MINERALOGICAL CHARACTERISTICS OF THE DEPOSITS AND TEXTURES OF THE ORE MINERALS

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ABSTRACT

The deposits in the Cobalt and Gowganda areas are vein-type deposits composed of ore minerals in carbonates. The ore minerals are arsenides, native metals, sulphides and oxides. The arsenides are present in assemblages classified as Ni-As, Ni-Co-As, Co-As, Co-Fe-As, and Fe-As, with the Co-As assemblage being most abundant. The main native metal is silver, and it forms a high-grade silver ore in the parts of the veins containing the Ni-Co-As and Co-As assemblages; the grade is medium to low in the parts containing the Co-As and Co-Fe-As assemblages, and low to very low in the parts containing the Fe-As and Ni-As assemblages. The silver occurs as cores of arsenide rosettes, as veinlets in arsenides and carbonates, and in association with sulphides. That at the cores of rosettes is interpreted as the earliest mineral in the ore, and the arsenides surrounding it as later minerals that were deposited around it. The silver occurring as veinlets in arsenides and carbonates, however, is interpreted as a late variety, and that associated with the sulphides as still later.

The sulphides are present as disseminated grains, veinlets, and colloform bodies. They occur in the ore veins, wall rock, and in Keewatin interflow rocks. Textural relationships suggest that most of the sulphides were in the rock prior to ore deposition, but that they were re-mobilized and re-deposited in and around the ore veins during the mineralization period. The distribution of ore minerals in the veins, however, suggests that some of the sulphides may represent a late phase of the main ore fluids.

INTRODUCTION

The mineralogical characteristics of silver deposits in the Cobalt-Gowganda region were determined from a study of approximately 1,000 samples collected from 13 mines during the period of 1964-67, and from 146 samples obtained from the Royal Ontario Museum. The samples collected during 1964-67 were taken from 70 ore veins, shear zones, and wall rocks. Wherever possible the samples were taken systematically along the veins and located with respect to positions within the veins, distances from the Nipissing diabase, and other geological features. The samples obtained from the Royal Ontario Museum had been taken from 46 mines during the period of about 1905 to 1930. The characteristics of the deposits determined in this study include most of those reported by previous workers (Campbell & Knight 1906; Ellsworth 1916; Todd 1926; Thomson 1930; Bastin 1949 and 1950; Montgomery 1948; Scott 1964; Kulkarni 1968; and Petruk 1966, 1967, 1968).

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The silver deposits consist of carbonates and ore minerals *. The carbonates occur as veins, and the ore minerals occur in the veins, and to a small extent in the wall rock and shear zones.

Carbonates

The carbonates occur as dolomite veins, calcite veins, and calcite veinlets. The dolomite veins occur in Huronian sediments, Keewatin volcanics and Nipissing diabase, and form most of the ore veins in the Cobalt area and Casey township. These veins are composed of dolomite, ore minerals, chlorite and calcite, and contain vugs lined with crystals of calcite, quartz and pyrite.

The calcite veins occur in Nipissing diabase, and in faults. They consist of calcite, ore minerals, and chlorite, and contain vugs lined with crystals of calcite, quartz and sulphides. The calcite is present as large translucent rhombohedral and scalenohedral crystals, white sugary-textured rhombohedral crystals and irregular pink rhombohedral crystals, and contains inclusions of quartz, dolomite and chlorite. Some of the large euhedral crystals are black, apparently coloured by minute inclusions of arsenides.

The calcite veinlets are present along the boundary between dolomite veins and the wall rock and are generally separated from the dolomite veins by a thin layer of chlorite. They contain inclusions and veinlets of quartz, chlorite and ore minerals.

Ore Minerals in the Veins

The ore minerals in the veins are arsenides, native metals, sulphides and oxides. They occur as masses and disseminated grains in the carbonate veins, and are present along the entire length of some veins, intermittently in others, and only in a few places in still others. In some places the mineralization extends across the entire width of the veins, whereas in others it is in the middle portions (Fig. 47), or on one or both sides (Fig. 48).

Arsenides

The arsenides found in the veins are nickel, cobalt, and iron varieties, and they occur in distinct mineral assemblages. The assemblages can be

* The term "ore mineral" as used in this report does not have an economic connotation.

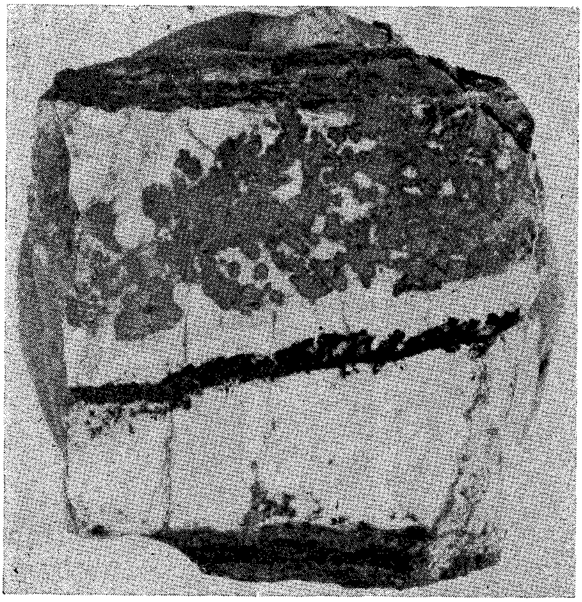

FIG. 47. Photograph of a polished face of a hand specimen of an ore vein showing the distribution of ore minerals (grey) in dolomite (white). The black areas in the photograph represent chlorite. This sample is about 2½ in. × 2½ in. (Patricia Vein, 91 foot level, Hi-Ho mine).

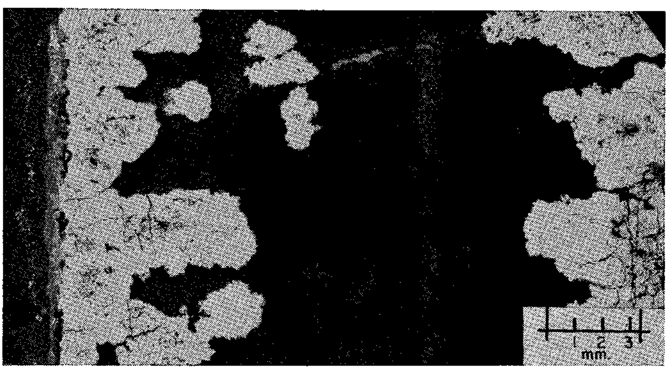

FIG. 48. Photomicrograph of a polished section of an ore vein showing arsenides at both sides of the vein (white), and sulphides at the boundary between the vein and wall rock (grey at left side of photograph). The block area between the arsenides represents dolomite in the middle of the vein. Grains of chalcopyrite and tetrahedrite are in calcite at the centre of the vein (from Petruk 1968).

classified as (1) Ni-As, (2) Ni-Co-As, (3) Co-As, (4) Co-Fe-As, and (5) Fe-As, and they generally occur in specific parts of the veins as shown in Table 12.

(1) *Ni-As assemblage* — The Ni-As mineral assemblage occurs at the ends, tops and bottoms of many veins, and in the main parts of a few small veins. The minerals in this assemblage are largely nickel arsenides and they occur as masses, botryoidal bodies, rosettes, layers, veinlets and disseminated grains in carbonate. The masses include simple monomineralic ones, more complex ones composed of nickeline intergrown with breithauptite, cobaltite and safflorite, and very complex ones composed of intergrowths of rammelsbergite, cobaltite, gersdorffite, pararammelsbergite, nickeline, skutterudite, safflorite and ullmanite. Some masses contain veinlets of late nickeline, cobaltite and sulphides.

The botryoidal bodies vary from one to three inches in diameter. They are composed of concentric layers of pararammelsbergite, nickeline, rammelsbergite, cobaltite and safflorite (Fig. 49). The cobalt arsenides (cobaltite and safflorite) form the outside layers, and pararammelsbergite the cores.

The rosettes are up to 6 millimeters in size. Some consist of a small core of nickeline and cobaltite, a wide central layer of rammelsbergite, an intermediate layer of cobaltite and nickeline, and an outer layer of safflorite (Fig. 50). Other rosettes consist of plumose-textured rammelsbergite surrounded by safflorite (Fig. 51).

The layers of arsenides in the Ni-As assemblage have the same mineralogy as the rosettes, with the minerals nearest the wall rock corresponding to the minerals at the cores of the rosettes, and the minerals in the centre of the veins corresponding to those in the outer layers of the rosettes (Fig. 52). Hence, the layers of minerals generally occur in the sequence cobaltite, nickeline, rammelsbergite, cobaltite, safflorite and arsenopyrite,

TABLE 12. IDEALIZED LOCATIONS OF ASSEMBLAGES IN VEINS.

	Location in Vein	
Assemblage	Veins above mid-line of diabase sill	Veins below mid-line of diabase sill
Ni-As	bottom, and occasionally at ends and top	top, and occasionally at ends and bottom
Ni-Co-As	lower part	upper part
Co-As	middle	middle
Co-Fe-As	upper part	lower part
Fe-As	top and ends	bottom and ends

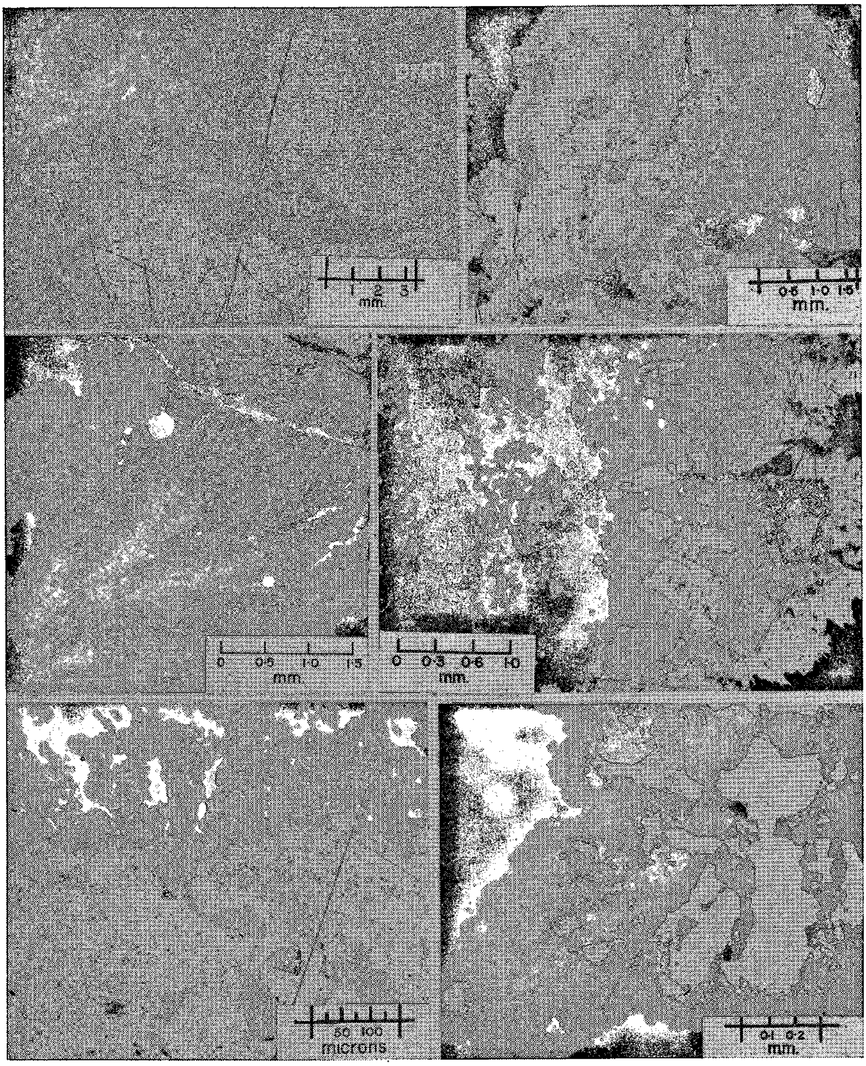

FIG. 49. (Top left) A boytryoidal body showing pararammelsbergite (prm) surrounded by concentric layers of nickeline (nic), rammelsbergite and nickeline (rm and nic), cobaltite (cob) and safflorite (saf). (Rusty Lake mine).

