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THE UNIVERSITY OF ALBERTA

A FLUID INCLUSION STUDY OF THE HIGHLAND VALLEY PORPHYRY COPPER DEPOSITS

by

Ⓒ MALCOLM F. MAWER

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA
SPRING, 1977

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled A Fluid Inclusion Study of the Highland Valley Porphyry Copper Deposits

submitted by Malcolm F. Mawer

in partial fulfilment of the requirements for the degree of Master of Science

Supervisor

R E Folinsbee

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C.M. Scarfe

Date April 18, 1977

ABSTRACT

Rock samples gathered from the Bethlehem, Lornex, Highmont and Valley Copper porphyry copper deposits of the Highland Valley, B.C. were subjected to petrographic examination, crushing, low temperature and high temperature tests in order to determine composition, temperature of entrapment, depth of emplacement and hydrostatic pressure of the fluids at the time of their entrapment.

Salinities of fluids in most of the inclusions from each deposit were found to range between 24 and 28 wt. % NaCl equivalent, with the majority of the inclusions being slightly undersaturated.

Hydrostatic pressure at the time of emplacement of one fluid inclusion containing liquid CO_2 from the Lornex deposit was determined as 457 ± 62 bars, corresponding to a maximum depth of emplacement of 3 to 4 km.

Boiling of the hydrothermal fluids apparently occurred, but was not widespread. It is postulated that release of pressure accompanying explosive brecciation, particularly in the Highmont and Bethlehem deposits, permitted intermittent boiling in fractures connecting to the ocean floor.

Homogenization temperatures of primary fluid inclusions from each of the deposits were generally found to be significantly lower than anticipated, with no homogenization temperatures exceeding 300°C, even though oxygen isotope studies previously undertaken on the Valley Copper deposit (Jones, 1975) had indicated temperatures of mineralization and alteration ranging between about 260 and 500°C.

Scattered inclusions containing appreciable carbon dioxide were observed, leading the writer to postulate the existence of two immiscible fluids at the time of entrapment. One fluid was rich and the other poor in CO_2.

K, Na, Mg and Ca were analyzed from a sample of massive quartz from the Valley Copper deposit. The K/Na atomic ratio of 0.5 obtained varied substantially from the anticipated ratio, indicating that the fluids were not in equilibrium with the co-existing granitic melt, either as a result of contamination due to the presence of potassium-bearing minerals in the sample, or from external sources.

ACKNOWLEDGEMENTS

The writer wishes to sincerely thank Dr. R.D. Morton, both for introducing him to the thesis topic, and for his guidance and assistance during the course of this study. His interest in the project was sometimes more enthusiastic than was that of the author.

Thanks are due to Dr. M.A. Olade, for kindly supplying the author with many samples from the subject area, and to Dr. D.G.W. Smith who, with Dr. R.D. Morton, accompanied the writer on a sample collecting field trip to the Highland Valley in the fall of 1973.

Dave Tomlinson has been an invaluable help to the writer. His advice, and the contents of his large tool box, helped to iron out several problems that the author was not prepared to deal with. Sincere thanks are offered to Frank Dimitrov for his help and advice in drafting the diagrams of this thesis, to Alex Stelmach for his assistance in carrying out the analytical work, and to Val Stephansson, who typed the manuscript.

Last, but not least, thanks are due to the writer's wife, Brenda, whose encouragement and moral support have been unfailing.

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Chapter 1

INTRODUCTION

A. AIMS OF THE THESIS

The principal objective of this thesis was to undertake a detailed study of fluid inclusions present in rocks from four porphyry copper deposits in the Highland Valley of southern British Columbia - specifically, the Bethlehem Copper, Valley Copper, Lornex and Highmont deposits - with a view to determining the composition of the mineralizing fluids, and the depositional environment. Figure 1 shows the locations of the subject deposits.

B. BACKGROUND TO THE THESIS

Samples examined during this study are from two sources. Whilst numerous specimens were kindly supplied to the author by Dr. M.A. Olade of the University of Ibadan, then at the University of British Columbia, the majority of the samples were collected by the author and Drs. R.D. Morton and D.G.W. Smith during a field trip to the area undertaken in the fall of 1973. Unavoidable sampling problems, combined with the minute size of the fluid inclusions, resulted in very little information being ascertainable about the fluids at the Bethlehem deposits.

Previous examinations of fluid inclusions from the Highland Valley deposits have been carried out by M.B. Jones, J.T. Nash and R. Schmuck. Jones (1974) has undertaken extensive investigations of the Valley Copper deposit, including fluid inclusion and stable isotope studies, whilst Nash examined a suite of rocks from the four major porphyry deposits of

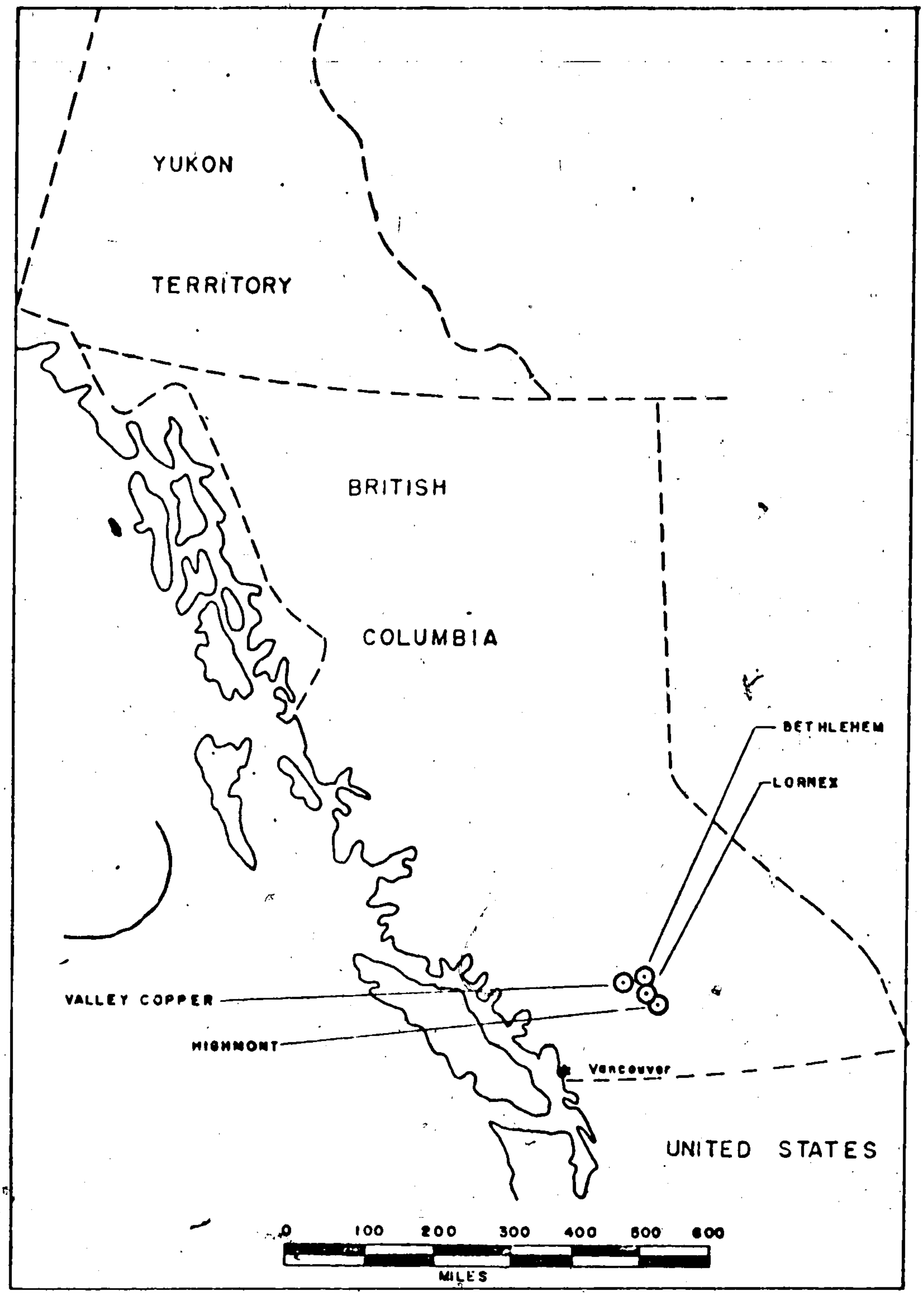


Fig. 1 Location of subject deposits, Highland Valley, British Columbia

the Highland Valley (Nash, 1976). The author knows of Schmuck only on the basis of mention of his results in Osatenko and Jones (1976).

C. METHODOLOGY

In order to accomplish the primary aim of the thesis, it was first necessary to install and calibrate the CHAIXMECA (model VT 2120) combined heating-freezing stage which was obtained in 1973 by the Geology Dept. of the University of Alberta. This instrument, which is designed for the study of fluid inclusions, is now in use at numerous research centres and is considered to be the best equipment for this purpose presently commercially available. The author has, however, found it inadequate in some aspects and has made recommendations for its improvement in these areas.

Calibration was accomplished using a variety of ultrapure organic liquid and inorganic solid chemical standards that were specifically selected for their well-defined freezing temperatures.

Subsequent to completion of the calibration, detailed examination of selected hand specimens was undertaken. This was followed by preparation of doubly-polished thick sections from suitable samples.

Tiny chips from each specimen were crushed in suitable fluid media while being observed under the microscope to determine the presence or absence of high pressure carbon dioxide or other gases in the inclusions.

Polished sections were studied petrographically before being subjected to freezing (to determine the concentration of dissolved salts), and heating (to determine homogenization temperatures) of their contained fluid inclusions.

One selected sample of quartz from the Valley Copper deposit was crushed and analyzed for K, Na, Ca and Mg in an attempt to determine whether the primary hydrothermal fluids were in equilibrium with the silicate melt.

Chapter 2

THE INSTRUMENT AND ITS CALIBRATION

A. THE INSTRUMENT

The CHAIXMECA model VT 2120 combined heating-freezing stage acquired by the Geology Department of the University of Alberta in 1973 comprises a read-out voltmeter, calibrated to register in degrees Celsius, and a bronze alloy sample chamber designed to fit on a microscope stage. A platinum resistance thermal sensor, mounted in the heating stage, is directly connected to the voltmeter.

Heating of the sample chamber is accomplished by means of an annular resistance heating coil, while cooling is effected by passing a stream of nitrogen gas through a copper coil within a liquid nitrogen bath and onwards through the freezing stage below the sample chamber.

The digital voltmeter has a resolution of 0.1°C. Tests of an analagous instrument, carried out by Poty _et al._ (1976), indicate a vertical gradient at 380°C of 0.9 to 1.0°C over a distance of up to 1 mm above the heating stage. Tests of the temperature gradient within the optic field of the heating stage, carried out by those authors at 380°C, indicated the horizontal variation from the center of the optic field to its margins to not exceed 0.8°C.

B. CALIBRATION PROCEDURE

Calibration of the instrument between -103°C and +6.5°C was effected using organic liquid standards. Between 37.7 and 480°C, inorganic standards were utilized. Only one standard was found to be suitable for calibration purposes at temperatures above 400°C. This was Thallium Bromide (M.P. 480°C). Chemical standards used during calibration are listed in Table 1.

Chemical standards used during calibration were sealed within 0.5 mm (I.D.) Lindemann glass X-ray diffraction capillary tubes. The outside diameter of the capillaries being very close to the 0.6 mm average thickness of the polished sample chips, vertical thermal gradients within the heating-freezing stage could be effectively discounted. Horizontal gradients were minimized by considering only that portion of the capillaries (and subsequently of the sample chips) covering the optic centre of the heating-freezing stage.

Between 37.8 and 315.6°C, the chemical standards were supplemented by the use of "Tempilabel" stickers[1]. These commercially available, adhesive backed stickers change color at specified temperatures and are claimed, by their manufacturer, to have an accuracy of ±1%.

All standards used were heated at a maximum rate of 1.2°C per minute with the temperature of melting being taken as the temperature at which the last solid at the optic axis of the heating stage melted.

In order to check the reproducibility of data, several consecutive readings were obtained on each standard. Rates of heating varied between 0.3 and 1.2°C per minute with those readings obtained from the lower heating rates considered to represent the more accurate results. Difficulty was encountered in obtaining closely reproducible data at high temperatures because the design of the heating stage makes it difficult to accurately control heating rates at such temperatures.

TABLE 1

HEATING-FREEZING STAGE CALIBRATION STANDARDS

Melting Temp. °C	Name	Formula
-103.5	Cyclohexene	C_6H_{10}
- 90.61	Heptane	C_7H_{16}
- 56.79	Octane	C_8H_{18}
- 25.18	O-Xylene	C_8H_{10}
- 11.5	Ethylene glycol	$HOCH_2CH_2OH$
0	Doubly distilled, demineralized water	
+ 6.55	Cyclohexane	C_6H_{12}
+ 37.7	Stannous Chloride	$SnCl_2$
+ 78.0	Barium Hydroxide	$Ba(OH)_2 \cdot 8H_2O$
+144.5	Tin Tetraiodide	SnI_4
+169.6	Ammonium Nitrate	$(NH_4)NO_3$
+236.0	Mercuric Bromide	$HgBr_2$
+271.3	Bismuth metal	Bi
+315.0	Arsenic trioxide	As_2O_3
+324.0	Anhydrous Sodium Acetate	$NaOOCCH_3$
+373.0	Lead Bromide	$PbBr_2$
+480.0	Thallium Bromide	$TlBr_2$

C. LEAST SQUARES REGRESSION FIT

A least squares regression best-fit curve was generated by computer on the basis of all calibration values. It produced a remarkably close fit to the data indicating linear drift in the thermocouple between -100°C and +480°C (see Figure 2). The method used was that described by York (1968), with a program written by S.L. Kuo.

D. CONCLUSIONS

1. Use of "Tempilabels"

Although the "Tempilabel" indicators used in this procedure are rated as having an accuracy of ±1%, in practice they were found to be less reliable than the independently selected chemical standards. It was observed that (a) individual "Tempilabels" changed color over a temperature range rather than at one specific temperature, and (b) when several "Tempilabels" rated at the same temperature were consecutively used in the heating stage, different color-change temperatures were recorded for each. Hence, future use of these temperature indicators for calibration purposes is not recommended.

2. Comment on Heating Rates

Literature received from the CHAIXMECA Corp. subsequent to completion of the calibration suggests that a maximum heating rate of 0.25°C per minute be employed within 10°C of the target temperature. This figure was unknown to the author at the time that initial calibration was effected. It is believed that although the higher heating rates used may have produced a somewhat wider spread of results than could be hoped for using the recommended rate, the values obtained are nonetheless valid.

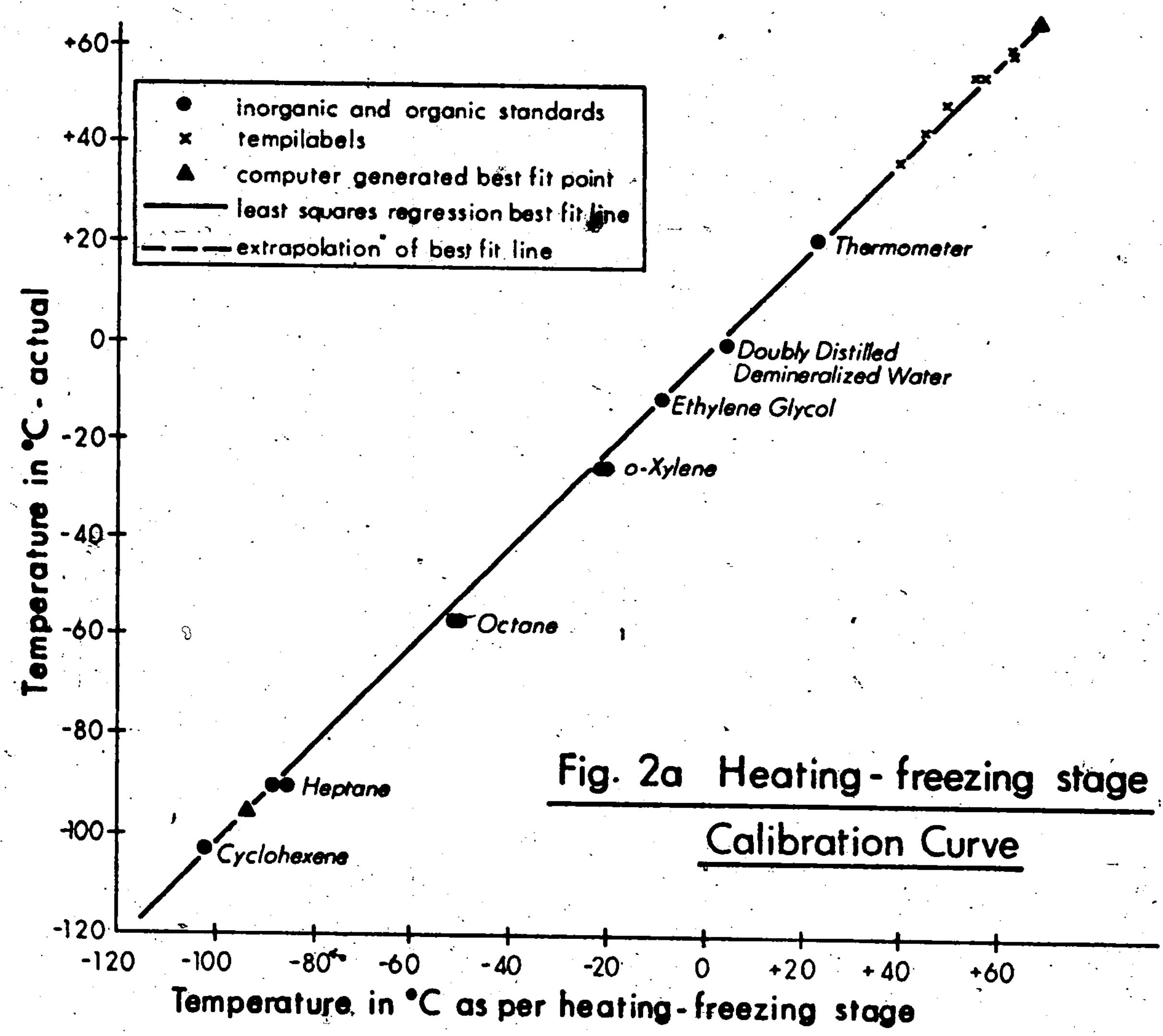


Fig. 2a Heating - freezing stage

Calibration Curve

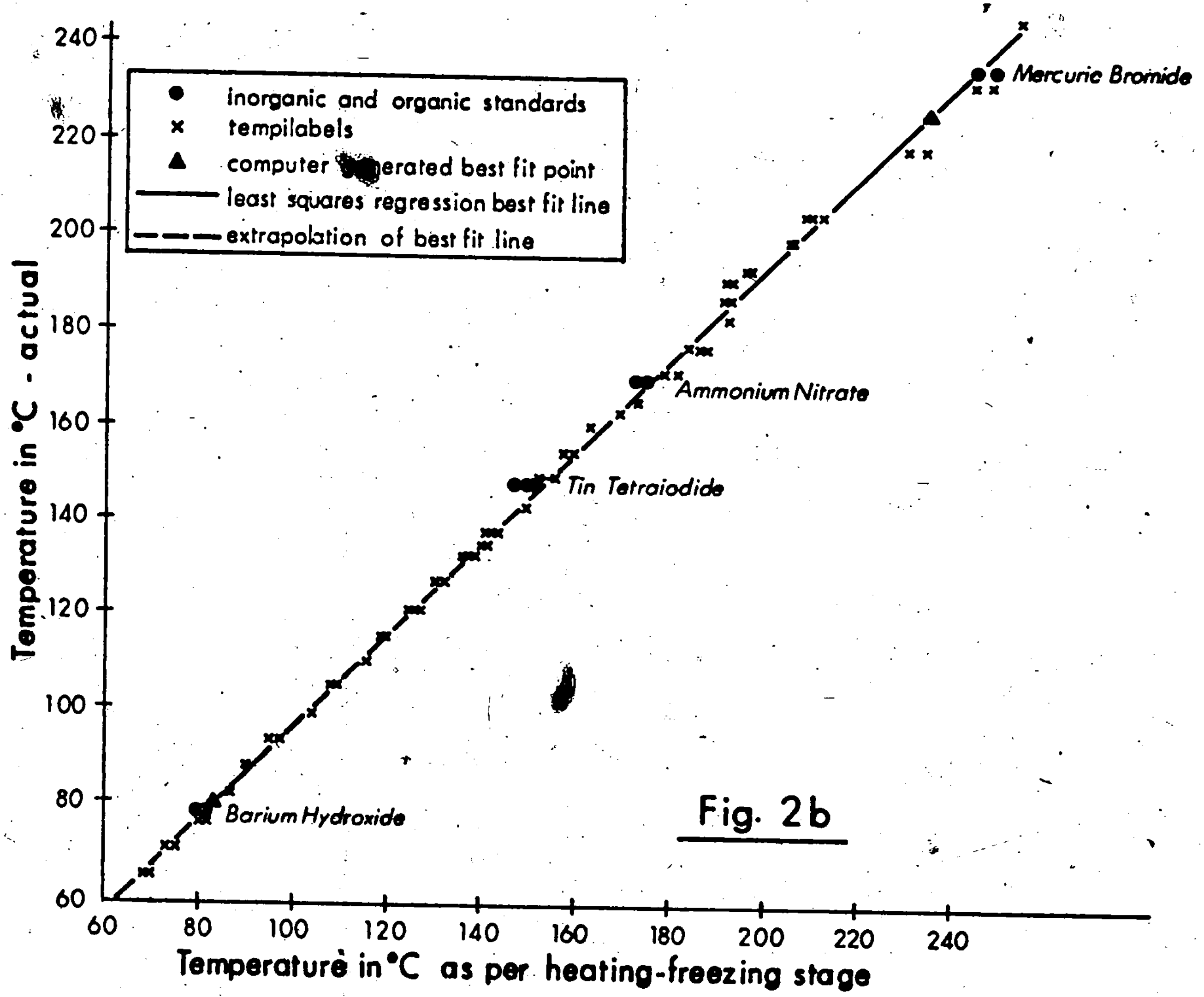

Temperature in °C - actual
240
220
200
180
160
140
120
100
80
60
● inorganic and organic standards
× tempilabels
▲ computer generated best fit point
least squares regression best fit line
extrapolation of best fit line
Mercuric Bromide
Ammonium Nitrate
Tin Tetraiodide
Barium Hydroxide
60
80
100
120
140
160
180
200
220
240
Temperature in °C as per heating-freezing stage

Fig. 2b

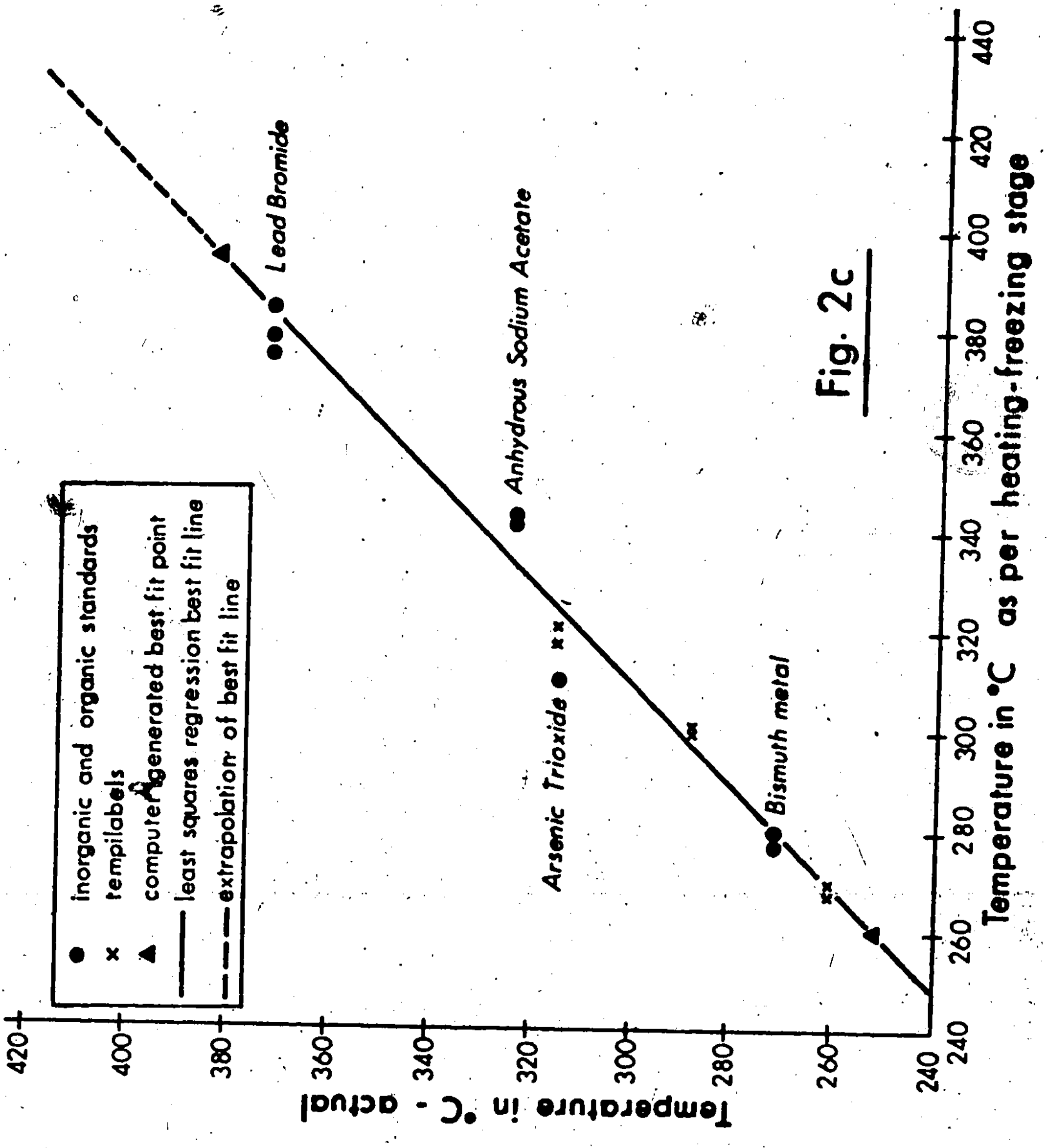

inorganic and organic standards
tempilabels
computer generated best fit point
least squares regression best fit line
extrapolation of best fit line
Lead Bromide
Anhydrous Sodium Acetate
Arsenic Trioxide
Bismuth metal
Temperature in °C - actual
240
260
280
300
320
340
360
380
400
420
Temperature in °C as per heating-freezing stage
240
260
280
300
320
340
360
380
400
420
440

Fig. 2c

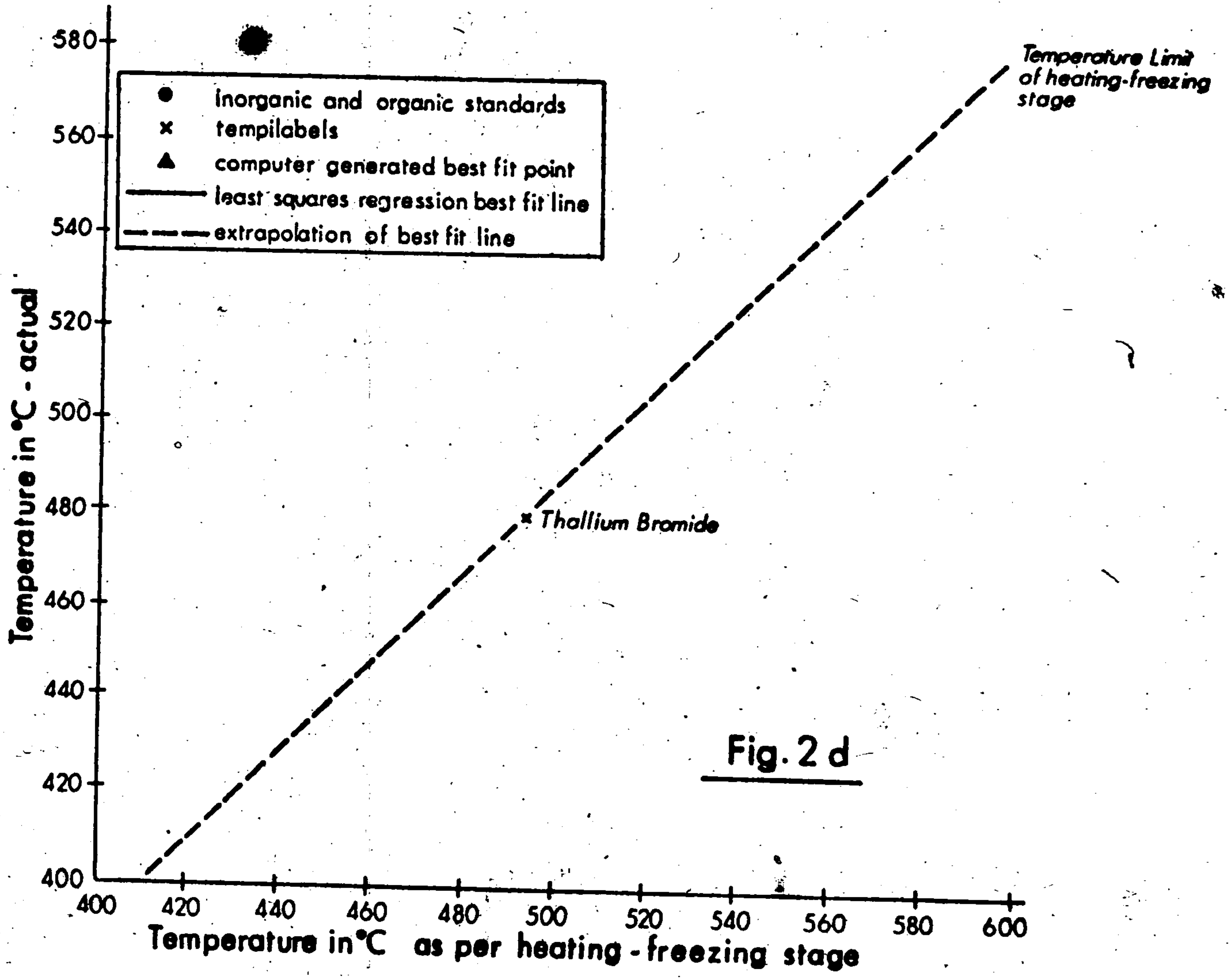

● inorganic and organic standards
× tempilabels
▲ computer generated best fit point
——— least squares regression best fit line
– – – extrapolation of best fit line
Temperature Limit of heating-freezing stage
Thallium Bromide
Temperature in °C - actual
400
420
440
460
480
500
520
540
560
580
Temperature in °C as per heating - freezing stage
400
420
440
460
480
500
520
540
560
580
600

Fig. 2 d

Yearly calibration checks subsequently undertaken in 1975 and 1976 using the suggested heating rate of 0.25°C per minute produced results closely correlative to those initially obtained.

