# GANGUE MINERALOGY

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## ABSTRACT

Calcite, dolomite, quartz, and chlorite make up more than 95 per cent of the gangue in the silver-arsenide veins of the Cobalt-Gowganda region. Deposition of quartz and chlorite was followed by that of dolomite and ore minerals. In most ore veins a younger silver-calcite assemblage was introduced along one of the vein walls.

Microprobe analyses of calcites and dolomites in two veins in the Silverfields mine, Cobalt, did not reveal any systematic variation in carbonate compositions along the veins. However, magnesium-rich chlorites are associated with nickel arsenides, and iron-rich chlorites with iron arsenides. The zonal trend points downwards, that is, the source was apparently above the veins rather than below.

## INTRODUCTION

Nearly all the ore veins in the region consist of arsenides and silver in dolomite and calcite. In the Gowganda area, the only carbonate in the veins is calcite. In the remainder of the region (Elk Lake, Cobalt, South Lorrain, Casey township), both calcite and dolomite are present.

Calcite, dolomite, quartz, and chlorite make up more than 95 per cent of the gangue in the veins throughout the region. Basically, therefore, the principal gangue mineralogy is simple; as a consequence, however, the unravelling of the different ages of gangue deposition is difficult.

## PRE-ORE VEINS

Implicit in the discussion of the gangue mineralogy is the assumption that the minerals under consideration are genetically related to the ore-forming process. While this tenet may seem obvious, it is worth emphasis because several types of older, pre-ore veins occur in the region. Some have no discernible association with silver mineralization, but others have been favourable structural loci for the later ore veins. Nearly all the pre-ore veins occur exclusively in the Archean basement and are characterized by a predominantly silicate gangue. Some of the veins contain sulphides, but most are barren; where sulphides do occur they are of the base metal type.

A few examples of veins not directly related to the younger period of silver-arsenide ore deposition may be cited. At Cobalt, numerous quartz veins in Archean volcanics form a discontinuous arcuate pattern for a length of more than a thousand meters near the northwestern margin of the Lorrain granite. Although some of the veins are more than a meter wide, most are small, irregular, and discontinuous. They do not penetrate the overlying Huronian sediments or Nipissing diabase, so that their Archean age is clearly indicated. A few of these quartz veins, however, have been fractured and filled with younger silver-arsenide minerals so that confusion can arise in interpreting the relationships in individual specimens. Similarly, some of the Archean rocks, particularly the interflow sediments, contain abundant base metal sulphides. Although there is little difficulty in identifying the distinctive silver-arsenide suite occupying fractures in such rocks, it is virtually impossible to sub-divide the mutually common minerals such as chalcopyrite. In barren veins the problem is compounded, for one can never be certain of the absolute age of their quartz and carbonate; they may be Archean or considerably younger.

Archean feldspathic veins have on occasion been incorrectly referred to as aplites because of their pinkish colour. The veins range from less than a centimeter to more than 15 cm in width and have maximum microcline as their principal constituent. In areas containing silver veins, a few steeply-dipping microcline veins have been fractured and the openings healed by silver-arsenide minerals. The probable Archean age of the feldspathic veins is indicated by their variable attitudes and flat-lying to vertical dips. Only the wider, vertical microcline veins have been the sites of later fracturing and gangue deposition, with ore occurrences being extremely rare. To this writer's knowledge, no microcline vein of this type has been found to extend from the Archean into the Proterozoic. In other cases, however, pink K-feldspar is present at vein margins as the result of wall rock alteration along silver-arsenide veins. An awareness of such complications clearly signals the need for a cautious approach in interpreting the nature of some of the ore-bearing veins cutting Archean rocks. Fewer complexities are present where the ore veins have Proterozoic sediments or Nipissing diabase as host rocks.

## ORE VEINS

### *General features*

Sharp contacts between the wall rocks and vein minerals are the rule. Inclusions of country rock are common and readily identifiable in hand specimens even though extensive alteration may be evident under the microscope. Calcite and dolomite make up 80 to more than 90 per cent of the gangue in more than 90 per cent of the veins. The remainder of the gangue is usually chlorite and quartz. Albite, epidote, actinolite, hematite, sphene, and other minerals are present in quantity in some veins; one or more of these is present in at least trace amounts in all veins. Although the proportions of the carbonates, silicates, and oxides are variable, rarely do the silicate minerals constitute the major part of the gangue in productive veins. The ratio of the ore and gangue minerals is also highly variable. Some veins consist of masses of arsenides with subordinate carbonate, but in most veins the gangue minerals predominate. Some massive arsenide veins do not carry sufficient silver to make ore; in other cases high-grade veins may consist almost entirely of carbonate gangue containing sparse arsenides and small amounts of silver (on a percentage basis). The proportion of gangue is thus not necessarily indicative of silver grade in a vein.

*Depositional sequence*

Basically, silicates were followed by dolomite, and dolomite by calcite. A fundamental ore relationship is that the arsenides are associated with dolomite where this gangue mineral is present. According to Petruk (p.

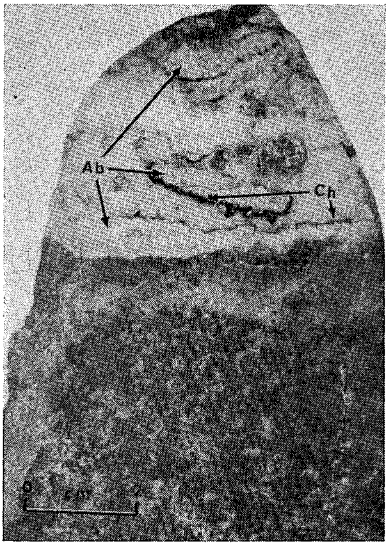


FIG. 163. Pink albite layer (Ab) coated with dark chlorite (Ch), with transported fragments suspended in white calcite. Prudential property, James township, Elk Lake.

138) the main influx of silver accompanied the arsenides. The post-dolomite calcite also contains important quantities of silver, but the association is primarily one of native silver and sulphides rather than arsenides. In contrast to the remainder of the region, the ore veins at Gowganda contain no dolomite. There are some indications at Gowganda that late silver and sulphides were accompanied by renewed or continued calcite deposition, but a two-fold subdivision analogous to the dolomite-calcite sequence is less readily definable because of the relative uniformity of the calcite.

For clarity, discussion of the representative gangue relationships has been simplified by taking into account only the steeply-dipping veins, and by assuming the presence of dolomite. With these qualifications, the depositional trends outlined below are considered to be valid throughout the region. All veins do not have an identical gangue mineralogy, but no major deviations in this succession of mineral deposition have been found :

1. White to pink albite and K-feldspar are the oldest minerals in some veins (Fig. 163). They are principally developed in altered wall rocks bordering the veins, but crystals project into veins (Fig. 168) and a poorly-developed crustification is present on some wall rocks.

2. The feldspars were succeeded by white to clear quartz which was commonly the first gangue mineral deposited. Many small veins are lined with euhedral quartz prisms 1 to 5 mm long. Although such veins may carry ore minerals, the productive veins as a general rule do not have this feature because later movements have destroyed the crustification.

3. Chlorite and carbonates are the most important gangue minerals and are present in all veins. It is not certain whether chlorite preceded, followed or overlapped quartz deposition. In many ore veins, however, quartz is not present and chlorite was the first gangue mineral deposited.

4. Dolomite and arsenides followed chlorite. Relatively small amounts of arsenides were deposited as thin layers along the vein walls and lie directly on chlorite. Most of the arsenides occur as masses and disseminated grains in carbonate. The earliest-formed arsenides are older than dolomite, but dolomite continued to crystallize after arsenide deposition had ceased.

5. The end of dolomite crystallization was marked by the formation of drusy vugs which were filled by calcite and/or quartz. Most of these cavities are less than a millimeter in diameter, but a great number of them may be present in a single specimen.

6. Dolomite and the above were followed by calcite associated with native silver and sulphides, some of which are silver-bearing species. In order to distinguish this association, it will be referred to as the silver-calcite stage. Calcite of this age occurs in nearly all dolomite veins and is always accompanied by signs of disturbance of the older minerals. In most

cases the silver-calcite assemblage was introduced along one of the vein walls, whence it spread by extensive replacement of vein dolomite. As mentioned previously, the main period of silver deposition apparently occurred with the arsenides, that is, prior to the formation of the silver-calcite veins.

7. Post-ore fracturing was accompanied by quartz-calcite veins (Fig. 164). They are of variable size, but usually have a width of several cm. Veins of this type may cut across the ore-bearing structures, but some also occur along one wall of the ore veins, thus giving a composite, banded structure. Although grouped as "quartz-calcite", the post-ore veins also include those with calcite alone, and those containing calcite with disseminated acicular actinolite. All commonly contain very small amounts of base metal sulphides. Some of these veins are probably genetically associated with the ore veins, but others may be unrelated.

FIG. 164. Ore vein with dark, asymmetrical alteration borders in diabase, Siscoe mine, Gowganda. Old quartz (q) coated with arsenides occurs in a dark grey arsenide-calcite vein irregularly cut by sulphide-bearing calcite (c). A barren, white, post-ore, quartz-calcite vein cuts the ore vein at right angles. (Width of sawn base 28 cm).

*Low-angle veins*

In addition to the steeply-dipping ore veins, low-angle quartz-calcite veins with dips of 10° to 40° occur at Cobalt. They were first described by Whitehead (1920), and were recently mentioned by Taylor (1970), who reported the occurrence of smythite in one.