FIG. 50. Photomicrograph showing a cluster of rosettes, each of which is composed of a core of nickeline (grey), a wide central layer of rammelsbergite (white), an intermediate layer of cobaltite (grey), and a narrow outer layer of safflorite (light grey). The black areas represent dolomite and calcite. (Vein 8, 4th level, Silverfields mine) (from Petruk 1968).

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outward from the wallrock. In some places, pararammelsbergite is present as large euhedral crystals, and in other places the cobaltite is partly replaced by gersdorffite that is intimately intergrown with rammelsbergite (Fig. 53).

In some places veinlets of nickeline and cobaltite, partly replaced by gersdorffite, are present along calcite grain boundaries and around chlorite inclusions in calcite. Some of the chlorite has been partly replaced by sulphides, hence the arsenide veinlets surround sulphide-chlorite grains.

(2) *Ni-Co-As assemblage* — The Ni-Co-As mineral assemblage occurs in the parts of the veins between the Ni-As and Co-As assemblages and large amounts of silver are generally associated with it. This assemblage is characterized by a predominance of nickel and cobalt arsenides, with nickeline being the main nickel arsenide nearest the Ni-As assemblage, and pararammelsbergite nearest the Co-As assemblage. The silver in the parts of the veins characterized by nickeline consists of complex intergrowths of native silver and allargentum, and is referred to as "Ag-Sb minerals" in this paper. The silver in those parts of the veins characterized by pararammelsbergite consists largely of native silver.

The ore minerals in the part of the Ni-Co-As assemblage characterized by the presence of nickeline occur as rosettes, veinlets and disseminated grains in carbonate. The rosettes are present as separate individuals and clusters of individuals (Fig. 54). Many of the separate rosettes are scattered haphazardly throughout the carbonate, but those near fault zones are attached end-to-end like a chain, and the chains are arranged in dendritic

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FIG. 51. Photomicrograph of a rosette composed of plumose-textured rammelsbergite surrounded by safflorite. The black spots represent points that were analysed by means of the electron probe microanalyser. (Vein 24, 420 level, Siscoe metals of Ontario, Gowganda).

FIG. 52. Photograph of a layered Ni-As assemblage which occupies the right half of the photograph. It consists of nickeline (dark grey), euhedral crystals of pararammelsbergite (white), cobaltite and safflorite (light grey, not distinguishable). The black area at the right side of the photograph represents carbonate in the vein and that in the left represents wall rock. The wall rock contains two layers of disseminated cobaltite parallel to the edge of the vein. (Vein 2, 3rd level, Silverfields mine) (from Petruk 1968).

FIG. 53. (Bottom, left) Photomicrograph of a polished section showing cobaltite (grey) partially replaced by gersdorffite (white). The gersdorffite is intimately intergrown with rammelsbergite and cannot be differentiated from rammelsbergite in this photograph. (Vein 1, 4th level, Silverfields mine) (from Petruk 1968).

FIG. 54. Photomicrograph of a rosette composed of "Ag-Sb minerals" (white) and nickeline (dark grey), surrounded by safflorite (medium grey). (Vein 1, 401 stope, Silverfields mine) (from Petruk 1968).

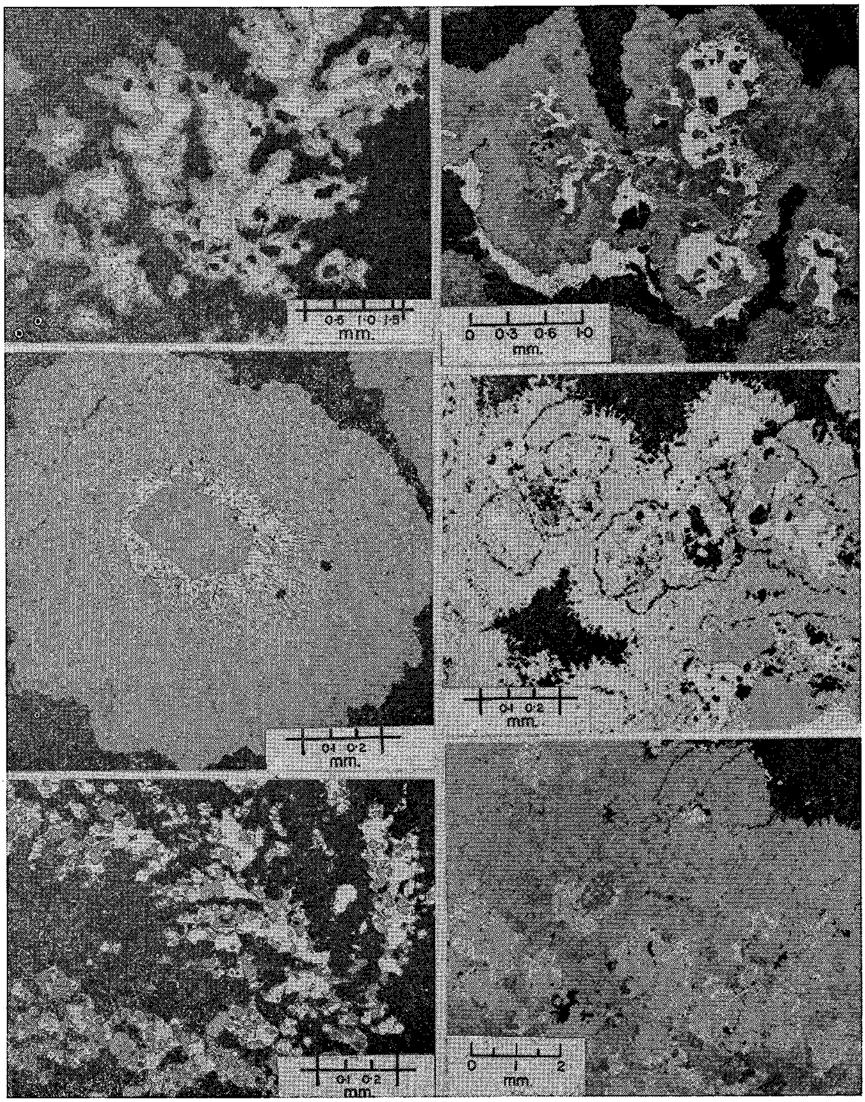

FIG. 55. (Top, left) Photomicrograph of a cluster of rosettes in the form of an algae-like structure. The white areas at the cores represent the "Ag-Sb minerals", and the grey areas around it represent safflorite intergrown with cobaltite. (Vein 11, 3rd level, Silverfields mine) (from Petruk 1968).

FIG. 56. Photomicrograph of a polished section of the Ni-Co-As assemblage showing rosettes surrounded by the "Ag-Sb minerals" (white) and containing "Ag-Sb minerals" (white) and nickeline (grey) at the cores. (Patricia Vein, 91 level, Hi-Ho mine).

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patterns. In other places the clusters of individuals are grouped together in such a manner as to form bodies that have the appearance of algae (Fig. 55), and in still others they are coalesced into masses. In many places the rosettes are surrounded by the "Ag-Sb minerals" (Fig. 56), and many contain veinlets of the "Ag-Sb minerals", pyrargyrite, stephanite, tetrahedrite and acanthite.

The rosettes are concentrically zoned. The outer portion consists of safflorite, cobaltite and/or skutterudite, and in some places is bordered by a layer of cobaltite (Fig. 57). Safflorite, the main constituent in the outer portion, is present as prismatic crystals in a radial pattern around the cores. In some places a second layer of prismatic safflorite crystals surrounds the safflorite and outer-layer cobaltite (Fig. 58). The safflorite in the outer layers coalesces with safflorite in other rosettes, thereby forming masses. The cores consist of different minerals with a variety of textures. Most consist of the "Ag-Sb minerals" with small and large inclusions of a variety of arsenides including nickeline, breithauptite, safflorite, cobaltite and skutterudite. In a few places acanthite, pyrargyrite and stephanite are associated with the "Ag-Sb minerals" as replacements.

In some places the "Ag-Sb minerals", and nickeline, breithauptite, cobaltite and safflorite are present as networks of veinlets and irregular grains in carbonate. About one-quarter to one-half of the minerals in the networks consist of the "Ag-Sb minerals"; hence the networks form a very high-grade silver ore (Fig. 59). The ore minerals in stope 606 in the Glen Lake mine, were present as networks of veinlets, and hence provide an example of this type of occurrence.

FIG. 57. (Centre, left) Rosette composed of a core nickeline (dark grey) surrounded by "Ag-Sb minerals" (white) then a layer of safflorite (light grey) and cobaltite (unresolved at this magnification) and finally a layer of cobaltite (grey). (Vein 11, 3rd level, Silverfields mine) (from Petruk 1968).

FIG. 58. A cluster of rosettes surrounded by safflorite. The clusters are outlined by a black line that represents the ends of the safflorite crystals in the outer layers of the rosettes. (Vein 11, 3rd level, Silverfields mine) (from Petruk 1968).

FIG. 59. (Bottom, left) Photomicrograph of a polished section showing a network of veinlets composed of "Ag-Sb minerals" (white) associated with nickeline and breithauptite (grey) unresolved in the photograph. (Vein 13, 3rd level, Silverfields mine) (from Petruk 1968).

FIG. 60. Pararammelsbergite portion of Ni-Co-As assemblage showing masses of ore minerals composed of clusters of rosettes. The rosettes consist of a core of pararammelsbergite (grey) native silver (white) and skutterudite (unresolved), and an outer layer of safflorite (grey) with minute cobaltite grains. A veinlet of native silver is also present outside the ore mineral mass. (Vein 1, 4th level, Silverfields mine) (from Petruk 1968).