3. Possible Improvements to the Equipment

During the course of this study, some thought has been given to possible improvements to the equipment. Those that are considered to be of most use are as follows:

(a) A digital ratemeter registering the rate of temperature change in degrees per minute. This unit should ideally register rate to two decimal places and have a wide enough range to allow for heating or cooling rates of up to 50°C per minute.

(b) A fine control circuit should be built into the unit in parallel with the variac for use at high temperatures, where control of heating rate is presently difficult at best.

(c) Instead of both (a) and (b), a programmable heating rate control unit might be installed.

(d) The present single memory built into the unit is inadequate for those cases where several inclusions with closely similar T_H are being observed simultaneously. To solve this problem, a ten-stack memory could be included.

(e) A foot-controlled cassette unit with microphone mounted on the microscope would allow verbal notes to be made during observations without the need to curtail observations in order to transcribe results.

Chapter 3

THE SIGNIFICANCE OF FLUID INCLUSIONS WITH PARTICULAR RESPECT TO PORPHYRY COPPER DEPOSITS

A. INTRODUCTION

Fluid inclusions are minute samples of aqueous solutions or other liquids which were trapped in rocks during or subsequent to their crystallization. In the cases of many ore bodies, the fluids within the inclusions are considered to represent relict ore-forming solutions. The study of fluid inclusions can therefore lead, in some cases, to a better understanding of the composition of the mineralizing fluids, and the physical conditions of those fluids either at the time of crystallization of the host rock, or at the time of subsequent hydrothermal activity.

The validity of fluid inclusion studies is predicated upon two conditions: (a) that the fluid is compositionally representative of the solution which was present at the time of entrapment, and (b) that no changes affected the fluid subsequent to its entrapment.

Studies by Roedder (1968, 1972) and others have indicated that leakage or addition of material, with the probable exception of hydrogen, to fluid inclusions subsequent to their formation is unlikely - particularly in the case of a hard, non-cleavable host mineral such as quartz. In addition, reaction between the entrapped liquid and the host mineral is not considered to be a serious problem in quartz. Ypma (1963) emphasizes that the solubility of SiO_2 in water at 400°C and 2000 kg/cm^2 pressure is no more than 2 mole percent.

Few experiments have been carried out to prove or disprove the first condition. Work by Barnes and Lusk (1972), despite the claims of the authors, is not conclusive (Weisbrod et al., 1976), although studies undertaken by Weisbrod, Poty and Touret (1976) apparently produced more substantive results. They claim that, particularly in the case of inclusions trapped in quartz, theoretical considerations (unspecified) leave them no doubts as to the validity of the studies.

B. TYPES OF INCLUSIONS

Fluid inclusions are classified under three types: (a) primary, (b) pseudosecondary, and (c) secondary. Primary inclusions are those which, as Roedder (1972) says, were trapped by "crystal growth irregularities or fluid inhomogeneities during the formation of the enclosing mineral". Pseudosecondary inclusions are those that were trapped during the healing of fractures formed during crystallization, while secondary inclusions are those that were formed during the healing of fractures subsequent to crystallization. While results obtained from primary and pseudosecondary inclusions are generally identical, those obtained from secondary inclusions may be grossly different, as such inclusions frequently reflect a different depositional environment from that existing at the time of host crystallization. Table 2 lists some of the criteria employed in distinguishing between the different classes of inclusions.

C. PRESENCE OF SALTS IN INCLUSIONS

The presence of salts in fluid inclusions lowers the freezing temperatures of the aqueous solutions. The degree to which these are lowered by NaCl has been quantified as shown in Figure 3 and, if the assumption is made that sodium chloride is the only electrolyte present in the inclu-

TABLE 2

SOME CRITERIA FOR DIFFERENTIATION BETWEEN PRIMARY AND SECONDARY INCLUSIONS

(from Roedder, 1976)

A. Primary Inclusions

1. Large size and/or equant shape in three dimensions relative to enclosing grain.
2. Isolated occurrence, away from other inclusions for a distance of about ≥5 times the diameter of the inclusion.
3. Occurrence on a compromise growth surface between two non-parallel crystals. (These inclusions have often leaked and may also be secondary.)
4. Negative crystal shape (seldom valid).

B. Secondary Inclusions

1. Planar arrays of inclusions outlining healed fractures that come to the surface of a crystal or are continuous across several crystals.
2. Very thin and flat inclusions, often in the process of necking down.

C. Pseudosecondary Inclusions

1. Occurrence as planar arrays outlining fractures that visibly terminate within crystals.
2. Frequently more equant and of negative crystal shape compared to secondary inclusions within the same sample.

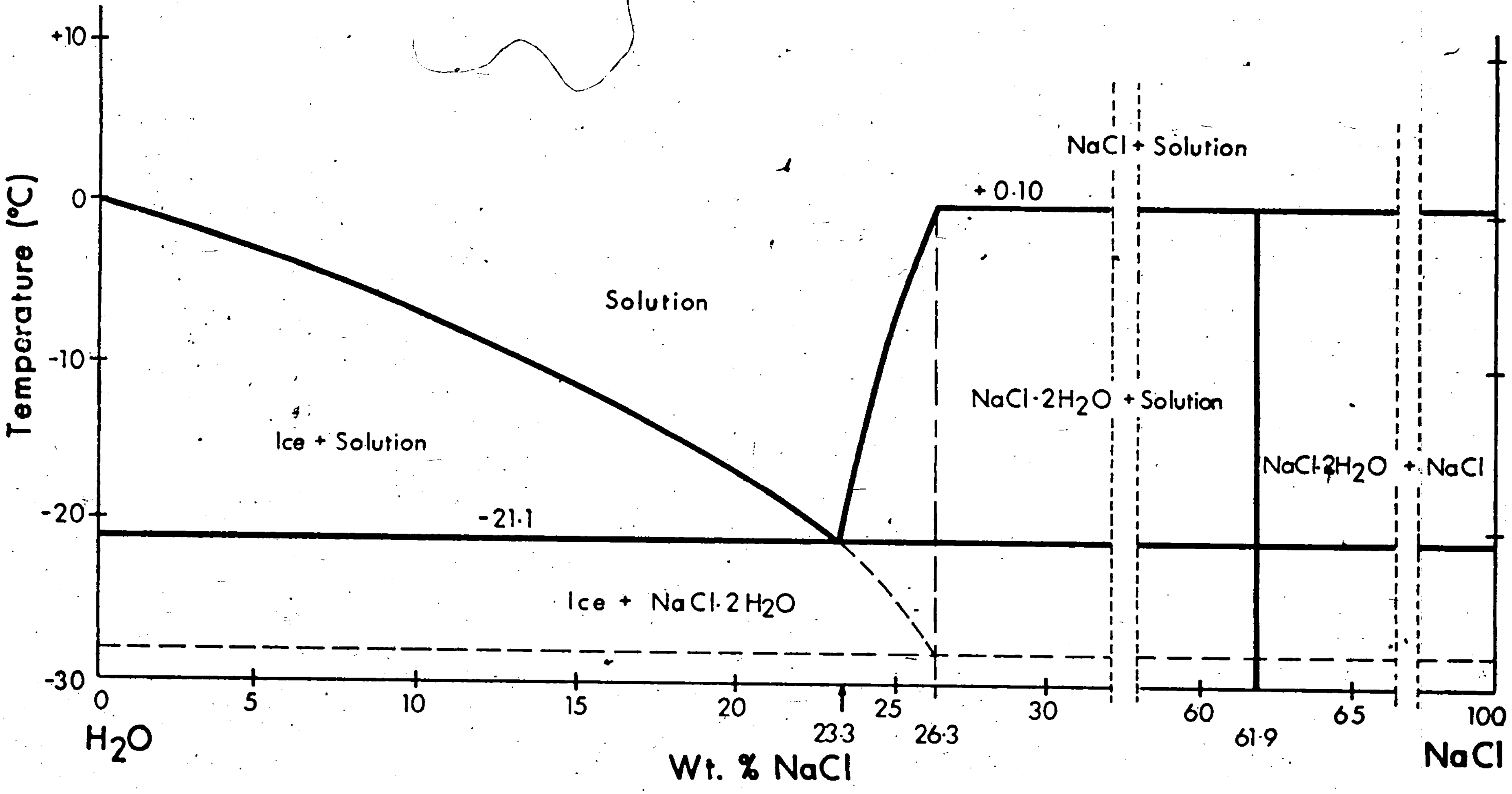


Fig. 3 The system $H_2O-NaCl$ Int. Crit. Tables IV. pp. 235, 1928 in Roedder, 1962, pp. 1059.

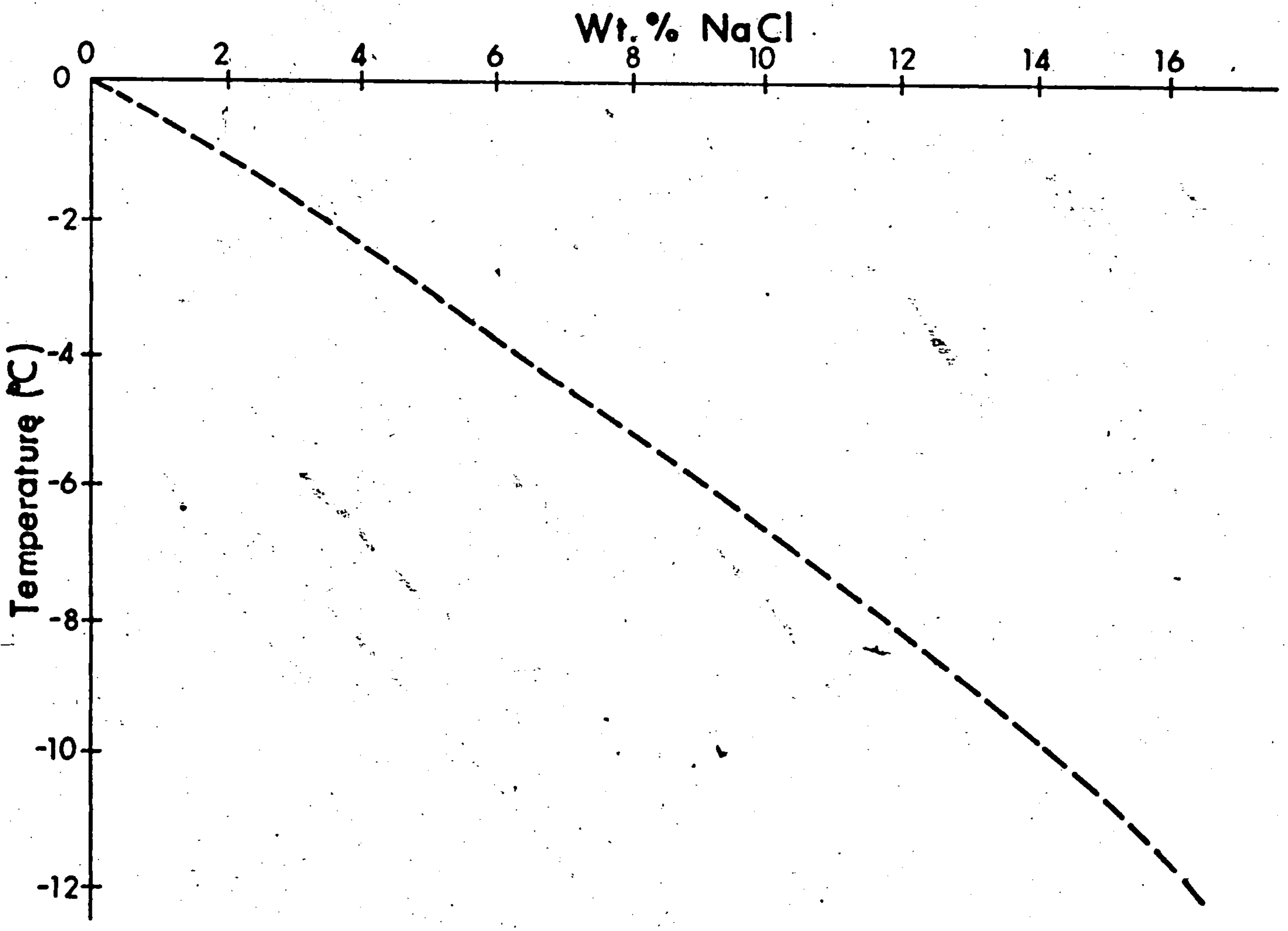


Fig. 3a Freezing temperature-salinity relationship
Int. Crit Tables IV.

sions, then observation of the melting temperatures of ice in the inclusions permits the weight percentage of dissolved salts to be calculated. Figure 3a presents an expansion of Figure 3 for the cases where salt concentration is less than 23.3 weight percent.

The presence of unknown concentrations of salts other than NaCl in the solution can result in some inaccuracies in estimates; however, as NaCl is usually the predominant (and frequently the only) salt phase present, such variations can often be disregarded.

At 25°C, a salt-saturated aqueous solution contains 26.4 weight percent NaCl. Greater concentrations result in the crystallization of a salt cube. In this eventuality, two alternative approaches are available to permit determination of the salt concentration. If the inclusions are regularly shaped, an estimate may be made as to the volume percent of the daughter crystals and the overall weight percent NaCl may then be calculated from this. Alternatively, the salt concentration may be estimated by slowly heating the inclusion until the salt crystal dissolves entirely and comparing this temperature to the values on the graph produced by Keevil (1942) which is presented in Figure 4.

D. HOMOGENIZATION OF INCLUSIONS

The homogenization temperature of a fluid inclusion is that temperature at which the distinct liquid and vapor phases within an inclusion merge to become a homogeneous fluid. The homogenization temperatures of aqueous solutions are considered to represent the minimum temperatures of entrapment of the original fluids.

These temperatures are a function of both internal pressure and of the salt concentration in the system. It is therefore important that the fluid

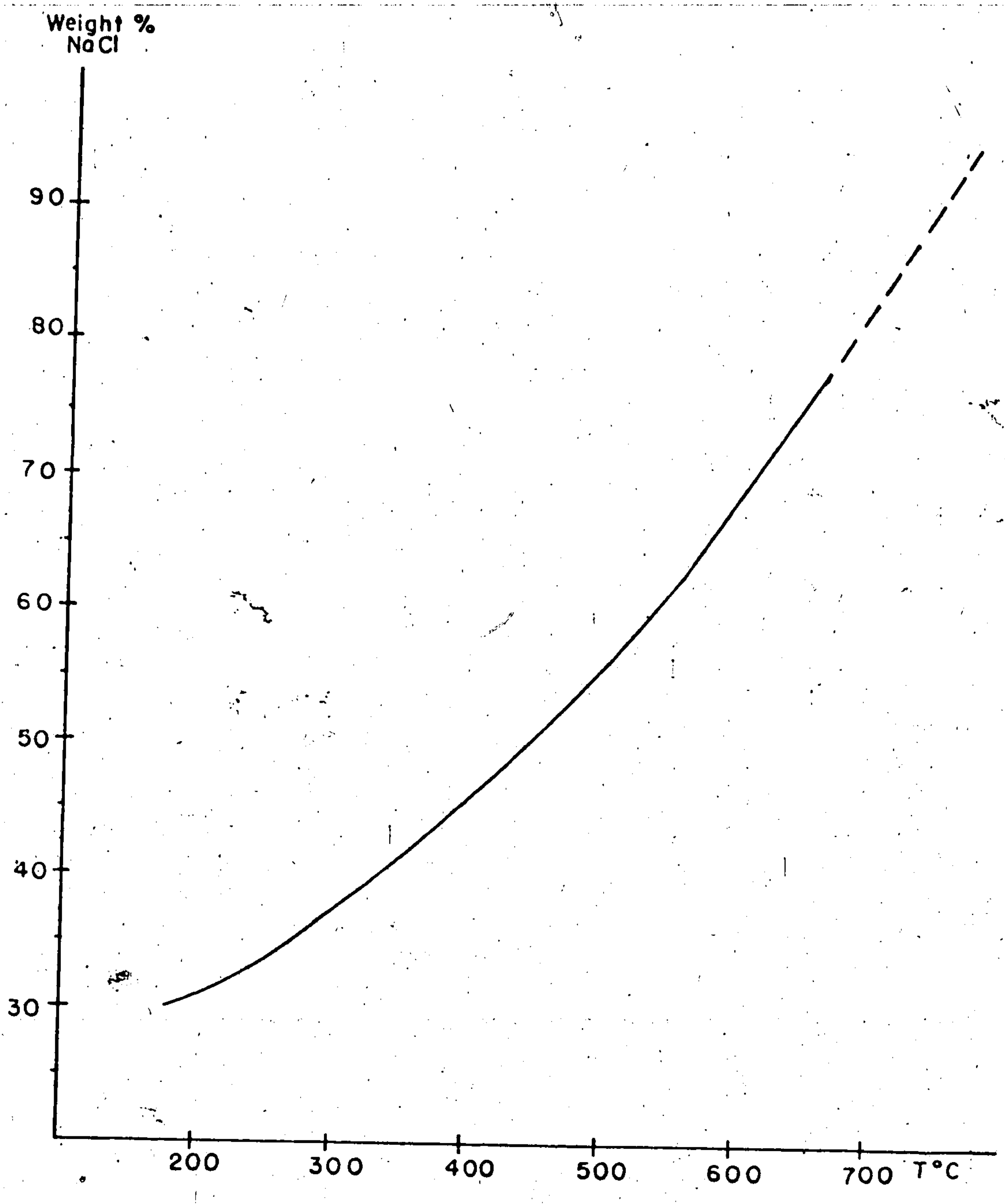


Fig. 4 Composition of the liquid phase of an NaCl saturated aqueous solution (from Keevil, 1942)

contain the same concentration of dissolved components at the homogenization temperature as were originally present at the time of entrapment. This usually necessitates the dissolution of any daughter salt crystals that have grown in the inclusion since the time of entrapment, and hence, very slow rates of heating when approaching the homogenization temperatures.

Frequently it is necessary to calculate a pressure correction which is added to the homogenization temperature in order to take into account the total pressure on the system. In porphyry copper deposits, evidence is generally present indicating boiling of the fluids at the time of entrapment. In this event, the pressure on the system at the time of entrapment of the fluids is equal to the pressure within the fluid inclusions at their homogenization temperatures so that no pressure correction is necessary.

E. PREVIOUS WORK ON PORPHYRY DEPOSITS

Numerous studies have been conducted on fluid inclusions in porphyry copper deposits. The majority of the studies in the western world have centered upon the porphyry deposits of the southwestern United States.

Roedder, in his 1971 paper on fluid inclusions in the Bingham, Butte and Climax porphyry deposits, points out that primary fluid inclusions within the core zone at Bingham generally contain high salt concentrations, sometimes exceeding 60 weight percent. These inclusions have high degrees of filling and generally homogenize above 375°C, and often above 600°C. These assertions are supported by Nash who, however, states (1976, pers. comm.) that during his work on porphyry deposits of the Highland Valley, he observed very few such high salinity inclusions. He interprets this to imply a deeper level of emplacement for the Highland Valley deposits compared with those south of the border.

In his studies of primary inclusions from deposits peripheral to American porphyry deposits, Roedder (1971) encountered low densities, with vapor phases often greater than 70 volume percent and low concentrations of dissolved salts. These low density inclusions tend to homogenize around 300°C. The apparent decrease in temperature and salt concentration away from the cores of porphyry deposits accords well with the hypothesis of White, Muffler and Truesdell (1971) that boiling of the hydrothermal fluids at depth in the hot cores of the intrusions may result in a refluxing action causing concentration of the deep brines.

Carbon dioxide in both liquid and vapor phases has been recorded in fluid inclusions from the core regions of numerous porphyry deposits. Nash (1976, pers. comm.) states that he found it to be particularly common in samples he examined from the Highland Valley. The present study has determined that the carbon dioxide is usually encountered only in very small, often sub-millimetric, patches throughout the rock indicating small scale variation of CO_2 concentration throughout the hydrothermal fluid at the time of crystallization. The homogenization temperatures of under 250°C encountered both by Jones (1974) and by the present author, for primary inclusions from deposits in the Highland Valley, combined with the low solubility of CO_2 in water at, and below, this temperature confirm the presence of two immiscible fluids - one rich and one poor in CO_2 at the time of entrapment.

Roedder (1971) has reported the presence of solid phases such as halite, sylvite, hematite, anhydrite and gypsum in fluid inclusions from the core regions of porphyry deposits, but points out that these daughter minerals are absent in inclusions from peripheral deposits. Other workers have identified numerous other daughter crystals including calcite, quartz, magnetite, pyrite and chalcopyrite. The very low solubilities of some of these products implies their entrapment perhaps as discrete grains rather than as solutions which subsequently crystallized.

Anhydrite and gypsum have been reported in fluid inclusions from numerous porphyry deposits. Jambor and McMillan (1976) suggest that the sulphates are associated with the potassic alteration zones of porphyry deposits. At El Salvador, in Chile, however, the sulphate zone was found to <u>overlap</u> several of the hydrothermal alteration zones.

Jones (1975) found that at Valley Copper, "...virtually all the anhydrite is below the 3400-foot level". Jambor and McMillan (1976) report that "...the top of the (sulphate) zone is a gently undulating surface below which primary anhydrite is present". They believe that the sulphate zone is of hypogene origin, more recent than the late stage silicification of the deposit, and suggest that a genetic relationship exists between argillic alteration and gypsum veining. According to Jambor and McMillan (1976):

> "Jones (1975) has established from isotopic data that the percentage of ocean water in the Valley Copper hydrothermal system reached its maximum at the time of gypsum deposition."

They suggest that,

> "The late stage influx of ocean water accelerated the temperature decline in the partly cooled hydrothermal system which was already rich in calcium and sulphate derived by leaching of the upper part of the potassic zone during argillic alteration."

They consider the top of the gypsum zone to represent the upper limit of significant hydrothermal activity.

Margaritz and Taylor (1976) claim that $\delta^{18}O$ and δD values are 'normal' in the Guichon batholith, implying that the rocks are not appreciably affected by meteoric-hydrothermal events. No further information on this is available at present.

White, Muffler and Truesdell (1971) proposed that porphyry copper deposits may form in "...the zone of boiling brine below vapor-dominated systems...". They point out that "...condensate from the discharge areas of vapor-dominated systems is high in sulphate. Some and perhaps much of this condensate may drain downward to the deep water table and account for the abundant anhydrite of many porphyry copper deposits".

Ridge (1974) supports the White, Muffler and Truesdell model by suggesting that "...the higher a fluid inclusion is in salt content, the more likely it is that it was derived from an ore fluid that boiled during some part of its journey toward the land surface or sea floor". He suggests that such boiling would result in the precipitation of the low solubility sulphides.

Chapter 4

GEOLOGY OF THE HIGHLAND VALLEY

A. INTRODUCTION

The Highland Valley of British Columbia is situated 54 km southwest of Kamloops between latitudes 50°20'N and 50°30'N and longitudes 120°58'W and 121°08'W. The porphyry deposits comprising the Highland Valley porphyry district are contained within the Guichon Creek batholith, a concentrically zoned, semi-concordant, domal pluton with a surface area of about 1000 km^2. The elliptical outcrop of the batholith is oriented with its long axis slightly west of north and intrudes sedimentary and volcanic rocks of the Permian Cache Creek Group and the Upper Triassic Nicola Group. It is unconformably overlain by Middle Jurassic to Middle Tertiary sediments and volcanics.

K-Ar geochronology has indicated an age of 198 ± 8 million years for the batholith (Northcote, 1969); however, it is a composite intrusion as indicated by contacts and enclosed xenoliths which appear to young towards the centre.

The porphyry mineralization is concentrated within the 65 km^2 central part of the batholith where aggregate ore reserves are considered to be around two billion tonnes of 0.45% copper equivalent (McMillan, 1976a). A summary of the sizes and grades of the sulphide deposits in the Highland Valley is presented in Table 3.

B. HISTORY

Prospecting activity in the Highland Valley began before the turn of

TABLE 3

Cu-Mo ORE BODIES OF THE HIGHLAND VALLEY (INITIAL RESERVES)

Name	Size (Millions of Tons)	Grade	Reference
Alwin	1.0	2.51% Cu	McMillan, 1972
Ann No. 1	48.0	0.27% Cu	McMillan, 1976b
Bethlehem[1]	100.3	0.461% Cu equivalent	Briskey and Bellamy, 1976
Highmont[2] No. 1	111.0	0.287% Cu, 0.042% MoS_2	Reed and Jambor, 1976
No. 2	24.0	0.273% Cu, 0.093% MoS_2	
	(Hylands, 1972; estimates 150+ M tons of 0.42% Cu equiv.)		
J.A.	260.0	0.43% Cu, 0.017% MoS_2	McMillan, 1976b
Krain	14.0	0.56% Cu equivalent	Christie, 1976
Lornex[3]	563.2	0.412% Cu, 0.014% MoS_2	N. Miner, March 24 1977 and Can. Mines Handbook, 1976-77
Minex	36.4	0.20% Cu, 0.016% MoS_2	Can. Mines Handbook, 1976-77
South Seas[4]	17.4	0.75% Cu equivalent	Hylands, 1972
Valley Copper[5]	790.0	0.48% Cu equivalent	Osatenko and Jones, 1976

[1] Includes Huestis, Iona, Jersey and East Jersey deposits.

[2] 5 additional deposits are known but incompletely explored.

[3] Ore reserve estimate, Dec. 31, 1976.

[4] Previously named Trojan.

[5] Calculated ore reserves to depth of 442 meters.

the century. During World War I, about 11,000 tonnes of high-grade copper ore was mined from vein deposits on what are now the Alwin and Bethlehem properties. Copper showings were, however, known at that time on the sites of almost all the presently known deposits.

Modern activity began in 1955 when Bethlehem Copper Corporation launched an extensive exploration program which culminated in production in 1962 at 3000 tonnes per day. A period of intensive exploration activity by Bethlehem Copper Corp. and numerous other companies resulted in delineation of the deposits within the valley, and in 1972 the Lornex deposit was brought into production by Rio Algom. Low copper and molybdenum prices, combined with unfavorable provincial government fiscal and royalty policies led to curtailment of exploration activity, and production plans for the Highmont and Valley Copper deposits were shelved.

C. GENERAL GEOLOGY

1. General Statement

The Guichon Creek batholith is a concentrically zoned, calc-alkaline pluton (see Figure 5) which gravity studies have indicated to be a flattened funnel-shaped body, the feeder of which apparently underlies the Highland Valley at a depth of 8 km and plunges 80° towards the northeast (Ager *et al.*, 1972).

Structural characteristics of the batholith are largely consistent with a proposed origin involving shallow compressional tectonic stresses.

