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PARAGENESIS OF KREMNICA ORE VEINS

(Plate VII—XII, Textfigs. 1—3)

Abstract. This work is a conclusion of paragenetic studies carried out in Kremnica Au, Ag, Sb deposit. Described are the supply periods of hypogene mineralization particularly of productive electrum bearing periods.

Introduction

Kremnica Au, Ag, Sb deposit represents together with Banská Štiavnica the most ancient mining centers in neovulcanic region of Central Slovakia. In spite of long tradition and unique position in gold mining of Kremnica little was known on mineralogy and paragenesis of this deposit. Submitting our studies we suggest that confrontation of partial results from all the Au, Ag deposits belonging to neogene subsequent vulcanism of Carpathian metalogenic province will contribute the explanation of genetic conditions controlling the formation of these deposits.

Brief Geological — Structural Characteristic of the Ore Field Vein System

Ore veins and traces of hydrothermal mineralization represent an ore field in the center of Kremnické hory Mts. covering an area of 33 sqkm. Center of the ore field includes practically the main part of ore veins.

Two vein systems are formed by a complex of mineralized dislocation fissures striking generally NNE — SSW (Textfig. 1). Axis of the Ist vein system is represented by large mineralized fault structure dipping steeply eastward. Its particular segments are known as Schrämen, Main and Kirchberg ore veins. The main fault structure however is found mostly as foot plane of vein bodies. In some of its parts 4—6 m thick mylonite zones were observed. Wide brecciated zone resulted in hanging wall of the fault replaced subsequently by vein quartz or penetrated by veinlet complex. Main veins: Schrämen, Main and Kirchberg consist usually of several branches. The total thickness of Schrämen vein adjacent to Ludovika shaft exeeds 50 m on the surface decreasing downwards.

Foot and hanging wall accompanying veins stand either in parallel or diagonal and antithetic position to the main veins. The fissures were formed as adjacent by movements along the main tectonic line. Those in the nearest neighbourhood frequently communicate with the main structure showing similar mineral composition. Accompanying veins in greater distances communicate with main structures indirectly along deep seated channels carrying therefore in majority the mineralization of younger and lower thermal periods. The thicknesses are substantially smaller ranging 1,5—2 m.

The whole vein system appears in a series of Middle Tortonian pyroxene andesites, intensively propylitized, argillitized and adularized. Subvulcanic bodies of diorite porphyres derived from andesite magma occur locally.

Characteristic for the IIst vein system are the rhyolite dykes accompanying the

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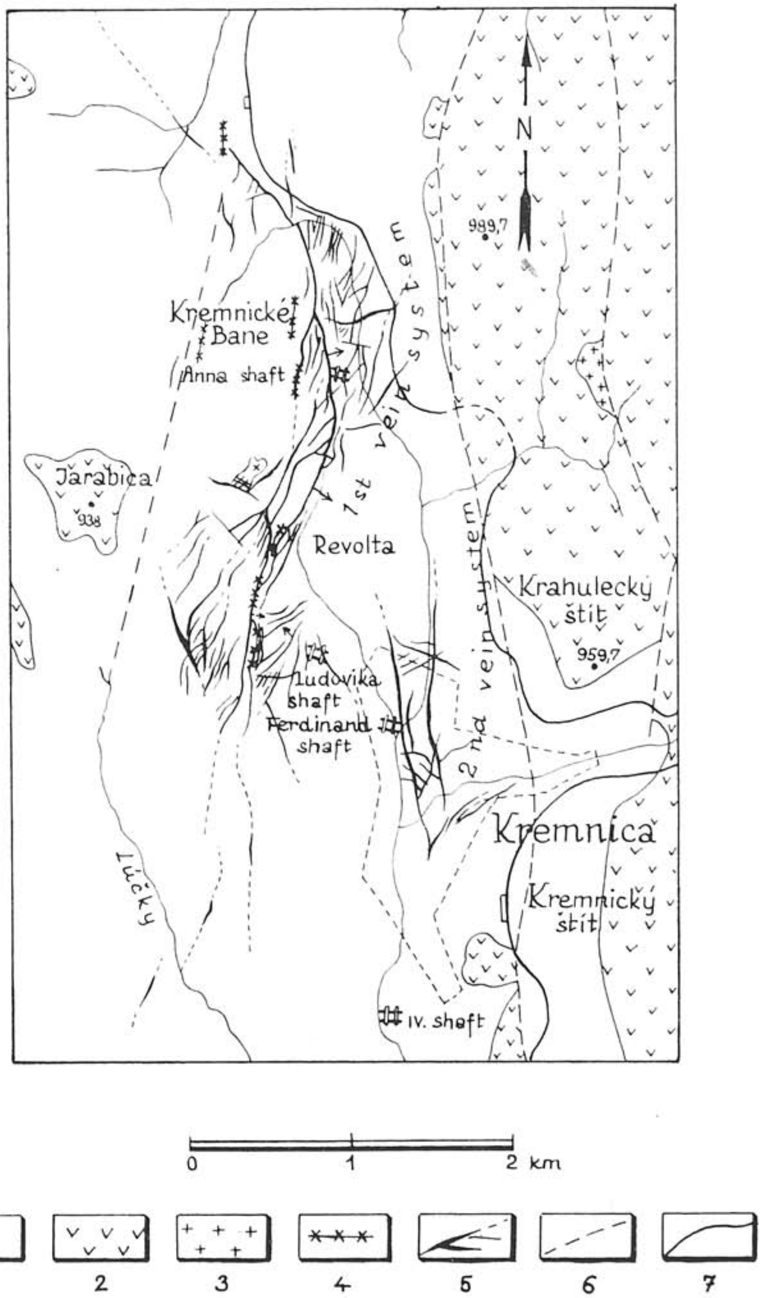


Textfig. 1. 1. Older pyroxene andezites, 2. younger hornblende — pyroxene and pyroxene andezites, 3. rhyodacite, 4. rhyolite dykes, 5. ore veins, 6. faults, 7. railway. Geologie according to F r. F i a l a.

main mineralized structures. These hypoabyssal bodies of extremly acid magma represent genetic controll of mineralization (M. B ö h m e r 1961).

The II[nd] vein system is located some 1,5 km from the first one in hanging wall block, striking generally N—S and dipping 50—80° eastward. Only a minor part of veins schows opposite dipping. Locally occuring between main structures are diagonal mineralized fissures. Vein thicknesses compared with foot and hanging wall veins of the first system are generally of the same order. The II[nd] system is equally localized within the same complex of altered pyroxene andesites with subsidiary tuffite conglomerate intercalations, tuffites and tuffs.