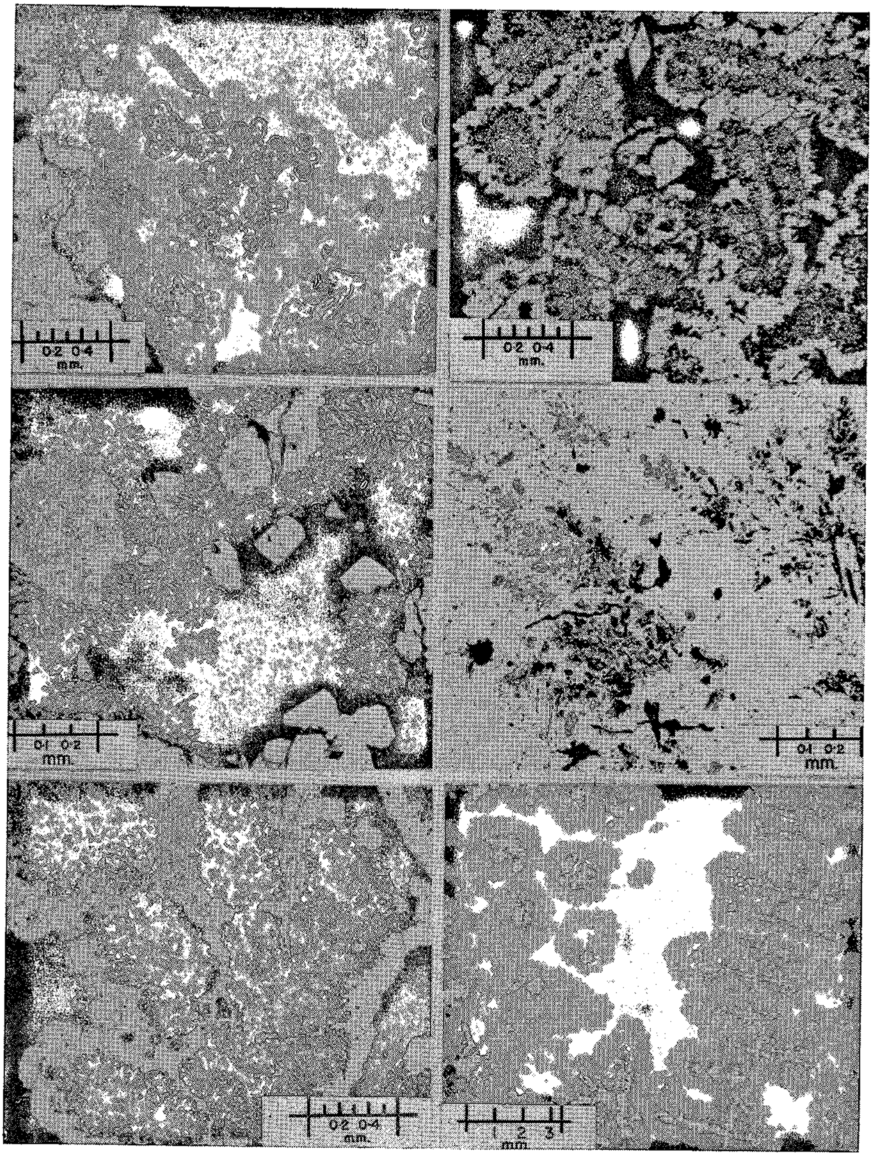

FIG. 61. (Top, left) Photomicrograph of a polished section of massive arsenides showing an area that was etched with HNO_3 in order to bring out the structure of the rosettes. The safflorite in the outer layers was attacked by acid and is dark grey, whereas the skutterudite and cobaltite were unaffected and are white. (Vein 11, 3rd level, Silverfields mine) (from Petruk 1968).

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The ore in the part of the Ni-Co-As assemblage characterized by the presence of pararammelsbergite is similar to that in the nickeline-rich portion, but most of the rosettes are clustered together into masses (Fig. 60). In addition, pararammelsbergite, rather than nickeline and breithauptite, is at the cores of the rosettes, and the native silver does not contain allargentum. It is further to be noted that pararammelsbergite and native silver at the cores are generally enclosed by skutterudite and in some places these minerals are intergrown with skutterudite in a graphic pattern.

(3) *Co-As assemblage* — The Co-As assemblage occurs in the main parts of most veins, and is characterized by large amounts of cobalt arsenides. The arsenides are present as (a) rosettes (b) irregular grains intimately intergrown, and (c) disseminated grains in carbonate.

The rosettes occur as clusters (Fig. 61), individuals aligned end-to-end like strings of beads (dendritic structure), and separate individuals in carbonate. They vary from massive varieties composed largely of arsenides to clusters of disseminated ore minerals in carbonate armoured with a corona of massive arsenides (Fig. 62). The massive varieties consist of an outer layer and a core (Fig. 63). The outer layer is safflorite that is generally present as prismatic crystals oriented radially around cores. In some places the safflorite is intergrown with cobaltite and skutterudite, and some is bordered by cobaltite and arsenopyrite. The cores consist of skutterudite ranging from large crystals to minute grains. Some of the large crystals are partly replaced by tetrahedrite, chalcopyrite, native silver, pararammelsbergite, safflorite, cobaltite and other minerals. These minerals are generally present as irregular grains and veinlets, but some occur in dendritic patterns

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FIG. 62. Rosettes composed of a corona of arsenides around cores of disseminated arsenides in carbonate. (Vein 2, 3rd level, Silverfields mine) (from Petruk 1968).

FIG. 63. (Centre, left) Photomicrograph of a polished section etched with HNO_3. It shows radial safflorite crystals (etched) around skutterudite-cobaltite cores (unetched). Large euhedral arsenopyrite crystals are present in the carbonate outside the rosettes (unetched). (Vein 4, 4th level, Silverfields mine) (from Petruk 1968).

FIG. 64. Large skutterudite grains at the cores of the rosettes. The skutterudite grains contain calcite (black) and tetrahedrite (grey) in the form of dendritic bodies. (Silverfields mine) (from Petruk 1968).

FIG. 65. (Bottom, left) A cluster of rosettes that contain cores of minute skutterudite grains embedded in calcite and grouped together into dendritic bodies. The dendritic skutterudite is surrounded by safflorite (white). (Vein 2, 3rd level, Silverfields mine) (from Petruk 1968).

FIG. 66. A dendritic texture formed by rosettes. The rosettes consist of an outer layer of safflorite with cruciform native silver. (Vein 20, 355 stope, Langis mine).

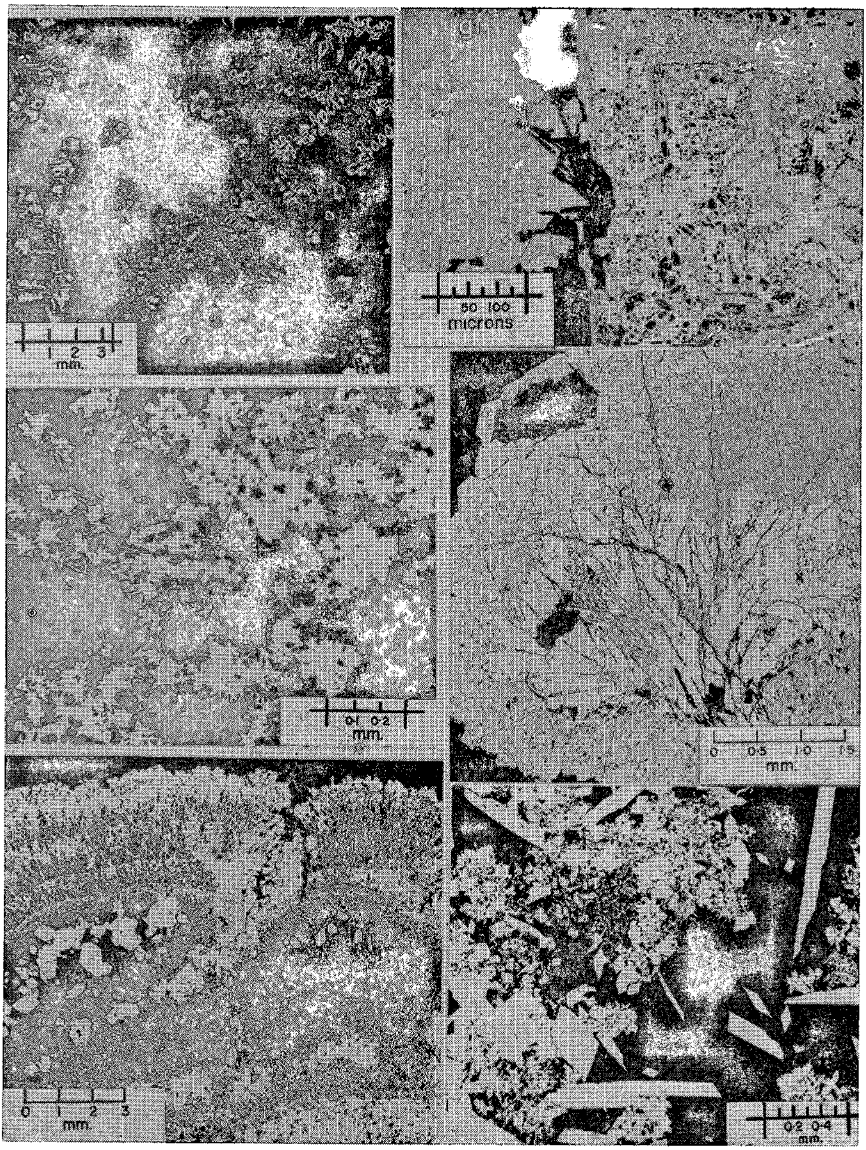

Fig. 67. (Top, left) A dendritic texture formed by rosettes aligned like strings of beads in calcite. The rosettes consist of cobaltite surrounded by skutterudite (unresolved at this magnification, and contain cruciform calcite. (Vein 37, 235 level, Langis mine).

Fig. 68. Photomicrograph showing a euhedral skutterudite crystal (sk) partially replaced by rammelsbergite (rm). Some safflorite (sf) and gersdorffite (gf) are also present. (Rusty Lake mine).

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(Fig. 64), and some have the appearance of graphic intergrowth. The minute skutterudite grains at the cores are disseminated in carbonate and some are also distributed in a dendritic pattern (Fig. 65). The presence of a dendritic pattern in the fine-grained skutterudite, and apparently preserved in the coarse-grained variety, suggests that the large skutterudite grains represent a recrystallized phase of the fine-grained variety. The pattern of the fine-grained skutterudite is similar to ice crystals on cold windows, and likely formed by crystallization of this mineral into an open space under suitable conditions. Arsenopyrite in the Co-As assemblage occurs as large euhedral crystals outside the rosettes, and as veinlets cutting the rosettes. The rosettes in this assemblage also contain a few minute veinlets of nickeline.

