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MINERAL ZONING AND FLUID INCLUSION STUDIES IN THE CANDEGO/MADELEINE MINES AREA, GASPE, QUEBEC

by

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Abstract

The Candego and Madeleine mines are the richest-known portions of a 80 km^2 vein system hosted by sedimentary rocks immediately northwest of the McGerrigle Mountains granitic complex in Gaspésie, Quebec. Zones in which veins are rich in quartz and/or Cu- and/or Fe-sulphides and/or Fe-oxides (Type 1, 2, 2B veins) or are rich in quartz, Zn-sulphide and Pb-sulphide (Type 2A, 3A veins) occupy central positions in vein-type zoning patterns; these central Type 1-2-2B-2A-3A vein zones form elongate corridors which radiate out from the McGerrigle Mountains contact. Veins rich in carbonates and one or more of Zn-, Pb-, Cu-Fe, or Fe-sulphide (Type 3, 3B, 4, 4A, 4B veins) occur inside and outside of the central Type 1-2-2B-2A-3A vein zones. The Type 3-3B-4-4A-4B vein zones probably overlie the Type 1-2-2B-2A-3A vein zones.

Homogenization temperatures of aqueous fluid inclusions in vein quartz are from 110° to 550°C; final melting temperatures in these inclusions are typically -14° to -2°C and rarely as high as +6-7°C. Homogenization and final melting temperatures of pure CO_2 inclusions in vein quartz are 18° to 26°C and -55° to -56°C respectively. Total homogenization or decrepitation temperatures of mixed aqueous/carbonic fluid inclusions in vein quartz are 160° to 500°C. Homogenization and final melting temperatures of the CO_2-rich portion of these inclusions are -74°C to +31°C and $\leq$ -70° to -55°C respectively. Final melting points of clathrate hydrates in these inclusions range from 3° to 12°C. Total homogenization or decrepitation temperatures of daughter-crystal-bearing inclusions in vein quartz are 235° to 335°C.

Average sample-site homogenization temperatures and salinities are highest in the parts of the central portions of the Type 1-2-2B-2A-3A vein zones nearest to the McGerrigle Mountains. Spatial coincidence in the Candego/Madeleine mines area of a zone in which the McGerrigle metamorphic aureole bulges out further than usual from the McGerrigle Mountains contact, and hydrothermal centres of vein mineralization which radiate outwards from the latter contact suggest that formation of the metamorphic aureole and vein mineralization were essentially contemporaneous.

RÉSUMÉ

Selon les connaissances actuelles, les mines Candego et Madeleine sont les portions les plus riches d'un système de veines de 80 km^2 développé dans les roches sédimentaires, immédiatement au nord-ouest du complexe granitique des Monts McGerrigle, en Gaspésie, Québec. Les zones où les veines sont riches soit en quartz, et/ou en sulfures de Cu et/ou Fe, et/ou en oxides de Fe (les veines des Types 1-2-2B) soit en quartz, en sulfure de Zn, et en sulfure de Pb (les veines des Types 2A, 3A) se retrouvent au centre des patrons régionaux de zonalité formés par la distribution des types de veines; ces zones centrales contenant les veines des Types 1-2-2B-2A-3A forment les corridors allongés et orientés approximativement perpendiculaires aux contacts des Monts McGerrigle. Des veines riches en minéraux carbonatés et un ou plusieurs sulfures de Zn, Pb, Cu, ou Fe (veines des Types 3-3B-4-4A-4B) se trouvent à l'intérieur et à l'extérieur des zones centrales des veines des Types 1-2-2B-2A-3A. Les zones de veines de Types 3-3B-4-4A-4B se situent probablement au-dessus des zones de veines de Types 1-2-2B-2A-3A.

Les températures d'homogénéisation des inclusions fluides aqueuses dans les quartz des veines sont de 110° à 550°C; les températures de fonte finale dans ces inclusions sont typiquement de -14° à -2°C et rarement aussi élevées que +6-7°C. Les températures d'homogénéisation, et de fonte finale, des inclusions dans le quartz des veines ne contenant que du CO_2 pur, sont de 18° à 26°C et -55° à -56°C, respectivement. Les températures d'homogénéisation totale, ou de décrépitation, des inclusions fluides dans le quartz des veines contenant le H_2O et CO_2 sont de 160° à 500°C. Les

températures d'homogénéisation, et de fonte finale, de la portion de ces inclusions riches en CO_2 sont de -74° à +31°C et ≤ -70° à -55°C, respectivement. Les températures de fonte finale des clathrates hydratés dans ces inclusions varient de 3° à 12°C. Les températures d'homogénéisation totale, ou de décrépitation, defs inclusions dans le quartz des veines contenant les phases solides, sont de 235° à 335°C.

Les températures d'homogénéisation et salinités moyennes des inclusions fluides sont les plus élevées aux sites d'échantillonage dans les parties des portions axiales des zones de veines des Types 1-2-2B-2A-3A, qui sont les plus rapprochés des Monts McGerrigle. Dans la région couverte par cette étude, l'auréole métamorphique des Monts McGerrigle s'étend plus loin qu'habituellement du contact des Monts McGerrigle. Dans ce rapport on démontre que les centres de minéralisation hydrothermale sont orientés perpendiculaire à ce contact. Ces observations suggèrent que la formation de l'auréole métamorphique et de la minéralisation hydrothermale étaient souvent ou toujours contemporaine.

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CHAPTER 1

INTRODUCTION

1.1 AIMS OF THIS REPORT

The Candego/Madeleine mines map area (Figs. 1, 2) is underlain by rocks of the Cambro-Ordovician Quebec Group, immediately northwest of the Devonian McGerrigle Mountains granitic complex. Quartz-carbonate veins, commonly containing base and/or precious metals, occur at about 200 separate localities, including the sites of the Candego (Pb-Zn-Ag) and Madeleine (Cu) mines. Veins relatively near to the granite-sedimentary rock contact are mainly Cu-Fe-bearing (e.g. the Madeleine mine) whereas Pb-Zn-Ag mineralization (e.g. the Candego deposits) occurs mainly in veins relatively distal to this contact.

This communication is an interim report of an investigation in which the principal aim is to examine the regional distribution of vein minerals and of the homogenization temperatures and compositions of fluid inclusions in vein crystals. It is hoped that these data will be useful in revealing whether one or more hydrothermal centres are present within the map area, and will provide clues as to the origins of the mineralizing fluids. Part of the mineral zoning data and all the samples of vein minerals for fluid inclusion studies were collected in the course of field work in the summer of 1985.

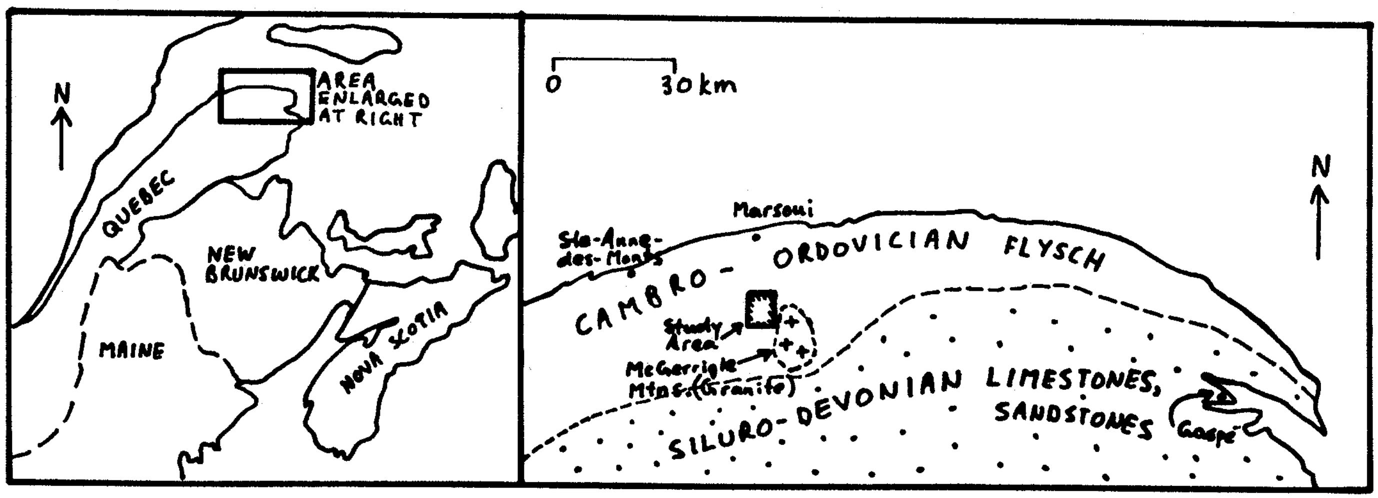

FIGURE 1: Regional geographic and geologic setting of the study area.

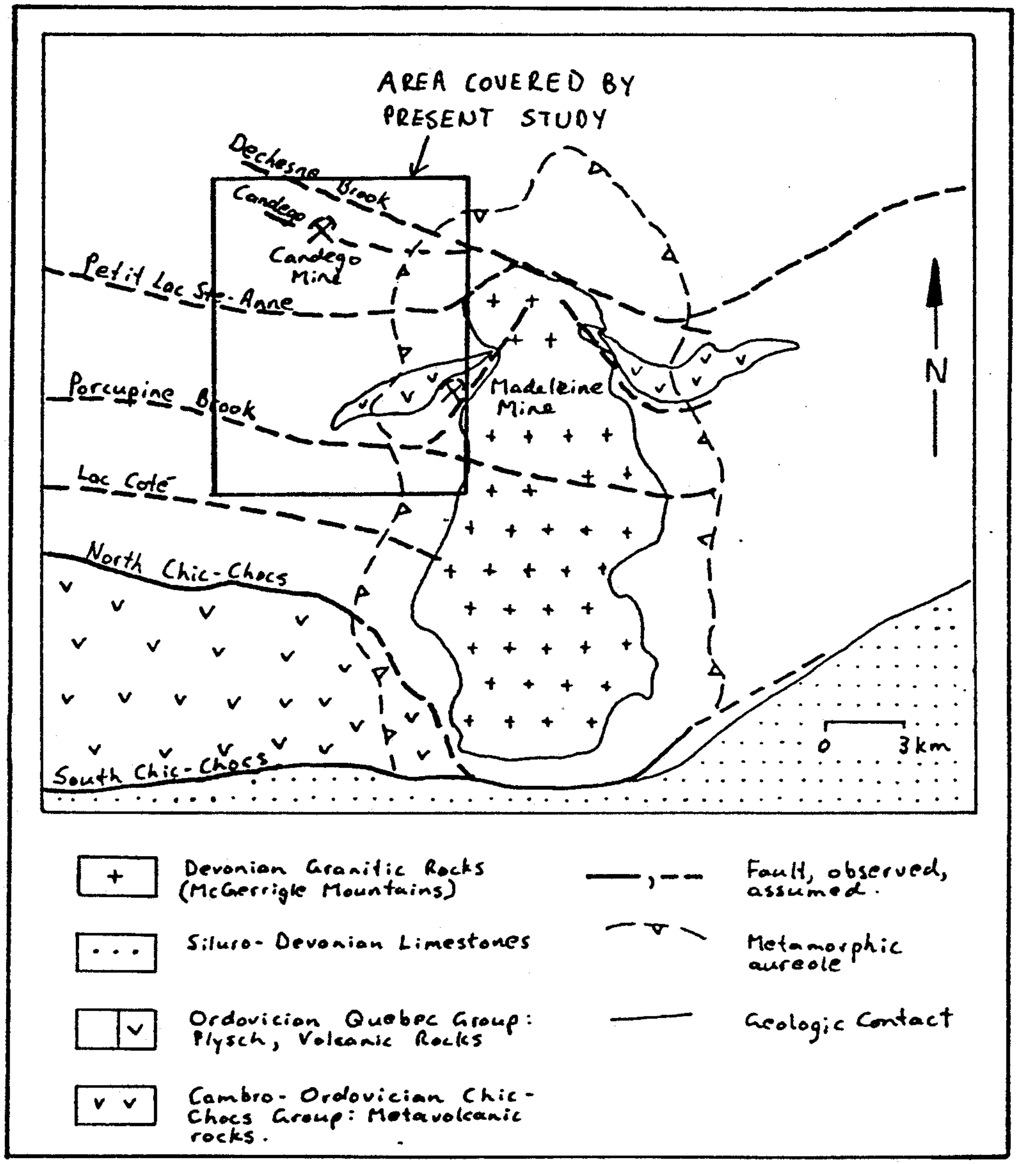

FIG. 2 : Generalized geology of the McGerrigle Mountains area (after Lachance and Duquette, 1977).

Additional mineral zoning data were obtained from diamond drill hole logs contained in exploration company assessment work files, and from accounts of geological studies of the Candego (Wolofsky, 1954) and Madeleine (Girard, 1971; Williams-Jones et al. 1986) mines. Fluid inclusion data is available from the Madeleine mine (Williams-Jones et al., 1986) and is used to supplement the fluid inclusion data of the present study.

The second aim of this study is to use mineral and fluid inclusion paragenesis data from the Candego mine to attempt to determine sequences of formation of different types of veins and flow of different fluid types at the site of the Candego mine and, by extension, in the entire map area.

1.2 PREVIOUS WORK

The geology and exploration/mining history of the Candego/Madeleine mines area were described by Lachance and Duquette (1977). The Candego mine was studied by Wolofsky (1954). The Madeleine deposit was reported on by Girard (1971) and is the object of ongoing investigations by A.E. Williams-Jones of McGill University and his co-workers (Williams-Jones et al., 1986), and by E. Procyshyn of Concordia University.

1.3 REGIONAL, LOCAL GEOLOGY

The following account of the geology of the map area and surrounding regions is condensed from Lachance and Duquette (1977).

The north-central part of the Gaspé peninsula is underlain by allochthonous sequences of Cambro-Ordovician flysch which form the Quebec Group (Fig.1). These rocks were folded and weakly metamorphosed in the Upper Middle Ordovician Taconic and Devonian Acadian orogenies; the fold axes parallel the axis of the peninsula. In the Devonian period these rocks were intruded and contact metamorphosed by granitic intrusions which make up the McGerrigle plutonic complex. Base and precious-metal-bearing mineralization is common in the fractured sedimentary rocks at many localities around the McGerrigle pluton but is apparently relatively rare within the pluton itself (see also de Romer, 1977). The richest known mineralized sites are those of the Candego and Madeleine deposits, situated northwest of the pluton and described below, and the Sullipek Cu-Mo deposit, situated south of the pluton.

On a local scale, the sedimentary rocks of the study area can be divided into a northern and a southern sequence (Fig. 3). The northern sequence is made up mainly of dark grey argillaceous and calcareous sandstone and siltstone, silty shale and black slate, with some dark grey calcsiltite and dolomitic limestone. The southern sequence consists mainly of grey, black

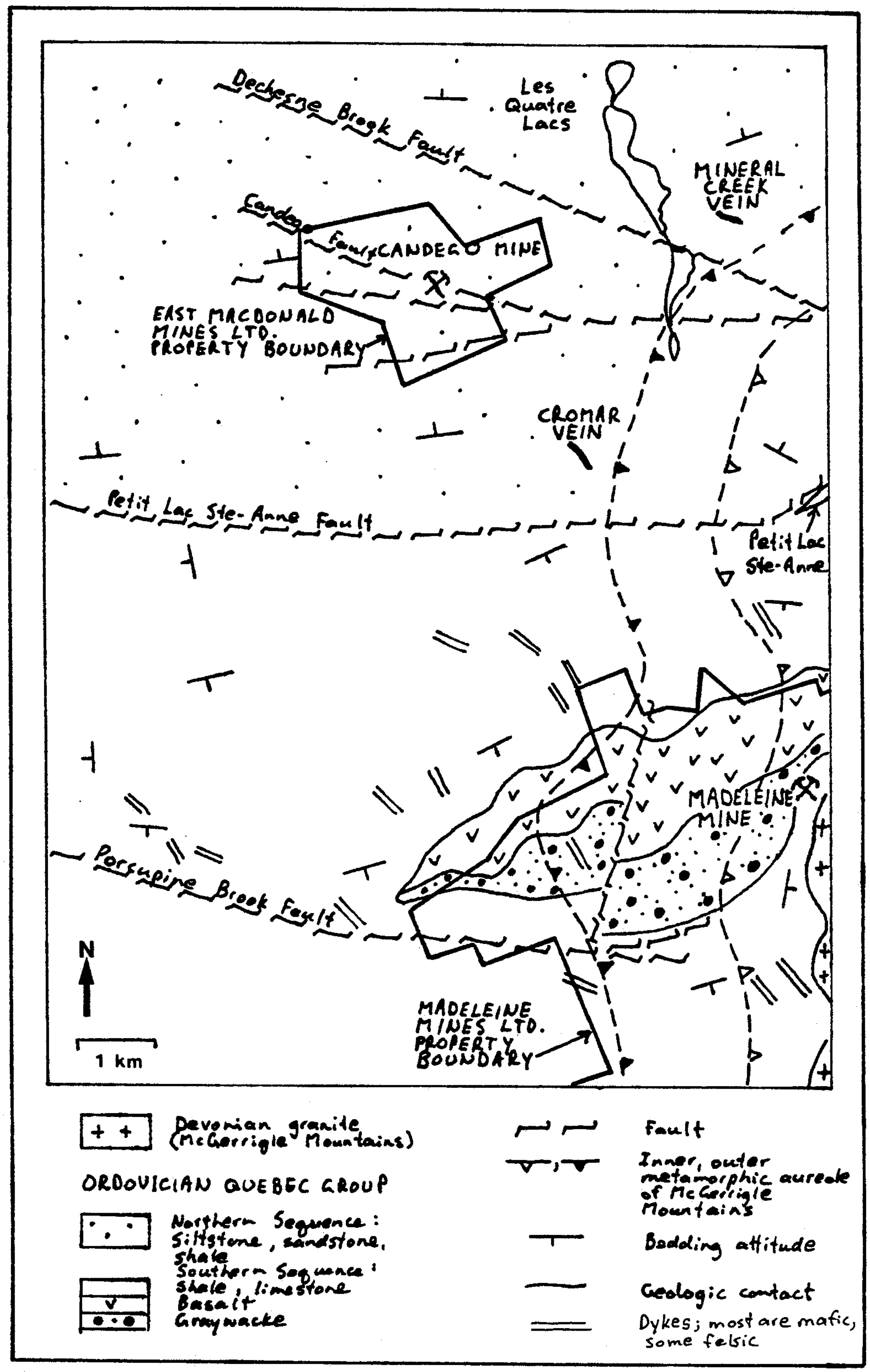

FIGURE 3: General geology of the Candego and Madeleine mines area (after Lachance and Duquette, 1977).

and green silty shale interbedded with grey-black argillaceous-siliceous limestone. In the southeast part of the map area, the southern sequence contains a southwest-striking lens of rocks which consists of basalt and magnetite-rich graywacke in the northern and southern halves of the lens, respectively.

