FLUID INCLUSION STUDY OF VEIN MINERALS FROM THE SILVER QUEEN MINE, CENTRAL BRITISH COLUMBIA (93L/2)

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INTRODUCTION

Silver Queen mine in central British Columbia, is located approximately 35 kilometres south of Houston and 3 kilometres east of Owen Lake (Figure 2-7-1). Although currently inactive, it was worked briefly in the early 1970s for gold, silver, copper, zinc, lead and cadmium. The deposit is hosted by Cretaceous rocks of the informal Tip Top Hill group (78.3 ± 2.67 Ma, K-Ar whole rock), with the age of mineralization bracketed by pre and post-mineralization dikes at 51.1 ± 1.8 Ma and 51.9 ± 1.8 Ma (K-Ar whole rock, Leitch *et al.*, 1990). Detailed descriptions of the regional and deposit geology are found in Lang (1929), Church (1970), Church and Barakso (1990) and Leitch *et al.* (1990).

The deposit is a complex epithermal vein system with ore generally restricted to delicately banded quartz-carbonate-sulphide-bearing veins (Plate 2-7-1). Hood *et al.* (1991) and Hood (1991) define four characteristic assemblages which represent early to late stages of mineral deposition within the veins. Stage I is characterized by the assemblage quartz-pyrite-hematite-barite, Stage II by the assemblage sphalerite and manganese-iron-rich carbonate, Stage III by quartz-chalcopyrite-tetrahedrite-galena and Stage IV by the assemblage quartz-barite-pyrite-calcite. Stage I and IV also contain bitumen as a coexisting mineral with barite. Rarely is a single vein comprised of all four stages; two consecutive stages are most common.

The composition and temperature of the fluid at the time of mineral deposition are estimated for the various paragenetic stages by measuring the homogenization temperatures of liquid and vapour phases and freezing point depression temperatures or temperatures of the disappearance of the last melt for the common minerals. These measurements provide important constraints for the interpretation of the geochemical and thermal evolution of the hydrothermal system that formed the Silver Queen deposit.