Many rosettes do not contain the ideal distribution of minerals described above, and some consist almost entirely of safflorite with cores of native silver.

The shell-like coronas on the rosettes consist of fine-grained safflorite, of cobaltite and skutterudite, of cobaltite intergrown with ullmanite, of fine-grained skutterudite surrounded by cobaltite, and of cobaltite surrounded by skutterudite. These coronas enclose barren carbonate, and carbonate with disseminated ore minerals. The disseminated ore minerals are present as minute grains and large euhedral crystals. The minute grains are composed of cobaltite, skutterudite, sulphides, native silver and native bismuth, and the larger euhedral crystals of either safflorite or arsenopyrite.

The rosettes aligned end-to-end like strings of beads simulate a dendritic texture (Figs. 66 and 67). Some of the cores of these rosettes are cruciform, some are euhedral, and others are irregular. They consist of calcite, native silver, acanthite, pyrargyrite, tetrahedrite, bornite, and calcite with disseminated arsenides and sulphides.

The irregular grains of intimately intergrown arsenides are present as masses of safflorite, skutterudite, cobaltite and arsenopyrite, and the distri-

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FIG. 69. (Centre, left) Stellate grains of safflorite in calcite. (Vein 2, 4th level, Silverfields mine) (from Petruk 1968).

FIG. 70. Rosette composed of alloclasite (grey) surrounding safflorite (white). (Vein 8, 4th level, Silverfields mine).

FIG. 71. (Bottom, left) Colloform body composed of layers of cobalt arsenides and euhedral crystals of arsenopyrite. (Vein 8, 4th level, Silverfields mine) (from Petruk 1968).

FIG. 72. Euhedral arsenopyrite crystals and very fine-grained arsenopyrite disseminated in carbonate. (Vein 13, 4th level, Silverfields mine) (from Petruk 1968).

bution is variable. Some of these masses form veins up to 15 inches wide, and most of these veins contain some bismuth and only trace amounts of silver. In a few places large cubic skutterudite crystals are present and they are partially replaced by calcite, cobaltite, pararammelsbergite, rammelsbergite and nickeline (Fig. 68).

The disseminated grains in carbonate are generally present as separate grains of the various arsenides described above. In a few places, stellate grains of safflorite are present (Fig. 69).

(4) *Co-Fe-As assemblage* — The Co-Fe-As assemblage of minerals is characterized by significant amounts of arsenopyrite. The arsenides in this assemblage are arsenopyrite, skutterudite, cobaltite, safflorite and alloclasite. They occur as rosettes, as disseminated grains in carbonate, as irregular intimately-intergrown grains, and as colloform bodies. The rosettes have similar characteristics to those in the Co-As assemblage but they are less common, and fewer exhibit the dendritic structure. In addition, they contain numerous arsenopyrite veinlets, large arsenopyrite crystals, and the outer layers of some rosettes are composed of either arsenopyrite or alloclasite. For example the rosettes at the west end of Vein No. 8 in the Silverfields mine, Cobalt, are composed of safflorite surrounded by alloclasite (Fig. 70).

Disseminated grains of cobalt arsenides in carbonate are more abundant in the Co-Fe-As assemblage than in the Co-As assemblage, and large euhedral arsenopyrite crystals replace and surround them. The disseminated grains are largely skutterudite and cobaltite, and are generally only a few microns in size. In some places, particularly in the Siscoe mine at Gowganda, stellate crystals of safflorite are surrounded by arsenopyrite.

The colloform bodies are composed of successive layers of arsenides and are up to several inches in size (Fig. 71). Each layer consists of radially-oriented dendrites, with a corona of massive arsenides around the ends of the dendrites. The dendrites are largely skutterudite, but they also contain some cobaltite, arsenopyrite and safflorite. The coronas of massive arsenides are largely of arsenopyrite, but some also contain cobaltite, safflorite and skutterudite.

(5) *Fe-As assemblage* — The Fe-As assemblage occurs at the ends of the veins and is characterized by large amounts of arsenopyrite, and only small amounts of the other arsenide minerals, notably skutterudite, cobaltite, loellingite and safflorite. In addition, the arsenides usually contain veinlets of native bismuth, galena and marcasite. The arsenopyrite occurs as large and small euhedral crystals, and as colloform bodies, whereas the other arsenides occur as remnants in arsenopyrite and as disseminated grains in carbonate. The large euhedral arsenopyrite crystals are present

as disseminated grains in carbonate (Fig. 72) and as masses. Some are zoned, and a few are bordered by narrow layers of loellingite. These euhedral crystals contain remnants of the other arsenides including loellingite and fine-grained arsenopyrite. Some remnants are present as irregular grains, others as rounded skutterudite grains, and still others as networks that are generally a very fine-grained anisotropic cobaltite (Fig. 73). The fine-grained arsenopyrite is present as disseminated grains in carbonate. Some is scattered haphazardly, and some is in the form of coronas. Some coronas surround zones of disseminated arsenides in carbonate, and others surround grains of other ore minerals. In one place in the Nipissing 407 mine, the coronas surround zoned magnetite. The skutterudite in the Fe-As assemblage generally surrounds cobaltite.

The colloform bodies are similar to those in the Co-Fe-As assemblage, but they consist largely of arsenopyrite.

In some places in South Lorrain township, veins containing the Fe-As mineral assemblage have alternate layers of barren carbonate and ore minerals in apparent stratification (Fig. 74). In the ore-mineral layers, large euhedral arsenopyrite crystals and rounded grains of a variety of arsenides are disseminated in the carbonate. This structure suggests that the main arsenides in this part of the vein were transported in the form of mineral grains from another part of the vein and re-deposited without recrystallization. The arsenopyrite crystals, however, were either deposited later or were recrystallized.

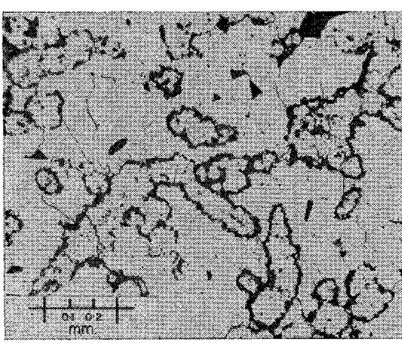


FIG. 73. Massive arsenopyrite with inclusions of very fine-grained cobaltite. (Vein 15, 5th level, Silverfields mine) (from Petruk 1968).

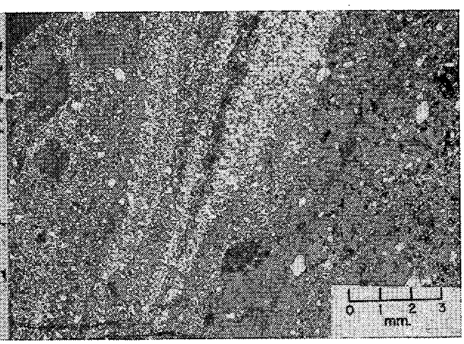
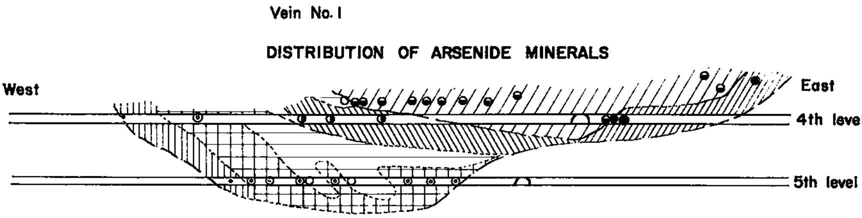


FIG. 74. Photomicrograph of a sample from South Lorrain township showing layers of ore minerals in carbonate. The large euhedral crystals are arsenopyrite, and the minute grains are arsenopyrite, cobaltite and skutterudite. (Canadian Keeley mine).



LEGEND

= Ni-As assemblage
= nickeline portion Ni-Co-As assemblage
= pararammelsbergite portion Ni-Co-As assemblage
= Co-As assemblage
= Co-Fe-As assemblage
= Fe-As assemblage

FIG. 75. Longitudinal section of Vein 1 in the Silverfields mine showing distribution of arsenides (from Petruk 1968).

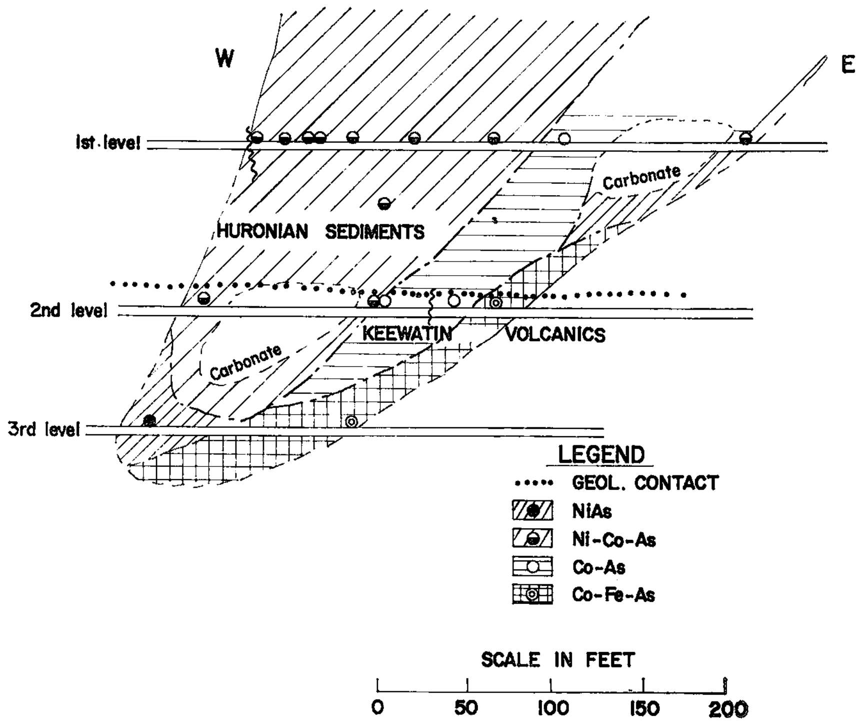


FIG. 76. Longitudinal section of Patricia vein in the Hi-Ho mine showing distribution of arsenides.

(6) *Distribution of the arsenide assemblages* — The arsenide assemblages are gradational from one to another, and are distributed systematically in most veins. Hence, veins below the diabase generally contain the Ni-As and Ni-Co-As assemblages near the top, Co-As and Co-Fe-As assemblages in the mid-parts and the Fe-As assemblage at the bottom. An example of a vein zoned in this manner is Vein No. 1 in the Silverfields mine which occurs in Huronian sediments below diabase (Fig. 75). Veins in the upper part of the diabase (Scott 1964), and in Keewatin volcanics above it, generally contain the Ni-As and Ni-Co-As assemblages at the bottom, the Co-As and Co-Fe-As assemblages in the mid-part, and the Fe-As assemblage at the top. This distribution of arsenides shows that the parts of veins nearest the centre line of the diabase are enriched in nickel arsenides, and the parts farthest away from it are enriched in iron arsenides.

