Geological, Mineralogical and Fluid-Inclusion Studies at the Dunbrack Lead-Silver Deposit, Musquodoboit Harbour, Halifax County, Nova Scotia

by

John R. Dickie

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Department of Geology
Dalhousie University
Halifax, Nova Scotia

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Abstract

The Dunbrack deposit consists of a steeply dipping vein with argentiferous galena and other sulphides and sulphosalts in a gangue of predominantly quartz, hosted by altered adamellite granite. The vein appears to be associated with a regional structural system of lineaments, faults and joint sets of probable post-batholith age.

The identification of an SiO_2 polymorph, previously reported as tridymite was not successful. The biaxial mineral occurs twinned into trillings as in tridymite, but other physical properties (x-ray diffraction patterns, specific gravity, indices of refraction) do not correspond to those of tridymite.

Fluid inclusions in quartz and in the alleged tridymite homogenize at ca. 134°C. The pressure of crystallization cannot be ascertained, but the above minimum temperature of entrapment should be corrected for pressure by ca. +56°C for every kilobar.

This study gives weight to previous suggestions that the Dunbrack deposit, despite its location within the Devonian batholith, may owe its genesis to processes not directly related to the emplacement of the granitoids and that it was formed in post-Devonian times.

Chapter 1

Introduction

The Dunbrack lead-zinc (silver) deposit is located 5 km northwest of Musquodoboit Harbour, Halifax county, Nova Scotia (fig. 1). Its coordinates are: Latitude, 40°49'10"N, Longitude 63°11'30"W. All that remains of the development that was done is the dump of the "number 2" shaft, located 20 m east of highway 357 (fig. 2).

Previous work:

The original discovery was made by a John Kerr in 1888. In 1910 James Dunbrack initiated development by starting two shafts. The operation was found to be too expensive and was abandoned. In 1916 the property was acquired by Robert Ewing of New Orleans, La. He extended the shafts and sampled the mineralized quartz vein. The report by A. O. Hayes (1917) on this deposit lists grades obtained by this sampling. Hayes states that there was an estimated 600 tons (544 tonnes) of 2% lead ore ready to stope. The actual amount removed from the mine is not stated in any report. J. P. Messerey (1928) described the distribution of mineralization and the progress of development. A report by F. J. Alcock (1930) is based almost entirely on Hayes' paper, although he did examine the dump material. J. S. Wroth (1937), like Hayes, was also able to observe the deposit while development was in progress. He gave a detailed report of both the geology of the deposit and the economic considerations of mining it. Mr. F. J. Hogan

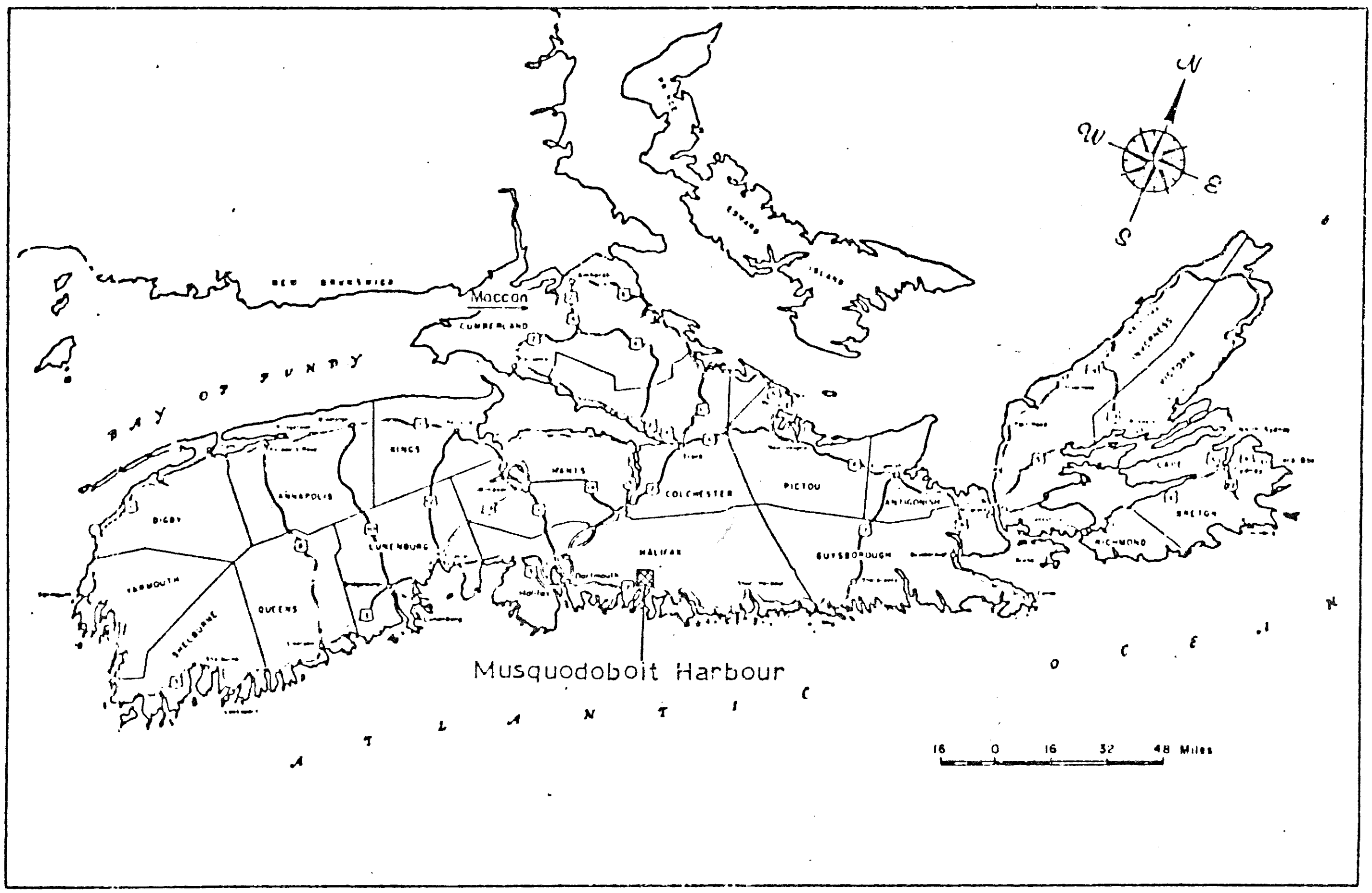


Fig. 1 Map of Nova Scotia Showing Location of Musquodoboit Harbour

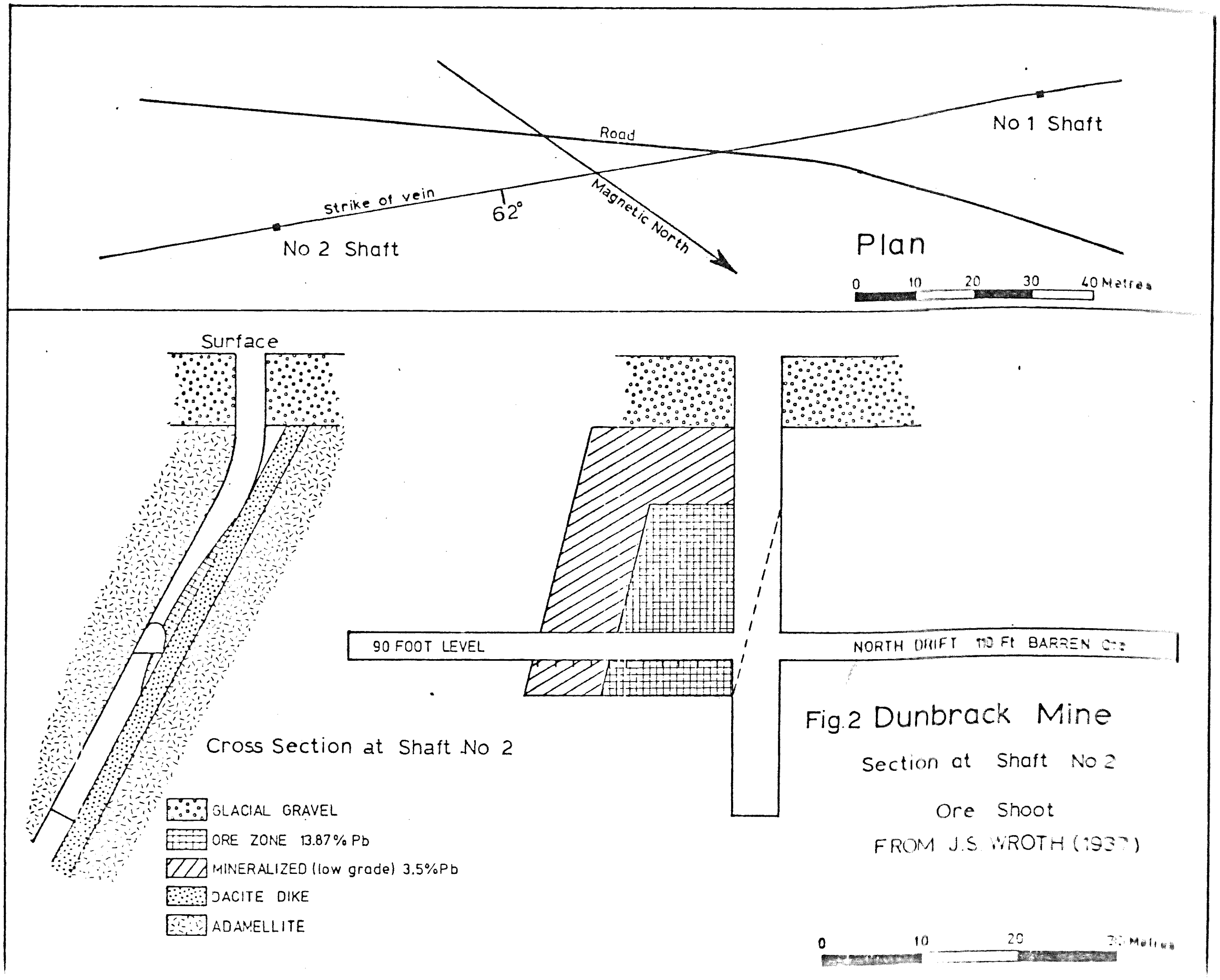


Fig.2 Dunbrack Mine

Section at Shaft No 2

Ore Shoot

FROM J.S. WROTH (1937)

(1954) had diamond core drilling done. This consisted of two holes through the mineralized zone. He also had semi-quantitative spectrographic analyses done by Lakefield Research Ltd., Ontario. Data for thirty-one elements were obtained. Ann Sabina (1964) described the minerals at Dunbrack from a collectors viewpoint. Peter VonBitter (undated) of the Nova Scotia Museum, Halifax, lists the minerals in the host rock, and both the primary and secondary vein minerals. C. G. I. Friedlaender (1968) observed the presence of tridymite in the gangue at Dunbrack. He followed this up with optical determinations of the properties of this mineral (Friedlaender, 1970). Friedlaender expressed doubt in the previous theories on the origin of the deposit. T. P. Macmichael (1975) in his honours thesis attempted to determine an origin for the mineralization. He discussed the mineral phases and also reported unpublished geochronological work by Dr. P. H. Reynolds of Dalhousie University on alteration sericite and host rock biotite. The latest work was done by A. K. Chatterjee (1977) who reported the presence of pyromorphite and meneghinite in the deposit and, like Friedlaender, suggested a "metamorphic" source for the mineralization.

Purpose and Scope

The Dunbrack mine represents one of the few mined base metal deposit noted in granitic rocks in southern Nova Scotia. It occurs at the margin of a northwest trending trough, covered by glacial deposits, which have impeded investigation of the lateral extent of mineralization. In addition the vertical extent has not been thoroughly investigated. This thesis attempts to increase the understanding of the regional geological setting of the deposit. Furthermore, the Dunbrack deposit represents an interesting metallogenic problem. The genesis of the vein has been ascribed by several authors to the intrusion of the Devonian batholith, either by hydrothermal fluids emanating from the granitoid or by contact metamorphic effects. However, several points argue against these genetic models: first there appears to be a difference of 70 million years in the radiometric date of the pluton and the sericitic alteration near the vein. Second, tridymite is generally believed to crystallize at temperatures above 800°C and at low pressures. Figure 3 shows the temperature-pressure range of the emplacement of the granitoid, as determined by C. McKenzie (1974). This is superimposed on a pressure/temperature diagram for SiO . It is notable that the low pressure limit of the granitoid emplacement is above the maximum pressure at which tridymite can exist. There is also a large difference in the temperature ranges. It appears that stable tridymite could not have crystallized under the pressure temperature conditions of the granitoid emplacement.

It appears necessary to confirm the presence of tridymite and to further investigate the conditions of crystallization of the vein material.

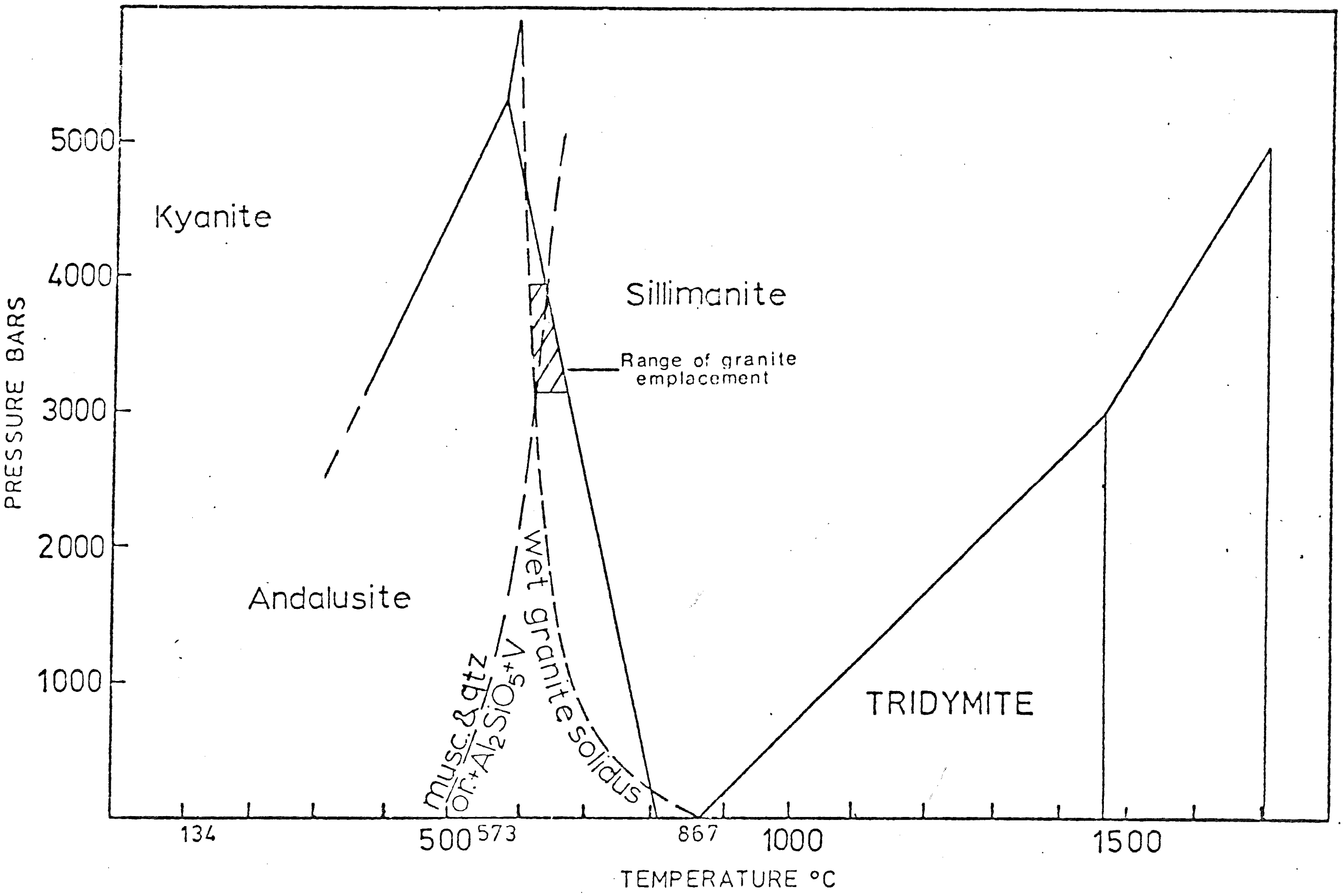


Fig. 3. Pressure-temperature diagram for SiO_2 (after Deer, Howie and Zussman, 1966) plotted with pressure-temperature range for the emplacement of the granite batholith (after MacKenzie, 1974).