Description of Mineral Associations of the Supply Periods

Paragenetic investigations started by a detailed study of vein filling structures. Due to the position of veins in exposed tectonic zones the mineralization has been several times interrupted by renewed movements bringing tectonic deformation to preceding mineral filling. Associations of supply periods were studied in the intersections of veinlets of various age and brecciated vein filling. Associations with praedominating carbonates show the younger periods penetrating along the tectonic lines supported considerably by internal replacement. In some cases useful for the determination of supply period were characteristic structures and textures (Colloform supply period).

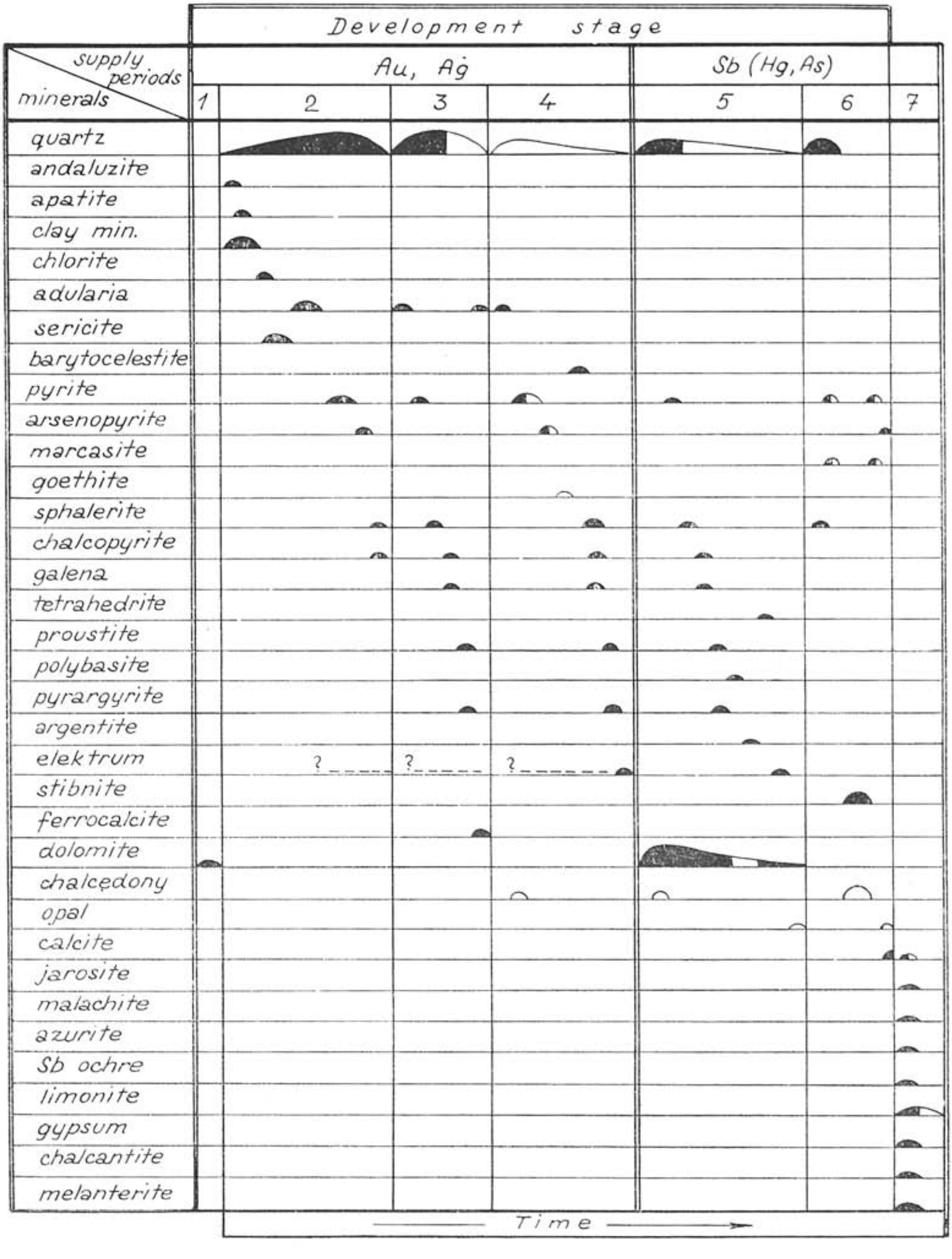
According to the above features we have distiguished six hypogene supply periods in the first and seven in the second vein system. Certain differences in mineralizing periods between the first and second vein system are due to local phases of intermineralization tectonics involving sometimes only one of the vein systems. The confrontation of related paragenetic associations however allows to parallelize mineralizing periods of both vein systems originated in a single geochemical hydrothermal process. Supply periods of both vein systems were compared in succession tables (Textfig. 2, 3) and marked by equal numbers in cases of direct relation and supplemented by alphabetic indexes for periods controlled by local intermineralization tectonics.

In the succession tables graphically indicated are the age relations of minerals, their abundance, colloform structures or its relicts. The character of mineralization periods is given further below.