In some veins variations and reversals of the zoning are present, and in others zoning is absent. For example, the Patricia vein which occurs in Huronian rocks below diabase in the Hi-Ho mine, Cobalt, has an assemblage of Ni-Co-As minerals in the top and mid-parts, Ni-As at the bottom at one end, and Co-Fe-As at the bottom at the other end of the vein (Fig. 76). Reversals in zoning are suggested from a study that was made by Thomson (1930), and from the reported occurrences of massive nickeline at the bottom of the Main La Rose vein at Cobalt which occurs in Huronian sediments below diabase (personal communication — local mine operators). Thomson (1930) found that nickeline was most abundant farthest from the diabase in the mines on the Mining Corporation and Nipissing Mines properties at Cobalt, and that arsenopyrite and loellingite are most abundant nearest the diabase in the O'Brien mine at Cobalt. The writer found that most small veins are not zoned, and that unzoned veins generally consist of the Co-Fe-As assemblage of minerals.

Parts of some veins are layered, with one layer being adjacent to the wall rock and another in the middle of the veins. In some places the layers adjacent to the wall rock consist of the Ni-As assemblage of minerals, and those in the centre of either the Co-As or Co-Fe-As assemblage (Fig. 77). Examples of this type of layering were found in the Cadesky vein in the Hi-Ho mine, Cobalt, and on the bottom level in the Millerfields mine, South Lorrain township. In most places, however, the layers adjacent to the wall rock, as well as those in the centre, consist of the same mineral assemblage, but the grain sizes of the minerals in each layer are different (Fig. 78).

The relative proportions of the various assemblages of the arsenides in the main parts of the veins were determined by classifying the samples collected. The results, plotted as a histogram (Fig. 79), show that a large proportion of the samples collected from the main parts of the veins contained the Co-As assemblage of arsenides, many contained the Ni-Co-As and Co-Fe-As assemblages, and only a few contained the Ni-As and Fe-As assemblages. Since most samples were collected systematically where possible, and randomly elsewhere, these proportions are probably reasonably representative of the distribution of arsenides in a typical vein. A few veins, however, do not contain this typical distribution of arsenides. The Patricia vein in the Hi-Ho mine contained a large amount of the Ni-Co-As assemblage of minerals, and Vein No. 37 in the Langis mine contains large amounts of the Co-As and Co-Fe-As assemblages of minerals. The histogram of the samples collected from the ends of the veins shows that the ends have a high proportion of the Fe-As assemblage of minerals, and more of the Ni-As assemblage than is present in the main parts (Fig. 79). Histograms prepared from samples taken from the various rock types show the same distribution of arsenides in the veins regardless of rock type. A large proportion of the samples taken from South Lorrain township, however, belong to the Co-Fe-As and Fe-As assemblages. This suggests that the arsenides in South Lorrain township are enriched in iron relative to the veins in the Cobalt area.

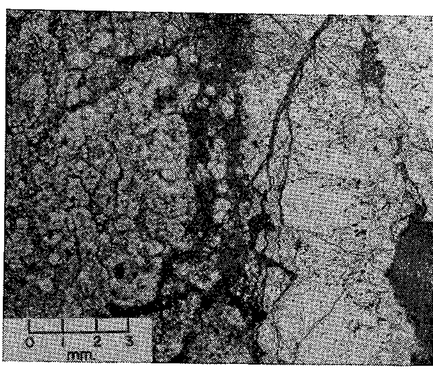


FIG. 77. Photomicrograph of a polished section showing a layer of Ni-As assemblage at the right side, and Co-As assemblage at the left side. The Ni-As assemblage was adjacent to the wall-rock, and the Co-As assemblage was in the middle of the vein. (Cadesky Vein, Hi-Ho mine).

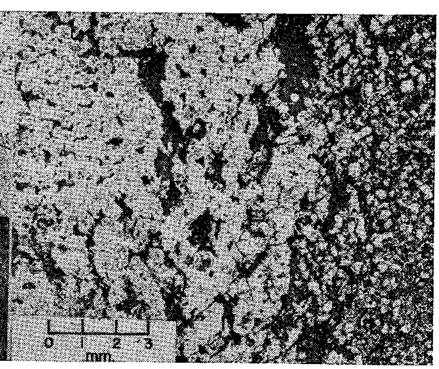


FIG. 78. Photomicrograph of a polished section showing two layers of Co-As assemblages. The one on the right side consists of fine-grained arsenides disseminated in carbonate, and the other consists of clusters of arsenides. (Giroux Lake vein, Hi-Ho mine).

The proportions of ore minerals to carbonate in veins in diabase in the Miller Lake area of Gowganda, and in some places in Keewatin rocks in the Cobalt area, is lower than that in veins in Huronian sediments in the Cobalt area and Casey township.

Native metals

The native metals found in the veins are silver, bismuth, gold and arsenic, but only silver is present in significant quantities. The *silver* is generally associated with the arsenides, but some is also present beyond

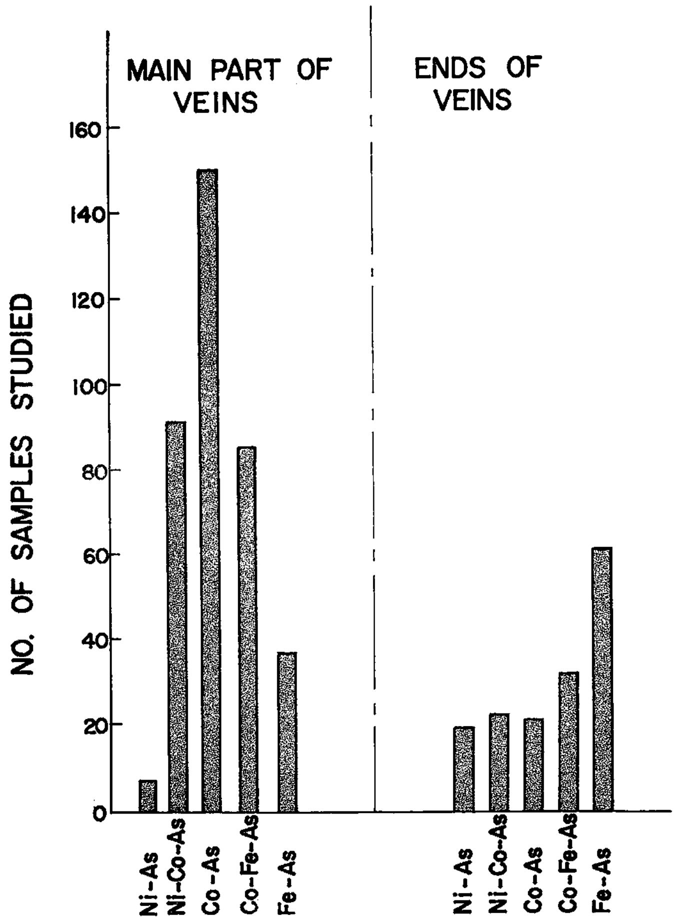


FIG. 79. Histogram showing distribution of arsenide assemblages in the main parts and at ends of veins.

the zone of arsenides mineralization, and some is associated with sulphides. That associated with arsenides occurs at the cores of rosettes, and as veinlets and disseminated grains in carbonates and arsenides. The silver at the cores of rosettes occurs in the Ni-Co-As and Co-As assemblages (Figs. 54 to 60 and 80), and forms a continuous zone of high-grade ore. That occurring as veinlets and disseminated grains occurs erratically along the entire lengths of the veins, but is most abundant in the Ni-Co-As, Co-As and Co-Fe-As assemblages. The veinlets occur along fractures in

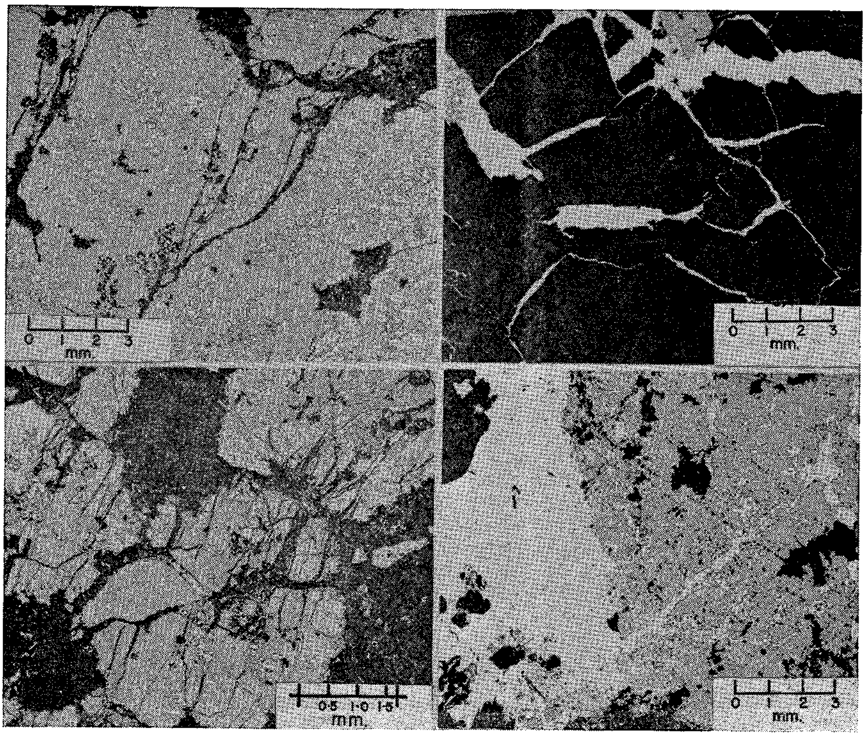


FIG. 80. (Top, left) Photomicrograph of a polished section showing silver at the cores of coalesced rosettes in the Co-As assemblage. (Vein 4, 4th level, Silverfields mine) (from Petruk 1968).

FIG. 81. Veinlets of silver (white) in calcite (black). (Cadesky Vein, 91 level, Hi-Ho mine).

FIG. 82. (Bottom, left) Veinlets of silver (white) in arsenides (grey). The black areas represent carbonates. (Vein 13, 4th level, Silverfields mine) (from Petruk 1968).

FIG. 83. Silver (white) occurring as veinlets in arsenides (grey), and as a wide veinlet along the boundary between the vein and wall rock. The black area at the left side of the photograph represents wall rock. (Silverfields mine) (from Petruk 1968).

carbonate and arsenides (Figs. 81 and 82), along boundaries between the vein and wallrock (Fig. 83), and along grain boundaries. The veinlets occurring along the boundaries between the vein and wall rock were found only in the Co-As, Co-Fe-As and Fe-As assemblages, and they extend into the wallrock as leaf silver wherever the wallrock is fractured.