2. Lithologic Descriptions

The phases of the batholith have been subdivided on the basis of compositional and textural criteria as follows:

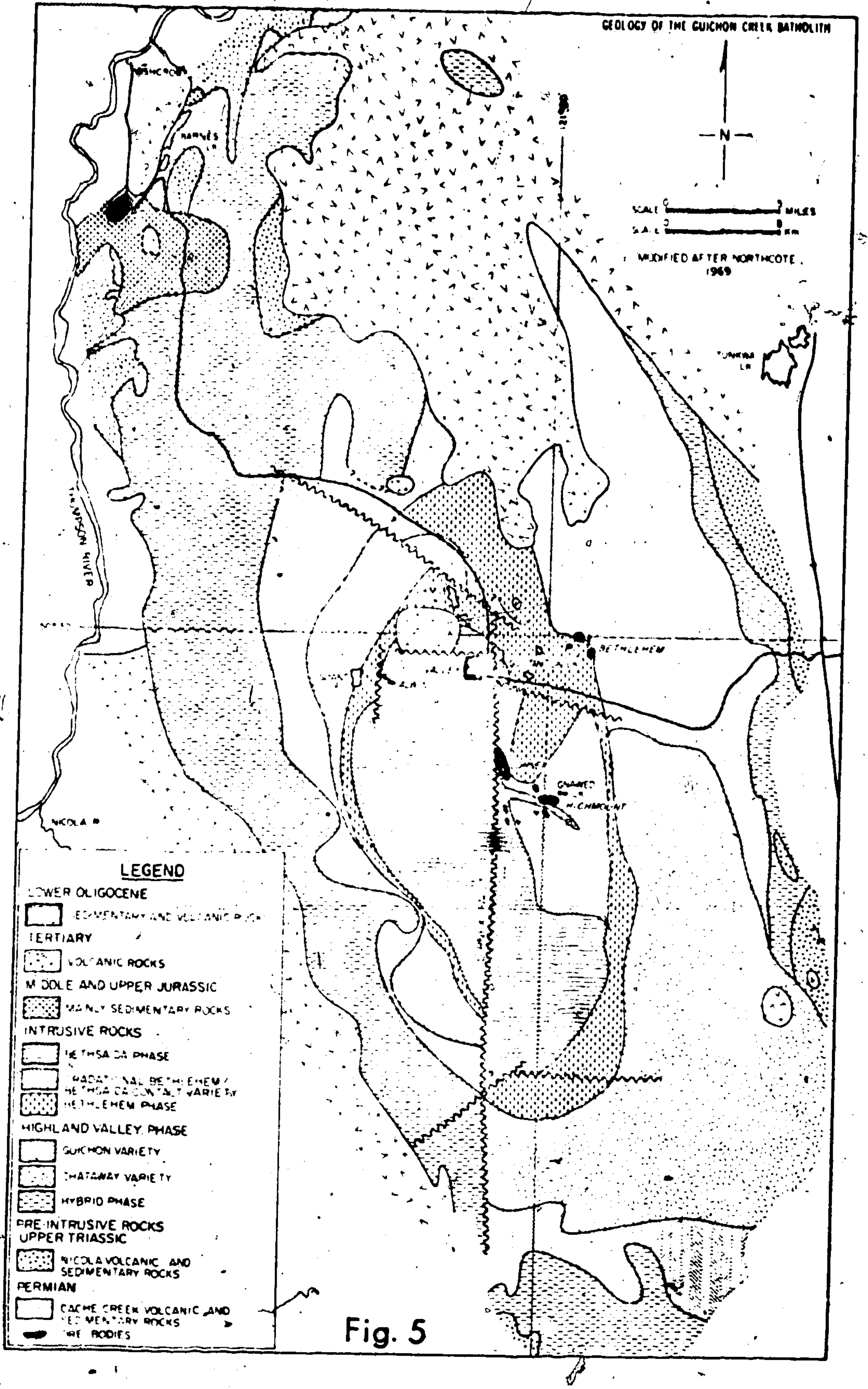

GEOLOGY OF THE GUICHON CREEK BATHOLITH
N
SCALE 0 5 MILES
SCALE 0 8 KM
MODIFIED AFTER NORTHCOTE, 1969
ASHCROFT
BARNES LK
TUNKWA LK
THOMPSON RIVER
BETHLEHEM
GNAWED
HIGHMOUNT
NICOLA
LEGEND
LOWER OLIGOCENE
SEDIMENTARY AND VOLCANIC ROCK
TERTIARY
VOLCANIC ROCKS
MIDDLE AND UPPER JURASSIC
MAINLY SEDIMENTARY ROCKS
INTRUSIVE ROCKS
BETHSAIDA PHASE
GRADATIONAL BETHLEHEM / BETHSAIDA CONTACT VARIETY
BETHLEHEM PHASE
HIGHLAND VALLEY PHASE
GUICHON VARIETY
CHATAWAY VARIETY
HYBRID PHASE
PRE-INTRUSIVE ROCKS
UPPER TRIASSIC
NICOLA VOLCANIC AND SEDIMENTARY ROCKS
PERMIAN
CACHE CREEK VOLCANIC AND SEDIMENTARY ROCKS
ORE BODIES

Fig. 5

(a) The Hybrid intrusive phase. This phase, which forms the peripheral sector of the batholith comprises a fine- to medium-grained mafic diorite or quartz diorite. It commonly contains xenoliths of the adjacent country rock and, due to contamination, locally ranges from amphibolitic to monzonitic in composition.

(b) The Highland Valley intrusive phase. This phase, which is surrounded by the Hybrid phase is comprised of two subtypes - the Guichon and Chataway granodiorites.

The Guichon variety ranges from quartz diorite to granodiorite and contains about 15% mafic minerals in evenly distributed clusters. Biotite and hornblende are equally abundant in the Guichon variety, while in the Chataway variety, which contains about 12% evenly distributed mafic minerals, medium-grained poikilitic hornblende crystals predominate. The two subtypes are gradational from one to the other.

(c) The Bethlehem intrusive phase. The granodiorite of this phase contains 8% mafic minerals. Irregularly distributed, coarse-grained, poikilitic hornblende crystals set in a matrix containing fine- to medium-grained mafic minerals characterize the rock. The Bethlehem phase is surrounded by the older Highland Valley phase and in turn usually grades into the youngest, innermost phase - the Bethsaida. Rocks of the gradational zone have been categorized as Skeena granodiorite.

(d) The Bethsaida intrusive phase. The rocks of this, the youngest plutonic phase, range in composition from quartz monzonite to granodiorite. They contain 6% mafic minerals - coarse-grained, euhedral biotite books and hornblende crystals, with frequent large quartz phenocrysts.

(e) The Porphyry dyke swarm. A post-Bethlehem phase, porphyritic dyke swarm cuts the batholith above the postulated 'spout' of the funnel.

These dykes comprise a north-south zone which includes the Bethlehem, South Seas and Krain deposits. They are believed to occupy dilation fractures caused by release of compressional stresses. Briskey and Bellamy (1976) suggest on the basis of textural and chemical similarities, that many of the dykes are coeval with rocks of the Bethlehem intrusive phase.

D. ZONING OF THE BATHOLITH

The overall zoning of the batholith is from more basic marginal phases to a more silicic core, with gradational contacts between plutonic phases. Several students of the region, including Ager (1972), Hylands (1972), McMillan (1976a) and Northcote (1969) propose an origin involving magmatic differentiation with injection of progressively more silicic magma. Hollister et al. (1975) state that stable isotope evidence, in addition to the temporal relationships of sulphide veinlets with the host rocks, indicates derivation of the Cu and Mo from a differentiating magma.

E. ORE DEPOSITS

1. Lithologic Settings of the Studied Deposits

The porphyry copper-molybdenum deposits of the Highland Valley have been emplaced in various host rocks. The Bethlehem porphyry deposits are situated near the contact between Guichon and Bethlehem phase granodiorites. The abundant igneous breccia which is present in the deposits is mainly localized within the Bethlehem phase, and sulphide mineralization is essentially restricted to the breccia and to the associated north-trending dyke swarm.

The Lornex and Highmont deposits are situated in Skeena quartz diorite. Highmont, like the Bethlehem deposits, is associated with abundant igneous breccia. Several of the Highmont deposits are cut by a west-northwesterly-trending composite dyke comprising a porphyritic quartz eye variety of the Bethsaida quartz monzonite, a leucocratic quartz porphyry and associated breccia. This dyke, known as the Gnawed Mountain Porphyry, extends to the northwest to transect the Lornex ore body.

The Valley Copper ore body is localized entirely within the Bethsaida granodiorite and, unlike the other deposits of this study, does not contain significant amounts of breccia or dykes.

2. Structural Setting of the Deposits

The Guichon Creek batholith is flanked to the east and west by long narrow, northerly-trending grabens which are partly filled with more recent sedimentary and volcanic rocks. Within the batholith itself, two major faults, the Lornex and Highland Valley faults, truncate each other. Hollister *et al*. (1975) suggest that the locus of the intersections of these faults has determined the sites of emplacement of the porphyry deposits.

According to Hollister's scenario, at a time when the Bethsaida phase had partly crystallized, emplacement of mineralization began at the intersection of the previously developed Lornex and Highland Valley faults. This intersection, which is postulated to overlie the feeder pipe of the batholith, shifted over a period of time as a result of continued movement of the two faults and the ore bodies were moved from their original positions to those they now occupy. The order of emplacement of the ore bodies is believed by Hollister to be: Highmont, Bethlehem, Lornex-Valley Copper, with the successive deposits being emplaced at progressively greater depths and temperatures.

Jambor (1976), however, questions several of Hollister's assertions. He claims that there is no evidence that initial hydrothermal activity occurred at Highmont, or that sulphide mineralization followed displacement of the intersection points of the Highland Valley and Lornex faults. He points out that age relationships for mineralization within the Lornex and Highmont deposits are identical; all sulphides being post-Gnawed Mountain Porphyry in age and some being post-aplite.

Despite these criticisms, much of Hollister's hypothesis remains attractive in providing (a) a reasonable explanation for the locations of the deposits, and (b) an interpretation of the irregular form of the batholith.

3. Environment of Ore Deposition and Composition of the Mineralizing Fluids

(a) Depth. Sutherland Brown (1976) has estimated depths of emplacement of 3.6 km for the Jersey deposit, 4 km for the Highmont deposit, 4.5 km for the Lornex deposit, and 4.75 km for the Valley Copper deposit. Jones (1975, 1976), in contrast, reported the presence of liquid CO_2 in fluid inclusions from the Valley Copper deposit. He suggests that these inclusions may be of primary origin and, based upon the proportion of liquid CO_2 in the inclusions, proposes a pressure of 100 to 300 bars, corresponding to a depth of emplacement of 1 to 2 kilometers.

(b) Temperatures of Emplacement. Temperatures of emplacement of mineralization at the Valley Copper site, based upon sulfur isotope studies using pyrite-sphalerite, and anhydrite-bornite geothermometers, are reported by Osatenko and Jones (1976) to be about 400°C. They indicate a temperature range for mineralization of between 370 and 500°C with the higher temperature corresponding to the deeper, central part of the deposit. These proposed temperatures of mineralization are in close accordance with temperatures for hydrothermal alteration at Valley Copper proposed by Jones (1975), on the basis of oxygen isotope studies using a quartz-sericite geothermometer. He infers a temperature range between 260°C, for early pervasive sericitic alteration, and 480°C for potassic alteration. He suggests that most vein sericitic alteration, like the mineralization, occurred at around 400°C.

Studies of fluid inclusions from the Valley Copper deposit, undertaken by Schmuck (in Jones, 1975) indicated homogenization temperatures lower than 200°C. He believed that these temperatures were obtained from secondary inclusions which, he suggests, originated during late stage hydrothermal activity. At the Lornex deposit, McMillan (1976a) quotes Schmuck as stating that post-mineralization fluid inclusions fall into groups that homogenize at 200°C, 160°C and 120°C.

(c) Composition of the Mineralizing Fluids. On the basis of their studies of the Valley Copper deposit, both Olade (1975) and Osatenko and Jones (1976) find evidence of a progressive decrease in acidity of the hydrothermal fluids with time. Jones, Allen and Field (1972) suggest, on the basis of sulphur isotope studies, a deep subcrustal source of sulphur and little contamination by meteoric water.

Osatenko and Jones (1976) indicate that the hydrothermal fluids, active during mineralization of the Valley Copper deposit, comprised a mixture of sea water and magmatic water. Oxygen isotope studies lead them to estimate that the influxed sea water fraction varied between 16 and 44% during the main period of sulphide deposition, and averaged about 25%.

On the basis of fluid inclusion studies, Nash (1976) suggests that most of the primary copper, and important amounts of molybdenum, were deposited from fluids of moderate salinity. He states that his studies of fluid inclusions from the Valley Copper and Bethlehem deposits indicate anomalously low salinities for fluids in these deposits, when compared to porphyry deposits of the southwestern United States. He indicates that gas-rich and halite-bearing inclusions, characteristic of the American deposits, are far less common in deposits of the Guichon batholith.

Osatenko and Jones (1976) state that Schmuck determined average salt concentrations to be about 5 weight percent NaCl eq. in the inclusions he examined from Valley Copper. Jones describes these inclusions as containing 70-80% liquid and 20-30% gas phases. However, Osatenko and Jones (1976) state that some chloride - presumably halite - crystals were identified, indicating the presence of considerably higher salt concentrations.

The present study, in contrast, has indicated salt concentrations of 24 to 29 weight percent NaCl equivalent for most of the inclusions indicating that they range in salinity from slightly undersaturated to slightly oversaturated.

Nash (1976) states that he saw no evidence of boiling in inclusions from the Highland Valley. He admits, however, that this may be due to limited sampling. The present study has indicated that minor boiling did in fact occur in all four of the studied deposits.

Nash concluded that the absence of halite-bearing inclusions, and apparent lack of boiling indicated a greater depth of emplacement than was the case in the American deposits. The present author, in contrast, following the model of White, Truesdell and Muffler, believes that the salinities he determined, augmented by the scattered highly saline inclusions, and the evidence of boiling, indicate a relatively shallow depth of emplacement.

4. Mineralogy and Ore Controls

Copper and molybdenum are the only economically significant metals in the studied deposits. Very minor lead, zinc, silver and rhenium have also been detected, but they are never found in significant concentrations.

Molybdenum has been found to decrease in abundance from north to south within the batholith and is present in recoverable concentrations only in the Lornex and Highmont deposits. Highmont, with the highest Mo:Cu ratio of any of the Highland Valley deposits can be considered to be economically feasible only due to the molybdenum concentration (see Table 3), as the copper grade is markedly lower than that of the three other major deposits.

At both Highmont and Lornex, it has been observed that the top of the molybdenite zone lies below that of the copper zone, while its base extends below that of the copper zone (McMillan, 1976a). Hollister et al. (1975) interprpet an early paragenetic origin for molybdenum, but this is disputed by Jambor (1976).

The sulphide mineralization consists mainly of chalcopyrite, bornite, molybdenite and pyrite. At the Valley Copper deposit and Bethlehem's Jersey deposit, concentric sulphide zoning is noted with a bornite core surrounded in turn by a chalcopyrite zone and a weak pyrite halo. At the Highmont site, sulphide zoning is present parallel to the Gnawed Mountain Porphyry dyke and, like the larger orebodies, dips away from the dyke (Reed and Jambor, 1976). Similar zoning, parallel to the quartz porphyry dyke or the structure along which it was emplaced, is evident at Lornex (McMillan, 1976a; Waldner et al., 1976).

Sulphide and hydrothermal alteration zones are partly correlative in all four deposits. While bornite zones at Highmont and Bethlehem's

Jersey deposit are associated with hydrothermal biotite, the bornite at Valley Copper and Lornex is present in phyllic and argillic alteration zones. Chalcopyrite is generally associated with argillic zones in all deposits while pyrite is usually found in zones of propylitic alteration.

In all four deposits, fracture density has been determined to be the major ore control. While minor copper and molybdenum mineralization is found disseminated throughout the deposits, by far the majority of the sulphide mineralization is concentrated within quartz veins filling fractures and fault zones. Studies at Highmont and Valley Copper indicate that the vast majority of the fractures are parallel either to the Lornex fault, or to the Highland Valley fault. Hollister _et al_. (1975) suggest that continued movement of these faults produced dilation zones within the batholith that were subsequently impregnated by the metal-bearing hydrothermal fluids.

F. HYDROTHERMAL ALTERATION

The following synopsis is in large part taken from McMillan (1976), and the reader is referred both to that article and to the numerous other studies on the Highland Valley for a more rigorous discussion of the subject.

1. Potassic Alteration

Potassic alteration, characterized by the presence of secondary hydrothermal biotite and K-feldspar, is variably developed in the Highland Valley porphyry deposits. At the Highmont and Jersey deposits, potassic alteration is at best very weakly developed, and is represented by extremely weak pervasive biotitization (Reed and Jambor, 1976). The Lornex

TABLE 4

ALTERATION PATTERNS IN HIGHLAND VALLEY PORPHYRY DEPOSITS

	Valley Copper	Lornex	Highmont	Bethlehem
Quartz stockwork	S	M-S	-	-
Potassic-K-feldspar	M-S	VW	-	-
Biotite	-	-	VW	M
Phyllic	S	M-S	W	-
Argillic	S	M	W-M	W-M
Propylitic	W	W	M	M
Tourmaline	-	-	W	M

(adapted from McMillan, 1976a)

S: strong
M: moderate
W: weak
VW: very weak
-: negligible

deposit displays weakly developed K-feldspathization, whilst the Valley Copper deposit contains moderately developed, fracture-controlled K-feldspar alteration in the deep core of the deposit. Hydrothermal biotite is developed in a scattered manner at the Lornex and Valley Copper deposits.

2. Phyllic Alteration

Phyllic alteration in the porphyry deposits of the Highland Valley is of two types, characterized by: (a) "fracture associated zones or vein envelopes of quartz and flaky sericitite" (McMillan, 1976a), or by (b) pervasive sericite-kaolinite alteration of the host rock (Osatenko and Jones, 1976).

At Valley Copper, the vein sericitic alteration is well developed and constitutes a major ore control in that bornite is restricted to this zone. In this deposit, vein sericitic alteration is often found associated with quartz veins cutting potassically altered host rock. Phyllic alteration, while important, is weaker at Lornex. At Highmont, although phyllic alteration is weakly developed, a fairly good correlation exists between it and those zones containing more than 0.2% copper equivalent. Thicknesses of sericitic envelopes bordering quartz veins have not been found to be related to the widths of the veins.

3. Argillic Alteration

Argillic alteration, characterized by alteration of feldspars and locally, of mafic minerals to sericite + kaolinite ± chlorite ± montmorillonite, is found within the ore zones of all the deposits, and often extends out beyond the 0.3% Cu isopleth. McMillan (1976a) states that at the Jersey Mine, argillic alteration is significant down to the 0.1% Cu isopleth. Intensities of argillic alteration range from weak to strong in the porphyry deposits, although it has been observed that higher copper grades are usually associated with stronger intensities of argillization.

4. Propylitic Alteration

Propylitic alteration is present to varying degrees in all of the Highland Valley porphyry deposits and often grades into argillic alteration. Epidote is the characteristic mineral of this type of alteration, in addition to chlorite, sericite, carbonates and clays. The epidote is present not only in the matrix, as an alteration product of the mafic minerals, but also in hairline to centimetric veinlets cutting the intrusives.

5. Silicification

Quartz stockworks and pervasive silicification are important at the Valley Copper and Lornex ore bodies where vein sericitic alteration is absent. The quartz, which is present as fracture fillings and overgrowths on primary crystals, is also observed to replace the country rock.

At both Valley Copper and Lornex, the stockworks form elliptical dome-like bodies which plunge towards the northwest (McMillan, 1976a). At Valley Copper (Osatenko and Jones, 1976), it has been observed that the 10% secondary quartz contour outlines the deposit, and areas with ≥0.5% Cu have 10-20% secondary quartz. It is believed that the secondary quartz in the stockworks originated within the host Bethsaida and Skeena intrusives. At Highmont, Bergey <u>et al</u>. (1971) have described four generations of quartz fracture fillings. These were defined on the bases of cross-cutting relationships and of mineral assemblages. They found copper mineralization in the two earliest stages of quartz veining, with molybdenum in the first three stages. The fourth stage comprised barren grey quartz and is post-mineralization in age.

6. Tourmalinization

Tourmaline is encountered within breccias from the Highmont, Bethlehem and South Seas deposits. It is commonly associated with quartz, specularite, calcite, epidote, copper sulphides and occasionally with actinolite (McMillan, 1976a), and is particularly common in the comminuted matrix of the breccia. At both Bethlehem and Highmont, the breccias carry copper sulphides, both in fragments and in the matrix, implying that some brecciation and tourmalinization occurred subsequent to the initiation of sulphide deposition (Reed and Jambor, 1976).

7. Sulphatization

Gypsum and anhydrite as veins, fracture fillings and microscopic grains, are well developed at Valley Copper and Lornex, but rare and sporadic at Highmont. In both deposits they are most abundant in the potassic zone of alteration - although they have also been reported in moderately argillized rocks and in quartz-sulphide veins at Valley Copper (Jones, 1975). At both Lornex and Valley Copper, a topographically defined "gypsum line" can be drawn at the highest level of sulphate mineralization. This is thought to represent the horizon at which significant hydrothermal activity ceased (Jambor and McMillan, 1976).

Chapter 5

SELECTION, PREPARATION AND CRUSHING OF SAMPLES

A. SELECTION

Rock samples used in this thesis are from two sources. While the majority were collected by the author and Drs. R.D. Morton and D.G.W. Smith during a field trip to the Highland Valley in October 1973, a large number of samples were kindly provided to the writer by Dr. M.A. Olade, then at the University of British Columbia.

Samples were collected by the author from each of the four deposits and from as wide a variety of hydrothermal alteration zones as was feasible. An effort was made to collect representative samples rather than vuggy, well formed vein materials. Whilst the latter often contain the largest best preserved inclusions, it has been found that inclusions in this material are frequently of very late stage origin and may not in any way represent the most economically important phases of mineralization and alteration (Nash, 1976).

At the Lornex deposit, samples were collected both in and around the pit, while at Highmont hand specimens and numerous drill core samples were obtained representing a broad variety of lithologic phases. At the Valley Copper deposit samples were available only from the bulk sample piles outside the sealed off exploration adit, while at the Bethlehem deposits, samples were chosen from a selection kindly collected by the mine staff for this purpose.

Hand specimens were carefully examined at the University of Alberta and described, with particular attention being paid to determination of the type of hydrothermal alteration displayed by each sample. Hand specimen descriptions are presented in tabular form in Appendix A.

B. PREPARATION OF THICK POLISHED CHIPS

Doubly polished chips, a maximum of 2 cm square and averaging 0.6 mm in thickness, were prepared from samples that were judged suitable for fluid inclusion study on the basis of examination with a binocular microscope. Suitable areas of the samples were outlined with a fine felt pen in order to guide subsequent procedures.

Sample chips were cut, and polished on both sides using successively finer grinding powders and pastes ranging from 400 grit silicon carbide powder to 1 micron diamond paste, following the procedure described in Appendix B.

C. USE OF A CRUSHING STAGE TO DETERMINE THE PRESENCE OR ABSENCE OF HIGH PRESSURE GAS

Minute grains of quartz and calcite from each of the hand specimens were crushed in a crushing stage while being examined through the petrographic microscope. The method used was that described by Roedder (1970). Depending upon the crushing medium employed, the presence or absence of various gases may be detected in quantities as small as 10^{-14} g.

Samples were initially crushed in anhydrous glycerine. While H_2O is immediately absorbed by the glycerine, both CO_2 and hydrocarbons are immiscible and are visible as small bubbles. Subsequently, barium hydroxide, and later CO_2 saturated kerosene were used as the crushing media. Barium hydroxide reacts with any CO_2 liberated from the inclusions to form a visible barium carbonate precipitate, whilst CO_2 saturated kerosene absorbs hydrocarbons but is immiscible with CO_2, which forms discrete bubbles in the fluid. 9

D. RESULTS

Detailed results of the crushing process are attached in tabular form in Appendix C. The presence of liquid CO_2 was indicated during crushing, and later confirmed by petrographic examination of rock chips from each of the studied deposits. The liquid CO_2 was present in a wide variety of rock types including the Bethsaida quartz diorite, Skeena quartz diorite, Bethlehem quartz diorite, the Gnawed Mountain Porphyry and volcanic breccia from Highmont, and the aplite dyke from Lornex.

In terms of hydrothermal alteration, the liquid CO_2 was encountered in rocks of the potassic, vein sericitic, argillic and propylitic alteration suites in addition to fresher rocks of the aplite and composite dykes and veins cutting these phases.

It was apparent, during petrographic examination of the polished chips, that the liquid CO_2 is frequently highly localized - often existing only in sub-millimetric patches in the samples. This was borne out by the apparent absence of CO_2 in some rock chips crushed under the microscope, even though it had been noted in these same polished chips during petrographic examination. Such localization of the liquid CO_2 is considered to be evidence of liquid immiscibility in the system at the time of entrapment (Touray, 1971).

Table 5 lists the samples in which liquid CO_2 was observed during petrographic examination, showing the rock type and alteration assemblage of each sample.

Due to the minute size of the fluid inclusions in rocks of the Highland Valley, they were only rarely visible as individual entities during crushing and never was an individual inclusion observed to be transected by a fracture during the procedure. The miniscule size of the inclusions also made it impossible to determine whether gases evolved during crushing originated

TABLE 5

SAMPLES IN WHICH LIQUID CARBON DIOXIDE WAS OBSERVED DURING PETROGRAPHIC EXAMINATION

Sample No.	Deposit	Rock Type	Hydrothermal Alteration Type
V5	Valley Copper	Qtz-Bn-Cp vein cutting Bethsaida quartz diorite	Vein sericitic alteration cutting potassically altered host rock
V6		Qtz-Cp-Bn vein	
V7		Quartz vein	
V9		Calcite vein cutting Bethsaida quartz diorite	Propylitic
V14		Qtz-Cp vein	
V20		Quartz vein cutting Bethsaida quartz diorite	Propylitic
V34		Bethsaida quartz diorite	Argillic
V35		Quartz vein	
V41		Bethsaida Granodiorite	Pervasive sericitic and kaolinitic
V42		Quartz veins cutting Bethsaida Granodiorite	Potassic
B153	Bethlehem Huestis Pit	Bethlehem quartz diorite	Propylitic
L201	Lornex	Quartz-sericite rock	Phyllic
L211		Quartz	
L231		Aplite dyke	Chloritization and sericitization
L240		Skeena quartz diorite	Propylitic
L243		Skeena quartz diorite	Propylitic
H309	Highmont	Qtz-Cp veinlet	Argillic
H314		Qtz vein; minor Bn, ser	
H323		Volcanic breccia	Tourmalinized matrix
H327		Qtz-Plag porphyry	
H336		Bethsaida Granodiorite	Propylitic
H337		Bethsaida Granodiorite	Argillic

from within primary or secondary inclusions. Consequently, the petrographic data are considered to be more meaningful than are the crushing data.

It is clear that this technique would be much more valuable in cases where larger inclusions were present, or in cases where many more demonstrably primary and fewer secondary inclusions were present in the rocks.

Chapter 6

PETROGRAPHIC EXAMINATION OF POLISHED THICK SECTIONS

A. INTRODUCTION

Each polished chip was initially examined under the petrographic microscope in order to determine: (a) the composition of the fluid inclusions, and (b) the suitability of the inclusions for heating and freezing tests.

Rock chips were examined at powers ranging between 150X and 2500X. It was found that after focusing the microscope on a region containing numerous inclusions, the most convenient method of examining them, due to their minute size, was often by means of oil immersion microscopy.

Petrographic descriptions of the fluid inclusions are attached in tabular form in Appendix D. Plates 1 to 8 present examples of the principle phase relationships observed in the polished chips.

B. CATEGORIZATION OF FLUID INCLUSIONS

1. Introduction

Descriptions of fluid inclusion from porphyry copper deposits prior to this thesis have included a variety of classifications of inclusions that, while often being based on similar criteria, were sometimes, nonetheless, ambiguous. For example, Roedder (1971) categorized fluid inclusions in the Bingham deposit as being of Types A and B, while Nash (1974) classed inclusions from the same deposit as Types 1, 2 and 3 - his Type 3 corresponding to Roedder's Type A, and his Type 2 to Roedder's Type B.

Whilst numerous papers have been published in which inclusions of moderate salinity are classified as Type 1, those that are vapor-rich as

TABLE 6

MORPHOLOGIC CLASSIFICATION OF FLUID INCLUSIONS

Shape	Ratio of length:width
Equant	1:1 to 2:1
Subequant	2:1 to 3:1
Bladed	3:1 to 5:1
Elongate	> 5:1
Irregular - angular, often amoeboid form, normally larger than surrounding inclusions	
Negative Crystal - a fluid filled vacuole bounded by crystal faces within an enclosing grain or crystal	

TABLE 7

KEY TO SYMBOLS USED IN FLUID INCLUSION CLASSIFICATION

Symbol (major phase)	Symbol (minor phase)	Meaning
B	b	brine
C	c	liquid CO_2
G	g	glass
S	s	sulphate daughter crystal
V	v	vapor
X	x	polyphase daughter crystals

1 = primary   p2 = pseudosecondary   2 = secondary

Type 2 and those that are polyphase as Type 3, no clear consensus has been established as to classification.

In order to avoid ambiguity, a new classification was devised for fluid inclusions from the porphyry deposits of the Highland Valley, based upon alphameric rather than numeric symbols. In this system, capital letters denote major phases, while lower case letters indicate minor phases. Subscripts 1, p2 and 2 indicate the apparent origin of the inclusion, whether primary, pseudosecondary or secondary, respectively.

Table 7 provides a key to the new recommended classification.

2. Classification of Inclusions from the Studied Deposits

(a) Type Bv inclusions. Rocks from the porphyry deposits of the Highland Valley are characterized by the presence of abundant planar arrays of demonstrably secondary and pseudosecondary fluid inclusions. These generally cross-cutting planes of inclusions represent healed fractures that are thought to be in part post-mineralization in age. They characteristically contain a vapor bubble of 0.1 to 5% volume within a saline brine (although occasionally, the vapor phase is entirely absent). Negative crystal forms are not uncommon. Small daughter crystals of halite are infrequently present, not exceeding 2% by volume.

Numerous inclusions of this type have also been tentatively identified as being of primary origin based on the criteria listed in Table 2. Inclusions of this type have been designated as Bv_1, Bv_{p2} and Bv_2 for those of primary, pseudosecondary, and secondary origins respectively.

Identical compositions of primary, pseudosecondary and secondary inclusions of this type would imply fracturing of the quartz veins, entrapment of secondary fluids and rehealing of the fractures soon after entrapment of the primary and pseudosecondary inclusions, while temperature, pressure and composition of the hydrothermal fluids were relatively unchanged.

(b) Type B_{20v} → V inclusions. These inclusions contain a high proportion of vapor, ranging from about 20 to almost 100% by volume. Halite daughter crystals are rarely observed in these inclusions. Two possibilities may account for the prominence of the vapor phase. These are: (a) necking of the inclusions, and (b) boiling of the system at the time of entrapment. As no evidence is present indicating extensive necking, the boiling hypothesis seems preferable.

(c) Type BXv inclusions. Type BXv inclusions are polyphase in nature. Volume of the vapor phase varies between one and five percent while halite crystals are ubiquitous, making up as much as 25 vol. %. Sylvite crystals commonly constitute up to 10% by volume and small euhedral to anhedral crystals of hematite are usually present. Small birefringent daughter crystals, considered to be either calcite, gypsum or anhydrite are sometimes observed.