The beds of the northern and southern sequences dip mainly northwest and southeast, respectively, and follow a general northeast trend. However, deviations from this simple picture are common due to complex folding and, near the contact of the McGerrigle Mountains, due to disruption of prevailing bedding attitudes by the pluton at the time of its emplacement. Three major faults traverse the map area (Figs. 2, 3): the east-trending Porcupine Brook fault in the south, the east-trending Petit Lac St-Anne fault in the centre, and the southeast-trending Dechesne Brook fault in the north. The west to northwest-trending Candego fault, located just south of the Dechesne Brook fault, is a subsidiary fault of the latter.

Red, coarse-grained granite of the western edge of the McGerrigle Mountains complex outcrops in the extreme southeast corner of the map area. At this locality the granite-sedimentary rock contact is steeply dipping. Porphyritic dykes, of which most are mafic and the rest felsic, are common in the southeast quarter of the map area and along the western part of the Porcupine Brook fault. The dykes are steeply dipping, strike predominantly northwest and are typically 1 to 2 m thick.

Sedimentary rocks of the northern and southern sequences are contact metamorphosed inside of a 2.5 to 3.0 km-wide aureole which surrounds the McGerrigle Mountains. Approximately the eastern fifth of the present map area south of the Mineral Creek Vein area lies within this aureole. The metamorphic rocks comprise pelitic and calc-silicate hornfelses. The characteristic pelitic and calc-silicate mineral assemblages in the outer and inner portions of the aureole, respectively, are quartz-biotite and quartz-biotite-cordierite, and quartz-tremolite-calcite-epidote and quartz-diopside-garnet, respectively (see Van Bosse (1986) for a detailed account of the McGerrigle aureole). Contact metamorphism/metasomatism is common in the wallrocks of veins throughout the study area (see also the next chapter). Regional metamorphic effects outside of the McGerrigle aureole within the present map area are of low to very low grade.

1.4 THE CANDEGO AND MADELEINE MINES

The following information concerning the Candego and Madeleine mines is taken from Lachance and Duquette (1977).

The Candego lead-zinc-silver deposits are situated about 6 km northwest of the McGerrigle Mountains in a NNW-trending series of quartz-carbonate fissure veins. Between 1948 and 1954, East MacDonald Mines Ltd. treated 62,332 tonnes of ore which had an average grade of 6.35% Pb, 4.28% Zn, 170 g/T Ag and 0.68 g/T Au.

The Madeleine copper mine consisted of steeply-dipping chimney-to tabular-shaped orebodies situated from 0 to 300 m from the McGerrigle Mountains-sedimentary rock contact. Madeleine Mines Ltd. worked this deposit from 1969 to 1982 and produced 7,876,050 tonnes of ore grading 1.15% Cu and 7.88 g/T Ag.

The Cromar and Mineral Creek Veins (Fig. 3) are important mineralized prospects which have been included on Fig. 3 for later reference purposes. Mineralization in the map area other than at the Candego and Madeleine mines is described in the following chapter.

CHAPTER 2

DESCRIPTION OF VEINS

2.1 INTRODUCTION

Veins containing quartz and/or carbonate minerals and/or metallic sulphide/oxide minerals occur at about 200 sites on the present erosion surface and at many others in the subsurface. Veined sites have elevations of 300 to 1200 m above sea level, a topographic interval that extends from the tops of the highest mountains in the field area to the bottoms of the deepest drill holes. There is no preferred horizon of vein occurence. On the present surface, vein outcrops or vein debris of local origin are exposed in stream beds, in exploration trenches and on bush roads. Sample material from the Candego ore-veins is available from the vein debris piles outside the mine adits. The Madeleine mine was not visited because data from this deposit required in the present study have kindly been made available to this writer by A.E. Williams-Jones of McGill University, who with his co-researchers is currently investigating this deposit (see for example Williams-Jones et al. 1986).

2.2 DESCRIPTION OF VEINS

The most common vein minerals are quartz and carbonate minerals. Quartz is typically white and transparent; less commonly it is milky and rarely it is grey and transparent. The carbonates comprise calcite of various colours (white, yellow and black are common, transparent is fairly rare, pink and brown are rare) tan to medium brown dolomite and rare pinkish-brown siderite. The following sulphides are common: sphalerite (amber to black), galena, chalcopyrite, pyrite, pyrrhotite and bornite. Chalcocite, magnetite , native copper and hematite are fairly common; tetratredrite and arsenopyrite are rare. Gold, bournonite and anglesite are very rare at the Candego mine; djurleite, digenite, covellite, breithauptite, linnaeite, niccolite, pararammelsbergite, rammelsbergite, safflorite-lollingite, cobaltite and cubanite are minor to rare minerals at the Madeleine mine.

Quartz and the carbonate minerals range from fine- to coarse-grained and from euhedral to subbedral to anhedral to massive; vugs are fairly common and growth banding is fairly rare. The ore minerals/elements noted above which are not particular to only the Candego or Madeleine mines occur as streaks, blebs, masses or crystals; crystals range from fine- to coarse-grained and from anhedral to euhedral. Veins are not zoned across strike and are too poorly exposed to permit recognition of possible along-strike zoning. On a regional scale, there is no preferred association between particular sulphide/oxide minerals and a given gangue mineral.

At least three quartz types occur in more than one part of the map area. White, anhedral, coarse-grained quartz with a slightly waxy lustre has been encountered in the Madeleine mine area, in the region between the

Madeleine mine property and the Cromar vein, in the Cromar and Candego areas, and to the northwest of Candego. Another distinctive quartz type is white to transparent, medium-grained, anhedral and commonly displays a fibrous, drawn-out-looking crystal texture. This type of quartz occurs at sites between the Madeleine mine property and the Cromar area, in the Cromar and Candego areas, and to the northwest of Candego. A third distinctive quartz type is grey to transparent, fine- to medium-grained and anhedral to euhedral. It occurs between the Madeleine mine property and the Cromar area, and in the Cromar and Candego areas.

The widths of most quartz and/or carbonate veins range from 1 cm to 2 m, although in the Cromar area there is a vein 11 m wide. Veins containing quartz and/or carbonates fill in some cases sets of parallel fracture planes, in other cases crackle breccias or stockworks and in others, relatively wide fissures. Veins which only contain sulphide and/or oxide minerals have widths which range from a hairline's width to about 0.5 cm and fill planar to irregular fractures which can locally form stockworks. The outcrops containing these veins invariably also contain disseminated sulphide mineralization which can follow schistosity or bedding planes or be associated spatially with the veins. Such disseminated mineralization takes the form of specks, clots, blebs, streaks and lenses.

It can be generally stated that there is no preferred host rock type in the map area and that veins can be concordant or discordant with bedding.

There is evidence of wallrock alteration associated with veining at numerous sites. Alteration features, with respect to those of unaltered rocks, take the form of colour changes, pyritization, chloritization and increased brittleness or compactness. All or only one of these features can be present at a particular veined site.

CHAPTER 3

MINERAL ZONING STUDY

3.1 INTRODUCTION

The aims of this chapter are 1) to describe the spatial distributions of the vein minerals in the Candego-Madeleine mines area in the horizontal and vertical planes and 2) to present a regional vein classification scheme based on minerals which commonly coexist in veins.

Vein minerals present at 110 surface sites were recorded in the course of field work. At most of these sites the data comes from outcrops or debris of local origin. Vein minerals in the Candego ore-veins were determined by examination of the debris piles outside each mine adit. Vein mineral zoning data was also collected from 74 logs of holes drilled on and around the Madeleine Mines Ltd property, ~1000 Madeleine mine logs, 4 logs from the Mineral Creek area, and from available geological reports (Kingsbury, 1948; Wolofsky, 1954; Girard, 1971; Williams-Jones et al., 1986).

3.2 GANGUE MINERAL ZONING

The lateral spatial distribution of vein quartz/carbonate proportions at surface and drill hole data sites is shown in Fig. 4. At sites indicated by dots, except those in the immediate vicinity of the Candego mine, the

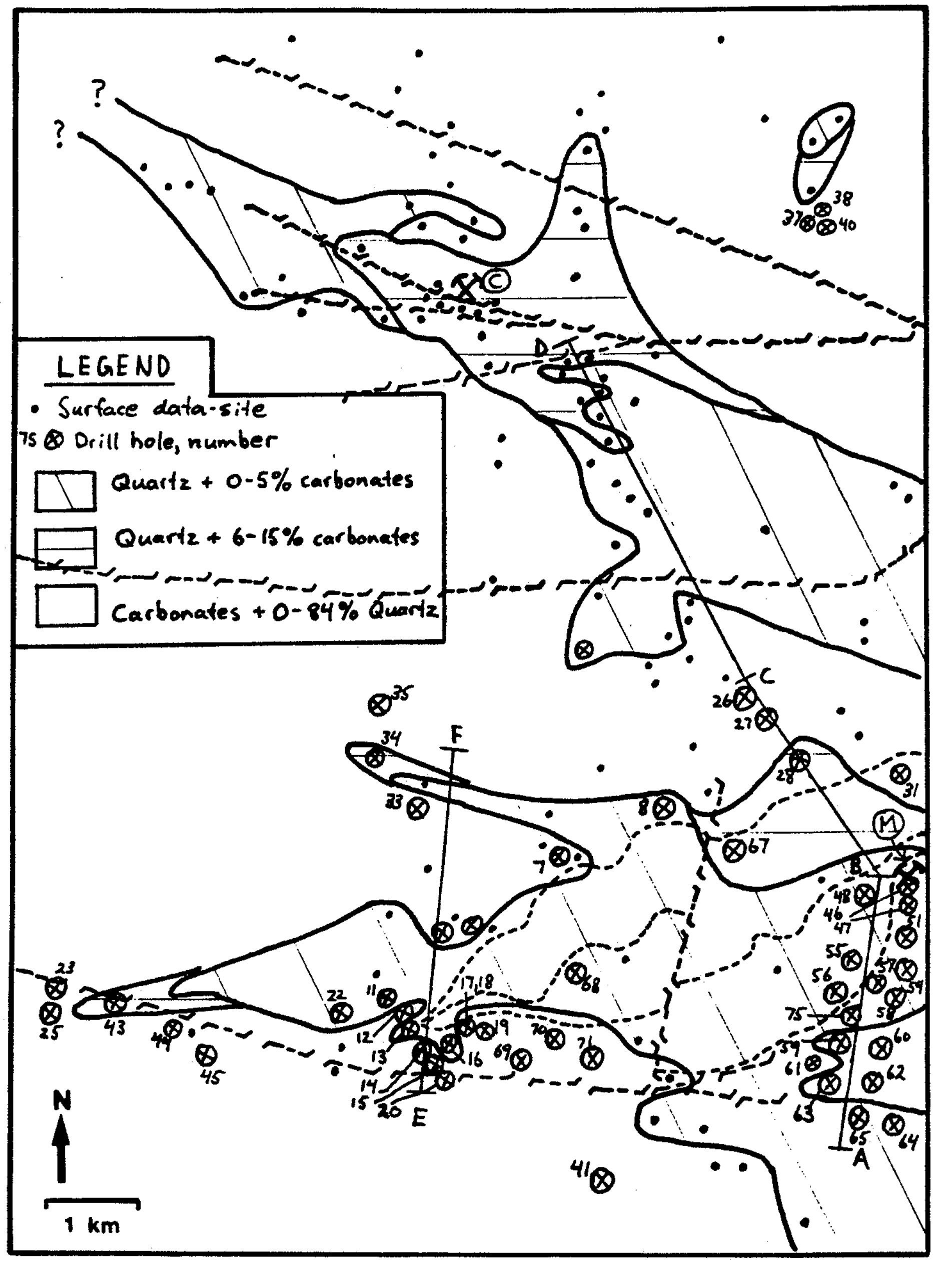

FIGURE 4: Lateral zonation of vein quartz/carbonates proportions at surface and drillhole data sites. Vertical sections ABCD and EF shown in Figure 5. Major faults and lithologic contacts from Fig. 3 included for reference.

relative proportions of quartz and carbonate vein minerals were estimated visually from outcrops or from vein-bearing debris of local origin; the vein types found at each site, e.g. quartz veins or quartz-carbonate veins, are shown in Fig. 8. The dots clustered about the Candego mine symbol in Fig. 4 represent sites where vein debris piles occur outside the main mine adits; the quartz/carbonate ratios of these debris piles were assumed to be representative of the quartz/carbonate ratios of the mined veins. The quartz/carbonate ratio associated with each drill hole site on Fig. 4 was estimated from the frequencies with which vein quartz and vein carbonate are reported in the log of the hole and the reported thicknesses of these veins. This method of determining drill hole quartz/carbonate ratios is not as quantitative as the procedure used to estimate surface site quartz/carbonate ratios but does not affect the conclusions which will ultimately be drawn from the gangue mineral zoning data.

Fig. 4 shows that the distribution of data-site quartz/carbonate ratios forms distinct zones. Veins typically contain quartz + 0-5% carbonates in two major elongate zones in the north and south parts of the map area, respectively. Both of these zones are widest near the McGerrigle pluton and narrow with increasing distance from the pluton. The southern quartz-rich zone is centred roughly on the southwest-trending lens of basalt and greywacke in the southeast part of the map area, and extends 9 km westward from the McGerrigle Mountains. The Madeleine mine is contained by this quartz-rich zone. Although not indicated on Fig. 4, the quartz/carbonate ratio of vein gangue material in the Madeleine mine as determined from inspection of ~1000 logs is similar to the quartz/carbonate ratios of holes on Fig. 4 in the vicinity of the Madeleine mine. The northern quartz-rich zone is at least 10 km long; it extends from Petit Lac Ste-Anne on the pluton-sedimentary rock contact, through the Cromar and Candego areas and into the region northwest of the Candego mine. In the central part of the northern quartz-rich zone vein carbonate mineral percentages rise slightly to 6 to 15%. Vein carbonate mineral percentages are also in the 6 to 15% range at a few drill hole sites on the periphery of the southern quartz + 0-5% carbonates zone.

Veins in areas between and surrounding the quartz-rich corridors typically contain carbonate + 0-84% quartz as their gangue. Exceptions to this general observation occur in the Mineral Creek vein area in the northeast corner of the map area (Fig.3) where the gangue is quartz at two vein-sites, and quartz + 6-15% carbonates at another site. Carbonate rich veins also form an inlier in the southern quartz + 0-5% carbonates zone, to the south of the Madeleine mine.

The vertical distribution of vein gangue minerals is portrayed in Fig. 5. The locations of the vertical lines of section ABC, CD and EF on the present erosion level are shown in Fig. 4. Surface vein data-sites are indicated as points on these sections. The types of veins reported in drill logs (quartz, carbonate or quartz-carbonate) are indicated at the appropriate

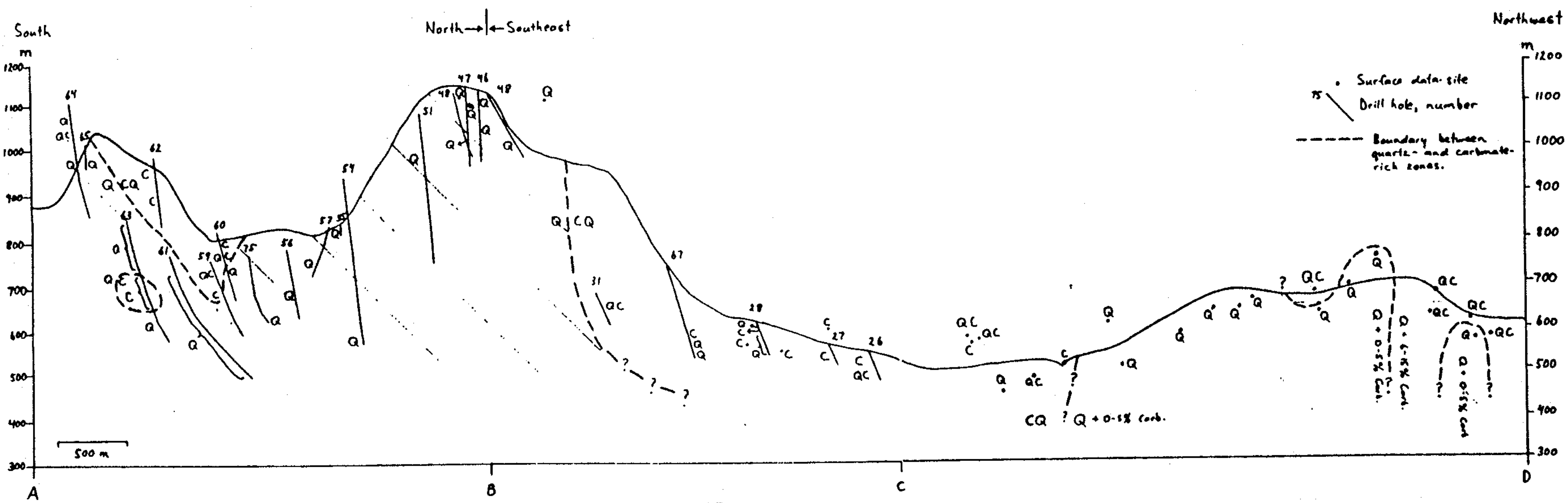

FIGURE 5: Vertical zonation of vein gangue minerals. Q = quartz, C = carbonates. Location of lines of section in horizontal plane shown in Fig. 4.