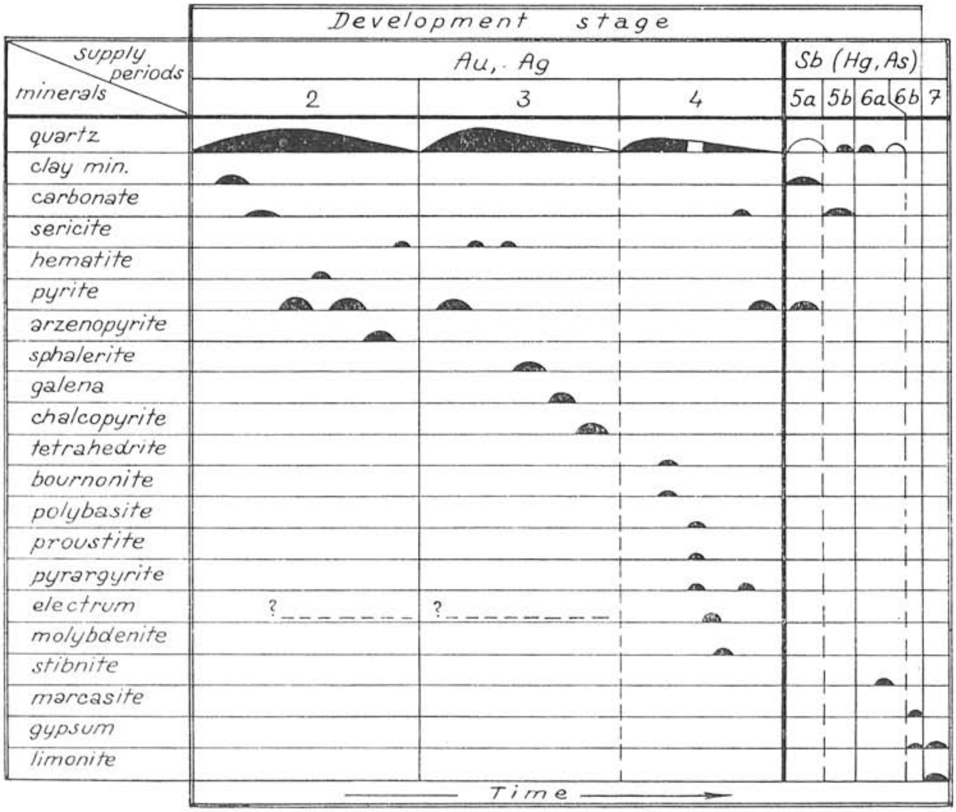
I[st] Vein System

C a r b o n a t e m i n e r a l i z i n g p e r i o d. The oldest mineral filling is represented by relicts of carbonate breccia found in the oldest gray quartz gangue of Schrämen vein. Part of Ca may have been derived from host andesites due to hydrothermal alteration along the main structures. The following quartz periods caused the leaching of carbonates partly trapped in the I[st] period quartz as fragments. These old carbonate breccias are responsible for the abundance of cavernous structures of the oldest quartz filling in some parts of ore veins.

I[st] q u a r t z p e r i o d. Occurs nearly in every ore vein representing in majority the main portion of quartz gangue. Quartz is of fine grained type, grain size ranging between 0,005—0,1 mm usuall with xenomorphe texture (Pl. VII, fig. 1). It was formed predominantly by replacement silicification of altered



Textfig. 2. Succesion of mineralization of I[st] vein system. Periods: 1. carbonate, 2. 1[st] quartz, 3. 2[nd] quartz, 4. pyrite 5. quartz carbonte, 6. stibnite, 7. supergene minerals.



Textfig. 3. Succession of mineralization of IInd vein system. Periods: 2. 1st quartz, 3. 2nd quartz, 4. productive subperiod, 5a. colloform, 5b. carbonate, 6a. stibnite, 6b. marcasite, 7. supergene minerals.

pyroxene andesite along the fault lines. Quartz is gray in colour due to abundant inclusions of minute secondary minerals derived from altered andesites. Predominating are particles of c l a y m i n e r a l s and s e r i c i t e together with small amounts of c h l o r i t e. As primary member of hydrothermal paragenesis occur subsidiary a p a t i t e. In some parts of ore veins the quartz of this period contains sporadic grains of a n d a l u s i t e. N. N. K u r e k (1954) regarded this mineral as a typical member of secondary quartzite paragenesis. A d u l a r i a occurs mainly in upper parts of Schrämen vein in the southern sector of vein system.

Ore minerals are represented by syngenetic p y r i t e (1—3 %), subsidiary a r s e n o p y r i t e. Sporadically pyrargyrite and electrum grains may be observed. E l e c t r u m particles range below 0,003 mm in size occuring mostly in pyrite. Although certain supply of Au, Ag, at the beginning of hydrothermal process cannot be excluded the majority of Au, Ag minerals is of epigenetic origin. Au, Ag minerals were precipitated in disturbed zones of vein filling due to the effect of older generation of sulphides. The minerals themselves however belong to younger mineralizing periods. The majority of gold in this period appears in submicroscopic form.

2[nd] quartz period penetrates the older filling forming complicated linked veinlet system. Crustified structures occur only in the direct hanging wall of Schrämen vein. Due to the limited process of replacement this quartz is already pure and white in colour. Quartz is of coarse grain with vugs in thinner veins. Colloform structures are frequent in higher levels. Near to the outcrop of Schrämen vein abundant adularia in two generations is observed. 2[nd] period quartz contains only local concentrations of galena, sphalerite and chalcopyrite precipitated at the end of supply period. Gold occurs in submisroscopic dispersions of epigenetic character and its amount in this period is low.

Pyrite supply period is formed by quartz with abundant pyrite and arsenopyrite. Veinlets of pyrite period intersect the quartz of older periods and are found frequently in the tectonically disturbed contacts of Schrämen vein. The period is rich in Au, Ag mainly in veins of the I[st] system. Ore contents 40—50 gr/t Au and 20—30 times more silver.

Main minerals of this period are: quartz, chalcedony, pyrite, arsenopyrite. Subsidiary are adularia, baritocelestine, goethite, galena, sphalerite, chalcopyrite, proustite, pyrargyrite and electrum. Quartz is of fine grained variety 0,01 mm and in majority of metacolloidal character. (Colloform structure is present also in pyrite). Part of SiO_2 occurs as chalcedony. Adularia forms either xenomorphic aggregates or automorphic individuals (Pl. VII, fig. 2). Baritocelestine (Pl. VIII, fig. 1) occurs in characteristic tabular or flaky grains 0,05—0,1 mm in size. Spectral analyses show besides Ba constant presence of Sr locally even predominating.

Among ore minerals most abundant is pyrite replaced frequently by arsenopyrite. For arsenopyrite charakteristic are prismatic aggregates (Pl. VIII, fig. 2). Goethite appears as dispersed crystallosol in quartz giving it a reddish-brown colouring. Goethite may further be precipitated as thin layer separating pyrite or arsenopyrite generations (Pl. IX, fig. 1). Such alternation indicates unstable sulphur and oxygen conditions during the crystallization of this period. Galenite, sphalerite, chalcopyrite, proustite, pyrargyrite and electrum occur in thin fissures (Pl. IX, fig. 2) of pyrite originated due to contraction of primary gels. Electrum is found dispersed in pyrite and arsenopyrite as isolated isometric grains ranging 0,02—0,001 mm and less. Confrontation with analyses indicate that the majority of electrum is dispersed in submicroscopical form as crystallosol. Typical electrum of this period is shown in fig. 1, Pl. X.

The general character of mineral associations and high Au, Ag tenors of this period makes it easy to distinguish from the previous ones. Pyrite period represents the main productive mineralozation of this vein system.

