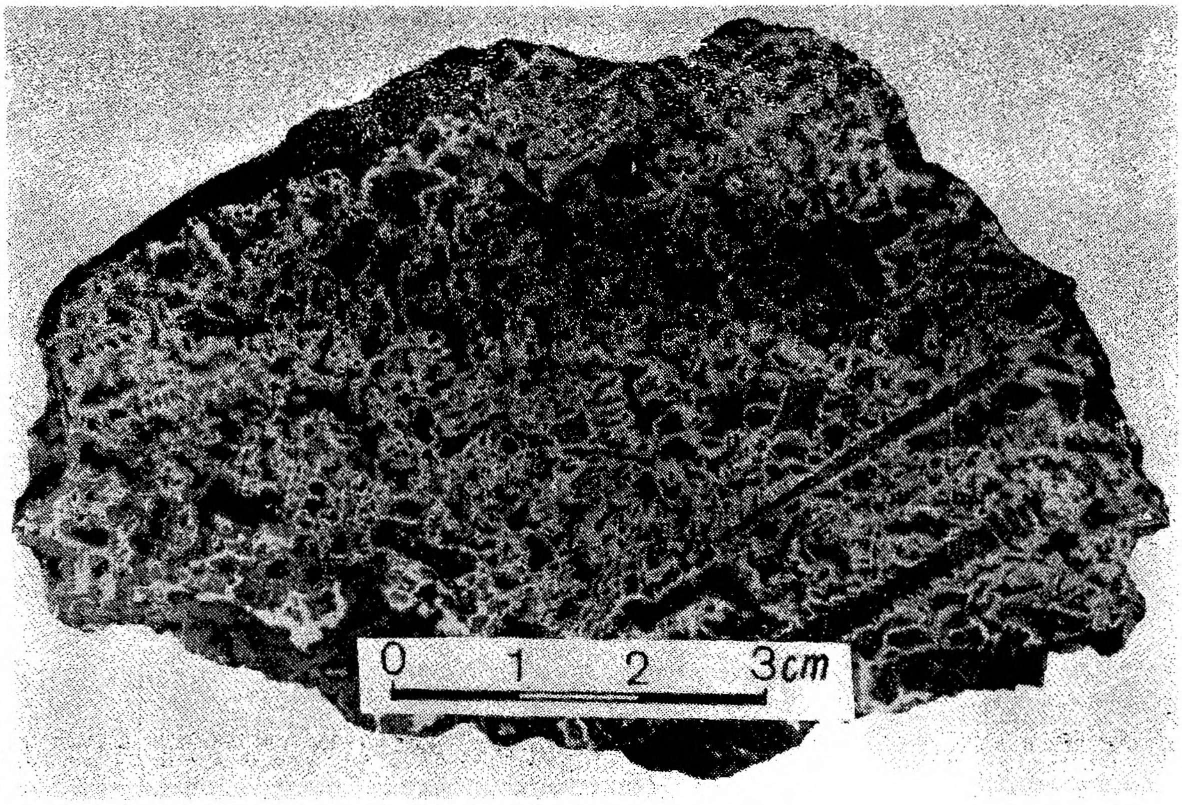

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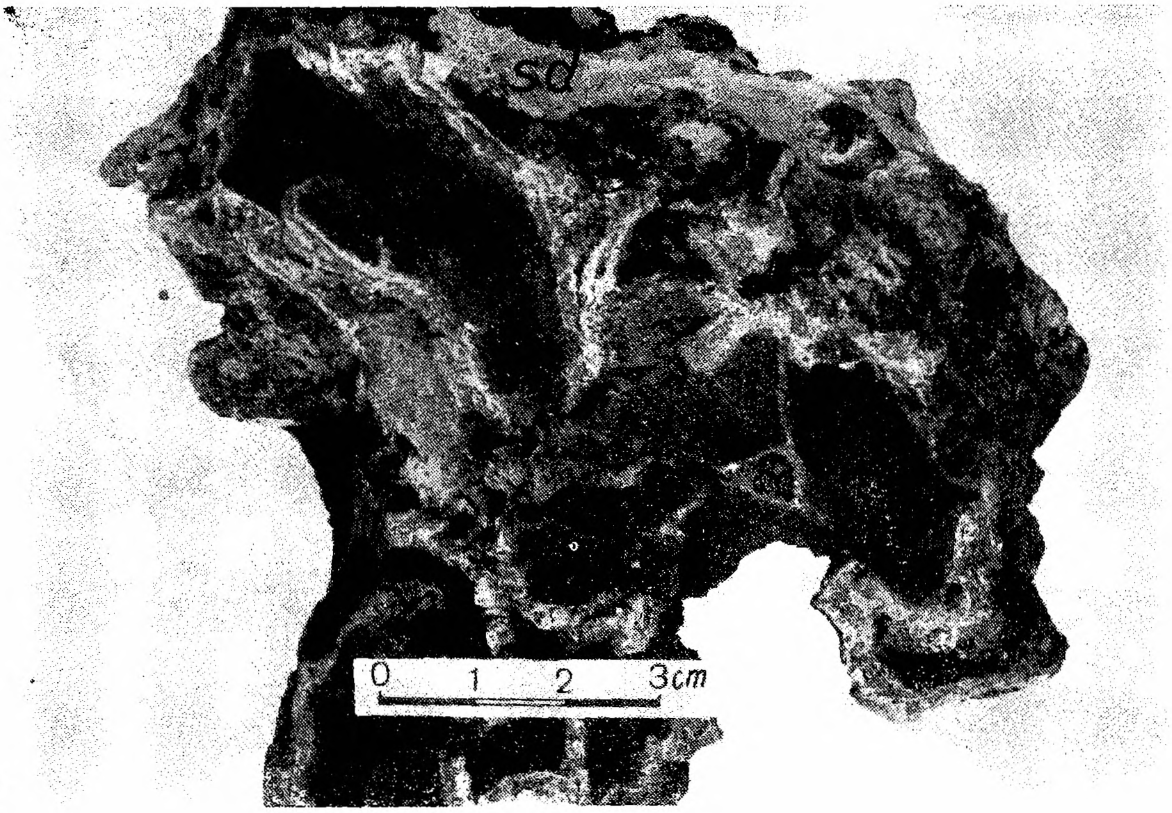