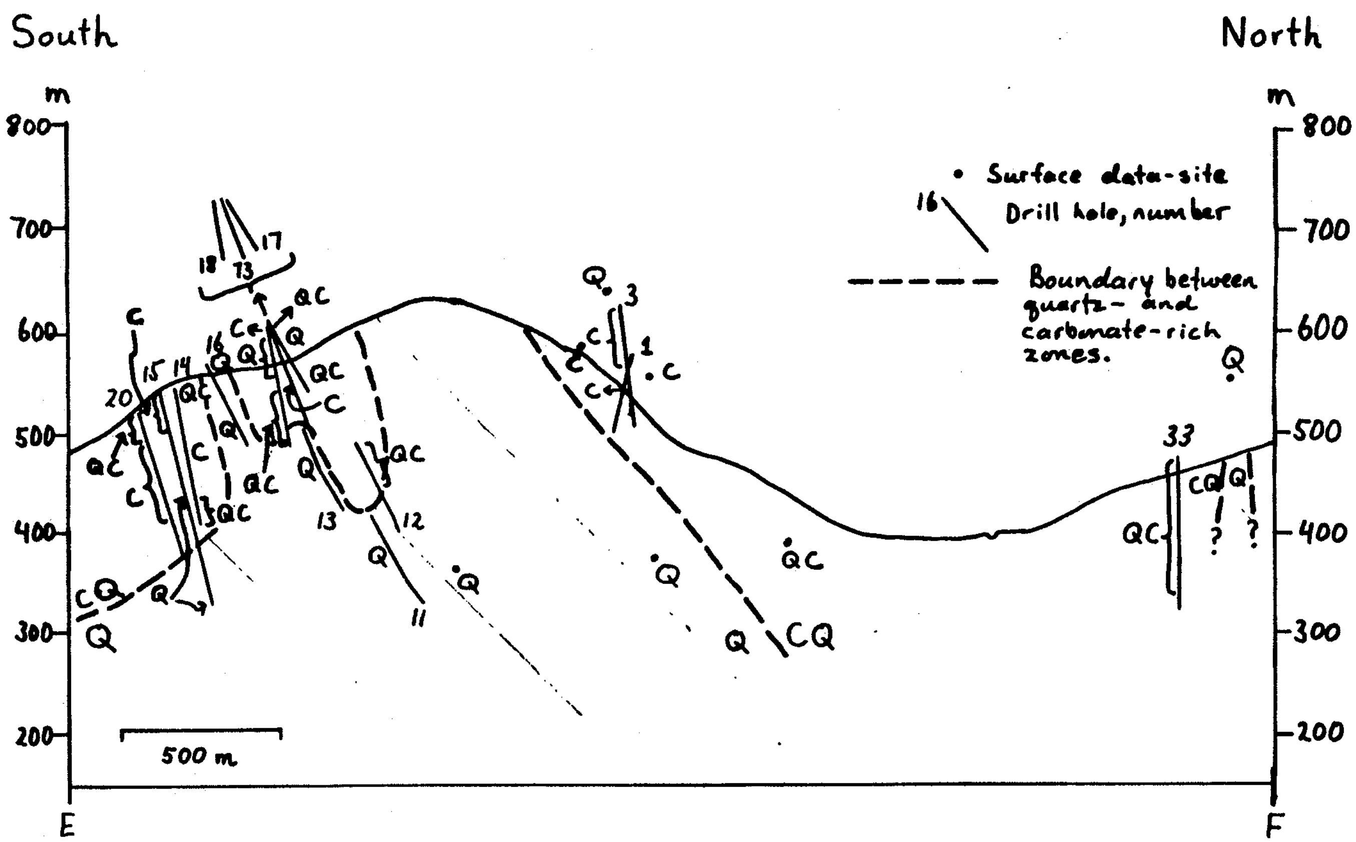

FIG. 5 : Continued

elevations in each hole. Because the quartz/carbonate ratios of individual quartz/carbonate veins are not reported in the drill logs, it is not certain whether these veins belong in the quartz + 0-5% carbonates, quartz + 6-15% carbonates or carbonates + 0-84% quartz vein categories. For this reason the vertical gangue mineral zoning as determined from drill hole data is presented in terms of quartz and quartz-carbonate zones. The quartz zones of Fig. 5 and the quartz + 0-5% carbonates zones of Fig. 4 coincide on the portions of the present erosion surface cut by sections ABC and EF. It is probable that a close correlation exists between the quartz zones of the vertical zonation and the quartz + 0-5% carbonates zones of the horizontal zonation elsewhere in the map area, on and below the surface. Statements analogous to the two preceding ones can be made concerning the relation between the quartz-carbonate zones of Fig. 5 and the quartz + 6-15% carbonates and carbonates + 0-84% quartz zones of Fig. 4, in the portions of the present surface cut by sections ABC and EF and elsewhere in the map area.

Evidence that quartz-rich zones underlie carbonate-rich zones is present in sections AB and EF of Fig.5. The portions of sections AB and EF which contain this evidence represent small portions fo the total field area, but the same vertical sequence of quartz- and carbonates-rich zones is suggested by the data in each of these sections. This sequence is thus tentatively proposed as being the sequence of these zones troughout the field area, and the boundaries between mineral zones in sections BC and CD have been drawn in according to this hypothesis. The data of Figs. 4 and 5 do not indicate whether the quartz + 6-15% carbonate zone occurs above or below the carbonate + 0-84% quartz zone. However, it is plausible that the quartz + 6-15% carbonates zones might represent zones transitional to underlying quartz + 0-5% carbonates and overlying carbonates + 0-84% quartz zones.

Calcite is the carbonate gangue mineral present in veins at all surface data-sites except those in the quartz + 6-15% carbonates portion of the northern quartz-rich zone (Fig. 4); here, the carbonates are brown dolomite and less commonly siderite. Where the vein carbonate mineral is identified in drill logs of holes in the southern part of the map area, it is calcite. At the Madeleine mine, Girard (1971) stated that microprobe analyses of carbonate minerals indicate that only calcite is present; Williams-Jones et al. (1986) report the occurrence of late-stage quartz-ankerite veins, but these are of minor abundance. The nature of the gangue carbonate minerals is not specified in the logs of holes drilled in the Mineral Creek area, but calcite is the only carbonate mineral contained at surface sites. The average length of the Mineral Creek holes is only about 53 metres; it is thus probable that the vein carbonate mineral in these holes is the same as that seen on surface, i.e. calcite. It is concluded from the preceding observations that calcite is the sole or major gangue carbonate mineral in all parts of the map-area except in the quartz + 6-15% carbonate portion of the northern quartz-rich zone, where the carbonate minerals are dolomite and siderite.

3.3 ZONING OF ORE MINERALS

The areas of common occurrence of sphalerite, galena, chalcopyrite, pyrite, pyrrhotite and bornite are indicated in Fig. 6. The distribution of the rarer vein sulphides, oxides and elements is given below. The data points on Fig. 6 are the sites at which the above-named minerals occur in outcrops, debris of local origin, adit debris piles (in the case of data-sites in the immediate vicinity of the Candego mine), or are reported in the logs of holes drilled at these sites.

Chalcopyrite and pyrite are common throughout the field area. Pyrrhotite is restricted to two elongate zones in the north and south parts of the map area, respectively. The northern pyrrhotite zone is about four kilometres long and extends from Petit Lac Ste-Anne to the Cromar area. The southern pyrrhotite zone is roughly centred on the southwest-trending basalt-graywacke lens in the southeast part of the map area, extends about six kilometres westward from the west edge of the McGerrigle pluton and decreases in width with increasing distance from the pluton. Bornite is common locally within the southern pyrrhotite zone.

There are two main zones within which sphalerite and/or galena are common, in the north and south portions of the field area, respectively. The northern sphalerite-galena zone forms a 5.7 km-long northwest-trending

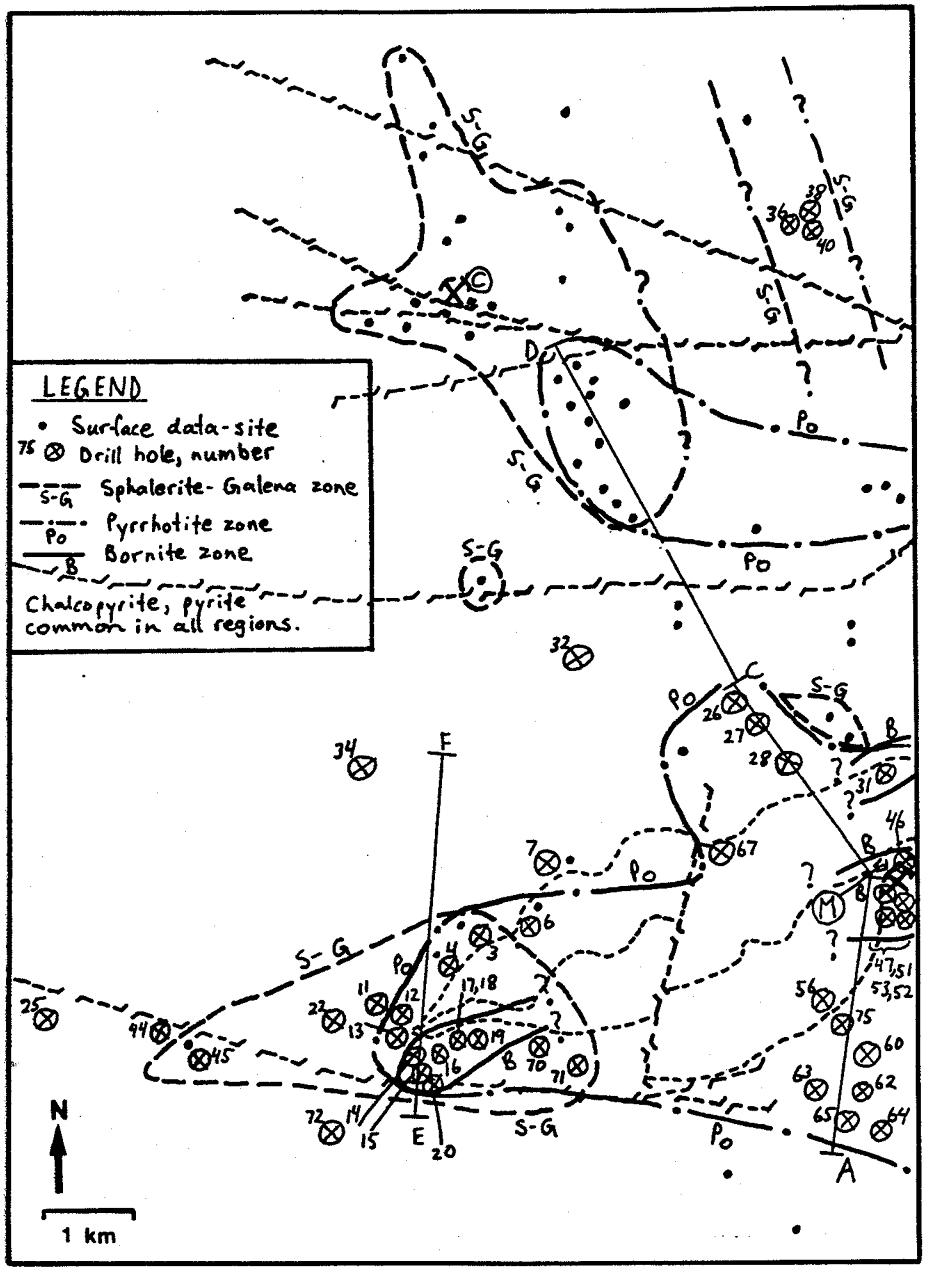

FIGURE 6: Regional distribution of the most abundant vein sulphides, showing limits of occurrence of pyrrhotite and bornite and zones of most common occurrence of sphalerite and galena. Vertical sections ABCD and EF shown in Fig. 7. Major faults and lithologic contacts from Fig. 3 included for reference.

corridor which extends from the Cromar area to northwest and north of the Candego mine. The southeastern half of the northern sphalerite-galena zone coincides spatially with the northwestern half of the pyrrhotite zone described above. Sphalerite and galena are common in the Mineral Creek area but there are no known sulphide mineral-bearing sites between the Mineral Creek and Cromar areas. It is thus unclear whether the Mineral Creek area veins constitute a discrete north-trending sphalerite-galena zone or whether they are part of a broader sphalerite-galena zone which includes the Cromar and Candego areas to the west, and possibly additional regions east of the northeast corner of the map area.

The southern sphalerite-galena zone extends from about 3.4 to about 8.2 km away from the west edge of the McGerrigle pluton, strikes east-west and narrows with increasing distance from the pluton. The eastern half of this sphalerite-galena zone overlaps the western end of the southern pyrrhotite zone.

Sphalerite-galena-bearing veins occur at only a few localities outside of the two main zones described above. Two isolated sphalerite-galena-bearing veins occur on the northern flank of the southern pyrrhotite zone, near to the pluton-sedimentary rock contact. Another sphalerite-galena-bearing vein occurs in the centre of the map area near the Petit Lac Ste-Anne fault.

Magnetite, hematite, chalcocite and native copper are reported in logs of holes drilled in the bornite zone situated within the zone of overlap of the southern sphalerite-galena and pyrrhotite zones. Hematite is also present in an outcropping vein in the Cromar area. Native copper is also reported on surface within the basalt portion of the basalt-graywacke lens in the southeast part of the map area, in the region where the basalt is cut by the NNE-trending fault (Lachance and Duquette, 1977). According to Wolofsky (1954) and confirmed in the present study, arsenopyrite and tetrahedrite are rare minerals in the Cromar and Candego areas. Gold, bournonite and anglesite are very rare in the Candego ore-veins (Wolofsky, 1954). Djurleite, digenite, covellite, breithauptite, linnaeite, niccolite, pararammelsbergite, rammelsbergite, safflorite-lollingite, colbaltite and cubanite are minor to rare minerals in the Madeleine mine (Girard, 1971).

Fig. 7 shows the spatial distribution of sulphide/oxide minerals in the vertical sections ABC, CD and EF. The locations of the lines of vertical section on the present surface are shown on Fig. 5 The data contained in section EF suggest strongly that in this part of the study area there is a lowermost zone comprised of Fe-sulphides and -oxides (pyrite, pyrrhotite, magnetite), an intermediate zone in which copper and/or iron sulphides (bornite, chalcocite, chalcopyrite), iron sulphides or oxides (pyrite, pyrrhotite, magnetite) and native copper are common, and an uppermost zone in which sphalerite galena, chalcopyrite, pyrrhotite and pyrite are common. This

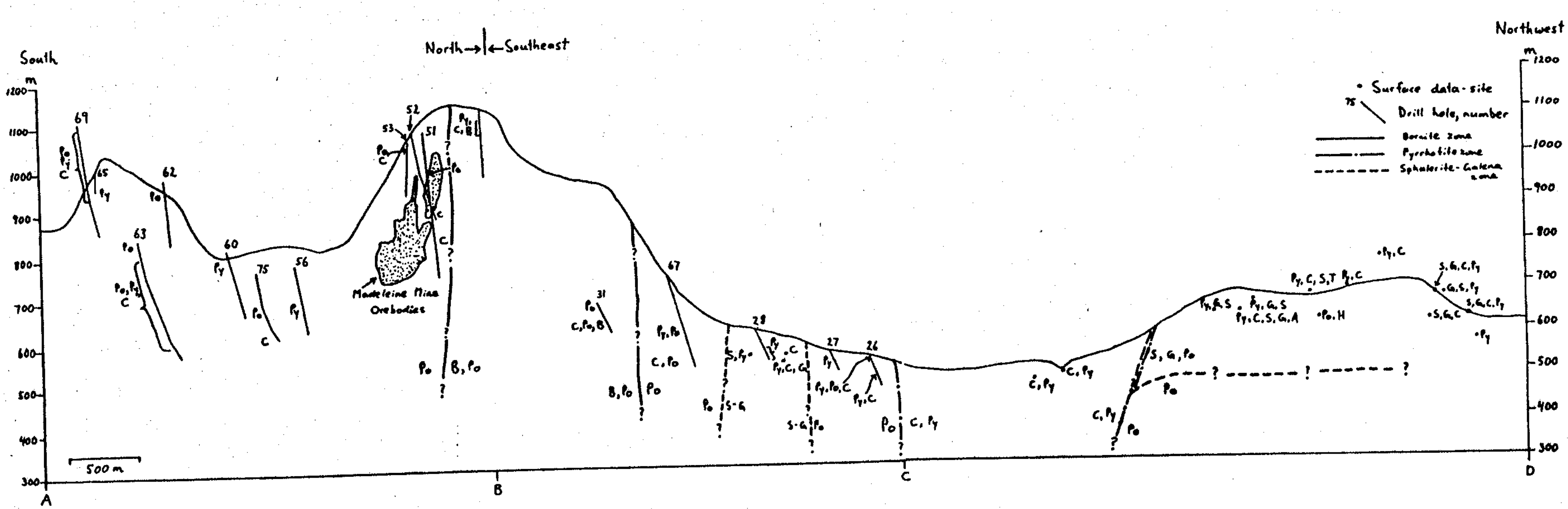

FIGURE 7: Vertical distribution of vein sulphides, oxides, native elements. S=sphalerite, G=galena, C=chalcopyrite, B=bornite, Cc=chalcocite, Cu=native copper, Py=pyrite, Po=pyrrhotite, M=magnetite, H=hematite. Parenthesized mineral symbols indicate that the mineral is rare.

