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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

TOPICAL REPORT NO. 80

REPORT ON SYMPOSIUM ON PROBLEMS OF POSTMAGMATIC ORE DEPOSITION WITH SPECIAL REFERENCE TO THE GEOCHEMISTRY OF ORE VEINS

BY

R. W. BOYLE

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INTRODUCTION

The Symposium on Problems of Postmagmatic Ore Deposition with Special Reference to the Geochemistry of Ore Veins was held in Prague Czechoslovakia during the period September 16th to September 21st, 1963. The symposium was preceded by a field trip to various western Czechoslovakian (Bohemian) ore deposits and hot springs during the period September 10-14, and followed by a field trip to various ore deposits and geological institutions in eastern Czechoslovakia (Slovakia) during the period September 22-27.

The symposium was dedicated to the memory of the Czech geologist, František Pošepný and was held on the occasion of the 70th anniversary of the publication of his well known work "The Genesis of Ore Deposits" (New York, 1893). The symposium was sponsored by the Czechoslovak Academy of Sciences and the Geochemical Society. It was attended by representatives of some 24 nations.

Assistant Professor J. Kutina, Faculty of Natural Sciences, Charles University, was the chairman of the symposium and organizing committee. He was assisted by Vice-Chairmen, J.H. Bernard, Z. Pouba, and M. Vaněček; Secretary General, M. Štemprok; Organizing Secretary, Z. Nýpl and sixteen members drawn from various geological institutions in Czechoslovakia. Professor Kutina and his organizing staff deserve the thanks of all those who attended the symposium for their efficiency in organizing the field trips, in preparing an interesting technical program, and arranging many social engagements which this writer feels sure were enjoyed by all participants. In addition J.H. Bernard, the leader of the field trip to the Bohemian deposits, and J. Burian the leader of the trip to the Western Carpathians are to be complimented on the efficient manner in which the field trips were executed.

FIELD TRIP A, WESTERN CZECHOSLOVAKIA, SEPTEMBER 10-14

Participants of this field trip visited the fluorite and barite-pyrite mineralization associated with hot spring activity near Teplice, the tin-tungsten-lithium deposits of Cínovec (Zinnwald), the hot springs and spas at Karlovy Vary (Karlsbad), the Ni-Co-Ag-As-U deposits of Jáchymov (Joachimsthal), the mofette fields near Háje, the spas and hot springs at Františkovy Lázně (Franzensbad) and Mariánske Lázně (Marienbad), the dumps of the Pb-Zn Milikov and other deposits near Stříbro, the Prazdroj brewery in Plzeň, home of Pilsner Urquell beer, the kaolin open pit mine in Kraznějov, and the polymetallic veins (Pb-Zn-Ag-Ni-Co-As-U) of Příbram.

The brief comments that follow are taken from the writer's notes. The details of the deposits are given in the guide book for Excursion A (1)[1].

The fluorite mineralization near Teplice is said to be the result of past hot-spring activity and in the Pisečný quarry occurs in narrow fractures in quartz-porphyry. The fractures are related to an extensive fault system. In other places near Teplice the fluorite replaces corals in Cretaceous limestone. Samples seen by the writer from the limestone area show an intimate replacement

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[1]Numbers in parentheses refer to References at the end of this report.

of the structures of the corals by the fluorite. The fluorite occurrences are of scientific interest only and as far as could be ascertained by the writer are too low grade to be economic.

The barite-pyrite mineralization in the Lahošť quarry is apparently also the result of past hot-spring activity. It occurs in thin fractures in Tertiary quartzites. Minerals associated with the barite and pyrite include small amounts of galena and sphalerite. The barite, pyrite, galena, and sphalerite are of scientific interest only and do not occur in sufficient quantities for exploitation. The quartzite is apparently quarried for road fill, although some of the purer material may be used for other purposes.

The thermal waters of Teplice are the typical sodium-hydrogen carbonate type and are said to carry relatively high contents of barium, fluoride, lead, zinc, and copper. The source of the water is uncertain. Čadek and Malkovský (2), who have done extensive work on the hot springs, think that the water is of meteoric origin. The present writer agrees with this hypothesis from the geological and geochemical facts presented. He wonders, however, if there may not be a contribution of metamorphic water (water exuded from underlying heated rocks) to the meteoric system. The theory that the barite, fluorite, and pyrite, in the fractures in quartzite, quartz porphyry, and in corals in limestone, were deposited from thermal waters related to those now issuing at Teplice seems fairly well substantiated.