The silver beyond the zone of arsenide mineralization occurs as an intricate network of veinlets in calcite, and as minute dissiminated grains in calcite. The former type of occurrence has been found in a few places in the Deer Horn mine as very high-grade silver ore in pockets up to 35 feet in size. In some places small amounts of tetrahedrite, arsenopyrite, galena, chalcopyrite, acanthite, pyrargyrite, stephanite, and other sulphides and arsenides were associated with this type of ore. The minute disseminated grains of silver in calcite were found in an ore body in the Siscoe mine in the Gowganda area. The disseminated grains in calcite vary from 20 to 200 microns in size and are too small to be seen with the naked eye on freshly broken surfaces. Exposed surfaces in the mines, however, become coated with a film of acanthite, locally referred to as "silver leach", and the presence of silver is indicated.

A small amount of silver is associated with the sulphides in the ore. It is present as veinlets in sulphides, envelopes around sulphide grains, and nearly sub-microscopic exsolutions in acanthite. Hence this silver was deposited later than the sulphides.

The quantity of silver associated with the arsenides in the vein, referred to as "grade of silver ore", appears to be related to the arsenide assemblages. High-grade silver ore generally occurs in the parts of the veins that contain the Ni-Co-As and Co-As assemblages of minerals, medium- to low-grade in the parts containing the Co-As and Co-Fe-As assemblages, and very low-grade in the parts containing the Fe-As and Ni-As assemblages (Fig. 84). Those samples referred to as high-grade ore are estimated to contain 500 to 5,000 ounces of silver per ton of vein material; medium grade, 200 to 1,000 ounces of silver per ton of vein material; low grade, 50 to 500 ounces of silver per ton of vein material; and very low grade, less than 100 ounces per ton of vein material.

The distribution of the grade of silver ore in Vein No. 1 in the Silverfields mine, shown in Figure 85, is considered to be typical for most of the veins in the Cobalt-Gowganda area. Some veins, however, do not have this typical distribution. The Patricia vein in the Hi-Ho mine, which contained a large amount of the Ni-Co-As assemblage of minerals, had a large amount of high-grade silver ore. The Cadesky vein in the same mine, and the Dolphin-Miller vein in the Langis mine, are wide veins containing masses of arsenides, and they had only small pockets of high-grade silver ore. Vein 37 in the Langis mine is also a wide vein composed of Co-As and Co-Fe-As assemblages of minerals in calcite, and to date no silver ore has been found in this vein.

Small amounts of native *bismuth* were found in many veins in all mineral assemblages. The bismuth occurs as veinlets, crystals in vugs, irregular grains in silver, and in bismuth-silver veinlets. The bismuth in the bismuth-silver veinlets interchanges intermittently with native silver

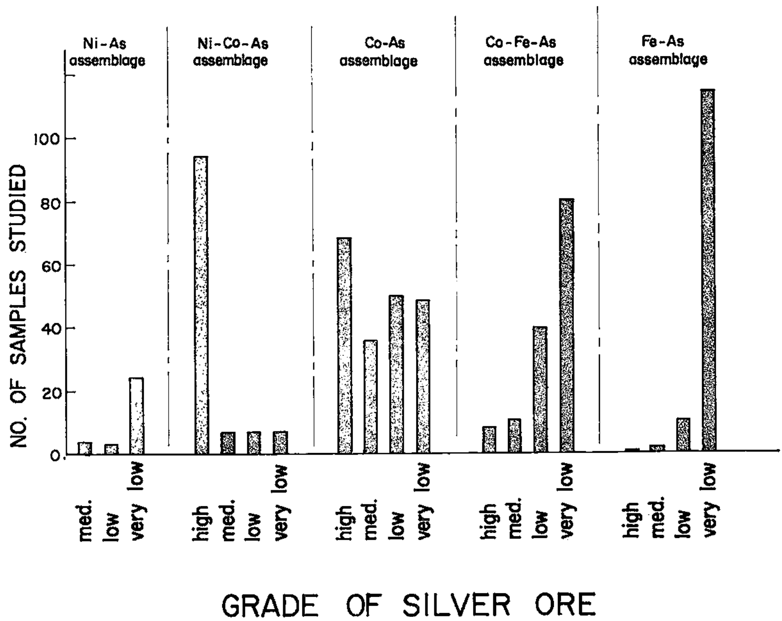


FIG. 84. Histogram showing grade of silver ore associated with the various assemblages of arsenides.

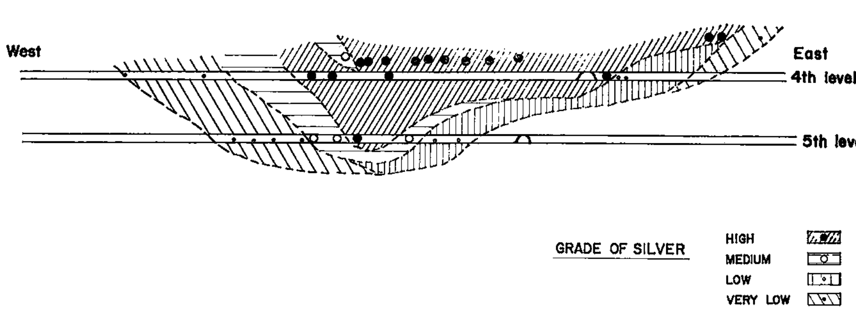


FIG. 85. Longitudinal section of Vein 1 in the Silverfields mine showing distribution of grade of silver ore (from Petruk 1968).

along the veinlet. Native bismuth appears to be most abundant near the ends of veins where it is associated with the Co-Fe-As and Fe-As assemblages of minerals and with sulphides. Large amounts of native bismuth were present where native silver was nearly absent in the Cadesky vein in the Hi-Ho mine, and in Vein No. 8 in the Silverfields mine.

Native *arsenic* was found only in one sample of high-grade silver ore in an assemblage of Co-As minerals from the Conisil mine, Cobalt.

Native *gold* has been reported from a few areas outside the areas containing silver mines, although none was seen in this study. The largest amounts of gold were reported from the Aconic property, northwest of Latchford (A. C. Bray, 1966, private report to Aconic Mining Company).

Sulphides

The sulphides found in the veins are chalcopyrite, tetrahedrite, bornite, chalcocite, stephanite, pyrargyrite, acanthite (argentite), proustite, polybasite, xanthoconite, galena, matildite, galenobismutite, bismuthinite, pavonite, parkerite, sphalerite, pyrrhotite, pyrite, marcasite, bravoite, violarite, siegenite, cobalt pentlandite, stromeyerite, wittichenite, covellite, smythite, and molybdenite. In addition, mckinstryite (Skinner *et al.* 1966) and samsonite (Ramdohr — personal communication) have been reported, although they were not observed in this study. The sulphides occur in the main carbonate veins, in narrow calcite veinlets that are present along the boundary between the carbonate veins and wall rock, and in cross-veins. Those in the main carbonate veins are present in both relatively barren carbonate and intensely mineralized sections that constitute ore, with the highest concentrations being immediately beyond the intensely mineralized sections. The sulphides occur as disseminated grains and veinlets in carbonate and arsenides, (Fig. 86), irregular grains replacing native silver and arsenides (Fig. 87), and as massive sulphides. The disseminated grains vary from 10 microns to several millimeters in size, and the veinlets are up to several millimeters wide.

Chalcopyrite and tetrahedrite are the most common sulphides in both the relatively barren carbonate and intensely mineralized sections, and in some places they are associated with native silver, with other copper-bearing minerals such as bornite and chalcocite, and with other sulphides.

Galena, sphalerite, marcasite and pyrite are also common in relatively barren carbonate, and in the Fe-As assemblage. The minerals in barren carbonate generally occur as irregular grains and parallel veinlets, and some of the marcasite and sphalerite veinlets have colloform textures. The galena in the Fe-As assemblage is commonly present as intergrowths with arsenopyrite, and some contains matildite.

The silver-bearing sulphides — stephanite, pyrargyrite, acanthite, proustite, polybasite, and xanthoconite — generally occur in the parts of the veins that contain significant amounts of native silver. They are commonly present in the sequence acanthite-pyrargyrite-stephanite outward from the silver, but in many places they have partly replaced silver along crystallographic directions. Xanthoconite is present only as a supergene mineral in the parts of the veins where the carbonate has been leached away from the arsenides and native silver.

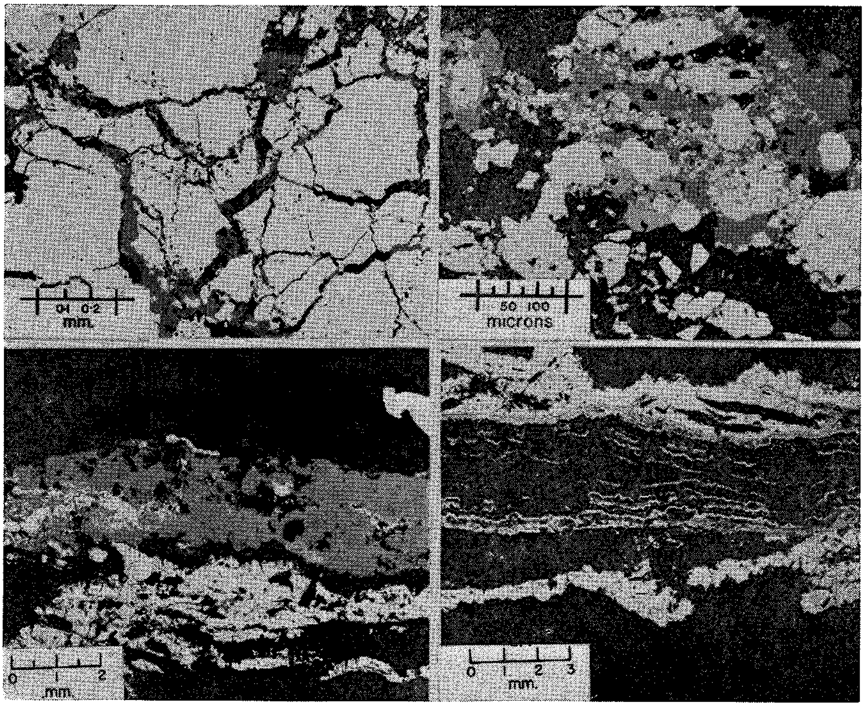


Fig. 86. (Top, left) Photomicrograph showing veinlets of sulphides (grey) in arsenides (white). (Silverfields mine) (from Petruk 1968).

Fig. 87. Photomicrograph showing irregular grains of sulphides (grey) containing inclusions of arsenides (white). (Silverfields mine) (from Petruk 1968).

Fig. 88. (Bottom, left) Photomicrograph of a polished section showing sub-veinlets of sulphides that occur in calcite veinlets between the ore vein and wall rock. The sub-veinlets in this photograph consist of sphalerite (grey), and galena and marcasite (white). (Patricia Vein, 91 level, Hi-Ho mine).