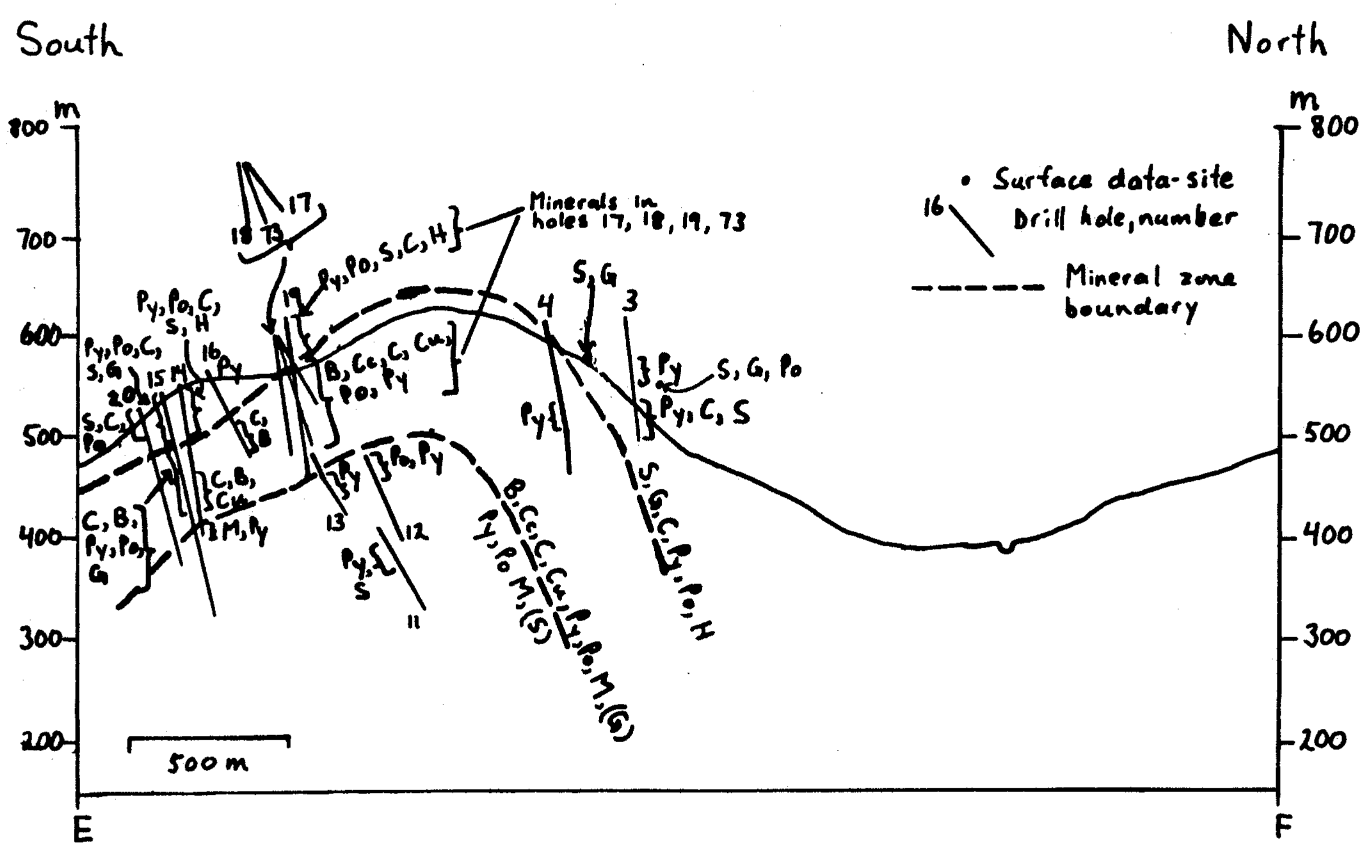

FIG. 7 : Continued

vertical sequence is analogous to that observed in the Lemieux Dome region, situated 30 km southwest of the present study area (Stevens, 1986). At the Lemieux Dome hematite and pyrite occur in veins at relatively low elevations, chalcopyrite, pyrite and hematite in veins at intermediate elevations and sphalerite, galena, chalcopyrite and pyrite in veins at relatively high elevations. A vertical sulphide/oxide zonation is demonstrable for only a small part of the Candego/Madeleine mines area. However, the fact that the observed sequence of mineral zones is analogous to that found at the Lemieux Dome permits speculation to the effect that the sequence displayed in section EF of the present map area is probably representative of the sequence for the entire study area. On the basis of this reasoning the writer hypothesized in section CD that the sphalerite- -galena zone gives way at depth to the pyrrhotite zone (both these zones are exposed on the present erosion surface (Fig. 5)).

3.4 CLASSIFICATION OF VEINS

A vein classification scheme based on commonly-occurring phase assemblages, is presented in Table 1. The veins are classified according to the following criteria: 1) presence or absence of quartz and/or carbonates; 2) if quartz or carbonates are present, the quartz/carbonates proportion; 3) presence or absence of opaque mineral phases and 4) presence or absence of Zn-Pb sulphides in the opaque mineral assemblage.

	Zn-Pb sulphides absent		Zn-Pb sulphides present		No. opaques present	
	Vein type	Diagnostic Phases	Vein type	Diagnostic Phases	Vein type	
Qtz., carb. absent	1	One or more of py, cpy, po, bo, Cc, mt, hem, Cu	1A	sp and/or ga, commonly py, cpy, po, hem		
Carb./Qtz. increases	2	QC^{0-5}, one or more of py, cpy, po, locally bo, Cc, hem	2A	QC^{0-5}, sp and/or ga, commonly py, cpy, po	2B	QC^{0-5}
	3	QC^{6-15}, one or more of py, cpy, po, locally po, Cc, mt	3A	QC^{6-15}, sp and/or ga, commonly py, cpy, po	3B	QC^{6-15}
	4	CQ^{0-84}, one or more of py, cpy, po, locally bo, Cc, mt	4A	CQ^{0-84}, sp and/or ga commonly py, cpy, po	4B	CQ^{0-84}

TABLE 1: Classification of vein types. Q = quartz, C = carbonates, py = pyrite, po = pyrrhotite, hem = hematite, mt = magnetite, bo = bornite, Cc = calcocite, cpy = chalcopyrite, sp = sphalerite, ga = galena.

Type 1 veins contain one or more of pyrite, chalcopyrite, pyrrhotite, bornite, chalcocite, magnetite, hematite and native copper, whereas Type 1A veins contain sphalerite and/or galena, and commonly pyrite, chalcopyrite, pyrrhotite and hematite. Type 2, 2A and 2B veins contain quartz + 0-5% carbonates; Type 2 veins also contain one or more of the Cu- and/or Fe-sulphides and Fe-oxides found in Type 1 veins, except for magnetite, whereas Type 2A veins also contain the same sulphide minerals as Type 1A veins, but no Fe-oxides. Type 3, 3A and 3B veins contain quartz + 6-15% carbonates; the Type 3 vein sulphide/oxide minerals are the same as those of Type 2 veins, but with magnetite replacing hematite, whereas Type 3A veins contain the same sulphide minerals as Type 2A veins. Type 4, 4A and 4B veins contain carbonates + 0-84% quartz; Type 4 veins contain the same sulphide/oxide minerals as Type 3 veins whereas the sulphide minerals found in Type 4A veins are the same as those in Type 3A veins.

In most drill logs, relative proportions of quartz and carbonate minerals are not specified in the veins which contain these minerals. To permit inclusion of the veins described in drill logs in the classification scheme, veins described as "quartz veins" (± sulphides, oxides or native copper) were assumed to be Type 2, 2A or 2B veins. Veins described as "quartz-carbonate" (± ore mineral phases) veins, and "carbonate" (± ore mineral phases) veins were assumed to be Type 3, 3A or 3B veins, and Type 4, 4A or 4B veins, respectively. Because veins described as "quartz-carbonate" veins could conceivably contain more than 15% or less than 6% carbonates (the upper and lower limits, respectively, for Type 3, 3A and 3B veins) it is possible that some of the veins classified as Type 3, 3A or 3B veins are in fact Type 2, 2A or 2B, or Type 4, 4A or 4B veins. However, as shown below, even if such errors were committed on a large scale, they would not change the conclusions of this section.

The vein types present at surface sample sites and reported in drill logs for drill hole data-sites are shown in Fig. 8. Fig. 8 shows that Type 1, Type 2 and Type 2B veins (i.e. veins containing mainly Cu- and/or Fe-sulphides and/or Fe-oxides and/or quartz) are restricted to two main zones which project west and approximately northwest away from the McGerrigle Mountains contact, respectively, in the south and north parts of the map area, respectively; these zones are hereafter referred to as Type 1-2-2B vein zones. The Type 1-2-2B vein zones increase in width, and may in fact merge, with decreasing distance from the McGerrigle pluton. The largest Type 1-2-2B vein zone trends parallel to the basalt-graywacke lens in the southeast part of the map area for the eastern three quarters of its length, and then appears to swing to the east to follow the Porcupine Brook fault. Another Type 1-2-2B vein zone occupies the extreme southeast corner of the map area and may be simply a branch of the larger zone immediately to the north. This southern most Type 1-2-2B vein zone extends for 3.8 km west of the McGerrigle Mountains and may continue outside of the present map area. Type 1, Type 2 and Type 2B veins

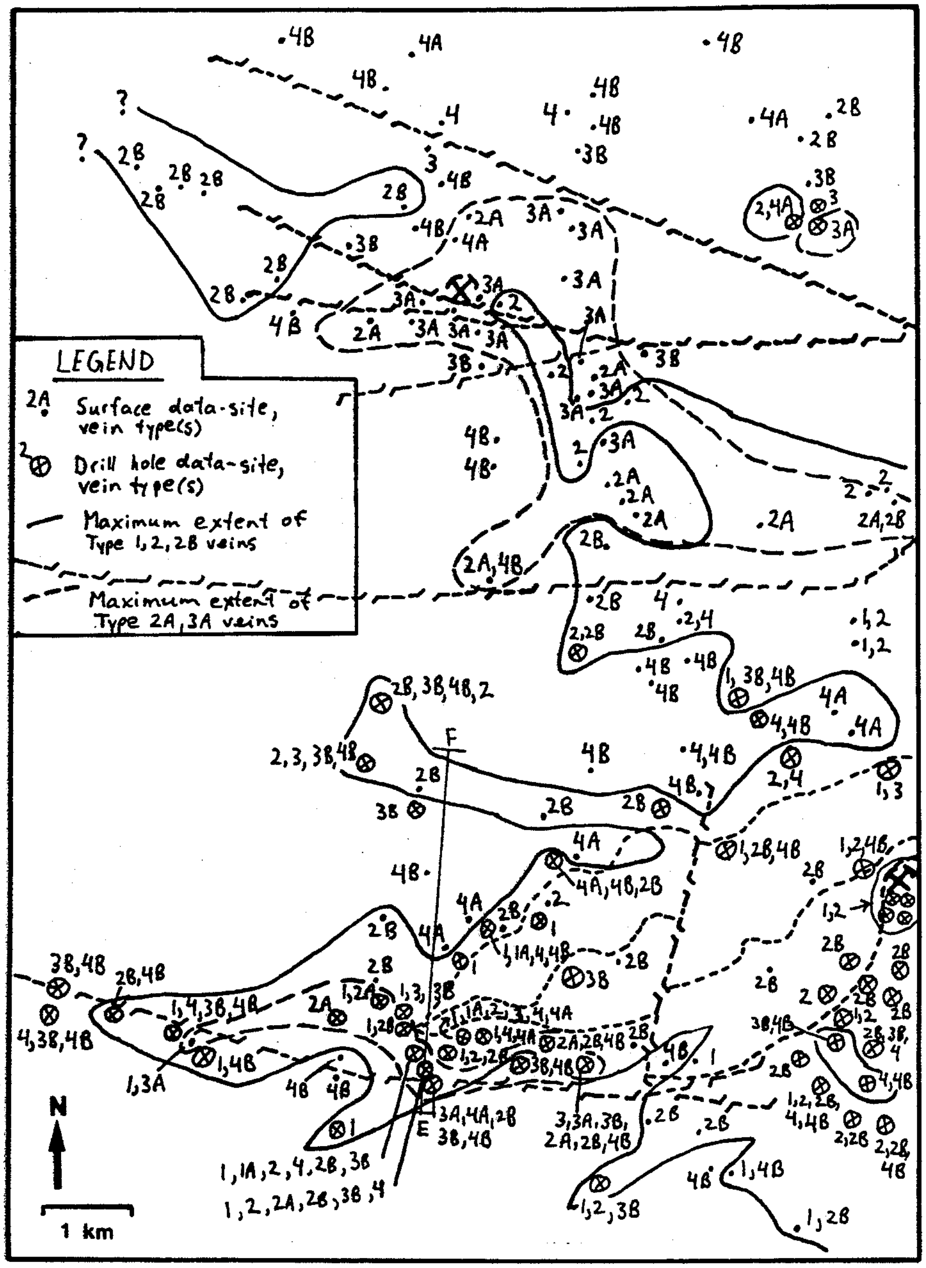

FIGURE 8: Spatial distribution of vein types as described in text and Table 1. Solid line shows maximum limit of occurrence of veins rich in quartz and/or Cu- and/or Fe-sulphides and/or Fe-oxides (Type 1, 2 or 2B veins). Dashed line shows limits of occurrence of veins rich in quartz and (sphalerite and/or galena) (Type 2A, 3A veins). Carbonate-rich veins, commonly bearing one or more of Zn-, Pb-, Cu-Fe, or Fe-sulphide, occur inside and outside of the Type 1-2-2B-2A-3A vein zones. Vertical section EF shown in Fig. 9. Major faults and lithologic contacts from Fig. 3 included for reference.

also occur with high frequency in the vicinity of Petit Lac Ste-Anne. This Petit Lac Ste-Anne zone would appear to extend at least 4 km westward from Petit Lac Ste-Anne. A northwest-trending zone of Type 2 veins traversing the Cromar and Candego areas may be a northwestward projection of the Petit Lac Ste-Anne Type 1-2-2B vein zone. A northwest-trending zone of Type 2B veins occurs northwest of the Candego mine.

Type 2A and 3A veins (quartz-sphalerite-galena-rich veins) occur in two main zones, in the north and south parts of the map area respectively. The southern Type 2A-3A vein zone is approximately west-trending, about 4 km long and occurs entirely within the major southern Type 1-2-2B vein zone. In the north, Type 2A and 3A veins form a northwest-trending belt in which most Type 2A and 3A veins are peripheral to the northwest-trending arm of the Petit Lac Ste-Anne Type 1-2-2B vein zone. Two Type 2A veins occur within the Petit Lac Ste-Anne Type 1-2-2B vein zone, near to the McGerrigle Mountains. Type 1A veins (Zn- and/or Pb-sulphide-bearing with no quartz or carbonates) only occur at two sites in the western part of the southern Type 1-2-2B vein zone. Vein types 3, 3B, 4, 4A and 4B, which are relatively carbonate-rich and contain one or more of Zn-, Pb-, Cu-Fe- or Fe-sulphide, occur within and without the Type 1-2-2B-2A-3A vein zones.

In the region cut by section EF (Figs. 4, 6) there is clear evidence of a vertical zonation of vein types (Fig.9). Fig. 9 shows that vein Types 1 and 2 are common at relatively high and low elevations but that vein types 1A, 3, 3A, 4, 4A and most Type 2A veins are restricted to relatively high elevations. Comparison of Figs. 9 and 5 reveals that the quartz-carbonate and carbonate veins of Fig. 5 (i.e. vein types 3B and 4B) occur mainly in the Type 1A-2A-3-3A-4-4A zone of Fig. 9, whereas the quartz-rich (Type 2B) veins of Fig. 5 occur in the Type 1-2 and Type 1A-2A-3-3A-4-4A zones of Fig. 9. Note that the section EF region is especially well-suited to the discernment of vein type zones because of the spatial coincidence of strong topographic relief and an abundance of veins of many different types. Such features do not coincide elsewhere as favourably as they do in the section EF region. Thus lack of evidence of vertical zonation of vein types elsewhere in the map area does not mean that it is not present.