The low-angle veins are up to 20 cm wide and characteristically consist largely of pinkish dolomite with abundant milky to colorless, watery quartz. The dolomite, which is younger than the quartz, is typically barren but was fractured and partly replaced by younger calcite. This calcite contains an assemblage of sulphides and native silver which is reported by Petruk (p. 131) to be identical to that found in the vertical silver-calcite veins. Whether the dolomites in the low-angle and vertical veins are coeval is not known, but the similarity of the silver-calcite assemblages in both strongly suggests that this part of the mineralization had a contemporaneous and common origin.

Because the low-angle veins have not been closely studied, and because they are relatively unimportant in comparison to the steeply-dipping, arsenide-bearing veins, only the latter are dealt with in this paper.

*Ore-gangue relationships*

As mentioned above, the ores in the steeply-dipping veins are associated with dolomite (point 5) and, to a lesser extent, with calcite (point 6). Dolomite-arsenide deposition did not involve one uninterrupted supply of material which filled the veins. Rather, deposition seems to have occurred during a series of jostling movements in which progressively younger arsenides and dolomite were added to the original veins and to new channels formed by loosening of the wall rocks. Thus a vein, or indeed a single hand specimen, may contain a layer of arsenides along the walls, followed by dolomite with masses of arsenides which were brecciated near one wall and healed by a vein of pinkish dolomite. Subsequent further dilation led to the asymmetrical accommodation of an additional vein of greyish barren dolomite. All these formed prior to the further disturbance which accompanied the emplacement of the silver-calcite veins (point 6). There is a remarkable uniformity in that the dolomite-arsenide assemblage always preceded that of silver-calcite. There is, on the other hand, a contrasting lack of uniformity in that the mutual relationships of dolomite and arsenides are variable from vein to vein. The relationships may be complex, as outlined above, or considerably simpler, with only one dolomite-arsenide period identifiable. In the full width of a vein, however, there is always evidence that intermittent minor fracturing or brecciation has

Banded ores from the Canadian Lorrain property, South Lorrain.

Fig. 165. (Top) Abundant streaked dark grey arsenides with black wall rock fragments and minor quartz (Q) in a predominantly pinkish dolomite gangue.

Fig. 166. (Bottom) Dolomite-calcite gangue containing streaks and bands of arsenides near the bottom of the specimen and near the sheared wall rock at the top.

occurred. There is also evidence that these disturbances occurred in different veins at different times, so that each vein responded to its local structural environment. The implication is that each vein need not have been depositing the same minerals at exactly the same time, and each vein need not have accommodated the full spectrum of mineralization. There is, on the other hand, a general uniformity in the mineralogy and a specific uniformity in the depositional sequence which must be the reflection of an ore-forming parent common to all the veins.

## GANGUE MINERALOGY

### *Major constituents*

As mentioned previously, the most abundant minerals in the veins are quartz, chlorite, calcite, and dolomite. In some cases albite is also important. These minerals will not be described in great detail, but some further general comments are appropriate.

Massive pink carbonate in the veins is dolomite, while a light grey carbonate may be either calcite or dolomite. When two carbonates are present in a specimen, as is usually the case, the more translucent one is usually calcite ; if veining relationships can be megascopically seen, the younger phase is usually calcite. The medium to dark grey appearance of some carbonates is rarely a true coloration ; this effect arises from the presence of sulphide and arsenide inclusions (hence the rule of thumb that "grey carbonate" is commonly ore-bearing).

Because most dolomites throughout the region weather to various shades of brown, the mineral is readily distinguishable from the relatively unaffected calcite in weathered specimens. Dolomites in the Elk Lake area are usually white, but those at Cobalt and South Lorrain are commonly, though not exclusively, pinkish. The finely-banded appearance characteristic of much of the ore from South Lorrain (Figs. 165, 166) is not a depositional feature, but is the result of post-ore movements along the veins.

Dolomite in most veins is fine-to medium-grained and is mottled when viewed in thin slices. The mottling may be due to a close association of dolomites of different relative ages. Although a crustified arrangement of zoned rhombs is occasionally observable, the depositional trend is otherwise usually not determinable.

Microprobe analyses of the carbonates in 4 specimens are given in Table 52. Substitution of ions in the calcites is rather limited, with the sum of the oxides of Mg, Fe, and Mn being less than 3 weight per cent.

The dolomites are more variable, and compositions extend well into the ankerite field of Deer, Howie & Zussman (1962), that is, atomic Mg : Fe + Mn $\leq$ 4 : 1.

Because of the intimate association of the ores and different gangue minerals (particularly calcite and dolomite), pure hand-picked carbonates are virtually impossible to obtain. With this qualification in mind, optical spectrographic results for Mn, Sr, and Ba in 27 vein carbonates are given in Table 53. The microprobe and spectrographic analyses of these elements do not reveal any well-defined differences between calcites and dolomites. There is, however, some indication that high MnO concentrations may be more common in dolomites, especially the ankeritic varieties.

No vein is free of chlorite. The mineral is always present regardless of whether a vein is ore-bearing or barren, and regardless of whether the host rock is Nipissing, Huronian, or Archean. The mineral is always dark

TABLE 52. MICROPROBE ANALYSES OF CALCITES AND DOLOMITES FROM COBALT AND GOWGANDA.

| No. | Location | Comments | Weight % | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | CaO | MgO | MnO | FeO | $CO_2$* | Sum |
| P 17 | Hi Ho mine, Cobalt | ankerite in silver-rich pocket in Cadesky vein | 29.6 | 14.9 | 3.1 | 7.1 | 45.7 | 100.4 |
| P324 | Vein 37, Langis | dolomite, main part of vein | 30.3 | 16.6 | 2.1 | 4.7 | 46.1 | 99.8 |
| | | calcite, replacement of main dolomite | 54.7 | 0.6 | 0.4 | 0.4 | 44.0 | 100.1 |
| | | main part of silver-calcite vein along one wall | 54.8 | 0.2 | 0.8 | 0.3 | 43.9 | 100.0 |
| | | partly replaced dolomite adjacent to above | 31.0 | 19.4 | 0.8 | 2.0 | 47.2 | 100.4 |
| JF69G–51 | Castle No. 3 shaft, Miller Lake, Gowganda | calcite near wall rock | | 0.3 | 1.6 | 0.3 | | |
| | | calcite near vein centre | | 0.14 | 0.6 | 0.2 | | |
| | | calcite between above two | | 0.4 | 0.9 | 0.5 | | |
| JF69G–36 | Siscoe mine, Miller Lake, Gowganda | main calcite in ore vein | | 0.3 | 0.25 | 0.65 | | |
| | | associated younger replacement of above | | 0.0 | 0.08 | 0.02 | | |
| | | calcite in younger quartz-calcite vein along wall | | 0.0 | 0.04 | 0.02 | | |

Analyst : A.G. Plant

* Calculated

TABLE 53. OPTICAL SPECTROGRAPHIC ANALYSES OF VEIN CARBONATES FROM THE COBALT-GOWGANDA REGION.

| *Calcites in diabase* | | Mn % | Sr ppm | Ba ppm |
|---|---|---|---|---|
| JF66–26 | Siscoe mine, Miller Lake, Gowganda (see Fig. 181) | 0.60 | 62 | 17 |
| P505 | Siscoe mine, 350 level | 0.07 | 24 | 13 |
| P785 | Siscoe; coarse crystals in vug with argentite | 0.18 | 30 | 34 |
| P798 | Siscoe 1000 level | 0.11 | 21 | 32 |
| JF68–313 | Siscoe, with hematite crystals in vein | 0.42 | 81 | 9 |
| P529 | Siscoe 1250 level | 0.49 | 53 | 8 |
| P532 | Siscoe 1250 level | 0.65 | 77 | 12 |
| JF69G–103 | Manridge property, Gowganda Lake | 0.16 | 72 | 33 |
| (2) | Manridge, second sample from above specimen | 0.51 | 100 | 12 |
| JF69G–105 | Manridge, from another vein | 0.50 | 83 | 23 |
| *Dolomites in diabase* | | | | |
| JF–CK17 | Canadian Keeley mine, South Lorrain | 1.8 | 80 | 21 |
| JF69L–40 | West side of Maidens Lake, South Lorrain | 0.10 | 78 | 8 |
| JF69–365 | Colonial mine, Cobalt | 0.15 | 60 | 25 |
| JF68–35 | Claim 1101, Gillies Limit tp., Cobalt (see Fig. 194) | 0.76 | 75 | 20 |
| *Calcites in Archean host rocks* | | | | |
| P401 | In lamprophyre dyke, Wood's vein, S. Lorrain | 0.37 | 55 | 20 |
| JF69–AL1 | Canadian Lorrain property (HR69), South Lorrain | 0.07 | 34 | 1 |
| JF69–363 | Colonial mine, Cobalt | 0.33 | 78 | 17 |
| (2) | Colonial, second sample from above specimen | 0.16 | 91 | 32 |
| JF66–48 | Mensilvo property, lot 5, conc. IV, Coleman tp., Cobalt | 0.98 | 100 | 10 |
| JF69–707 | Langis mine, Casey township | 0.20 | 38 | 27 |
| JF69G–72 | 230 level, Lower Bonsall mine, Gowganda | 0.29 | 76 | 72 |
| *Dolomites in Archean and Proterozoic rocks* | | | | |
| P415 | Archean; vein in Beaver fault, S. Lorrain | 0.14 | 110 | 410 |
| JF69–AL9 | Archean; Canadian Lorrain property, S. Lorrain | 0.28 | 63 | 110 |
| JF69–850 | Archean; Deer Horn mine, Cobalt | 0.26 | 46 | 17 |
| P9524 | Huronian; Silverfields mine, Cobalt | 0.18 | 60 | 7 |
| P9552 | Huronian; Silverfields mine, Cobalt | 0.21 | 62 | 20 |
| JF68–244 | Huronian; Ethel Copper property, James tp., Elk Lake | >2 | 33 | 19 |

Analyses by spectrographic laboratory, GSC. Accuracy stated as being ± 15% of value reported.