The tin-tungsten-lithium deposits of Cínovec (Zinnwald) have been mined for many years. An underground visit to one of the mines revealed that the cassiterite, wolframite, and zinnwaldite (lithium mica) occur mainly in quartz veins and pegmatitic feldspar veins and lenses in granite and in a variety of quartz porphyry invaded by the granite. Greisenization and sericitization are common, and albite is developed extensively in many zones. Kaolin (or some variety of hydrous mica) occurs in places. Veins of nearly pure zinnwaldite with a little euhedral quartz are common in some parts of the mine. Fluorite is a common mineral in all types of veins, and scheelite occurs in some veins. The deposits resemble some of those seen by the writer in Cornwall, England.

The deposits yield commercial quantities of cassiterite, wolframite, and lithium mica. The writer was told that relatively large greisen and zinnwaldite zones have been drilled and are being prepared for mining in the Cínovec area. These will yield mainly lithium and perhaps tin and tungsten as minor by-products.

The geochemistry and origin of the Cínovec deposits is of considerable interest to this writer. The marked introduction of lithium in consort with tin, tungsten, and silica suggests a mineralization stage somewhat akin to that which produces pegmatites in all granitic areas. It is certain that the veins and lenses were formed long after the consolidation of the granite, and one wonders just how this took place by magmatic differentiation. Individual veins and lenses also seem to be isolated in what may be tension fractures or dilatant zones in the granite and quartz porphyry. Diffusion processes seem to be the only solution to the problem. Probably the original quartz porphyry and granite contained an original high content of lithium (in the feldspars) and tin and tungsten (in the mafic minerals such as biotite). These may well have been mobilized during the fracturing stage and may have concentrated where low pressure zones were formed. While it is easy to envisage the process we require detailed geochemical data to substantiate it. The Cínovec deposits would seem to offer good possibilities for testing the hypothesis.

The classical deposits of Jáchymov (Joachimsthal)are well known and hence require little description. Only the dumps were visited on the excursion, but excellent suites of minerals were seen at the famous old mint in Jáchymov. One mine is said to be still working, but because this produces uranium the group were not permitted to see it. Historically it will be recalled that Jáchymov was the area that supplied the pitchblende from which Madame Curie first separated radium. In the past the veins have produced considerable quantities of Ag, Ni, Co, Bi, and U. Apparently these veins provided the bulk of the uranium mined in the Communist countries during the period 1948-1955.

The country rocks of the Jáchymov district are pre-Hercynian coarse- to medium-grained schists and gneisses of sedimentary origin and orthogneisses representing early granitic intrusives. The sediments pass into phyllites, quartzites, and graphitic schists in the less metamorphosed terrains. The sedimentary rocks are folded in an E-W direction and are invaded by Late Variscian granites and related granite porphyries and lamprophyres. Tertiary rocks include dykes of basalt and various tuffs.

Three distinct types of veins occur in the area. The oldest are quartz and quartz-feldspar veins containing small amounts of molybdenite, arsenopyrite, wolframite, cassiterite, and tourmaline. These occur near the granite and are intersected and offset by two later systems of veins. One of these systems strikes NE-SW and is mineralized with an early generation of quartz, galena, sphalerite, bornite, and chalcopyrite; the other strikes NW-SE to N-S and has a varied mineral association which consists of quartz, calcite, ankerite, uraninite, dolomite, rarely fluorite, various arsenides (skutterudite, rammelsbergite, niccolite, safflorite, lollingite), dendritic native silver, native bismuth, native arsenic, proustite, stephanite, realgar, argentite, bismuthinite, pyrite, sphalerite, galena, chalcopyrite, bornite, and arsenopyrite. From samples seen in the mint at Jáchymov and from those in the mineralogical museum of the National Museum in Prague the writer observed that the mineralization has occurred in a number of stages that were punctuated by extensive reopening of the various fissures. This is also borne out by the recent descriptions of the deposits (2) and by older descriptions in the literature of economic geology.

The sequence of elemental deposition in the Jáchymov deposits is of interest. Examination of samples and a study of the literature suggests the following sequence. A more detailed account may be found in the paper by Mrňa (2).

Stage 1. SiO_2, K, Na, Al, Mo, As, W, Sn, B, and S, present in quartz, feldspar, molybdenite, arsenopyrite, wolframite, cassiterite, and tourmaline.

Stage 2. SiO_2, Pb, Zn, Cu, Fe, S, present in quartz, galena, sphalerite, bornite, and chalcopyrite.

Stage 3. SiO_2, Ca, Fe, CO_2, present in barren quartz, calcite, and ankerite.

Stage 4. U, Ca, Mg, CO_2, F (rare), present in pitchblende, dolomite, and rare fluorite.