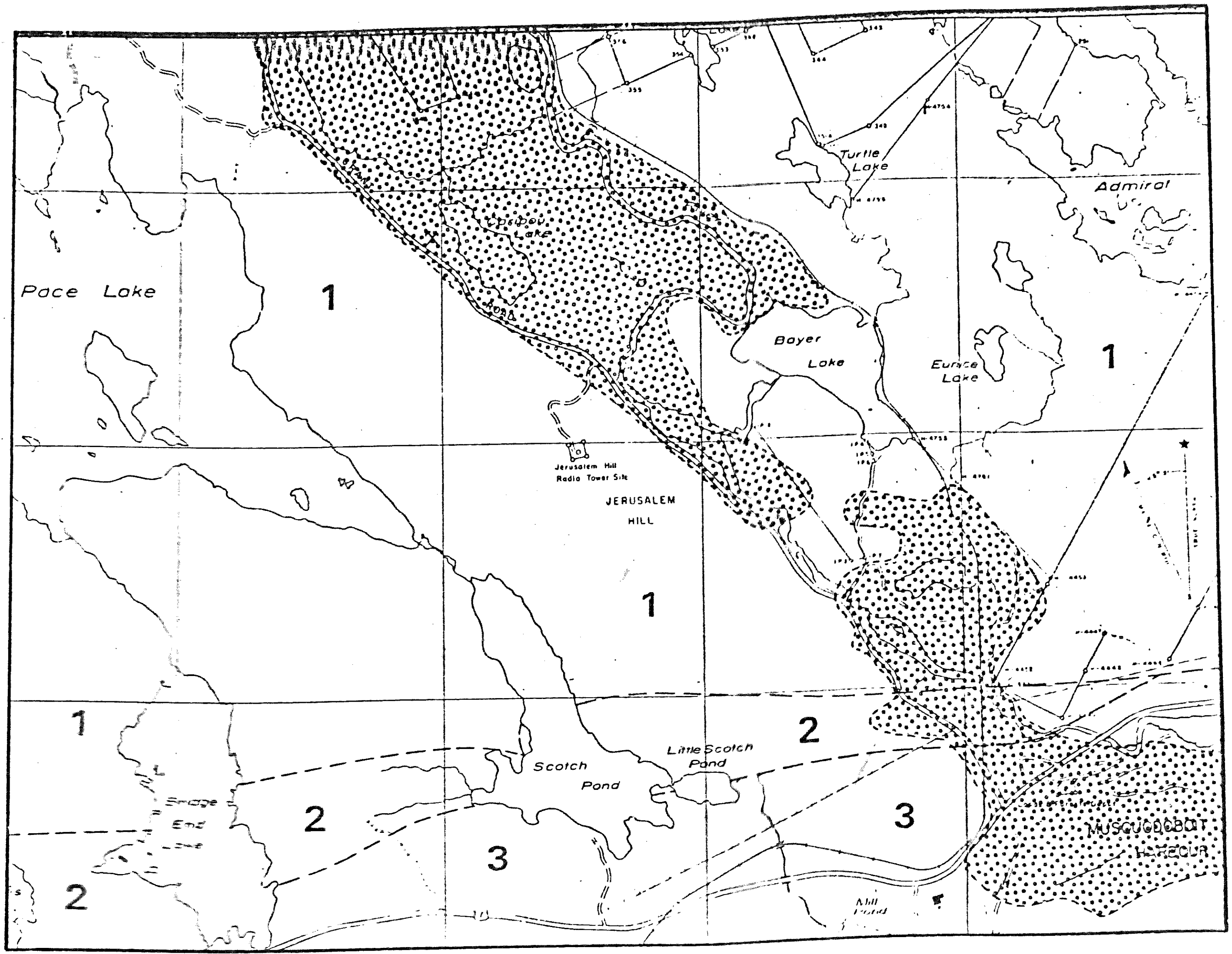
This thesis describes the regional geologic setting of the Dunbrack deposit, discusses the (still-unresolved) problem of the tridymite on the basis of new observations and presents fluid inclusion data on the gangue minerals of the vein. A model for the genesis of the vein is proposed and suggestions on further research are made.

The Approach

Due to the lack of outcrop in the vicinity of the deposit, details on its geological relations had to be obtained from previous reports. New data consisted of that which could be obtained from dump samples and regional geology.

Joint and lineament sets were measured to obtain structural data. Fluid inclusion studies were done to establish the temperature-pressure conditions of the environment of formation of the deposit. Petrographic, heavy liquid and x-ray diffraction methods were used in mineral identifications.

Fig.4 Bedrock and surficial geology of the Musquodoboit Harbour map area.



MUSQUODOBOIT HARBOUR

HALIFAX COUNTY

Scale One Inch equals Twenty Chains

Bedrock geology
adapted from Faribault
(1907)

1 ADAMELLITE
2 QUARTZITE

☐ Granite till

▨ Sand&gravel

Chapter 2

Regional geology (Fig. 4)

The Musquodoboit batholith in which the deposit is contained is primarily a muscovite-biotite leucogranite (Jones and Macmichael, 1976). It generally contains cordierite and has been subdivided into three types on the basis of the percentage of this mineral, (Jones and Macmichael, 1976).

Type # 1	cordierite < 5%
Type # 2	cordierite > 5%
Type # 3	no cordierite

The rock in the vicinity of the mine has no cordierite. It is a light grey coarse grained two mica adamellite with alkali feldspar phenocrysts. The major minerals are zoned plagioclase, quartz, alkali feldspar, biotite and muscovite. Accessory minerals include apatite, zircon, iron oxides, andalusite and tourmaline (Plate 1).

The area is cut by numerous narrow dikes ranging from 1 cm to 1.5 m in width. These dikes are mostly aplitic and fine grained adamellitic but there has been one pegmatite dike located on the eastern shore of Pace Lake (Macmichael, 1975).

The Musquodoboit batholith intrudes Ordovician metasediments of the Meguma group. These consist of large thicknesses of quartzites and meta-argillites overlain by slates.

Metamorphism is of very low intensity with a maximum in the lower greenschist facies, (Taylor and Schiller, 1966).

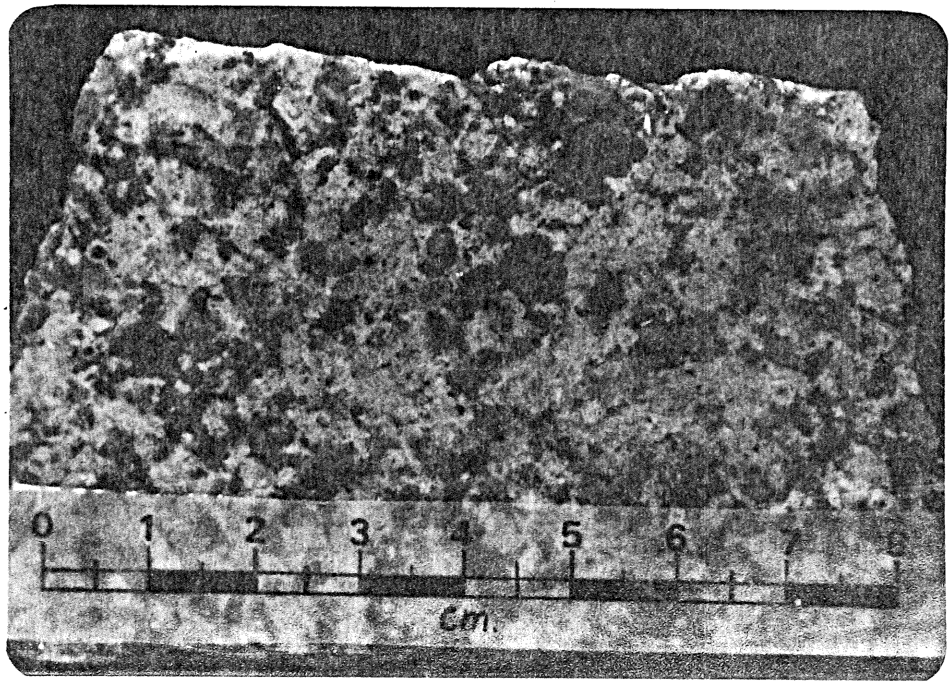


Plate 1. Adamellite sample from the vicinity of the Dunbrack Mine.

Folding of the Meguma rocks has occurred in three stages. These consist of a series of pre-granite, isoclinal, northeast trending anticlines and synclines; pre-granite northerly trending Z-folds and post-granite S-kinks trending in a northwesterly direction (Fyson, W. K. 1966).

Structural geology

Lineaments: The most obvious structural feature in the area is a series of lineaments, many of which have been mapped as faults. E.R.T.S. imagery over the Eastern Shore area reveals most of these lineaments. Azimuths of 42 of these, within the Musquodoboit batholith, were measured and plotted on a rose diagram (fig. 5). These resolved into two sets striking, on an average, 320° and 220°.

Joints: Jointing is extensive in the adamellite in the Musquodoboit Harbour area. These joints show no slickensliding or extension. A total of 101 were measured, most of which were obtained from outcrop in the railway cut to the east of the Musquodoboit river. When poles of these are plotted in the meridian stereonet (fig. 6) two major trends can be observed. Average attitudes of these are 316/48 and 206/77. When plotted on a rose diagram (fig. 7) the major trends of the joint strikes are very similar to those obtained for the lineaments.

W. K. Fyson (1966) reported post-granite s-kinking in Meguma rocks in this area with azimuth 135°. This is identical with one joint and lineament trend. Fyson proposed an east-west compressional stress as the tectonism necessary to produce this type of kinking. It is possible that the joint systems mapped represent a response of the adamellite to the same tectonism. This type of stress should produce