FIG. 167. (Left) Characteristic appearance of spheroidal vein chlorite (transmitted light, crossed nicols).

FIG. 168. (Right) Vein albite projecting into calcite and partly replaced by it. Finer twinning is present along the sides and top of the grain (transmitted light, crossed nicols). Length of scale line, 0.1 mm.

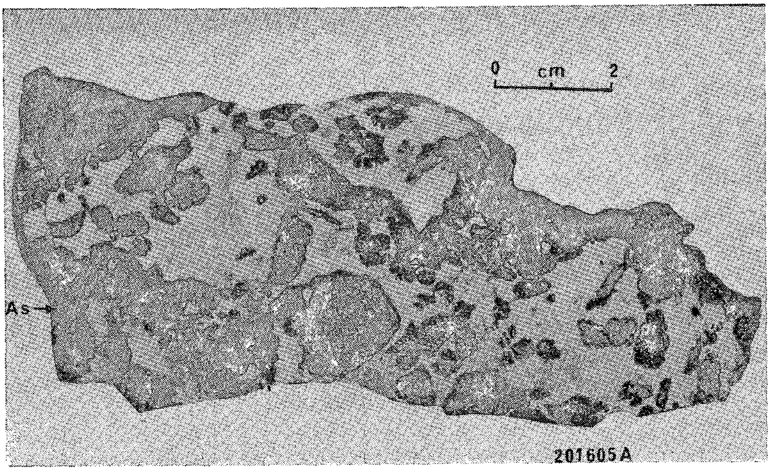


FIG. 169. Brecciated wall rock fragments, coated with narrow, dark rims of chlorite, in a matrix of carbonate (mostly dolomite) and minor arsenides (As) ; Foster property, Coleman tp., Cobalt.

green to greenish black in hand specimens, and is invariably present near the vein walls. Although laths and compact masses are present in some veins, most chlorite occurs as radiating laths and sheaves, or complete spheroids (Fig. 167). Whether coating the vein walls or wall rock fragments (Fig. 169), chlorite thicknesses in both small and large veins rarely exceed 1 to 2 mm. Likewise, the diameter of chlorite spheroids is restricted to this maximum size range.

In nearly all veins, repeated movements have disturbed the chlorites so that fragments wrested from the walls are very commonly randomly scattered in the younger carbonates. There are, in addition, clear indications that chlorite deposition in some veins did not everywhere abruptly cease; disseminated spheroids in undisturbed carbonate show that some minor overlap was present.

Microprobe analyses of vein chlorites from several localities are given in Table 54. The proportions of ferrous and ferric oxide calculated by means of the procedure given in the accompanying appendix are also shown for those chlorites amenable to this procedure. In several other cases the calculations showed very slight octahedral cation deficiencies suggestive of oxidized chlorites.

The microprobe analyses show that the vein chlorites have a wide range of compositions. MgO, for example, ranges from 10.7 to 24.3 per cent. Discouraging with respect to the possibility of systematic compositional variations being present is the fact that chlorite heterogeneity within a thin section is the rule rather than the exception. Individual chlorite sheaves and spheroids are also commonly variable in composition, but this at least is useful for, despite the presence of some compositional fluctuations, the general trend is one of magnesium enrichment in the outer, latest-formed parts of the grains.

Also given in Table 54 are the identifications of the chlorite polytypes according to the structural scheme described by Bailey & Brown (1962). The vein chlorites in the region are the monoclinic IIb, Ib, and Ia polytypes. The proportions of these is adequately reflected in Table 54, that is, the IIb structure is by far the most common, but Ib polytypes are by no means rare. The Ia polytype has been found in only 3 specimens. There seems to be no restriction on the occurrence of the types as both the IIb and Ib structures have on more than one occasion been found within a single thin section.

Finally, some brief comments on the vein quartz are necessary. The fluid inclusion study by Scott & O'Connor (p. 263) usefully focuses attention on some of the difficulties in interpreting the relative ages of the gangue minerals. The depositional sequence outlined in the present study

TABLE 54. MICROPROBE ANALYSES OF ASSORTED VEIN CHLORITES FROM THE COBALT-GOWGANDA REGION.

| No. | Location | Habit | Opt. sign | Interf. colour | Poly-type | Analytical weight % | | | | Calc. wt. % | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $SiO_2$ | $Al_2O_3$ | MgO | FeO* | FeO | $Fe_2O_3$ |
| JF68–366 | Colonial mine, Cobalt (in diabase host) | compactly intergrown aggregates | + | blue | Ib | 27.9 | 18.1 | 16.4 | 26.7 | | |
| JF69–NS2 | "Aplite" dyke, E. shore of Peterson L., Cobalt | radiating sheaves | + | blue | Ib | | | 10.7 | 31.4 | | |
| JF68–485 | Claim T29502, Gillies Limit tp., Cobalt; quartz-specularite vein in Cobalt sediments | radiating sheaves | — | brown | IIb | 24.7 | 17.4 | 18.9 | 24.0 | 16.8 | 8.0 |
| JF68–901 | Silverfields mine, Cobalt; vein in Cobalt sediments | radiating sheaves | — | green | IIb | 25.5 | 18.0 | 19.8 | 21.8 | 17.5 | 4.7 |
| P17 | Hi Ho mine, Cobalt; Cadesky vein | radiating sheaves, zoned | —<br>+ | green<br>blue | | 26.1<br>range | 18.6 | 19.1<br>16.7–24.3 | 23.5<br>18.6–27.3 | | |
| JF68–42 | Silver Queen property, Cobalt; vein in Archean | radiating sheaves | — | green | IIb | 26.4 | 24.1 | 14.8 | 24.6 | | |
| JF68–45 | Silver Queen; Archean host | radiating sheaves | + | blue | IIb | 25.9 | 19.1 | 13.6 | 27.9 | | |
| JF66–2 | Foster property, Coleman tp., Cobalt; Archean host | radiating sheaves | + | blue | IIb | 26.8 | 18.6 | 18.1 | 23.4 | 22.6 | 0.9 |
| JF68–191 | Hunter property, Bucke tp.; vein in Archean interflow sediments | coarse, not radiating | + | blue | IIb | 25.2 | 19.5 | 13.1 | 27.2 | | |
| JF68–179 | Red Rock property, Bucke tp., Cobalt; in Archean | fibrous aggregates | + | grey | Ib | 29.0 | 14.8 | 14.8 | 30.4 | | |
| P395 | Canadian Keeley 6th level, S. Lorrain; in Archean | radiating sheaves | — | brown | IIb | 26.6 | 18.9 | 20.3 | 21.7 | | |
| JF68–216 | Prudential property, James tp., Elk L.; in diabase | spherulitic | + | blue | IIb | 26.8 | 16.9 | 18.9 | 21.7 | 21.4 | 0.3 |

Analyst: A.G. Plant

* Total Fe as FeO; calculated values are based on the procedure given in the appendix.

involves quartz of three different ages. The oldest, pre-carbonate quartz is considered to be by far the most important in terms of abundance, and it is suggested that most quartz in ore veins is of this age. It is necessary to recognize, however, that most productive veins have been subjected to repeated minor movements so that, where quartz is abundant, it has very frequently been dislodged from the vein walls and incorporated in the carbonate gangue. The same spatial effect is achieved by the characteristic insertion of younger gangue minerals along only one of the vein walls. Thus the fact that most of the quartz in a specimen may not be near the present vein walls is not of direct chronological significance. In such circumstances, however, it is difficult, if not impossible, to determine whether later quartz deposition has also occurred. The oldest vein quartz ranges from euhedral to anhedral in habit, with growth zoning present in some specimens and absent in others. A common feature is what Spry (1969) terms "growth mosaic" zoning (Fig. 170), but again this is not always present. As far as is known, the intermediate-age quartz (point 5) lacks growth mosaic zoning. The importance of quartz of this age is difficult to ascertain : as the grain size of the quartz increases, the position of the mineral in the depositional sequence is increasingly obscured by younger minerals and later movements. With this in mind, the writer is nevertheless

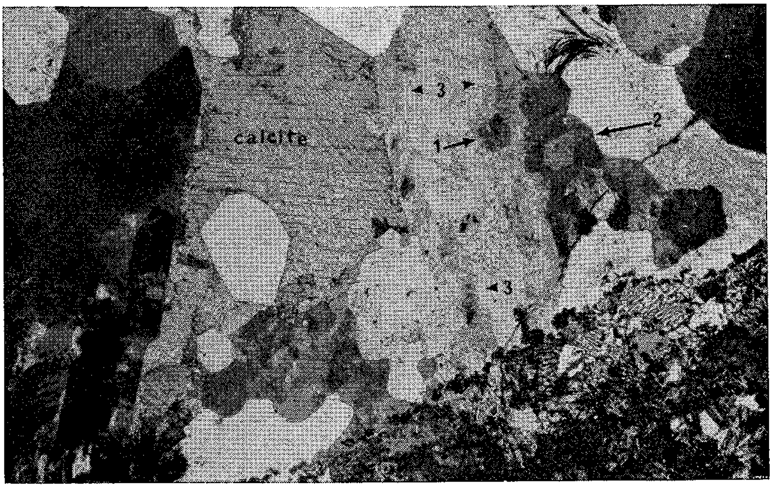


FIG. 170. Common features of vein quartz in the Cobalt-Gowganda region. Arrows point to (1) radial fibrous quartz with segments extending to core; (2) a single crystal core surrounded by a rim of fibrous quartz; (3) large crystal cut parallel to elongation, with arrow heads pointing to optically irregular, growth-mosaic borders. (JF66-122, Morrison property, Gowganda. Width of field is 4.6 mm).

