

FLUID INCLUSIONS IN VEIN QUARTZ, SILVERFIELDS MINE, COBALT, ONTARIO

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ABSTRACT

A reconnaissance study of primary (?) fluid inclusions in quartz from the principal ore veins of the Silverfields mine near Cobalt, Ontario has revealed four types of inclusions containing various combinations of vapour, liquid, and a halite crystal as follows: I (liquid only), II (liquid + halite crystal), III (liquid + vapour), and IV (liquid + vapour + halite crystal). Repeated chilling and thawing induced nucleation of the vapour phase in types I and II, but did not precipitate a halite crystal in types I and III. The anomalous behaviour of types I, II and III is thought to be due to metastability caused by the very small size of the inclusions (< 10 microns).

Heating experiments show that the included brines contain > 30 wt % NaCl. There are two distinct populations of filling temperatures with median values of 165°C and 250°C, but only one population is found in a sample. Depositional temperatures of the two quartz populations, corrected for confining pressures of 400 to 1200 atm as estimated from geological evidence, range from 195° to 260°C and 285° to 360°C.

INTRODUCTION

The silver ores of the Cobalt-Gowganda region are generally considered to be hydrothermal in origin. If fluid inclusions in the gangue minerals are truly primary samples of the ore-forming fluids, they should yield information on the composition of the ore fluid and pressure-temperature limits during deposition.

We have undertaken a reconnaissance study of fluid inclusions from the principal ore veins of the Silverfields mine at Cobalt to determine what, if any, information could be obtained. Except for a brief description of inclusions from a low-angle (cross) vein in the Silverfields mine by Taylor (1970), there is a surprising scarcity of fluid inclusion data from Cobalt. Taylor found the inclusions to contain various proportions and combinations of aqueous, solid NaCl, and vapour phases and to fill between 40° and 120°C.

The principal ore veins consist of arsenides, sulphides and native silver in a gangue predominantly of calcite and dolomite with variable amounts of chlorite and milky quartz. The quartz, on which the fluid inclusion study was conducted, commonly occurs as large masses of anhedral grains

in the centres and margins of the veins. Smaller quartz grains (few mm) are scattered throughout the carbonate matrix and quartz stringers cut the wall rocks. According to Jambor (p. 235) there are two principal generations of quartz separated by deposition of dolomite and all ore minerals except the very late sulphides. These are an "old" quartz that is associated with chlorite and occurs as inclusions in the ore-bearing carbonates which it pre-dates, and a "young" quartz associated with a young calcite and probably the very late sulphides. Jambor also recognized an "intermediate" quartz that post-dates the arsenides and associated silver, but may be almost contemporaneous with the deposition of sulphides. This quartz is present as small grains associated with calcite in drusy vugs.

Samples were collected both in and away from ore shoots on the 3rd level (2 samples), 5th level (3 samples) and 6th level (7 samples). At the time, we were not aware of the three ages of vein quartz and so did not specifically collect all types. Our samples did not contain "intermediate" quartz but unfortunately, we were not able to distinguish between "old" and "young" quartz in our hand specimens. Individual veins within a lode pinch out and bifurcate, but because this was a reconnaissance study, no conscious attempt was made to collect from a single continuous vein. Likewise, the veins were not studied over their entire extent so the sample distribution was probably not wide enough to detect possible lateral or vertical variations in fluid inclusions about the ore zones.

DESCRIPTION OF THE FLUID INCLUSIONS

Flat plates from 0.5 to 1 mm thick and polished on both surfaces were prepared from all twelve samples. Optical studies were completed prior to subjecting the plates to filling and freezing experiments. Fluid inclusions were found both in the quartz and the carbonate. However, the carbonate was extremely fractured with a dark shadowy appearance which made detailed observation impossible. Therefore, studies were confined to the quartz.