Fig 5 ROSE DIAGRAM OF LINEAMENTS AT MUSQUODOBOIT HARBOUR

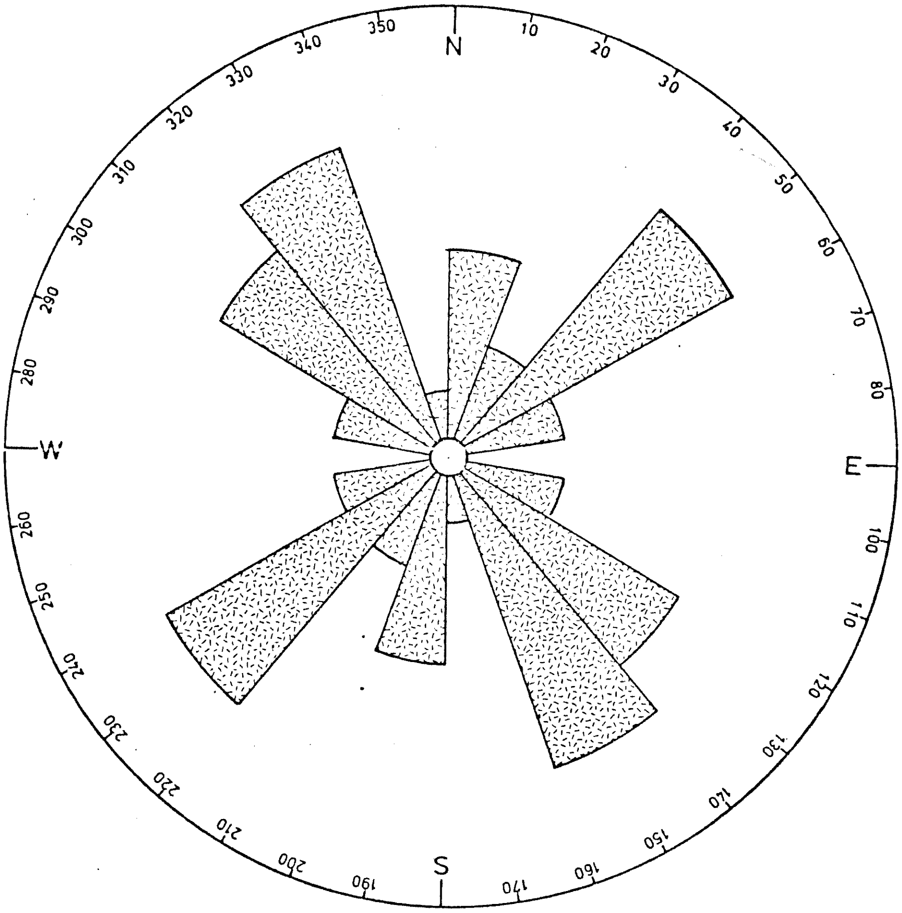


Fig6 STEREOGRAPHIC PROJECTION OF POLES OF JOINTS AT MUSQUODOBOIT HARBOUR

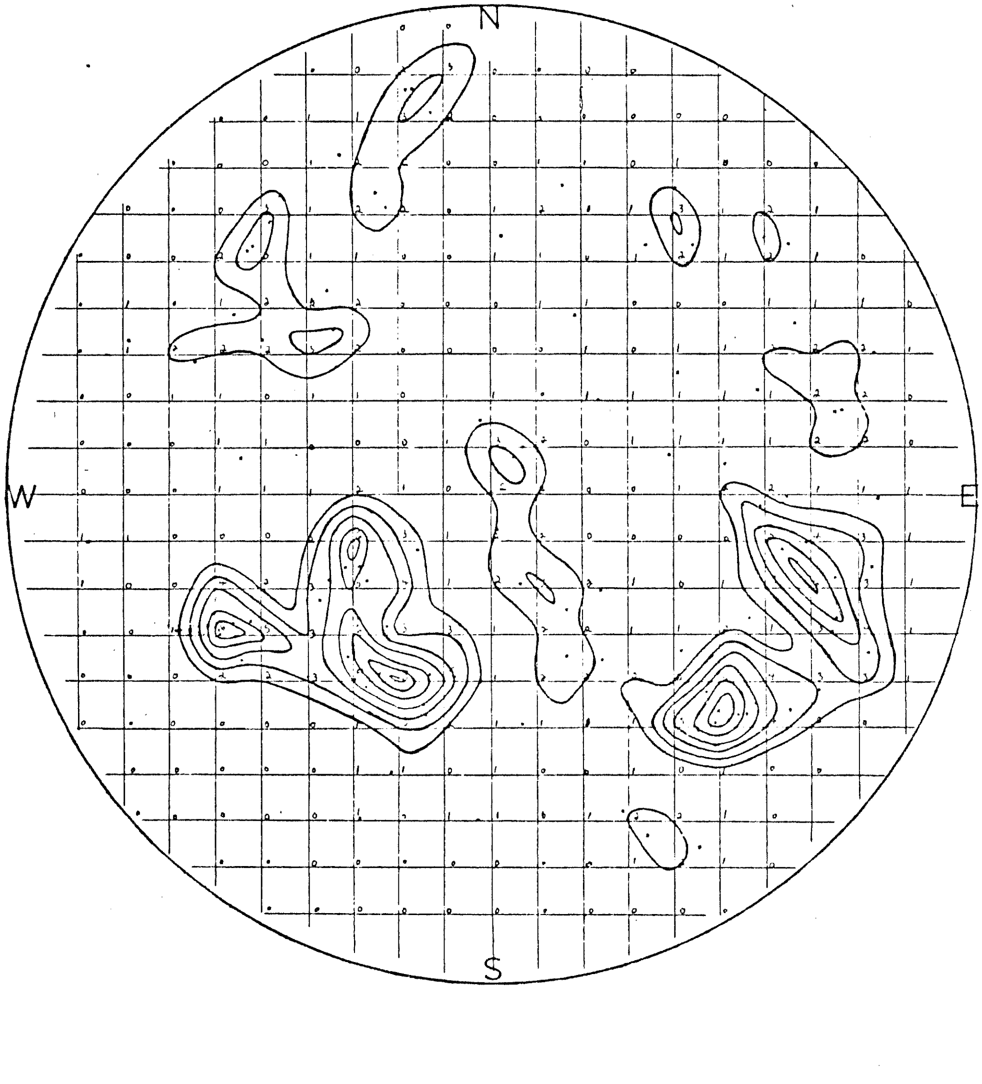
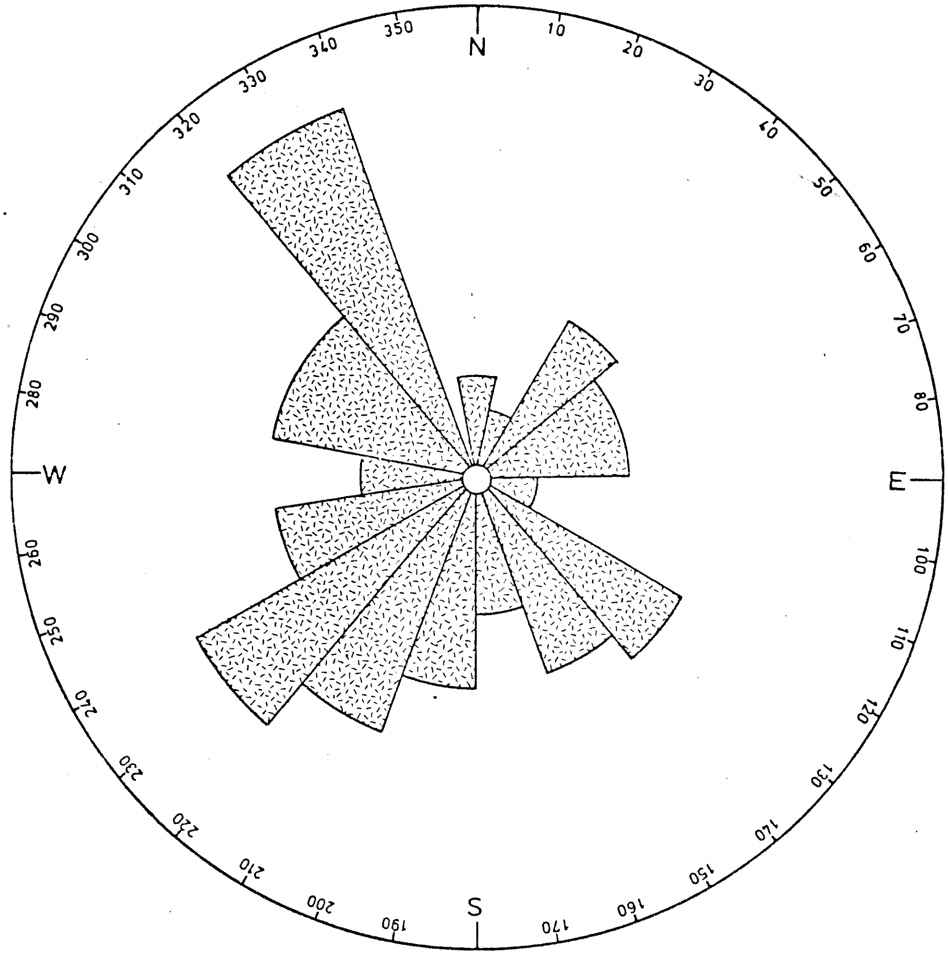


Fig 7 ROSE DIAGRAM OF JOINTS AT MUSQUODOBOIT HARBOUR



gaping fractures striking east west but these do not appear. The reason for this is not known.

Surficial geology

The Musquodoboit Harbour area, like the rest of Nova Scotia was extensively glaciated during the Quaternary. Most of the surficial deposits, therefore, consist of glacial drift (fig. 4). The glacial deposits are of: (1) unstratified nature and (2) stratified nature.

(1) The unstratified material occurs within an extensive till sheet. This tends to cover the lower areas and leave large areas of bedrock exposed on the highlands. The thickness of the sheet is variable with a maximum of about 6 m as can be ascertained from Nova Scotia Dept. of Mines well log records (Nova Scotia Dept. of Mines 1968, 1970).

The till is a light gray, loose, silty-sand type with numerous coarse, angular quartz and feldspar fragments. Its properties are similar to what is known as an ablation till characteristically developed over granitic rocks of the eastern shore. It extends several kilometers southward of the contact between the adamellite and Meguma rocks. This extension is probably due to the relatively high resistance to abrasion of its clasts, eg. quartz and feldspar.

(2) The stratified drift consists of both kame terraces and outwash gravel.

Kame terraces appear on both sides of the Musquodoboit river valley and are responsible for the lack of outcrop in the vicinity of the Dunbrack mine. Like the tills the kame deposits are generally thin, although there is one area with a substantial thickness of about 10 m. This is located 0.5 kilometres northwest of Musquodoboit Harbour and is presently being excavated for sand and gravel.

The outwash deposits are extensive throughout the Musquodoboit river valley. They tend to occur mainly in the lowest points of the valley and leave high points in the bedrock exposed (fig. 4). None are of a sufficient thickness to excavate commercially for sand and gravel.

Chapter 3

Geology of the Deposit

At the mine site a dike exists in the granite. It averages 4 feet in thickness and has an attitude of 290/62N. This dike is made up of a red to gray, fine-grained porphyritic rock with feldspar phenocrysts (Wroth 1937) (Plate 2). It is mainly quartz and feldspar and has been described as "resembling a dacite" (Wroth 1937). This rock was examined petrographically and found to be of granitic composition according to the percentages of mafic minerals, quartz, alkali feldspar and plagioclase.

The dike forms the foot wall of the mineralized quartz vein. The two are known to continue in association for at least 150 metres. Adamellite forms the hanging wall of the vein. The following is a typical sequence through the vein, (Wroth, 1937):

(1) Hanging wall: fairly soft, kaolinized granite.
(2) A zone of quartz, mixed with granite fragments and usually barren, but may contain specks and pockets of galena.
(3) A zone of mixed quartz and galena, the latter in massive streaks and pockets.
(4) The dike rocks, usually reddish in colour and more or less silicified, although the soft kaolinized variety is common.
(5) The granite footwall beyond the dike. (fig. 2)

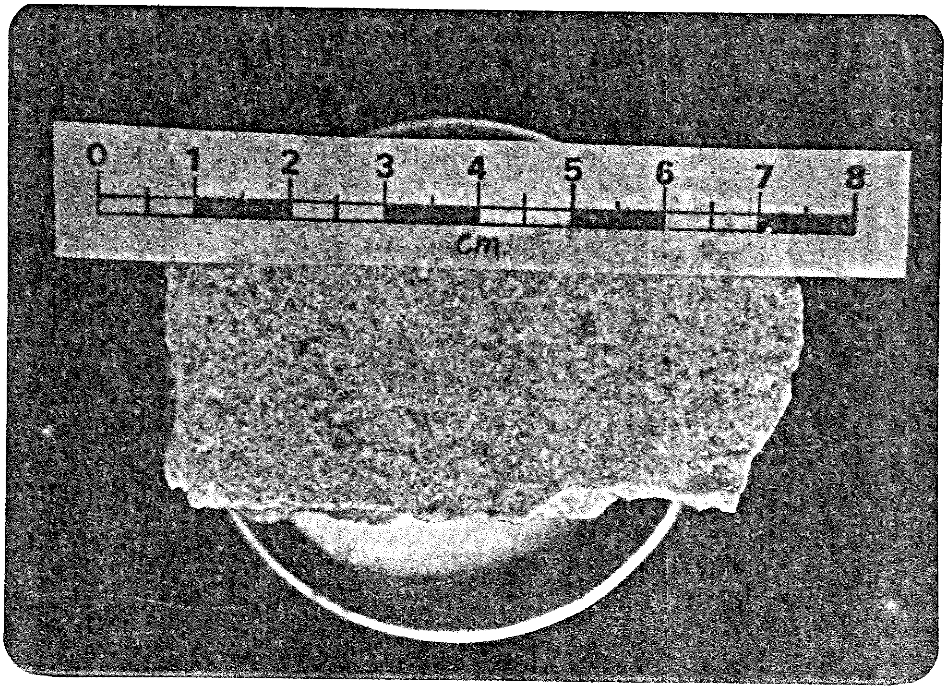


Plate 2. Dike rock

Macmichael (1975) found that the reddish colouration of the dike was imparted by iron staining and occurred only in the zone of alteration of the deposit.

The only significant mineralization was found in a single shoot. This extended from the surface to the 30 metre level in the number two shaft. It continued for 15 metres along the strike of the vein (Wroth 1937).

Chapter 4

Mineralogy

The Ore Minerals

The vein contains both primary (hypogene) and secondary (supergene) minerals.

Primary: The principal ore mineral is argentiferous galena which occurs in massive streaks and pockets in the quartz. Grades range up to 26.39% lead and 4.6 oz/ton silver. The average high grade ore runs 13.87% lead and 2.3 oz/ton silver (Wroth, 1937) (fig. 2).

Pyromorphite ($Pb_5 Cl(PO_4)_3$) has been reported at Dunbrack by Von Bitter (undated) who suggested it had a secondary origin. Chatterjee (1977) also observed it and reported "Its presence as well formed crystals with quartz and tridymite, and also its association with unoxidized pyrite and meneghinite in meta-arkose suggest a primary origin." Meneghinite ($Pb_{13} Sb_7 S_{23}$) also reported by Chatterjee (1977) occurs in black striated crystals and can be identified in hand specimen Its origin is not known.

The copper minerals include chalcopyrite and bornite and are disseminated through the quartz in small specks. They are present in a very minor amount.

Sphalerite occurs in low grades and has been observed by several authors. Zinc values for drill core given by F. J. Hogan (1954) are quoted at 1.37 and 1.85%.

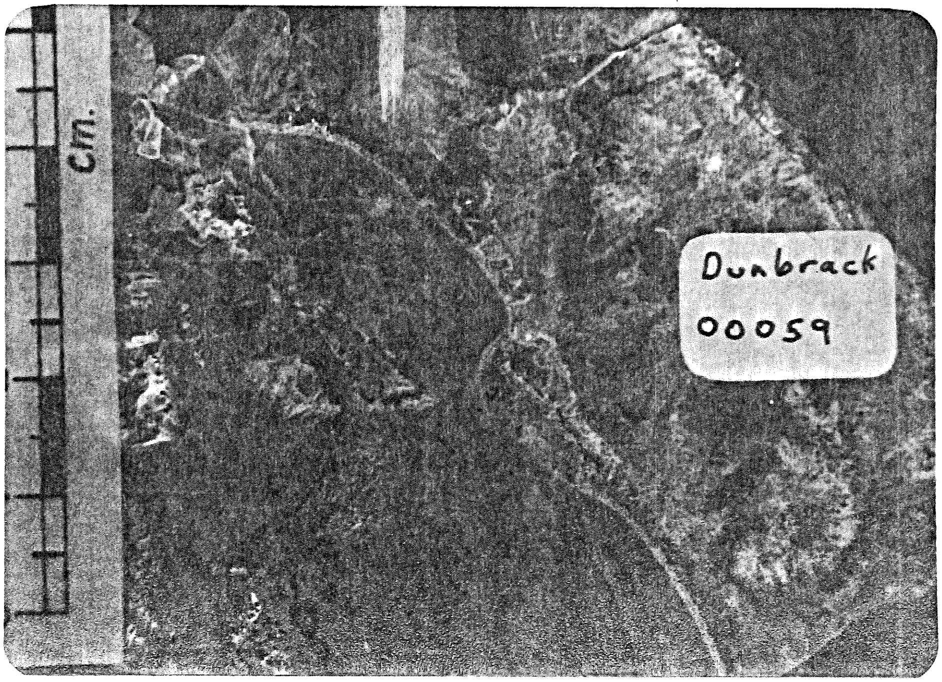


Plate 3. Laminated jasperoid, note the fragments of quartz in the microcrystalline matrix. Also note the zone of drusy quartz at the margin of the jasperoid.