FLUID INCLUSIONS

Fluid inclusions within minerals represent fluid which has been trapped either by irregularities during the growth of the host crystal, that is primary inclusions, or by the healing of later fractures to form secondary inclusions. Fracturing may also occur during crystal growth and healing of these fractures can produce pseudosecondary inclusions. In practise, distinguishing primary, pseudosecondary or secondary inclusions is not always straightforward. Generally, primary inclusions are found along well-defined growth zones, secondary inclusions occur as distinct trails which
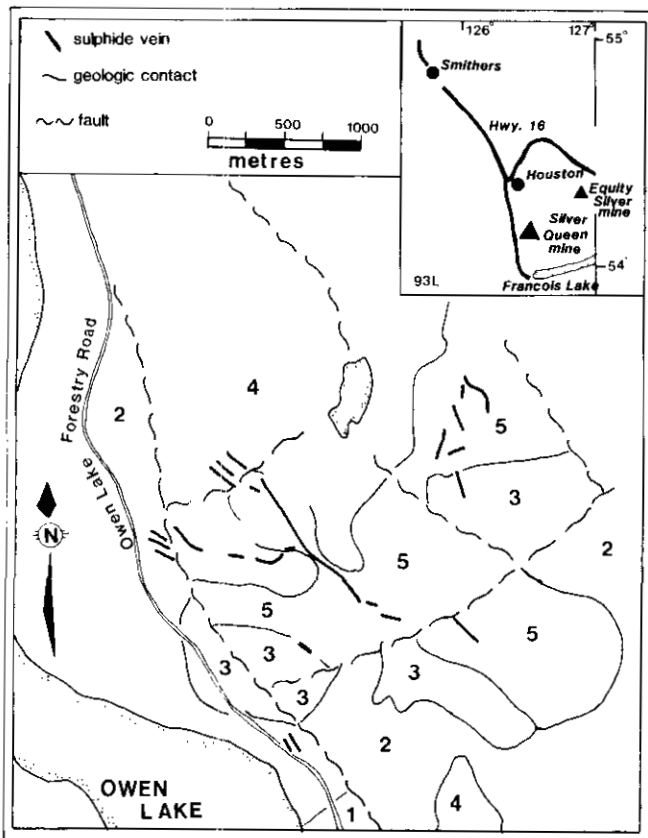
Figure 2-7-1. Location and simplified geologic map of the Silver Queen mine area.
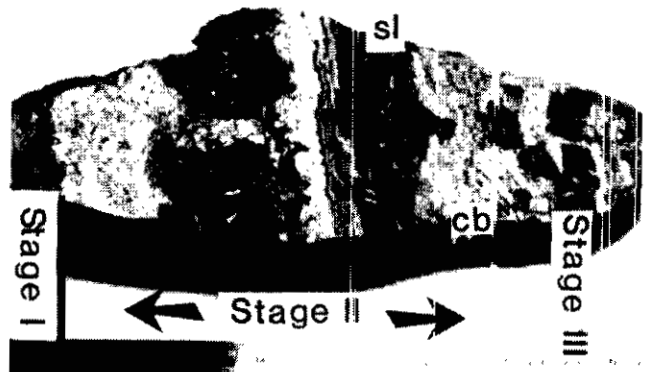
Plate 2-7-1. Photograph of typical ore vein within the Silver Queen mine. The left side of the sample (light grey) represents Stage I pyrite-quartz assemblage. The sample is dominated by Stage II sphalerite and carbonate, with minor Stage III carbonate to the right.
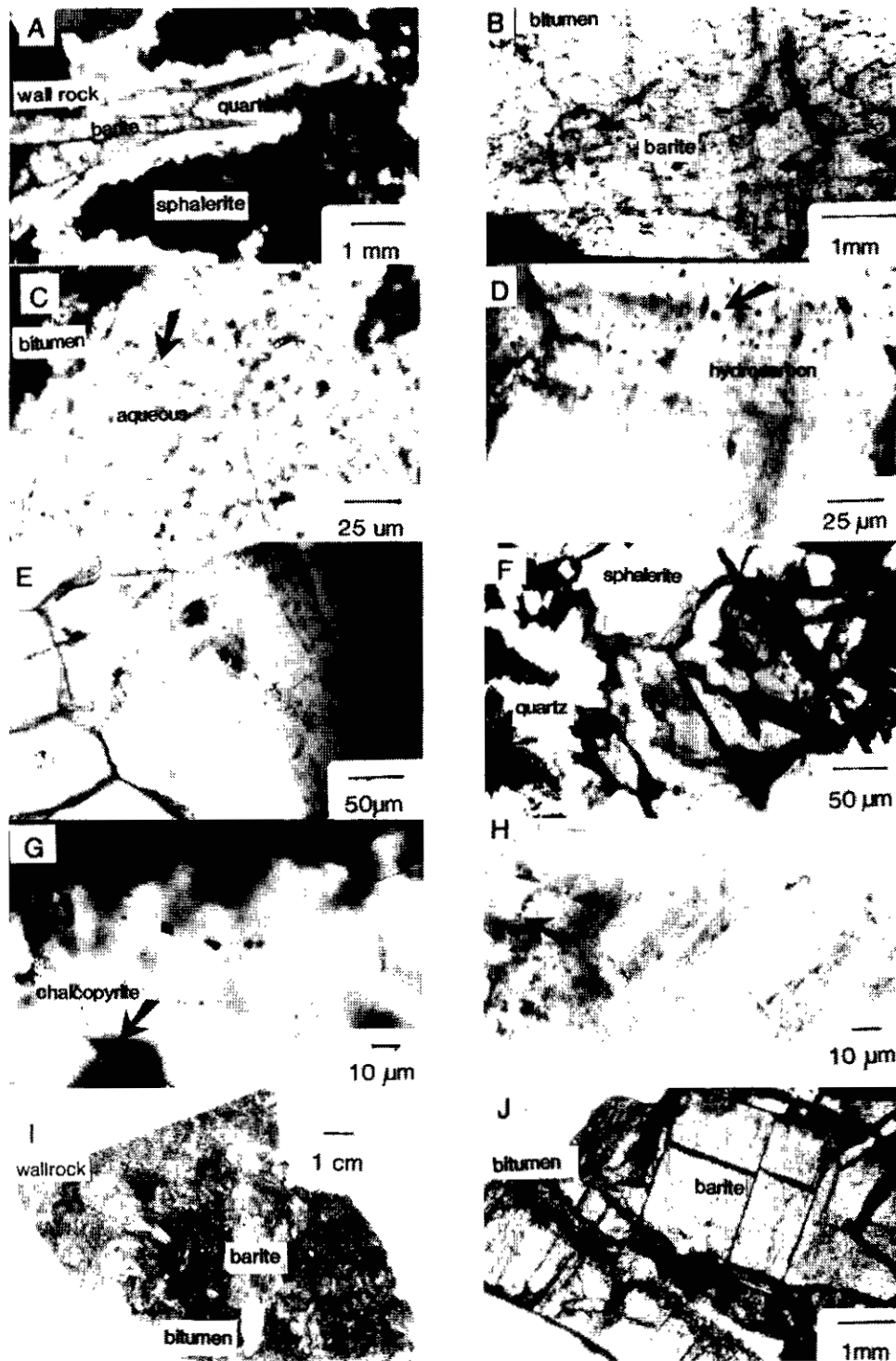
Plate 2-7-2. (a) Stage I barite blades oriented perpendicular to the vein wall. (*Photomicrograph slightly out of focus*); (b) Stage I barite with included bitumen; (c) colourless, aqueous, primary or pseuosecondary fluid inclusion within Stage I barite (arrow points to fluid inclusion with clear liquid and vapour phase); (d) amber-coloured, hydrocarbon-filled fluid inclusions within Stage I barite (arrow points to fluid inclusion with liquid and vapour phase); (e) Stage I, subhedral quartz crystals cut by trails of secondary aqueous fluid inclusions, dark inclusions are hematite; (f) Stage II sphalerite intergrown with euhedral quartz crystals; (g) primary or pseudosecondary fluid inclusions within Stage II sphalerite, fine inclusions of chalcopyrite (arrow) occur within sphalerite; (h) Stage III carbonate illustrating chevron-shape of banding and nature of primary fluid inclusions (arrow); (i) core sample of Stage IV barite with bitumen; (j) Stage IV barite, note blocky shape compared to needle shape of Stage I barite.