of the opinion that when the composite size of crystals or aggregates of quartz approaches or exceeds about 3 mm, then the material is of old rather than intermediate age. Even where the vein walls of a specimen do not have quartz, it is suggested that transportation from another part of the vein has occurred. This suggestion is supported by the presence of chlorite and attached pieces of wall rock in association with many suspended quartz fragments. As a final comment, it should be pointed out that the suggested grain size criterion is not valid if the post-ore, quartz-calcite phase has been added to the vein. Thus the reconnaissance fluid inclusion data given by Scott & O'Connor are extremely difficult to interpret in terms of ore deposition temperatures. The bimodal distribution of filling temperatures may be an indication that two different ages of quartz are present, but it is also possible that all the material belongs to the oldest period of deposition. In the latter case the lowest temperatures might represent the initiation of quartz crystallization, and the highest temperatures the termination. Carbonates and arsenides followed.

### *Minor constituents*

Minerals in this group make up less than 5 per cent of the total volume of vein gangue throughout the region. Specific minerals may, however, be important in certains veins, or parts of veins. *Hematite,* for example, can be found in trace amounts in many veins, but is abundant in few. The pinkish pigmentation of feldspars in granophyres and in zones of wall rock alteration along veins is due to finely dispersed iron oxide which is undoubtedly hematite. Although the pinkish colour of dolomites is a primary trait, this seems not to be the case for the relatively rare pink calcites ; in every calcite of this type which was examined in detail in this study, very fine hematite powder was found along cleavage planes or as inclusions in the carbonate. Likewise, a few dolomites have yellow and red patches of powdery iron oxide which are usually confined to the vicinity of the vein walls. Specular hematite is present in some veins. It is, for example, one of the principal gangue minerals in certain silver-bearing veins at the Tonopah property, Miller Lake, Gowganda, and in the copper-rich veins of the Ethel Copper property, James township, Elk Lake. In minor occurrences the mineral is typically fibrous and radiating. Quartz is characteristically associated and forms the base from which the fibrous hematite grains radiate into carbonate at the vein centre. *Magnetite* and other opaque minerals are reported by Petruk (p. 131) to be present in the veins in small amounts.

Perhaps the most widespread minor gangue mineral is *actinolite*. Never does it attain the status of being a major primary constituent in productive veins, but it does occur in at least trace amounts in most ore veins and abundances of 2 to 3 per cent are not uncommon in individual hand specimens. The mineral is characteristically present in carbonate as disseminated pale green needles having a length that generally ranges from 0.1 to 0.4 mm. A microprobe analysis of actinolite from one vein was given previously (Table 10, p. 73).

*Sphene* never occurs in large quantities, but it has the distinction of being the most pervasive of the minor gangue minerals. Euhedral crystals 0.1 to 0.2 mm in maximum dimension are not rare, though smaller subhedral to anhedral grains and aggregates in carbonate are the typical habit. *Rutile* occurs in considerably fewer specimens and in these it is much less abundant than sphene. The disseminated euhedral grains, twins, and aggregates of rutile rarely exceed 0.1 mm in size. *Anatase* occurrences are only slightly less common than those of sphene, but grain sizes are similar to those of rutile. In addition to their role as vein minerals, the titanium-bearing trio has also been formed by alteration of ilmenite in zones of wall rock alteration. Some material of this type has been incorporated into the gangue where fracturing and movement occurred along the vein walls.

Apple-green *epidote* is abundant in some specimens, but is not important in most productive veins. The mineral was deposited very early in the depositional sequence and most has penetrated with carbonates into wall rock, particularly where this is diabase. Microprobe analyses of epidote grains in 2 specimens are given in the paper on wall rock alteration (Table 69, p. 284). In addition to well-defined vein material, irregular green masses and veinlets are common in Archean volcanics, but these are believed to be unrelated to ore deposition.

Three rare earth minerals are known to occur in the veins. Of these, *cerite,* a silicate of cerium and lanthanum, was identified in one specimen from the 1000 foot level of the Siscoe mine, Miller Lake, Gowganda. The mineral occurs in calcite as scattered pale pink aggregates averaging about 0.1 mm in diameter, and is associated with abundant native silver which is practically the only ore mineral in the specimen. X-ray powder diffraction patterns of the cerite are in good agreement with data given by Glass *et al.* (1958). Microprobe analyses indicate that the mineral is heterogeneous with respect to most elements, particularly the rare earths. Calcium ranged from about 8 to 18 weight per cent, the higher values being accommodated by a corresponding decrease in cerium and lanthanum. The very high calcium content of the mineral is unusual, but in view of the lack of quantitative data, it is assumed that this enrichment could be accepted within the simplified structural formula given by Gay (1957) : $(Ca,La)_3Si_2(O,OH,F)_9$.

The presence of an *unidentified yttrium silicate* in the Christopher mine, Cobalt, was described by Thomson (1961e, p. 78) :

> "A mineral collected by W. C. Martin from one of the Columbus East shaft veins and submitted to the writer was identified by D.A. Moddle, Provincial Assayer, Ontario Department of Mines as a silicate of yttrium, containing calcium and iron also. The silicate was in the form of bright red rather angular fragments up to 1/8 inch enclosed in pink calcite. The writer has not seen this mineral in any other place in the Cobalt camp, but Barry (at one time geologist for Cobalt Lode Mines) reported similar occurrences in the adjacent Cobalt Lode property."

The present writer was unable to find any of this mineral in the dumps of either the Christopher or Cobalt Lode properties. D. A. Moddle reported (written communication, September 4, 1968) that the material submitted by Thomson is unavailable.

The most abundant of the rare earth minerals is *allanite*. It has been identified in a great number of veins and is in fact one of the most persistent of the minor gangue minerals. Nowhere, however, does it occur in abundance. The mineral is easily recognized because of its characteristic dark brown colour, strong pleochroism, and acicular habit. Where the mineral is sparse, single acicular grains from 0.05 to 0.25 mm in length are isolated in carbonate. In the presence of many grains, a partly radiating to spheroidal habit is common. Allanite compositions have been examined in only two specimens ; in JF66-114 (Fig. 189), partial microprobe analysis gave the following weight percentages : CaO 13.9 ; $Al_2O_3$ 13.6 ; $SiO_2$ 31.2 ; total iron as FeO 15.7. Checks for other elements indicated that rare earths account for most of the remainder of the total. Only cerium and lanthanum are abundant, and these are present in approximately equal proportions. In the second specimen (P9567, Table 56), less iron is present but the composition is otherwise similar.

Although veins containing allanite are unrestricted with respect to the type or age of their host rocks, the mineral occurs in the largest quantities in veins in diabase. The afore-mentioned cerite-bearing specimen also contains allanite, and it is interesting that both these minerals have cerium and lanthanum as their principal rare earths. The unidentified mineral of Thomson seems to be quite different in that yttrium is the main rare earth element.

*Apatite* is relatively rare, but has been found in about half a dozen veins. Numerous subhedral grains up to 2 mm long occur in dolomite at the Ethel Copper property, Elk Lake, but in the remainder of the occurrences only 1 or 2 colorless grains less than a millimeter in cross-section have been found. It is not known whether the mineral contains rare earths.

In the Archean volcanics there are several minor occurrences of purple *axinite* in vein-like masses, some of which are more than 15 cm in width. The more massive occurrences are associated with normal green epidote. Smaller, narrow veins composed largely of actinolite and epidote have in some cases a purple hue attributable to associated fine-grained axinite. Such veins have commonly been the sites of movement as indicated by slickensided surfaces and alignment of the amphibole. Major post-ore faults in the Nipissing diabase, such as the Glory Hole fault at Gowganda (p. 30), are in several cases filled with similar material.

Axinite has been noted to occur in ore veins at several localities, but the mineral is a minor feature and is absent in most veins. Although well-formed, clear crystals have been found in veins in the diabase at the Morrison property, Gowganda, in most occurrences of this type throughout the region the colour is a drab greenish-brown to dull purple. Crystal faces are usually visible, and well-formed crystal aggregates 2 to 3 cm in diameter have been found.

Dark brown *stilpnomelane* is a rare mineral and has been noted in only 4 specimens (2 at Gowganda, and 1 each at South Lorrain and Cobalt). In all of the specimens the mineral is associated with barren calcite and the relationship with the ore minerals is not discernible. Stilpnomelane has been noted to occur in small amounts in granophyric diabase, and is associated with pre-ore actinolite veins in the Gowganda Lake area.

Orange-colored *barite* is the main gangue mineral at the barren terminal portion of an ore vein which cuts the Archean in the Lower Bonsall mine, Gowganda. This is the sole occurrence of barite, in the silver veins, known to the writer.