(d) Type Cbv inclusions. Type Cbv inclusions consist of two liquid and one vapor phases. Liquid CO_2 comprises up to 50 vol. % with up to 30% vapor phase and CO_2 saturated brine constituting the rest. These inclusions tend to be sparsely and widely distributed reflecting locally high CO_2 fugacities at the time of entrapment as discussed previously in this thesis.

(e) Type G inclusions. Type G inclusions are composed of glass. Shrinkage vacuoles generally constitute about 2% by volume of the inclusion, but in rare cases, vacuoles of up to 20 volume percent were observed. They are of all shapes and are considered to represent siliceous fluid trapped between quartz grains during crystallization. Devitrification was prevented by the absence of water in the isolated droplets of melt (Bloss, 1971). The glass inclusions may be coeval with the hydro-saline primary fluid inclusions. Criteria used to differentiate the glass inclusions are as follows:

(a) no movement of the vacuole, either as a result of Brownian motion, or in response to an imposed thermal gradient.

(b) vacuole often appears flattened or irregularly shaped.

(c) deep cross-cutting fractures often transect the inclusion.

(d) several vacuoles may be present in the same inclusion.

(e) in one instance a fluid inclusion was observed within a glass inclusion.

(f) Type Bsv inclusions. Type Bsv inclusions contain anhydrite or gypsum as birefringent daughter crystals that, on occasion, comprise up to 60 volume percent of the inclusion. Generally, no other daughter crystal is present with the sulphate. Vapor phases are usually in the one to two volume percent range. These inclusions are considered to be of late origin.

C. RESULTS

Table 8 shows the relative abundances of each type of fluid inclusion from each of the studied deposits.

1. Valley Copper

Inclusions in samples from Valley Copper are usually minute (commonly less than 5 microns in diameter), although rare exceptions of 25 microns diameter were observed in some samples. Inclusions considered to be of pseudosecondary or primary origin were somewhat larger than secondary

TABLE 8

FLUID INCLUSION TYPES AND RELATIVE ABUNDANCES IN THE STUDIED DEPOSITS

Type of Inclusion	Valley Copper	Bethlehem	Lornex	Highmont
Bv	Abundant	Abundant	Abundant	Abundant
B20v → V	Rare	Rare	Rare	Rare
Bxv	-	Rare	Rare	-
Cbv	Rare	Rare	Rare	Infrequent
G	Rare	-	Infrequent	Rare
Bsv	Rare	-	-	Rare

inclusions. While secondary and pseudosecondary inclusions were most commonly equant (frequently spherical or oblate) or faceted, primary inclusions were most commonly angular, and bladed to elongate or irregular in form (see Table 6).

The vast majority of fluid inclusions from this deposit are of Type Bv, with a vapor phase seldom exceeding 5% by volume, and with scattered halite crystals in primary, and rarely in pseudosecondary and secondary inclusions. Occasional grains of what is believed to be hematite, and rare [illegible] sylvite were observed in some Type Bv_1 inclusions.

S[illegible]e B20v → V inclusions were observed with vapor phases of [illegible]ume percent, and with occasional halite crystals. No evidence w[illegible] encounter[illegible] to indicate leakage in these inclusions, and the prominence of their vapor phases is taken to be indicative of boiling at the time of initial fluid entrapment.

Type Cbv inclusions were occasionally observed comprising up to 10 volume percent liquid CO_2, a vapor phase consisting of gaseous CO_2 + water vapor, generally of less than two volume percent, and a CO_2 saturated aqueous phase. These inclusions are considered to be of primary or pseudosecondary origin. As previously stated, Type Cbv inclusions tend to be highly localized within samples.

Type G inclusions, generally considerably larger than other inclusions in the samples, were infrequently observed. They are frequently very irregularly shaped with numerous cross-cutting fractures and irregularly shaped vacuoles.

Type Bsv inclusions, believed to be of late origin, are most frequently of angular, irregular form and are generally substantially larger than most surrounding inclusions.

It is considered likely that three stages of fluid entrapment are represented at Valley Copper. Primary inclusions of Type B20v → V, Cbv and Bv1 were presumably entrapped simultaneously at the time of crystallization of the host rock. These were followed by the generation of Type Bv_2, secondary inclusions, and at some later date, by Type Bsv sulphate-bearing inclusions.

2. Bethlehem

As at Valley Copper, Type Bv inclusions make up the majority of the inclusions observed. These are supplemented, particularly in sample B153, by the presence of primary inclusions of Types B20v → V, Bxv and Cbv.

The B20v → V inclusions contain up to 60% vapor with rare acicular, strongly anisotropic daughter crystals, thought to be gypsum or anhydrite. These inclusions are frequently faceted. Occasional inclusions consist entirely of vapor with no liquid phase, indicative of boiling at the time of fluid entrapment, or of leakage.

The Type Bxv inclusions are generally of less than 10 microns diameter. They comprise a vapor phase, not exceeding 5% by volume, with halite crystals of up to 25%. Sylvite, if present, constitutes up to 10%. Hematite normally comprises less than one volume percent, but in one exceptional case, constitutes 30 to 40 volume percent. Occasionally, a small, birefringent acicular crystal is present comprising less than one volume percent. It has been tentatively identified as a sulphate mineral, either gypsum or anhydrite.

The Type Cbv inclusions comprise up to 50 volume percent liquid CO_2, up to 30 volume percent vapor phase, and a CO_2 saturated aqueous phase. No daughter crystals were observed in these inclusions.

3. Lornex

The vast majority of the inclusions noted from the Lornex deposit fall into category Bv. Generally the primary inclusions are somewhat larger than secondaries and pseudosecondaries, but shape is not a criterion for differentiation.

Glass inclusions of Type G are not infrequent. They are usually larger than the fluid-filled inclusions, ranging between 10μ and 68μ in diameter.

Type B20v → V inclusions are uncommon. They are of all shapes and sizes and normally contain 15 to 30 volume percent vapor phase, although in some cases the vapor phase approaches 100%. Their prominent vapor phase, primary characteristics and lack of daughter crystals are considered to imply boiling at the time of entrapment.

Type Cbv inclusions contain less than 5% liquid CO_2 in an aqueous liquid with a vapor phase not exceeding 5% by volume. No daughter crystals were observed in these inclusions, which were all considered to be of either primary or pseudosecondary origin.

Very few inclusions of Type Bxv were observed in the samples from the Lornex deposit. In the few cases in which they were noticed, a vapor phase of one to two volume percent; small halide crystals (either halite or sylvite); a black, non-magnetic, cubic grain suspected to be pyrite, and a minute grain of hematite were present.

4. Highmont

The majority of fluid inclusions observed in quartz from the Highmont deposits are of Type Bv. This includes very numerous demonstrably secondary inclusions, many other inclusions classified as pseudosecondary, and a large number of inclusions of primary appearance. In many cases, these Type Bv inclusions contain halite crystals of up to 5 vol. % and rarely to 50 vol. %.

In this latter case, it is presumed that a halite crystal existed prior to entrapment of the fluid, and probably acted to hinder crystallization of the host, resulting in the formation of a fluid inclusion. In addition, small hematite grains are often present, never exceeding 2% by volume. Neither size nor shape appears to be a valid criterion in differentiating between primary and secondary inclusions of this type.

Type B20v → V inclusions are uncommon in rocks from Highmont. Those that were observed were all small (less than 10μ diameter), and never contained any daughter crystals. Vapor phases varied from 15 to 100 vol. %. This variation in vapor content, combined with a total absence of daughter crystals, is considered to be evidence of pressure release through boiling during entrapment of the fluid.

Occasional glass inclusions were observed with vacuoles of 1 to 2 volume percent in inclusions of up to 25μ diameter. No daughter crystals were present in these inclusions.

Numerous inclusions of Type Cbv were observed; these being found in all rock types and alteration zones of the Highmont deposits. Liquid CO_2 content varies widely from 5 to 50 vol. %. Hematite was the only daughter mineral observed in these inclusions, and this never exceeded 0.1% by volume.

5. Halite-bearing Inclusions, Their Occurrence and Significance

Halite-bearing inclusions were observed in samples from all four of the studied deposits. Of the four, they were by far the most common in samples from the Valley Copper deposit, where they were observed in 34 of the 60 sections examined.

Halite-bearing primary inclusions were observed in 33 samples, while pseudosecondary salt-saturated inclusions were observed in four sections, and secondary salt-saturated inclusions in six.

At Bethlehem, halite-bearing primary inclusions were observed in four of the 16 sections examined, while no halite was observed in secondary inclusions. Although the population is far too small to draw any major conclusions, it was noted that in the samples from the Bethlehem deposits, the halite-bearing inclusions were present only in quartz veins cutting propylitized granodiorite of the Bethlehem and Guichon phases.

At the Lornex deposit, halite-bearing inclusions were observed in 16 of 57 samples examined. Generally, the halite daughter crystals were minute, occupying no more than two volume percent of the inclusion. However, in three sections from the quartz-porphyry dyke, primary halite-bearing inclusions of 10 to 20 volume percent were observed. Demonstrably secondary inclusions containing halite daughter crystals were recorded in only two sections, while they were observed within primary inclusions in 14 sections (including the quartz porphyry dyke).

Primary halite-containing fluid inclusions were observed in quartz veins cutting the Skeena quartz diorite, the Bethsaida quartz monzonite, the aplite phase and the quartz porphyry dyke. They are distributed in rocks which have suffered argillic, phyllic and propylitic alteration.

In samples from the Highmont deposits, halite crystals were observed in 11 of the 40 samples examined. They were found to be present in secondary inclusions in four sections, and in primary inclusions in nine sections. It is interesting to note that with the exception of section H328, a quartz porphyry sample believed to originate from the composite dyke, all of the halite-bearing secondary inclusions from the Highmont deposits were found within volcanic breccia samples. This is interpreted as signifying explosive brecciation of the rocks, resulting in extensive shattering of the host rocks, release of pressure on the hot hydrothermal system and active boiling. This would result, following the model of White et al. (1971), in upward movement of concentrated brines from deep within the system and nucleation of halite crystals upon cooling of the supersaturated solutions.

The large halite crystals present in some of the inclusions were probably formed deeper within the system as a result of refluxing and concentration of the brine due to boiling, and were subsequently transported upward during the pressure releasing event. Inclusions of this type are considered to be of more recent origin than are the primary inclusions. Type Bsv inclusions were rarely observed at Highmont. Crystal habit, in the few cases recognized, indicated that the daughter mineral present is anhydrite, or possibly calcite. The daughter minerals do not exceed one volume percent in abundance. It is considered probable that, as at Valley Copper, the sulphate daughter minerals observed at Highmont are indicative of late stage fluid entrapment.

C. Significance of Sylvite and Sulphate Daughter Crystals

Sylvite was rarely observed in rocks from the studied deposits. Where present, it is postulated that it probably resulted from kaolinization of potassium feldspar resulting in the release of K^+ ions, which would then react with the chloride in the metal-bearing brines to form KCl. As kaolinization of feldspar is a hydration reaction, the volume of hydrothermal fluid would be locally reduced with a concomitant increase in salt concentration within the brines.

It is also likely that argillization of calcic plagioclase locally released calcium ions which reacted with sulphate ions present in percolating sea water or condensing magmatic waters to produce the anhydrite and gypsum occasionally observed in all the deposits.

Chapter 7

K/Na STUDIES

A. INTRODUCTION

K/Na atomic ratios have been found to be of value in some cases in helping to interpret the origins and temperatures of hydrothermal fluids. In natural and experimental systems, the K/Na atomic ratios of hydrothermal fluids exchanging with granitic rocks increase with temperature (Rye and Haffty, 1969). Figure 6 presents a generalized curve as compiled by Robinson (1971) from White (1968) and Gammon et al. (1969), showing this relationship.

Rye and Haffty (1969) point out that the precise position of the curve, for a given system, is dependent upon the total pressure on the system and on the composition of the enclosing rocks - particularly their calcium content. In addition, they state that the position of the curve is a function of the salinity of the system.

B. PROCEDURE

Due to the almost ubiquitous presence of sericite in samples from the Highland Valley, only one quartz specimen was considered to be suitable for determination of K/Na ratios. This was sample #V30, a massive, white quartz vein sample from the Valley Copper deposit.

The sample was first coarsely crushed into fragments of less than 5 mm. These were carefully hand-picked in order to exclude those fragments in which visible sericite or other minerals occurred.

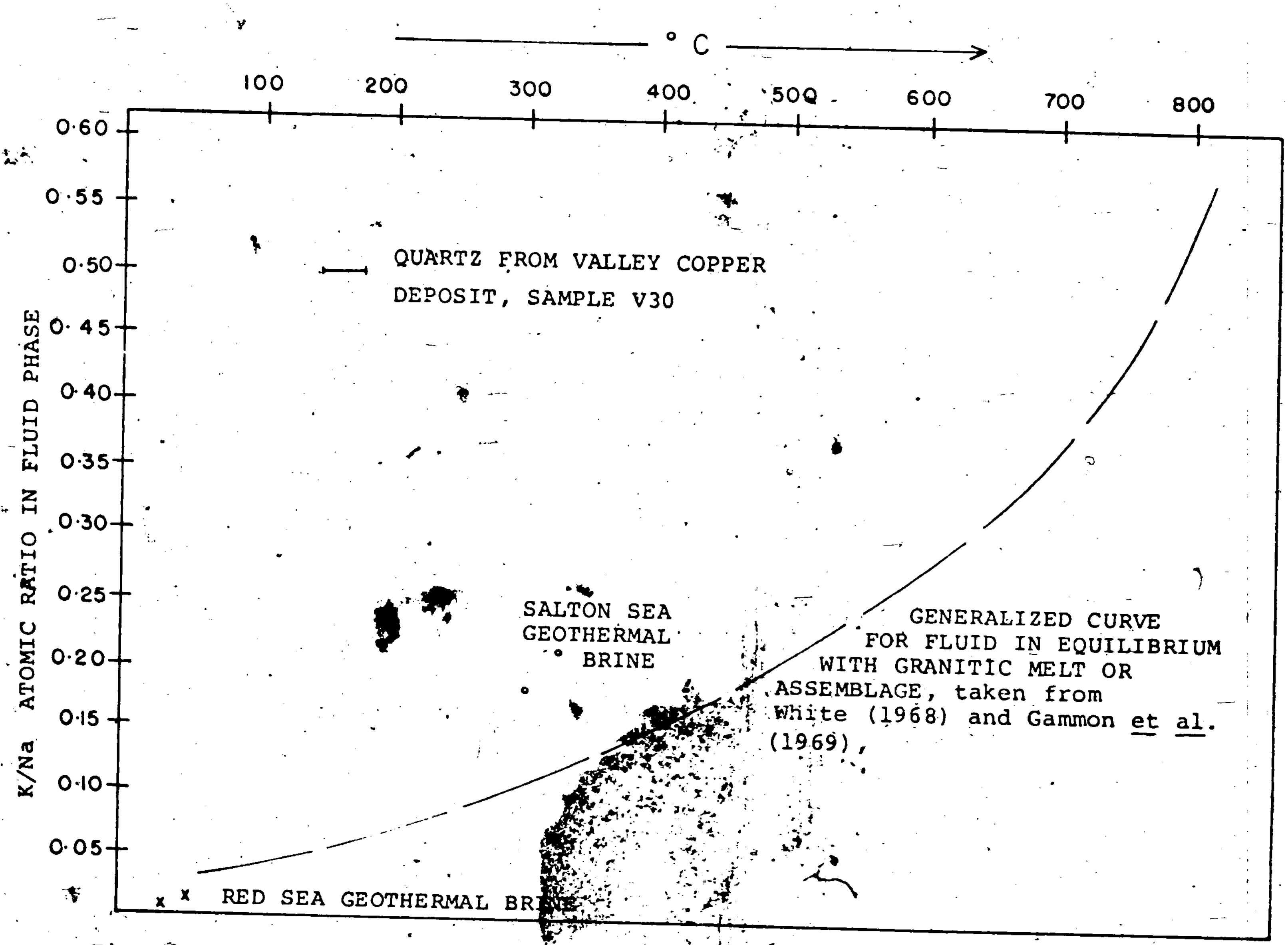


Fig. 6. Relationship between T_h and K/Na ratio of fluid from inclusions from a sample from the Valley Copper deposit with relation to other data.

The selected quartz chips were first thoroughly washed with tap water, and then distilled water. The quartz was then placed in 200 ml of 1:1 HCl in a polyethylene beaker and left overnight at a constant 60°C. After the quartz had been drained and rinsed with demineralized, distilled water, it was placed in 200 ml of 1:1 nitric acid and again left overnight at 60°C. The cleaned quartz was thoroughly rinsed with doubly distilled, demineralized water and with acetone, and stored in a sealed polyethylene beaker to avoid contamination.

The fragments were next hand-picked for a second time, divided into four portions and placed in electrolytic cleaning cells, constructed according to the specifications of Pinckney (1972), to remove ionized material from the surface of the chips.

Within the electrolytic cleaning cells, the quartz was covered with demineralized, doubly distilled water and subjected to a potential of 50 volts DC. The sample was cleaned for five days with frequent changes of water until the current through the cells reached a constant low value corresponding to that for the demineralized, doubly distilled water. The quartz was then dried in a covered plastic beaker at 60°C with a stream of nitrogen gas passing over it.

The cleaned, deionized quartz was crushed for three minutes in a tungsten-carbide swing mill that had previously been cleaned with acetone and demineralized, doubly distilled water. The powder was transferred to a filter paper and leached into a polyethylene bottle.

A blank sample, comprising crushed quartz glass was subjected to the same procedures in order to serve as a reference and a check on contamination.

A Perkin Elmer Model 503 flame emission and atomic absorption spectrometer was used to analyze the samples for Na_2O, MgO, CaO and K_2O, with standard solutions of known concentrations providing comparative readings.

C. RESULTS

Analytical results are presented below in Table 9.

TABLE 9

ANALYTICAL RESULTS FROM SAMPLE V30

	Sample (ppm)	Blank (ppm)	Corr. Conc. (ppm)
K_2O	8.0	1.4	6.6
Na_2O	10.0	1.3	8.7
MgO	0.8	0.1	0.7
CaO	8.7	0.4	8.3

From the above data, a K/Na atomic ratio of 0.50 was calculated. The homogenization temperature of primary inclusions from sample V30 was plotted against the K/Na ratio on Figure 6. The wide discrepancy between the analytical and theoretical results may be due to one or more of several causes. (a) The hydrothermal fluid may not have been in equilibrium with the granitic melt. This is entirely feasible considering that there was, according to Jones (1975), apparently a large component of sea water percolating through the intrusive. In addition, much of the fluid leached from the sample presumably originated from secondary inclusions of unknown temporal relationship, rather than from primaries. (b) Some sericite may have remained in the sample even after cleaning, resulting in a considerably higher potassium concentration than anticipated. (c) Due to the crude nature of the crushing and leaching techniques employed, compared to those recommended by the Equipe de Recherche sur les Equilibres entre Fluides et Mineraux of Nancy, France (Poty et al., 1974), it is likely that some contamination may have been introduced during processing of the sample and blank, and (d) Denis (1974) states that even tiny amounts of potassium feldspar in a sample cause a strong anomaly in the apparent concentration of K^+, as the potassium ion is immediately absorbed into solution during leaching of the crushed samples. He notes further that in the quartz veins from the porphyry copper deposits he studied in the southwestern United States, secondary potassium feldspar is frequently present, and sometimes intimately intergrown with the quartz. To eliminate contamination from this source, he recommends initial washing of the samples for two hours in cold HF prior to treating them with warm HNO_3 and warm HCl. The cleaning procedure used during this study, being essentially that of Robinson (1971) which excluded the use of HF, it appears feasible that minor K^+ contamination may have been introduced into the system in this way.

No K/Na ratios are quoted for the deposits of the Highland Valley, but it is interesting to note that Roedder (1971) mentions a K/Na ratio of 0.26 for the Bingham deposits, compared to Denis' (1974) results of 0.10 for fluids in mineralized quartz veins at Sierrita, Arizona. Denis states that this difference is not surprising, considering that in a monzonite at 400°C, such as that at Bingham, feldspars buffer the K/Na ratio by as much as 0.16. In the Guichon Creek batholith, where temperatures of mineralization are estimated to be around 400°C, it is probable that sufficient potassium feldspar existed, both in primary, and as alteration features to significantly buffer the potassium concentration of the fluids.

Table 9 shows that while Na^+ is the dominant cation in the fluid, K^+ and Ca^{++} are also present in significant concentrations. As can be seen from Figure 3a, the effect of KCl and $CaCl_2$ in NaCl brines is to raise the freezing temperature of the brines. Thus, the freezing temperatures encountered during low temperature studies of the fluid inclusions could be indicative of slightly higher NaCl concentrations than would be initially presumed.

Chapter 8

LOW TEMPERATURE STUDIES

A. INTRODUCTION

Freezing of the fluids in salt undersaturated fluid inclusions is a valuable means of determining the concentration of dissolved salts in the inclusions. This process involves the cooling of the sample within the heating-freezing stage until the fluid in the inclusion being studied has frozen, and then gradually warming the sample while observing it under the microscope to record the temperature of melting of the last solid fragment. This temperature is then compared to the graphs of Figures 3 or 3a in order to determine the weight percentage of dissolved salts.

Because of the unavoidable problem of thermal lag, both within the sample chamber and in the sample, a warming rate not exceeding 0.25°C per minute within 10°C of the predicted melting point is recommended by CHAIXMECA for the instrument.

Because of the frequent occurrence of supercooling in small inclusions, the fluids generally freeze at temperatures far lower than their melting points. Supercooling of 40-50°C was commonly observed during studies of specimens from the thesis area.

New phases appearing in the inclusions as a result of freezing include ice, hydrohalite, ($NaCl\cdot 2H_2O$), and carbon dioxide hydrate, ($CO_2\cdot 5.7H_2O$).

Hydrohalite forms from the reaction at low temperature of saturated brine with daughter NaCl crystals or, alternately from the freezing of near-saturated brine (Kelly and Turneaure, 1970). In large inclusions, it is characterized by high relief and strong birefringence. Unfortunately, because of the minute size of the inclusions dealt with in this thesis, the thickness of the presumed hydrohalite phases observed was insufficient to produce visible birefringence.

It is apparent from Figure 3 that in fluids with salinities between 23.3 and 26.3 weight percent NaCl, $NaCl \cdot 2H_2O$ will persist from the temperature of freezing of the supercooled fluids, right up to the melting temperature of the solid phases, even though no NaCl daughter crystal forms at room temperature. The highly varied melting temperatures of fluid inclusions with salinities falling within this range reflect the steepness of the $NaCl \cdot 2H_2O$ liquidus in the system $NaCl-H_2O$.

Carbon dioxide hydrate is a particularly difficult solid phase to detect in inclusions because of its isotropism and index of refraction - which is very close to that of water. $CO_2 \cdot 5.7H_2O$ is most commonly noticeable as a result of apparently irregular liquid-vapor phase boundaries, or because of the apparent rapid movement of solid or vapor phases in the inclusion as they are pushed around by the melting hydrate. The melting temperature of this compound is a function of the vapor pressure of CO_2 within the inclusion and commonly ranges between about -5.6°C and +5°C (Kelly and Turneaure, 1970). Depending on CO_2 concentration and vapor pressure, the hydrate dissociates either to water + CO_2 gas, or to water + liquid CO_2. None of this compound was visible during the course of freezing studies, even in those inclusions containing visible liquid CO_2.

Ice is characterized by its very low birefringence (absent in very thin crystals), high negative relief and by the formation of round grains above the temperature of initial melting.

B. RESULTS

Results of low temperature studies carried out on suitable polished

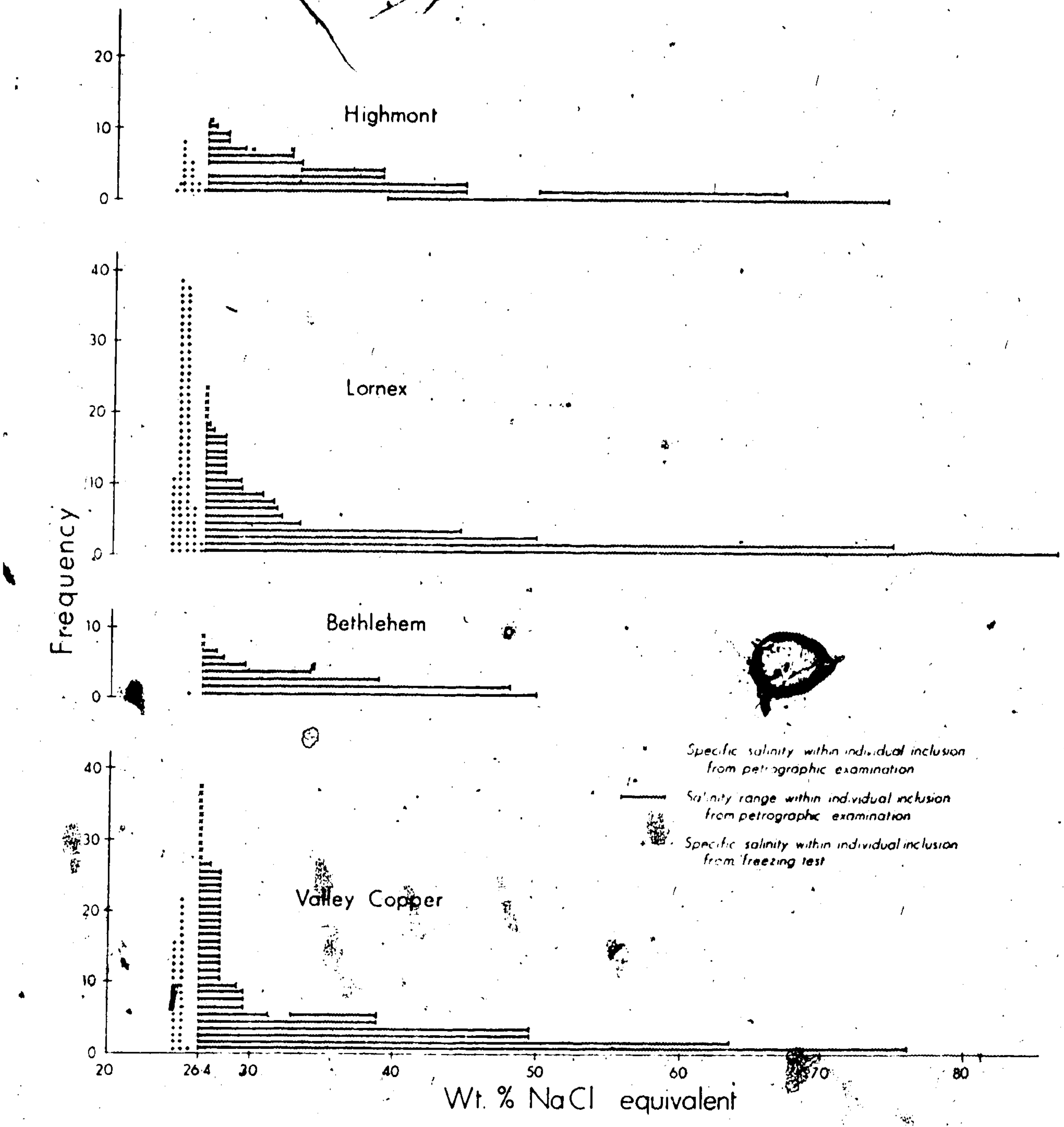


Fig. 7 Salinities of fluid inclusions as determined by petrographic and freezing studies.

sections are compiled in tabular form in Appendix E. A melting temperature range of -12.9°C to +1.0°C was recorded for the undersaturated primary and secondary inclusions of Type Bv, corresponding to salt concentrations of 24.2 to 26.3 weight percent NaCl equiv. Melting temperatures above 0°C are considered to indicate the presence of $CO_2 \cdot 5.7H_2O$ in amounts too small to be visible. This compound would, in the event of low concentration and vapor pressure within the inclusion, dissociate to H_2O + CO_2 gas.

Figure 7 shows the salt concentrations in saturated and undersaturated inclusions determined from freezing tests and volumetric phase proportion calculations. Concentrations and frequency of observed occurrences are plotted for each deposit. It is apparent that the hydrothermal fluids were of very similar composition in each deposit, with salinities most commonly ranging between 24 and 28 weight percent NaCl equiv. Rarely, inclusions with salinities of up to 75 weight percent were observed, but these concentrations are considered to reflect the trapping of discrete salt crystals rather than a distinct hydrosaline fluid.

It is presumed that much lower salt concentrations would be present in inclusions of Type B20v → V. Osatenko and Jones (1976) state that Schmuck encountered salinities of about 5 weight percent NaCl equiv. in inclusions from the Valley Copper deposit. These inclusions are described as comprising 70-80 vol. % liquid and 20-30 vol. % vapor. Unfortunately, no inclusions of this type, suitable for freezing studies, were encountered by the author in his samples from the Valley Copper deposit.