As expected from its milky appearance, the quartz is crowded with inclusions which caused difficulty in relocating particular inclusions during various experiments. The inclusions are extremely small, the largest being 30 μm and the vast majority much smaller ($< 10 \mu\text{m}$). Scanning electron microscopy revealed numerous inclusion cavities down to 0.2 μm and it is likely that even smaller ones are present (Roedder 1967a, p. 517). The small size of the inclusions necessitated the use of a $100 \times$ oil immersion objective which limited optical resolution and created technical difficulties in the heating and freezing experiments.

Primary vs. secondary inclusions

The inclusions selected for detailed study are of all shapes from faceted (negative crystals) through ellipsoidal to completely irregular. They are enclosed within homogeneous quartz devoid of growth features to which the inclusions could be genetically related. Undoubted secondary inclusions occur in abundance on fracture planes, but these were avoided in the study. Thus, although there is no *prima facie* evidence that the inclusions studied are primary, neither is there any indication that they are not.

Because of the large number of inclusions in the field of view and the very limited depth of focus at $1000 \times$ magnification, it was not possible to identify with certainty post-entrapment changes such as necking down. Such changes are expected (Roedder 1967a) and may account, in part, for the scatter in the filling temperatures.

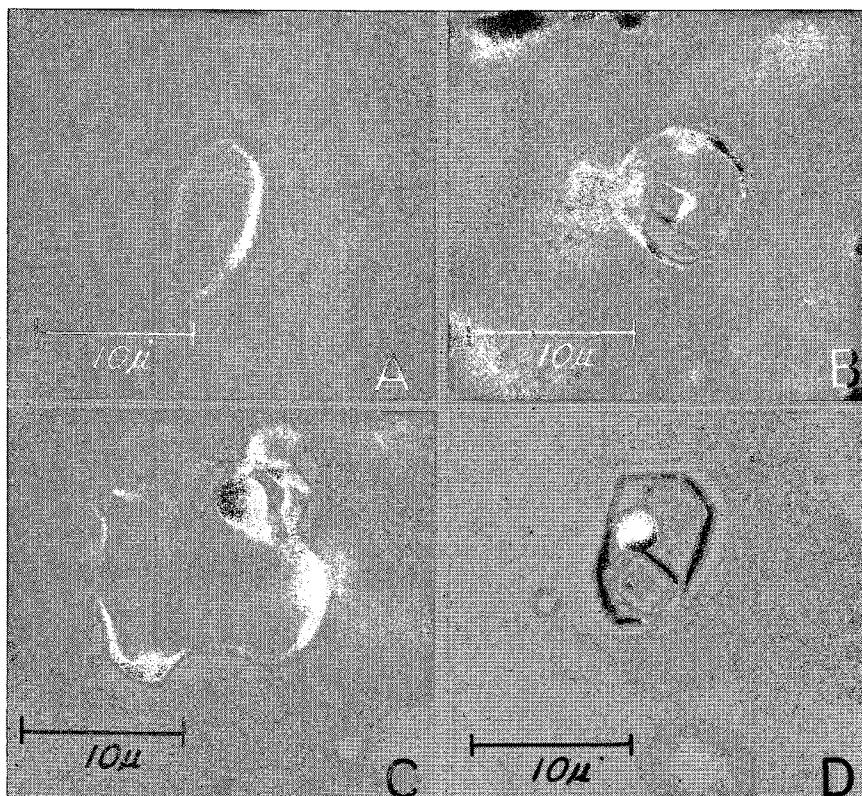


FIG. 179. Photomicrographs of the four types of fluid inclusions in vein quartz. (A) Type I (B) Type II (C) Type III (D) Type IV.

Classification of inclusions

Four types of inclusions exhibiting several combinations of aqueous, solid, and vapour phases were recognized :

- Type I : Single-phase inclusions consisting entirely of liquid (Fig. 179A)
- Type II : Two-phase inclusions of liquid and a cubic crystal (Fig. 179B)
- Type III : Two-phase inclusions of liquid and vapour (Fig. 179C)
- Type IV : Three-phase inclusions of liquid, a cubic crystal, and vapour (Fig. 179D)

All four types can be found in each sample, but types III and IV are by far the most abundant. The cubic crystals in types II and IV are halite as determined by their transparency, isotropism, low thermal coefficient of solubility and high relief compared to liquid. No other daughter minerals were seen, but because of poor optical resolution at $1000 \times$ their presence is not precluded.