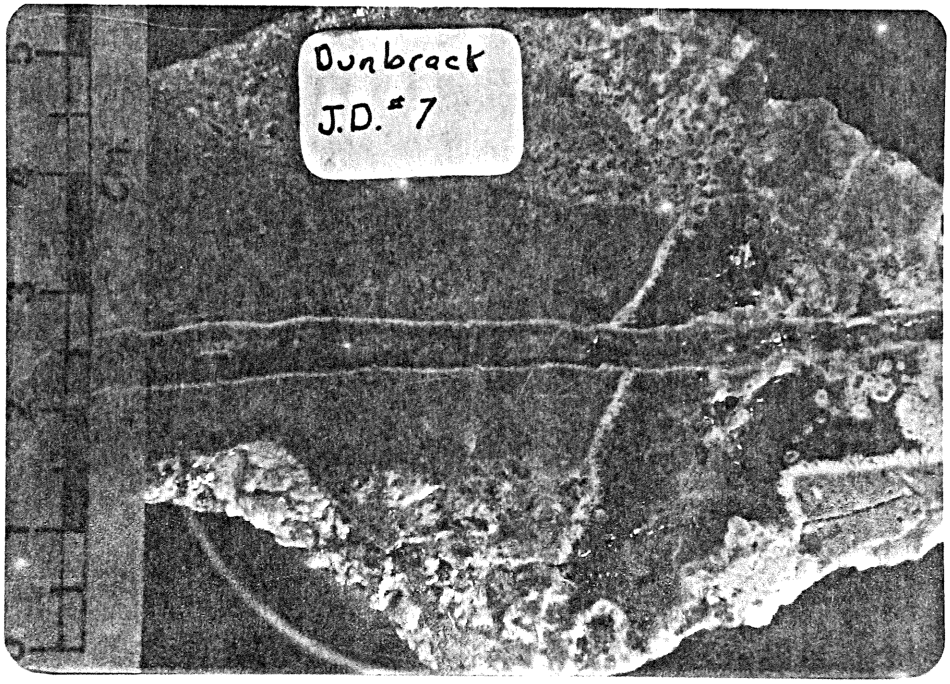


Plate 4. Massive jasperoid. Note cross cutting relationship of late quartz. Also note druse similar to Plate 3.

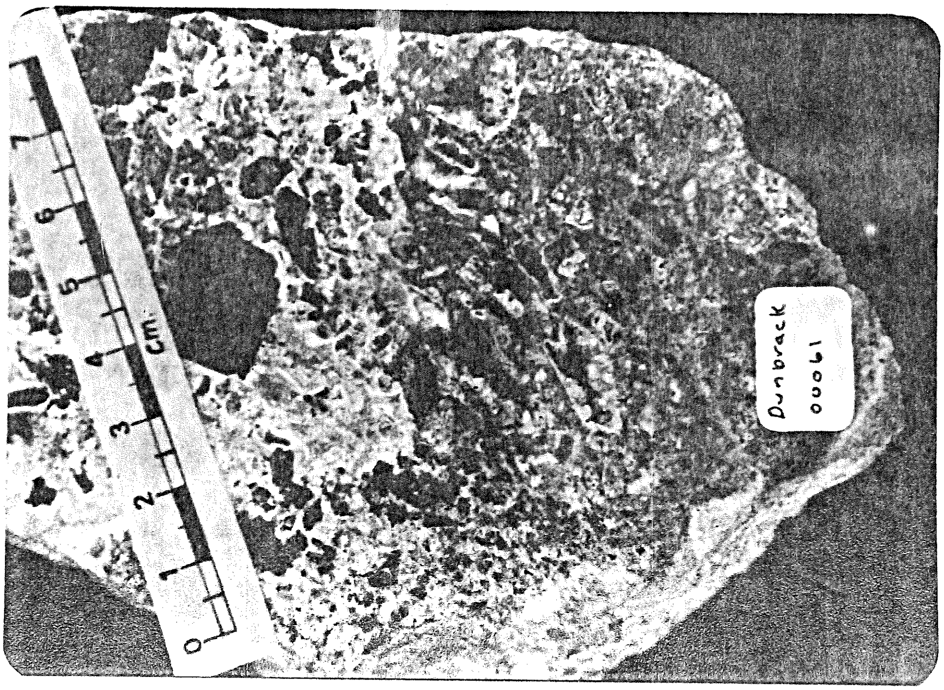


Plate 5. Ore zone. Note lining of medium grained quartz in cavities. This has the same optical properties as the druse in Plates 3 and 4.

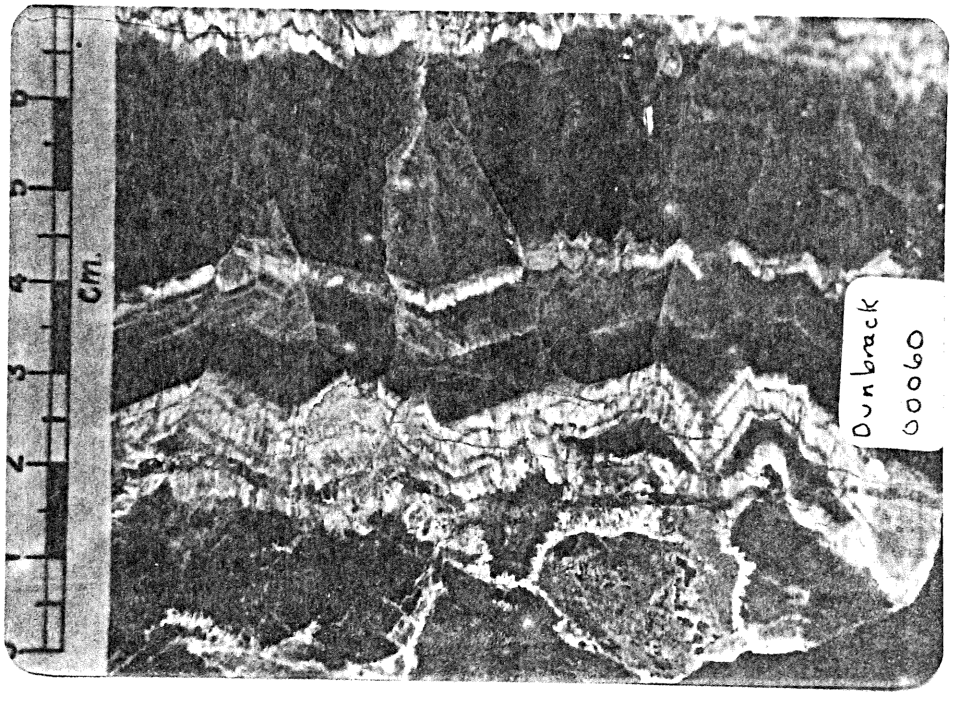


Plate 6. Macrocrystalline smoky quartz with chalcocite after galena.

Secondary: Although cerussite is common, the copper minerals are the most impressive secondary minerals. These include chalcocite, djurleite, digenite, chrysocolla, covellite, malachite, azurite and cuprite. These are formed by supergene enrichment and may replace primary minerals, e.g. chalcocite after galena (Macmichael, 1975).

Limonite is common in oxidized ores. Kaolin as an alteration mineral has been reported by both Von Bitter and Wroth (1937). Fluorite, ilmenite and pyrolusite were observed by Macmichael (1975).

The SiO_2 minerals

Quartz occurs in numerous phases at the Dunbrack mine. Both coarse grained crystalline and cryptocrystalline varieties are present.

The cryptocrystalline quartz is a hematite-stained jasperoid. It occurs in both laminated (Plate 3) and massive (Plate 4) varieties and contains numerous fragments of coarse grained quartz. It appears to have been deposited in a zone of brecciation of previous coarse grained crystalline quartz.

On the margins of the zones of jasperoid (Plate 3) and lining veins cutting it (Plate 4) there appears a druse with medium grained prismatic quartz. This type of quartz also occurs as a lining of vugs (Plate 5), which may or may not be subsequently filled with coarse grained quartz. When examined petrographically it shows hexagonal, sector twinning. It is most likely this material that has been described by Friedlaender (1970) as tridymite. This will be discussed in the following chapter.

Coarse grained quartz occurs in several varieties. These include milky, amethystine, and smoky quartz (Plate 6).

Chapter 5

The Tridymite Problem

Introduction: Tridymite is a high temperature, low pressure polymorph of quartz. Its stability range can be seen in figure 8. It can exist metastably, in α and β forms, at all temperatures below its melting point of 1670°C (Deer , Howie and Zussman, 1966).

C. G. I. Friedlaender reported the presence of tridymite trillings at Dunbrack (Friedlaender, 1968). He did numerous optical determinations with the universal stage and found axial angles in the trillings averaging 16°. Lamellae in quartz, resembling polysynthetic twinning had axial angles of about 30°. A Debye Scherrer photograph by Friedlaender of the material gave, with the exception of one line (d = 3.7231), only quartz lines. On this evidence he suggested a high temperature, possibly metamorphic origin for the deposit.

Work done: The trillings described by Friedlaender (1970) were observed by the author in thin section. Determinations were done using Zeiss instrumentation with pol 2.5, pol 10, pol 40 and pol 63 objectives and pol 8X and kpl 20X oculars.

The crystals are divided into six sectors (Plate 7). Interference figures of individual sectors are biaxial with a 2v of 5-10°. Small V-shaped internal sectors, also described by Friedlaender (1970) (Plate 7) were found to have a fairly constant 2v of 20-25°.

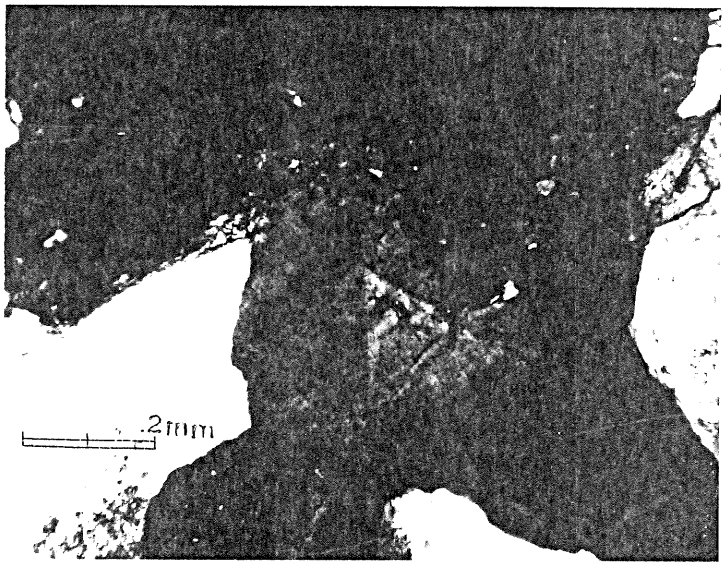


Plate 7. Note triangular sectors of crystal with smaller internal V-shaped division.

Refractive index was measured using index of refraction liquids. To facilitate the determinations the coverglass was removed from a thin section and the balsam dissolved. The epoxy was scraped away and the refractive index was measured on the thus exposed grains and was found to be 1.548. There was no difference in refractive index between the small internal sectors and the large wedge shaped sectors previously mentioned.

Numerous powder x-ray diffraction runs were done on all varieties of quartz. These included runs using both glass slides and aluminum sample holders. Only quartz peaks were found (Appendix 3).

The specific gravity of quartz is 2.65 while that of tridymite is 2.26. It should, therefore, be possible to separate the two using heavy liquids. A sample was chosen in which the presence and grain size of tridymite could be observed in thin section. In accordance with the average grain size of .25 mm observed, the sample was crushed and dry sieved and the 3ϕ fraction used in the separation. A mixture of tetrabromoethane and acetone of specific gravity 2.58 was used. Very little material floated and it rose very slowly. The light fraction was examined with powder x-ray diffraction but still only quartz peaks were observed. The grains were examined petrographically and were seen to contain many fairly large fluid inclusions which accounts for their lower specific gravity.

Considering the possibility that the preparation technique of crushing the sample for powder x-ray diffraction causes meta-stable tridymite to revert back to quartz, x-ray diffraction was done using the Straumanis camera method with an uncrushed, single crystal. A single trilling was picked off a thin section, mounted on a spindle and x-rayed for 24 hours (see Appendix 2 for film). Only quartz lines were found (Table 1). Even the single tridymite line found by Friedlaender (1970) did not appear. The origin of this line is uncertain though it does correspond with lines produced by probable associated minerals.

Tridymite has an open crystal structure. This allows aluminum to substitute for silicon in the crystal and it is also reported to cause trapping of alkalis in the crystal (Deer, Howie and Zussman, 1966).

Analyses of the trillings were done by Mr. R. M. MacKay using the electron microprobe. Only background values were obtained for Na, K and Ca but aluminum was about 1%. It is not certain whether the microprobe can discriminate between the amount of Al in solid solution in the crystal structure or that in minute solid inclusions observed in the grain. A grain of quartz was also measured and the crystal itself had only background aluminum. Inclusions in it however had values comparable to the value obtained in the trilling. (Table 2)

Discussion

Observed here is a mineral with the x-ray diffraction pattern of quartz. It also has the refractive index and specific gravity of quartz. Quartz however has not been previously known to twin in the

Table 1

Straumanis Camera X-ray Diffraction Pattern of Trilling

°2θ	D-spacing
20.82	4.281
26.54	3.359
36.54	2.458
39.43	2.284
42.40	2.130
45.70	1.984
50.15	1.817
54.91	1.671
60.06	1.539
68.16	1.375

Table 2

Electron microprobe analysis of trilling for silicon and aluminum

	Si counts	Al counts	Al%
Quartz standard	675114		
JD 17 grain # 1	675550		
JD 17 grain # 2	673326		
JD 17 grain # 3	668540		
JD 17 grain # 4	673069	8320	1.24
JD 17 grain # 5	682627	1612	0.24

form of the trillings described. It also is uniaxial except in strained crystals. The maximum 2V in such a strained crystal however, is only 10° (Kerr, 1959). The value of 20-25° obtained, greatly exceeds this.

At this point it would be well to note that fluid inclusion homogenization temperatures are very low (fig. 8). They describe a pressure-temperature range for the deposit far below the stability field of tridymite. The identification of this mineral is therefore open to question and necessitates further investigation.