Chapter 9

HIGH TEMPERATURE STUDIES

A. INTRODUCTION

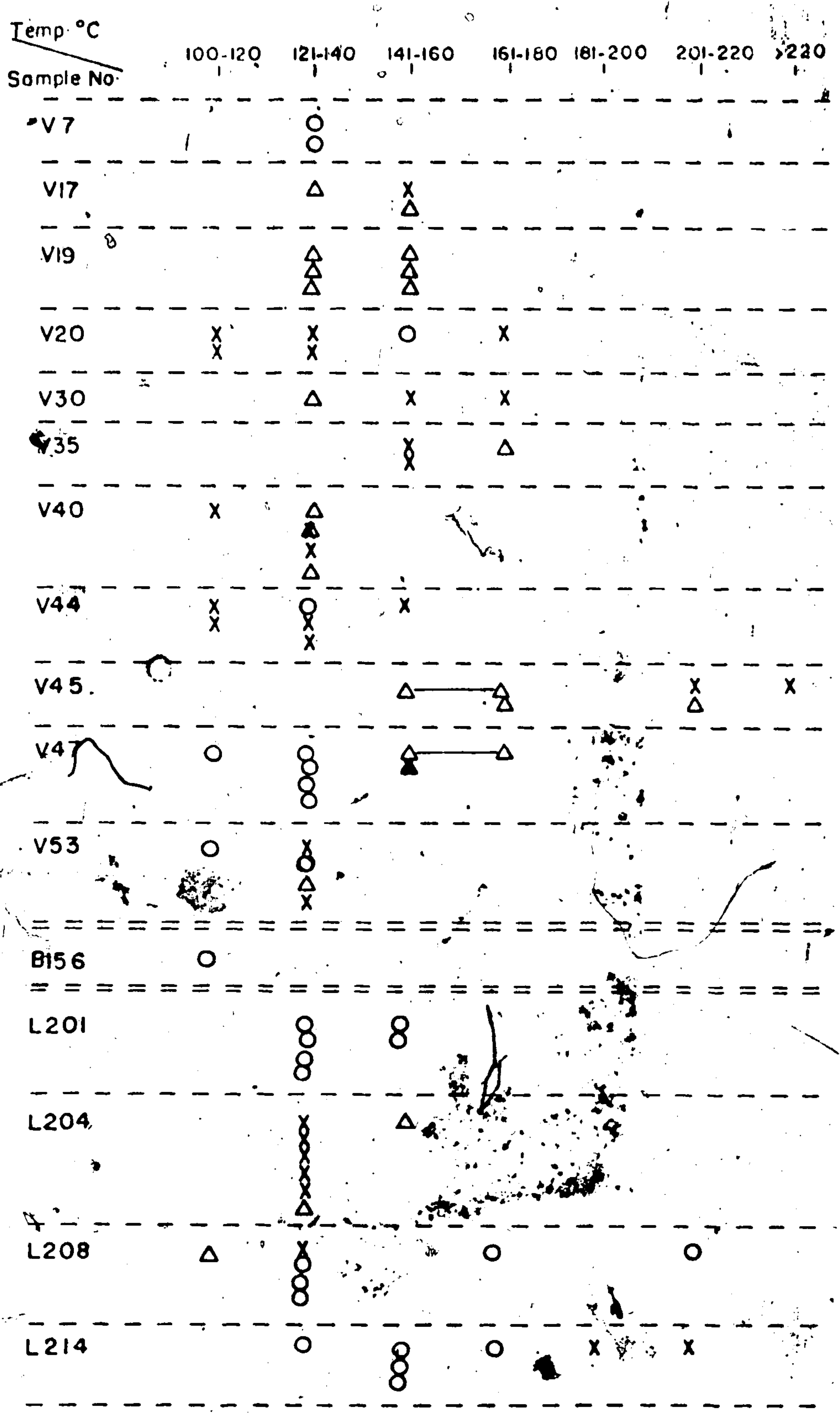
Homogenization temperature, T_h, determinations were effected upon suitable samples from each deposit. Because of the inferiority of the optics when heating, as contrasted to when freezing inclusions, it was not feasible to examine as many inclusions as hoped.

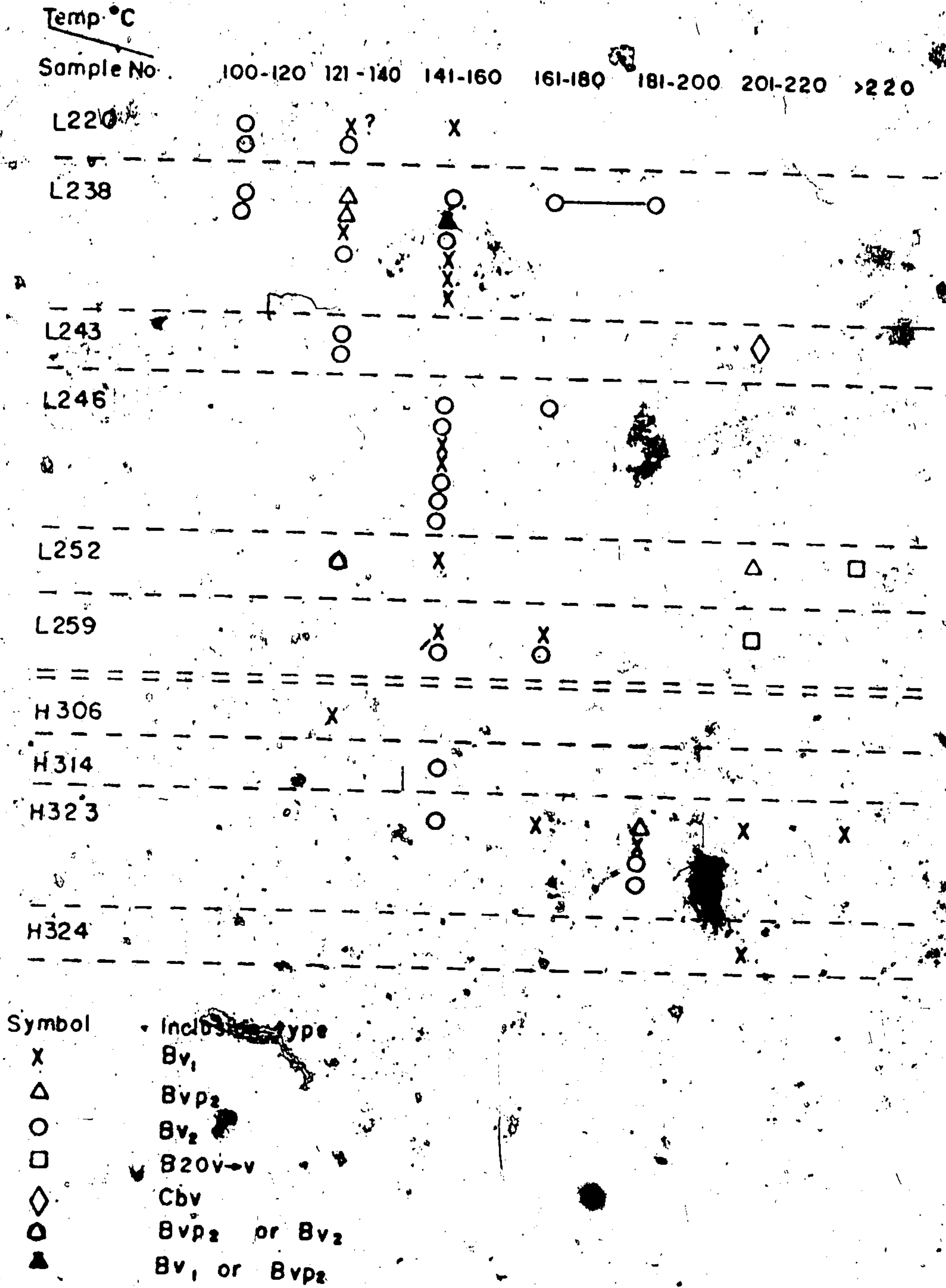
Whilst an attempt was made to obtain at least two readings of T_h for each inclusion, failure of the vapor phase to renucleate after homogenization frequently made this impractical. In addition, it was found that heating of a sample to temperatures above the T_h of low temperature inclusions, in order to obtain the T_h of the higher temperature inclusions, frequently resulted in very different results being obtained for the low temperature inclusions on subsequent repetition. It is presumed that this phenomenon reflects minor leakage and incipient decrepitation caused by internal pressure within the inclusions at temperatures above that of homogenization.

Halite daughter crystals, where observed, were not found to dissolve at temperatures below that of homogenization. Whilst Keevil's (1942) data apply only to salinities in excess of 30 weight percent NaCl equiv., the majority of the saturated inclusions observed in this study were found to contain less than this concentration. It is likely that substantially lower rates of heating would eventually have resulted in dissolution of the halite crystals.

No sylvite was observed in those inclusions subjected to homogenization studies.

Fig. 8 Schematic representation of homogenization temps. of fluid inclusions from Highland Valley




Temp °C
Sample No.
100-120
121-140
141-160
161-180
181-200
201-220
>220
L220
?
L238
L243
L246
L252
L259
H306
H314
H323
H324
Symbol
Inclusion type
X
Bv1
Δ
Bvp2
O
Bv2
□
B20v→v
◊
Cbv
Bvp2 or Bv2
Bv1 or Bvp2

B. RESULTS

Homogenization data are presented in tabular form in Appendix F, and graphically in Figure 8.

1. Valley Copper

Homogenization temperatures of inclusions from the Valley Copper deposit may be seen to be widely variable. No pronounced tendency is apparent for primary inclusions to exhibit higher T_h than secondary inclusions, and, in addition, homogenization temperatures of inclusions from vein sericitic and potassic alteration zones were found to be substantially lower than anticipated. Only two samples from the core region, V45 and V47, were found to contain primary inclusions with $T_h > 200°C$, while sample V44, also from the core region, contained primary inclusions with $T_h < 120°C$.

It is postulated that the wide range of temperatures obtained is indicative of several pulses of fracturing and quartz veining accompanied by entrapment of fluids of differing temperatures, but similar compositions. The wide discrepancy between the homogenization temperatures determined by the author and R. Schmuck (Osatenko and Jones, 1976) and Jones' (1975) oxygen isotope determined temperatures of 260-500°C for mineralization and alteration may be attributable to destruction of original primary inclusions, and entrapment of cooler fluids during successive mineralization and alteration phases.

2. Lornex

Several samples of Skeena quartz diorite, L214, L220, L238, L243, L246 and L259, were heated to determine the homogenization temperatures of their inclusions. Figure 8 shows that homogenization temperatures of primary inclusions in the argillically altered samples L214, L259 and L220, are generally substantially higher than those of the propylitically altered samples. Table 10 emphasizes this variation.

TABLE 10

HOMOGENIZATION TEMPERATURES (°C) OF INCLUSIONS FROM SKEENA QUARTZ DIORITE

	Inclusion Types		
Alteration	Primary	Pseudosecondary	Secondary
Propylitic	125.5°-166.5°	129.5°-146.0°	107.3°-207.5°
Argillic	142.4°-216.0°		112.0°-161.3°

3. Highmont and Beth[illegible]

Insufficient data were obtainable from samples from these two properties to draw any definitive conclusions. It is interesting to note, however, the high homogenization temperatures obtained from sample H323, a quartz phenocryst in volcanic breccia from the Highmont deposits. Homogenization temperatures of primary inclusions from this sample were found to range between 170 to 261.2°C, whilst secondary inclusions had T_h ranging between 148.6 and 186.7°C. It is postulated that explosive brecciation and associated release of pressure on the system was accompanied by upward injection and entrapment of high temperature hydrothermal fluids. The wide range in homogenization temperatures of these primary fluids may reflect varying vapor contents of the fluids at the time of entrapment due to active boiling.

4. Application of Pressure Correction to Homogenization Temperatures

Osatenko and Jones (1976) report that for the Valley Copper deposit, the presence of inclusions containing liquid CO_2 is indicative of pressures

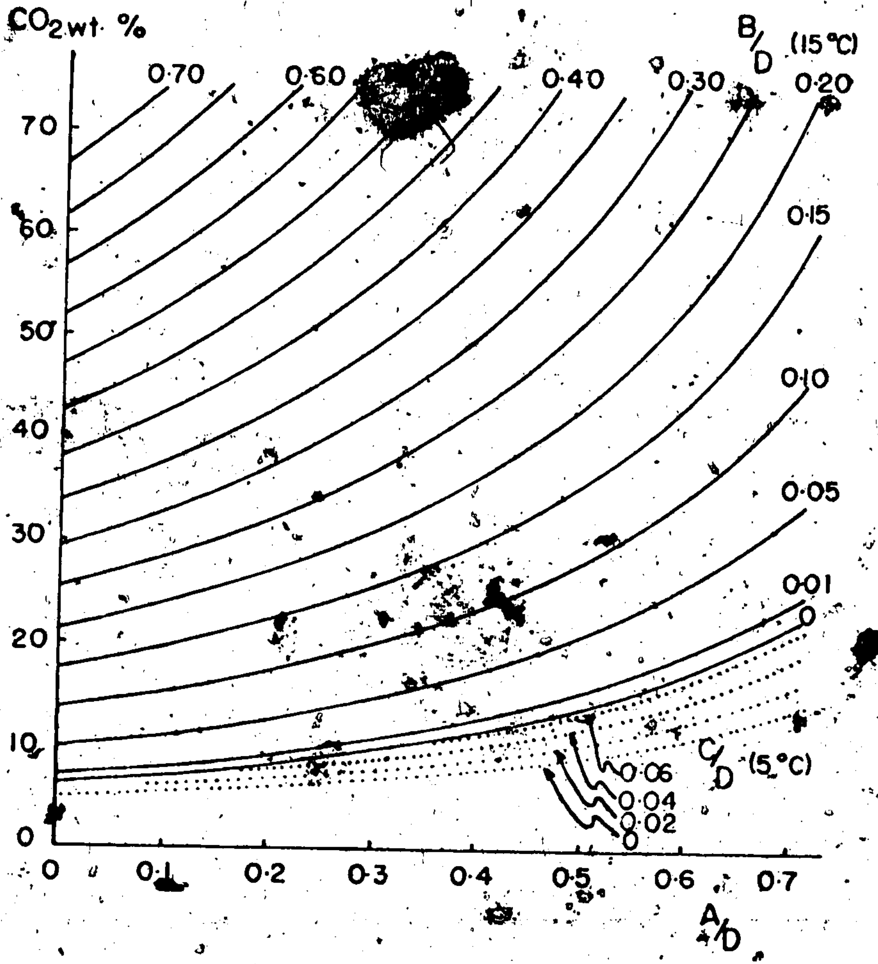


Fig. 9. A diagram for estimating CO_2 wt. % by volume ratios of phases in fluid inclusions; A: vapor phase volume; B: liquid CO_2 volume; C: CO_2 hydrate volume; D: inclusion volume (After Takenouchi, 1971).

of up to 100-300 bars and depths of formation of 1 to 2 km. As no Type Cbv inclusions suitable for homogenization temperature determinations were encountered in samples from that deposit during this study, these data will be accepted without argument. Such a pressure, combined with homogenization temperatures of less than 300°C would, for undersaturated inclusions comprising H_2O + NaCl, demand a pressure correction of less than 25°C in the absence of boiling of the fluids (Lemmlein and Klevtsov, 1961). As some evidence of boiling of the fluids was observed, it is believed that the true pressure correction would be substantially less than 25°C.

One sample from the Lornex deposit, L243, contained a Type Cbv inclusion suitable for T_h determination. T_h for this inclusion containing about 5-7 vol. % liquid CO_2 was found to be 216.3 ± 1.7°C. At 15°C this volume of liquid CO_2 corresponds to 10 to 12 wt. % (see Figure 9), and to 4.82 ± 0.46 mole % CO_2. This, in turn, implies a hydrostatic pressure of 497 ± 62 bars (Takenouchi and Kennedy, 1964) and a depth of empla[illegible] 3 to 4 km. Such a depth and pressure would, for undersatura[illegible] primary inclusions consisting of H_2O + NaCl, with 25 weight % dissolved NaCl equiv. and homogenization temperatures of 142-210°C and 125-160°C for material that has suffered argillic and propylitic alteration respectively, necessitate a pressure correction of about 20°C.

In contrast to the depth estimate based on the presence of liquid CO_2 in inclusions, an estimate of depth of emplacement may be made based on the data of Haas (1971). Assuming homogenization temperatures of 125-210°C for primary inclusions, and salinities of 25 wt. % NaCl equiv., Haas' data suggest a hydrostatic head of 5 to 133.6 m. As total pressure on the system at these depths is lower than the vapor pressure of liquid CO_2 at room temperature, the presence of Type Cbv inclusions is contraindicated. For this reason, no confidence is placed in these estimates.

Chapter 10

SUMMARY AND CONCLUSIONS

This study has generated new information, part of which supports, and part of which is in sharp contrast to previous work.

Problems inherent in this study included the unavoidably poor control of sampling, particularly in the case of specimens from the Bethlehem and Valley Copper deposit, both as a result of the author not having personally collected all of the samples, and as a result of unavailability of access to in situ rock in the cases of the first two deposits mentioned. Additionally, major problems were encountered as a result of the minute size of the vast majority of inclusions in samples examined. As a result of this last consideration, many of the polished sections prepared from rock samples proved to be unsuitable for heating and freezing tests.

As mentioned by Nash (1976 and pers. comm.), intermediate igneous intrusives containing halite-bearing fluid inclusions often host porphyry-type mineralization. This association may prove to be an important exploration tool in the search for porphyry deposits. Nash (1976) has indicated that he believes the fluid inclusions from deposits of the Highland Valley to be unusual in that they lack sufficiently high salt concentrations to produce halite daughter crystals. He further suggested that boiling of the hydrothermal fluids did not occur at these deposits.

The present study, in contrast, has produced evidence indicating that the majority of fluid inclusions in quartz veins from the porphyry deposits of the Highland Valley do actually contain salt concentrations ranging between 24 and 28 wt % NaCl equiv. While halite daughter crystals are far from ubiquitous, and are as a rule, of minute size, they are reasonably abundant, particularly in inclusions of less than 10μ diameter. As most of the copper and molybdenum sulphide mineralization is found associated with fluid inclusions having salt concentrations in this range, the writer believes that these fluids are representative of the hydrothermal fluids which deposited much of the copper and molybdenum sulphides of the deposits.

Densities of the fluid inclusions were found, at 20°C to range between 0.48 and 1.52 g/cc. However, the extremes of the range correspond to the scarce vapor-rich and halite-rich inclusions, whilst most of the fluid inclusions have densities of 1.15 to 1.21, corresponding to slightly salt undersaturated, to slightly oversaturated inclusions with small vapor phases.

Evidence of boiling of the fluids has been found in inclusions from all of the deposits. Whilst boiling does not appear to have been extensive, it is postulated that its occurrence may have been associated with fracturing and pressure releasing (venting) events subsequent to entrapment of the [illegible] fluids. In such an event, boiling might have occurred only in those fluids occupying fractures connecting to the ocean floor. Upward movement of highly saline fluid and discrete halite crystals would explain the presence of scattered large halite cubes in the deposits, in inclusions with exceptionally and unexpectedly high salt concentrations. The rarity of inclusions of this type may be due to the presence of sea water percolating through the deposits diluting some of the highly saline fluids.

Whilst Nash (1976) suggested that the porphyry deposits of the Highland Valley were emplaced at greater depths than those of the southwestern United States, the present writer, in accordance with the ideas of Jones (1975), believes this to be in error. This belief is based upon the evidence of boiling of some of the fluids, low homogenization temperatures, the absence of fluid inclusions containing large halite crystals and high salt concentrations (with the exception of the anomalous exceptions mentioned above), and upon depth estimates obtained by Jones (Osatenko and Jones, 1976) for the Valley Copper deposit, and by the present author for the Lornex deposit.

The writer has determined a maximum depth of emplacement of 3 to 4 [illegible] for the Lornex deposit, including the depth of the postulated overlying ocean. This determination was made on the basis of the presence of liquid CO_2-bearing primary inclusions with homogenization temperatures of 216.2 ± 1.7°C in propylitized Skeena quartz diorite. Depth of emplacement of the other deposits was not ascertainable, but Jones (1975) has estimated a depth of emplacement of 1-2 km for the Valley Copper deposit based, again, on the presence of liquid CO_2 in fluid inclusions. The discontinuous boiling in all deposits supports this contention of shallow origin.

Pressure corrections for the Valley Copper and Lornex deposits, and probably for the Bethlehem and Highmont deposits also, are ≤25°C. This figure is derived from the salinity of the fluid inclusions, and the homogenization temperatures of <300°C, in the absence of boiling (Lemmlein and Klevtsov, 1961). Assuming the maximum pressure correction of ≤25°C, temperatures of entrapment of primary inclusions from the Lornex deposit range from 150.5 to 181.5°C for propylitized, and 167.4 to 235.0°C for argillized Skeena phase. One Type B20v → V inclusion in a sample from quartz porphyry dyke rock was observed to homogenize at a pressure corrected temperature of 315-317°C, far higher than the temperature recorded for other primary inclusions in the adjacent primary inclusions. It is postulated that the fluid in this inclusion comprised a boiling mixture of liquid and steam at the time of its entrapment. This would account for the wide T_h discrepancy with the other primary inclusions.

At the Valley Copper deposit, pressure corrected temperatures of fluid entrapment in pervasively sericitized rocks range from 137.5 to 187.7°C. Primary inclusions in rock that has suffered phyllic alteration have homogenization temperatures falling into three ranges, namely 141.0 to 177°C for vein sericitization, 141.0-154.2°C and 258.8-260.8°C for vein sericitization cutting potassic alteration. Primary inclusions in pervasively kaolinized rock homogenize at temperatures of 231.8 to 251.8°C. Homogenization temperatures for primary inclusions from the Lornex deposit were all obtained from quartz veins, generally containing sulphide mineralization, cross-cutting host intrusive. It is considered likely, therefore, that they represent the temperatures of emplacement of the mineralization.

Whilst the highest temperatures for sericitic and kaolinitic alteration determined from this fluid inclusion study accord well with the lowest temperatures suggested by Osatenko and Jones (1976) for pervasive sericitic and kaolinitic alteration, fluids representative of his proposed higher temperature mineralization and alteration phenomena were not encountered. This may be due to the minute size of fluid inclusions, particularly in samples that have suffered potassic alteration, making them unsuitable for freezing and heating tests.

Although insufficient data were obtainable from samples from the Highmont and Bethlehem deposits to allow any definitive conclusions to be reached, several tentative conclusions can be drawn with respect to the Highmont deposits. Primary and pseudosecondary inclusions from quartz phenocrysts in volcanic breccia from these deposits were found to homogenize at temperatures ranging between 170.0°C and 261.2°C. Secondary inclusions homogenized between 152.0 and 186.7°C. The wide temperature range recorded for the primary and pseudosecondary inclusions is not explicable on the basis of the data available. The significantly lower T_h for secondary inclusions in these samples, and particularly in quartz veins cutting the samples, is probably due to entrapment of cooler fluids during late stage brecciation and pressure release.

Carbon dioxide was found to be a significant component of inclusions from all deposits studied, often comprising 10 wt. % and rarely, 40-50 wt. % of the fluids in individual inclusions. It was, however, noted that the liquid carbon dioxide was present only in scattered, sub-millimetric patches of inclusions, and was absent from many samples. The author has concluded that two immiscible fluids existed at the time of entrapment, one rich and one poor in CO_2, as proposed by Touray (1971).

Occasional glass inclusions were observed in all deposits. These large, irregularly-shaped inclusions characteristically contain small irregular shrinkage vacuoles of 1-2 vol. % and were not observed to contain any daughter crystals. They are interpreted as having been formed by the entrapment of minute drops of silicate [illegible] between crystals or on growth faces. These droplets are prevented from devitrifying as a result of their isolation from the water of the hydrosilicate melt (C.M. Scarfe, verbal comm.; Bloss, 1971).

The remarkable consistency of salt concentrations determined [illegible] the Type Bv inclusions from the four deposits studied argues that mixing of sea water with the hydrothermal fluid was not an important factor at the time of entrapment of the fluids.

Determinations of K, Na, Ca and Mg abundances were effected upon fluids from one sample of massive quartz from the Valley Copper deposit resulting in the determination of a K/Na ratio of 0.5. The value is substantially higher than that obtained from analyses of fluids from porphyry copper deposits of the southwestern United States (Denis, 1974; Roedder, 1971). This may be due to buffering of potassium in the fluids resulting from the presence of minute amounts of potassium feldspar or sericite (Denis, 1974), contamination of both the sample and blank due to the relatively crude technique employed, or due to the mixing of fluids of differing compositions from primary and secondary inclusions.

Further work on this thesis topic, which should be considered, includes the following:

1. Analysis of oxygen, hydrogen and sulfur isotopes from the Highmont, Lornex and Bethlehem deposits to determine temperatures of mineralization and alteration and whether mixing of sea water with the hydrothermal fluid is as important at these deposits as has been suggested for the Valley Copper deposit.

2. Comparison of fluid inclusions and isotope data from other porphyry deposits in the Quesnel Trough having a similar age to the Guichon Creek Batholith to data from deposits of the Highland Valley.

3. Comparison of fluid inclusion and isotope data from the Craigmont deposit to those from the Highland Valley deposits to compare the environment of mineralization and hydrothermal alteration at the core of the batholith to that at its margin.

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APPENDIX A

HAND SPECIMEN DESCRIPTIONS OF SAMPLES

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
Valley [illegible]opper				
V1	Quartz vein	Cp	Vein sericitic	Sericite envelopes
V2	Quartz vein	Bn		
V3	Quartz vein	Minor Mo		
V4	Quartz vein	Bn	Vein sericitic	Sericitic gangue in vein
V5	Quartz vein cutting Bethsaida Granodiorite	Intergrowths of Cp and Bn	Vein sericitic alteration cutting potassically altered intrusive	
V6	Quartz vein	Bn + Cp		
V7	Quartz vein			
V8	Quartz vein	Mo + Cp	Vein sericitic	Sericite envelopes
V9	Bethsaida Granodiorite cut by calcite vein		Propylitic	
V10	Quartz vein	Bn	Vein sericitic	Mino[illegible]eldspar in matrix
V11	Quartz vein in Bethsaida Granodiorite		Vein sericitic	
V12	Quartz vein	Mo		
V13	Quartz vein			
V14	Quartz vein	Cp		
V15	Quartz vein	Mo		

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
V16	Quartz vein	Mo + Cp		Minor sericite
V17	Quartz vein		Vein sericitic ?	Sericite envelopes
V18	Quartz vein	Cp	Vein sericitic	Sericite envelopes
V19	Quartz veins cross-cutting	Cp	Vein sericitic	
V20	Quartz vein cutting Bethsaida Granodiorite	Cp	Pervasive sericitic	Scattered sericite and minor primary K-feldspar in granodiorite
V21	Vuggy quartz vein cutting Bethsaida Granodiorite	Bn	Vein sericitic cutting potassically altered granodiorite	Sericite envelopes
V22	Quartz porphyry			Angular quartz eyes to 3 mm, scattered millimetric euhedral feldspar phenocrysts
V23	Quartz porphyry			
V24	Quartz porphyry			
V25	Quartz porphyry			
V26	Quartz porphyry			
V27	Quartz porphyry			
V28	Quartz porphyry			
V29	Quartz porphyry			
V30	Quartz vein			
V31	Vuggy quartz vein cutting Bethsaida Granodiorite	Bn, Cp	Vein sericitic	Minor K-feldspar in quartz vein; sericite envelopes

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
V32	Quartz vein	Bn	Vein sericitic	Sericite envelopes
V33	Quartz vein	Cp		Sericite in vein
V34	Bethsaida quartz diorite	Bn + Cp + Py	Argillic (?)	Primary biotite
V35	Quartz vein	Bn	Vein sericitic	Sericite envelopes
V36	Quartz vein	Cp	Vein sericitic	Strong sericite envelopes
V37	Quartz-sericitic assemblage	Bn	Pervasive sericitization	Biotite visibly chloritized; feldspars saussuritized
V38	Bethsaida Granodiorite	Cp in quartz veinlet	Pervasive sericitic alteration	Biotite visibly chloritized; feldspars altered-chalky
V39	Quartz veins	Bn	Sericitic replacement associated with potassic alteration	Minor secondary K-feldspar in veins and envelopes, sericite envelopes
V40	Bethsaida Granodiorite	Cp	Pervasive sericitic and kaolinitic alteration	Kaolinized feldspars, abundant sericite
V41	Bethsaida Granodiorite		Pervasive sericitic and kaolinitic alteration	Kaolinized feldspars, abundant sericite
V42	Bethsaida Granodiorite		Pervasive sericitic and kaolinitic alteration	Biotite visibly chloritized, feldspar chalky, abundant sericite

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
V43	Bethsaida Granodiorite		Potassic	K-feldspar envelopes to quartz veins and in matrix; good primary biotite books; scattered sericite
V44	Bethsaida Granodiorite cut by quartz vein	Bn + Cp	Vein sericitic associated with potassic alteration	Abundant secondary K-feldspar in intrusive
V45	Quartz vein cutting Bethsaida Granodiorite		Pervasive kaolinization	
V46	Supergene alteration of intrusive			
V47	Quartz vein cutting Bethsaida Granodiorite	Py	Vein sericitic associated with potassic alteration	Sericite envelopes to quartz veins cutting secondary K-feldspar of potassically altered intrusive
V48	Quartz vein cutting Bethsaida Granodiorite		Vein sericitic overprinted on potassically altered intrusive	
V49	Quartz vein cutting Bethsaida Granodiorite		Potassically altered intrusive; weak sericite envelopes to quartz vein	
V50	Bethsaida Granodiorite		Phyllic	Feldspars extensively sericitized
V51	Bethsaida Granodiorite		Phyllic	Feldspars extensively sericitized
V52	Quartz vein	Cp + Bn		Sericitic envelopes
V53	Quartz vein	Mo	Phyllic	Sericite gangue in vein