cross grain boundaries and pseudosecondary inclusions form as trails which are restricted to single grains and do not cross grain boundaries (c.f. Roedder, 1984).

The trapped fluid is commonly aqueous; however, in this study hydrocarbon-rich fluids are also present. Vapour and solid phases may also be present. The vapour may contain a mixture of water, carbon dioxide and methane or other gases, although water is usually the dominant phase. In most cases, the solid inclusion phases are alkali salts precipitated from the liquid (Roedder, 1984).

Homogenization temperatures (T_h) and melting temperatures (T_m) are the two data sets which were determined from the samples studied. Homogenization temperature represents the temperature at which the isovolume line intersects the liquid-vapour line. As most fluid has been trapped in inclusions at pressures and temperatures above the liquid-vapour curve, a correction for pressure is applied to T_h to determine the trapping temperature (T_t) as described by Potter (1977).

The melting temperature (T_m) provides an indication of the composition of the fluid. The freezing temperature of an aqueous solution containing dissolved salts is depressed relative to the freezing temperature of pure water. This temperature can be interpreted in terms of the percentage of NaCl dissolved in the solution that gives a freezing point depression temperature identical to the experimental value. The values presented are calculated after Roedder (1984). In every case, an attempt was made to make two determinations for every fluid inclusion, but this was not always possible. In some cases melting temperatures were not determined because of inability to clearly see a change in the inclusion during the heating of a super-cooled inclusion.

METHODOLOGY

For this study doubly polished rock plates were prepared on standard size thin-section glass. Fluid inclusions in quartz, barite, carbonate and sphalerite were examined. A Fluid Inc. adapted United States Geological Survey gas-flow heating and freezing stage system located at the Geological Survey of Canada (Vancouver) was used. Temperature calibration using SYN-FLINC® as described by Reynolds (1988; unpublished manual) results in an accuracy of 0.4°C from 56.6 to 660°C and a precision of ±1 per cent up to 200°C and ±2 per cent above 200°C.

The problem of the susceptibility of aqueous inclusions within barite to stretching when overheated past the homogenization temperature (Ulrich and Bodnar, 1988), and when frozen (Keenan et al., 1978) was taken into consideration. Individual barite blades averaged 5 to 10 millimetres in length, allowing several chips to be taken from a single blade. The samples were frozen first and heated a maximum of three times. After heating, the ratio of volume of vapour to volume of liquid was observed to determine if stretching had occurred. If the inclusion had stretched, the vapour: liquid volume ratio would have decreased. No significant change was noted in any of the samples.