Thus, the principal conclusions of the vein type zoning study are 1) that quartz-Cu-Fe-sulphide-Fe-oxide mineralization (Type 1-2-2B veins) occupies a central position and occur at relatively low elevations in the vein type zoning patterns, 2) veins rich in quartz, sphalerite and galena (Type 2A, 3A veins) occur within or immediately peripheral to the Type 1-2-2B vein zones, and possibly mainly at higher elevations than the Type 1-2-2B veins, and 3) carbonate-rich veins containing one or more of Zn-, Pb-, Cu-Fe- or Fe-sulphide occur within and without the Type 1-2-2B-2A-3A vein zones and at relatively higher elevations than Type 1,2 and 2B veins. With respect to the

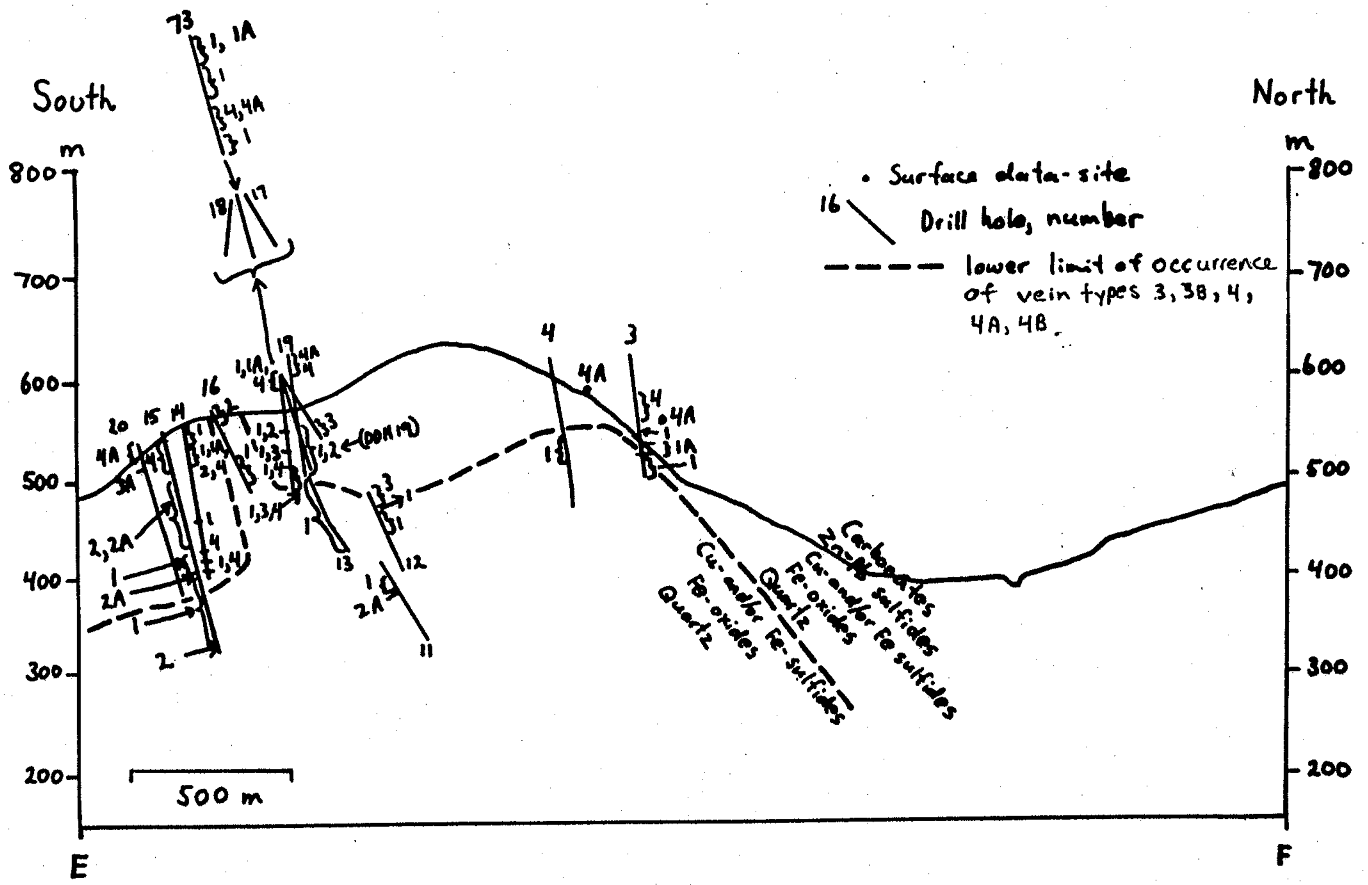

FIGURE 9: Vertical distribution of opaque-mineral-bearing vein types showing lower limit of occurrence of carbonate-rich veins which may also contain one or more of Zn-, Pb-, Cu-Fe-, or Fe-sulphides (vein types 3, 3A, 4, 4A). Veins rich in quartz and/or Cu- and/or Fe-sulphides and/or Fe-oxides (Type 1, 2 veins) occur at relatively high and low elevations. Compare this figure with Fig. 5 to see vertical distribution of non-opaque-mineral-bearing veins. Location of section EF in horizontal plane shown in Fig. 8.

possible misclassification of Type 3, 3A or 3B veins in drill holes discussed above, the reader will note that replacement in Figs. 8 and 9 of all Type 3 veins in drill holes by either Type 2 or Type 4 veins, or of all Type 3A veins by Type 2A or Type 4A veins, or replacement in Fig. 8 of all Type 3B veins in drill holes by Type 2B or 4B veins, does not change the above conclusions.

CHAPTER 4

FLUID INCLUSION STUDY

4.1 INTRODUCTION

Samples of quartz, sphalerite and calcite for use in fluid inclusion heating/freezing studies were taken from veins throughout the map area. The aim of these studies is to determine whether regional zoning patterns exist in the spatial distribution of average sample-site homogenization and melting temperatures. Of the minerals sampled, quartz has a spatial distribution and a degree of transparency which makes it the most useful mineral for regional mapping of fluid inclusion homogenization temperatures and melting points. Fluid inclusions in calcite and sphalerite will nevertheless be useful for comparing the ranges of homogenization and melting temperatures observed in these minerals with the quartz homogenization/melting temperature data. In this chapter fluid inclusion data from quartz crystals are presented; the sphalerite and calcite data will be included in the final report of this investigation.

The quartz samples used in the regional zoning studies represent a variety of quartz types (e.g. milky, white, transparent), grain sizes, morphologies (e.g. anhedral vs euhedral), and come from different positions within veins (contact, centre, etc.). It is hoped that regional zoning of fluid inclusion homogenization and melting temperatures, if present, is independant of such features.

4.2 EXPERIMENTAL PROCEDURES

Fluid inclusions were studied in 300 µm-thick slices of quartz polished on both sides. The microthermometric work was performed on a Chaixmeca Heating-Freezing Stage MTM-85 which had been calibrated between -56.6° and 398°C against the melting points of various pure standards. Differences between "true" and measured melting points are from -0.40° to +0.24°C over the range -56.6° to 100°C. From 100° to 398°C deviations of measured melting points from "true" values increase linearly from -0.32°C at 100°C to -15.74°C at 398°C. Temperature measurements ≥100°C in this study have been corrected for instrument error. Homogenization temperatures and freezing points were checked regularly for repeatability..

Homogenization temperatures of two-phase inclusions (liquid + vapour) were determined by gradually heating the inclusions and observing the temperature at which the vapour bubble in each inclusion shrank to disappearance or expanded to fill the inclusion cavity. Partial and total homogenization temperatures of inclusions containing three or more phases at room temperature (e.g. 2 immiscible liquids + a vapour phase or liquid + vapour + solid(s)) were determined from the temperatures of disappearance of different phases during heating. Melting points of CO_2, ice and clathrate hydrates were determined by chilling inclusions until completely frozen and then, during gradual reheating, observing the temperature of disappearance of the last CO_2, ice or clathrate crystal.

4.3 DESCRIPTION OF INCLUSIONS

The shapes of inclusion cavities range from regular (negative crystals, spheres, cylinders) to irregular. Most inclusion diameters or lengths are from 10 to 100 mm and average 30 to 40 mm.

Some inclusions are randomly distributed, isolated from other inclusions and are far from or bear no obvious relation to fractures; these inclusions are interpreted as being primary. Most samples are weakly to heavily fractured; fractures are commonly lined with or surrounded by aureoles of inclusions which are interpreted as being secondary or pseudosecondary. It is possible to distinguish between primary, secondary and pseudosecondary inclusions in some samples; in others this distinction is rendered impossible by overprinting effects. In the histograms and maps presented later in this chapter, no attempt is made to distinguish between data obtained from primary, secondary or pseudosecondary inclusions.

Vapour:liquid ratios of aqueous inclusions, and CO_2:H_2O volume ratios of inclusions containing visible liquid CO_2, typically span a wide range of values in each sample; this indicates that the temperatures of fluids which passed through each sample site and which deposited crystals or healed fractures, were highly variable.

4.3.1 FLUID INCLUSION TYPES

Inclusions in the Candego/Madeleine mines area can be divided into four types on the basis of the phases visible in them at various temperatures: Type 1 inclusions (common): Two phases are visible in these inclusions at room temperature: liquid and a vapour bubble which occupies from 5 to almost 100% of the inclusion volume (Fig. 10). No other vapour or liquid phases are visible in these inclusions at any other temperature. Liquid- and vapour-rich Type 1 inclusions homogenize to the liquid and vapour phases respectively; their homogenization temperatures (which are the only means of distinguishing Type 1 inclusions from certain Type 2 inclusions, described below) range from ~110° to >500°C.

Type 2 inclusions (rare): some of these inclusions have two phases at room temperature: liquid and a vapour bubble which occupies from 10 to 80% of the inclusion cavity. Other Type 2 inclusions appear "empty" at room temperature but evolve a vapour bubble upon cooling. Type 2 inclusions homogenize to the liquid phase at or below 26°C.

Type 3 inclusions (common): some of these inclusions contain three phases at room temperature: an inner liquid globule which floats immiscibly within an outer liquid phase which bathes the inclusion walls, and a vapour bubble within the inner liquid globule (Fig. 11).

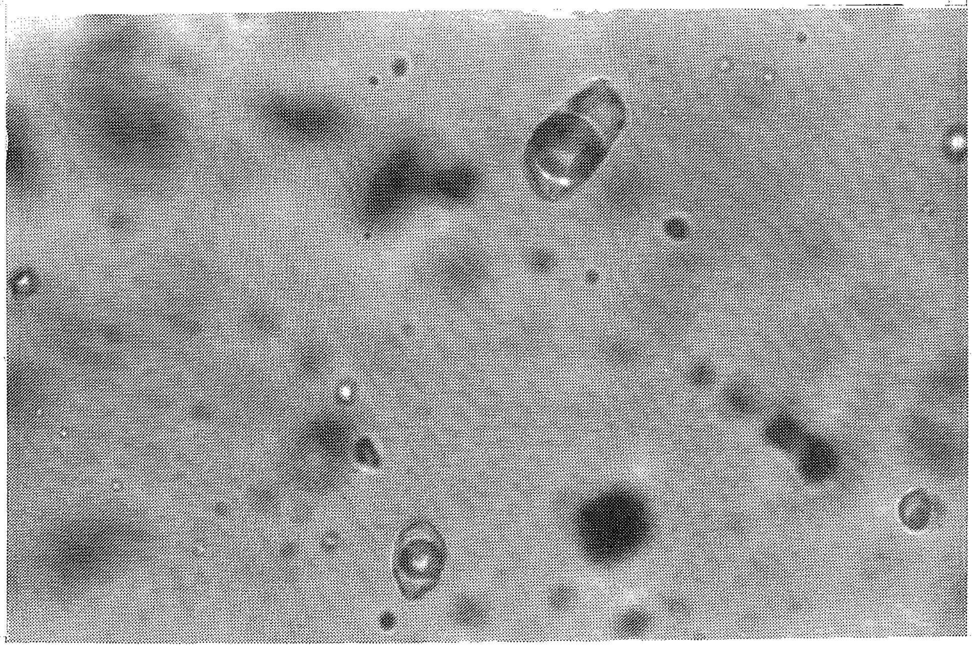

FIGURE 10: Type 1 inclusions, sample K85-31, X625. Photo field width 0.3 mm.

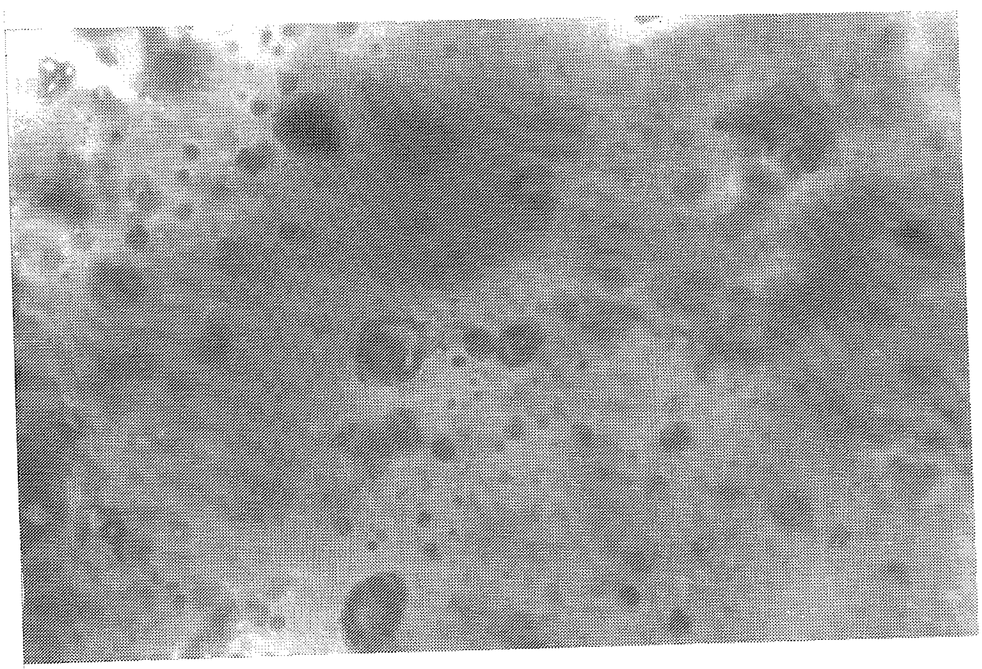

FIGURE 11: Type 3 inclusions, sample K85-84, X625. CO_2 vapour bubble discernable within CO_2 liquid phase in the large inclusion at the centre of the photo. Photo field width is 0.3 mm.

Other Type 3 inclusions resemble Type 1 inclusions at room temperature but develop a second vapour bubble within the primary "vapour" bubble when the inclusion is cooled. The vapour + inner liquid and "vapour" portions of Type 3 inclusions which contain three and two phases at room temperature respectively, occupy from 5 to almost 100% of the inclusion volume. On heating Type 3 inclusions to a maximum temperature of about 31°C the vapour bubble gradually shrinks to disappearance or rarely expands until its diameter matches that of the inner liquid globule. At higher temperatures Type 3 inclusions homogenize either by shinkage or expansion of the inner liquid globule which became homogeneous at $T \leq 31°C$.

Type 4 inclusions (fairly rare): these inclusions contain a liquid phase, from one to four daughter crystals which together occupy up to 50% of the inclusion volume, and a vapour bubble which occupies ≤20% of the inclusion volume; invariably one of the daughter crystals is a cubic mineral which is assumed to be halite (Fig. 12). The other daughter crystals have a variety of cross-sectional shapes: hexagonal, rectanglar, rounded, and bulbous. Some Type 4 inclusions homogenize by vapour phase shrinkage following dissolution of all solids; in others vapour phase disappearance precedes dissolution of solids.

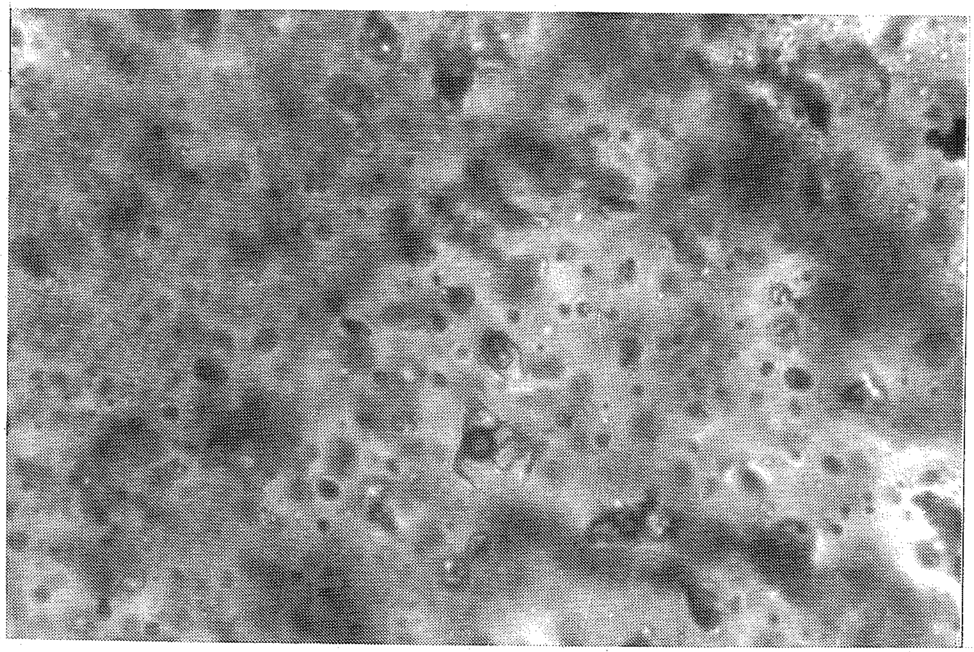

FIGURE 12: Type 4 inclusions, sample K85-38, X625. Halite cube discernable in large inclusion in lower centre part of photo. Photo field width 0.3 mm.

4.4 PRESENTATION, INTERPRETATION OF HEATING/FREEZING DATA

The homogenization temperatures and freezing points determined from the four inclusion types are shown in Figs. 13 to 16. Tables of data obtained from individual samples will be provided with the final report of this project.

Homogenization temperatures of Type 1 inclusions (Fig. 13) range from 110° to 550°C, but 96% of these temperatures are ≤400°C. There is a peak at about 195°C and a secondary peak at about 255°C. The highest values (450°-550°C) were obtained from vapour-rich inclusions. 97% of all Type 1 inclusions homogenized in the liquid phase. Melting of Type 1 inclusions typically begins at temperatures ≥-21°C. Final melting points range from -14° to -2°C (Fig. 16). Among the sub-0°C final melting points, values of -10° to -2°C predominate. Final melting temperatures of +6°C were observed in three Type 1 inclusions and +7°C in a fourth.

The homogenization/freezing behaviour of most Type 1 inclusions indicate that they contain a dilute aqueous-salt solution in equilibrium with an essentially pure-H_2O vapour bubble (see for e.g. Lemmlein and Klevtsov, 1961). Initial melting points above ~-21°C reveal that the dissolved salts are NaCl and/or KCl (Crawford, 1981). Rare Type 1 inclusion final melting points of 6° and 7°C can be attributed to the presence of small amounts of

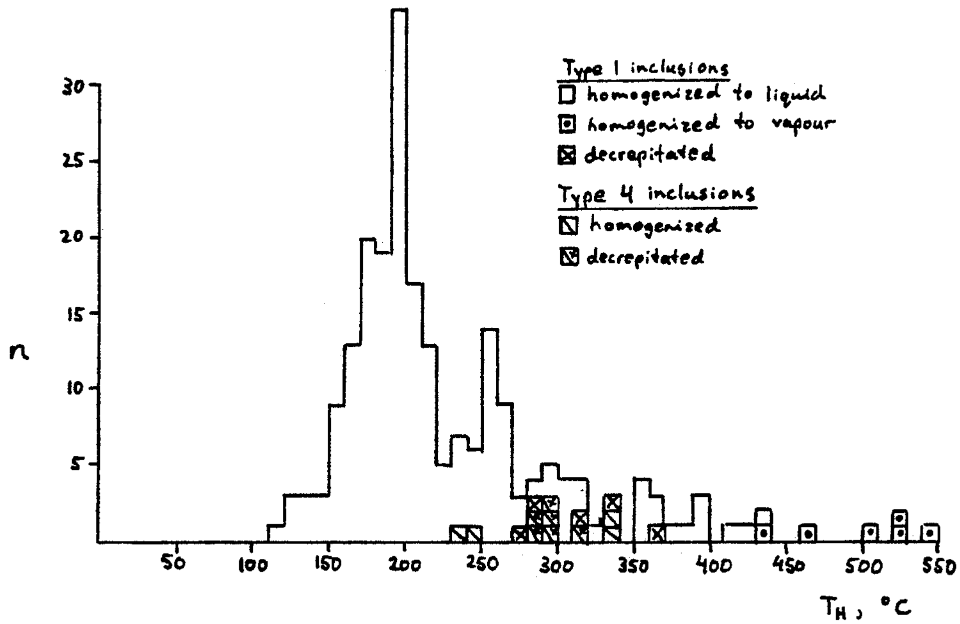

FIGURE 13: Homogenization or decrepitation temperatures of Type 1 and Type 4 inclusions.