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
V54	Quartz vein	Cp		Sericite envelope
V55	Vuggy quartz vein	Mo		
V58	Quartz vein cutting Minette		Vein sericitic	
V59	Quartz vein cutting Minette		Vein sericitic	
V60	Bethsaida Granodiorite		Pervasive kaolinization	Biotite partly chloritized and sericitized; feldspars chalky
Bethlehem				
B101	Highly chloritized qtz + chl + plag + bi rock cut by qtz vein	Cp in quartz vein		East Jersey pit
B102	Quartz vein cutting highly altered intrusive	Cp + Bn in both vein and intrusive	Propylitic	East Jersey pit
B103	Highly altered intrusive; cal + qtz + chl + ser	Bn ± Cp	Argillic or propylitic ?	East Jersey
B104	Qtz-calcite vein cutting qtz-ser-chl kaolinite rock	Bn vein; Cp-Mal in host rock	Argillic	East Jersey
B105	Cal + qtz + chl + ser	Bn + Cp	Argillic or propylitic	East Jersey
B120	Calcite vein			Jersey pit

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks.
B121	Large calcite crystal cut by tourmaline veinlet in qtz + plag + chlorite rock	Mo + Cp	Propylitic	Jersey pit
B122	Crowded dacite porphyry		Argillic	Jersey pit; epidote + kaolinized feldspars
B123	Crowded dacite porphyry	Cp + Hem	Argillic	Jersey pit; epidote + kaolinized feldspars
B124	Comminuted breccia	Cp	Argillic	Jersey pit
B125	Bethlehem quartz diorite		Argillic	
B126	Bethlehem quartz diorite	Bn	Propylitic	Abundant calcite and sericite
B151	Guichon Granodiorite	Mt + Cp	Propylitic	Huestis pit
B152	Bethlehem quartz diorite	Hem	Propylitic	Huestis pit
B153	Bethlehem Granodiorite cut by quartz vein	Cp, Mo in quartz vein	Propylitic	Huestis pit
B156	Quartz-sericite vein	Bn		
Lornex				
L201	Quartz-sericite rock	Mo		
L202	Quartz-sericite rock	Mo		
L203	Quartz-calcite vein	Cp-Mo	Phyllic	Sericite envelopes
L204	Quartz-calcite vein	Mo-Cp		
L205	Quartz	Mo + Cp		

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
L206	Skeena quartz diorite cut by quartz vein	Cp + Bn in qtz vein and hairline fractures	Argillic	
L207	Quartz-sericite rock	Bn	Phyllic	
L208	Quartz-calcite vein	Mo + Cp		Sericite gangue
L209	Skeena quartz diorite cut by quartz vein	Bn + Cp in qtz vein	Argillic	Sericite envelope to quartz vein
L211	Quartz	Bn + Cp		
L212	Quartz	Mo + Cp		
L213	Quartz-calcite-sericite rock	Cp + Mo		Crosscutting chlorite veinlet
L214	Skeena quartz diorite cut by quartz vein	Cp in quartz vein	Argillic	Sericite envelope around qtz vein
L215	Quartz vein	Cp + Mo		
L216	Quartz	Cp + Mo		
L217	Quartz	Cp + Mo		
L218	Quartz vein	Cp + Mo		
L219	Quartz vein	Cp + Bn + Mo	Phyllic	Sericite envelopes
L220	Skeena quartz diorite cut by quartz vein	Bn in quartz vein	Argillic	
L221	Quartz	Cp + Mo		
L222	Quartz-calcite-sericite vein	Cp + Mo		Sericite envelope
L223	Quartz vein	Cp + Mo	Phyllic	Sericite envelope
L224	Quartz	Cp + Mo		
L225	Quartz-calcite-sericite vein	Cp + Mo		

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
L231	Aplite dyke			Minor chloritization and sericitization along fracture faces
L232	Bethsaida quartz monzonite		Lightly propylitized	Minor calcite, chlorite
L233	Bethsaida quartz monzonite			Intrusive cut by millimetric secondary K-feldspar veinlet
L234	Bethsaida quartz monzonite			Millimetric crosscutting secondary K-feldspar veinlet
L235	Bethsaida quartz monzonite			Millimetric crosscutting secondary K-feldspar veinlet
L236	Bethsaida quartz monzonite			
L237	Bethsaida quartz monzonite			
L238	Skeena quartz diorite		Propylitic	Epidotized
L239	Sheared Skeena quartz diorite	Hem	Propylitic	
L240	Skeena quartz diorite		Propylitic	Epidote veins
L241	Skeena quartz diorite		Propylitic	Mafics epidotized and chloritized
L242	Skeena quartz diorite		Propylitic	Epidotized
L243	Skeena quartz diorite		Propylitic	Epidotized
L244	Skeena quartz diorite		Propylitic	

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
L245	Skeena quartz diorite		Propylitic	
L246	Skeena quartz diorite		Lightly propylitized	Epidote veinlets
L247	Skeena quartz diorite			Biotite chloritized
L248	Skeena quartz diorite			
L249	Quartz porphyry dyke rock	Cp		
L250	Quartz porphyry dyke rock	Mo on fracture facings		
L251	Quartz porphyry cut by quartz vein	Bn in quartz vein	Phyllic	Sericite envelope
L252	Quartz porphyry dyke rock			
L253	Quartz porphyry dyke rock			
L254	Quartz porphyry cut by quartz vein	Cp in quartz vein		
L255	Quartz porphyry cut by quartz vein	Cp + Bn in qtz vein	Phyllic	Sericite envelope
L256	Skeena quartz diorite		Argillic	
L257	Skeena quartz diorite cut by quartz vein	Cp + Bn in qtz vein	Argillic	Intrusive is qtz-ser-clay-chl-calcite assemblage
L258	Skeena quartz diorite cut by quartz vein	Bn in quartz vein	Argillic	
L259	Skeena quartz diorite		Argillic	
L260	Quartz	Cp, Mo		

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
L263	Quartz	Mo		
L264	Quartz vein	Mo		
L265	Skeena quartz diorite cut by quartz vein	Bn + Cp in qtz vein	Argillic	
Highmont				
H301	Quartz vein	Mo		
H302	Quartz vein	Cp		
H303	Quartz vein	Cp + Mo	Phyllic	Sericite envelope
H304	Quartz vein	Cp + Mo		
H305	Quartz vein	Cp		
H306	Quartz vein	Mo + Cp	Phyllic	Sericite envelope
H307	Quartz vein	Cp		
H308	Quartz vein	Cp		Highly fractured
H309	Quartz vein	Cp	Argillic ?	Minor chalky feldspar at edge of vein
H310	Quartz-sericite rock	Bn + Mal		
H311	Quartz vein	Hem		
H312	Quartz vein	Mo		
H313	Quartz vein	Mo		
H314	Quartz-sericite vein	Bn		
H315	Calcite-siderite vein		Argillic ?	
H316	Quartz vein	Cp + Mo		Scattered sericite
H317	Quartz vein			

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
H318	Quartz vein	Cp		Drusy quartz growing into a vug
H319	Quartz vein	Cp + Mo	Phyllic	Sericite envelope
H320	Quartz vein	Cp + Mo		
H321	Skeena (?) quartz diorite cut by qtz vein	Cp in quartz vein	Phyllic	Sericite envelope to quartz vein
H322	Quartz	Mo		
H323	Volcanic breccia; large, angular varied fragments cemented with tourmaline + hematite			Quartz eyes in quartz porphyry fragments studied
H324	"			"
H325	"			"
H326	"			"
H327	Qtz-Plag porphyry			Part of composite dyke quartz eyes
H328	Quartz porphyry	Bn + Mal		
H329	Volcanic breccia	Mal + Bn; minor Mo, Mt		
H330	Volcanic breccia	Bn + Mal		
H331	Quartz eye porphyry breccia	Mal + Cp + Hem	Argillic	Feldspars chalky
H332	Volcanic breccia	Cp, Mal		Quartz and qtz eye-porphyry fragments

Sample No.	Rock Type	Opaque Phases	Hydrothermal Alteration	Remarks
H333	Quartz vein	Mo		
H334	[illegible]lehem quartz diorite		Weak propylitic	
H335	Bethlehem Granodiorite			
H336	Bethsaida Granodiorite	Bn	Weak propylitic	
H337	Bethsaida Granodiorite		Argillic	Biotite chloritized, feldspars chalky
H338	Bethsaida Granodiorite slightly sheared		Argillic	Biotite chloritized, feldspars chalky
H339	Bethsaida Granodiorite		Argillic	
H340	Quartz eye porphyry	Hem		Part of composite dyke

APPENDIX B

PREPARATION OF DOUBLY POLISHED THICK SECTIONS

Hand specimens were examined under the binocular microscope to select those parts most suitable for fluid inclusion study. Areas of transparent, and where possible, coarsely crystalline quartz were marked and cut to a size not exceeding 2 cm square with a thickness averaging 5 mm.

The chips were then hand-ground with 400 and 600 grit silicon carbide powder prior to being glued onto frosted glass standard petrographic slides using Lepage's plastic cement. This glue was used in order to avoid possible thermal reactions within inclusions which might be induced by their being heated to the temperature range necessary when using cements such as Canada Balsam. For reasons of stability in grinding, and as a time-saving measure, two chips were cemented to each slide, side by side. Care was taken to exclude all air bubbles from between the slides and the rock chips.

The rock chips, cemented to the glass slides, were ground down to a thickness of approximately 0.7 mm using a Brot slide grinding machine. The ground sides of the slides were then hand-ground with 400, 600 and 1000 grit alumina powder prior to being polished with 6μ, 3μ and 1μ diamond pastes on paper laps for periods of 1 hour, 30 minutes, and 1 hour respectively. It was noted that the presence of even minute air bubbles between the rock chip and the glass slide frequently resulted in plucking of the chip from the slide during polishing.

Subsequent to polishing, the rock chips were removed from the slides by dissolving the cement in acetone, carefully cleaned in acetone with a soft camel hair brush, and glued back onto the slides with the polished side face down. Again, the chips were hand-ground with 400, 600 and 1000 grit silicon carbide powder prior to being polished. Finally the polished specimens were removed from the slides with acetone.

The finished, unattached polished sections, with an average final thickness of 0.6 mm, were carefully examined under the petrographic microscope, and suitable areas for fluid inclusion studies were outlined with a fine felt-tip marking pen.

APPENDIX C

CRUSHING DATA

Sample No.	Crushing Medium Anhydrous Glycerine[1]	 CO_2 Saturated Kerosene[2]	 Barium Hydroxide[3]	Remarks
Valley Copper		Gas evolved		
V1	Minor	No	No	
V2	Abundant	No	No	
V3	Abundant	No	No	
V4	Abundant	Abundant	No	II inclusions visible
V5	Minor	Minor	No	II inclusions visible Liquid CO_2 observed petrographically
V6	Minor	Minor	No	Liquid CO_2 observed petrographically
V7	Minor	No	No	Liquid CO_2 observed petrographically
V8	Minor	Minor	No	
V9	Minor	Minor	No	Liquid CO_2 observed petrographically
V10	Minor	No	No	
V11	Minor	No	Minor	
V12	Minor	-	Minor	
V13	Abundant	No	No	
V14	Minor	No	No	Liquid CO_2 observed petrographically
V15	Minor	Abundant	No	
V16	Very Minor	Very Minor	No	
V17	Very Minor	Minor	No	
V18	Minor	Minor	No	
V19	Very Minor	Minor	Very Minor	
V20	Very Minor	Minor	No	Liquid CO_2 observed petrographically
V21	Abundant	Abundant	No	II inclusions visible Liquid CO_2 observed petrographically
V22	Minor	No	No	
V23	Minor	No	No	
V24	Abundant	No	No	
V26	No	No	No	
V28	Minor	No	No	
V29	Minor	No	No	
V30	Minor	Abundant	No	
V31	Minor	-	No	
V32	Minor	No	No	
V33	Abundant	No	Minor	
V34	Abundant	No	No	Liquid CO_2 observed petrographically
V35	No	No	No	Liquid CO_2 observed petrographically
V36	Minor	Minor	No	
V37	Minor	No	No	
V38	Very Minor	No	No	
V39	Minor	Abundant	No	
V40	Minor	No	No	
V41	Minor	Abundant	No	Liquid CO_2 observed petrographically
V42	Very Minor	Minor	No	Liquid CO_2 observed petrographically
V43	Minor	Minor	No	
V44	Abundant	Minor	No	

Sample No.	Crushing Medium			Remarks
	Anhydrous Glycerine[1]	CO_2 Saturated Kerosene[2]	Barium Hydroxide[3]	
		Gas evolved		
V45	Abundant	No	No	
V47	Minor	Minor	No	
V48	Minor	No	No	
V49	Abundant	No	No	
V50	Minor	No	No	
V51	Minor	Minor	No	
V52	Minor	Minor	No	
V53	Minor	Minor	No	
V54	Minor	No	No	
V55	Minor	No	No	
V58	Very Minor	No	No	
V59	Minor	No	No	
V60	Minor	Minor	No	
<u>Bethlehem</u>				
B101	No			
B102	No			Calcite
B103	Very Minor	No	No	Calcite
B103	No			
B104	Very Minor			
B105	Minor	Minor	No	
B105	Minor	Minor	No	Calcite
B120	Minor			Calcite
B121	No			Calcite
B122	No			
B123	Very Minor			
B124	No			
B125	No		No	
B126	Minor	Minor	No	
B151	No			
B152	Very Minor			
B153	No			Liquid CO_2 observed petrographically
B156	Very Minor			
B157	No			
B158	No			Calcite
B159	No			Calcite
<u>Lornex</u>				
L201	Minor	Minor	No	Liquid CO_2 observed petrographically
L203	Moderate	Minor	No	
L204	Moderate	No	No	
L205	Abundant	Minor	No	
L206	Very Minor	Minor	No	
L207	Minor		No	
L208	Minor		No	
L209	Moderate		No	
L211	Minor		No	Liquid CO_2 observed petrographically

	Crushing Medium			
Sample No.	Anhydrous Glycerine[1]	CO_2 Saturated Kerosene[2]	Barium Hydroxide[3]	Remarks
		Gas evolved		
L212	Abundant		Minor	
L213	No		No	
L214	Moderate		No	
L215	Abundant		No	
L216	Moderate			
L217	No		No	
L218	Moderate		No	
L220	Minor		No	
L222	Moderate		No	
L223	No		No	
L224	No		No	
L225	Minor		No	
L231	No		No	Liquid CO_2 observed petrographically
L232	No		No	
L233	Moderate		No	
L234	Moderate		No	
L235	Moderate		No	
L236	No		No	
L237	No		No	
L238	No		No	
L239	No		No	
L240	Moderate		Minor	Liquid CO_2 observed petrographically
L241	Minor		No	
L242	No		No	
L243	Minor		No	Liquid CO_2 observed petrographically
L244	Abundant		No	
L245	No		No	
L246	Moderate		No	
L247	Moderate		Very Minor	
L248	No		No	
L249	No		No	
L250	Minor		Minor	
L251	No		No	
L251	Moderate		No	
L252	Very Minor		Moderate	
L253	Minor		No	
L254	Minor		No	
L255	No		No	
L256	Moderate		No	
L257	Minor		Minor	
L258	No		No	
L259	Very Minor		No	
L260	Very Minor		No	
L263	Minor		No	
L264	No		No	
L265	Moderate		No	

	Crushing Medium			
Sample No.	Anhydrous Glycerine[1]	CO_2 Saturated Kerosene[2]	Barium Hydroxide[3]	Remarks
Highmont		Gas evolved		
H302	No	No	No	
H303	Abundant	Abundant	No	
H304	Abundant	Abundant	No	
H305	Moderate	Abundant	No	
H306	Moderate	Abundant	No	
H307	Minor	Moderate	No	
H308	Moderate	No	No	
H309	Moderate	Moderate	No	Liquid CO_2 observed petrographically
H310	Moderate	Moderate	No	
H311	Moderate	Minor	No	
H312	Minor	Abundant	No	
H313	Moderate	Minor	No	
H314	No	Moderate	-	
H317	Moderate	Minor	No	
H318	Moderate	Minor	No	
H319	Moderate	No	No	
H320	Abundant	No	No	II inclusions visible
H321	Abundant	No	No	
H322	Abundant	No	Minor	
H323	No	No	-	Liquid CO_2 observed petrographically
H324	Moderate	Minor	No	II inclusions visible
H325	Moderate	No	No	
H326	No	No	No	
H327	Moderate	No	No	Liquid CO_2 observed petrographically
H328	Abundant	No	No	
H330	Moderate	No	No	
H331	Moderate	Minor	No	
H332	Minor	Minor	No	
H333	Moderate	Minor	No	
H334	Moderate	No	No	
H335	Abundant	Moderate	No	
H336	Moderate	No	No	Liquid CO_2 observed petrographically
H337	No	No	-	Liquid CO_2 observed petrographically
H338	No	Minor	-	

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[1] Hi pressure gas indicator

[2,3] CO_2 indicator

APPENDIX D

PETROGRAPHIC DESCRIPTIONS OF FLUID INCLUSIONS

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % χCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
Valley Copper								
V1								Sub micron inclusions in milky quartz. Unuseable.
V2	≤7	Bv_1	0.1					
	0.8	Bv_2 or Bv_{p2}	0.1					Strongly defined planes of inclusions.
V3	0.8 - 5.0	Bv_1	0.1-1		Rare halite cubes 0.1%	≤26.4	1.19	Slide too milky for good determinations.
V4	≤10	Bv_1	0.5-3.0					
	≤4	Bv_2	5					
V5	1 - 5	Bv_1	2		Rare halite cubes ≤1%	≤27.9	1.18	Solid identified as halite.
	≤3	Bv_{p2}	2		Rare halite ≤1%	≤27.9	1.18	
V6	≤6	Bv_1	2-10		Rare hematite and halite cubes ≤1%	≤27.9	1.18 to 1.09	
	0.8 to 1.6	Bv_2	2					
V7	≤12	Bv_1 or Bsv	5		Rare halite ≤1%. Rare daughter crystals probably of anhydrite. Rare specks opaque probably pyrite.	≤27.9	1.15	Rare χCO_2. Vapor-rich inclusions rare.
	≤12	B20v → V	30					
	0.5 - 2	Bv_2	1-5					

Sample No.	Size (in µ)	Inclusion Type	Vol % vap.	Vol % CO$_2$	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
V8	≤12.5 ≤12.5	Bv$_1$ B30v	5 30		Rare halite <1%	≤27.9	1.15	
	0.5 - 1.5	Bv$_2$	≤1					Vapor-rich inclusions usually elongate. Well-defined healed fracture planes.
V9	2.5 0.5 - 2.5	Bv$_1$ Cbv$_{p2}$	5-10 1	~5				Difficult to make determinative measurements because of poor viewing conditions.
	0.5 - 1.5	Bv$_2$	5					
V10	≤8	Bv$_1$	0-2		Rare halite cubes to 10%	≤38.7	1.27 to 1.30	Vapor phase rarely to 25% vol.
	≤2	Bv$_2$ or Bv$_{p2}$	0-1					
V11	≤6 0.4 - 1.5	Bv$_1$ Bv$_2$	5-10 ≤5					
V12	0.3 - 1.0	Bv$_1$, Bv$_2$, B30v	0-30					Quartz very milky, poor viewing conditions.
V13	≤9	Bv$_1$	5		Rare hematite <1%. Rare halite ≤1%.	≤27.9	1.16	
	0.75 - 2.0 0.75 - 2.0	Bv$_2$ B20v	2 20					
V14	≤6 ≤6 2.5	Bv$_1$ Cbv Bv$_{p2}$	2.5 1 2-5	2				Planar control.
V15	1 - 8	Bv$_1$	1-10		Rare halite <1%	≤27.9	1.09 to 1.20	
V16	≤3.5	B60v	60		Rare halite <1%. Rare anhydrite <1%.	≤29.65	0.48	

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % LCO$_2$	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
V17	3 - 17	Bv$_1$	1-10		Rare specks halite 0.1%. Rare specks hematite.	≤26.4	1.08 to 1.19	
	1	Bv$_2$	1-10		Frequent halite cubes 0.5%.	≤27.2	1.09 to 1.9	Planar control.
V18	≤9 0.5 - 2.0	Bv$_1$ Bv$_2$	1-5 1-5					
V19	≤20 commonly 2-4	Bv$_1$ & Bsv	<<1-5		Frequent halite cubes <0.1%. Rare cubes to 35% vol. Rare anhydrite needles.	26.4 Rarely ≤63.0	1.14 to 1.19 Rarely 1.48 to 1.52	
	≤3	Bv$_2$	2-5					
V20	≤27	Bv$_1$	0.5-1.0		Rare halite cubes ≤1%. Rare specks hematite.	≤27.9	1.20	
	≤4 ≤1.5 7.2	Bv$_{p2}$ Bv$_2$ Cbv	0 1 1	 5				
V21, V22								Optically unsuitable quartz porphyry.
V23	≤1.5	Bv$_2$	≤10					
V24-V29								Optically unsuitable quartz porphyry.
V30	≤3.5	Bv$_1$	1-2		Occasional halite cubes <1%. Rare specks hematite.	≤27.9	1.20	
	18	Bv$_1$	1		Rarely halite ≤20%. Rare opaque specks, possibly pyrite	≤49.5	1.19 to 1.38	
	≤4	Bv$_2$	1					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
V31	≤11 Commonly ~3	Bv_1	1-2		Rare halite cubes <1%. Rare hematite specks.	≤27.9	1.20	
	≤3.5	Bv_{p2}	2-5					
V32	≤13 Commonly 3-5	Bv_1	0.1-2		Halite 0.1%. Rare hematite. Possible sylvite.	26.4	1.19	
	0.5 - 1	Bv_2	~5					Planar control.
	≤13 Commonly 1-6	Bv_{p2}	1		Rare halite cubes <1%. Very rare specks hematite.	≤27.9	1.19	Discontinuous planar feature.
V33								Optically unsuitable.
V34	≤24	Bv & Bv_{p2}	2-5		Rare specks hematite. Occasional sylvite ≤0.1% and halite ≤0.1%.	≤10.3% KCl ≤21.0% NaCl	1.17 to 1.21	
	≤1.2	Bv_2	1-2					Planar control.
V35	≤17	Cbv_1 or p2	1	10				
	≤17	Bv_1	1					
	≤5	Bv_{p2} or Bv_2	2					Planar control.
V37	≤16	Bv_1	2		Frequent halite cubes to 2%.	≤29.1	1.19	
	≤13.5	Bv_{p2}	2-5		Rare halite <1%. Frequent hematite <1%.	≤27.9	1.17 to 1.21	Discontinuous planes of
	≤13.5	B40v	≤40					
	<1	Bv_2	2					
V38	≤14 Commonly ~5	Bv_1	1-2		Occasional halite <1%. Rare specks hematite.	≤27.9	1.19	
	≤4	Bv_2	1-2					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % ℓCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
V39	≤8	Bv_1 or Bsv	1-2		Occasional halite <1%. Rare rods of anhydrite (?).	≤27.9	1.19	
	≤4	Bv_2	0.1-1					
V40	≤33	Bv_1	1		Rare halite ≤1%	≤27.9	1.20	
V41	≤15	Bv_1	1		Rare halite ≤1%	≤27.9	1.20	
	12	Cbv	1	2				
	4	Bv_2	0-2					
V42	≤10	Bv_1	1-2		Occasional halite <1%. Average 0.5%. Rare specks hematite.	≤27.9	1.20	
	≤2	Bv_2	1		Rare hematite <<1%.			
V43	≤22	Bv_1	0		Rare halite 0.1%	26.4	1.20	Planar healed fractures.
	≤4	Bv_2	1-2					
V44	≤22	Bv_1	2-5		Occasional halite cubes to 1%	≤27.9	1.17 to 1.21	
	≤10	Bv_2	1-2					
	34	G	2					
V45	≤15.5	Bv_1	0.1-2		Rare halite, possible sylvite <<1%. Rarely halite to 35%.	<27.9 Rarely to 76.2	1.19 to 1.21 Rarely 1.51 to 1.53	No reaction to thermal gradient. Large cross-cutting fracture.
	≤14	Bv_2	1		Rare halite <0.1%	≤26.4	1.19	
V47	≤19	Bv_1	0.1-5		Rare halite <1%	≤27.9	1.14 to 1.19	
V48	≤10	Bv_2	0.1-2					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salt	Density at 20°C	Remarks
V49	≤15.5 ≤6	Bv$_1$ Bv$_2$	1-3 1		Halite 0.1%	26.4	1.16 to 1.19	
V50$_1$	≤10 Rarely 18	Bv$_1$	1					
	Commonly ≤6	Bv$_2$	1-2					
V50$_2$	≤24	Bxv	1-5		Halite 5-10%. Hematite <1%. Unidentified isotropic daughter crystal - rodlike, white, translucent.	32.8 to 38.8	1.19 to 1.28	
	≤20	Bv$_2$	2		Halite rarely 10-20%.	Rarely ≤49.6	1.18 to 1.37	
V51	≤12.4	Bv$_1$	2-5		Occasional halite <1%	<27.9	1.17 to 1.21	
	15 - 24 ≤15	Bv$_1$ Bv$_2$	5 2		Halite 1%-2%	≤29.5	1.17 to 1.23	Elongate inclusions.
V52	≤10	Bv$_1$	1-5		Occasional halite ~2%	≤29.5	1.16 to 1.21	
	≤8	Bv$_2$	2					
V53	≤21	Bv$_1$	0.1-0.5		Occasional halite cubes <0.1%	≤26.4	1.20	
	≤10	Bv$_2$	0.1-2		Occasional halite cubes 0.1%	≤26.4	1.18 to 1.19	
V54$_1$	16 ≤12	Bv$_1$ Bv$_2$	1 0-2		Halite 0.1%	26.4	1.19	
V54$_2$	≤9 ≤10	Bv$_1$ Bv$_2$	2-10 0-2					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salt	Density at 20°C	Remarks
V59	≤16	Bsv	1		Abundant anhydrite and possible carbonate.			
	≤10	Bv_2	0-5					
V60	≤22	Bv_1	<1-2					
	≤16	Bv_2	1-2		Rare halite ~0.2%	≤26.5	1.19	
Bethlehem								
B101	~4	Bv_1	0.1-1					
	≤6	Bv_2	1-2					
B102	≤18	Bv_1	2-10		Halite commonly to 5%. Rarely to 20%.	≤34.1 Rarely to 49.7	1.13 to 1.22 Rarely to 1.37	
	≤10	Bv_2	2					
B105	≤8	Bv_1	2					Calcite host.
B120	≤18	Bv_1	<1-5					Calcite host.
	≤5	Bv_{p2}	5					
B151	≤12	Bv_1	0.1-2		Halite <<0.1%	≤26.4	1.20	
B152	≤12	Bv_1	1-2		Occasional halite <<0.1%. Rarely 5-10%.	≤26.4 Rarely 38.8	1.19 Rarely to 1.28	
	≤12	B50v	50					
	≤4	Bv_{p2}	0.1-1					
B153	≤10	B50v	50-60		Rare anhydrite			Occasional necking down visible.
	4	Bxv	1		Halite 10-20%; sylvite 10%; hematite 1%; sulphate (?) - anhydrite (?) or possibly calcite.	Halite ≤47.8 Sylvite 27.4	1.43 to 1.52	

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
B153	4	Bv_1	1-2		Halite 1-2%	Halite 27.9 to 29.5	1.18 to 1.21	
	5	Cbv_{p2}	30	50				
	4	V	100					
Lornex								
L201	≤13	Bv_1	3		Rarely halite to 50%	≤74.8	1.64	
	9	Cbv	0.1	2				
	≤24	Bv_2	5-10					
L202	≤10	G	~5					
	≤8	Bv_1	2					
	2.5	Bv_2	1					
L203	≤12.4	Bv_1	0-10					
	≤5	Bv_2	2-5					
L204	≤19	G	1					Flattened bubble. No response to imposed thermal gradient.
	≤60	Bv_1	1-3					
	≤7	Bv_{p2}	1-2					Discontinuous planes of inclusions.
L205	≤12	Bv_1	10					
	≤4	Bv_{p2}	10					
	≤4	B20v	20-25					
L206	7	Bv_1	~5		Halite 0.1-0.2%	≤26.7	1.14	
	≤4	Bv_2	5-10					
	≤31	G	~5					
L207	≤13	Bv_1	1-2					
	28	G	~0.5					
	≤4	Bv_{p2}	2					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
L208	≤20	Bv_1	1-2		Halite 1%. Unidentified brown crystal present - either hem. or bi. <<0.1%	27.9	1.19	
	≤2	Bv_{p2}	2					
	≤5	Bv_2	2					
L209	≤12	Bv_1	~3-5		Halite ~1%. Frequent grains hematite.	≤27.9	1.15 to 1.20	Negative crystals.
	≤2.5	Bv_2	1-5					
L210	9	Bv_1	2-5					
	~7	Bv_{p2}	5					
	≤4	Bv_2	5					
L211	~36	Bv_1	3-5					
	21	Bv_1	2					
L212	8	Bv_1	2		Halite <<0.1%	26.4	1.18	
	≤3	Bv_{p2}	1-10					
	≤3.5	Bv_2	1-5					
L213	≤15	Bv_1	0-15		One halite cube 1% observed.	≤27.8	1.15	
	≤6	Bv_2	5					
L214	≤12	Bv_1	15-20,		Halite 0.5%	27.1	1.20	
	7	Bv_1	0.5					
	≤6	Bv_2	0-1					
L215	2.5	Bv_1	10-15					
	2.5	Bv_1	1					
	2	Bv_{p2}	1					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % X_{CO_2}	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
L216	6	Bv_1	1-2					
	15	G	2					
	≤6	Bv_2	2		Frequent opaque specks <0.1%; possibly pyrite.			Opaques non-magnetic.
	12	G	2+0.1					2 vacuoles visible in inclusion.
	28	G	1					
L217	9	Bv_1	2-3					
	9	Bv_1	2					
	6	Bv_2	1-2					
	23	G	2-3					
L219	9	Bv_1	2					
	≤4	Bv_2	2-5		Rare opaque specks; possibly pyrite.			Opaques non-magnetic
	3	Bv_1	5		Halite 0.1%	26.6	1.14	
L220	≤15	Bv_1	0.5-2					
	≤6	Bv_2	2					
L221	12	Bv_1	1					
	18	G	2-3					
	≤8	Bv_2	0-1					
L222	≤3.5	Bv_2	5					
	2	B30v	30					
	9	Bv_1	2		Rare halite <0.1%	≤26.5	1.18	
L223	9	Bv_1	2		Rare halite <0.1%. Opaque specks <0.1%; possibly pyrite	≤26.5	1.18	
L224	21	G	1-2					Flattened vacuole. Large cross-cutting fracture.
	12	Bv_1	2					
	6	Bv_2	5					