Stage 5. Ni, Co, Fe, As, Ag, Bi, and SiO_2, present in various arsenides, native silver, native bismuth, and ore-bearing quartz.

Stage 6. As, Sb, S, Ag, Bi, Ca, Mg, CO_2, present in various sulpharsenides and sulphantimonides, native arsenic, realgar, argentite, bismuthinite, dolomite, etc.

Stage 7. Fe, Zn, Pb, Cu, S, As, Ca, CO_2, SiO_2 (minor), present in pyrite, sphalerite, galena, chalcopyrite, calcite, and locally quartz.

The Jáchymov deposits are similar to those at Great Bear Lake, N.W.T. Canada. In some respects the depositional sequence of elements is similar although there are some marked differences. The arsenide minerals both in texture and type are similar to those at Cobalt, Ontario. The sequence of deposition of the elements is also similar in both these deposits. One wonders why uranium is not present at Cobalt. Mercury is present in small amounts at Cobalt, but as far as could be ascertained by the writer this element is lacking in the deposits at Jáchymov.

The three deposits - Jáchymov, Great Bear Lake, and Cobalt - present numerous difficulties in fixing an origin for their constituent elements. The similarities are so great in their elemental and mineralogical constitution that after seeing the three deposits one is drawn to the conclusion that some fundamental geochemical process is involved. At Cobalt the source of the elements is thought to be the Nipissing diabase, but few basic rocks are present at Jáchymov or at Great Bear Lake to which one might ascribe a source for the Ni, Co, Ag, etc. About the only correlative factor in the three deposits is the presence of sedimentary rocks - tuffs and cherts at Great Bear Lake; greywackes and conglomerates of the Cobalt series, and Keewatin black phyllites and schists at Cobalt; and meta-phyllites, etc. at Jáchymov. Could these sediments be the source beds for the elements in the deposits? Further research is required on this particular problem.

Visits were made to the hot springs and spas at Karlovy Vary (Karlsbad), Františkovy Lázně (Franzensbad), Mariánske Lázně (Marienbad), and the mofette field near Háje. Much work has been done on all of these hot springs both as regards their chemical composition and volume.

The springs at Karlovy Vary have a temperature of about 72°C and contain much sodium carbonate, sodium chloride, sulphate ion, and relatively large amounts of CO_2. Traces of many metals have been detected. They issue from faults largely restricted to granite. The warm springs of Františkovy Lázně are mainly alkaline and saline with large amounts of CO_2. One is a sodium sulphate (Glauber's salt) spring. Those at Mariánské Lázně differ greatly in their chemical composition. Most are cold springs, some are slightly acidic, others are alkaline and saline. All contain considerable CO_2. One visited by the writer contained a high ferrous sulphate content and was charged with CO_2. The mofette field near Háje consists of several vents, apparently along a fault, from which issue large amounts of CO_2 and smaller amounts of H_2S.

All of the springs are highly developed with sumptuous spas, sanatoria, baths, and modern hotels. The waters are said to have various curative properties especially for rheumatism, gout, and skin diseases, but also for cardio-vascular disorders, urinary diseases, asthma, hypertension, etc. Each spring has its own curative power. A strict regimen is prescribed for the patient and plenty of exercise and rest is advocated. The writer is of the opinion that it is the latter, rather than the spring waters, that contributes most to the betterment of the health of the patients. Certainly some of the spring waters containing Glauber's salts would soon remove any tendency to constipation and other similar disorders. Tens of thousands of Czechoslovak people visit the springs each year, and the three main spa areas enjoy an increasing influx of foreign tourists who come to "take the waters".

Despite a large amount of research on the springs there seems to be no uniform opinion on the origin of the water and their dissolved salts. The older idea is that the springs are the last gasp of magmatic activity in the areas. This idea is still adhered to by some of the Czech geologists. Others consider the springs to be of meteoric origin. The large amount of CO_2 in most of the springs is a puzzle. Determination of the source of this constituent would certainly help to solve the problem of the origin of these interesting geological phenomena.

The Milikov and other deposits near Stříbro are mainly quartz veins containing galena, sphalerite, and pyrite. The silver content of the galena is low. The veins are in an extensive series of faults that cut through quartzites, phyllites, and graphitic schists. At least two mines are working in the area.

The Příbram ore district has several working mines producing lead, zinc, silver, and some uranium. Some members of the excursion visited the underground workings of the Anna Mine in Březové Hory and others visited the "25 únor" mine in Bohutin. Prior to the underground visits all members of the excursion studied the fine mineral collection of the Příbram deposits in the new museum in Březové Hory.