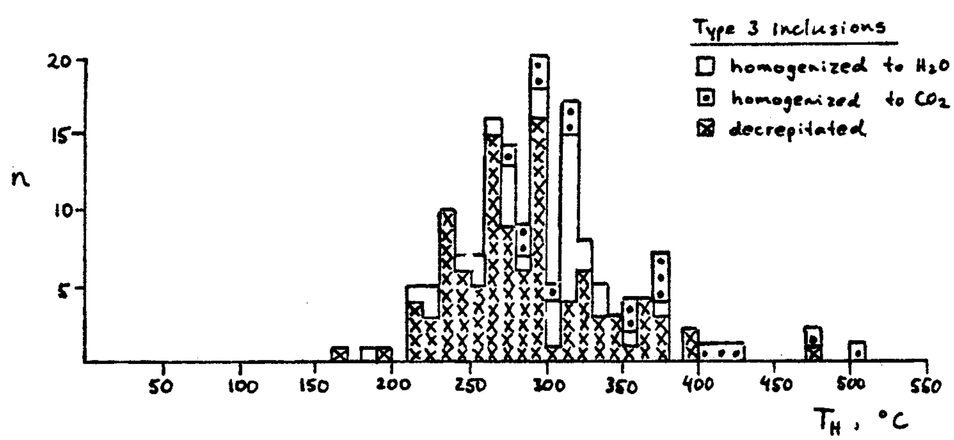

FIGURE 14: Homogenization or decrepitation temperatures of Type 3 inclusions.

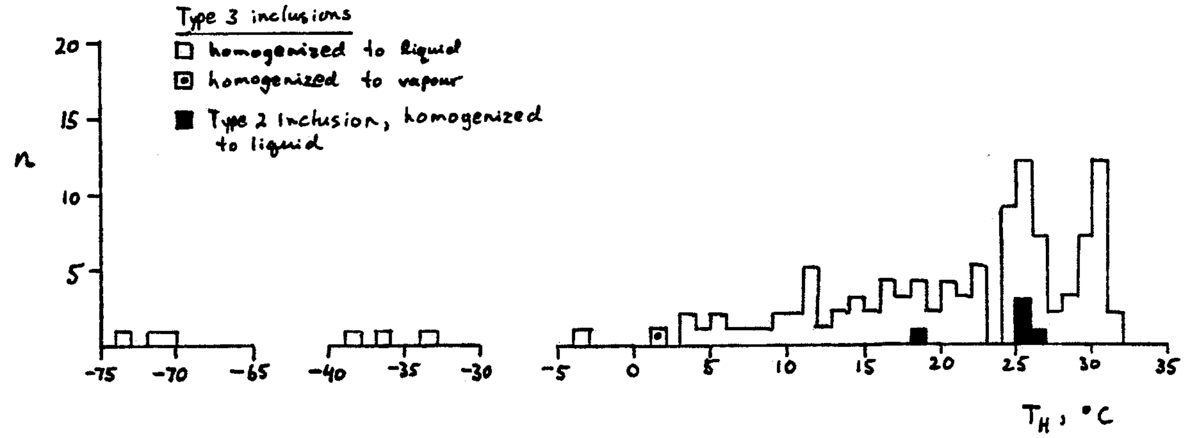

FIGURE 15: Temperatures of homogenization of Type 2 inclusions and the vapour + inner liquid portion of Type 3 inclusions.

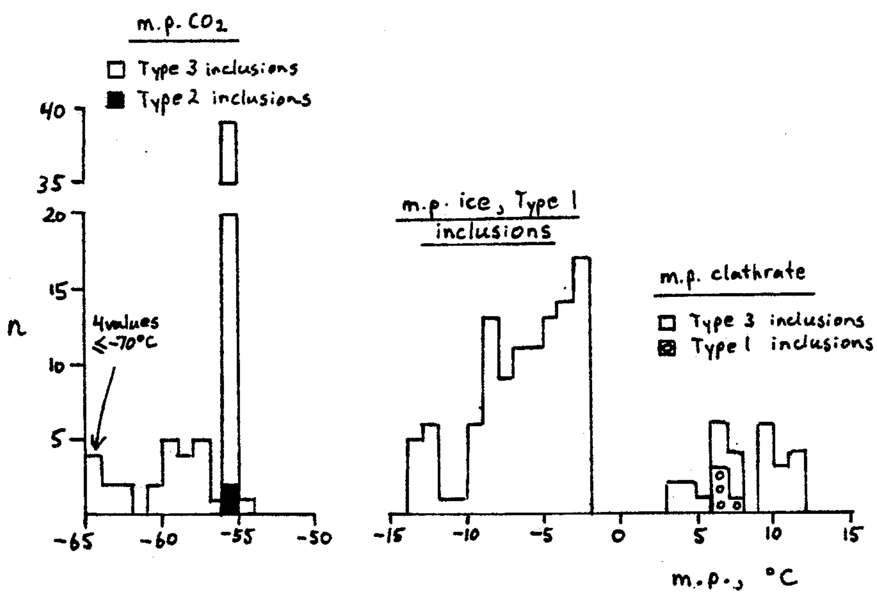

FIGURE 16: Temperatures of final melting of Co_2 in Type 2 and 3 inclusions, of ice in Type 1 inclusions and of clathrate hydrates in Type 1 and 3 inclusions.

dissolved CO_2: it is shown below that CO_2 is present in all Type 2 and Type 3 inclusions. In water CO_2 forms a clathrate hydrate at low temperatures which has the approximate formula $CO_2 . 5\ 3/4\ H_2O$ and which melts at $T \lesssim 10°C$ at CO_2 pressures $\lesssim 45$ bars. Such low CO_2 pressures in Type 1 inclusions are indicated by the absence of a discrete liquid CO_2 phase (Hedenquist and Henley, 1985).

Five Type 2 inclusions were homogenized; they did so in the liquid phase at temperatures from 18° to 26°C (Fig. 15). Final melting in two Type 2 inclusions occurred at -55.6° and -55.8°C, respectively (Fig. 16). These observations indicate that Type 2 inclusions contain essentially pure CO_2 (Hollister and Buruss, 1976).

Homogenization of the vapour + inner liquid portion of Type 3 inclusions occurred at temperatures of -74° to +31°C; the great majority of these temperatures are $\gtrsim 1°C$ (Fig. 15). There are peaks at 25° and 30°C. In all but one of these inclusions, the homogenization phenomenon referred to above occurred in the liquid phase. Type 3 inclusions homogenize completely or more commonly decrepitate at temperatures from 160° to 500°C (Fig. 14). 95% of these temperatures are between 210° and 380°C and there is a peak in the data at about 295°C. Total homogenization of Type 3 inclusions occurs in some cases by shrinkage and disappearance of the inner immiscible globule and in other cases by expansion of this globule to fill the inclusion;

homogenization temperatures of inclusions which homogenize by globule expansion are on average higher than the homogenization temperatures of inclusions which homogenize by globule shrinkage. Homogenization temperatures $\geq$400°C were obtained only from inclusions which homogenized by globule expansion.

The liquid phase which wets the walls of Type 3 inclusions melts at temperatures of 3° to 12°C (Fig. 16). Melting of this liquid phase is extremely difficult or impossible to detect because the index of refraction of the frozen crystals is similar or equal to that of the liquid phase. Deformation of the inner liquid globule by these crystals is commonly the only evidence of the presence of the latter. In most cases outer liquid melting precedes homogenization of the vapour + inner liquid but in some inclusions the reverse situation occurred. Temperatures of final melting of the inner liquid in Type 3 inclusions vary from -55° to $\leq$-70°C, with a pronounced peak at -55° to -56°C (Fig. 16). For Type 3 inclusions from which inner liquid melting points and vapour + inner liquid homogenization temperatures were obtained, there is a positive correlation between progressively lower homogenization temperatures below about 20°C and inner liquid melting points increasingly less than about -56°C (Fig. 17).

The homogenization and freezing behaviour of Type 3 inclusions can be explained in terms of phase equilibria in the systems H_2O-CO_2-salts or

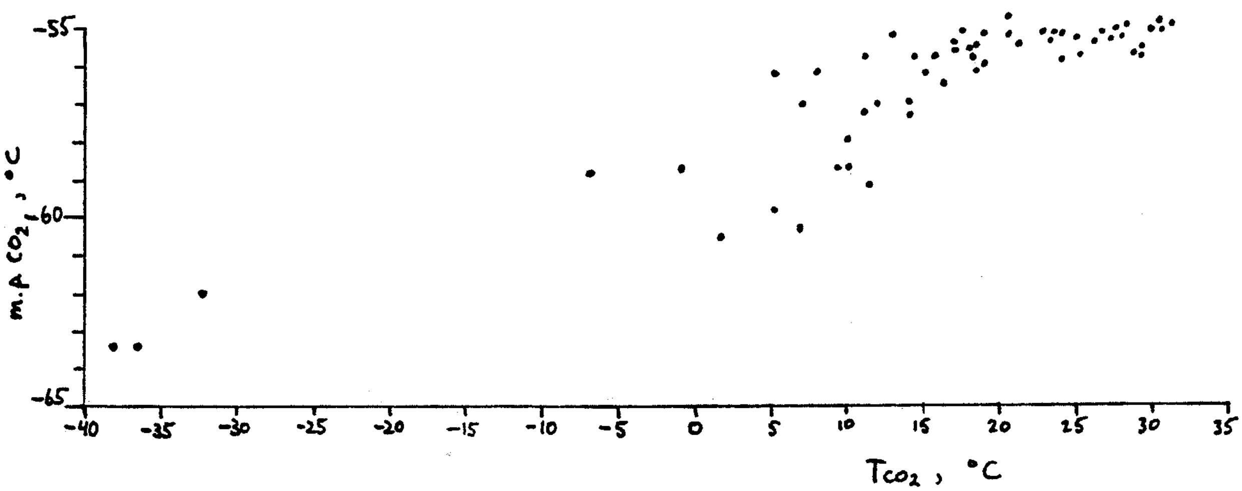

FIGURE 17: Plot of final melting temperature of inner liquid phase vs vapour + inner liquid homogenization temperature in Type 3 inclusions.

H_2O-CO_2-CH_4-salts (Hollister and Buruss, 1976; Buruss, 1981). The vapour bubble + inner liquid portion of these inclusions is composed of CO_2 or mixtures of CO_2 and CH_4. Pure CO_2 is indicated by a final inner liquid melting point of -55° to -56°C. Increasing degrees of depression of this melting point below about -56°C reflects the presence of increasing amounts of dissolved CH_4. Addition of CH_4 to CO_2 also depresses the boundary of the liquid + vapour field in the CO_2-CH_4 system to lower temperatures than in the pure CO_2 system (Hollister & Buruss, 1976). This results in progressively lower homogenization temperatures for increasingly CH_4-rich fluids. In Type 3 inclusions from the present field area there is a marked positive correlation between decreasing vapour + inner liquid homogenization temperatures below about 20°C and decreasing inner liquid melting temperatures below about -56°C (Fig. 17). This suggests strongly that in the Candego/Madeleine mines area samples in general, homogenization temperatures increasingly less than 20°C reflect the presence of increasing amounts of dissolved CH_4. Vapour + inner liquid homogenization temperatures as low as -74°C are below the minimum homogenization temperature possible in the pure CO_2 system (-56.6°C) and are close to the critical point of pure methane, -82°C. Such inclusions therefore probably contain mainly methane only slightly diluted by CO_2.

The outer liquid in Type 3 inclusions comprises mainly H_2O + salts and minor CO_2 with or without CH_4. CH_4 forms a clathrate hydrate that is completely miscible with the CO_2 clathrate hydrate mentioned earlier.

Clathrate melting increasingly $\geq 10°C$ in the presence of H_2O liquid, CO_2 liquid and CO_2 vapour reflects the presence of increasing amounts of CH_4 (Hollister & Buruss, 1976). Clathrate melting increasingly less than 10°C in the presence of H_2O liquid, CO_2 liquid and CO_2 vapour reflects the presence of increasing amounts of NaCl (Collins, 1979).

Total homogenization or decrepitation temperatures of ten Type 4 inclusions range from 235° to 335°C (Fig. 13). Of the four inclusions which homogenized, vapour disappearance preceded dissolution of daughter crystals in two cases whereas the reverse situation occurred in the other two cases. Of the six inclusions which decrepitated prior to total homogenization, vapour disappearance preceded dissolution of solids in three inclusions, in another inclusion vapour disappearance and dissolution of solids would have occurred at approximately the same temperature, and the other two inclusions decrepitated before prediction of the probable order of disappearance of different phases became possible. Final melting points of the liquid phase in Type 4 inclusions were not measured precisely but were in each case $\leq 0°C$.

Type 4 inclusions which contain only liquid, vapour and halite are composed mainly of H_2O and NaCl; other salts may be present in amounts smaller than that of NaCl. Where other daughter crystals are present there are obviously additional components but it is not possible to deduce what they might be from their physical appearances and homogenization/freezing phenomena.

For the balance of this report, the following abbreviations will be used to identify the homogenization and melting temperatures described in this section:

T_{H_2O}	homogenization temperature of Type 1 inclusions
T_{CO_2}	homogenization temperature of Type 2 inclusions or the vapour + inner liquid portion of Type 3 inclusions
$T_{H_2O + CO_2}$	total homogenization temperature of Type 3 inclusions
T_4	total homogenization temperature of Type 4 inclusions
T_{134}	average homogenization temperature of all Type 1, 3 and 4 inclusions homogenized in a sample
m.p.ice	final ice melting point of Type 1 inclusions
m.p.clathrate	final clathrate melting point in Type 1 or Type 3 inclusions
m.p.CO_2	final inner liquid phase melting point in Type 3 inclusions

4.5 SPATIAL DISTRIBUTION OF AVERAGE SAMPLE-SITE FLUID INCLUSION HOMOGENIZATION AND MELTING TEMPERATURES

The spatial distribution of average sample-site temperatures of homogenization and melting, for the homogenization/melting phenomena described in the previous section, are shown in Figs. 19, 20, 21, 22, 23, 24 and 25.

Data for the point representing the Madeleine mine are from Williams-Jones et al. (1986). The locations of the samples studied in this investigation and from which the data of Figs. 19 to 25 were obtained are shown in Fig. 18. Vein-type zoning boundaries from Fig. 8 are included for reference purposes in each of Figs. 19 to 25. Lack of a value at a particular sample site on a particular figure (for Figs. 19-25) reflects in some cases absence of the appropriate fluid inclusion type(s) at that sample site and in other cases experimental difficulties encountered in observation of homogenization/freezing phenomena.