Only one grain of deep blue *tourmaline,* a fraction of a millimeter in length, was found in calcite in a dolomite vein in the Beaver Fault on the 1200 foot level of the Canadian Keeley mine, South Lorrain.

*Prehnite* is not quite as rare, though it has been found only in microscopic amounts in a few veins, all of which are in Nipissing diabase.

*Garnet* has been found only in vein specimens from the Morrison property, Miller Lake, Gowganda. The principal association is with quartz, some of which is choked with anhedral garnet grains averaging about 0.01 mm in diameter. They are commonly clustered along the quartz growth zones. Garnet grains several times the above size also occur at the quartz-calcite boundaries. Their cell size of 13.051 ± 0.005 Å is identical to that of andradites in the most salic varieties of the Nipissing diabase.

## VARIATIONS WITHIN A VEIN

### *Introduction*

Insofar as the veins in the Gowganda area lack dolomite, there is a regional variation in carbonate mineralogy. The microprobe analyses of calcites, dolomites, and chlorites which have already been given indicate that the compositions of these minerals are highly variable within the region, and variable in veins from the same general locality.

Petruk has shown (p. 108) that the arsenide ore minerals within the veins can be classified into 5 groups as follows : Ni, NiCo, Co, CoFe, and Fe. In most veins the characteristic assemblages are systematically distributed, that is, the veins are chemically and mineralogically zoned. For carbonates and chlorites, it has not been possible to correlate compositions from one vein to another even where the comparison is between material containing identical arsenide assemblages. Because of this lack of correlation, two veins were selected for a more detailed study in order to establish the compositional ranges within each vein. Petruk (1968) has described the arsenide variations in the veins at the Silverfields mine, Cobalt, and he has kindly provided the samples used for this study. The location of the veins in the mine is shown by Petruk (1968, p. 513), and a partial cross-section showing the location and arsenide environment of the individual samples used here is given in Figure 171. The veins strike approximately normal to the elongation of an eroded Archean trough filled with

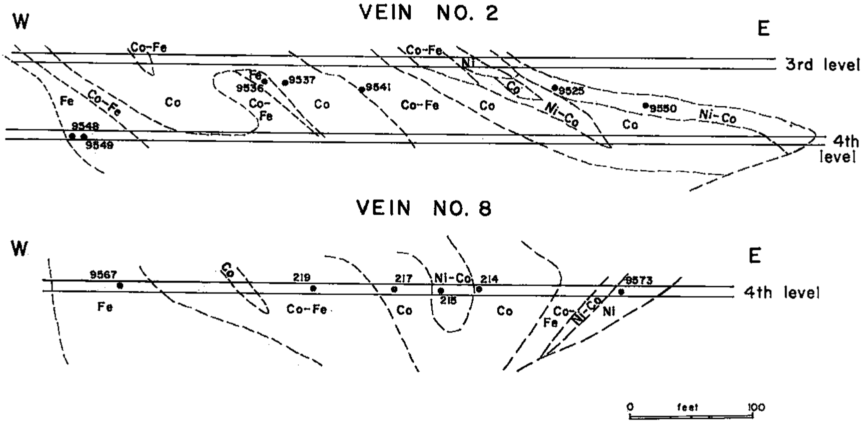


FIG. 171. Longitudinal sections of parts of veins 2 and 8 in the Silverfields mine, Cobalt, showing the arsenide zones as determined by Petruk and the location of the P-series samples for which microprobe analyses of chlorites, dolomites, and calcites are reported in this paper.

Gowganda (Coleman) sediments. The western end of Vein 2 cuts Archean volcanics at the edge of the trough; samples P9548 and P9549 have Archean host rocks, and the remainder are in Gowganda sediments. In Vein 8, only P9567 is enclosed by the Archean.

### *Chlorite compositions, Vein 2*

Microprobe analyses of chlorites in 7 samples from this vein are given in Table 55. Chlorites in the Fe arsenide zone have blue interference colours and are length slow whereas those in the Co- and Ni-bearing zones are predominantly green and length fast. All are IIb polytypes.

TABLE 55. MICROPROBE ANALYSES OF CHLORITES IN VEIN 2, SILVERFIELDS MINE, COBALT.

| Zone & No.* | Comments | Weight % | | | | |
|---|---|---|---|---|---|---|
| | | $SiO_2$ | $Al_2O_3$ | MgO | FeO** | MnO |
| P9548 Fe | coarse laths in arsenides | 26.2 | 15.9 | 14.2 | 28.9 | |
| | second thin section from same sample | 23.3 | 18.8 | 13.0 | 29.6 | 0.54 |
| | composition range in second section | 22.9–23.6 | | 12.7–13.3 | 29.1–30.1 | 0.53–0.55 |
| P9549 Fe | radiating sheaves in contact with arsenides | 27.5 | 15.7 | 14.8 | 27.5 | 0.46 |
| | range | 26.3–29.0 | | 13.7–16.6 | 26.3–29.0 | 0.39–0.56 |
| | compact masses on wall rock fragment | 25.5 | 16.1 | 13.6 | 28.7 | 0.50 |
| | range | | | 13.0–14.0 | 28.2–29.0 | 0.44–0.56 |
| P9536 Fe | small spheroid in contact with arsenides | 24.4 | 18.2 | 13.7 | 27.5 | |
| P9537 Co | radiating sheaf in contact with arsenides; the range represents a 0.11 mm width across a single sheaf | 22.4–24.0 | 18.0–18.7 | 13.6–15.2 | 25.9–27.4 | 0.30–0.32 |
| P9541 CoFe | aggregates of laths at vein wall | 22.8 | 17.9 | 14.4 | 27.4 | 0.35 |
| | range | 22.4–23.3 | 17.7–18.1 | 13.8–14.8 | 27.2–27.5 | 0.33–0.38 |
| P9525 NiCo | aggregates of sheaves from vein wall | 21.8–24.3 | 16.7–17.6 | 15.2–20.8 | 20.2–27.3 | 0.30–0.34 |
| P9550 | sheaves from vein wall, | 24.6 | 17.2 | 15.4 | 26.4 | range |
| NiCo | in dolomite; | 25.1 | 17.1 | 16.5 | 25.6 | 0.2–0.6 |
| | spot analyses | 26.0 | 17.3 | 18.9 | 21.6 | |
| | | 26.2 | 17.0 | 20.6 | 20.4 | |

Analyst: G.R. Lachance

* Sample number and associated arsenide zone.

** Total iron as FeO.

As is the usual case, different chlorite areas within a single polished thin section do not have identical compositions. The procedure used was to find an "average" composition in a very small area, and then to check other areas to establish a compositional range. With the limited number of samples studied and the relatively few, random analyses, a systematic compositional trend would more likely be missed rather than established fortuitously. The ranges in weight per cent MgO and FeO (FeO + $Fe_2O_3$) for the chlorites in each of the arsenide zones in Vein 2 are summarized in Table 57. The data indicate that the median value of FeO is highest in the iron arsenide zone and progressively decreases toward the nickel-bearing zone. Although the median value for MgO does not have the same type of zoning, the highest value is nevertheless in the nickel-bearing zone. It is possible that manganese abundances roughly parallel those of iron.

### *Chlorite compositions, Vein 8*

Microprobe analyses of chlorites in 6 samples from this vein are given in Table 56. Interference colours are blue except in P217, which is partly

TABLE 56. MICROPROBE ANALYSES OF CHLORITES IN VEIN 8, SILVERFIELDS MINE, COBALT.

| Zone & No.* | Comments | Weight % | | | | |
|---|---|---|---|---|---|---|
| | | $SiO_2$ | $Al_2O_3$ | MgO | FeO** | MnO |
| P9567 Fe | partly radiating sheaves coating wall rock | 24.1 | 17.5 | 14.8 | 26.7 | 0.6 |
| | range | 23.9–25.0 | 17.1–18.1 | 13.2–16.4 | 25.4–27.9 | |
| P219 CoFe | partly radiating sheaves coating wall rock | 24.1 | 16.8 | 14.7 | 27.8 | 0.5 |
| | range | | 16.8–18.6 | 12.2–17.2 | 25.9–29.2 | 0.5–0.7 |
| | chlorite in wall rock, 5 mm from vein | 23.5 | 18.2 | 15.7 | 26.3 | 0.20 |
| P217 Co | laths and sheaves, loosened from wall; interference colours green to blue; spot analysis and | 23.3 | 17.8 | 18.6 | 21.4 | 0.10 |
| | range | 21.4–24.9 | 16.8–18.2 | 12.8–19.2 | 21.2–29.1 | 0.1–0.2 |
| P215 NiCo | fibrous to sheaf-like; homogeneous | 24.0 | 15.6 | 13.8 | 26.3 | 0.3 |
| P214 Co | compact intergrowth along vein margin | 24.0 | 18.3 | 14.4 | 26.3 | 0.3 |
| | range | 23.7–24.2 | 17.5–19.2 | 14.1–15.2 | 25.9–26.9 | |
| P9573 Ni | laths, partly in contact with arsenides | 24.9–28.9 | 15.2–17.1 | 22.3–30.0 | 8.5–15.6 | 0.0–0.2 |

Analyst: G.R. Lachance

* Sample number and associated arsenide zone.