No melting temperatures were obtained for the hydrocarbon inclusions. Cooling to −90°C produced no visible freezing behavior within the liquid and subsequent warming produced no changes either.

SAMPLES

Fluid inclusions from six samples representing the four paragenetic stages were measured as follows: Stage I, barite and quartz; Stage II, sphalerite and carbonate; Stage III, sphalerite and carbonate; Stage IV, barite. Fluid inclusions in quartz from the wallrock of a Stage I vein were also measured. A summary of the inclusion descriptions can be found in Figure 2-7-2.

STAGE I INCLUSIONS

Stage I barite occurs as tapered blades, 1 to 8 millimetres long, rooted in and oriented perpendicular to the vein wall (Plate 2-7-2a, b). Clear aqueous and amber-coloured hydrocarbon inclusions occur within single blades Plate 2-7-2c, d). The blades are clouded by evenly distributed, rectangular aqueous inclusions, 3 to 15 microns wide (average 5 μm), interpreted to be either primary or pseudosecondary. Primary or pseudosecondary hydrocarbon inclusions are less common, larger than the aqueous inclusions (average 15 μm) and tend to occur in patches. Trails of secondary aqueous and hydrocarbon inclusions clearly crosscut grain boundaries. They are rounded to oblong, and are smaller than the primary inclusions (3–10 μm wide).

Stage I quartz occurs as euhedral crystals, 1 to 3 millimetres wide, infilling hematite blades. Primary inclusions, 3 to 7 microns wide, occur with growth zones 0.5 millimetre wide, parallel to the hexagonal crystallographic outline. Secondary inclusions form distinct trails which crosscut boundaries of quartz grains and are parallel to vein walls (Plate 2-7-2e). The inclusions range in width from less than 4 microns to 8 microns, and average about 5 microns wide

STAGE	MINERAL	TYPE	SIZE	SHAPE	L:V
I	BARITE	AQ (P-PS)	3-15 (5)		5-10 (6)
		H (P-PS)	6-15 (10)		5-20 (10)
	QUARTZ	AQ (P)	3-7 (3)		10 (3)
		AQ (S)	4-5 (5)		6-10 (8)
		WR	3-5 (5)		5-10 (5)
II	SPHALERITE	AQ (P)	5-15 (10)		15-30 (20)
	CARBONATE	AQ (P)	5 (6)		15 (15)
III	SPHALERITE	AQ (P)	3-20 (5)		5-15 (8)
	X	AQ (PS)	3-15 (5)		5-10 (5)
	CARBONATE	AQ (PS)	3-5 (5)		5
IV	BARITE	AQ (P-PS)	3-10 (4)		10-20 (15)
		H (P-PS)	6-20 (6)		5-15 (8)

Figure 2-7-2. Summary of descriptive data determined for fluid inclusions in minerals from the four paragenetic stages in the Silver Queen veins. Bracketed values represent mean value. AQ, aqueous; P, primary; PS, pseudosecondary; HC, hydrocarbon; L:V, liquid to vapour ratio.

STAGE II INCLUSIONS

Stage II sphalerite occurs as bands 1 to 3 millimetres wide that parallel the vein wall. An intergrowth with euhedral quartz gives the sphalerite bands a wormlike outline (Plate 2-7-3f). The sphalerite is transluscent, zoned from colourless to honey coloured, with 0.5-millimetre bands of densely packed, large chalcopyrite blebs 1 micron wide (Plate 2-7-2g). Inclusions which occur singly with irregular distribution are interpreted as primary and those which occur in trails are pseudosecondary. The primary inclusions are irregular in shape, generally elongate (Plate 2-7-2g) and range in size from 3 to 20 microns long (averaging 10 μm). Pseudosecondary inclusions are rounded and range in size from 1 to 10 microns.

Carbonate occurs dominantly as patches of chevron-shaped bands 1 to 5 millimetres wide (Plate 2-7-2h). Most fluid inclusions in carbonate are difficult to measure because of high internal reflections and small size (<1 μm). Primary fluid inclusions, 1 to 10 microns wide, are best developed and measurable along the growth zones of the bands.