The average temperature of homogenization or decrepitation of inclusion Types 1, 3 and 4 (T_{134}) at each sample site is shown on Fig. 19. The average T_{134} values shown are based on the T_H values of an average of 11.2 inclusions per sample. Type 2 inclusion T_H values were not included in the calculation of overall average sample-site T_H values because these inclusions are rare and their T_H values are so low as to be of little value as estimates

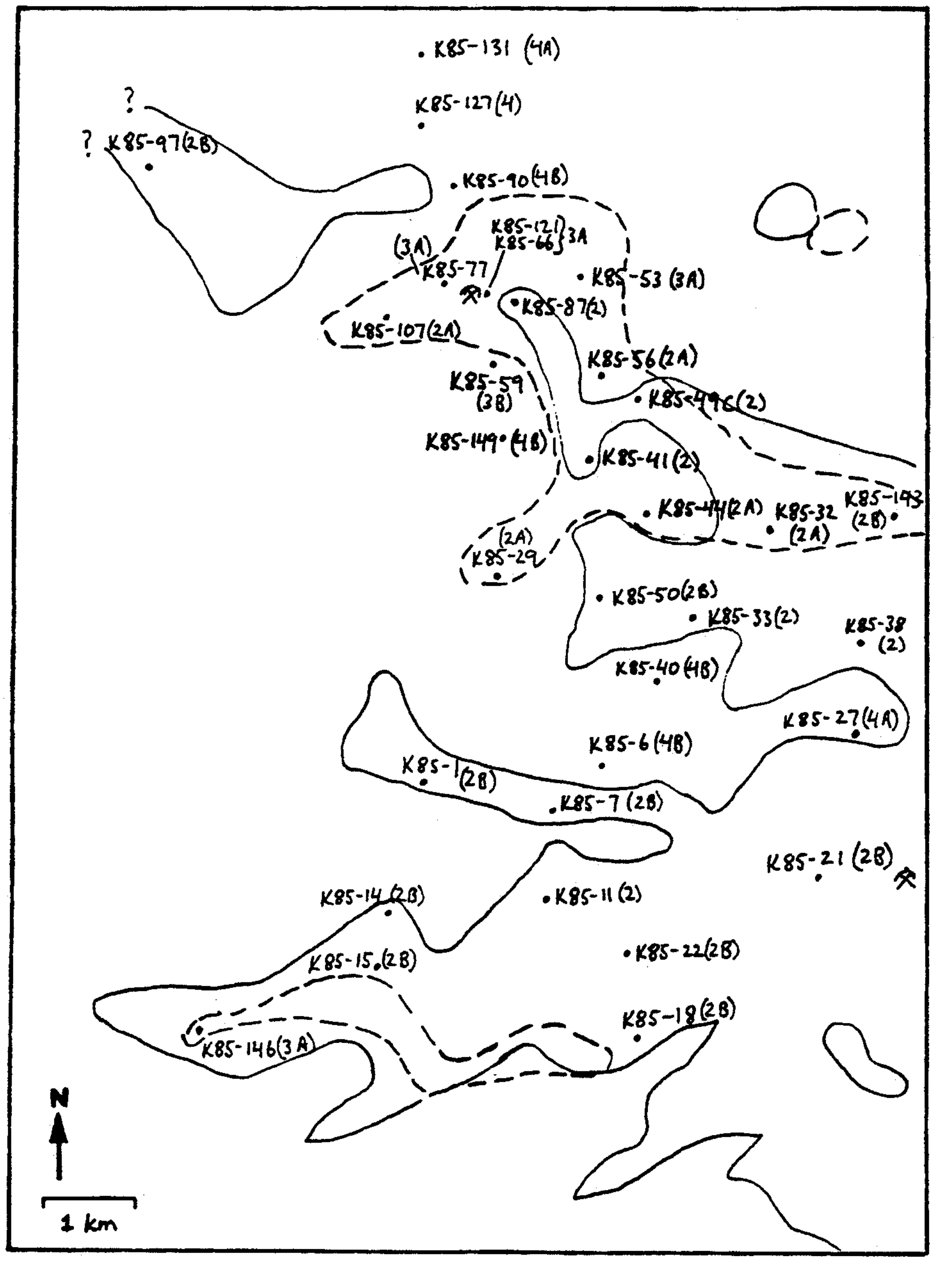

FIGURE 18: Locations of samples from which homogenization or freezing temperature data is reported on Figs. 19-25

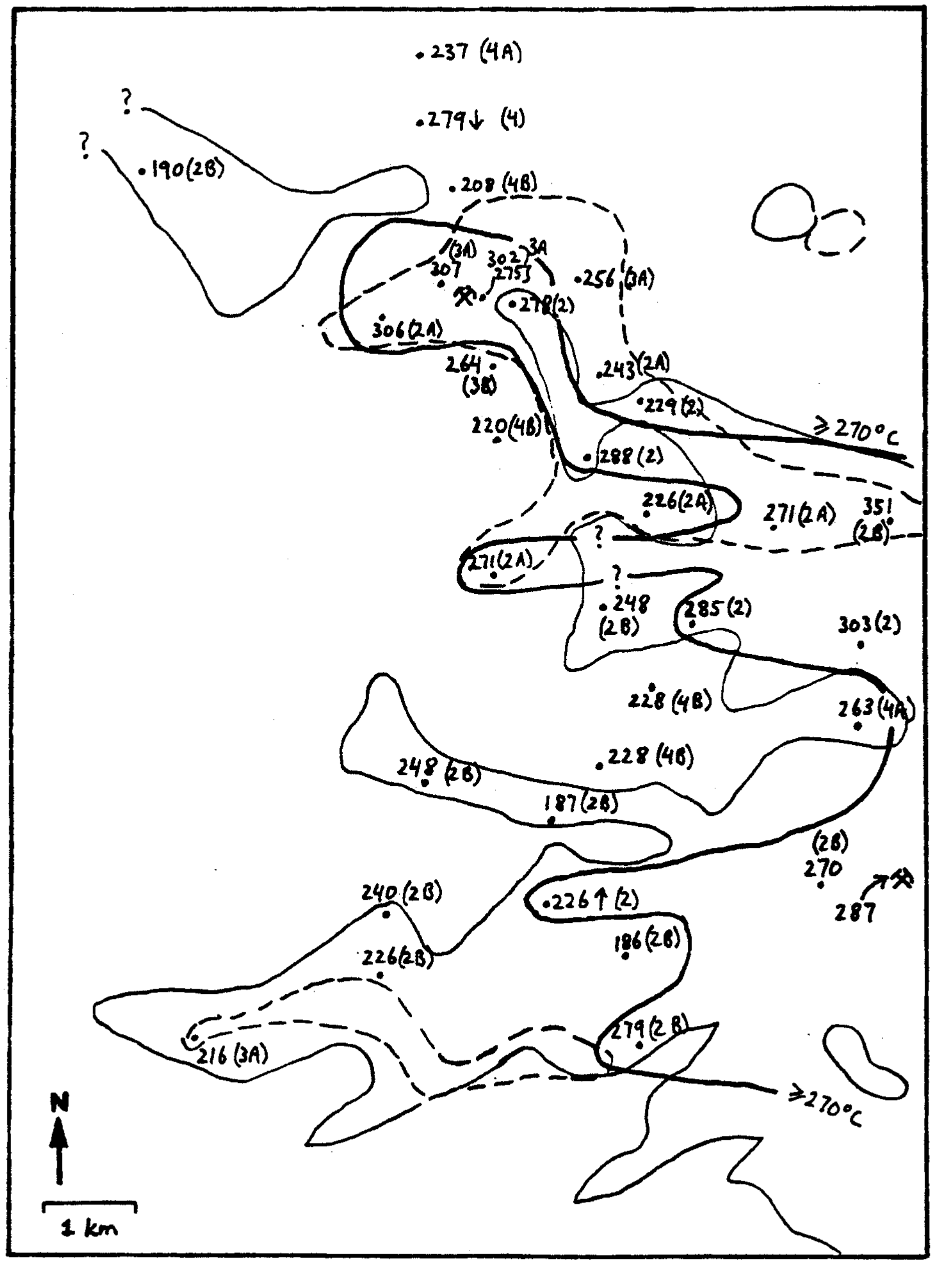

FIGURE 19: Average sample-site temperatures of homogenization in °C of inclusion Types 1, 3 and 4. Upward- and downward-pointing arrows indicate that true average homogenization temperatures are much higher or lower respectively than the reported values, based on comparison of v:l and CO_2:H_2O volume ratios of homogenized and unhomogenized Type 1 and Type 3 inclusions, respectively, in the samples concerned. Vein types from which fluid inclusion samples were taken are given in parentheses. Vein-type zones from Fig. 8 included for reference.

of the minimum temperatures of vein-forming processes. Upward- and downward - pointing arrows at sample sites K85-11 and K85-127, respectively, indicate that the actual average T_{134} values at these sites are considerably higher and lower, respectively, than the plotted values, based on comparison of room-temperature v:l and CO_2:H_2O volume ratios of homogenized and non-homogenized Type 1 and Type 3 inclusions, respectively, in these samples.

There are two zones in which average T_{134} values are $\geq$270°C and range as high as 351°C. Outside of these zones, average T_{134} values range from 187° to 264°C. The southern $T_{134}\geq$270°C zone coincides with the part of axial portion of the southern Type 1-2-2B vein zone which is nearest to the McGerrigle Mountains. The northern $T_{134}\geq$270°C zone occurs within and strikes parallel to the corridor of Type 1, 2, 2B, 2A and 3A veins which strikes northwest from Petit Lac Ste-Anne.

Average Type 3 inclusion temperatures of total homogenization or decrepitation ($T_{H2O+CO2}$) for each Type 3 inclusion-bearing sample are shown in Fig. 20. The average values presented here were computed from an average of 6.1 measurements per sample site. There are two zones in which average $T_{H2O+CO2}$ values are $\geq$285°C and range as high as 367°C. Outside of these two zones average $T_{H2O+CO2}$ values vary from 213° to 284°C. The southern $T_{H2O+CO2}\geq$285°C zone parallels the part of the central portion of the southern Type 1-2-2B vein zone which is nearest to the McGerrigle Mountains.

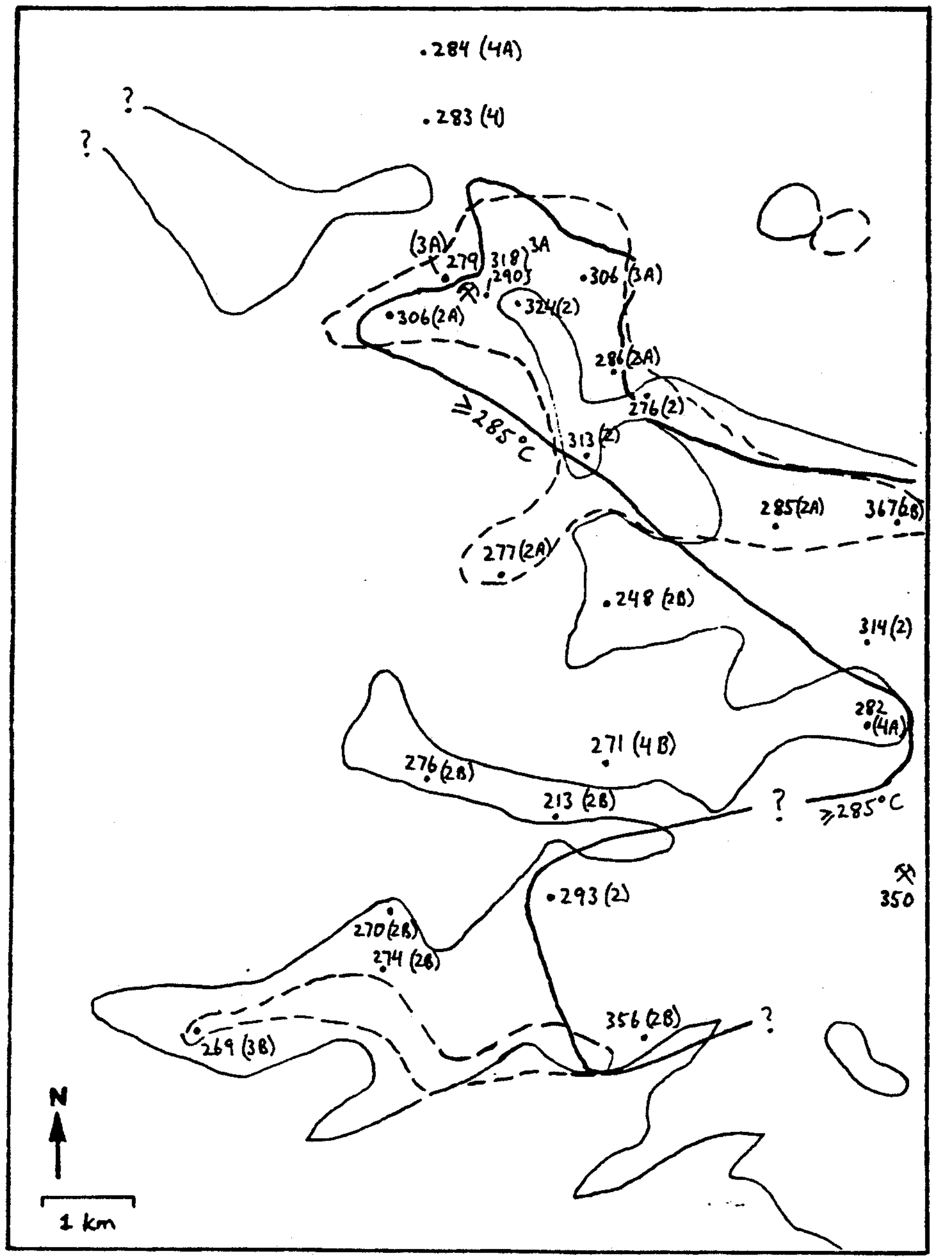

FIGURE 20: Average sample-site total homogenization or decrepitation temperatures in °C of Type 3 inclusions. Vein types from which fluid inclusion samples were taken given in parentheses. Vein-type zones from Fig. 8 included for reference.

The northern $T_{H2O+CO2}$≥285°C zone coincides with the northwest-trending belt of Type 1, 2, 2B, 2A and 3A veins which extends from Petit Lac Ste-Anne to the Candego mine.

Average sample-site homogenization or decrepitation temperatures of Type 1 inclusions (T_{H2O}) are shown in Fig. 21; an average of 7.1 homogenization/decrepitation temperatures per site were used to obtain the average values shown. Most average T_{H2O} values ≥ 210°C occur in a corridor which extends from the Madeleine mine area to north of the Candego mine; the trend of this corridor is northwest from the Madeleine mine area to the centre of the map area, northnorthwest from the centre of the map area to the Candego mine and north from the Candego mine to the northern edge of the map area. Within this major T_{H2O}≥210°C zone average T_{H2O} values rise locally to ≥250°C. A small T_{H2O}≥210°C zone is located towards the western end of the southern Type 1-2-2B vein zone. There is no obvious preferred spatial association between the T_{H2O}≥210°C zones and a particular vein-type zone.

Average sample-site final melting points of ice in Type 1 inclusions are shown in Fig. 22; the plotted averages are based on an average of 4.0 ice melting temperatures per site. There are two main zones in which m.p.ice values are ≤-5°C and as low as -17.9°C. Outside these zones most m.p.ice values are from -2.5° to -4.7°C. One m.p.ice≤-5°C zone strikes southeast within the portion of the central part of the southern Type 1-2-2B vein zone which is most proximal to the McGerrigle Mountains. The other m.p.ice≤-5°C

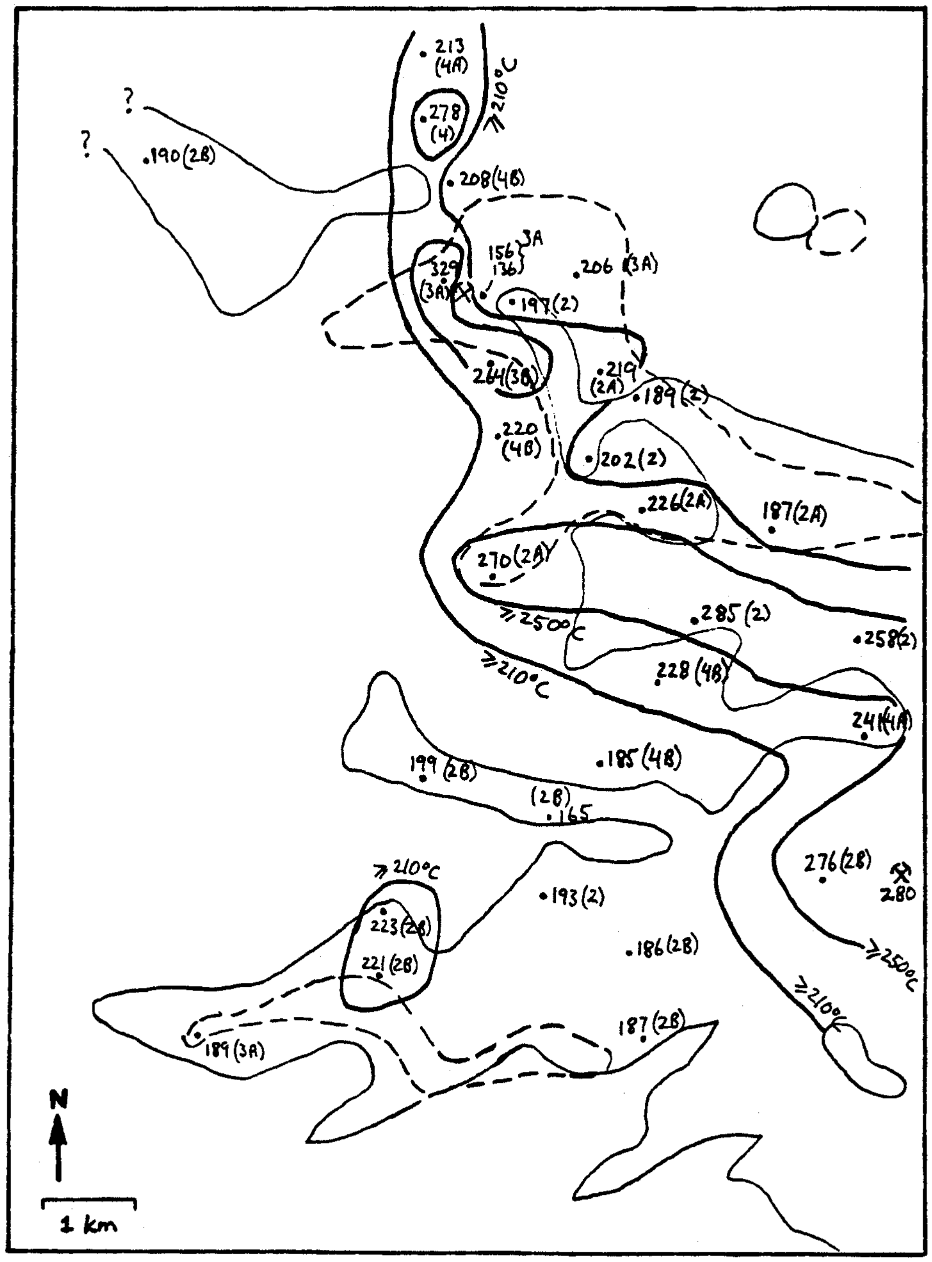

FIGURE 21: Average sample-site homogenization temperatures in °C for Type 1 inclusions. Vein types from which fluid inclusion samples were taken given in parentheses. Vein-type zones from Fig. 8 included for reference.