Metastability

Type I and II inclusions which lacked a vapour bubble are quite peculiar for they appear to indicate filling not far above room temperature. However, when subjected one or more times to a chilling (in a dry ice + acetone bath at -78.5°C) and thawing cycle, most, but not all, of these inclusions nucleated a vapour phase. Subsequent filling temperatures were not determined, but estimated volume ratios of vapour to liquid appeared comparable to type III and IV inclusions in the same section.

The initial absence of a vapour bubble is not uncommon in fluid inclusions in minerals (Roedder 1963, 1967a; Touray & Sabouraud 1970) and is caused simply by the failure of the vapour phase to nucleate. Such inclusions contain a metastably "stretched" aqueous phase which usually can be eliminated (or induced; Roedder 1967b) by repeated freezing and thawing.

A similar attempt to nucleate a halite crystal from type I and III inclusions by freezing and thawing was unsuccessful. Thus, in addition to vapour metastability, some of the inclusions from Silverfields also exhibit extensive metastable supercooling perhaps, in part, due to their small size (Roedder 1962, 1967a).

FILLING STUDIES

Filling temperatures were determined on a Leitz model 298 heating stage containing a thermocouple calibrated against the melting points of

appropriate compounds. Portions of the polished specimen plates were broken into pieces which fit within the heating element. Unfortunately, the thermocouple does not contact the sample, but by calibrating the stage in the same configuration as the filling experiments, errors due to thermal gradients were minimized. The use of the $100 \times$ oil immersion objective necessitated the removal of the upper insulating plate from the stage. Of greater concern, however, the immersion oil smoked above 200°C and boiled near 300°C which placed an effective upper limit on the study although the stage itself is capable of much higher temperatures. Thermal lag between the sample and the thermocouple was minimized by using a heating rate of 10°C per minute. Considering the difficulties of optical resolution and the possibility of thermal lag and gradients, the estimated uncertainty of the filling temperatures is $\pm 10^\circ\text{C}$.

Filling experiments were performed on six of the twelve samples that had been studied optically. Inclusions which filled at the lowest temperatures were examined first. The temperature of disappearance of the bubble on heating was repeated several times for each inclusion.

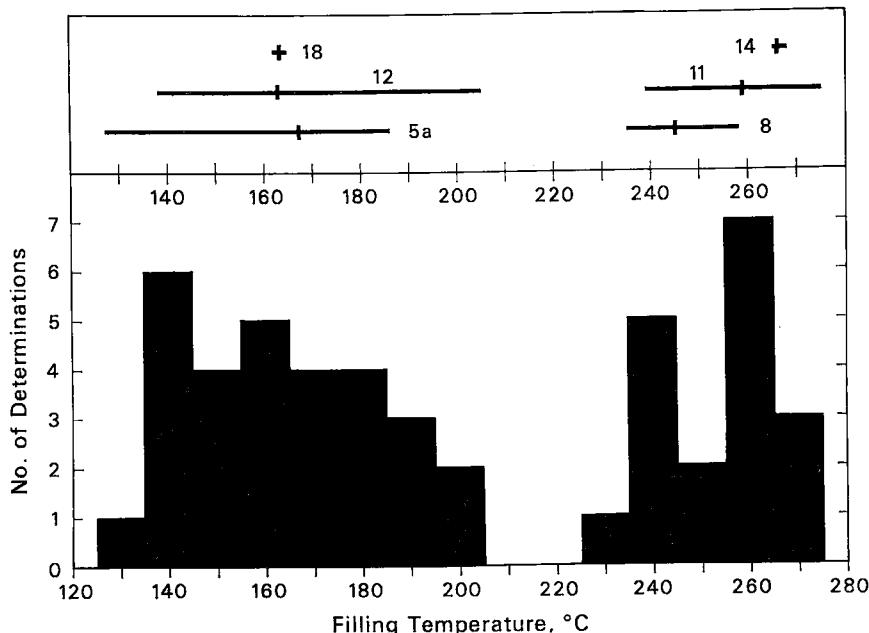


FIG. 180. Histogram showing the bimodal distribution of filling temperatures. Upper diagram shows the range and mean values of filling temperatures for each sample.