STAGE III INCLUSIONS

Stage III sphalerite is massive, occuring as subhedral grains 1 to 10 millimetres wide, mostly isolated in carbonate matrix. Stage III sphalerite is brecciated, with grains clearly broken and rotated in a carbonate-quartz matrix. The inclusion style is the same as that for the Stage II sphalerite.

Stage III carbonate is massive, with no clear banding developed. Fluid inclusions occur evenly distributed, and range in size form 1 to 5 microns wide.

STAGE IV INCLUSIONS

Stage IV barite occurs as large (5-15 mm long) blades randomly oriented within the veins, with bitumen generally forming the matrix (Plate 2-7-2j). Fluid inclusions form in zones, generally within the core of a blade. Both aqueous and amber-coloured hydrocarbon inclusions are present. The aqueous inclusions are primary or pseudosecondary, with a rectangular to angular shape, and range from 3 to 10 microns long. The hydrocarbon inclusions are also primary or pseudosecondary, rounded to irregular in shape, and range from 6 to 20 microns long.

RESULTS

A total of 186 temperature measurements were completed, with the results summarized in Figures 2-7-3 and 4.

There is no independant geobarometer available to calculate the load pressure during deposition of the minerals studied. Quartz textures, although in no way a rigourous geobarometer, can be used to suggest the relative depth of deposition. Chalcedony may form a sinter in the surface or near-surface environment (Bodnar et al., 1985) and as no sinter is found at the Silver Queen mine it is assumed that the vein formed at depth. Epithermal deposits occur within the upper 1.5 kilometres of the crust, therefore we can assume that the load pressure probably did not exceed 50000 kilopascals and was probably somewhat less. Given

this maximum pressure, the temperature correction for the pressure differential (after Potter, 1977) of those inclusions with a T_h of approximately 220°C and salinity of 6.5 per cent NaCl equivalent is a maximum of 40°C, and for those inclusions with a T_h of 100°C and salinity of 2 per cent NaCl equivalent, a maximum of 50°C. Homogenization temperatures represent the minimum trapping temperature and the true trapping temperature is from zero to 50°C higher. Because of this uncertainty, reference will be made to the homogenization temperature in the following discussion.

Stage I fluid is relatively saline with a mode of 6.4 per cent NaCl equivalent and hot, with two populations of T_h at 260°C and 210°C. The primary inclusions in vein quartz and wallrock alteration quartz are more saline and hotter than the secondary inclusions in the quartz.

Stage II fluid shows a similar range of homogenization temperatures and salinity as Stage I. The peak T_h are slightly cooler, with modes at 230°C and 180°C and salinity is slightly elevated with a mode of 7.5 per cent NaCl equivalent.

Stage III homogenization temperatures are equivalent to the secondary inclusions in the vein quartz of Stage I, however, the salinity shows a complete range with the mode equivalent to that of Stage II fluids at 7.5 per cent NaCl equivalent. The limited sampling of fluid inclusions within brecciated sphalerite shows no significant difference between it and the *in situ* sphalerite.

Stage IV fluids are less saline and cooler than the other stages, although a broad compositional range is indicated. The homogenization temperature of hydrocarbon fluid is less than that of the aqueous fluid inclusions.

DISCUSSION

The variation in salinity of the aqueous fluid inclusions within and between each mineral stage suggests the presence of two distinct aqueous fluids within the system. The early stage fluid is relatively more saline than the later fluid. In hydrothermal systems saline fluids (> 25% NaCl equivalent) are generally associated with a heat source, commonly an intrusive body (Henly, 1985). Such fluids are more saline than the strongest brines encountered in the Silver Queen samples. Weakly (< 1.7% NaCl equivalent) to nonsaline inclusions are generally associated with meteoric fluids (Henly, 1985). It is suggested that mixing of these two fluids could result in salinity values noted in this study.

Independant evidence of a meteoric source for the weakly saline fluid comes from the hydrocarbon inclusions and associated bitumen. Carbon isotope values from bitumen of $\delta^{13}C \approx -27$ per mil from Stages I and IV indicate the source of the hydrocarbon to be the same and to be terrestrial plant material (Thomson et al., in press). The difference in salinity between the two periods of hydrocarbon trapping and deposition represents a process of differential mixing with the more saline fluid.