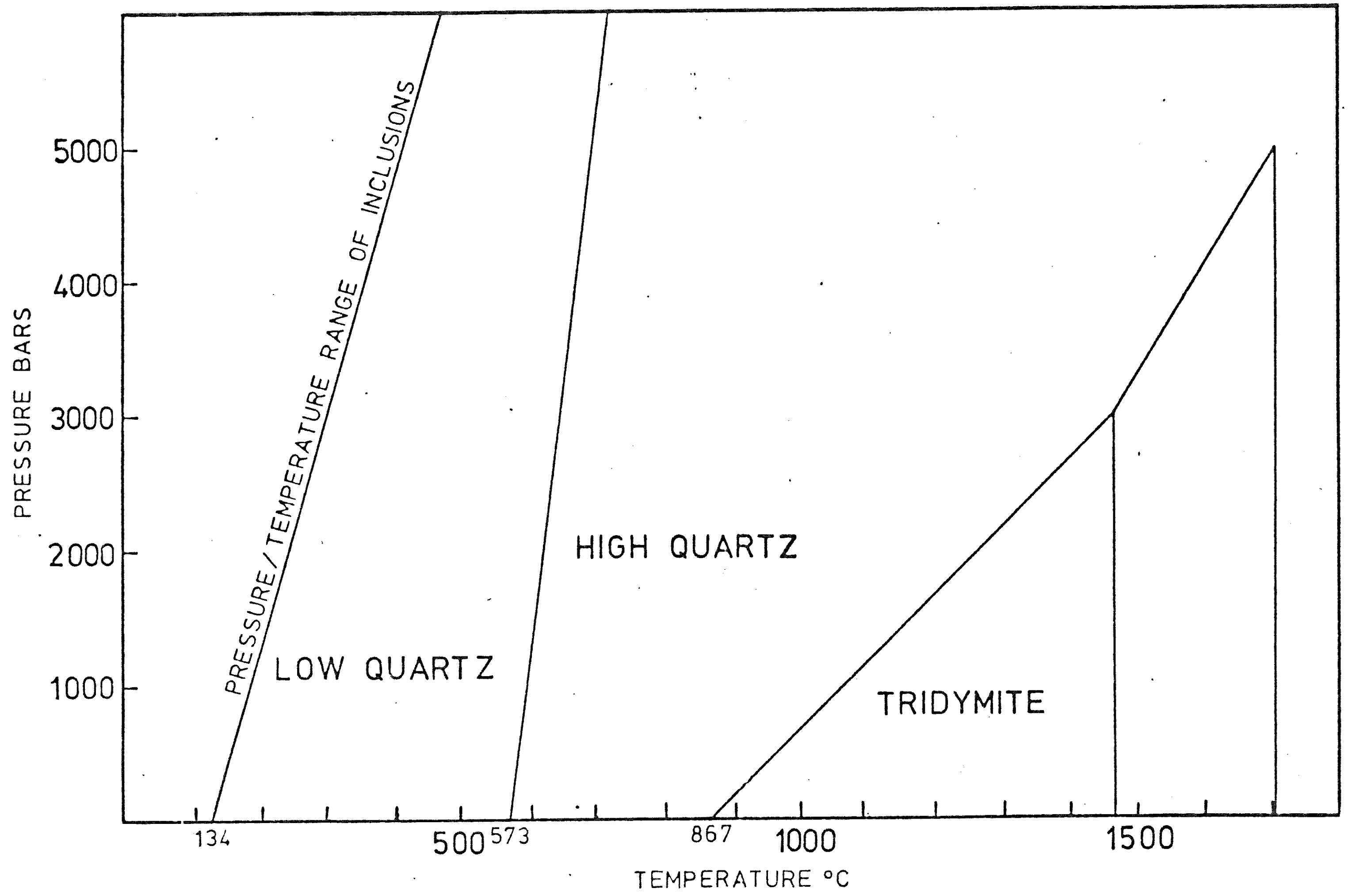


Fig 8 PRESSURE-TEMPERATURE DIAGRAM FOR SiO_2 (after Tuttle, O.F. and Bowen, N.L., 1958, Mem. Geol. Soc. Amer., no. 74)

Chapter 6

Fluid Inclusion Geothermometry

The objective of studying fluid inclusions from this deposit was to obtain temperatures of formation of the mineralization. It would have been preferable to use inclusions in the ore minerals themselves, but, unfortunately, the ore minerals at Dunbrack are all opaque. This makes optical observation, of inclusions contained within them, impossible. It was therefore necessary to use gangue minerals contemporaneous with the mineralization. Contemporaneaty was established by observing the "compromise" growth surface between the ore and gangue minerals which is characteristic (e.g. Roedder, 1976) of two crystals growing at the same time.

1 mm thick doubly-polished sections were used. Due to the transparency of the quartz this thickness did not interfere with observation and allowed a greater volume of sample to be searched for good inclusions.

Primary inclusions were selected on the basis of negative crystal shape, occurrence in 3 dimensional formations and occurrence with a great separation from other inclusions in the crystal (Roedder, 1976). Secondary inclusions were identified on the basis of occurrence in discrete planes in the crystal and on evidence of "necking-down." (Roedder, 1976). These secondary inclusions give erratic unreliable homogenization temperatures and were not used.

A Zeiss binocular research microscope was used with objectives UD20 and UD40 and 12.5X oculars. Heat was supplied to the sample by the use of a stage with an electrical heating element in which the current could be varied. This allowed control over the rate of temperature increase. Temperature was measured with a chromel-alumel thermocouple with a digital millivolt readout. The millivolt reading was converted to °C using the conversion chart for this thermocouple.

Homogenization temperatures were measured on a total of 51 primary inclusions in various types of quartz. 46 of these were in the various macrocrystalline quartz varieties and 5 were in the trillings. The temperatures obtained ranged from 98°C to 253°C with a mean of 134°C (fig. 9) (Table 3).

Inclusion fluid is compressible. Therefore the mass-per-unit volume (density) varies with pressure. This means that a larger amount of fluid will be trapped in an inclusion formed at high pressure. The bubble size in such an inclusion will therefore be smaller than one formed at the same temperature and low pressure. This will decrease the measured homogenization temperature. It is possible to calculate a correction factor for the effect of increasing pressure on homogenization temperatures. Roedder,(1967) shows a graph on which homogenization temperature and pressure data are plotted with density of the inclusion fluid (fig. 10). It is possible to use this graph to obtain pressure corrections for inclusions of any density. This was done for inclusions at Dunbrack and a correction factor of 56.8° per kilobar was obtained

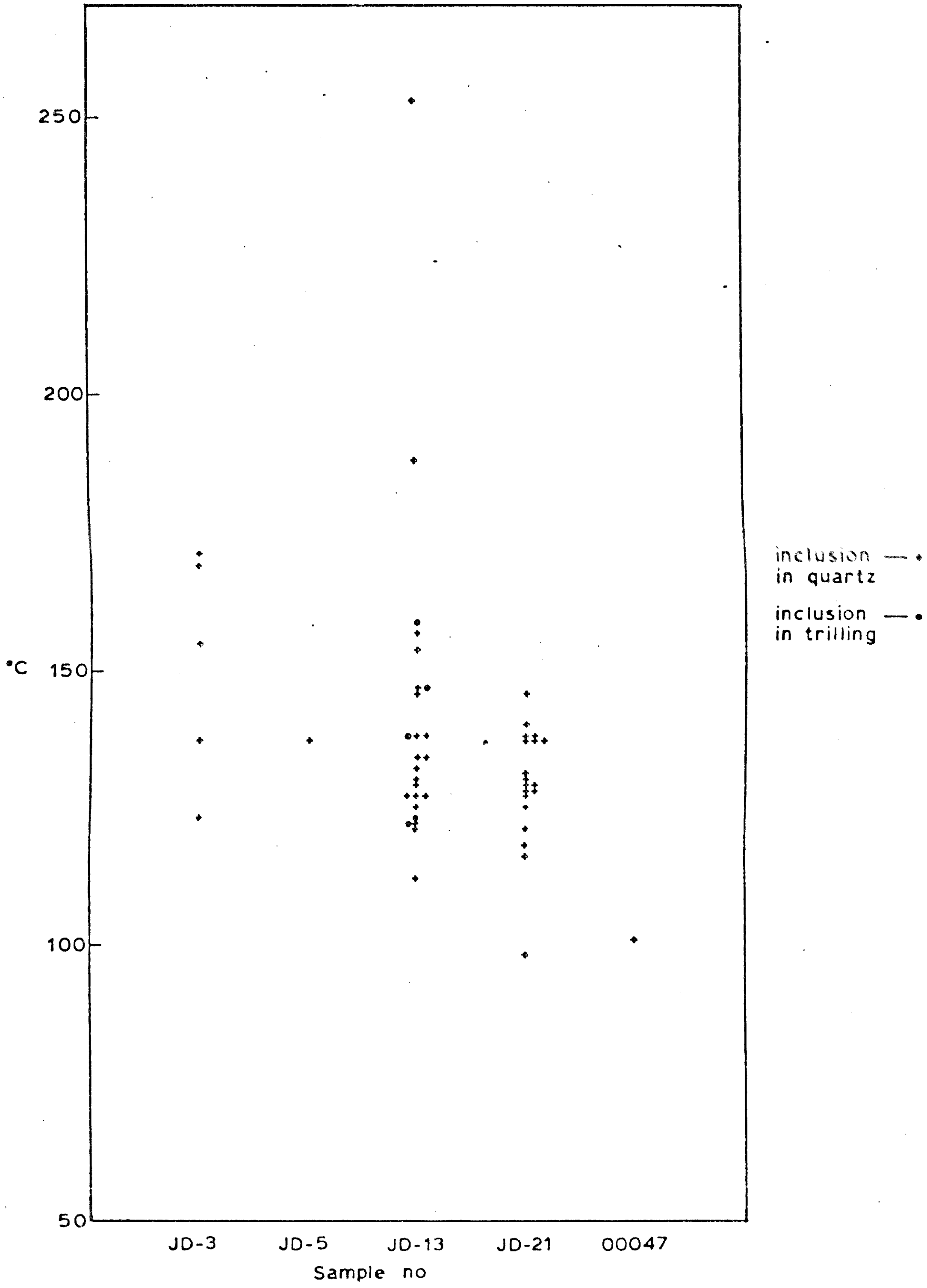


Fig9 FLUID INCLUSION HOMOGENIZATION TEMPERATURES FROM DUNBRACK QUARTZ

Table 3

Sample #	Inclusion #	Millivolts	Temp. °C
JD # 3	1	5.02	123
	2	5.62	137
	3	6.32	155
	4	7.00	171
	5	6.88	169
JD # 21	1	5.31	130
	2	6.00	146
	3	4.94	121
	4	5.21	127
	5	5.60	137
	6	5.66	138
	7	5.30	129
	8	4.79	116
	9	4.83	118
	10	?	?
	11	5.71	140
	12	5.60	137
	13	5.60	137
	14	?	?
	15	5.30	129
	16	5.10	125
	17	5.65	138
	18	4.00	98
	19	5.35	131
	20	5.25	128
JD # 5	1	5.60	137
00047	1	4.12	1.01
JD-13 quartz	1	5.14	125
	2	6.30	154
	3	5.51	134
	4	4.97	121
	5	4.58	112
	6	5.30	130
	7	5.19	127
	8	5.65	138
	9	5.50	134
	10	5.00	122

Sample #	Inclusion #	Millivolts	Temp. °C
JD-13 (cont.)	11	5.20	127
	12	5.20	127
	13	5.41	132
	14	7.64	188
	15	10.27	253
	16	6.43	157
	17	5.66	138
	18	5.98	146
	19	6.02	147
trilling	1	6.50	159
	2	5.66	138
	3	5.02	122
	4	?	?
	5	6.09	147
	6	5.03	123

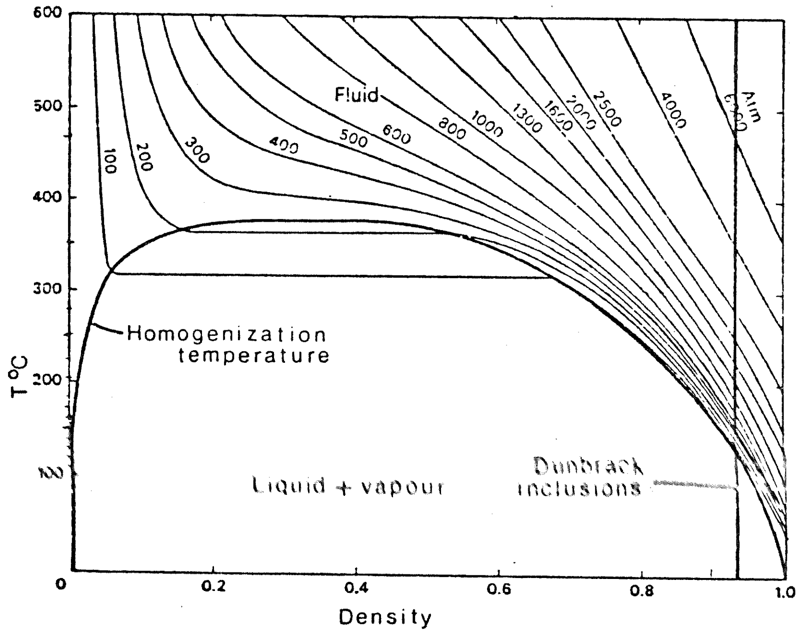


Fig. 10 Dunbrack inclusions plotted on a temperature-density diagram. Density is the ratio of the volume of liquid in an inclusion to the volume of liquid plus vapour. Pressure is determined relative to temperature for the Dunbrack inclusions.

(fig. 8). This correction varies with the salinity of the fluid (Roedder, 1976) due to the effect of salinity on the compressibility of the fluid but this variation is negligible.

Discussion

The fluid inclusion data indicates a low temperature of formation for the deposit. If the pressure on the deposit was 1 k bar, equivalent to 3.5 kilometers of cover, the temperature would still be below 200°C. This effectively rules out the possibility of the existence of stable tridymite in the deposit.

Figure 11 is a plot of the temperature-pressure range of the formation of the inclusions on the same graph as the emplacement conditions for the batholith. At the calculated pressure of formation of the batholith the observed temperature of the inclusions is 350°C lower than the temperature of crystallization of the batholith. This is a large discrepancy and is difficult to account for.

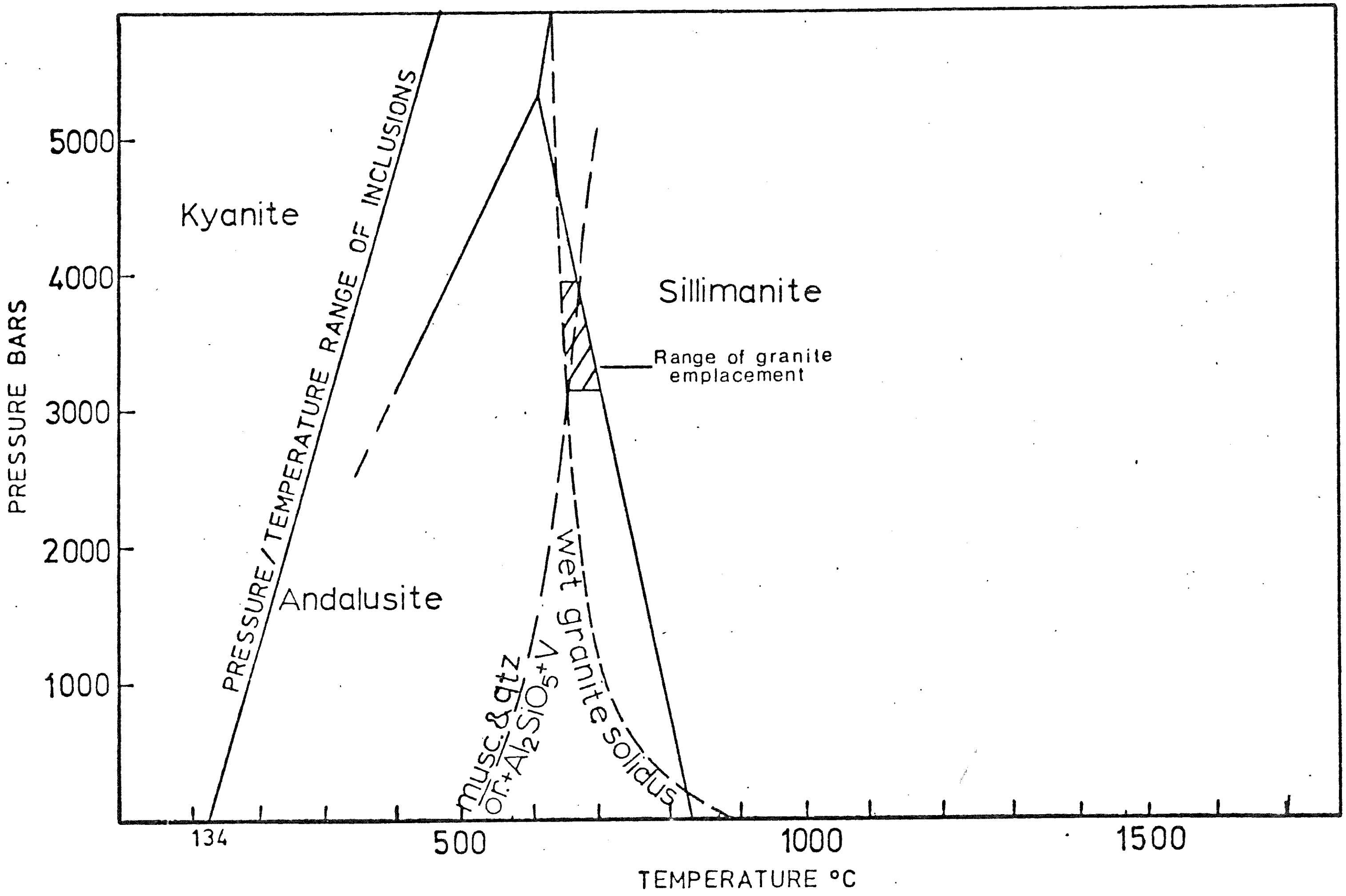


Fig. 11 Pressure-Temperature range of emplacement of the granite plotted on the same diagram as the pressure-temperature range of formations of the inclusions at Dunbrack. (After McKenzie 1974).