Fig. 89. Photomicrograph of a polished section of a cross-vein showing parallel marcasite veinlets (white) in calcite (black). The marcasite has a colloform texture. (Patricia Vein, 181 level, Hi-Ho mine).

The bismuth-bearing sulphides — bismuthinite, pavonite and parkerite — occur in association with native bismuth, but only bismuthinite is abundant.

The massive sulphides in the veins occur as bodies several inches in size in sulphide pockets several feet in size. These bodies are composed of a variety of sulphide assemblages. For example, the bodies in one pocket in an ore zone in Vein No. 8 in the Silverfields mine contained galena, tetrahedrite, pyrargyrite, stephanite, chalcopyrite and pyrrhotite intimately intergrown. Those in pockets in a fault vein within 300 feet of an orebody in the Langis mine contained parkerite, cobalt pentlandite, siegenite, bravoite, bismuthinite, galena, marcasite, pyrite, chalcopyrite and sphalerite (Petruk *et al.* 1969), and those in the Foster mine, Cobalt contained stromeyerite, tetrahedrite, chalcopyrite, bornite, wittichenite, acanthite, galena and pyrite.

The sulphides in the narrow calcite veinlets that occur along the boundary between the carbonate veins and wall rock are present as parallel sub-veinlets and disseminated grains (Fig. 88). The sub-veinlets are up to several feet long. The sulphides commonly occur as a sequence of stephanite-sphalerite-galena-marcasite veinlets towards the wall rock. The disseminated grains vary from a few microns to several millimeters in size. It is to be noted that the silver-bearing sulphides stephanite, pyrargyrite, acanthite and proustite generally occur near the parts where the carbonate veins contain significant amounts of native silver. In addition, these silver-bearing sulphides contain veinlets of a late silver.

Sulphides are also present in cross-veins that offset the ore veins several feet; these sulphides occur as parallel veinlets and disseminated grains (Fig. 89). Galena, marcasite, pyrite and sphalerite are the most common sulphides in the cross veins; marcasite commonly has a colloform texture. The sulphides in one cross vein in the Silverfields mine have a dendritic texture (Fig. 90). This texture is produced by an unusual arrangement of worm-like chlorite and sphalerite veinlets along apparently incipient fractures in carbonate (Petruk 1968).

Oxides

Small amounts of hematite, magnetite, rutile, anatase, ilmenite and wolframite occur in the veins. The *hematite* was found in the Elk Lake area, Miller Lake area and at Cobalt outside the main ore-bearing area. It is present as hematite veins and veinlets (MacKean 1968, Moore 1956 and Todd 1926), and as dissiminated grains in carbonate. The genetic relationships of this mineral are described by Jambor (page 246).

Magnetite was found in pre-ore quartz veins in Keewatin rocks in the Christopher and Canadian Keeley mines, and in an iron-arsenides assemblage in an ore vein in the Nipissing 407 mine. The magnetite in the pre-ore veins is present as masses up to several inches in size and is associated with chalcopyrite and pyrite. The magnetite in the iron arsenide assemblage occurs at the cores of arsenide rosettes and as separate grains, some with *chromite* coronas and some with lamellar hematite at the edges.

Rutile, anatase, and *ilmenite* are present largely as separate grains in wall rock inclusions in carbonate, and are generally associated with chlorite. Some of the ilmenite is present as crystals exsolving from mafic minerals and is partly bordered by rutile and or anatase. This mineral trio is discussed fully by Jambor (page 247).

A few minute grains of *wolframite* (identified by *x*-ray *diffraction*) were found in carbonate veins and diabase near ore zones.

Ore Minerals in Shear Zones

Ore minerals in shear zones occur in fault gouge, fracture zones and mud seams. The fault gouge consists of crushed rock cemented with calcite and contains marcasite, chalcopyrite, galena, sphalerite and other sulphides including silver-bearing varieties (Fig. 91). The marcasite generally occurs as parallel veinlets and commonly has a colloform texture. The other sulphides occur as veinlets, separate grains and intergrowths.

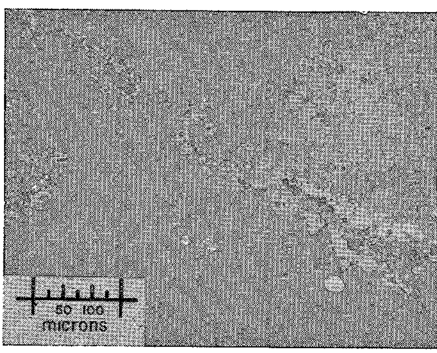


FIG. 90. Photomicrograph of a polished section showing a dendritic pattern produced by sulphides in a cross-vein. The pattern is produced by sphalerite grains with calcite cores. (Silverfields mine) (from Petruk 1968).

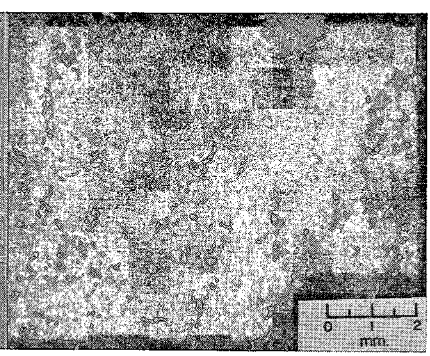


FIG. 92. Photomicrograph showing disseminated grains of sulphides in Keewatin interflow rocks. (Silverfields mine) (from Petruk 1968).

The fracture zones consist of broken rock, and some rock faces are coated with ore minerals and graphite. One fracture zone in Keewatin rocks formed part of Vein No. 7 in the Christopher mine, Cobalt, and contained about 15 ounces of silver per ton of rock (personal communication, B. Thorniley, Geologist, Agnico Mines Ltd.). The ore minerals coating rocks faces in this zone are galena, chalcopyrite, sphalerite, bornite, covellite, djurleite, pyrite, pyrrhotite, native silver and graphite. The chalcopyrite, galena and sphalerite are intimately intergrown, and the chalcopyrite and bornite are partly replaced by covellite, and goethite.

Mud seams occur in faults wherever the crushed rock has not been re-cemented, and some contain significant amounts of ore minerals. Examples of mud seams were found in Vein No. 1, in the O'Brien mine, Cobalt and Vein No. 7 in the Christopher mine, Cobalt. The mud seam in Vein No. 1 contained native silver, arsenopyrite and sphalerite partly replaced by acanthite and goethite, and the one in Vein No. 7 contained hematite, magnetite, arsenopyrite, pyrite, chalcopyrite, nickeline, rutile and goethite in a matrix of chlorite with small amounts of mica, feldspar, quartz and calcite. An intensely oxidized part of the Wood's vein

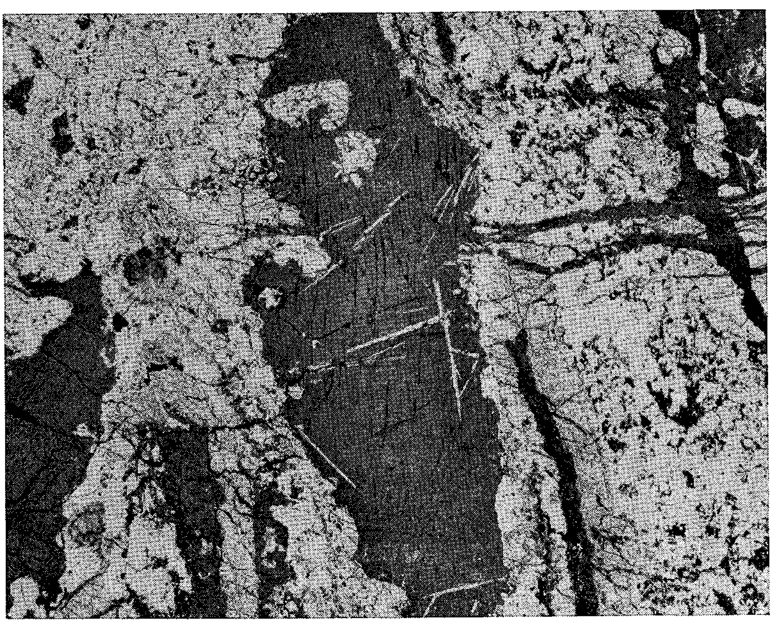


FIG. 91. Photomicrograph of a polished section of a fault vein showing veinlets and grains of sulphides (grey and white) cemented with calcite (grey). (Silverfields mine). X3

in South Lorrain township was reported to contain large amounts of red, brown, yellow, green and blue mud, wire silver, argentite, and spongy accumulations resembling miniature stalactites (Bell 1923). The mud apparently contained hematite, goethite, erythrite, annabergite and azurite (see pages 368 to 371).

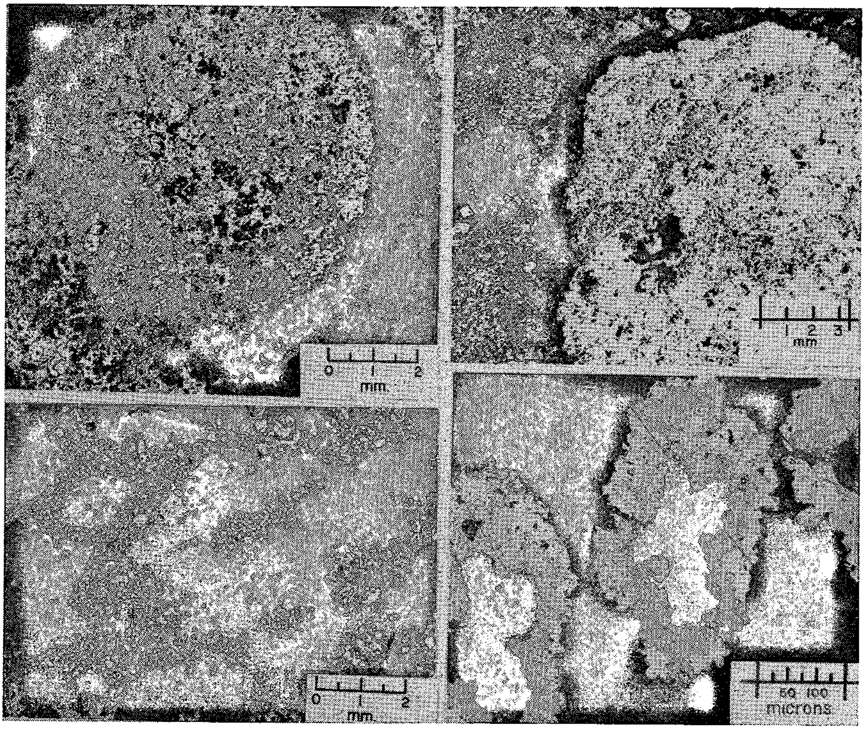


FIG. 93. (Top, left) Photomicrograph of a cross-section of a rod-shaped body of massive sulphides in Keewatin interflow rocks. This body consists largely of sphalerite (grey) and contains some chalcopyrite, pyrite and pyrrhotite (white; individual minerals are not resolved). (Silverfields mine) (from Petruk 1968).