Mineral deposition in the sulphide-bearing Stages II and III (Hood et al., 1991) appears to be related to more saline fluids. This is consistent with the model of chloride as a complexing agent, transporting metals to the site of deposi-

tion (Barnes, 1979). Interestingly, the deposition of sphalerite appears to be insensitive to temperature, forming in a range from 255°C in Stage II to 85°C in Stage III. Corroborating the lower temperature of ore deposition in Stage III is the occurrence of the galena-matildite pair which is limited to a low-temperature stability range (Hood, 1991).

Boiling, or mixing of two fluids are the two common mechanisms invoked for the deposition of metals in epithermal deposits (Bodner et al., 1985). When boiling occurs the steam phase and liquid phase are trapped in separate inclusions, producing a spatially related population of liquid-rich and vapour-rich inclusions (Roedder, 1984). Complicating this interpretation, however, is the possibility that the same texture was produced through secondary necking of a primary inclusion. During necking the vapour from the primary inclusion is not equally distributed into the newly formed pseudosecondary inclusion. Clearly care must be taken when interpreting the textures. In this study, there is no significant variation in the liquid:vapour ratio within a single population of fluid inclusions, suggesting that boiling probably did not occur within the system. This further supports a model of mixing of the two fluids.

The overall homogenization temperature, and therefore the trapping temperature, show a general decrease from Stage I to Stage IV. The similar homogenization temperatures and salinities of Stage III and the Stage I secondary fluid inclusions suggest that the early stage mineral assemblages were accessible to later stage fluids, probably through intermittent brecciation and veining.

Stage II is characterized by the presence of abundant manganese-iron carbonates, however, there is no evidence of the presence of measurable carbon dioxide within the attendant fluid. This absence of visible carbon dioxide in inclusions indicates its low partial pressure in the ore fluid (Fournier, 1985).

INTERPRETATION

The fluid inclusion data summarized here indicate two probable sources of fluid. One which was relatively hot and saline and one which was cooler and weakly to nonsaline. The hot, saline fluid is most likely related to a magmatic body interpreted to be at depth, as evidenced by the intimate association of dikes with the ore veins (Thomson and Sinclair, 1991). The cooler fluid is probably meteoric in origin,

Figure 2-7-3. Histogram of homogenization temperatures. Patterns denote minerals studied. P, primary; S, secondary; and x, breccia.

heated by the magmatic body. Initial mixing of these two fluids resulted in the deposition of metals within the veins. With time, the mixed fluid became dominated by cooler, weakly saline fluid, indicating either the exhaustion of hot saline fluid or the sealing of the transport path.

Thomson and Sinclair (1991) have shown physical evidence of continuous fracturing and brecciation within the Silver Queen veins. The present study corroborates this by showing that a single crystal can contain several types, and therefore several generations of fluid inclusions. This will have significant impact on the choice of mineral grains for future stable isotope studies. Randomly choosing any grain may result in stable isotope data which represent a mixture, not end-member representatives of the fluid sources.

The Equity Silver mine, approximately 20 kilometres to the northeast of Silver Queen, is of comparable age and geology (Church and Barakso, 1990). Wojdak and Sinclair (1984) describe results of a fluid inclusion study of the Equity Silver ores and a comparison with Silver Queen data is interesting. The Equity Silver ore assemblages of arsenopyrite-sphalerite-chalcopyrite and chalcopyrite-tetrahedrite are broadly comparable to the Stage III and Stage II assemblages respectively at the Silver Queen deposit (Hood et al., 1991). The homogenization temperatures of the Equity Silver mine assemblages are approx-

imately 320 to 400°C and 260 to 310°C, a full 100°C hotter than those of the comparable Silver Queen assemblages. The melting temperatures or per cent NaCl equivalents of the Equity Silver inclusions are, however, remarkably similar to the comparable assemblage in the Silver Queen deposit, ranging from 3 to 10 per cent and 3 to 8 per cent for the two assemblages. It appears that the Equity Silver orebody may represent a deeper depositional environment, and in particular may have formed closer to the heat source than Silver Queen orebody.

CONCLUSIONS

● Two fluids are involved in ore deposition at the Silver Queen mine. One is saline and relatively hot and the other is weakly saline and relatively cool.

● The weakly saline fluid is probably meteoric in origin. Evidence comes from the presence of associated hydrocarbons derived from terrestrial plants.

● The source of the hotter, more the saline fluid is probably related to a magmatic body at depth.