Quartz — carbonate period foolowed after an intense intermineralization tectonic phase resulting in a series of new fissures mainly in the hanging wall parts of chief vein structures. Major constituent of this period is dolomite enclosing thin syngenetic crusts and lenses of quartz. Quartz of subsequent generations shows in upper vein levels metacolloidal character. Mineral association related to quartz contains also sulphides, sulphosalts and even microscopic electrum. Due to the vast predominance of dolomite gangue over quartz association the ratio of ore bearing minerals however is so small that quartz — carbonate period as a whole represents only gangue filling.

Stibnite period closed the hypogene mineralozation of the I[st] vein system accompanying in veins frequently the quartzcarbonate period.

Simple mineral association is composed of quartz and chalcedony gangue, stibnite, pyrite and marcasite as ore minerals. Stibnite occurs locally in workable concentrations. As to gold and silver content this period is equally barren. Quartz is dark or black in colour due to dispersed pyrite and stibnite inclusions. The variety is a fine grained one resembling hornstone. Frequent are chalcedony and lutecite modifications. Pyrite is abundant and almost always forming concentric zoned colloform textures with dark nuclei surrounded by radial contraction cracks (Pl. X, fig. 2). Part of pyrite appears as melnikovite. Stibnite is also abundant predominantly as nedle shaped crystals in quartz or chalcedony matrix (Pl. X, fig. 3). Massive stibnite ore shows xenomorphic texture. As minor admixtures in this period arsenopyrite and sphalerite were determined. Mineralization ended with precipitation of small amounts of opal.

II[nd] Vein System

Supply periods determined within the II[nd] vein system correspond in general to the I[st] system periods. The chief difference serving since long as distinguishing feature is the presence of visible electrum concentrated in relatively rich bonanzas of the II[nd] vein system. Different further is the limited abundance of two youngest quartz — carbonate and stibnite periods as well as the timing of intermineralization tectonic phases. (Younger phases were less effective). The geochemical development of both vein systems however is generally equal.

1[st] quartz period is practically the same as in the I[st] vein system. In addition red quartz variety occurs coloured by dispersed haematite crystallosol pigment.

2[nd] quartz period is represented by coarse grained, white quartz with abundant vugs cementing the brecciated zones and filling younger fissures and fractures. In banded structures in found in the middle of veins. Separated by a slight tectonic phase and a short break in crystallization followed the final suply of mineralization forming bonanzas of visible electrum. The first subperiod although supplying the vast majority of quartz of this period is very poor in ore minerals carrying only small amounts of pyrite and sporadic syngenetic concentrations of galena, sphalerite and chalcopyrite accompanying the subsequent quartz generations.

Productive subperiod is composed of subsidiary frequently colloform quartz and a rich association of sulphides and sulphosalts accompanying rich bonanzas of megascopic electrum. Typical forms of this electrum are the following:

a) Electrum related to tectonic craks and intergranular spaces of quartz in the 2[nd] quartz period (Pl. XI, fig. 1).

b) Electrum filling the small vugs of 2[nd] quartz period (Pl. XI, fig. 2).

c) Electrum replacing the older pyrite generations (Pl. XI, fig. 4).

d) Electrum lining the vugs and druse surfaces as sheets (Pl. XI, fig. 3) vires and bunches.

e) Electrum forming dendrites in druse vugs (Pl. XII, fig. 1).

f) Minor electrum occurs in the tectonically crushed quartz of the 1st quartz period or in the adjacent host rock accompanied by minerals of productive subperiod.

In all the above examples the epigenetic character of electrum and other ore minerals of the productive subperiod in relation to quartz, pyrite eventually galena, sphalerite and chalcopyrite of the second quartz period may be more or less clearly determined. In spite of this the presents of quartz formed during 2nd quartz period controlls the occurence of productive subperiod. Productive subperiod associations besides electrum and minor quartz and pyrite carries polybasite, proustite, pyrargyrite, burnonite, tetrahedryte and molybdenite. Typical electrum — pyrargyrite intergrowht is shown in fig. 2, Pl. XII.

Structural etching indicated colloform texture of electrum in majority of cases. Colloform zones consist of layers with variable Au : Ag ratio. Colloform textures of electrum and the interpretation of bonanza formation from colloidal Au Ag solutions were decribed in previous paper M. Böhmer (1964).

Colloform period is composed entirely of metacolloidal quartz and opal. Concerning Au Ag the period is totaly barren. Carbonate period is represented by dolomite veinlets with subsidiary quartz. It is free of ore minerals. Stibnite period. Although its share in the total of vein filling is small the period is extensively developed in many veins of the IInd vein system disturbed by younger phases of intermineralization tectonics.

The mineral association includes needle-form stibnite aggregates crystallizing in druse vugs. Stibnite is accompanied by minor quartz and opal.

Marcasite period appears at the end of hypogene mineralization of IInd vein system. Local mineralization is represented by thin layres and crusts of marcasite with subsidiary gypsum.

The last four supply periods terminating the hypogene mineralization are characterized by heavy decrease even interruption of Au, Ag supply in hydrothermal sollutions.

Conclusions Based Upon the Paragenetic Study of Ore Veins

Productive gold and silver associations. As indicated by paragenetic studies workable electrum concentrations in Kremnica ore veins are related to certain supply periods. In the first vein system paiable ore is carried by pyrite period while in the second vein system by productive subperiod. The character of these periods is in full agreement with the model of productive associations according to N. V. Petrovskaja (1955).

Due to a sudden decrease in Au, Ag supply after both productive periods as well as considerable differences in paragenesis of younger mineralization periods two development stages in J. Kutina (1963) sense may be determined.

a) Au, Ag development stage comprissing the carbonate, first quartz, second quartz and pyrite supply periods in the first and 1st, 2dn quartz and productive subperiod in the second vein system.

b) Sb (Hg, As) development stage comprising the carbonate and stibnite supply period in the first and colloform, carbonate, stibnite, marcasite supply periods in the second vein system. This development stage may be characterized by decrease or interruption of Au, Ag feeding in hydrothermal solution. The leading element of this development stage for both vein systems is antimony (also Hg and As) mainly if mineralization in the periphery of vein systems the whole ore field and adjacent Kremnické hory Mts. are taken in to consideration. Cinnabar is found among heavy minerals around the northern, southern and eastern ore field margin. In the eastern periphery of Kremnické hory Mts. occur abandoned cinnabar mines in Malachov and realgar and orpiment mineralization in the vicinity of Tajov.