Sample No.	Size (in µ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
L225	≤6	Bv_1	0.5-5					
	6	Bv_2	8-10					
	18	G	1					
L231	≤12	Bv_1	0.5-1		Occasional halite cubes ~15%	≤44.3	1.20	
	18	G	1					
	6	Cbv	0.5	1				Large cross-cutting fractures. No reaction of vacuole to imposed thermal gradient.
	36	Bxv	0.2		<0.1% halite; <0.1% sylvite; 0.1% pyrite (?)	≤21.0% halite ≤10.3% sylvite	1.20	
L232	12	Bv_1	5-10		Occasional halite 2-3%	≤30.5	1.08 to 1.17	
	8	Bv_2	2					
	24	G	1-2					
	≤9	Bv_1	0					
L233	≤8	Bv_2	0-10					
	2.5	Bv_{p2}	15					
L234	≤9	Bv_2	1-2					
L235	6	Bv_1	~1					
	≤7	Bv_{p2}	2-5					
	4	Bv_2	10					
L238	≤20	Bv_1	1-5					
	10	Bxv	1		Halite 1%; hematite (?) 0.5%; opaque <0.1%; sylvite (?) 0.5%	22.3% halite; 10.9% sylvite.	1.26	
	≤9	Bv_{p2}	2					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
L240	≤18	Bv_1	<1-2		Occasional halite <0.1%	26.4	1.19	
	5	Cbv_{p2}	1	3				
	≤4	Bv_2	2-5					
L241	≤11	Bv_1	0.1-5		Occasional halite ≤1%	≤27.9	1.14 to 1.20	
	35	G	1-2					
L243	6	Bv_1	1-2					
	≤8	Bv_{p2}	1-2					
	≤3	Bv_2	5					
	18	Cbv	1	2				
L244	≤18	Bv_1	0.5-2					
	≤6	Bv_2	2					
	≤6	Bv_{p2}	0.1-1					
L245	5	Bv_1 (?)	10					
	≤6	Bv_2	5-10					
L246	≤21	Bv_1	≤1					
	≤9	Bv_2	5-10					
	≤4	Bv_{p2}	2-5					
L247	≤15	Bv_1	1					
	≤9	Bv_{p2}	1-2					
	≤11	Bv_2	2					
L248	≤9	Bv_1	2					
	≤5.6	Bv_2	10-15					
L249 quartz phenocryst	≤15	Bv_1 or Bxv	1-2		Halite ≤1%. Occasional opaque 0.1%; possibly pyrite; rarely hematite (possibly biotite)	≤27.9	1.17 to 1.19	

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % CO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
L249 quartz phenocryst	≤20	Bv_1	1-5		Halite ≤70%	≤86.3	≤1.86	
	4	Bv_2	<1-5					
L249 quartz vein	9	Bv_1	1					
	≤9	Bv_2	1					
L250	18	Bv_1	0.5-1		Halite 0.5%; sylvite 0.1%	Halite 21.6; sylvite 10.3	1.23	
	68	G	2					
	10	Bv_{p2}	2					
	≤2	Bv_2	1-2					
L250 quartz vein	≤3.5	Bv_2	0.5-1					
	7	Bv_1	3					
	25	Bv_1	1					
L251	6	Bv_1	1-2		Halite 4%	31.6	1.21 to 1.22	
	24	Bv_1	1					
	24	G	1					
	≤3	Bv_{p2}	2-5					
L251a	12	Bv_1	15					
	34	G	1-2					
	≤20	Bv_1	0-2					
	≤2	Bv_2	1-2					
L252	≤15	Bv_1	2-3					
	≤3	Bv_2	3-5					
L253	≤18	Bv_1	0.3-3		Halite 20%	49	1.38	
	4	Bv_1	1					
	13	G	20					
	3	Bv_2	2					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
L254	18	G	1					
	9 - 14	Bv$_1$	0.2-2					
	3	Bv$_2$	1-5					
L255	15	G	0.5					
	≤15	Bv$_1$	1-2		Frequent halite 1-2%	29.1	1.18 to 1.21	
	≤9	Bv$_{p2}$	1		Halite 1-2%	29.0	1.19 to 1.21	
	≤17	Bv$_2$	≤5					
L256	≤10	Bv$_1$	2-5					
	≤4	Bv$_{p2}$	5					
	≤4	B20v	20					
L257	13	Bv$_1$	1-2					
	≤25	Bv$_1$	6-8					
	4	Bv$_2$	1					
L258	15.5	G (?)	1					
	9	Bv$_1$	2					
	6	Bv$_2$	2					
L259	≤20	Bv$_1$	1-5		Rare halite ≤1%	≤27.9	1.13 to 1.20	
	16	G	0.2					Fluid inclusion visible within glass inclusion.
	6	Bv$_1$	10					
	≤6	Bv$_2$	2-5					
L260	10	G	1					
	≤9	Bv$_1$	1-2					
	6	Bv$_2$	1					
<u>Highmont</u>								
H302	≤5.5	Bv$_1$	1-2		Rare halite ≤15% Rare hematite <0.1%	≤44.4	1.19 to 1.33	
	≤1.5	Bv$_{p2}$	1					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume-% Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
H303	≤16 ≤8	Bv_1 Bv_2	0.1-2 1-2		Rare halite <1%	≤27.7	1.19	
H304	≤6 ≤3	Bv_1 Bv_2	1-2 1					
H306	≤24	Bv_1	0.5-1		Halite 0.1% visible in only one inclusion	26.5	1.20	
	≤10	Bv_2	0-1					
H307	3.2	Bv_1	5-10					
H308	≤2	Bv_2	~2					
H309	3.5 5	Cbv Bv_1	2 1-5	15	Hematite 0.1%		1.19	
H311	~2	Bv_2	2-10					
H312	≤3.5	Bv_1	1-5					
H313	1 1-3	Bv_1 Bv_2 or Bv_{p2}	1-2 0-10					
H314	≤8	Bv_1	1		Rare halite ≤2%. Rare hematite <0.1% Rare calcite (?) to 20%	≤29.1	1.20	
	27	Bxv	10					
	≤10 ≤6	Cbv Bv_2	0.1-2 1	5-50				
H315	≤19	Bv_1	0.1-1					
H316	≤16 <4	Bv_1 Bv_2	0.5 0-5					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % CO$_2$	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
H317	≤5	Bv$_1$	0					
	1	B20v	20					
H318	≤4	Bv$_1$	0-1		Hematite <0.1%; commonly halite <10%		≤1.30	
	≤2	B20v	20			≤38.7		
H319	2.5	Bv$_1$	10					
H320	3.2	Bv$_1$	1					
H321	≤8	Bv$_1$	5-10					
	≤5	Bv$_2$	1-2					
H323	5	Bv$_1$	2-5					
	≤15	Bv$_2$	1-2		Halite 5%, rarely to 15%; hematite 0.1%, rarely to 5%	Halite 32.8, rarely ≤44.4	≤1.23 Rarely to 1.33	
	7	Cbv	10	5				Cbv type inclusions rare.
H324	≤15	Bv$_1$	1-5					
	≤6	Bv$_2$	1-2		Halite 20-40%. Rare hematite <0.1%	49.5 to 66.9	1.37 to 1.57	
	≤15	Bv$_2$	0					
H325	≤4.5	Bv$_1$	5		Rare hematite ≤0.1%.	≤33.1	1.14 to 1.19	
	≤5.6	Bv$_2$	5		Rare halite ≤5% Rare hematite ≤1%			
H326	4	Bv$_1$	1		Halite 5-10%	32.8 to 38.8	1.24 to 1.28	
	≤4	Bv$_2$	1-2		Commonly halite ≤1%	≤27.9	1.18 to 1.19	
H327	≤4.5	Bv$_2$	0-2					
	≤5	Cbv	2	4				
	2.5	Bv$_1$	5					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % CO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
H328	≤5.5	Bv_1	5-10		Commonly halite ≤1%. Rare hematite <0.1%	≤27.9	1.00 to 1.15	
	5	Bv_2	1		Halite 10-50%	38.8 to 74.1	1.28 to 1.67	
H329	2.5	Bv_1	0.2-5		Halite cubes ≤5% common	≤32.8	1.24	
	≤3.5	Bv_2	1-2					
H330	≤4 ≤4	Bv_2 $B50v_2$	5-15 ≤50					
H332	≤2.5	Bv_{p2}	2					
H333	≤3.5	Bv_{p2}	5					
H334	4	Bv_1	1		Halite 1-2%. Hematite <0.1%	29.5	1.18 to 1.19	
	≤2.5	Bv_2	2-5					
H335	≤9 ≤2.5 ≤3	Bv_1 Bv_{p2} Bv_2	2 2-5 2					
H336	4	Bv_{p2}	1-2					
	≤12	Bsv	1		Anhydrite (?) 1%			
	≤5.5	Cbv_{p2}	0.5-1	5				
H337	8	Bv_1	2-5					
	≤7.5	Cbv	2-5	10-50	Rare hematite <0-1%			
	≤4	Bv_2	5					

Sample No.	Size (in μ)	Inclusion Type	Vol % vap.	Vol % λCO_2	Volume % Solid Phases	Calc'd wt. % salts	Density at 20°C	Remarks
H338	≤18	Bv_1	10-15					
	25	G	1-2					
	≤4	Bv_{p2}	2-5					
	≤7.5	Bv_2	2-5					
H339	13	Bv_1	2					
	≤6	Bv_2	10					
H340	[illegible]	Bsv	0.1-2		Rare calcite or gypsum <1%			
	21	Bv_1	2					
	≤15	Bv_2	<1					

APPENDIX E

FREEZING DATA FROM STUDIES OF FLUID INCLUSIONS IN QUARTZ FROM THE HIGHLAND VALLEY

Sample No.	Rock Type	Inclusion Type	No. Tested	Freezing Temp. (°C)	Wt. % NaCl Equivalent	Alteration Type	Comments
Valley Copper							
V7	Quartz vein	Bv$_1$	3	-7.5	25.0		
		Bv$_1$		-4.3 to -6.0	25.3 to 25.5		
		Bv$_1$		-8.5 to -8.9	24.8		
V9	Bethsaida Granodiorite	Bv$_1$	1	+9.0 to +9.6	24.7 to 24.8	Propylitic	
V17	Quartz vein	Bv$_1$	4	-8.5	24.8	Vein sericitic	
		Bv$_1$ sat.		-6.6 to -6.9	25.1 to 25.2		Visible halite crystal <1% volume. True weight % NaCl must be >26.4 and <27.9.
		Bv$_1$		-6.6 to -6.8	25.1 to 25.2		
		Bv$_1$		-6.0 to -6.1	25.2		
V19	Quartz vein	Bv$_1$	3	-3.8 to -4.3	25.5 to 25.6	Vein sericitic	
		Bv$_1$		-5.6	25.3		
		Bv$_1$		4.7 to -5.1	25.3 to 25.4		
V20	Quartz vein cutting Bethsaida Granodiorite	Bv$_1$	2	-5.2 to -5.6	25.3 to 25.4	Pervasive sericitic	
		Bv$_1$		-4.6 to -5.6	25.3 to 25.4		
V30	Quartz vein	Bv$_1$	2	-5.9 to -6.3	25.1 to 25.2		
		Bv$_1$		-5.4 to -5.5	25.2		Initial melting observed at -6.8°C.
V35	Quartz vein	Bv$_1$	3	-8.2 to -8.3	24.8	Vein sericitic	
		Bv$_1$		-8.5 to -8.7	24.8		
		Cbv					Liquid CO_2 homogenized at +25.9°C.
V40	Bethsaida Granodiorite	Bv$_1$	3	-5.0	25.4	Pervasive sericitic and kaolinitic	
		Bv$_1$		-6.7 to -7.0	25.0 to 25.1		
		Bv$_1$		-4.7 to -4.8	25.4		
V41	Bethsaida Granodiorite	Bv$_{p2}$	3	-9.8 to -10.8	24.5 to 24.7	Pervasive sericitic and kaolinitic	
		Bv$_1$		-5.9 to -6.1	25.3		
		Bv$_1$		-5.6	25.3		

Sample No.	Rock Type	Inclusion Type	No. Tested	Freezing Temp. (°C)	Wt. % NaCl Equivalent	Alteration Type	Comments
V43	Bethsaida Granodiorite	Bv_1 Bv_1	2	-4.7 to -6.3 -7.5	25.2 to 25.4 25.0	Potassic	
V44	Quartz vein	Bv_1 Bv_1	2	-6.7 to -6.9 -6.9 to -7.4	25.1 to 25.2 25.0 to 25.2	Vein sericitic	
V45	Quartz vein cutting Bethsaida Granodiorite	Bv_1 Bv_1	2	-6.7 to -6.8 -7.5 to -7.6	25.2 25.0	Pervasive kaolinization	
V47	Quartz vein cutting Bethsaida Granodiorite	Bv_1 Bv_1 Bv_1 Bv_1	4	-7.4 -7.4 to -7.5 -7.6 to -7.7 -7.4 to -7.7	25.0 25.0 25.0 24.9 to 25.0	Vein sericitic associated with potassic	
$V50_2$	Quartz vein cutting Bethsaida Granodiorite	Bv_1 Bv_1 Bv_1	3	-7.9 -7.7 -7.7	24.9 24.9 24.9	Potassic	
V51	Bethsaida Granodiorite	Bv_1 Bv_1	2	-4.6 -4.7 to -6.0	25.5 25.2 to 25.4	Phyllic	
V53	Quartz vein	Bv_1	1	-4.7 to -5.1	25.4	Phyllic	
Bethlehem							
B156	Quartz-sericite vein	Bv_1	1	-3.8 to -5.3	25.4 to 25.6		
Lornex							
L201	Quartz-sericite rock	Bv_1 Bv_1 Cbv Cbv	4	-6.4 to -6.6 -6.7 to -6.9 -6.0 to -6.1 -6.9 to -7.0	25.2 25.1 to 25.2 25.2 25.0 to 25.1		

Sample No.	Rock Type	Inclusion Type	No. Tested	Freezing Temp. (°C)	Wt. % NaCl Equivalent	Alteration Type	Comments
L202	Quartz-sericite rock	Bv_1	3	-7.2 to -8.4	24.8 to 25.0		
		Bv_1		-6.4	25.2		
		Bv_1		-7.3 to -7.4	25.0		
L203	Quartz-calcite vein	Bv_1	3	-6.8	25.1	Phyllic	
		Bv_1		-7.3 to -7.4	25.0		
		Bv_2		-3.7 to -3.8	25.6 to 25.7		
L204	Quartz-calcite vein	Bv_1	1	-7.5	25.0		
L207	Quartz-sericite rock	Bv_1	5	-6.6	25.2	Phyllic	
		Bv_1		-5.6 to -5.7	25.3		
		Bv_1		-3.9 to -4.0	25.6		
		Bv_1		-7.7 to -7.9	24.8 to 25.0		
		Bv_1		-6.1 to -6.4	25.2 to 25.3		
L208	Quartz-calcite vein	Bv_1	3	-8.3 to -8.5	24.8 to 24.9		
		Bv_1		-7.5	25.0		
		Bv_1		-8.7	24.7		
L209	Quartz vein cutting Skeena quartz diorite	Bv_1	4	-5.5 to -5.7	25.3	Argillic	
		Bv_1		-5.2	25.3		
		Bv_1		-6.2 to -6.3	25.2		
		Bv_1		-5.8	25.3		
L211	Quartz	Bv_1	4	-4.8 to -5.5	25.3 to 25.4		
		Bv_1		-3.2 to -4.3	25.5 to 25.7		
		Bv_1		-2.3	25.9		
		Bv_1		-7.6 to -7.9	24.9 to 25.0		
L214	Quartz vein cutting Skeena quartz diorite	Bv_1	5	-6.5 to -6.6	25.1	Argillic	
		Bv_1		-6.4 to -6.8	25.1		
		Bv_1		-7.0 to -7.3	25.0		
		Bv_1		-6.9	25.1		
		Bv_1		-6.9 to -7.0	25.0 to 25.1		

Sample No.	Rock Type	Inclusion Type	No. Tested	Freezing Temp. (°C)	Wt. % NaCl Equivalent	Alteration Type	Comments
L219	Quartz vein	Bv_1	3	-8.3	24.8	Phyllic	
		Bv_1		-4.6 to -4.9	25.4 to 25.5		
		Bv_1		-6.1 to -6.3	25.2		
L220	Quartz vein cutting Skeena quartz diorite	Bv_1	3	-4.0 to -4.3	25.5 to 25.6	Argillic	
		Bv_1		-6.1 to -6.3	25.2		
		Bv_1		-7.2	25.0		
L222	Quartz-calcite-sericite vein	Bv_1	1	-7.2 to -7.4	25.0		
L223	Quartz vein	Bv_1	3	-7.6 to -7.8	24.9		
		Bv_1		-6.3 to -7.4	25.0 to 25.2		
		Bv_1		-6.9 to -7.3	25.0 to 25.1		
L224	Quartz	Bv_1	3	-2.7 to -2.9	25.8		
		Bv_1		-6.5	25.2		
		Bv_1		-4.3	25.5		
L231	Aplite dyke	Bv_1	4	-8.1 to -8.2	24.8		
		Bv_1		-10.0 to -10.1	24.7		
		Bv_1		-12.6 to -12.9	24.2 to 24.3		
		Bv_1		-5.1 to -5.4	25.2 to 25.3		
L232	Bethsaida quartz monzonite	Bv_1	3	-3.9 to -4.2	25.5	Propylitic	High melting temperatures may reflect the presence of $CO_2 \cdot 5H_2O$ in CO_2 containing inclusions.
		Bv_1		+0.5 to +1.0	26.3		
		Bv_1		+0.8 to +0.9	26.3		
L238	Skeena quartz diorite	Bv_1	3	-7.7 to -7.8	24.9	Propylitic	
		Bv_1		-8.6	24.8		
		Bv_1		-8.6 to -8.9	24.8 to 24.9		
L240	Skeena quartz diorite	Bv_1	3	-8.0	24.9	Propylitic	
		Bv_1		-7.8 to -8.3	24.8 to 25.0		
		Bv_1		-7.7 to -7.8	24.9 to 25.0		

Sample No.	Rock Type	Inclusion Type	No. Tested	Freezing Temp. (°C)	Wt. % NaCl Equivalent	Alteration Type	Comments
L241	Skeena quartz diorite	Bv_1 (?)	4	-3.7 to -3.8	25.7	Propylitic	
		Bv_1 sat.		-12.7	24.3		
		Bv_1		-9.0 to -9.2	24.8		Visible halite crystal <1% vol. True weight % NaCl must be >26.4 and <27.9.
		Bv_1		-9.4	24.7		
L243	Skeena quartz diorite	Bv_1	3	-10.9 to -11.6	24.3 to 24.5	Propylitic	
		Bv_1		-8.2 to -8.5	24.3		
		Bv_1		-5.6 to -5.7	25.3		
L244	Skeena quartz diorite	Bv_1	3	-8.1 to -10.3	24.6 to 24.8	Propylitic	
		Bv_{p2}		-12.0	24.3		
		Bv_2		-4.1 to -4.7	25.4 to 25.5		
L246	Skeena quartz diorite	Bv_1	5	-5.1	25.3	Propylitic	
		Bv_1		-12.7 to -13.2	24.2		
		Bv_1		-12.6 to -12.7	24.2		
		Bv_1		-13.3	24.2		
		Bv_1		-11.7 to -11.8	24.4		
L247	Skeena quartz diorite	Bv_1	2	-6.4	25.2		
		Bv_1		-6.4	25.2		
L249	Quartz porphyry dyke rock	Bv_1	2	-11.3 to -11.6	24.4 to 24.5		
	Quartz phenocryst	Bv_1		-12.2 to -12.4	24.3		
L250	Quartz porphyry dyke rock	Bv_1	3	-7.5 to -7.9	24.9 to 25.0		
		Bv_1		-7.5 to -7.6	25.0		
		Bv_1		-7.9	24.9		
L251	Quartz porphyry cut by quartz vein	Bv_1	3	-6.2 to -6.5	25.1 to 25.2	Phyllic	
	Quartz phenocryst	Bv_1		-7.0 to -7.1	25.0		
		Bv_1		-6.4	25.2		

Sample No.	Rock Type	Inclusion Type	No. Tested	Freezing Temp. (°C)	Wt. % NaCl Equivalent	Alteration Type	Comments
L252	Quartz porphyry dyke rock	Bv_1	3	-7.7	24.9		
	Quartz phenocryst	Bv_1		-7.3 to -7.4	25.0		
		Bv_1		-6.4 to -6.7	25.1 to 25.2		
L253	Quartz porphyry dyke rock	Bv_1	3	-5.8	25.3		
	Quarz phenocryst	Bv_1		-7.7 to -7.8	24.9		
		Bv_1		-7.5	25.0		
L255	Quartz porphyry (quartz phenocryst)	Bv_1	1	-4.5 to -4.6	25.4	Phyllic	
L256	Skeena quartz diorite	Bv_1	3	-8.8	24.8	Argillic	
		Bv_1		-9.1	24.8		
		Bv_1		-7.6 to -7.7	24.9 to 25.0		
L257	Quartz vein cutting Skeena quartz diorite	Bv_1	3	-7.5	25.0	Argillic	
		Bv_1		-7.0 to -7.1	25.0		
		Bv_1		-7.2 to -7.3	25.0		
L259	Skeena quartz diorite	Bv_1	1	-5.1	25.4	Argillic	
<u>Highmont</u>							
H303	Quartz vein	Bv_1	1	1 to +0.1	26.2 to 26.4	Phyllic	
H306	Quartz vein	Bv_1	1	-3. to -3.5	25.6 to 25.7	Phyllic	
H314	Quartz-sericite vein	Bv_1	1	-4.6 to -5.0	25.4		
H323	Volcanic breccia	Bv_1	4	-6.2	25.2		
		Bv_1		-11.0	24.5		
		Bv_1		-6.9	25.0		
		Bv_1		-7.2	25.0		

Sample No.	Rock Type	Inclusion Type	No. Tested	Freezing Temp. (°C)	Wt. % NaCl Equivalent	Alteration Type	Comments
H324	Volcanic breccia	Bv_1	1	-2.9 to -3.0	25.7		
H335	Bethlehem Granodiorite	Bv_1	1	-8.9 to -9.2	24.7 to 24.8		
H338	Bethsaida Granodiorite	Bv_1	3	-7.2	25.0	Argillic	
		Bv_1		-7.5 to -7.6	25.0		
		Bv_1		-9.0	24.8		
H340	Quartz-eye porphyry	Bv_1	4	-11.8	24.4		
		Bv_1		-6.5	25.2		
		Bv_1		-6.5	25.2		
		Bv_1		-6.2	25.2		

APPENDIX F

HOMOGENIZATION TEMPERATURES OF FLUID INCLUSIONS

mple o.	Inclusion Type	Homo. Temp.	Comments
7	Bv_2	130.0-131.7	Quartz vein.
	Bv_2	134.8-135.3	
17	Bv_1	143.3-144.7	Quartz vein. Vein sericitic alt.
	Bv_{p2}	149.3-150.7	
	Bv_{p2}	135.8-137.0	
9	Bv_{p2}	132.0-134.0	NaCl cube, 1% vol.; did not dissolve at Th.
	Bv_{p2}	146.0-147.5	
	Bv_{p2}	157.2-159.0	Cross-cutting quartz veins. Vein sericitic alt.
	Bv_{p2}	135.8-137.5	
	Bv_{p2}	130.5-132.0	NaCl cube, 1% vol.; did not dissolve at Th.
	Bv_{p2}	152.8-154.7	
0	Bv_1	161.2-162.7	Quartz vein cutting Bethsaida Granodiorite. Pervaisve sericitic alt.
	Bv_1	112.5-114.8	
	Bv_1	124.2-126.0	
	Bv_1 or $p2$	137.9-139.8	
	Bv_1 or $p2$	117.8-119.2	
	Bv_2	140.6-141.7	
	Bv_1	172.1-174.0	Quartz vein.
	Bv_1	142.2-143.8	
	Bv_{p2}	128.7-130.0	NaCl cube, 5% vol.; did not dissolve at Th.
	Bv_1	147.3-151.0	Quartz vein. Vein sericitic alt.
	Bv_1	149.3-150.8	
	Bv_{p2}	176.8-179.3	
	Bv_{p2}	123.2-124.7	Bethsaida Granodiorite. Pervasive sericitization and kaolinization.
	Bv_1 or $p2$	129.9-131.3	
	Bv_1	115.3-116.7	
	Bv_1	133.2-134.5	
	Bv_{p2}	137.1-138.5	
	Bv_2	128.0-130.5	Quartz vein cutting Bethsaida Granodiorite. Vein sericitic alt. cutting potassic alteration.
	Bv_1	150.5-152.0	
	Bv_1	117.0-118.5	
	Bv_1	116.0-117.5	
	Bv_1	127.8-129.2	
	Bv_1	121.3-123.0	

Sample No.	Inclusion Type	Homo. Temp.	Comments
V45	Bv_1	224.6-226.8	NaCl cube, 1% vol.; did not dissolve at Th. Quartz vein cutting Bethsaida Granodiorite. Pervasive kaolinization.
	Bv_1	206.8-208.6	
	Bv_{p2}	158.5-161.0	
	Bv_{p2}	178.0-179.5	
	Bv_{p2}	217.5-219.5	
V47	Bv_1	233.8-235.8	Quartz vein cutting Bethsaida Granodiorite. Vein sericitic alteration cutting potassic alteration.
	Bv_2	137.5-139.2	
	Bv_2	117.3-119.0	
	Bv_2	127.3-129.3	
	Bv_2	127.3-219.3	
	Bv_2	138.3-140.0	
V53	Bv_1(?)	121.3-123.0	Quartz vein. Phyllic alt.
	Bv_{p2}	159.4-160.6	
	Bv_2	125.2-126.6	
	Bv_1 or $p2$	148.2-149.5	
	Bv_{p2}	131.8-133.2	
	Bv_2	112.2-113.5	
	Bv_1(?)	125.2-126.7	
B156	Bv_2	118.7-120.2	Quartz-sericite vein.
L201	Bv_2	136.0-137.4	Quartz-sericite rock.
	Bv_2	120.0-122.0	
	Bv_2	144.6-146.7	
	Bv_2	127.0-129.2	
	Bv_2	130.3-131.8	
	Bv_2	147.8-149.3	
L204	Bv_1	132.0-133.8	Quartz-calcite vein.
	Bv_1	132.8-134.5	
	Bv_1	137.0-138.6	
	Bv_1	130.0-131.9	
	Bv_1	125.5-127.2	
	Bv_{p2}	141.5-142.7	
	Bv_{p2}	139.0-140.6	
L208	Bv_1	138.5-140.0	Quartz-calcite vein.
	Bv_2	136.3-137.3	
	Bv_2	124.7-126.1	
	Bv_2	136.0-137.2	
	Bv_2	118.6-120.5	
	Bv_2	162.6-164.2	
	Bv_2	206.0-207.5	

Sample No.	Inclusion Type	Homo. Temp.	Comments
L214	Bv$_2$	160.0-161.3	Skeena quartz diorite cut by quartz vein. Argillic alt.
	Bv$_2$	133.3-134.8	
	Bv$_1$	196.2-197.6	
	Bv$_1$	208.2-210.0	
	Bv$_2$	155.8-157.2	
	Bv$_2$	156.8-158.3	
	Bv$_2$	146.0-147.6	
L220	Bv$_1$	133.0-134.6	Skeena quartz diorite cut by quartz vein. Argillic alt.
	Bv$_1$	143.2-144.6	
	Bv$_2$	123.0-124.9	
	Bv$_2$	112.0-114.2	
	Bv$_2$	118.8-120.2	
L238	Bv$_{p2}$	129.8-131.3	Skeena quartz diorite. Propylitic alt.
	Bv$_2$	116.0-117.5	
	Bv$_{p2}$	129.5-131.2	
	Bv$_1$	130.8-132.3	
	Bv$_2$	143.2-144.5	
	Bv$_1$ or p2	144.5-146.0	
	Bv$_2$	147.2-148.6	
	Bv$_2$	178.5-181.5	
	Bv$_2$(?)	107.3-109.3	
	Bv$_1$	147.8-149.2	
	Bv$_1$	154.8-156.5	
	Bv$_1$	155.0-156.5	
	Bv$_2$	124.7-126.5	NaCl cube, 2% vol.; did not dissolve at Th.
L243	Cbv	214.5-218.0	Liquid CO_2 homogenized 25[illegible]
	Bv$_2$	128.7-130.5	Skeena quartz diorite. Propylitic alt.
	Bv$_2$	128.3-130.0	
L246	Bv$_2$	144.0-146.0	Skeena quartz diorite. Propylitic alt.
	Bv$_2$	146.3-148.2	
	Bv$_1$	141.7-143.0	
	Bv$_2$	172.0-173.8	
	Bv$_1$	142.0-143.5	
	Bv$_2$	142.7-144.2	
	Bv$_2$	150.8-152.6	
	Bv$_2$	154.9-156.5	
L252	Bv$_1$	139.9-141.3	Quartz porphyry dyke rock.
	Bv$_{p2}$	139.8-141.2	
	B$_{20}$v→V	290.0-292.0	
	Bv$_{p2}$	205.2-207.7	

Sample No.	Inclusion Type	Homo. Temp.	Comments
L259	Bv_1	162.0-164.1	Skeena quartz diorite. Argillic alt.
	Bv_1	142.2-144.0	
	Bv_2	143.3-145.0	
	Bv_2	161.9-164.0	
	B30v	213.3-215.3	
H306	Bv_1(?)	127.9-129.5	Quartz vein. Phyllic alt.
H314	Bv_2	148.6-150.1	Quartz-sericite vein.
H323	Bv_2	152.0-153.4	Quartz phenocryst in volcanic breccia.
	Bv_{p2}	194.0-196.2	
	Bv_1	188.6-190.3	
	Bv_1	170.0-173.0	
	Bv_2	180.7-183.2	
	Bv_1	200.0-202.2	
	Bv_1	259.8-261.2	
	Bv_2	185.0-186.7	
H324	Bv_1	210.0-212.0	Quartz phenocryst in volcanic breccia.