● Fluid ingress and veining occurred repeatedly, over-printing earlier vein assemblages. This has implications for stable isotope analysis of vein minerals. Detailed examination of the samples is important to
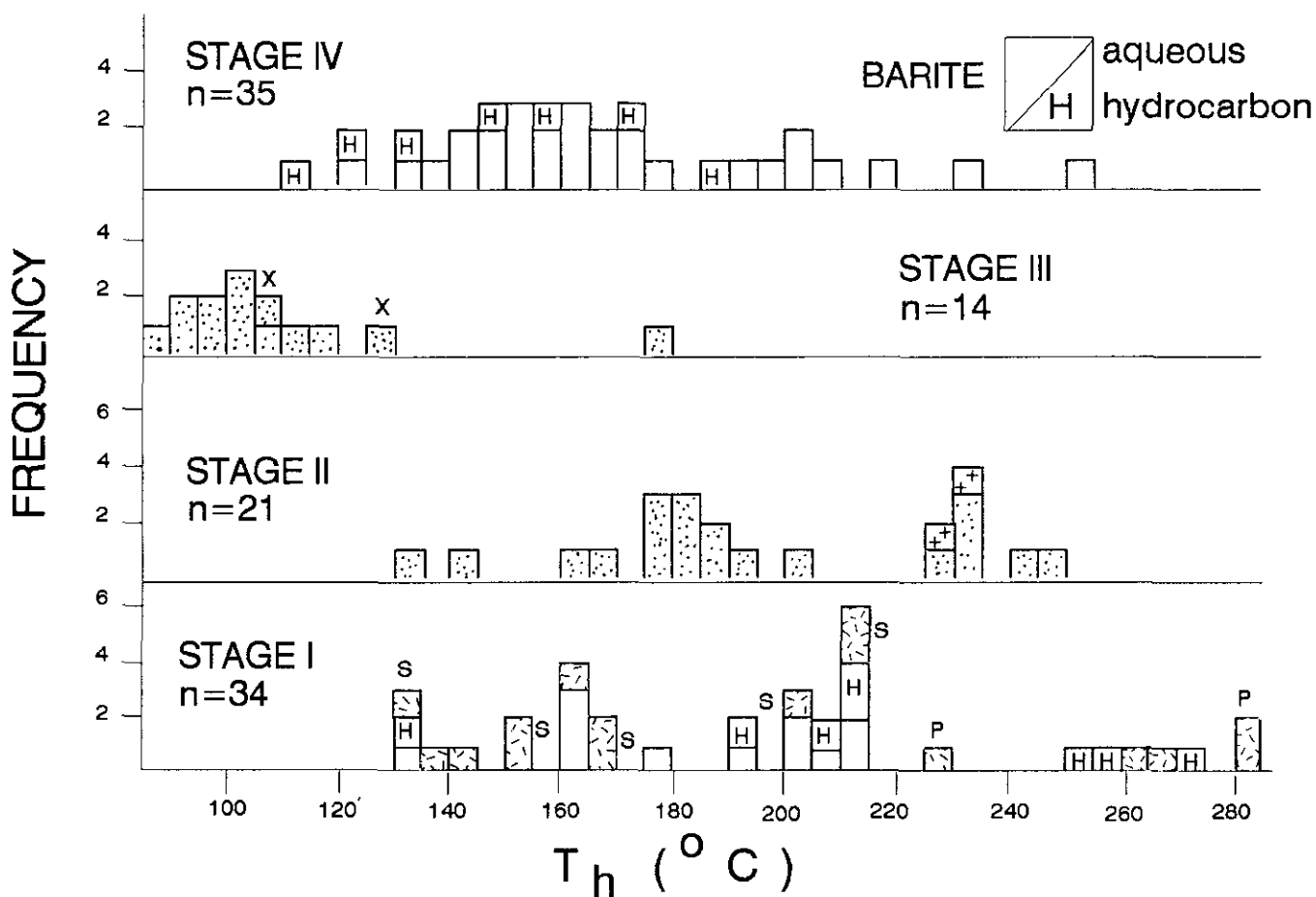

Figure 2-7-4. Histogram of melting temperatures with per cent NaCl equivalent as determined by equations given by Roedder (1984).

confirm if more than one episode of mineral deposition has affected the sample, allowing for possible re-equilibration.