The country rocks in the Příbram district are folded Palaeozoic greywackes, phyllites, and slates intruded by diorite. Dykes of diabase (greenstone) are numerous and are followed by several of the steeply dipping veins. The veins have considerable vertical extent, and mining is carried out at depths of 2,000 metres or more. The veins are banded, and several stages of mineralization are indicated. Briefly these can be grouped in two stages as follows:

Stage 1. Argentiferous galena, sphalerite, pyrite, chalcopyrite, and siderite with smaller amounts of boulangerite, jamesonite, stibnite, arsenopyrite, specularite, hematite, chlorite, and quartz.

Stage 2. Ni-Co arsenides, pitchblende, carbonates, and minor quartz.

One of the highlights of the field trip in Bohemia was the visit to the famous Urquell brewery in Pilsen, home of Pilsener beer. After a visit to the brewing chambers and the underground caverns holding the great casks for aging the brew, the party attended a beer party in the great hall of the brewery. The beer spring flowed 12° Pilsener for several hours, and it is needless to say that the party was enjoyed by all. There were about 150 on the field trip, and it was said later that some 1,000 litres of brew were consumed. Singing and dancing topped the evening off.

SYMPOSIUM, SEPTEMBER 16-21

The symposium was opened by an impressive ceremony in the Carolinum Hall of Charles University. The rector of the university presided, and there were speeches of welcome by Mr. M. Šnajdr of the Central Geological Office and Professor Kutina, Chairman of the Organizing Committee of the Symposium. Following this there was a lecture by Academician Koutek on the life work of Pošepný and a guided tour of the Carolinum building with accompanying lectures on the history of Charles University, one of the oldest universities in Europe. It may be of interest to some that Charles University was the institution in which the martyr John Huss (1369-1415), one of the precursors of the reformation, lectured and of which he later became rector. For his heresies, Huss was burned at the stake at Gottlieben on the Rhine in 1415.

The symposium lectures and discussions were spread over 5 days and included the following subjects.

1. Zoning in ore deposits and ore districts
2. Modes of metal transport
3. Pneumatolysis
4. Formation of metacrysts
5. Selective replacement processes.

The principal views on all of these subjects have been published in 105 papers in the pre-symposium volume (2). It is not possible to summarize all these here. Only the writers impressions of the discussions on some of the topics can be given.

The concept of zoning is of course an old one, but it was apparent from the discussions that zoning means different things to different investigators. All seem to agree that there are three types of zoning.

(1) Zoning on a broad regional scale within geosynclinal belts, etc.

(2) Zoning within individual ore districts - this type of zoning is often related to granitic contacts or metamorphic fronts, etc.

(3) Zoning within individual orebodies.

Most of the confusion seems to occur in the latter type of zoning, but there is also some difficulty in clearly defining zoning on a broad regional scale and within ore districts.

Kutina and his school distinguish what they call "Polyascendent zoning and Monoascendent zoning". Polyascendent zoning is said to arise from a series of separate and distinct solutions ascending at different periods to the place where the mineral assemblage is being studied. Monoascendent zoning originates from an uninterrupted ascending solution. To the present writer the terms polyascendent and monoascendent refer to processes and not to the occurrence of minerals or elements as one sees them related to some point or plane in space. The terms, therefore, combine fact and interpretation, a situation which is not entirely scientific.

Professor Park and others maintain that zoning in ore deposits and districts results from one continuous flow of mineralizing fluids rather than an introduction of fluids in time separated surges. He also maintains that structural features play a significant part in determining the composition and loci of the zones.

It was generally realized as the discussion proceeded that definitions were required for the terminology of zoning in order that all investigators know clearly what the features of zoning are and what the term "zone" means. Professor Park of Stanford University would welcome any written or verbal communications on the subject since he was appointed to chair a committee to look into the problem of clearly defining what zoning is.

While there were many excellent descriptions of zoning in ore deposits and ore districts there were practically no new ideas on just what mechanisms lead to zoning. Surely it is not beyond the wit of man to discover the precise reasons why one finds tin and tungsten deposits near granites or in high grade metamorphic terrains and lead-zinc-copper-silver, antimony, and other deposits farther removed from these contacts, generally in the low grade metamorphic (cooler) zones. Similarily, it should be possible by a judicious application of chemical principles to elucidate the processes which give rise to a sequence of elements in single deposits and to answer the problems of paragenesis.

The discussions on the modes of elemental transport brought out several ideas, none of them particularly new or conclusive.