After the determination of development stages it is obvious that Au, Ag concentration is remarkable at the end of the development stage. Such a sequence is one of the most characteristic features for hydrothermal gold deposits. Productive associations of the above age relations are considered as the late productive association (N. V. Petrovskaja 1955). Late productive associations of the pyrite period and productive subperiod bear all the typical features in the sense of N. V. Petrovskaja (1955) — complicated polymetallic character and a very close time relation between the precipitation of productive association minerals and electrum. Consequent to this is also a very close space relation between electrum and minerals of productive association. Due to the described features of both productive associations their minerals serve as reliable mineralogical indicators of enriched zones of ore veins.

Early productive gold associations controlled by the influence of older mineral generations upon younger Au, Ag carrying hydrothermal solutions in the Kremnica ore deposit are important, mainly in the first vein system (1st quartz period). The minerals of these period appear in great thickness at the main ore veins carrying locally increased pyrite amounts causing together a more intense Au, Ag precipitation due to pyrite and arsenopyrite influence.

Basing upon paragenetic studies the differences existing between the first and second vein systems in the electrum grains dimmensions may be explaned. The fact that visible gold in the second vein system represents the greit part of exploited ore since long has been a distinguishing feature of both vein systems. A. Helke (1938) included the second vein system to the formation of veins with free gold (Freigoldformation) and the first vein system to the formation of gold veins with invisible Au mineralization (Formation der Golderzgänge mit nicht sichtbaren Gold). The differences in the electrum particles dimmensions between the first and second vein system are due to different mineral associations of productive periods. The first vein system caries in the productive — pyrite period high pyrite and arsenopyrite tenors frequently as predominating vein filling. Gold deposits with higher sulphide ratios contain usually submicroscopic or microscopic gold only. This gold occurs either as disseminated crystallosol in sulphides or due to intense „topomineral influences" the gold appears disseminated in great number of minute particles in suplhides replacing the host minerals.

Free gold is characteristic for quartz veins carrying subsidiary sulphides. Such character may be observed with second quartz period and productive subperiod of the IInd vein system. The thicknesses concerning the first quartz period in which the eventual Au, Ag dispersion could have taken place are here substantially smaller as in the Ist vein system. Such conditions did not favour the Au, Ag dispersion during the productive subperiod. Due to the above processes electrum was precipitated under specific conditions in certain parts of ore veins forming rich concentraticns. According to studies of colloform textures we came to the conclusion that bohanzas are originated by coagulation of colloidal electrum in favourable sites of vein structures (M. Böhmer 1964).

Our paragenetic studies contributed also the explanation of primary zoning in the depcsit and the whole ore field. Discussed below are the problems of zoning in the sense of J. Kutina (1963).

Monoascendent zoning i. e. zoning within a single supply period may be determined in the Ist vein system where carbonates are increasing toward the surface and in the direction from the main hydrothermal feeding channel. Such changes are evident in the second quartz and carbonate mineralization periods. Far more remarkable however is the polyascendent zoning appearing in the characteristing distribution of individual supply periods in relation to the main fault structure which includes the Schrämen — Main and Kirchberg veins. All these veins are filled almost exclusivelly with quartz of the first and second quartz periods. The rich pyrite period is only subsidiary. Quartz carbonate and stibnite low — thermal periods in the Schrämen vein structure occur only rarely. These later periods however are typical for hanging and foot wall accompanying veins of the main fault system. Such a zoning is controlled mostly by the tectonic development of the vein system. During the movements along the main fault line conjugate fissures were formed in both hanging and foot wals. These younger structures carry also younger products of periods. Simultaneously effective were also the changes in the character of mcnoascendent zoning. Combination of the above processes resulted in the zoning related to the main fault structure. In the complex zoning evident is the concentration of younger periods products and low temperature associations in greater distances from the main fault system. (valid for the whole first vein system). Foot and hanging wall veins are characterized by greater mineralogical variability and Au : Ag ratio in favour of silver (Au : Ag = 1 : 25 — 1 : 40 whereas in the Schrämen vein 1 : 4,5 — 1 : 10.)

The scheme of zoning in ore field periphery is supplemented by cinnabar occurences found by heavy minerals investigation.

Telethermal mineralization of Sb, Hg, As development stage shows considerable areal dispersion with several independent occurences distant from the Kremnica ore field. All these plotted occurences indicate regional zoning with Au, Ag mineralibation in the center and cinnabar, realgar orpiment occurences at the periphery of the Kremnica ore district.

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Review by M. Koděra.

Explications of the Plates

Plate VII

Fig. 1. Xenomorphic granular quartz aggregate. Kremnica, Shaft Anna, thin section, magn. 156, x. N. — Fig. 2. Qartz of pyrite period with adularia. Automarphic adularia grains with typical rhomboid sections. Dark — pyrite and arsenopyrite. Kremnica Schrämen vein, thin section, magn. 50, p. N. Photo L. Oswald.

Plate VIII

Fig. 1. Barytocelestine aggregate in vein quartz. Dark — pyrite. Kremnica Schrämen vein thin section, magn. 410, p. N. — Fig. 2. Characteristic arsenopyrite sections in quarz of pyrite period. Kremnica, Schrämen vein, polished section, magn. 136, p. N. Photo L. Oswald.

Plate IX

Fig. 1. Zones of goethite (light gray) alternating with arsenopyrite. Dark — gray — quartz. Kremnica, Schrämen vein, pol. sect., mang. 136, p. N. — Fig. 2. Loose grains of proustite — light gray and sphalerite — dark gray replacing pyrite — white. Dark — quartz. Kremnica, Schrämen vein, pol. sect., magn. 136, p. N. Photo L. Oswald.

Plate X

Fig. 1. Grain of electrum — white in pyrite — gray. Quartz — dark gray. Kremnica, Schrämen vein, polish. sect., magn, 24, p. N. — Fig. 2. Pyrite aggregate showing colloform, concentric zoned structure and radial cracks. Kremnica, Václav adit, Sb vein, polish sect., magn. 34, p. N. — Fig. 3. Neddle form stibnite intergrown with chalcedony. Kremnica, Václav adit. Sb vein, thin section, magn. 18, x N. Photo L. Oswald.