● The temperature of ore deposition ($\approx 250°C$) at the Silver Queen mine is about $100°C$ cooler than for comparable stages of mineralization at the Equity Silver mine, although the salinities of the fluids are similar (3-10% NaCl equivalent). This suggests that the Equity Silver orebody formed at a greater depth, closer to the magmatic heat source.

ACKNOWLEDGMENTS

REFERENCES

Barnes, H.L. (1979): Solubilities of Ore Minerals; *in* Geochemistry of Hydrothermal Ore Deposits, Barnes, H.L., Editor, *John Wiley & Sons*, pages 404-460.

Bodnar, R.J., Reynolds, T.J. and Kuehn, C.A. (1985): Fluid Inclusion Systematics in Epithermal Systems; *in* Geology and Geochemistry of Epithermal Systems; Berger, B.R. and Bethke, P.M., Editors, *Society of Economic Geologists*, Reviews in Economic Geology, Volume 2, pages 73-98.

Church, B.N. (1970): Nadina (Silver Queen); *in* Geology, Exploration and Mining in British Columbia 1969, *B.C. Ministry of Energy, Mines and Petroleum Resources*, pages 126-139.

Church, B.N. and Barakso, J.J. (1990): Geology, Lithochemistry and Mineralization in the Buck Creek Area, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-2, 95 pages.

Fournier, R.O. (1985): Carbonate Transport and Deposition in the Epithermal Environment; *in* Geology and Geochemistry of Epithermal Systems, Berger, B.R. and Bethke, P.M., Editors, *Society of Economic Geologists*, Reviews in Economic Geology, Volume 2, pages 63-72.

Henly, R.W. (1985): The Geothermal Framework for Epithermal Deposits; *in* Geology and Geochemistry of Epithermal Systems, Berger, B.R. and Bethke, P.M., Editors, *Society of Economic Geologists*, Reviews in Economic Geology, Volume 2, pages 1-24.

Hood, C.T.S. (1991): Mineralogy, Paragenesis, and Mineralogic Zonation of the Silver Queen Vein System, Owen Lake, Central British Columbia; unpublished M.Sc. thesis; *The University of British Columbia*, 275 pages.

Hood, C.T., Leitch, C.H.B. and Sinclair, A.J. (1991): Mineralogic Variation Observed at the Silver Queen Mine, Owen Lake, Central British Columbia; *in* Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-1, pages 185-191.

Keenan, J.H., Keyes, F.G., Hill, P.G. and Moore, J.G. (1978): Steam Tables, Thermodynamic Properties of Water Including Water Vapor, Liquid and Solid Phase (SI units); *Wiley Interscience*, 156 pages.

Lang, A.H. (1929): Owen Lake Mining Camp, British Columbia; Summary Report, 1929, Part A; *Geological Survey of Canada*, 93 pages.

Leitch, C.H.B., Hood, C.T., Cheng, X.C. and Sinclair, A.J. (1990): Geology of the Silver Queen Mine Area, Owen Lake, Central British Columbia (93L); *in* Geological Fieldwork 1989, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-1, pages 287-295.

Potter, R.W. II (1977): Pressure Corrections for Fluid Inclusion Homogenization Temperatures Based on the Volumetric Properties of the System NaCl-H₂O; *United States Geological Survey*, Journal of Research, Volume 5, pages 603-607.

Roedder, E. (1984): Fluid Inclusions; *in* Reviews in Geology, *Mineralogical Society of America*, Volume 12, 644 pages.

Thomson, M.L. and Sinclair, A.J. (1991): Syn-hydrothermal Development of Fractures in the Silver Queen Mine Area, Owen Lake, Central British Columbia (93L/2); *in* Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 991-1, pages 191-197.

Thomson, M.L., Mastalerz, M., Sinclair, A.J. and Bustin, R.M. (in press): Implications of Bitumen and Hydrocarbon Fluid Inclusions to Fluid Source and Thermal History of Polymetallic, Epithermal Vein Deposits, Central British Columbia; *Mineralium Deposita*.

Ulrich, M.R. and Bodnar, R.J. (1988): Systematics of Stretching of Fluid Inclusions II: Barite at 1 Atmosphere Confining Pressure; *Economic Geology*, Volume 81, pages 1037-1046.

Wojdak, P.J. and Sinclair, A.J. (1984): Equity Silver-Copper-Gold Deposit: Alteration and Fluid Inclusion Studies; *Economic Geology*, Volume 79, pages 969-990.

NOTES