PLATE 1

Photomicrograph of a halite-bearing primary fluid inclusion of Type Bvl in a quartz vein of the Valley Copper deposit. The cubic phase, h, is halite, v is the vapor bubble and l is salt-saturated brine.

Photomicrograph of a primary fluid inclusion of Type Bsv from the Valley Copper deposit. The birefringent and prismatic phase, x, is probably gypsum or anhydrite, v is the vapor bubble and l is liquid.

Photomicrograph of a primary polyphase fluid inclusion of Type Bxv in a quartz vein of Bethlehem Copper's Huestis deposit. Cubic phase h is halite, s is sylvite, v is the vapor bubble and l is salt-saturated brine.

PLATE 1

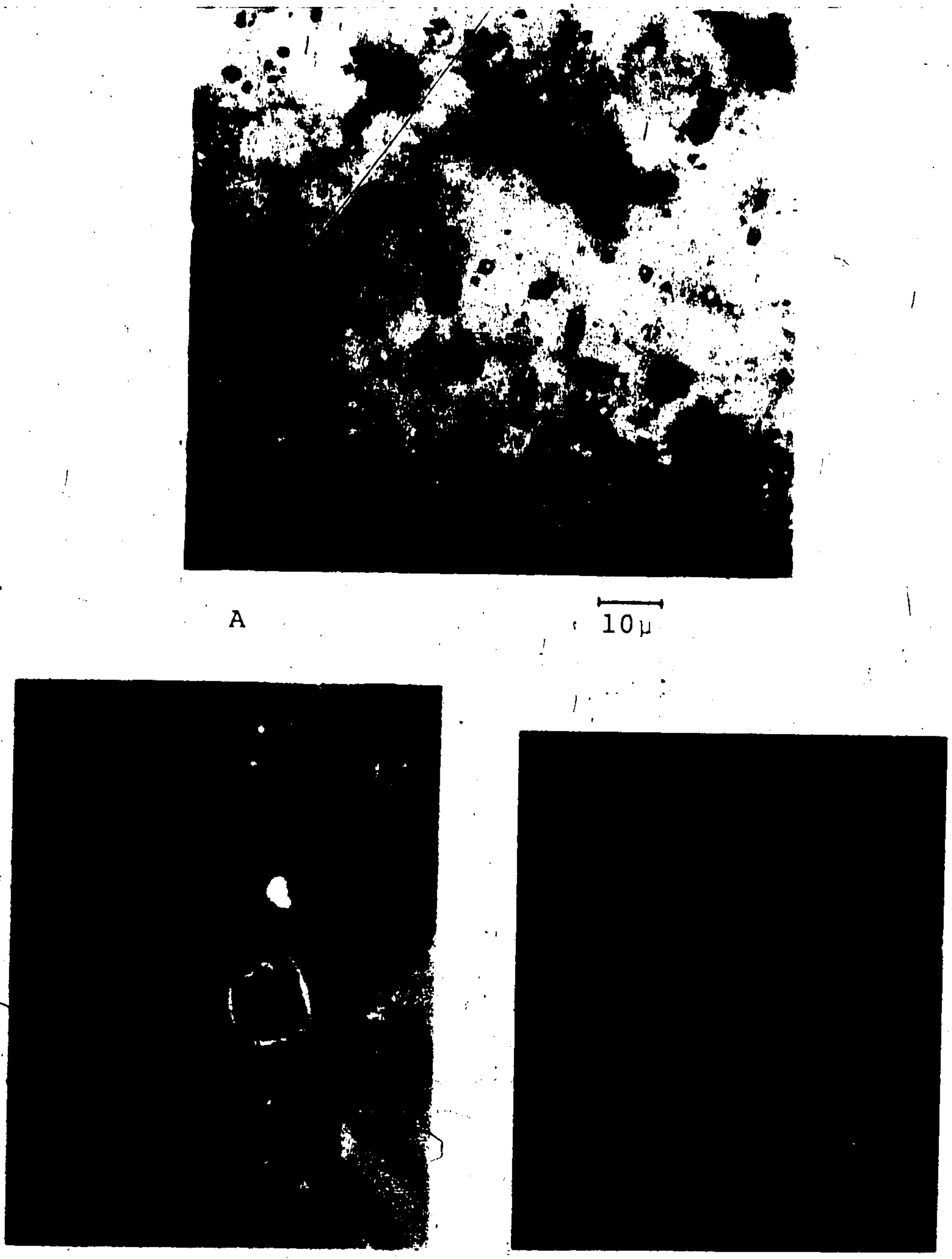


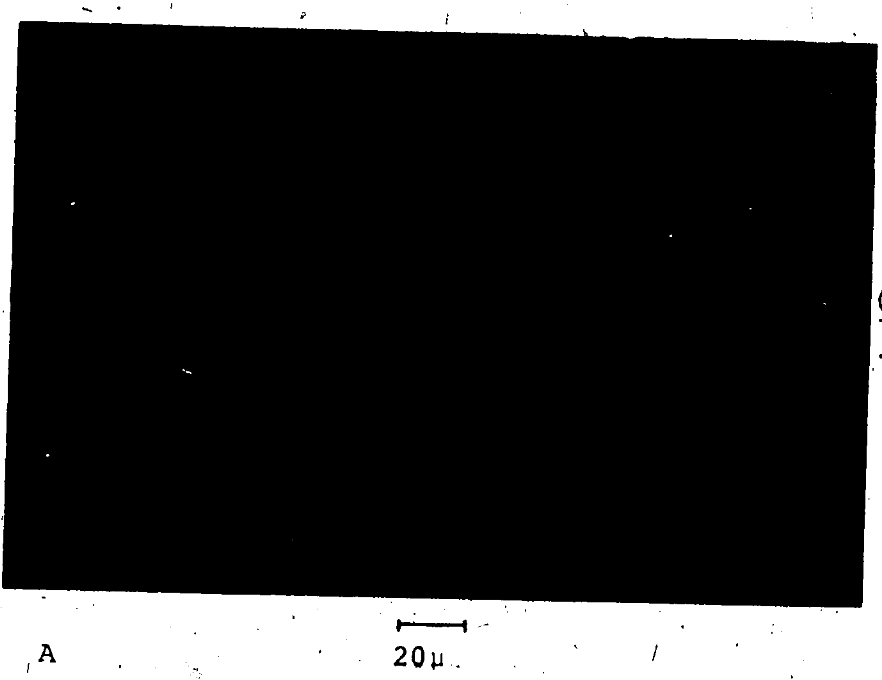
PLATE 2

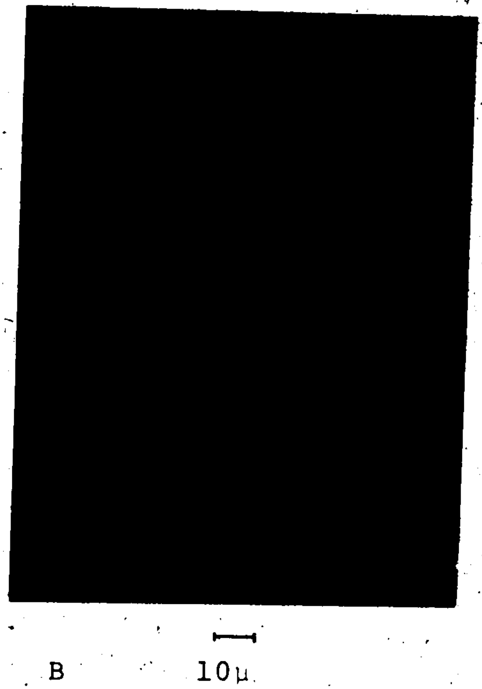
A. Photomicrograph of primary inclusions of Type Bvl from the Lornex deposit. v is the vapor bubble, h is a mass of small halite crystals occupying 60-70 vol. % of the inclusion and l is salt-saturated brine.

B. Photomicrograph of primary inclusions of Type Bvl from the Lornex deposit. The cubic phase, h, is halite, v is the vapor bubble and l is salt-saturated brine.

C. Photomicrograph of a primary polyphase inclusion of Type Bxv from a quartz vein in the Huestis deposit of Bethlehem Copper. Cubic phases, h and s, are halite and sylvite respectively, v is the vapor bubble, hm is hematite and the two daughter minerals, x, are unidentified opaque phases.

PLATE 2


A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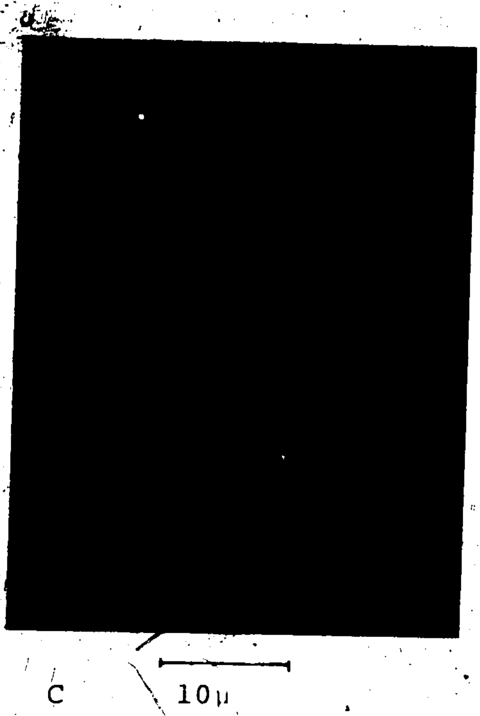

C

PLATE 3

A. Photomicrograph of a Type Bvl salt-undersaturated primary fluid inclusion from the Valley Copper deposit. v is the vapor bubble, l is brine.

B. Photomicrograph of necking down in a primary salt-undersaturated fluid inclusion of Type Bvl from the Lornex deposit. Necking is not complete as a small link still exists between the two parts of the inclusion. The vapor bubble is restricted to the large part of the inclusion.

PLATE 3

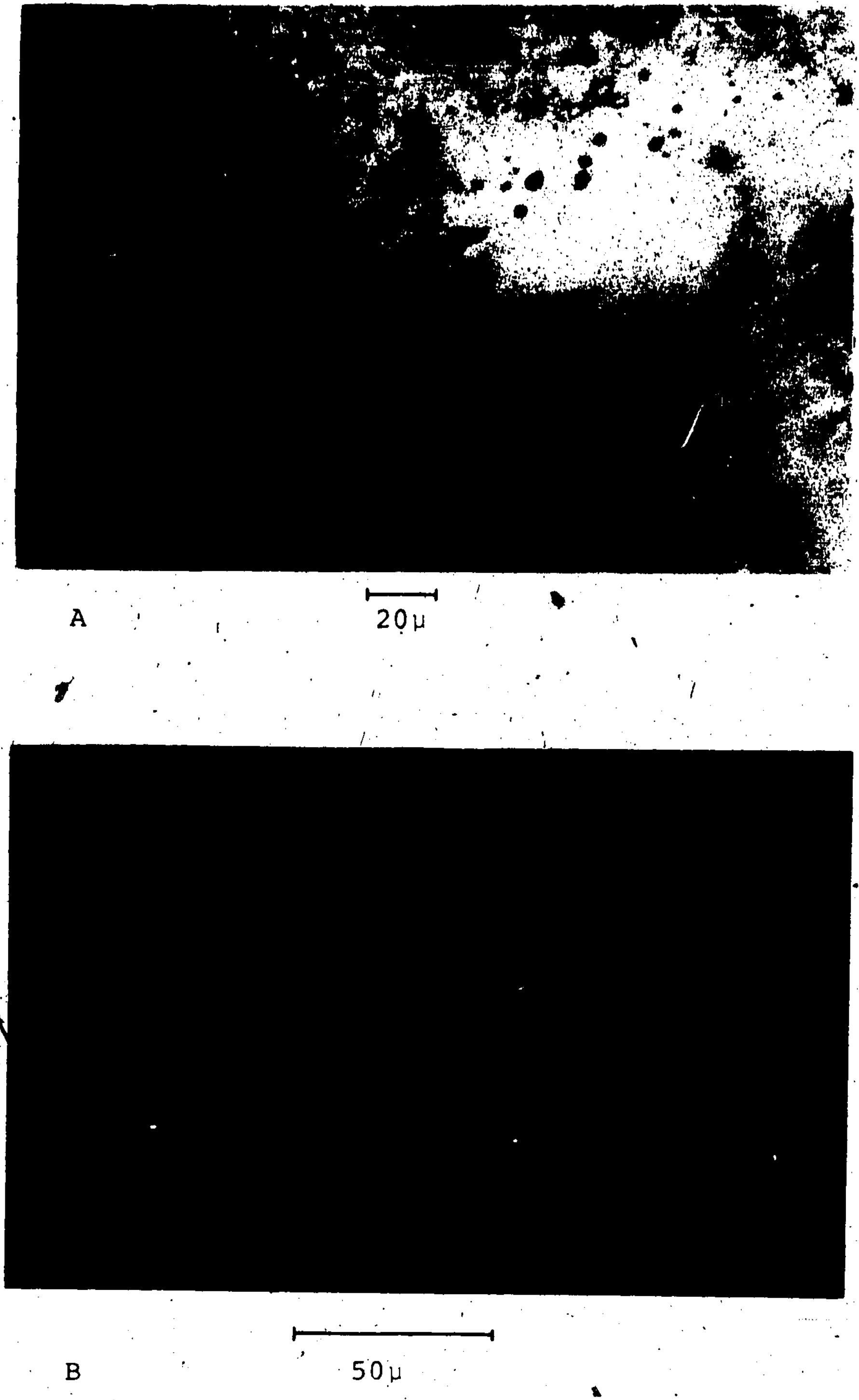


PLATE 4

A. Photomicrograph of a primary CO_2-bearing fluid inclusion of Type Cbv from a quartz vein of the Valley Copper deposit. Two liquid, and one gaseious phase are present. v is CO_2 gas, lc is liquid CO_2 and l is aqueous liquid. Homogenization of the two CO_2 phases occurs in the liquid phase at temperatures ≤31.1°C. This can result from absorption of infrared radiation from the microscope illuminator unless an infrared filter is placed between the light source and the specimen.

B. Photomicrograph of primary CO_2-bearing fluid inclusion of Type Cbv from a quartz vein in Bethlehem Copper's Huestis deposit. Two liquid and one gaseous phase are present. v is CO_2 gas, lc is liquid CO_2, and l is aqueous liquid.

C. Photomicrograph of primary CO_2-bearing fluid inclusion of Type Cbv from the Valley Copper deposit. v is CO_2 gas, lc is liquid CO_2 and l is aqueous liquid.

PLATE 4

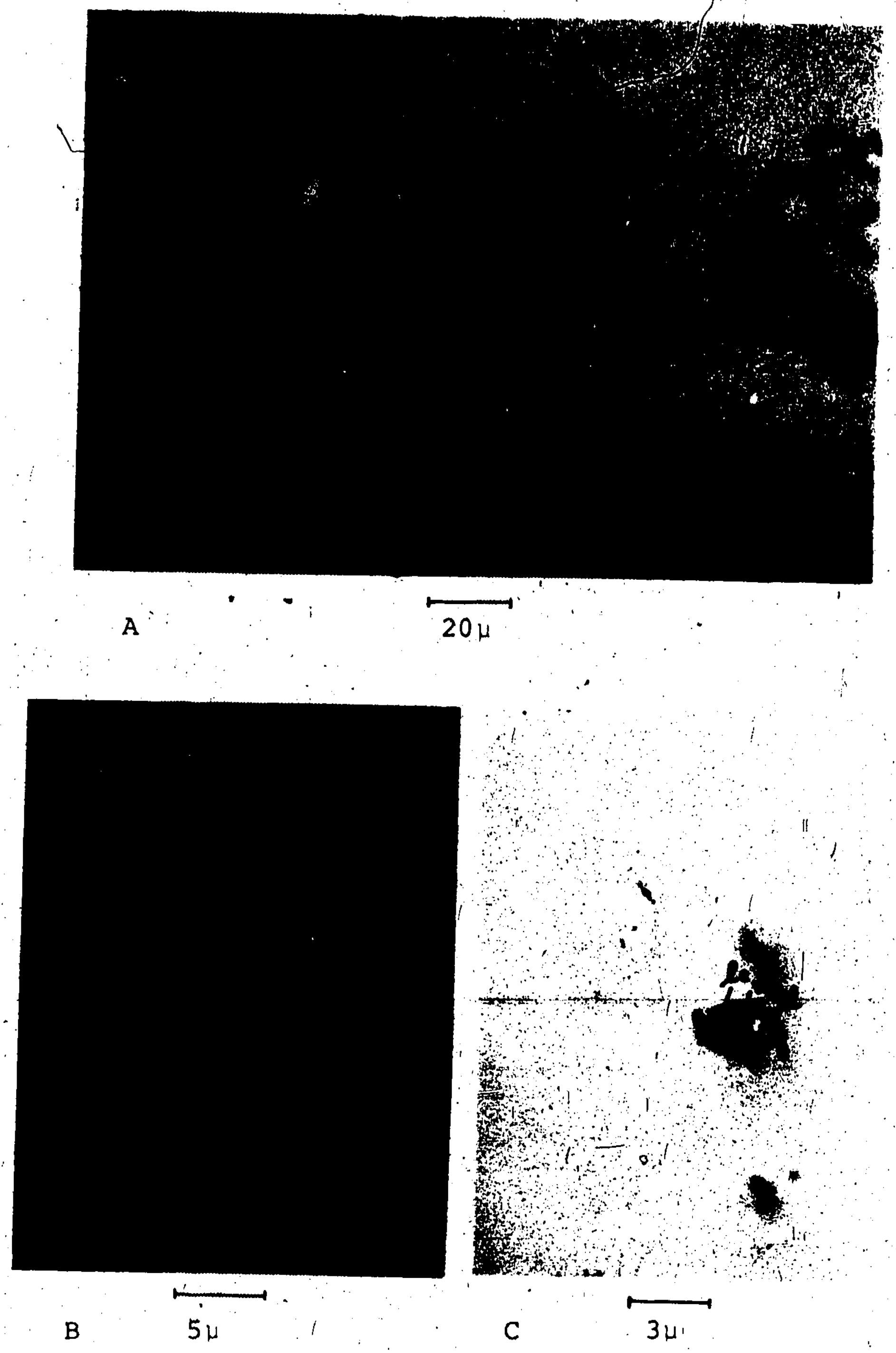
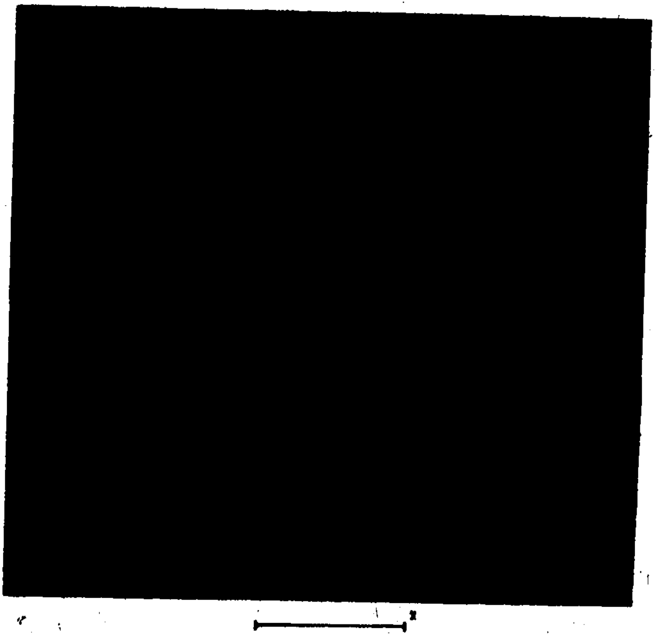


PLATE 5

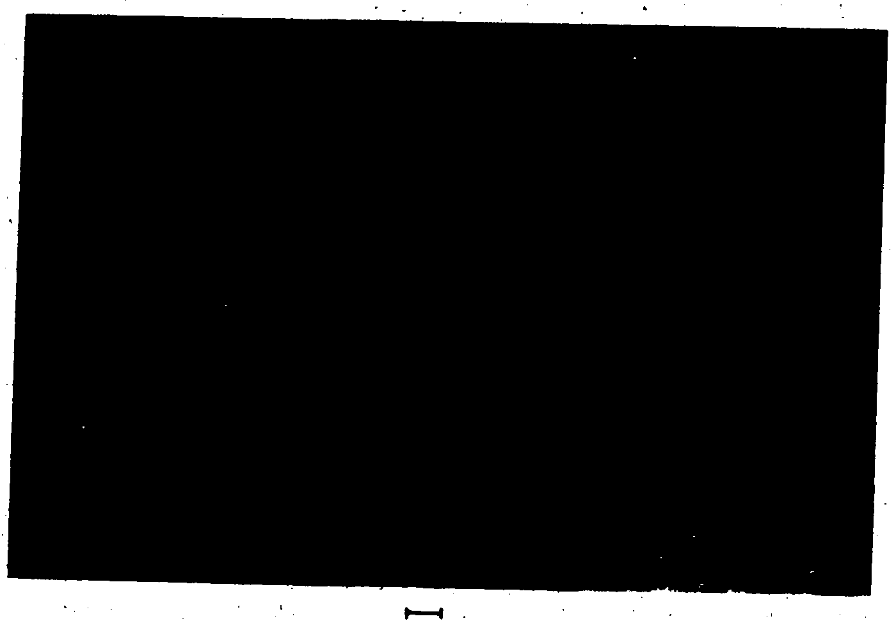
A. Photomicrograph of a primary CO_2-bearing fluid inclusion of Type Cbv from a quartz vein of the Valley Copper deposit. v is the CO_2 gas bubble, lc is liquid CO_2 and l is aqueous liquid.

B. Photomicrograph of an array of secondary fluid inclusions of Type Bv_2 from the Lornex deposit.

PLATE 5



A



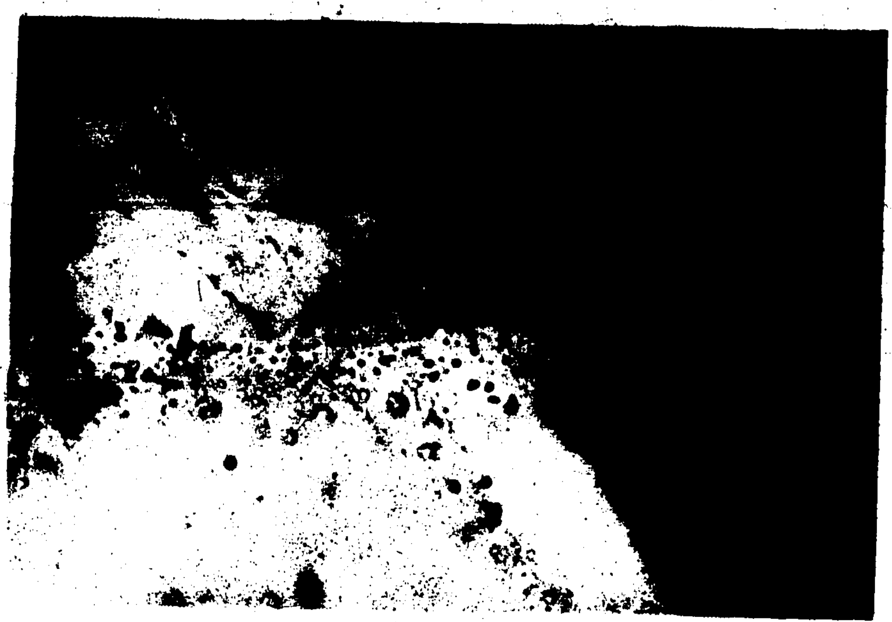
B

PLATE 6

A,B. Photomicrographs of planes of secondary inclusions of differing ages from the Valley Copper deposit. The well defined cross-cutting relationships support the author's contention of several events of shattering and injection of hydrothermal fluids at this deposit.

PLATE 6

A



B

PLATE 7

A. Photomicrograph of an inclusion, probably of Type Bv_1, from the Lornex deposit. Identification of this inclusion is not conclusive, and it may alternatively be a glass inclusion of Type G. The triangular dark phase is a thick crystal of hematite. No movement of the bubble was observed when a thermal gradient was imposed across the inclusion.

B. Photomicrograph of a glass inclusion of Type G from the Lornex deposit. In addition to the slight flattening of the vapor bubble, deep cross-cutting fractures are visible across the inclusion. No movement of the bubble was observed when a thermal gradient was imposed across the inclusion.

PLATE 7

A

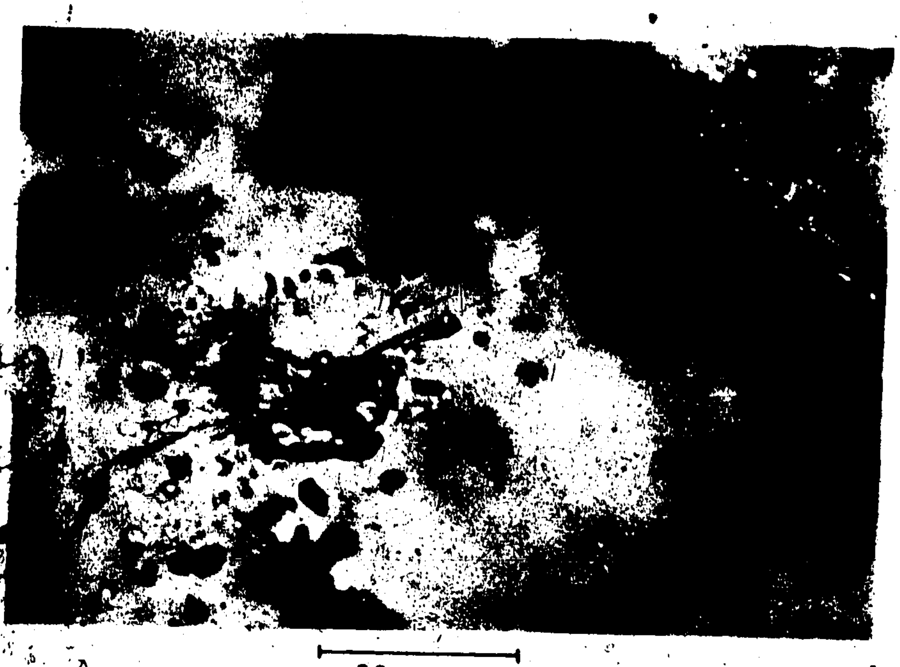
B

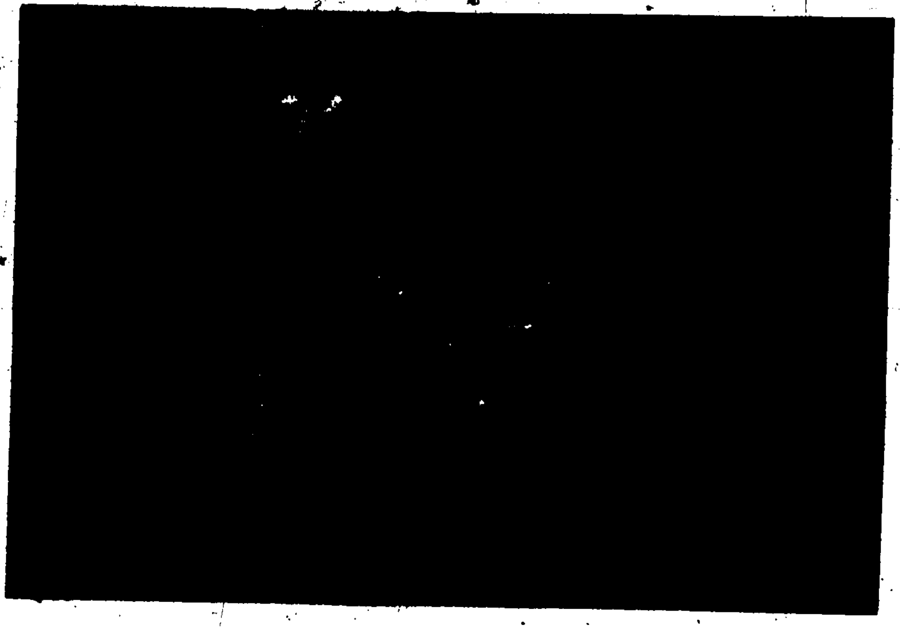
PLATE 8

A. Photomicrograph of a glass inclusion of Type G from a quartz vein in the Valley Copper deposit. A deep fracture is visible cross-cutting the inclusion, and the bubble appears to be slightly flattened. No movement of the bubble was observed when a thermal gradient was imposed across the inclusion.

B. Photomicrograph of a glass inclusion of Type G from the Valley Copper deposit. Deep cross-cutting fractures are visible. No movement of the bubble resulted from imposition of a thermal gradient across the inclusion.

PLATE 8





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