The results of the filling experiments are given in Table 62 and Figure 180. There is a well-defined bimodal distribution of filling temperatures with median values of 165° and 250°C. Only one of the two populations was found in each sample and average values for samples in each population lay between 163-167° and 245-266°C, respectively. The two median temperatures do not correlate with vein system, mine depth¹, or proximity to ore. Neither is there any obvious relationship between filling temperature and type of inclusion. For example, in sample number 8 two, two-phase type III inclusions filled at 248° and 255°C and six, three-phase type IV inclusions filled between 235° and 258°C.

In all cases, the halite crystal in the type IV inclusions did not dissolve completely at the filling temperature. Homogenization temperatures are more meaningful in inclusion thermometry than filling temperatures (Smith 1953) but we were unable to determine them because of the aforementioned difficulties encountered with the immersion oil at high temperatures.

Attempts to determine the filling temperatures by the decrepitation method (Smith 1963) were unsuccessful, presumably because the decrepitation from the tiny inclusions was not loud enough to activate the ratemeter.

DISCUSSION

NaCl content of included solutions

To obtain depositional temperatures of the quartz from the filling temperatures, it is necessary to make a pressure correction, the magnitude

TABLE 62. FILLING TEMPERATURES.

Sample	Mine Level	Vein No.	Filling temperatures, °C		
			Range	N	Average
5a	5	1	127-186	8	167
8	6	1	235-258	8	245
11	6	1	239-275	7	259
12	6	1	138-205	19	163
14	6	1	265-268	3	266
18	6	7	162-165	2	164

N = Number of inclusions studied.

¹ The fifth and sixth levels are 100 feet apart.

of which depends on the concentration of dissolved salts in the included brine. Because halite was the only daughter mineral encountered, the included fluid is treated here as a pure NaCl solution.

The halite crystal in the type IV inclusions did not dissolve at the filling temperatures ranging from 127° to 275°C indicating that these inclusions must have contained greater than 28 to 33 wt % NaCl, respectively, when trapped (Keevil 1942). The coefficients of thermal expansion of very concentrated NaCl solutions are similar (Lemmlein & Klevtsov 1961) which obviates the need for accurate compositional information. Therefore, for the present purpose of making pressure corrections, the 30 wt % NaCl isopleth, the most concentrated solution for which P-V-T data are available, was taken as being representative of the fluid inclusions studied.

The absence of systematic differences in filling temperatures between the type III (liquid + vapour) and type IV (liquid + vapour + halite crystal) inclusions demonstrates that the type III inclusions, although lacking a salt crystal through metastable supercooling, nevertheless have high salinities comparable to the type IV inclusions. If the type III inclusions are indeed undersaturated in NaCl at room temperature they should have filled at a significantly lower temperature than the type IV inclusions (see Roedder 1967a, Fig. 12.2).

Pressure corrections

The veins at Silverfields are younger than and occur immediately below the approximately 1000 feet thick Nipissing diabase "sill" which intruded the gently-dipping Coleman conglomerate and greywacke sediments. Unfortunately the geologic profile at Cobalt is not known well enough to enable us to estimate the confining pressure at which the veins were formed. However, both field and theoretical studies indicate that there is a certain depth interval within which sills are emplaced in sedimentary basins. Carey (1958) has deduced this interval to be between 5,000 and 15,000 feet. From field studies of 54 localities, Mudge (1968) states that concordant igneous bodies have intruded nearly flat-lying sedimentary rocks where the thickness of cover was from 3,000 to 7,500 feet. However, according to Bradley (1965) some major sills appear to have been intruded at depths of 10,000 to 20,000 feet. In a theoretical study on the mechanisms of sill intrusion Gretener (1969) refuted some of Mudge's arguments and suggested that sills are emplaced under conditions of lateral compression in the sediments which could occur at much greater depths than given by Mudge. Roberts (1971) disagrees with Gretener in detail, but supports a tectonic model of sill intrusion and calcu-