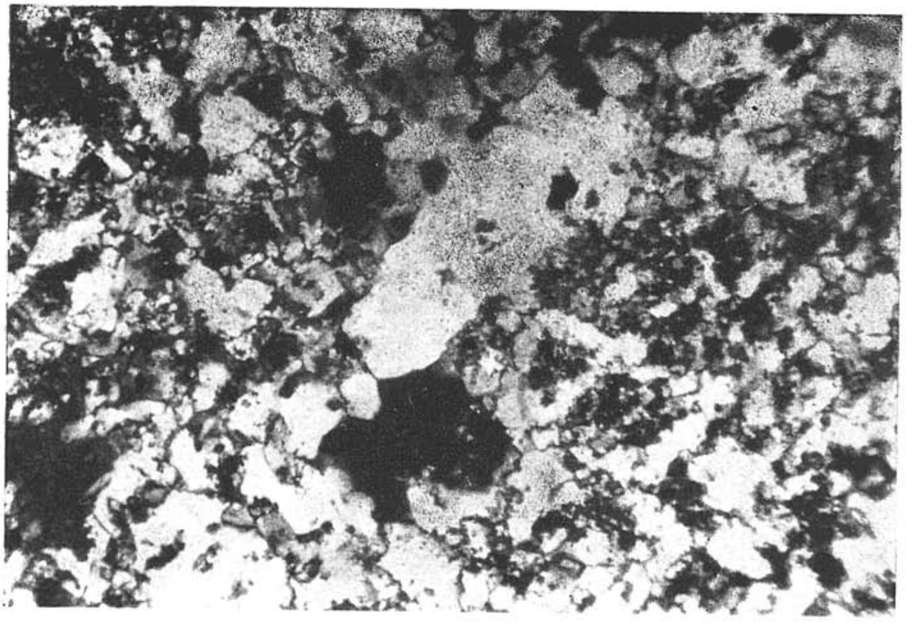
Plate XI

Fig. 1. Electrum black — filling minute cracks and interstitial spaces after tectonic deformation of quartz. Kremnica, Gold vein, thin section, magn. 40, x N. — Fig. 2. Electrum white, filling minute druse vugs in quartz. Kremnica, Gold vein, polished scet. magn. 96, p. N. — Fig. 3. Fragment of electrum sheet in quartz vug. Colloform electrum structure visible after etching. (Porous matrix — dentacryl cement.) Kremnica, Gold vein, polish, sect., magn. 109, p. N. — Fig. 4. Electrum — white with a rugged surface replacing pyrite. Dark gray — sphalerite. Black — quartz. Kremnica, Gold vein, polished section, magn. 40, p. N. Photo L. Oswald.

Plate XII

Fig. 1. Electrum dendrites in quartz druses. Kremnica, Gold vein, magn. 2,5. — Fig. 2. Intricate electrum pyrargirite intergrowth (electrum — white, pyrargirite — gray with negative relief). Dark — quartz. Kremnica, Gold vein, polished section, magn. 120, p. N. Photo L. Oswald.

Translated by J. Kováčik.



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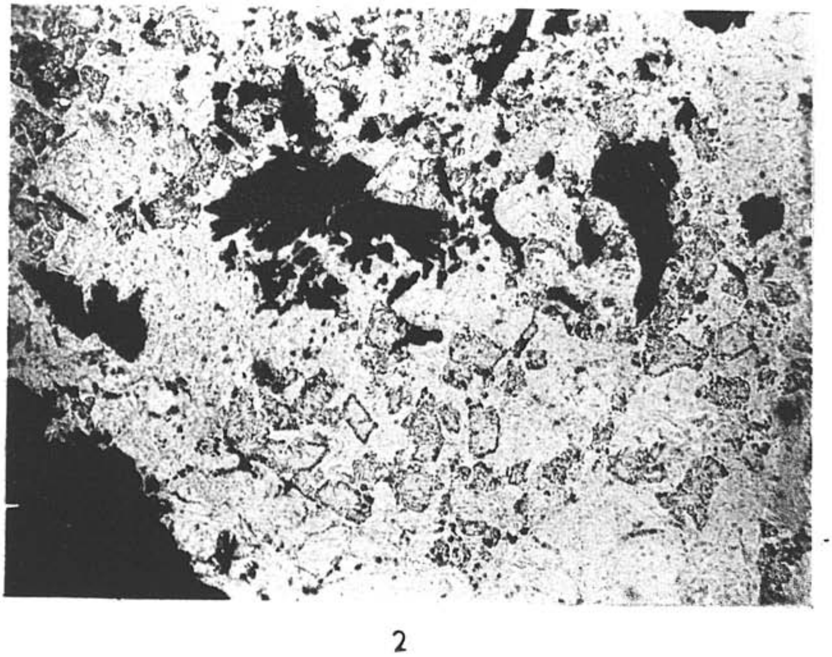

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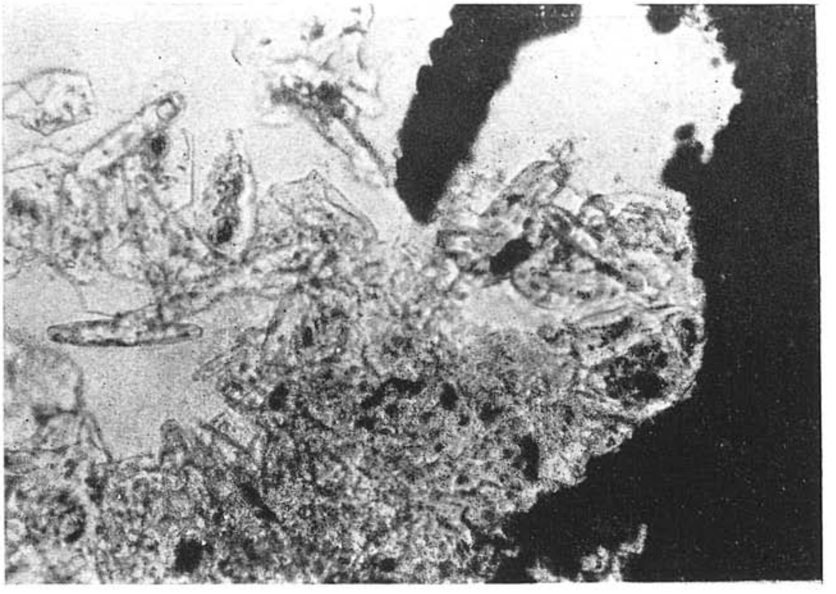