** Total iron as FeO

TABLE 57. RANGES AND MEDIANS OF FeO AND MgO IN CHLORITES, VEINS 2 AND 8, SILVERFIELDS MINE, COBALT.

| | Arsenide zone | Weight % FeO range | Weight % FeO median | Weight % MgO range | Weight % MgO median |
|---|---|---|---|---|---|
| Vein 2 | Fe | 26.3–30.1 | 28.2 | 12.7–16.6 | 14.7 |
| | CoFe | 27.2–27.5 | 27.4 | 13.8–14.8 | 14.3 |
| | Co | 25.9–27.4 | 26.7 | 13.6–15.2 | 14.4 |
| | NiCo | 20.2–27.3 | 23.7 | 15.2–20.8 | 18.0 |
| Vein 8 | Fe | 25.4–27.9 | 26.7 | 13.2–16.4 | 14.8 |
| | CoFe | 25.9–29.2 | 27.6 | 12.2–17.2 | 14.7 |
| | Co | 21.2–29.1 | 25.2 | 12.8–19.2 | 16.0 |
| | NiCo | 26.3 | 26.3 | 13.8 | 13.8 |
| | Ni | 8.5–15.6 | 12.1 | 22.3–30.0 | 26.2 |

TABLE 58. MICROPROBE ANALYSES OF DOLOMITES IN VEIN 2, SILVERFIELDS MINE, COBALT.

| Zone & No.* | Comments | CaO | MgO | MnO | FeO | $CO_2$[a] | Sum |
|---|---|---|---|---|---|---|---|
| P9548 Fe | 1. dolomite with arsenides | 29.9 | 19.6 | 0.6 | 2.7 | 46.9 | 99.7 |
| P9549 Fe | 1. main vein dolomite | | 16.5 | 0.5 | 3.9 | 48.1 | 101.0 |
| P9536 Fe | 1. bilaterally-distributed arsenides with dolomite in centre: a) main dolomite | 30.4 | 21.9 | 0.1 | 0.5 | 48.1 | 101.0 |
| | b) clear edge of rhombs projecting into calcite | 30.1 | 21.2 | 0.2 | 0.8 | 47.3 | 99.6 |
| | 2. "younger" arsenide-poor vein between arsenides and wall rock: a) dol. abutting arsenides | 29.7 | 21.8 | 0.1 | 0.6 | 47.6 | 99.8 |
| | b) centre of vein, near calcite in vug | 29.6 | 21.9 | 0.1 | 0.4 | 47.4 | 99.4 |
| P9537 Co | 1. dolomite near centre of vein | | 21.5 | 0.4 | 2.0 | | |
| | 2. 2 mm from above | | 20.8 | 0.5 | 2.5 | | |
| | 3. 5 mm from above, closer to vein wall | | 22.6 | 0.25 | 0.9[b] | | |
| P9541 CoFe | 1. dol. with arsenides, ~ 2 mm from wall rock | | 22.0 | 0.1 | 1.0 | | |
| | 2. adjacent area, < 1 mm from above | | 21.7 | 0.2 | 1.0 | | |
| | 3. closer to vein centre, ~ 7 mm from above | | 22.0 | 0.2 | 0.7 | | |
| | 4. in another area, near vein centre (?) | | 22.6 | 0.15 | 0.7 | | |
| P9525 NiCo | 1. main vein dolomite | | 18.7 | 0.55 | 4.5 | | |
| | 2. with arsenide rosettes, 2 mm from above | | 19.2 | 0.7 | 3.9 | | |
| P9550 NiCo | 1. main vein dolomite | | 22.9 | 0.2 | 0.2 | | |
| | 2. near wall; largely replaced by silver-calcite vein | | 23.0 | 0.1 | 0.25 | | |
| | 3. random spots close to 2 above | | 23.3 | 0.1 | 0.15 | | |

Analyst: A.G. Plant

* Sample number and associated arsenide zone.

[a] Calculated

[b] Dolomite projects into calcite; dolomite FeO ranges from 0.5 to 1.5 (lowest near calcite).

green, and P9573, which is grey. All the chlorites are the IIb polytype. The composition ranges and medians within the specific arsenide zones are given in Table 57. The progression found in Vein 2 is not present in Vein 8. In both veins, however, there is a fairly good indication that chlorites farthest from the Fe zone are relatively enriched in magnesium and depleted in iron.

### *Compositional variations in carbonates*

Microprobe analyses of dolomites in veins 2 and 8 are given in Tables 58 and 59; analyses for calcites are given in Tables 60 and 61. Because the depositional sequence of the carbonates is complex, zoned dolomite rhombs projecting into cavities were also examined in order to determine whether compositional trends are systematic. No correlations are evident.

TABLE 59. MICROPROBE ANALYSES OF "DOLOMITES" IN VEIN 8, SILVERFIELDS MINE, COBALT.

| Zone & No.* | Comments | Weight % | | |
|---|---|---|---|---|
| | | MgO | MnO | FeO |
| P9567 | 1. 10 mm from wall rock | 19.4 | 0.7 | 2.8 |
| Fe | 2. 22 mm from wall rock | 21.5 | 0.6 | 1.6 |
| P219 | 1. main vein dolomite | 21.2 | 0.5 | 2.1 |
| CoFe | 2. second area | 20.4 | 0.7 | 2.0 |
| P217 | 1. in core of arsenide rosette | 21.3 | 0.5 | 1.7 |
| Co | 2. mottled main vein dolomite | 22.6 | 0.7 | 1.3 |
| | 3. 2 mm from above | 15.3 | 3.5 | 7.4 |
| P215 | 1. main vein dolomite (7 spots) | 19.6 | 1.3 | 2.7 |
| NiCo | 2. as above, 2 iron-rich spots | 13.0 | 3.3 | 9.7 |
| | 3. one spot, another area | 20.0 | 0.8 | 1.7 |
| P214 | 1. near centre of vein | 18.6 | 0.7 | 1.4 |
| Co | 2. near wall rock; composition highly variable | 11.9 | 3.0 | 8.5 |
| | | 19.6 | 0.8 | 1.6 |
| P9573 | 1. main vein dolomite | 22.6 | 0.4 | 1.2 |
| Ni | 2. rosette core | 21.1 | 0.4 | 1.6 |

Analyst: A.G. Plant

* Sample number and associated arsenide zone.

Calcites are in some respects paragenetically less complex. Except for P9536 in Vein 2, all the analyzed specimens most probably belong to the silver-calcite stage of deposition. Calcites of this type occur as clear veinlets close to the wall rocks, and spread into the veins from this position (Figs. 172-174). Although the most extensive replacement occurs at the calcite vein boundary, the second most favoured penetration is to the rims and cores of arsenide rosettes (Figs. 175-177). The microprobe analyses thus

TABLE 60. MICROPROBE ANALYSES OF CALCITES IN VEIN 2, SILVERFIELDS MINE, COBALT.

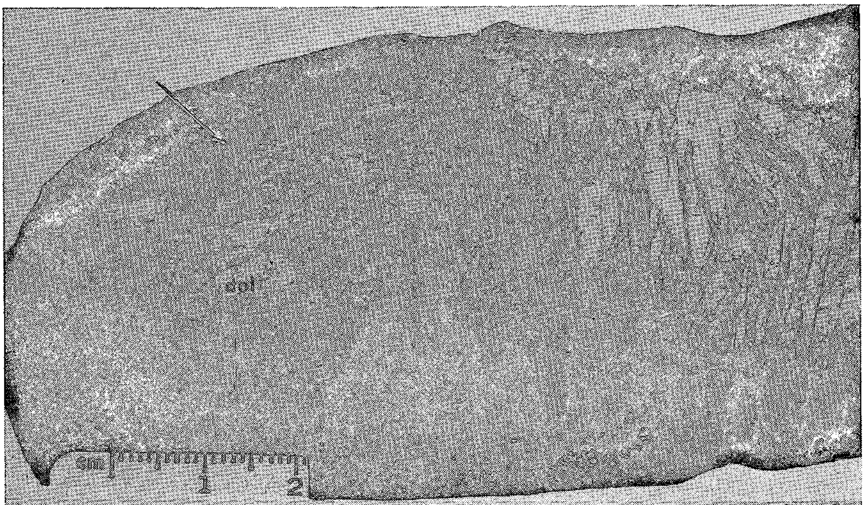
| Zone & No.* | Comments | Weight % | | | | | |
|---|---|---|---|---|---|---|---|
| | | CaO | MgO | MnO | FeO[a] | $CO_2$[b] | Sum |
| P9548 Fe | 1. in contact with arsenides and dolomite (footnote [c]) | 53.5 | 0.5 | 0.9 | 0.8 | 43.6 | 99.3 |
| | 2. same general area as above | 54.9 | 0.3 | 0.7[d] | 0.2 | 43.9 | 100.0 |
| | 3. calcite vein at wall | 55.4 | 0.4 | 0.5 | 0.0 | 44.2 | 100.5 |
| P9549 Fe | 1. calcite adjacent to dolomite (MnO range in calcite: 0.2-2.3) | | 0.2 | 1.1 | 0.2 | | |
| P9536 | 1. calcite with dolomite 1b | 55.5 | 0.1 | 0.6 | 0.1 | 44.1 | 100.4 |
| Fe | 2. with dolomite 2b | 55.1 | 0.1 | 0.7 | 0.2 | 43.9 | 100.0 |
| P9537 Co | 1. with dolomite 3 | | 0.3 | 0.4 | 0.1 | | |
| P9541 | 1. with dolomite 4 | | 0.6 | 0.3 | 0.15 | | |
| CoFe | 2. veinlet, 0.6 mm wide, cutting inclusion of wall rock | | 0.15 | 0.3 | 0.2 | | |
| | 3. same veinlet, 12 mm from above | | 0.15 | 0.5 | 0.1 | | |
| P9525 | 1. with dolomite 2 | | 0.3 | 0.4 | 0.2 | | |
| NiCo | 2. silver-calcite veinlet along wall; with dolomite 1 | | 0.3 | 0.8 | 0.3 | | |
| | 3. centre of above veinlet and 8 mm along strike | | 0.0 | 0.6 | 0.2 | | |
| P9550 | 1. with dolomite 1 | | 0.15 | 0.4 | 0.1 | | |
| NiCo | 2. with dolomite 2 | | 0.15 | 0.3 | 0.1 | | |