Other Geothermometry

In fig. 8 temperature of formation varies with pressure. If temperature could be obtained independently then it would be possible to determine both the temperature and pressure conditions under which the deposit was formed. This was attempted at Dunbrack.

W. H. Dennin and W. H. Blackburn (1970) report that the amount of aluminum replacing silicon in the quartz structure varies directly with the temperature of crystallization. They have determined that the magnitude of this variation is approximately 1 ppm aluminum per 3.6°C. (fig. 12) and that in addition it is pressure independent.

Grains of quartz from Dunbrack were crushed and examined using a 15X binocular microscope. Transparent quartz grains with no visible inclusions or discolouration were chosen. These were crushed in an iron mortar. Measurements were done at the Nova Scotia Technical College by Mr. Cyril Cole by emission spectrographic procedure.

The aluminum concentration was found to be about 500 ppm (Table 4). Unfortunately this is far above the maximum value seen by Dennin and Blackburn (1970) (Fig.12). It is likely that the sample was contaminated at some time during the preparation procedure.

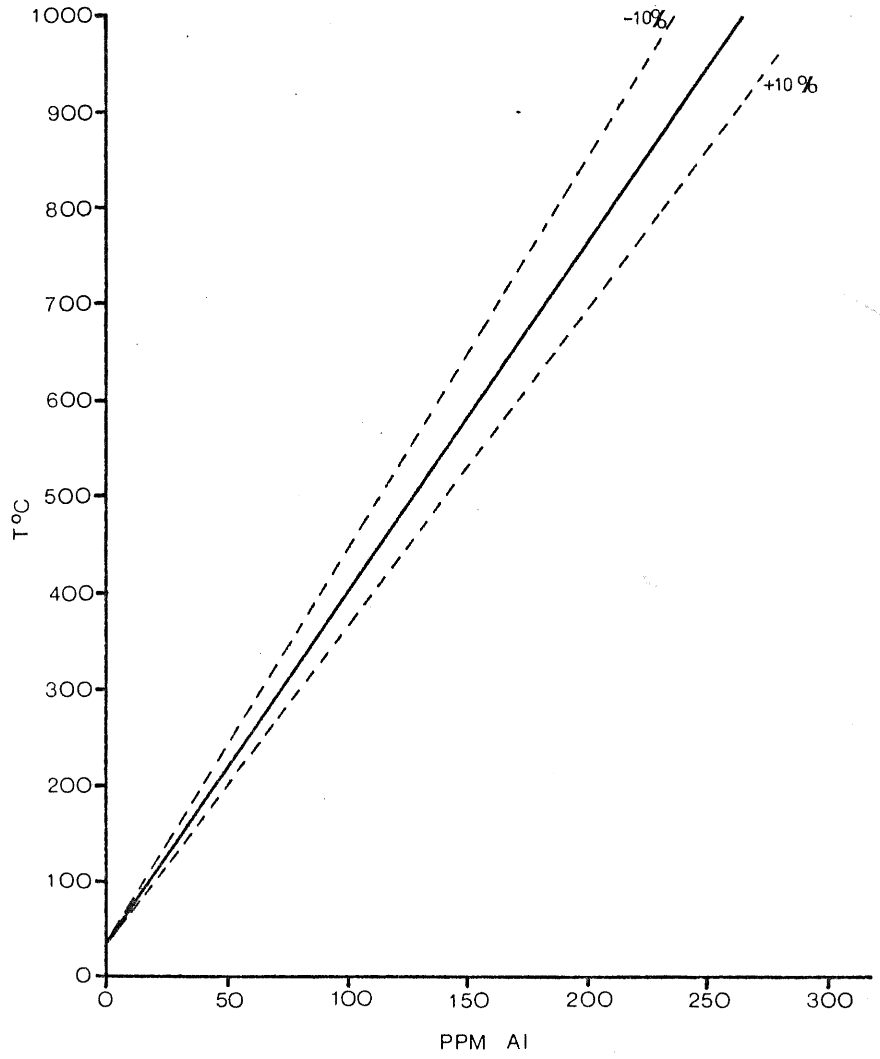


Fig. 12 Concentration of aluminum replacing silicon in the quartz structure as it varies with temperature of formation (after Dennin and Blackburn, 1970).

Table 4

Aluminum content in ppm. of transparent megacrystalline quartz from Dunbrack

Line measured	Al 3092.71	Al 3082.16
Trial no. 1	740	695
Trial no. 2	690	620
Trial no. 3	485	475

Chapter 8

General Discussion

The tridymite reported by Friedlaender (1970) as an indicator of a contact metamorphic origin for the deposit does not appear to be tridymite. If Friedlaender is correct in his determination, however, this does not necessitate high temperature conditions during the formation of the deposit.

Jones and Segnit (1972) described a process by which metastable tridymite can be formed at low temperatures. This involves the formation of hydrated silica polymers which initiate the tridymite structure in low temperature aqueous solutions. If there is insufficient energy in the system these original bonds are not broken and the crystal continues to form the tridymite structure. Contrary to what Friedlaender (1970) suggests this would imply not a very high temperature of formation but a very low one.

In addition metastable tridymite is highly sensitive to high pressure. A pressure of greater than one kilobar will cause it to revert back to quartz (Jones and Segnit 1972). Therefore it the mineral observed at Dunbrack is tridymite, as claimed by Friedlaender, this would date its formation as being fairly young, unaffected by Carboniferous-Triassic buried episodes documented for Nova Scotia.

The occurrence of the deposit in a fracture which has the same orientation as the regional joint and lineament trend and also the fractured nature of the dike and vein material is distinctive. It implies that the mineralization was introduced during the period which produced the regional fracturing in this area. If this is the case the deposit may not be unique. Numerous reports of galena in float in widely distributed locations are further evidence to support this possibility. The Dunbrack deposit itself has not been adequately explored. The mineralization was seen to continue below the 90 foot level but was not explored past this level. There is no reason to expect that the mineralization does not continue to substantial depths.

Chapter 9

Conclusions

The mineral, reported by Friedlaender (1970) as tridymite, appears to be a form of quartz. If Friedlaender was correct the low temperatures obtained from fluid inclusions necessitate that it is metastable tridymite. In either case both the pressure temperature conditions and the geochronology indicate that it was not related to the intrusion of the adamellite in either a hydrothermal or contact metamorphic sense.

The association of the deposit with the regional fracture pattern suggest that is was emplaced during a regional tectonic event. Therefore the possibility exists not only that this deposit may be more extensive but that numerous other such deposits may exist. That none of these have been found is probably due to the extensive cover of till.

Recommendations for Future Work

(1) To do detailed optical and x-ray diffraction determinations to positively identify the tridymite-like mineral.

(2) To do sulfur isotope work to obtain a temperature and therefore an accurate pressure correction for the deposit.

(3) To do complete dating of alteration produced by the mineralizing fluids.

Acknowledgements

The author wishes to express his deepest gratitude to Dr. M. Zentilli for his support and guidance throughout the course of study. Thanks are extended to Dr. D. B. Clarke for his assistance with the universal stage microscope. The author also wishes to express his gratitude to Mr. Bob MacKay for his microprobe analysis. of Quartz. Thanks are due to Mr. Dan Plasse for his assistance with camera x-ray techniques. Thanks are also due to Mr. Dean Cutting for his assistance with photography and the use of his camera.

References

Alcock, F. J. (1930). Zinc and Lead Deposits of Canada. Geologic Survey of Canada, Economic Geology Series # 8, pp. 61-63.

Chatterjee, A. K. (1977). Comments on the Association of Tridymite, Pyromorphite and Meneghinite from Dunbrack Prospect. Nova Scotia Department of Mines and Mineral Resources Division, Report of Activities, pp. 99-102.

Deer, W. A., Howie, R. A., and Zuissman, J. (1966). An Introduction to the Rock Forming Minerals. Longman, London, New Impression 1971, 528 pp.

Dennin, W. H., and Blackburn, W. H. (1970). Aluminum in Quartz as a Geothermometer, Contr. Min. and Petrology, v. 27, pp. 332-342.

______________ (1971). Reply to the Discussion on Aluminum in Quartz as a Geothermometer. Contr. to Min. and Petrology, v. 30, pp. 356-358.

Friedlaender, C. G. I. (1968). Tridymite in Mineralized zone at Dunbrack, Musquodoboit River, Nova Scotia. The Canadian Mineralogist, vol. 9, pp. 572.

______________________ (1970). Tridymite in the Gangue of a Pb-Cu-Zn Occurrence, Schweiz., Min. Petrol. Mitt., vol. 50, pp. 183-199.

Fyson, W. K. (1966). Structures in the Lower Paleozoic Meguma Group, Nova Scotia. Geological Society of America Bulletin, vol. 77, no. 9, pp. 931-943.

Hayes, A. O. (1917). Investigations in Nova Scotia. Geological Survey of Canada Summary Report, (1917), part F, pp. 20-30.

Hogan, F. J. (1954). Certificate of Analysis, Lakefield Research Ltd., Lakefield, Ontario. Reference no. 4049045-8.

Jones, B. E. and Macmichael, T. P. (1976). Observations of the Geology of a Portion of the Musquodoboit Harbour Batholith. Nova Scotia Dept. of Mines, Mineral Resources Division, Report of Activities (1975) Report 76-2, pp. 63-71.

Jones, J. B. and Segnit, E. R. (1972). Genesis of Cristobalite and Tridymite at Low Temperatures. Journal of Geological Society of Australia, vol. 18, pt. 4, pp. 419-422, June 1972.

Kerr, P. F. (1959). Optical Mineralogy, McGraw Hill Book Company, Toronto, 1959.

McKenzie, C. B. (1974). Petrology of the South Mountain Batholith, Western Nova Scotia. Masters Thesis, Department of Geology, Dalhousie University, Halifax, N.S., April 1974.

Macmichael, T. P. (1975). Origin of the Lead, Zinc, Silver Ores and Alteration of the Surrounding Granite at the Dunbrack Mine, Musquodoboit Harbour, Nova Scotia. Honours thesis, Department of Geology, Dalhousie University, April 1975.

Messervy, J. P. (1928). Lead and Zinc in Nova Scotia, Nova Scotia Dept. of Public Works and Mines, Annual Report on Mines, Pamphlet no. 15.

Nova Scotia Dept. of Mines (1968). Water Well Records Nova Scotia, (1966) and (1967). Groundwater Section Report 68-4.

__________________________ (1970). Water Well Records Nova Scotia, (year ending December 31, 1969), Groundwater Section Report 70-2.

Roedder, E. (1967). Fluid Inclusions as Samples of Ore Fluids. In: Barnes, H. L. (ed.) Geochemistry of Hydrothermal Ore Deposits. Holt, Rinehart and Winston Inc., Montreal, pp. 515-567.

___________ (1976). Fluid Inclusion Evidence on the Genesis of Ores in Sedimentary and Volcanogenic Rocks. In: Wolfe, K. H., (ed.) Handbook of Strata-bound and Stratiform Ore Deposits, Vol. 2, pp. 67-110, Elsevier Scientific Publishing Co., N.Y.

Sabina, A. P. (1964). Rock and Mineral Collecting in Canada. Misc. Rept. Geol. Surv. Can., Vol. II.

Taylor, F. C. and Schiller, E. A. (1966). Metamorphism of the Meguma Group of Nova Scotia, Can. Jour. of Earth Sciences, vol. 3., pp. 959-973.

VonBitter, P., Minerals of the Dunbrack Mine, South Meadow Lake, Musquodoboit Harbour, Halifax County, Nova Scotia. Nova Scotia Museum, Halifax, N. S., unpublished.

Wroth, J. W. (1937). Report on the Dunbrack Mine, Nova Scotia, Canada, Nova Scotia Dept. of Mines Assessment File, unpublished.

APPENDIX

Appendix 1

Joint Sets Measured in the Railway Cut East of the Musquodoboit River

290/72
222/39
46/80
308/45
193/75
353/90
137/85
211/86
267/26
238/37
326/73
351/33
311/56
323/26
147/57
23/88
181/72
285/50
330/77
173/60
124/15
240/67
122/71

229/75
115/51
305/41
168/48
328/53
51/65
315/65
191/72
79/90
302/55
191/87
303/59
189/76
46/58
306/54
202/84
150/81
237/52
160/90
273/77
220/62
289/50
240/90

288/57
8/68
226/76
306/59
121/11
129/76
216/84
333/74
248/20
140/87
194/82
224/75
140/87
332/68
223/71
167/83
51/81
323/71
359/39
35/75
333/44
243/75
39/52

92/64
167/82
167/82
263/10
159/70
221/78
69/76
200/84
282/49
157/87
81/86
24/77
254/26
203/90
78/90
246/47
34/68
66/84
246/85
181/87
134/38
219/79
287/59

206/85
332/49
121/81
263/59
183/67
103/75
206/70
45/80
70/73
331/41
333/74
81/20

APPENDIX 2

APPENDIX 2a

ROM

ROYAL ONTARIO MUSEUM

DEPARTMENT OF MINERALOGY & GEOLOGY

100 Queen's Park
TORONTO, ONTARIO, CANADA M5S 2C6
Telephone (416) 978-3645
Cables: ROMA-Toronto

March 10th, 1978.