2

Fig. 1. Struktura warstwowana sfalerytu III (ciemniejsze pasma) i dolomitu (jaśniejsze pasma), obserwowana w bezpośrednim sąsiedztwie szczeliny inkrustowanej blendą I (cs) zawierającą galenę II (g)

Fig. 2. Transition from sphalerite (s) to colloform sphalerite (cs). Note isolated grains of galena II developed along contact between sphalerite and colloform sphalerite

Fig. 2. Przejście sfalerytu III (s) w blendę I (cs). Na pograniczu znajdują się drobne pojedyncze ziarna galeny II (g)

Plate — Tablica V

Detail of incrustation composed of minerals of 2 stage and marcasite. cs — colloform sphalerite I (1, 2 and 3 succesive bands of colloform sphalerite); g II — galena II; g III — galena III; m — marcasite

Fragment naskorupienia utworzonego z minerałów drugiego stadium i markasytu. cs — blenda I-szej generacji; (1, 2 i 3 — kolejne pasma blendy); g II — galena drugiej generacji; g III — galena III-ciej generacji; m — markasyt

Plate — Tablica VI

Fig. 1. Crossing and bifurcating ore veins composed of minerals of substage "B" of second stage (2M). Note bleaching zones in dolomite (d) along its contact with sphalerite IV (s); g — galena III.

Fig. 1. Fragment zespołu przecinających i rozwidlających się żył zbudowanych z minerałów należących do podstadium B w drugim stadium mineralizacji (2M). Widoczne charakterystyczne wąskie strefy wybieleń w dolomicie (d) na kontakcie ze sfalerytem IV (s). g — galena III generacji

Fig. 2. Dolomite fragments (d) enveloped by minerals of sub-stage "B" of second stage (2M). Note bleaching zone in dolomite along contacts with sulfides. g — galena III; s — sphalerite IV

Fig. 2. Okruch dolomitu (d) otoczony minerałami podstadium B drugiego stadium (2M). Na kontakcie z siarczkami charakterystyczne wybielenia. g — galena III; s — sfaleryt IV

Plate — Tablica VII

Fig. 1. Relics of collofrm sphalerite I (cs) enveloped by galena III (g). d — dolomite

Fig. 1. Relikty blendy I (cs) w galenie III (g). d — dolomit

Fig. 2. Galena II (gII) enveloped by colloform sphalerite I (cs). Both sulfides partly replaced by galena III (gIII)

Fig. 2. Galena II generacji (gII) otoczona blendą I (cs). Oba siarczki zastąpione częściowo galeną III generacji (gIII)

Plate — Tablica VIII

Fig. 1. Fragments of dolomite (d) in a matrix containing sphalerite V and disaggregated dolomitic particles (s/d)

Fig. 1. Okruchy dolomitu (d) na tle spoiwa złożonego ze sfalerytu V i ziarn dolomitu (d/s)

Fig. 2. Detail of breccia composed of dolomite fragments and fragments of colloform sphalerite I (csI) in a matrix made up of dolomite grains and spha-

lerite V (s/d). Note well developed colloform sphalerite II (csII) containing galena IV (g IV)

Fig. 2. Detal brekcji zawierającej okruchy dolomitu i fragmenty blendy I (csI) w spoiwie złożonym z ziarn dolomitu i sfalerytu V (s/d). Widoczna dobrze wykształcona struktura blendy II (csII) zawierająca galenę IV (gIV)

Plate — Tablica IX

Fig. 1. Fragment of colloform sphalerite I (cs) enveloped by marcasite (m). Note calcite crystals (c) on top of marcasite

Fig. 1. Okruch blendy I (cs) i galeny II (g) otoczony makasytem (m). Na markasycie kalcyt (c)

Fig. 2. Minerals filling fissure from zone III in fig. 8. g II — galena II; cs — colloform sphalerite I; g III — galena III

Fig. 2. Minerały wypełniające szczelinę (strefa III na fig. 8). g II — galena II generacji; cs — blenda I generacji; g III — galena III generacji

Plate — Tablica X

Fig. 1. Skeletal structure of galena II (dark grey) and colloform sphalerite I (white)

Fig. 1. Struktura szkieletowa galeny II generacji (ciemnoszara) oraz blendy I generacji (biała)

Fig. 2. Cavernous structure. Network of sphalerite and pyrite-marcasite enclosing empty voids left after dissolution of dolomite fragments. Note the relics of "sanded" dolomite (sd)

Fig. 2. Struktura jamista. Piryt-markasyt wraz ze sfalerytem tworzą „skorupy" ograniczające puste przestrzenie pozostałe po okruchach wyługowanego dolomitu. W górnej części okazu widoczne są pozostałości spiaszczonego dolomitu (sd)