Professor Barnes (2) was of the opinion that bisulphide complexes provide the fundamental mechanism for the aqueous transport of metallic sulphides in epithermal and telethermal deposits. These may be aided in part by the presence of halides (chlorides). Bisulphides seem capable of transporting Zn, Pb, Hg, Ag, and perhaps some other metals, but in the writer's opinion difficulty would arise with Fe and perhaps Ni. Since pyrite and pyrrhotite are so common in deposits one wonders whether bisulphides are really important.

Complexes of various types seem to be in vogue and are certainly a step in the right direction in metal transport since these chemical species are readily formed in many cases and render soluble many otherwise insoluble or slightly soluble compounds. Ganeev (2) calls upon fluoride, chloride, carbonate, sulphide, and hydroxide complexes for the aqueous transport of a variety of elements among which are Hg, Fe, Cd, Ag, Be, Cu, Al, Sn, U, Sc, Zr, and Th. Gouorov and Stunzhas (2) also call on carbonate and alkali chlorocarbonate complexes for the transport of beryllium in alkaline hydrothermal solutions highly charged with CO_2. Others call on a variety of complexes for the aqueous transport of tungsten, iron, and other elements.

Chlorides are also popular as soluble species in hydrothermal solutions and also in gaseous transport. Donald White described his recent findings of considerable quantities of the common ore metals in highly heated saline water vapour in a recent deep hole in a thermal area in California. The quantity of copper, zinc, silver, gold, and other metals is considerable and would certainly lead to a mineral deposit if precipitated. Apparently there is very little H_2S or sulphide ion present in the extracts, but if such heated vapours came into contact with other waters or sediments containing H_2S deposition of sulphides would certainly occur. Professor Krauskopf (2) discussed the role of the volatility of various metal chlorides, oxides, and hydrated oxides in metal transport. He felt that lead, zinc, iron, manganese, copper, silver, tungsten, molybdenum, and some other metals could be carried out of the crystallizing magma as volatile chlorides, oxides, or in some cases as hydrated oxides. Difficulties arise, however, with tin and in some cases with copper where this element is associated with lead and zinc in deposits.

Many investigators postulate solutions as the mode of transport of the ore and gangue elements. Others think that the metals, and presumably the gangue elements as well, are carried in the gaseous state. The present writer (2) has called on diffusion mechanisms to explain the transport of metals and gangue elements under deep seated conditions and solutions under near surface conditions. Most of the investigators call on magmas as the source of the ore and gangue elements but Boyle (2) and Bogdanov and Kutyrev (2) find a ready source for the elements in the rocks containing the deposits.

The nature of the ore bearing solutions, likewise, seems in some doubt. Certain investigators, Korzhinski, Zharikov and others (2), think that the magmas yield an acidic wave of components (CO_2, HCl, HF, H_2S) and later highly reactive acid hydrothermal solutions capable of carrying the ore and gangue elements. Others are of the opinion that the ore bearing solutions are alkaline. If the facts derived from certain volcanic phenomena have any bearing on the problem of ore solutions it seems probable that the latter are acid at the beginning. As the solutions react with the rocks through which they pass they are probably neutralized and may become alkaline. Hence both views may actually be true. The correct hypothesis (acid or alkaline) would seem to depend at which point in time and space one is dealing with the solutions.

The discussions dealing with pneumatolysis seemed to divide into two schools — those who believe that a pneumatolytic phase is possible and those who deny the existence of such a phase. This is an old question about which much has been written. An excellent review of the problem is given by Štemprok (2) and the various criteria for and against a pneumatolytic phase are well presented. To the present writer the discussions seemed to add little to the solution of the problem. Štemprok and others felt that it is doubtful whether it is useful to make a distinction between pneumatolytic and hydrothermal deposits. They argue that the field criteria such as the presence of tourmaline, topaz, and cassiterite, minerals containing volatile elements such as B and F or easily transported as volatile compounds such as SnF_4, are not sufficient to support the theory. They also point to data from various laboratory experiments which are not in agreement with the theory. On the other hand several Russian investigators, Lazarenko et al (2), Ovchinnikov (2), and Turovskii and Nosyrev (2), feel that their field and laboratory data support a pneumatolytic phase and would classify certain types of deposits, among which are some skarns, greisens, and high temperature quartz veins, etc., as the products of pneumatolysis.

The writer did not attend the short meeting on the formation of metacrysts or on selective replacement processes but took advantage of an offer to visit the laboratories of the Institute of Mineral Raw Materials in Kutna Hora, an old mining town some 50 kilometres from Prague.