Dr. Marcos Zentilli,
Dept. of Geology,
Sir James Dunn Building,
Dalhousie University,
Halifax, N. S.
B3H 3J5

Dear Marcos:

Thank you for your letter of March 3, 1978. This is the type of work I like to do, especially if it does not take too much time. I have to admit that I was scared after I read the first paragraph in which you thank me for teaching you the U-stage methods. After such an overstatement, I was afraid that you might suggest a more time consuming project.

As it turned out, I was able to get some results after only a few hours. After so many years of research pretending to be a scientist, I have learned not to give a straight answer, even if I know it. In this case, I do not even know the answer, and all I can do is to describe what I saw.

I have examined two grains with the universal stage. They look exactly as the grain in Friedlaender's paper in Can. Mineral., v. 10, p. 705 (1970). My measurements are very similar to his, only I was not able to get such accurate results. I had trouble during the determination of the position of Y in parts marked 1,2,3,4,5,6. I am not sure that the position I gave on the drawing is really so. Those parts of the grain (1,2,3,4,5,6) are too small to give a conoscopic figure, even if I tried with the objective UM 50x and have used a special condenser. All I could see was a conoscopic figure of the whole grain, with a rather wide cross.

So I tried to measure the positions of Y and X in the usual way, but had trouble distinguishing between them. When I finally was satisfied that Y is set parallel to A4, and had A4 at 45° to the nicols, I could not see two extinctions corresponding to the two optic axes. The grain

Cont'd.

was dark, or in extinction, during the tilting on A4 for 10° - 15°. This may indicate that 2V is about 10° - 15°.

In both grains there are three areas or three lamellaes (marked 1', 3', 5'), which have larger 2V than the rest of the grain. These were also too small for a conscopic figure, but 2V was large enough to allow more accurate determinations. 2V for all those parts (marked in red, blue and green on the drawing) is about 30° (± 3). The positions of Y are marked on the drawing. They are much more reliable, than the positions of Y shown for other parts of the grain.

Therefore, there are two optically different phases in the grains. They are related by some kind of trigonal symmetry. They may even be twinned. The only difference which I can see between the two phases is in 2V. There is no difference in refractive indices. I could not measure birefringence because on all grains with the hexagonal outline Z was nearly vertical, and for accurate measurements we need either Nz - Nx or Nz - Ny.

As you can see I really cannot say whether it is trydimite or quartz. The indices of refraction seem to be that of quartz; the described grains have the same index as the grains on the edge of the thin section, which have "n" higher than balsam or epoxy (presumably 1,52-1,54). This indicates that this is quartz, with some areas of the grain with larger 2V, than the rest. All parts or zones are arranged according to the trigonal symmetry, or they are twinned parts of the biaxial mineral arranged to show pseudo-trigonal symmetry.

I leave you with these and several other similarly disturbing thoughts. Is it possible that heating of the thin section during the preparation, had caused strange effects? Is it possible to pick out a grain and have it x-rayed? Would it be possible to clean out the balsam and measure indices of a grain?

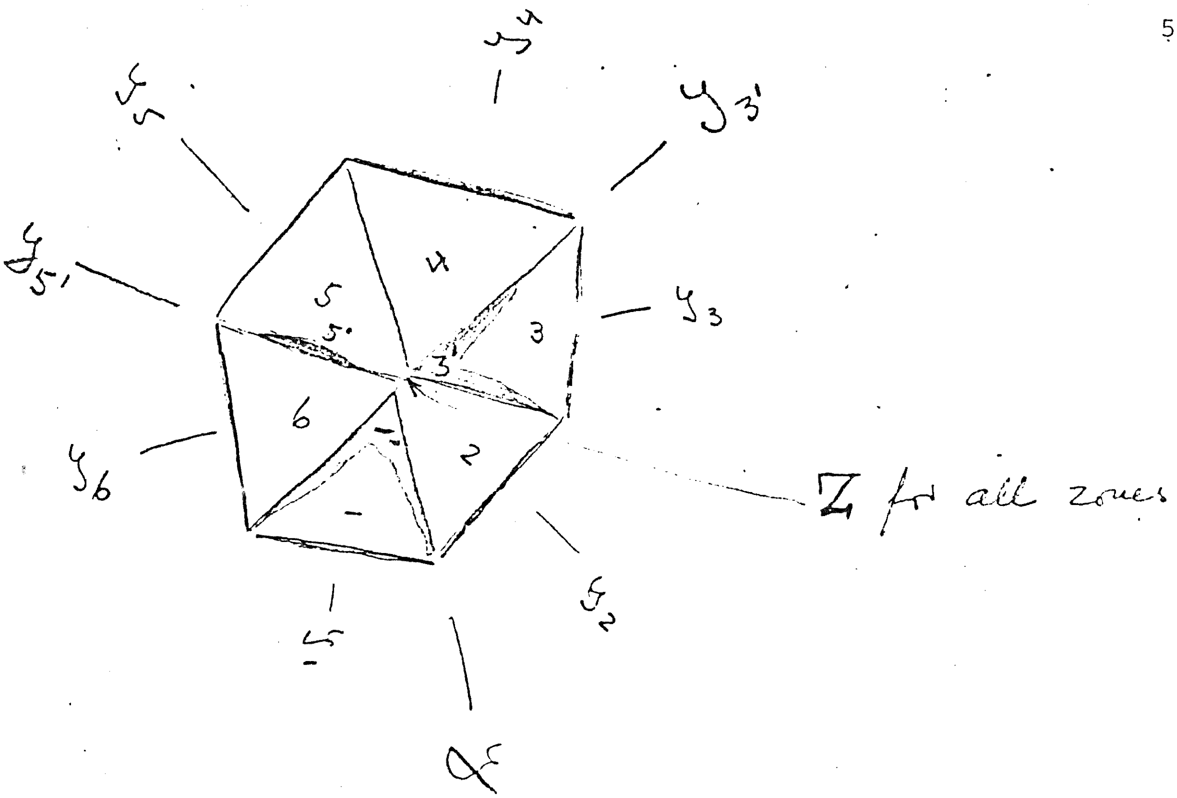
I am sure that this letter will only confirm some of your observations. I am sorry that I cannot give you a more definite answer. Let me finish this letter with a positive note. After 5 years here, I have finally equipped our lab with microscopes and instruments for special methods. I will be glad to help any way I can, when you need some determinations which require special methods.

Yours sincerely,

BDS/hd

B. D. Sturman,
Assistant Curator.

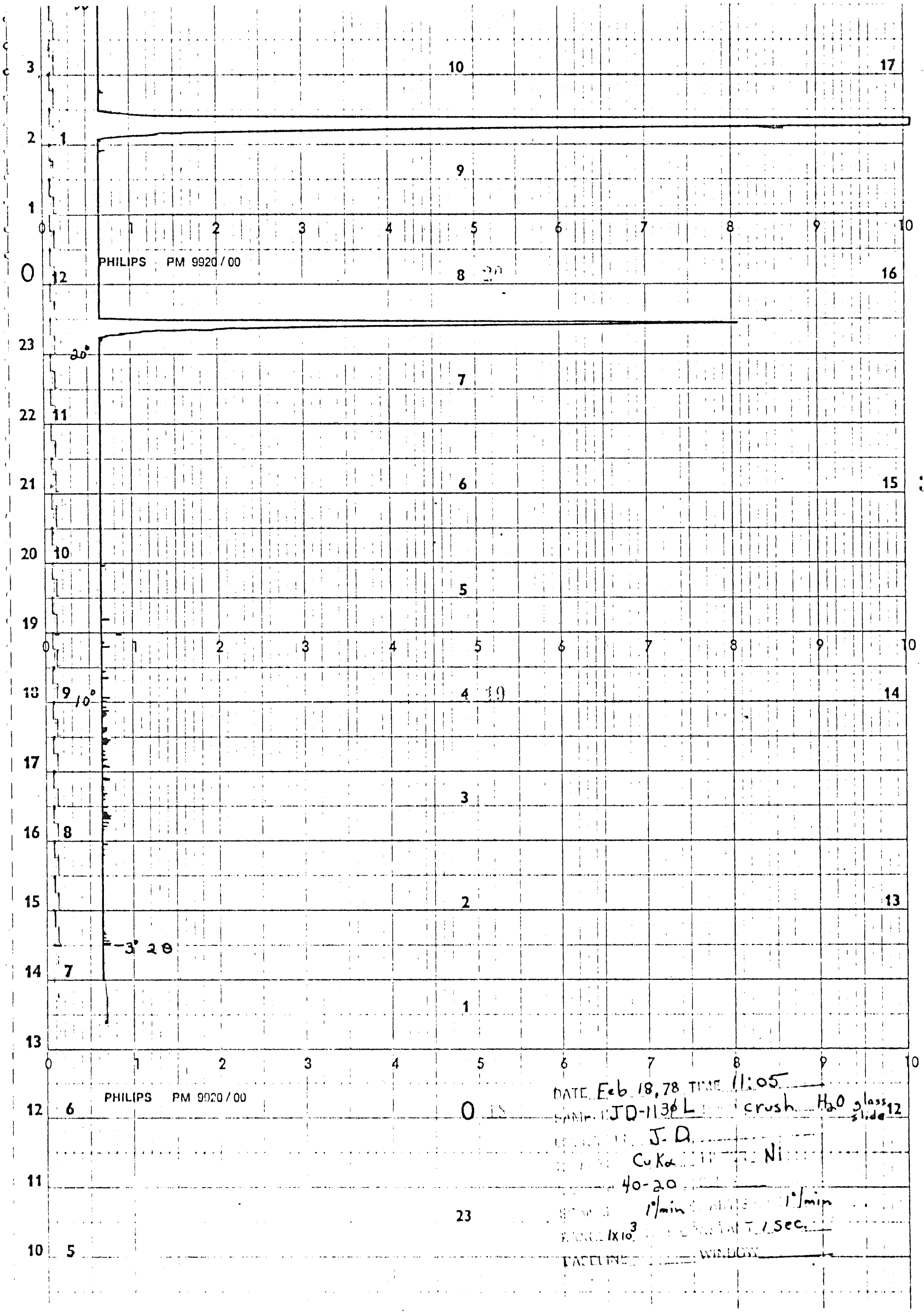
P.S. I have never finished my graduate Ph.D. studies at the U. of T. I am still only a plain mineralogist.



This is a drawing from Friedlaender's paper (Can. Min. 10, p.705). My grain is very similar.

Appendix 3

Examples of Powder X-ray Diffraction Patterns
for Dunbrack Quartz



DATE Feb 18, 78 TIME 11:05

JD-113φL crush H_2O glass slide

J. D.

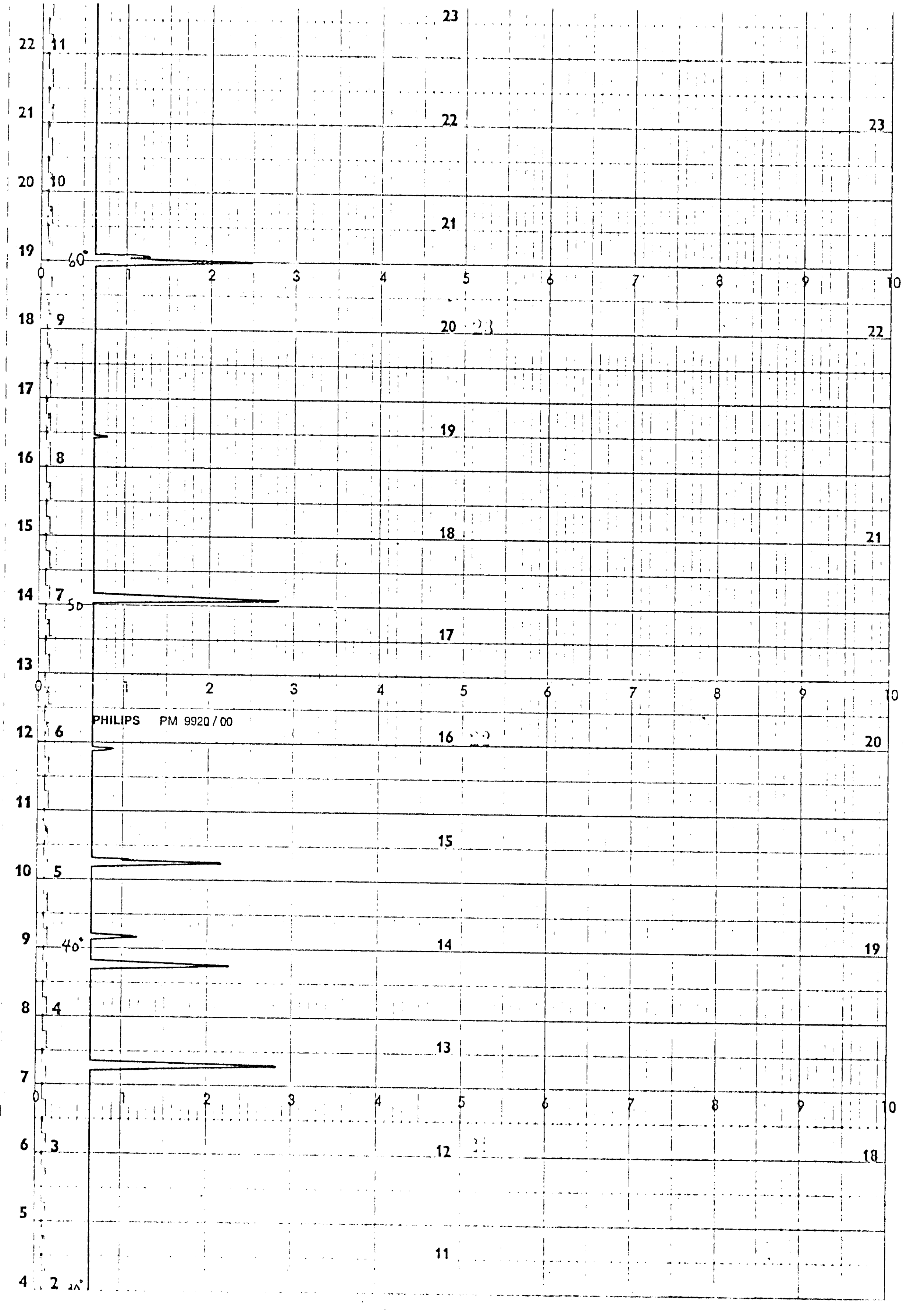
CuKα Ni

40-20

1°/min 1°/min

1x10^3 1 sec.