lates, for a set of arbitrary but geologically reasonable stress conditions, that sill intrusion would occur within 1 and 2 km (3,300 and 6,600 feet) of the surface (Roberts 1970).

If the assertion is correct that the Silverfields veins are temporally related to the Nipissing diabase (Petruck 1968), then approximate pressure corrections based on the possible depth of sill intrusion can be calculated for the observed filling temperatures. In Table 63, we have made such corrections to the two median values of the bimodally distributed filling temperatures using the data of Lemmlein & Klevtsov (1961) for the 30 weight percent NaCl isopleth and for sill depths of 5,000 to 15,000 feet corresponding to lithostatic loads of approximately 400 to 1200 atm. The resulting temperatures of 195° to 260°C and 285° to 360°C, corresponding to the lower and higher median filling temperatures respectively corrected for the minimum and maximum pressure, are estimated depositional temperatures of the quartz.

When the same pressure corrections are applied to Taylor's (1970) maximum filling temperature of 120°C, depositional temperatures between 145° and 200°C are obtained. This range is considerably lower than we have found. However, Taylor's samples are from a low-angle (cross) vein in which the quartz is of unknown age and need not have been deposited at the same temperature as quartz in the vertical, ore-bearing veins.

CONCLUSIONS

Within the limitations that the inclusions examined are primary and that the anomalous behaviour of the type I, II and III inclusions is a consequence of metastability, this study shows that the quartz at Silverfields was deposited from a very saline brine of greater than 30 wt % NaCl. The bimodal distribution of filling temperatures indicates that the quartz was deposited within two different temperature intervals. The depositional temperatures, corrected for estimated confining pressures of

TABLE 63. PRESSURE CORRECTIONS TO THE MEDIAN FILLING TEMPERATURES.

Median Filling Temperature, °C	Pressure ¹ , atm. Min.	Max.	Correction ² , °C Min.	Max.	Depositional temp., °C Min.	Max.
165	400	1200	30	95	195	260
250	400	1200	35	110	285	360

¹ Nipissing diabase sill emplaced at 5,000 and 15,000 feet, respectively (see text).

² 30 wt % NaCl isopleth (Lemmlein & Klevtsov 1961).

400 to 1200 atm based on possible depths of intrusion of the Nipissing diabase, range from approximately 285° to 360°C and 195° to 260°C. These temperatures correspond to the lower end of the early depositional stage and to the intermediate depositional stage, respectively, as estimated from various sulphide assemblages in the Cobalt camp by Petruk (1970). Sulphide deposition, however, post-dates the deposition of arsenides and "old" quartz, and pre-dates "young" quartz.

It is tempting to equate the two ranges of filling temperatures with two ages of quartz in the veins. However, because we were not able to positively distinguish between "old" and "young" quartz in our samples, such a correlation remains speculative until we can examine fully characterized specimens.

Our reconnaissance study has demonstrated that the vein quartz at Silverfields and probably the entire Cobalt camp is amenable to fluid inclusion methods. Extensive metastability must be contended with and, as well, the very small size of the Silverfields inclusions necessitates modification of the standard investigative methods. Obviously, we have only scratched the surface in this study and our conclusions are tentative until we can fill in the many gaps in our data. When completed, these data could provide information on temperature-pressure limits that existed prior to ore deposition, during the late phases of ore deposition, and in the post-ore depositional period. When combined with the arsenide and sulphide geothermometry, the record of the depositional history of the veins will be relatively complete.

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