FIG. 94. Photomicrograph showing a pyrite nodule (white) in pyrrhotite (light grey) in a mineralized Keewatin interflow rock. The black area around the pyrite nodule represents a zone of silicates.

FIG. 95. (Bottom, left) Photomicrograph showing disseminated arsenides along calcite grain boundaries. (Vein 37, Langis mine).

FIG. 96. Photomicrograph of a polished section showing three rosettes constituting part of a dendritic texture. Each rosette consists of a calcite core (black), an intermediate layer of cobaltite (grey), and an outer layer of skutterudite (white). (Vein 37, Langis mine).

ORE MINERALS IN THE WALL AND COUNTRY ROCKS

Ore minerals also occur in mineralized Keewatin rocks and the other rock types. Those in Keewatin interflow rocks are chalcopyrite, sphalerite, galena, pyrite, pyrrhotite, marcasite, arsenopyrite, native silver and graphite. The minerals are present as disseminated grains (Fig. 92) and massive sulphides in the interflow bands. The disseminated grains vary from a few microns to several millimeters in size and occur in clusters. The massive sulphides are composed of compacted clusters of disseminated grains that form small bodies commonly several inches in size, and large ones several tens of feet in size. The small bodies are irregular, rounded, ellipsoidal and rod-shaped, and are scattered haphazardly throughout the interflow rocks. Some consist of complex mixtures of ore minerals (Fig. 93) and others are nearly mono-minerallic. The large bodies were found only in the Deer Horn mine. They consist largely of pyrrhotite and pyrite, and contain some chalcopyrite. Some of the pyrrhotite contains rounded pyrite nodules that vary from 0.5 to 2 centimeters in size, and are enclosed in an envelope of silicate minerals and goethite (Fig. 94). These nodules consist of weakly anisotropic pyrite, and contain minute inclusions of pyrrhotite and marcasite.

The mineralized Keewatin interflow rocks adjacent to mineralized veins have a modified distribution of sulphides and are enriched in arsenides. Thus large bodies of massive sulphides adjacent to ore veins are layered, and small ones contain inclusions of arsenopyrite and molybdenite. The layers outward from a mineralized vein in a body of massive pyrrhotite on the 9th level in the Deer Horn mine, Cobalt are sphalerite layers 1 to 10 millimeters wide, galena layers 0.1 to 1 millimeter wide, and chalcopyrite layers 2 to 10 centimeters wide.

The ore minerals also occur in Huronian sediments, Keewatin volcanics and Nipissing diabase. Those found in Huronian sediments are chalcopyrite, pyrite, pyrrhotite, galena, sphalerite, arsenopyrite, safflorite, cobalite, nickeline, tetrahedrite, chalcocite, native silver, rutile, wolframite, and molybdenite. They occur as disseminated grains, films along fracture surfaces, and pebbles in conglomerate, but the arsenides, native silver and some of the sulphides occur only near ore veins. The disseminated grains vary from 1 micron to several millimeters in size and some preferentially replace chlorite. Thus many chlorite spots near ore veins contain grains of ore minerals. It was noted that a slate-like greywacke near an ore vein in the Silverfields mine contains galena, sphalerite and arsenopyrite in the siliceous part of the greywacke at the tops of beds, and chalcopyrite and tetrahedrite as replacements of chlorite at the bottoms of the beds.

Some minerals, and particularly native silver, are present as films along fractures and along blocks of slate-like greywacke near ore veins.

A few pebbles of massive sulphides, up to 2 inches in size, are present in conglomerate in the Silverfields mine. These pebbles are generally composed of chalcopyrite, pyrrhotite, pyrite, sphalerite, arsenopyrite, galena and freibergite. Some have sharp to gradational boundaries with the surrounding rocks and some have an outside layer of oxide. In some places calcite veinlets cut the sulphide pebbles but the portions of the calcite veinlets that are in the pebbles are replaced by sulphides. Hence the pebbles were originally cut by calcite veinlets, and subsequently both the pebble and calcite were replaced by sulphide minerals.

The ore minerals in Keewatin rocks near veins are pyrite and chalcopyrite, and they are present as disseminated grains and cores of "chlorite spots". The Nipissing diabase contains only trace amounts of ore minerals, with the largest quantities occurring as veinlets and coatings along fractures near ore veins.

Disscussion

The textural relationships and distributions of the minerals provide a record of the depositional history of the ore. The numerous cross-cutting relationships and replacement textures show that the early minerals are arsenides and native silver, and the late ones are sulphides. The significant textures produced by the early minerals are the rosettes, the dendritic textures, the clusters of disseminated grains in carbonate, and coronas on arsenides.

The rosettes consist of cores and outer layers, and are interpreted to have been deposited outward from the cores. The cores in the nickeline portions of the Ni-Co-As assemblage are present as networks of "Ag-Sb minerals", nickeline, breithauptite and cobaltite, and those in the Co-As and Co-Fe-As assemblages consist of skutterudite. The networks of "Ag-Sb minerals" etc., shown in Figure 59 are interpreted as representing the first stage in the development of rosettes in the nickeline portion of the Ni-Co-As assemblage. Deposition of safflorite, skutterudite and cobaltite around the networks represents a second stage (Fig. 55), and completed rosettes represent the last stage (Fig. 56). The skutterudite cores do not appear to be present as networks (Figs. 61 and 63), hence rosettes with skutterudite cores are judged to be different from those containing cores of "Ag-Sb minerals" etc. The author interprets these rosettes to have formed by deposition of skutterudite onto existing surfaces in an open space followed by deposition of an outer layer of safflorite. Subsequent rosettes would build upon the first ones.

The minerals at the cores of rosettes have been modified by remobilization, replacement and redeposition. The "Ag-Sb minerals" are present as veinlets that cut across the outer layers of the rosettes and pass into the surrounding carbonates. The "Ag-Sb minerals" in these veinlets blend indistinguishably into those at the cores, and contain similar amounts of the allargentum as those at the cores. This suggests that the "Ag-Sb minerals", originally present as cores of rosettes, have been remobilized and redeposited nearby as veinlets. Similarly, nickeline which is present as late veinlets in the arsenides and wall rock up to 100 feet beyond the Ni-Co-As assemblage, may have been remobilized from the cores and redeposited nearby.

The outer layers of the rosettes consist of concentric layers of arsenides, with the widest layer being composed of prismatic crystals oriented radially around cores. Thus the rounded nature of the rosettes was apparently produced by radial crystallization of prismatic crystals around irregular grains, and the concentric layers surrounding the cores reflect the sequence of deposition. In addition, some minerals are present as replacements. Pararammelsbergite is present as large euhedral crystals that cut across nickel and cobalt arsenides, and gersdorffite apparently replaced cobalite. The gersdorffite is generally intergrown with rammelsbergite and pararammelsbergite, and may even be a reaction product resulting from replacement of cobalite by rammelsbergite.

The coronas around clusters of disseminated grains appear to have formed by arsenides growing around grains of carbonates. The first phase in such a suggested growth is shown in Figure 95. Recrystallization of this phase would produce the texture shown in Figure 62. Polished-section studies show that the coronas consist of a reversed sequence of skutterudite and cobaltite which suggests that the coronas were formed by growth from the outside.

The dendritic textures result from rosettes aligned like strings of beads. Most of these rosettes consist of arsenides surrounding cruciform and irregular grains of silver (Fig. 66), calcite (Fig. 67) and silver partly replaced by sulphides. It has been suggested that they formed by precipitation of silver into a dendritic form followed by deposition of arsenides around the silver (Todd 1926; Bastin 1949 and 1950; Montgomery 1948; and Kulkarni 1968). This is consistent with the proposed mechanism for the development of rosettes with silver cores. Bastin (1949) and Kulkarni (1968) further suggested that the dendritic silver was subsequently replaced by calcite and other minerals. Replacement textures studied by the author show that the dendritic silver has indeed been replaced by sulphides, but the textures cited as evidence for replacement by calcite are less convincing. It is therefore suggested that the silver was remobilized from the cruciform grains and redeposited elsewhere, and the voids were subsequently filled with a late calcite.

The mechanism described above for the formation of dendritic textures does not appear to apply to the dendritic arsenides in a barren vein (Vein No. 37) in the Langis mine (Fig. 67), nor to the wormlike chlorite and sphalerite veinlets in a cross-vein (Fig. 90). The rosettes in Vein No. 37 have a reverse distribution of skutterudite and cobaltite (Fig. 96) which suggests growth from the outside around calcite grains. It is further noted that the strings of rosettes forming the dendritic textures cut across calcite crystals and calcite grain boundaries, and appear to occur along incipient fractures in carbonate. No actual fractures have been found, but it is expected that such fractures would be completely healed and no evidence of them would be left. It is thus suggested that this variety of dendritic texture was formed by deposition of arsenides around calcite grain boundaries to form atoll-like rosettes, and the rosettes were aligned along incipient fractures in carbonate. A similar mechanism could produce the sphalerite-chlorite dendritic texture in the cross-vein.

The silver and "Ag-Sb minerals" in the ore are present as cores of rosettes, veinlets in arsenides, and veinlets in sulphides. Those at the cores of rosettes and in dendrites represent early varieties that were deposited as networks of veinlets and as dendritic silver, and formed the nuclei of rosettes. The silver minerals present as veinlets represent later varieties that may have been redeposited from the cores of the arsenide rosettes, or introduced into the ore late in the sequence of arsenide deposition. The native silver associated with the sulphides represents a late silver that was deposited with the sulphides. This silver, however, accounts for only minor amounts of silver in the ore.

The sulphides occur in mineralized Keewatin interflow rocks, ore veins and wallrock. Replacement textures suggest that those in the ore veins were mobile at the same time as those in Keewatin interflow rocks, and other rock types. Hence, they may represent sulphides that have been remobilized from the interflow rocks and concentrated and redeposited adjacent to, and in, the ore veins. On the other hand, they may represent a late phase of the main ore fluids. It is noted that chalcopyrite and tetrahedrite are common sulphides in all parts of the veins, and thus they appear to be related to the ore solutions from which arsenides and silver were deposited. The silver sulphides, on the other hand, occur only near silver ore in the main part of the veins, which suggests that the silver may have served to localize the silver sulphides deposition. The other sulphides are present in both the ore veins and wall rock, and do not permit any obvious conclusions to be made regarding their origin.

The sequence of layers of minerals in the rosettes and the presence of colloform bodies shows that there was a certain amount of rhythmic deposition. The general sequence of arsenide deposition is nickel, cobalt, and iron arsenides. This sequence also corresponds to the zoning of arsenides away from the diabase. It seems noteworthy that the sequence for these three elements is the same as that in the electromotive force series (Gucker & Meldrum 1950), and as that found in metallurgical speisses (Liddell 1926). A more detailed discussion on origin is given in a separate paper near the back of this issue.