VISITS TO LABORATORIES

The Institute of Raw Materials in Kutna Hora (Director, V. Zykla) is the institute charged with the investigation of all types of mineral deposits in the Czechoslovak Republic. The institute is in a relatively old building, but the laboratories are modern, well equipped, and well staffed. All of the modern methods of analysis, including assay, spectrographic, X-ray, colorimetric, and polarographic are used extensively. Especially impressive was the polarographic laboratory for the determination of traces and minor amounts of metals in practically all natural materials. The laboratory does not have a mass spectrograph, and no isotopic work is done.

Projects under investigation at Kutna Hora include a country-wide survey of the indium and other trace element content of sphalerite in all types of deposits. Two large volumes on this work have been published. Several geochemical prospecting surveys have been carried out, using water and soils in a number of mineral districts. Other investigations include various mineralogical, petrographic, and geochemical studies of ore deposits and potential ore deposits. The work is similar to that being done in the Geological Survey of Canada and in other Surveys and Geochemical Institutes.

In Prague the writer visited the teaching and research laboratories of the Faculty of Geology of Charles University. These are well appointed and would compare in most respects with other universities. Considerable work is being done on clay minerals under the direction of Professor J. Konta.

The Mineralogical Museum of the National Museum in Prague contains excellent suites of minerals, all well displayed. All of the ore minerals of Czechoslovakia can be seen, together with the gems found in the country and the tektites found in southern Bohemia and southwestern Moravia. Those interested in tektites will be pleased to know that the source of some tektites has been discovered by the Czech geologists. The source is apparently a meta-sediment (schist) and the tektites occur in depressions in the schist from which they weather out and collect in the soil. A paper describing the details will be published in the near future by the Czech geologists.

On the second field excursion the writer visited the Mining and Geological Academy in Košice. This Academy is principally a teaching institution. It has a fine mineral collection in which most of the minerals from the deposits in Czechoslovakia, and particularly those in Slovakia, can be viewed. The laboratories of the Geological Survey in Bratislava (GUDS) were also visited. This institution is housed in a new building, and the laboratories are well equipped and staffed. There are X-ray laboratories, chemical laboratories, a mass spectrographic laboratory, a spectrographic laboratory, a decrepitation laboratory, etc. Work on lead isotopes is being pursued, decrepitation of minerals is carried out, and other work common to all geological surveys is in progress.

FIELD TRIP B, EXCURSION TO SLOVAKIA, SEPTEMBER 22-27

Participants of this field trip visited the High Tatra Mountains, the barite-siderite-sulphide deposits of Rudňany, the Nižna Slaná deposit (Mano siderite orebody), the Bankov magnesite pit, the Maria Baňa siderite-tetrahedrite deposit, and the lead-zinc-copper-silver deposits of the Banská Štiavnica (Schemnitz) district. Social events included a campfire and sing-song at Počúvadlo Lake and a sightseeing tour of Bratislava.

Only brief comments will be made about the deposits visited since detailed descriptions are given in the guide-book covering the excursion (3).

The High Tatra Mountains form a part of the central zone of the western Carpathians. The geology of the western Carpathians is complex. The crystalline core consists of granitoids and folded crystalline schists developed largely from Palaeozoic sediments, volcanics, and intrusive rocks of a varied nature. Mantling these are Mesozoic, sedimentary and volcanic rocks again of a complex and varied nature. On this basic geological structure the Mesozoic series were overthrust in the form of great nappes. The individual ranges are separated by numerous basins filled with Eocene and more recent sediments.

The principal mineral bearing range in the western Carpathians is the Spišsko-gemerské rudohorie (ore mountains) which trend in a southwest direction from Košice to Banská Štiavnica and beyond. This ore mountain range is made up of a highly folded and metamorphosed Palaeozoic series of porphyritic acid volcanic rocks (now what the writer would call quartz-feldspar augen schists), tuffs, phyllites, quartzites, limestones, diabases (greenstones), etc. The Palaeozoic rocks more or less form the core of the range which is rimmed by Mesozoic complexes largely consisting of Triassic sediments. Faulting, thrusting, overthrusting with the formation of huge nappes, and uplifting continued from the middle of Palaeozoic time into the Recent making the detailed structure of the ore mountains very complex indeed.

The types of rocks and the sedimentary-volcanic history of the Spišsko-gemerské rudohorie mountains is somewhat similar to that in the Bathurst-Newcastle mineral district in New Brunswick, Canada. In both places the development of quartz-feldspar augen schists (apparently from porphyritic acid volcanic rocks and tuffs) is particularly marked. As a whole the geology of the western Carpathians is similar in many respects to that of the western Cordillera of Canada. The similarity of the geomorphology in places is also striking.