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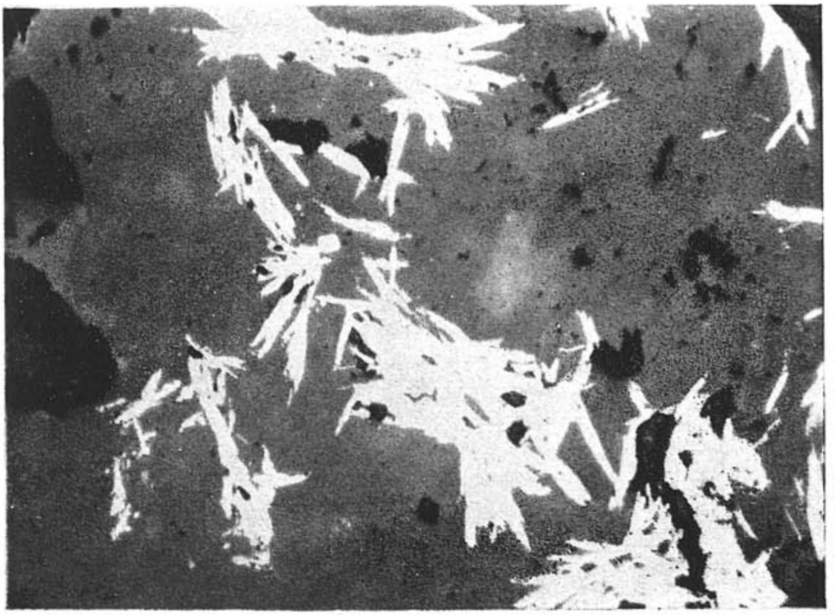

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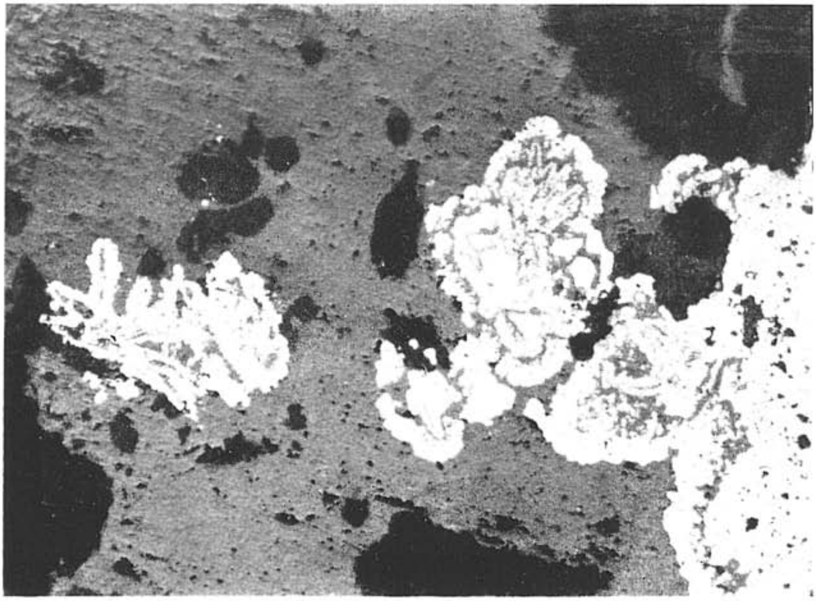

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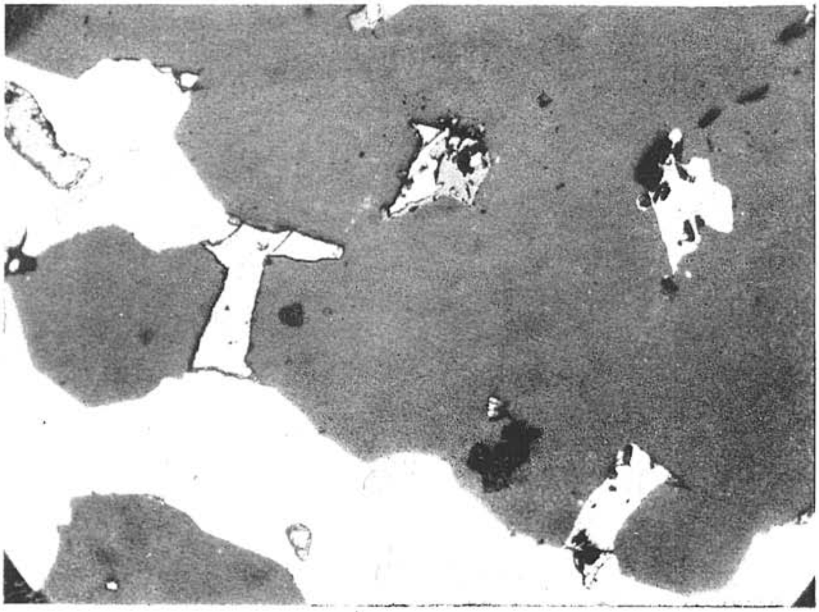

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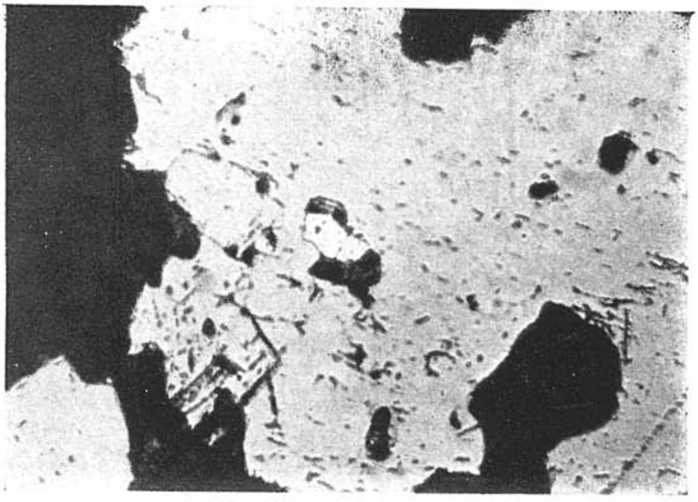

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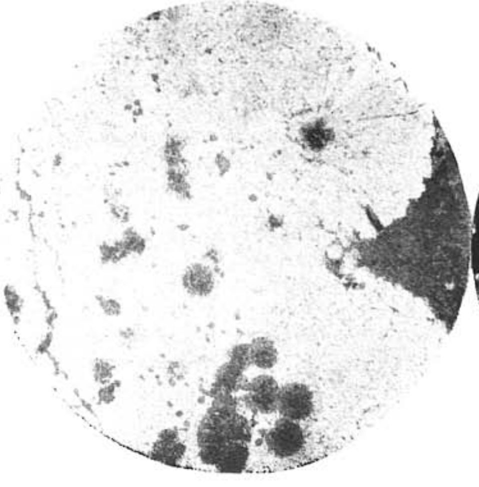