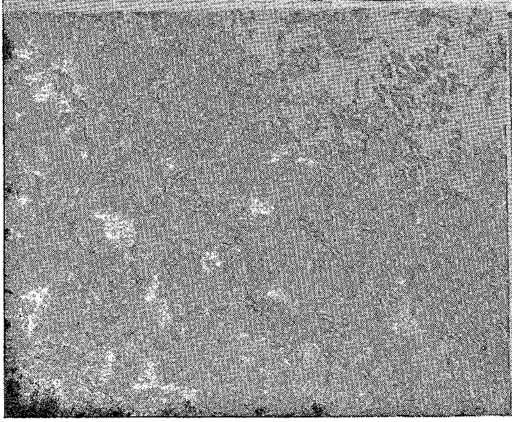
Analyst: A.G. Plant

* Sample number and associated arsenide zone.

[a] Total iron as FeO; [b] calculated; [c] references are to the corresponding dolomites in Table 58; [d] MnO ranges from 0.5 to 0.9, with the highest values being closest to dolomite.

represent both clear vein calcite and material that has replaced dolomite. The exception, P9536, is of the isolated "vug" type without feeder veinlets and is believed to be temporally related to the local termination of dolomite crystallization (point 5, p. 235). The calcites of all types are relatively





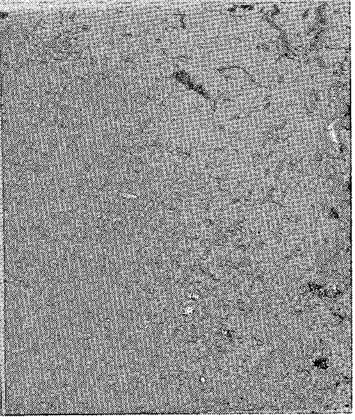


Fig. 172. (Top) Dolomite vein fractured and partly replaced by calcite (dark; stained with alizarin red). The top left shows dolomite (dol) and darker, mottled areas (arrow) that consist of residual dolomite in calcite (see Fig. 174).

Fig. 173. (Lower left) Progression of dolomite replacement by calcite, showing network texture developed in the initial stages.

Fig. 174. (Lower right) Advanced stage of calcite replacement, with relict dolomite. Figs. 173, 174: carbon-coated polished thin sections, reflected light.

pure. Within the limited range of variability no specific pattern has emerged. The data for P9541 and P9525 in Vein 2 indicate that a compositional trend is unlikely to be found.

## VEIN ZONING

### *Chlorites*

Petruk has shown that the parts of veins nearest the centre line of the diabase are enriched in nickel arsenides whereas the parts farthest away are enriched in iron arsenides. A corresponding zonation seems to be present in chlorites : magnesium-rich compositions are associated with nickel-cobalt arsenides.

Because chlorite is remarkably consistent with respect to its spatial and depositional (paragenetic) position in the whole of a vein structure, the inference is that all chlorite deposition occurred at approximately the same time. The zonal trend noted in individual chlorite sheaves and spheroids is toward magnesium enrichment at the rims. Combining this trend with that of magnesium enrichment associated with the nickel-cobalt arsenides, the over-all chlorite zonal pattern points downward, that is, material in the Silverfields veins was apparently added from the top rather

TABLE 61. MICROPROBE ANALYSES OF CALCITES IN VEIN 8, SILVERFIELDS MINE, COBALT.

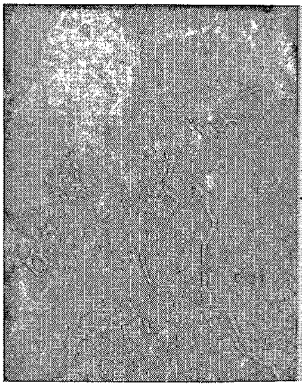
| No. | Arsenide zone | Comments | Weight % | | |
|---|---|---|---|---|---|
| | | | MgO | MnO | FeO |
| P9567 | Fe | 1. vein at wall rock boundary | 0.3 | 0.5 | 0.06 |
| | | 2. with dolomite 1* | 0.15 | 0.8 | 0.1 |
| | | 3. with dolomite 2 | 0.3 | 0.6 | 0.15 |
| P219 | CoFe | 1. with dolomite 2 | 0.6 | 0.5 | 0.2 |
| | | 2. in wall rock, 5 mm from vein | 0.3 | 0.8 | 0.5 |
| P217 | Co | 1. vein at wall rock boundary | 0.3 | 0.6 | 0.3 |
| | | 2. between dolomites 2 and 3 | 0.3 | 0.8 | 0.3 |
| P215 | NiCo | 1. vein at wall rock boundary | 0.3 | 0.8 | 0.4 |
| | | 2. intergrowth with dolomites 1 and 2 | 0.4 | 0.8 | 0.6 |
| P214 | Co | 1. intergrowth with dolomite 2 | 0.7 | 0.7 | 0.4 |

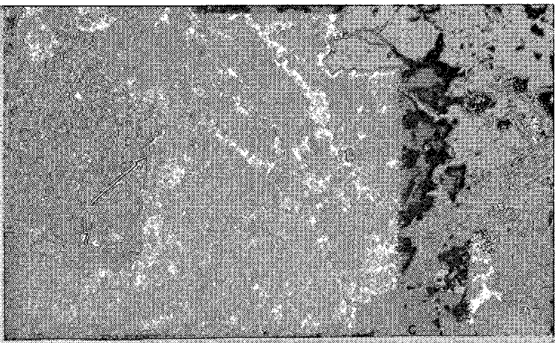
Analyst : A.G. Plant

* References are to the corresponding dolomites in Table 59.

than from the bottom. The development of the chlorite compositional zoning is therefore assumed to be a response to differences in the physical and/or chemical conditions between the "top" (nickel-rich) and "bottom" of a vein. Pressure gradients are unlikely to have been significant, so that temperature is reasonably considered as the prevailing physical factor.

Further conjecture on the depositional conditions is more tenuous. The synthesis of chlorites by Turnock (1960), Hellner *et al.* (1965), and Fawcett & Yoder (1966), indicates that under comparable conditions the upper stability limit of magnesium chlorite lies at higher temperatures than that of iron chlorite. Although there are many variables to be considered, if it is assumed that a trend toward iron enrichment coincides with de-





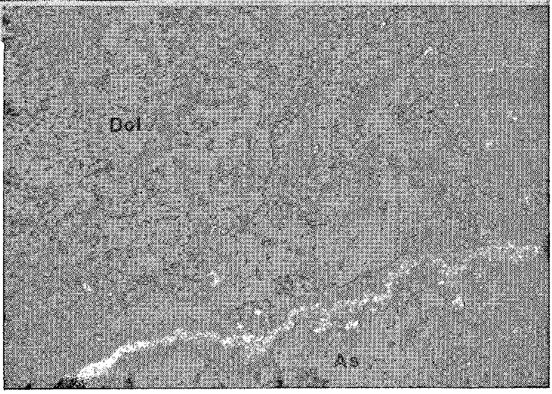


FIG. 175. (Upper left) Network calcite in dolomite (dol) and at arsenide (As) grain boundaries.

FIG. 176. (Upper right) Dark arsenide rosette with a dolomite core. Calcite (c, right, smooth, with residual dolomite) cut the arsenides and partly replaced the dolomite core.

FIG. 177. (Lower right) Calcite replacement of dolomite, with the area to the left showing the selective penetration along the rim of an arsenide rosette. Figs. 175, 176, 177: carbon-coated polished thin sections, reflected light.

creasing temperatures, then the inference may be drawn that the nickel-rich zone is in that part of a vein having the higher temperature. Referring again to Petruk's demonstration that, in veins both above and below the diabase, the nickel arsenides are closest to the intrusion, then it follows that (a) the veins are thermally zoned with respect to the Nipissing diabase, (b) the higher temperature parts occur closest to the intrusion and the lower temperature parts farthest away, and (c) the direction of movement of vein material was outward from the diabase.

The conclusion was expressed earlier in this paper that vein deposition occurred during a series of jostling movements. The constancy of the mineral associations and paragenetic relationships suggests that no time hiatus of any significance occurred until after the ore-bearing phases had been deposited. These two concepts have important genetic implications: (a) the jostling movements basically require only a single tectonic activation source rather than a complex series of events in which material was added to veins at different times and possibly from different sources; (b) deposition of the vein matter involved a relatively continuous, albeit changing, supply of material from the source. The effects of such an open system may again be examined in terms of the chlorites in the Silverfields mine.