The High Tatra Mountains are composed mainly of granitic rocks with some highly metamorphosed sedimentary rocks. Lapping up on these in a most complicated manner are the Mesozoic rocks. The Tatra bear an Alpine imprint with numerous peaks, cirques, and other evidence of glaciation. There are, however, no permanent glaciers now present in the Tatras. The highest mountain in the range (and in the Carpathians) is Mt. Gerlachovka with an elevation of 2,655 metres (8,737 ft.). Mt. Lomnica has an elevation of 2,632 metres. It was a great thrill to ascend to the top of this mountain by cable car from Tatranská Lomnica. It was also interesting to see Strbske Pleso (lake).

The scenery here is much like that one sees at Banff and Lake Louise in the Canadian Rockies.

The Rudňany (formerly Kotterbach in German) ore district is characterized by a number of veins in major faults with several offshoots. The Drozdiak vein is the larger and more important of the deposits now being exploited. Most of the mining is carried out on the deeper levels, but there is some near surface activity on one of the veins. The ores now being won from the deposits include siderite and barite with smaller amounts of sulphides, mainly chalcopyrite. In the past the veins have produced silver and copper and some mercury.

The country rocks of the Rudňany deposits are mainly Palaeozoic sediments and associated igneous rocks, principally phyllites, basic tuffs, conglomerates, sandy shales, sandstones, and diabase. These were folded during the Hercynian epoch and later faulted and sheared principally in an east-west direction. The main veins of the Rudňany district occur in the east-west faults and shear zones. The veins show evidence of repeated faulting followed by mineralization. Near the close of the mineralization period the veins were block faulted in a NE-SW direction.

The principal minerals in the deposits are siderite, quartz, and barite; of less importance are ankerite, iron-dolomite, chalcopyrite, tetrahedrite, hematite, and pyrite; rare are native mercury, chalcocite, bornite, covellite, sphalerite, cinnabar, stibnite, and arsenopyrite. The principal supergene minerals in the gossans are limonite, psilomelane, and small amounts of cinnabar.

There are three generations of siderite, several generations of quartz, and two of barite, although the second generation of barite is rare. The ankerite and iron dolomite occur in two generations, pyrite is present in a number of generations, and there are three generations of chalcopyrite.

The tetrahedrite accompanies chalcopyrite and is the second most important copper mineral. An interesting feature of the tetrahedrite is the fact that it contains from 1 to 19 per cent mercury. The cinnabar and small amounts of native mercury in the gossans are evidently due to the oxidation of the mercurian tetrahedrite.

Considerable work on the zoning of elements in the deposits has been done by Bernard (3). He finds an increase of quartz with depth and a general decrease of siderite in some veins. In the Drozdiak vein ankerite, however, tends to increase with depth. Remarkable depth changes have been found in the chemical composition of siderite. The MnO content decreases with depth; in the upper parts of the veins it varies between 2.75 and 3.60 per cent, whereas in the lower parts it ranges from 2.00 to 2.75 per cent. The nickel content of siderite also decreases from 0.005 to 0.001 per cent downward in the veins. Barite is the predominant mineral in the upper sections of veins and decreases appreciably downward. Of considerable interest is the variation of the chemical composition of tetrahedrite with depth. Near the surface it contains up to 19 per cent Hg. With increasing depth the content of mercury drops to values ranging from 1 to 10 per cent. Concomitant with the decrease in mercury with depth is a slight increase of Cu, Pb, Zn, and As in the tetrahedrite.

The Bankov magnesite deposit near Košice is a series of bedded or elongated lense-like deposits within sedimentary rocks including schists, dolomites, and limestones. The lenses or beds are mined by open pit methods. The lenses have a relatively steep dip and are composed essentially of white- to greyish-white magnesite with associated dolomite. The deposits are said to be of metasomatic origin, magnesium solutions having replaced limestones, dolomites, or limy schists. To the writer they appeared to be mainly of sedimentary origin, with perhaps some local redistribution of magnesia during the metamorphism of the sediments.

The Maria Baňa copper veins in Rožňava lie principally in volcanic porphyrites (quartz-feldspar augen schists and sericite schists) which are interbedded in places with phyllites. The vein has been mineralized in two stages - the first led to the development of siderite and the second to quartz and sulphides. The sulphides include tetrahedrite (which carries up to 2.2 per cent Hg and 1.6 Bi), pyrite, pyrrhotite, chalcopyrite, arsenopyrite, and very small amounts of gersdorffite, ulmannite, sphalerite, galena, and various bismuth and lead sulphosalts. Barite occurs in places, tourmaline and albite are common, and magnetite is present in some of the ore seen by the writer. Native bismuth is rare. In the oxidized zone the principle minerals are limonite and quartz with some barite. Secondary cinnabar from the oxidation of mercurian tetrahedrite is common, and there is some malachite, azurite, delafossite, native copper, covellite, and native silver in the gossan or in the zone immediately below the gossan.