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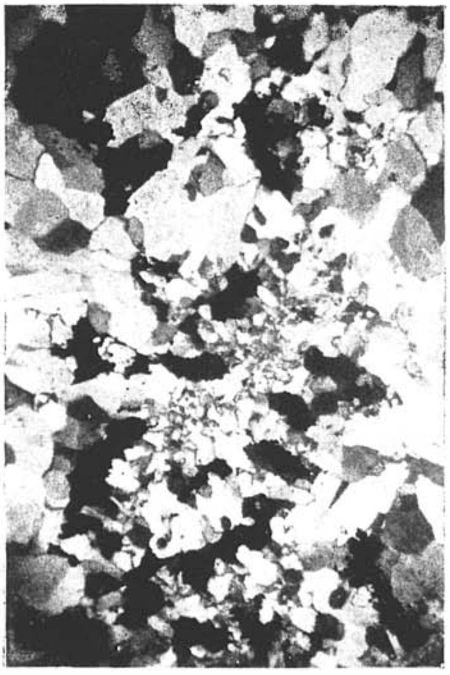

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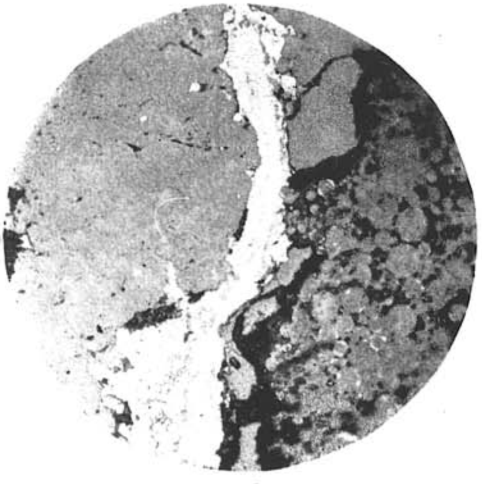

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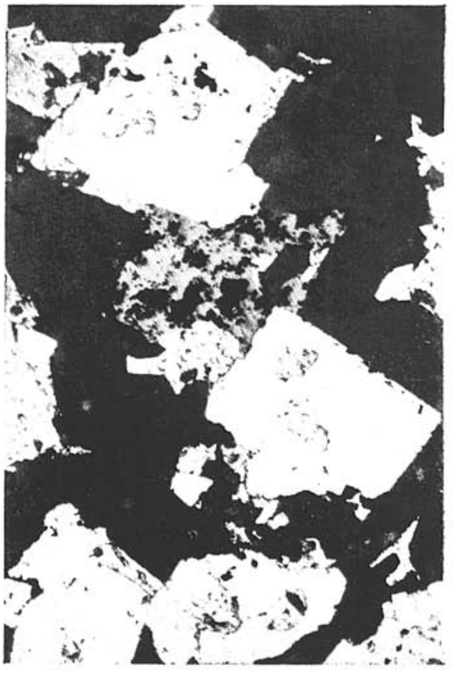

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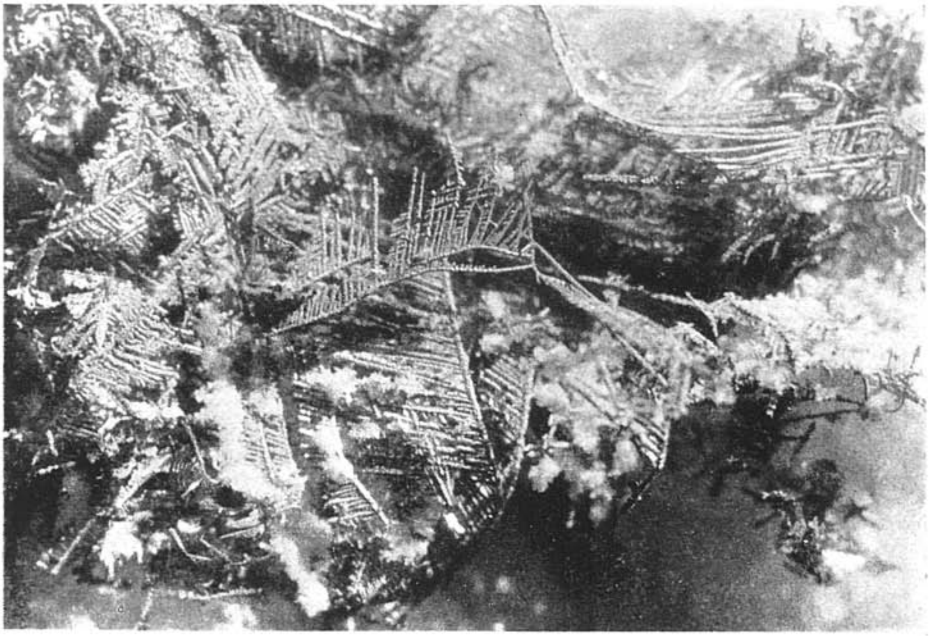

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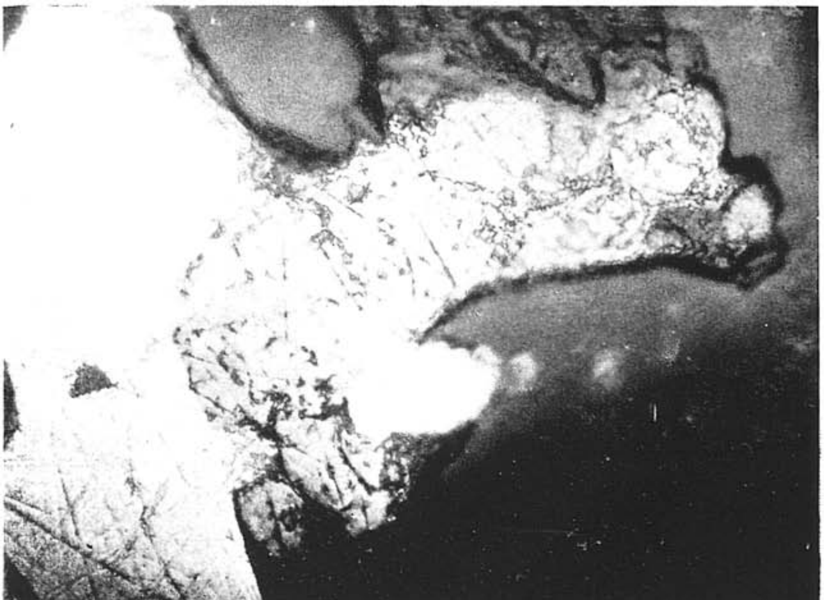

2

The text see on the page 93