A multitude of chemical factors may have been involvd in bringing about chlorite deposition, and the activity of Mg in the system is referred to only to simplify the visualized process. In the initial depositional stage in which chlorite was deposited on the wall rocks, the mineral in the upper part of a vein was more magnesium-rich than that at the bottom part. The trend toward magnesium enrichment in the last-formed chlorites in the bottom of a vein could have involved increasing temperatures, increasing Mg activity independent of temperature, or a combination of both. In the presence of an approximately static thermal gradient encompassing the whole vein, any addition of new material from the top had the effect of increasing Mg deposition in chlorites throughout the whole vein, thus suggesting that the new material was effectively more magnesium-rich, and possibly at a higher temperature. If temperature was important, then the trend in the bottom parts of a vein was toward a warming prior to arsenide deposition. Thus the over-all scheme in each vein may have involved a progressive increase in temperature accompanying the initial stages of gangue deposition. Temperatures would reach their maximum at a point coinciding with the deposition of the early-formed arsenides, thus providing a correlation with Petuk's observation that partial nickel-rich envelopes are present in some veins. The later-formed (iron-rich) arsenides and even younger sulphides were deposited in the subsequent decline from this temperature peak. A schematic diagram of the progression is shown in Figure 178.

In the above discussion a proverbial house of cards has been built from limited data on two veins below the diabase. Clearly, there is a need for more data on veins below the diabase, but especially for veins above it.

### *Carbonates*

Attempts to decipher compositional trends in carbonates were unsuccessful. The gross pattern is dolomite followed by calcite, and in this respect the depositional trend is towards less magnesium, iron, and manganese in the youngest carbonate. Ore veins at Gowganda are in diabase and have calcite as the sole carbonate mineral. Ore veins in diabase in the remainder of the region contain both calcite and dolomite, but the reason for this difference is not known. The importance of dolomite as a gangue mineral was not recognized until relatively recently. Thus the "older calcite" given in parageneses by Bastin (1950) is dolomite. It is the most abundant gangue mineral in the productive veins at Cobalt.

## SOURCE OF THE GANGUE MINERALS

Conclusions about the probable source of the vein minerals were made from the nature of the chlorite zoning. Apart from the zonal patterns, an additional factor is the presence of a few, rare, "tracer" minerals in the veins. It may be significant that andradite occurs in the veins and in the most salic parts of the diabase. Likewise, prehnite is a deuteric mineral in

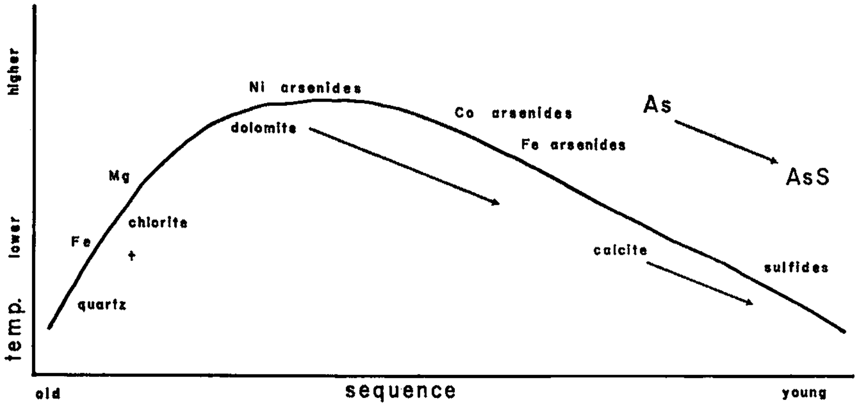


FIG. 178. Schematic diagram showing the inferred relative sequence and temperatures of deposition of the major gangue and ore minerals in the ore veins of the region.

the diabase and is present in small amounts in some veins. Presumably, however, it could have formed by reaction of the ore-forming solutions with the diabase. No such reaction can explain the appearance of allanite in many ore veins, but the mineral has also crystallized in granophyric diabase. Although not unequivocally resolving the source rock problem, the presence of such minerals is relevant.

## Appendix

### *Calculation of chlorite compositions*

In most instrumental analyses the total iron content of a sample is reported as either FeO or $Fe_2O_3$ because oxidation states are not normally determinable by microprobe, *x*-ray fluorescence, or optical spectrographic methods. Optical and *x*-ray diffraction properties are useful in determining approximate chlorite compositions (see for example Hey 1954; Shirozu 1958; Albee 1962), but for the chlorites at Cobalt the main problem was directly overcome by obtaining extensive microprobe data. This information was in turn used to resolve a subordinate problem, namely, the proportion of ferric iron in the analytically-determined total iron. The procedure used in calculating this proportion is given below. The analytical data used in the examples are taken from volume 3 of Deer, Howie, & Zussman (1962).

The procedure given below involves the calculation of the numbers of cations per unit cell with the premise that all iron is present as (a) FeO, or (b) $Fe_2O_3$. In each case the cationic valences per unit cell are adjusted to 56 (Foster 1962), and the usual procedure in allocating cations to tetrahedral and octahedral groups is followed. The fundamental assumption is that the octahedral cations will total exactly 12, and any excess or deficiency is attributable to the proportion of ferrous and ferric iron present in the sample. This assumption is clearly idealistic and is also heavily dependent on good analytical data for *all* the cations present in a chlorite. Despite these limitations, however, it is possible to obtain an indication of the ferric iron abundance in a sample. Although it has not been attempted on other minerals, the same procedure should be applicable to any species whose structural formula is known.

*Example 1:* Deer, Howie & Zussman, **3**, p. 138, analysis 5
Analytical weight per cent: FeO 37.96   $Fe_2O_3$ 8.70
Total Fe calculated as FeO = 45.79; as $Fe_2O_3$ = 50.89

(a) *All iron as FeO:*

| | | Gram | *Unit cell* | |
|---|---|---|---|---|
| | | equivalents | valences | cations |
| $SiO_2$ | 20.82 ÷ ( 60.04/4) | = 1.3871 ÷ 0.0697* | = 19.9010 ÷ 4 | = 4.9752 |
| $Al_2O_3$ | 17.64 ÷ (101.96/6) | = 1.0381 ÷ 0.0697 | = 14.8938 ÷ 3 | = 4.9646 |
| FeO | 45.79 ÷ ( 71.85/2) | = 1.2746 ÷ 0.0697 | = 18.2869 ÷ 2 | = 9.1435 |
| MgO | 4.15 ÷ ( 40.32/2) | = 0.2058 ÷ 0.0697 | = 2.9526 ÷ 2 | = 1.4763 |

* Adjustment to 56 cationic valences per unit cell: 3.9056 ÷ 56 = 0.0697

Tetrahedral Al: 8.0000 — 4.9752 = 3.0248

Octahedral Al: 4.9646 — 3.0248 = 1.9397

$$\text{Octahedral cations:}\quad \left.\begin{array}{l} \text{Al} = 1.9397 \\ \text{Fe} = 9.1435 \\ \text{Mg} = 1.4763 \end{array}\right\} 12.5595 \qquad \text{Excess} = 0.5595$$

(b) *All iron as* $Fe_2O_3$*:*

| | wt. % | | cations per unit cell |
|---|---|---|---|
| $SiO_2$ | 20.82 | ⟶ | 4.2759 |
| $Al_2O_3$ | 17.64 | ⟶ | 4.2667 |
| $Fe_2O_3$ | 50.89 | ⟶ | 7.8582 |
| MgO | 4.15 | ⟶ | 1.2688 |

Tetrahedral Al: 8.0000 — 4.2759 = 3.7241
Octahedral Al: 4.2667 — 3.7241 = 0.5426

$$\text{Octahedral cations: } \left.\begin{array}{l} \text{Al} = 0.5426 \\ \text{Fe} = 7.8582 \\ \text{Mg} = 1.2688 \end{array}\right\} 9.6696 \qquad \text{Deficit} = 2.3304$$

*Ferrous-ferric partition:* the number of cations per unit cell more closely approaches the ideal 12 when all iron is calculated as FeO. Therefore, most of the iron in the chlorite is present in the ferrous state.

Sum of cation excess and deficit: 2.3304 + 0.5595 = 2.8899
Proportion of $Fe^{2+}$ : (2.3304 ÷ 2.8899) × gram equivalents FeO in (a) above = 1.0278
Weight per cent FeO: 1.0278 × (71.85/2) = 36.92
Proportion of $Fe^{3+}$ : (0.5505 ÷ 2.8899) × gram equivalents $Fe_2O_3$ in (b) above = 0.3702
Weight per cent $Fe_2O_3$ : 0.3702 × (159.70/6) = 9.85

*Summary:*

| | Analysis wt. % | Calculated |
|---|---|---|
| $SiO_2$ | 20.82 | (20.82) |
| $Al_2O_3$ | 17.64 | (17.64) |
| $Fe_2O_3$ | 8.70 | 9.85 |
| FeO | 37.96 | 36.92 |
| MgO | 4.15 | ( 4.15) |
| $H_2O$ | 10.31 | (10.31) |
| Sum | 99.58 | 99.69 |

*Example 2:* Deer, Howie & Zussman, **3**, p. 138, analysis 2

| | Analysis, wt. % |
|---|---|
| $SiO_2$ | 25.35 |
| $Al_2O_3$ | 22.06 |
| $Fe_2O_3$ | 18.97 |
| FeO | 8.36 |
| MnO | 0.08 |
| MgO | 15.06 |
| $H_2O$ | 11.41 |
| | 101.29 |

Total Fe as FeO: 25.51
Total Fe as $Fe_2O_3$ : 28.35

All FeO: octahedral cation deficit = 0.0261
All $Fe_2O_3$ : octahedral cation deficit = 1.5102

The appearance of a double deficit is indicative of a highly oxidized chlorite. In order to calculate a structural formula, it is necessary that all Fe be expressed as $Fe^{2+}$.