The Banská Štiavnica (Schemnitz) ore district is one of the oldest mining areas in Europe (4) and certainly one of the most fascinating for a student of ore genesis. It is said that mining commenced with the Celts and it has continued intermittently to the present day. In the 15th and 16th centuries the veins yielded mainly gold and silver from the enriched oxidized parts of the deposits. In the 18th and 19th centuries the veins continued to produce gold and silver in addition to lead and some copper. After 1866 the output declined, and mining more or less ceased by the twentieth century. After the Second World War a development program outlined sizable ore reserves and mining was begun again using modern methods and machinery. The deposits now are chiefly exploited for their lead, zinc, and copper ores.

The country rocks in the vicinity of the Banská Štiavnica deposits are mainly Neogene volcanics which were poured out during the final magmatic phase of the Alpine-Carpathian orogenesis. They consist of a complex series of rocks, principally pyroxene andesites and their associated pyroclastics, tuffs, amphibole-biotite andesite, basalts, dacites, dacite dykes, rhyolites, rhyodacites, trachytes, fresh water quartzites, and water-lain tuffs. These rocks in part are invaded by granodiorite and quartz diorite. Some of the basic rocks are extensively chloritized (propylitized), but it is said that this alteration is not intimately related to the mineralization of the veins.

The veins are developed in faults, principally in strongly propylitized pyroxene-andesites and less commonly in dacite, granodiorite, and diorite. The gangue mineral is principally quartz with hematite in places, and there is some carbonate, rhodonite, and barite in some parts of the veins. The sulphides include pyrite, galena, sphalerite, chalcopyrite, and tetrahedrite. The near surface parts of the veins are highly oxidized and have yielded much silver and gold. The principal supergene mineral is limonite in which some malachite, gypsum, calcite, and various secondary silver and lead minerals are present.

The andesites, dacites, granodiorites, and diorites have been propylitized for considerable distances from the veins and in places the propylitization takes on a regional character. Immediately adjacent to several of the veins there is an intense kaolinization in some places and silicification in others.

The individual veins are extremely complex bodies in which several periods or stages of mineralization can be discerned. In the Terezia vein the writer could make out at least five stages and there may be more. The first stage appears to have given rise mainly to rhodonite or quartz in places, followed by galena, sphalerite, chalcopyrite, etc. Then followed a further introduction of quartz, hematite, and carbonate. Brecciation then took place and was followed by the deposition of quartz, carbonates, and chalcopyrite. The last period resulted mainly in the deposition of vuggy quartz. The vein structures are very complex, exhibit a marked brecciated character, and have well developed cockade structures, crustified banding, and numerous vuggy parts. This makes the determination of the mineralization stages difficult and uncertain during a short visit. Kodera (3) has, however, given an extensive account of the veins and the zoning in the Banská Štiavnica district to which the interested reader is referred for details.

CONCLUSIONS ON THE SYMPOSIUM

In the writer's opinion the symposium accomplished the following:

1. It brought together economic geologists and geochemists from some 24 nations to discuss formally and informally data on all types of ore deposits and modes of formation of these deposits.

2. The 105 papers published in the Symposium Volume and the discussions which will be published later probably encompass all of the views now extant on topics such as zoning, elemental transport, pneumatolysis, and selective replacement. The volume is, therefore, an up-to-date account of the state of our knowledge on epigenetic deposits.

3. The field trips which formed part of the symposium permitted those who attended them to see in a general way the geology of Czechoslovakia and in a more detailed way some of the features of the classical deposits of Bohemia and Slovakia. Since these deposits, particularly those in Bohemia, have been described since Agricola's time and since many of the theories of origin of epigenetic deposits have been based on the facts gained from a study of these particular deposits, one could gain a historical sense of the theory of epigenetic ore genesis.

4. The opportunity to meet a large number of geologists and geochemists from numerous other lands probably helped many, especially the younger ones, to orient themselves and to realize that the problems in ore geology are the same throughout the world and not restricted to political boundaries.

At the close of the Symposium it was agreed to hold another in two or three years time. The country suggested was Yugoslavia. The topics are yet to be decided. Suggestions should be sent to Professor J. Kutina, Faculty of Geology, Charles University, Prague or to the organizing committee of the new symposium when it is formed.

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