WINDOW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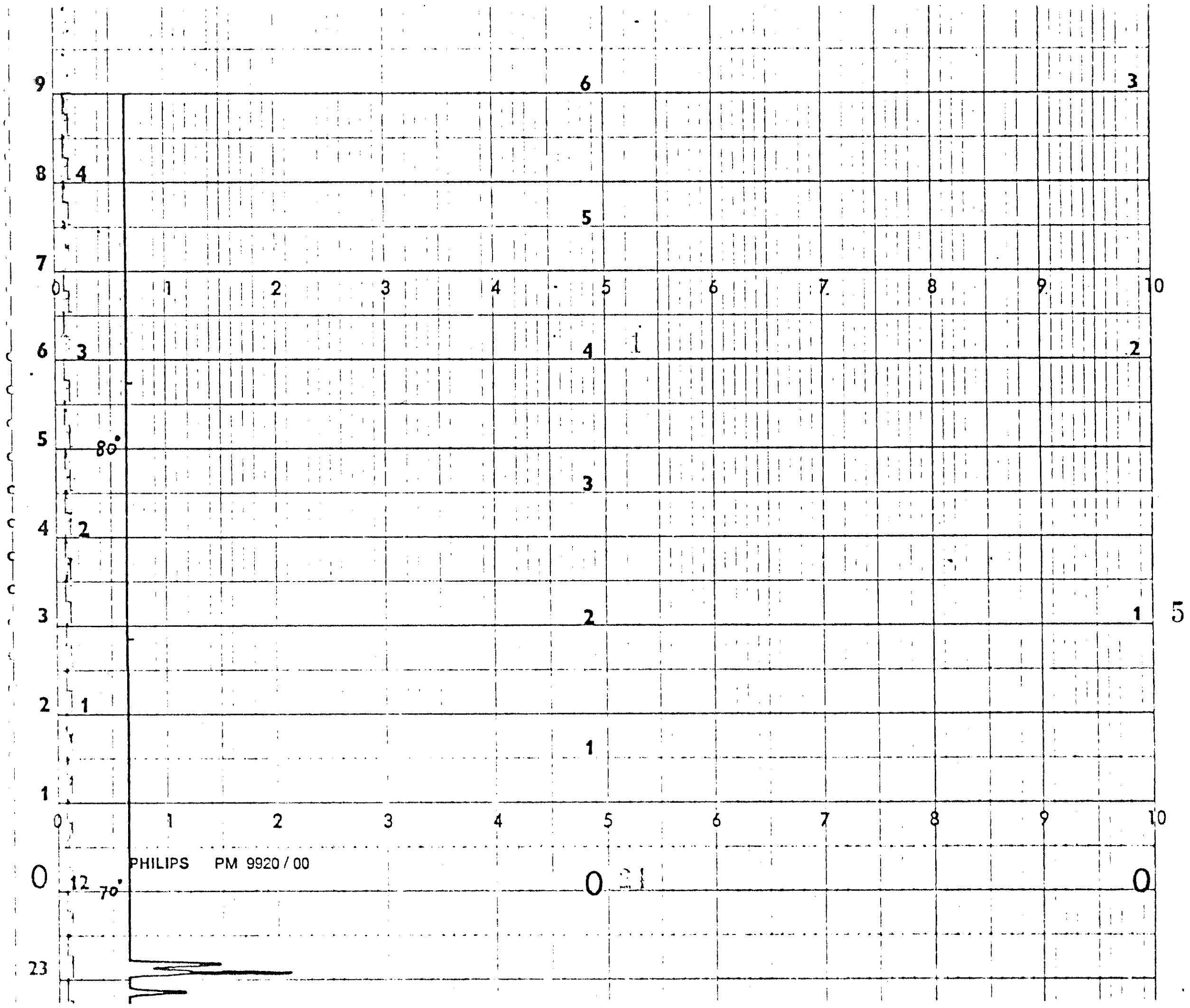
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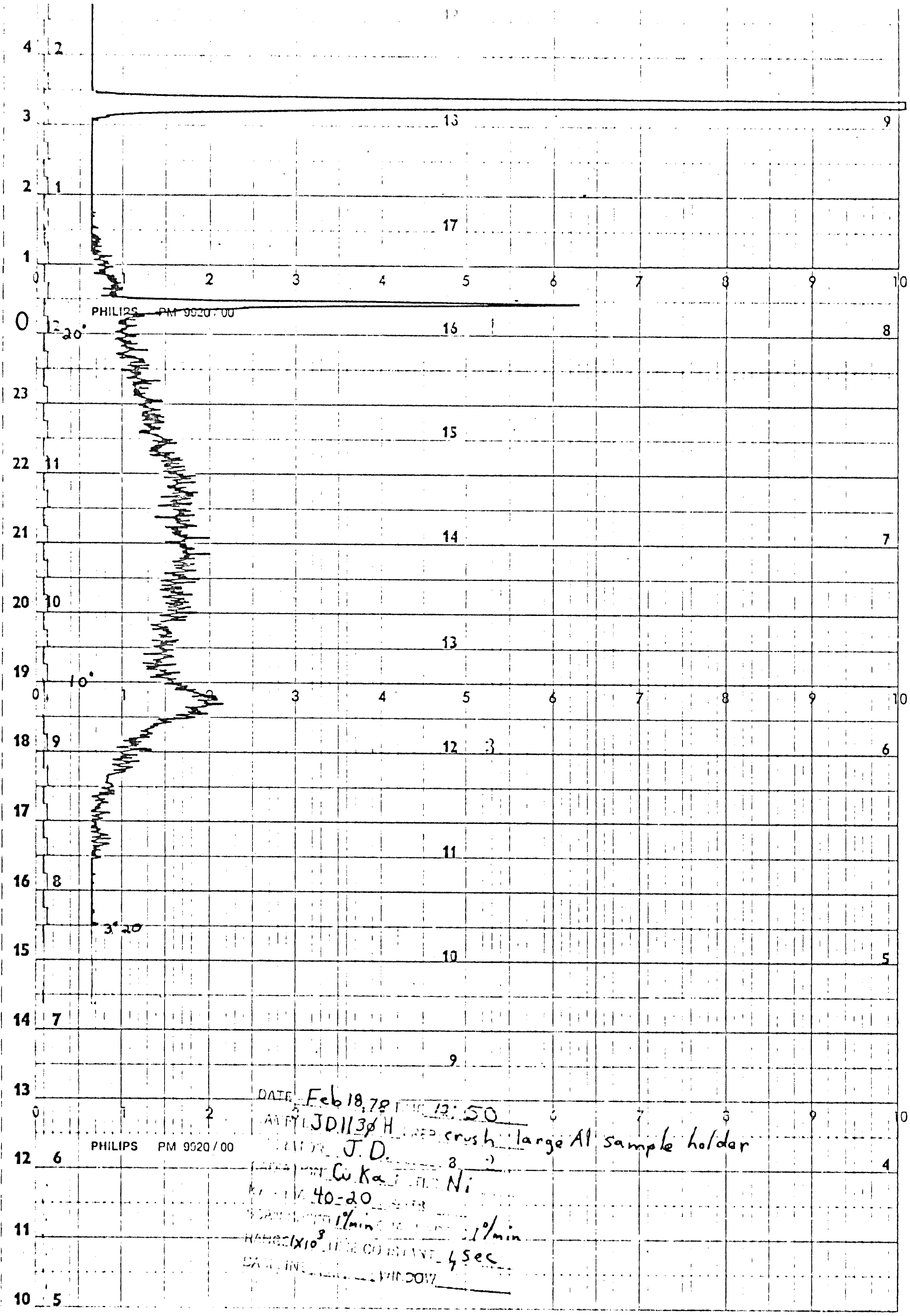
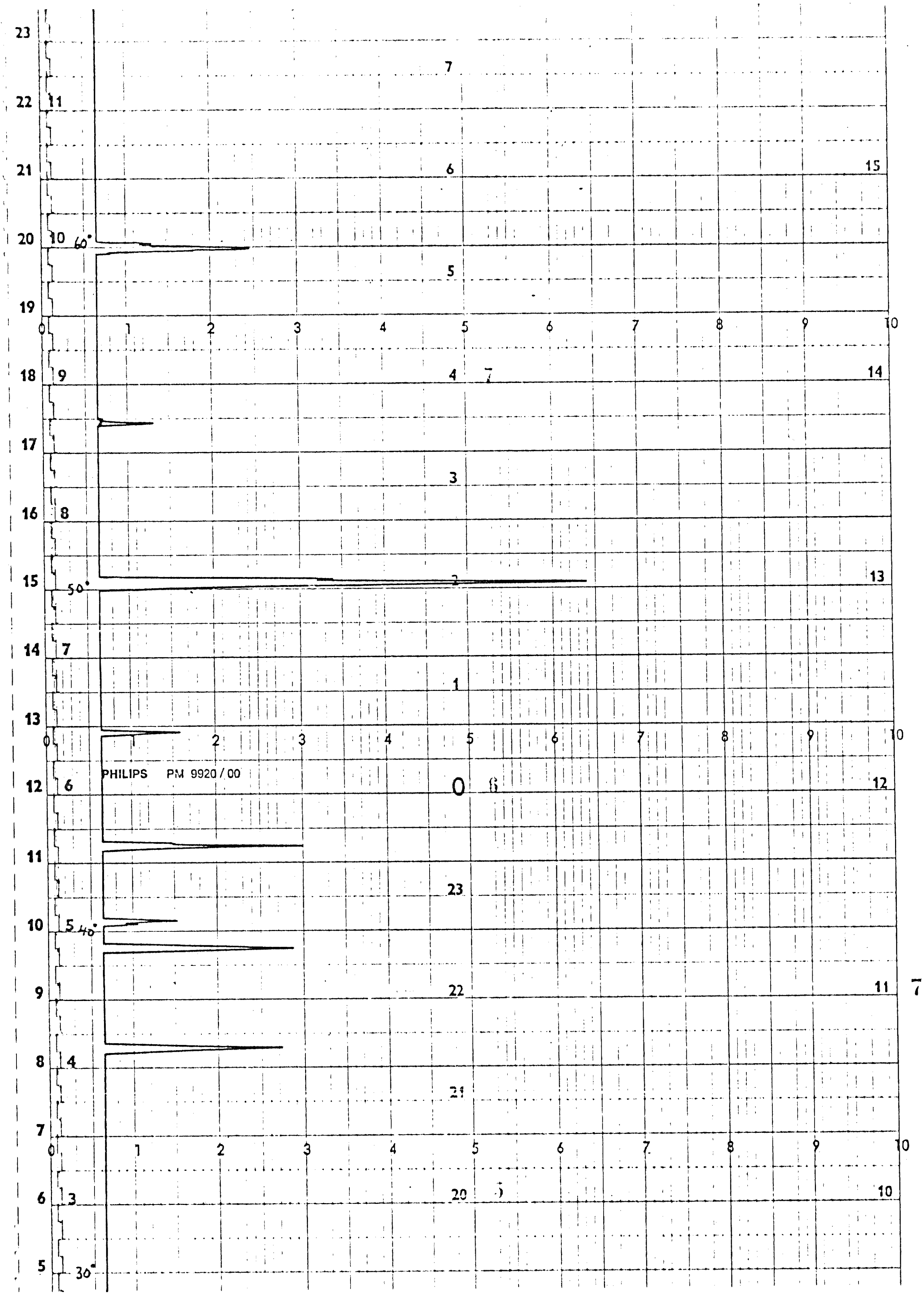


DATE Feb 18, 78 TIME 12:50
SAMPLE JD1130 H PREP crush large Al sample holder
OPERATOR J.D.
RADIATION Cu Ka FILTER Ni
KV-MA 40-20
SCAN SPEED 1°/min CHART SPEED 1°/min
RANGE 1x10^3 TIME CONSTANT 4 sec
BASELINE WINDOW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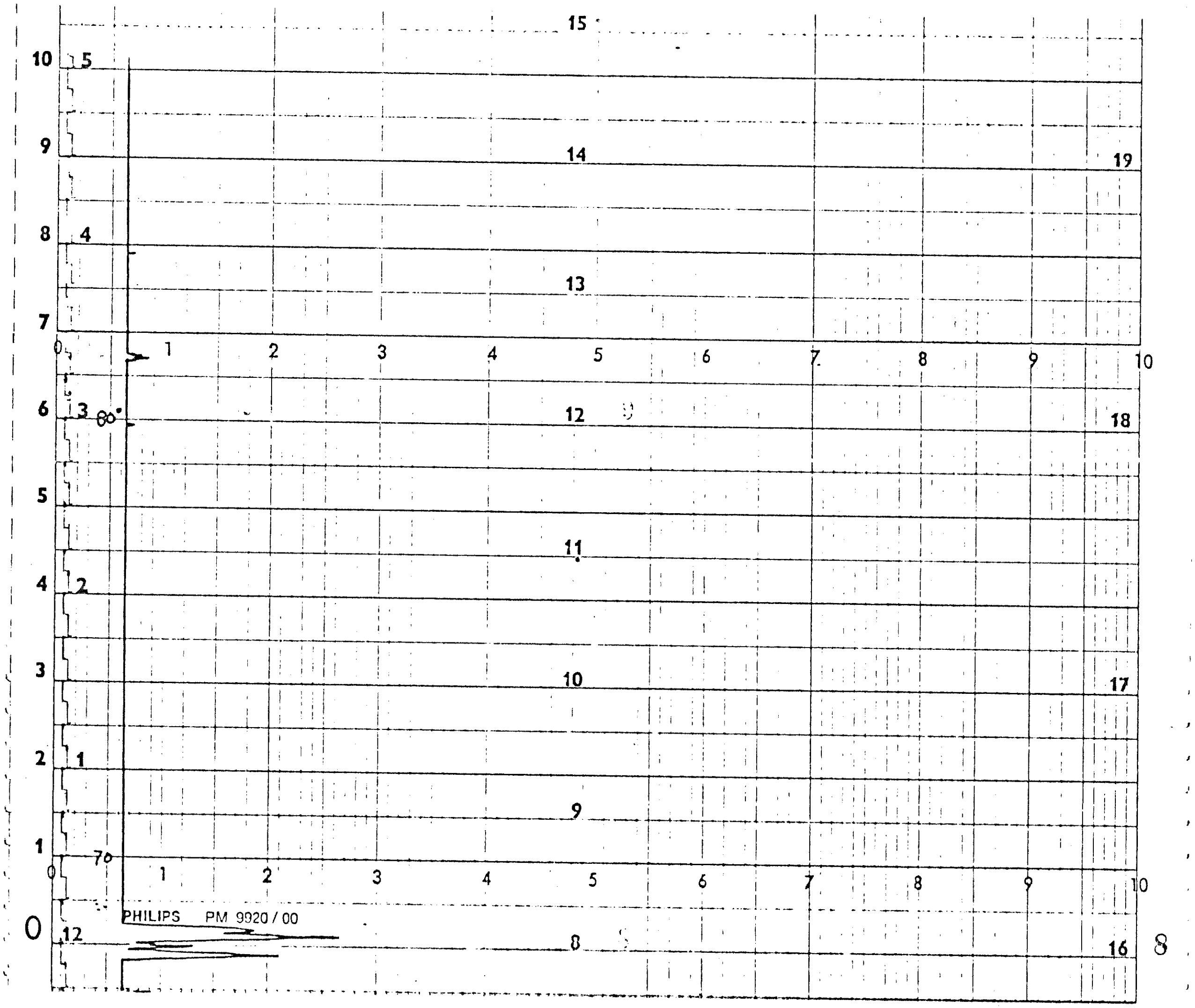
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70
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