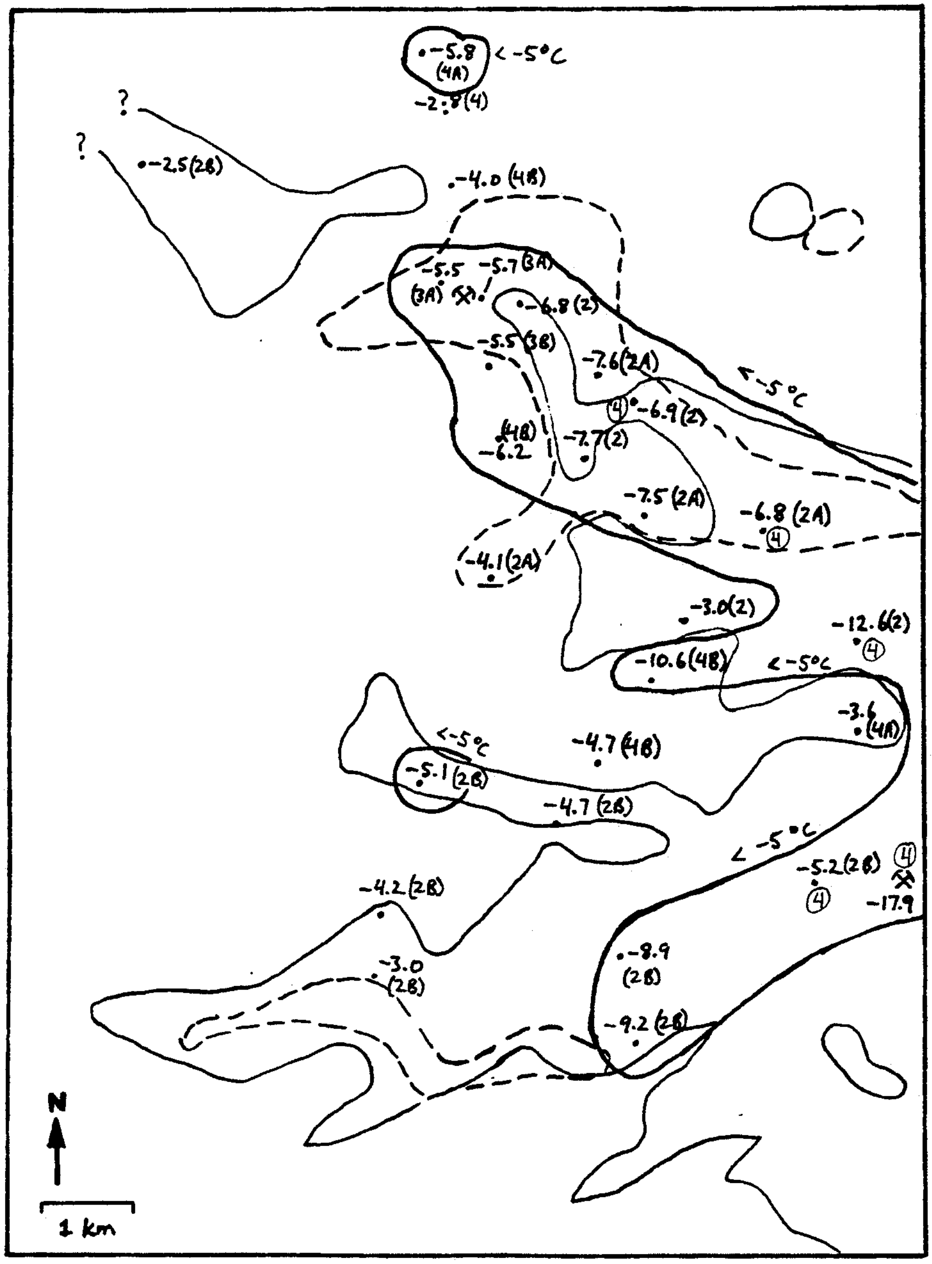

FIGURE 22: Average sample-site final melting temperatures in °C of Type 1 inclusions. Vein types from which fluid inclusion samples were taken given in parentheses. Vein-type zones from Fig. 8 included for reference. Circled numeral 4 indicates a site at which Type 4 inclusions occur.

zone occurs mainly within the corridor of Type 1, 2, 2B, 2A and 3A veins which strikes northward from Petit Lac Ste-Anne to the Candego mine. Within the zones in which veins have a quartz-rich gangue (the Q + 0-5% carb and Q + 6-15% carb zones of Fig. 4) average m.p.ice values decrease towards the McGerrigle Mountains. Sample sites at which Type 4 (daughter crystal bearing) inclusions were noted are also indicated on Fig. 22. All five of these sites occur in the central portions of Type 1-2-2B-2A-3A vein zones, relatively near to the McGerrigle Mountains.

Average sample-site clathrate final melting temperatures (m.p.clathrate) are shown in Fig. 23. The great majority of the data of Fig. 23 was obtained from Type 3 inclusions; m.p.clathrate values of a few Type 1 inclusions were also used. The average values shown in Fig. 23 were calculated from an average of 1.7 m.p.clathrate values per sample. Most average m.p.clathrate values ≤7.0°C occur in a poorly-defined zone stretching from south of Petit Lac Ste-Anne to the Candego mine. Outside of this zone most average m.p.clathrate values range from 7.7° to 11.6°C.

Average sample-site inner liquid final melting temperatures in Type 3 inclusions (m.p.CO_2) are shown on Fig. 24; these average values were determined from an average of 3.3 m.p.CO_2 values per sample site. Average m.p.CO_2 values are -55° to -56°C relatively far from the McGerrigle Mountains, and decrease to as low as ≤ -70°C with decreasing distance from the

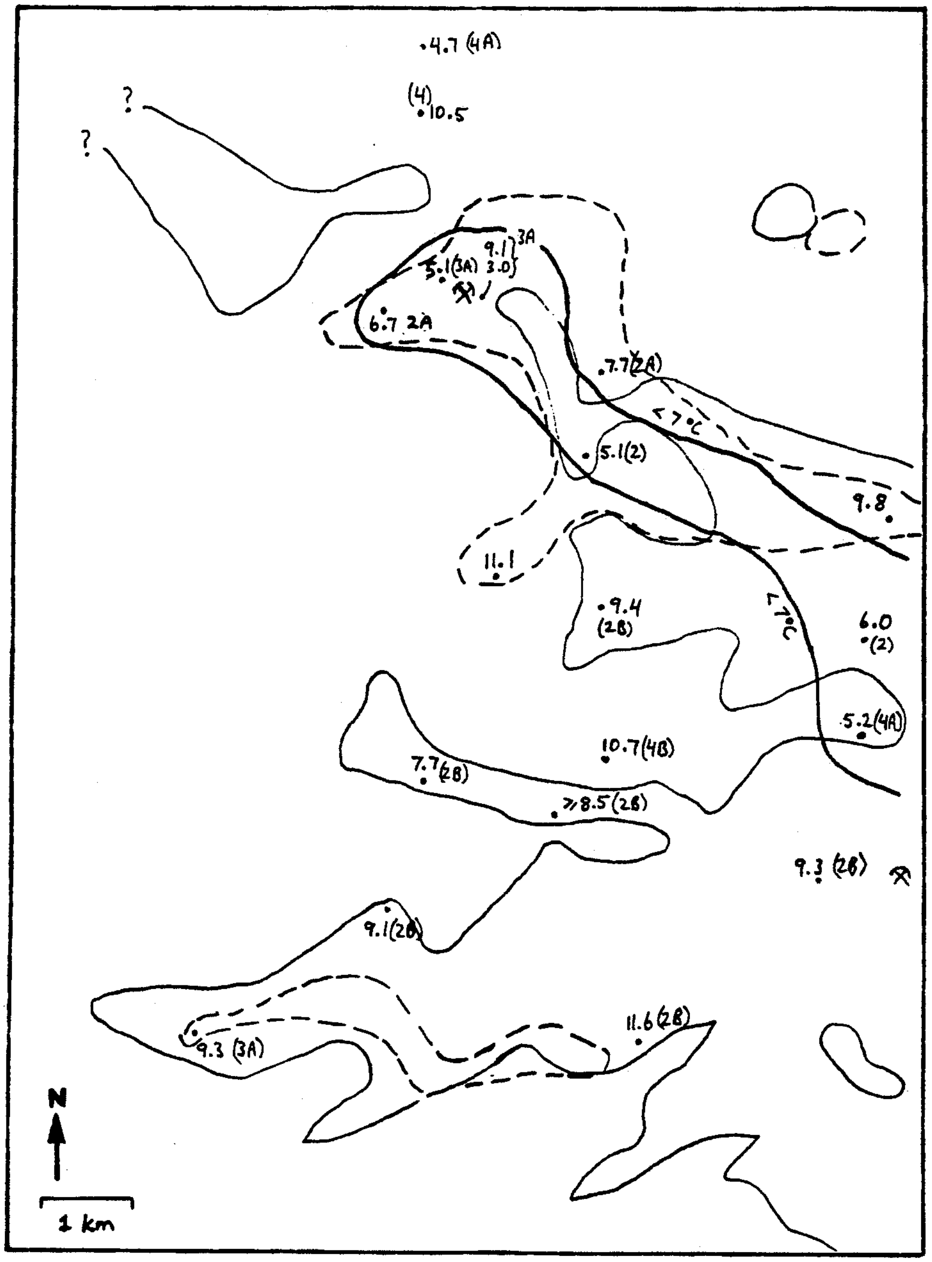

FIGURE 23: Average sample-site clathrate hydrate melting temperatures in °C in Type 3 and Type 1 inclusions. Vein types from which fluid inclusion samples were taken given in parentheses. Vein-type zones from Fig. 8 included for reference.

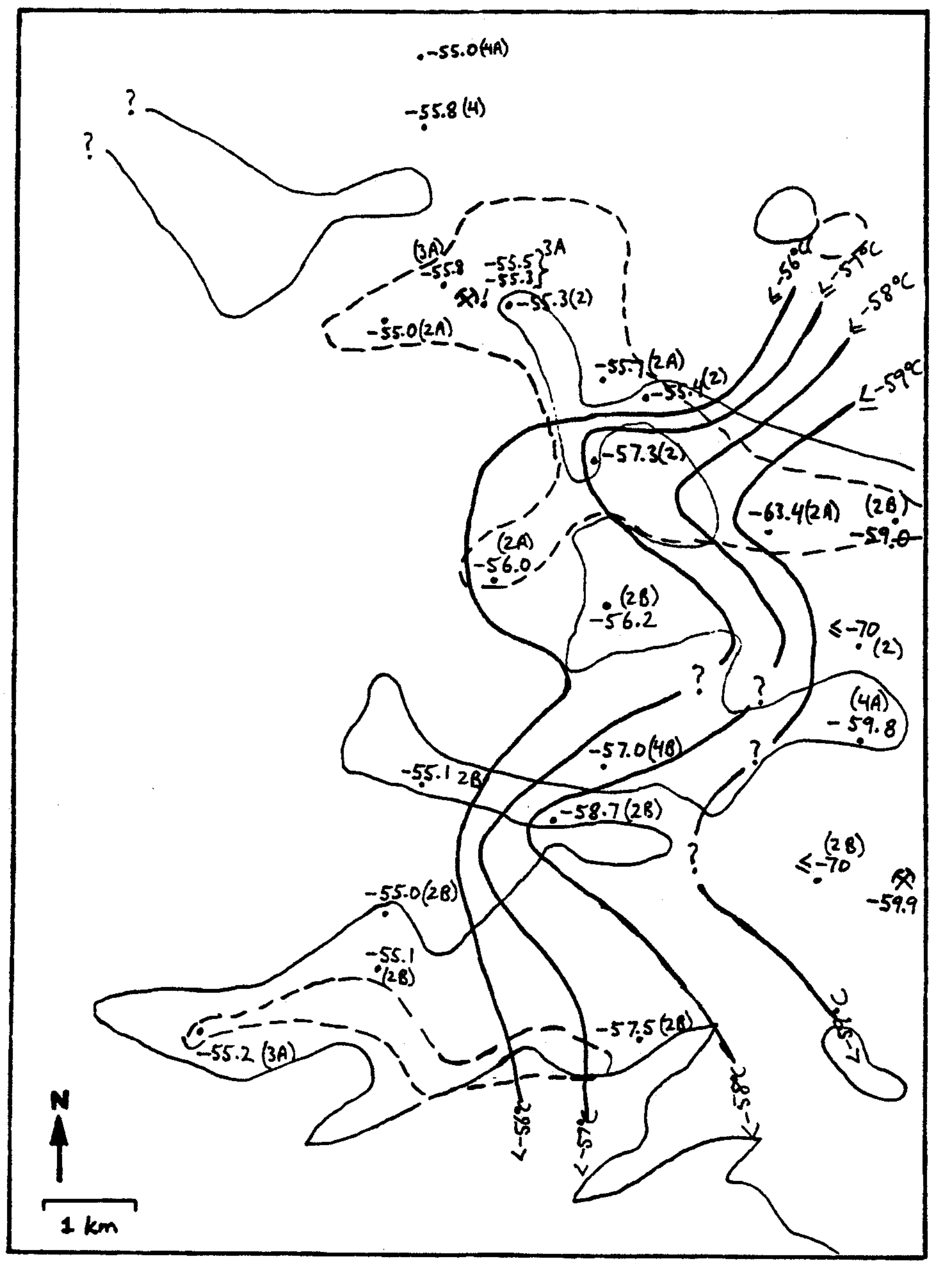

FIGURE 24: Average sample-site final melting temperatures in °C of inner liquid in Type 3 inclusions. Vein types from which fluid inclusion samples were taken given in parentheses. Vein-type zones from Fig. 8 included for reference.

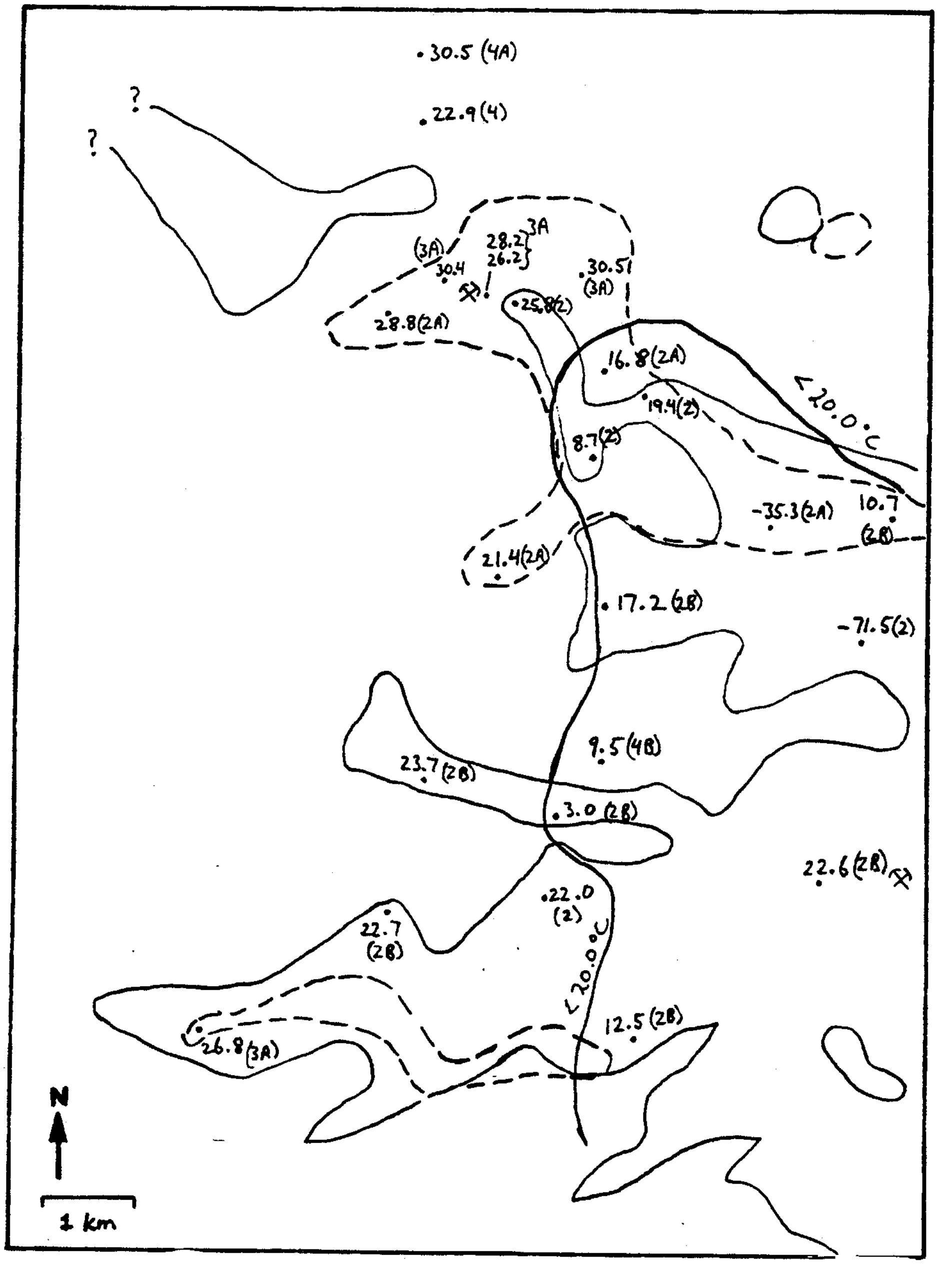

FIGURE 25: Average sample-site vapour + inner liquid homogenization temperatures in °C in Type 3 inclusions. Vein types from which fluid inclusion samples were taken given in parentheses. Vein-type zones from Fig. 8 included for reference.

pluton-sedimentary rock contact. More data points are needed to firmly establish the true shape of the zoning contours within the region where average m.p.CO_2 values are $\lesssim$-56°C but the available data are consistent with the following interpretations. Within the region proximal to the McGerrigle Mountains in which m.p.$CO_2 \lesssim$-56°C, m.p.CO_2 values are $\lesssim$-58°C in two zones which project outwards from the McGerrigle Mountains contact and which are associated fairly closely with the portions of the two major Type 1-2-2B vein zones which are nearest to the McGerrigle Mountains. These two zones of very low m.p.CO_2 merge towards the McGerrigle Mountains. Between the two zones of very low m.p.CO_2 values, m.p.CO_2 values are slightly higher, in the range -56° to -58°C. This zone of moderately low m.p.CO_2 values may extend relatively near to the McGerrigle Mountains.

Average sample-site vapour + inner liquid homogenization temperatures (T_{CO2}) in Type 3 inclusions are shown in Fig. 25. An average of 5.4 T_{CO2} values per site were used to obtain the average values plotted on Fig. 25. All average T_{CO2} values $\lesssim$20°C are associated with sites relatively near to the McGerrigle pluton; average T_{CO2} values range from 19.4° to -71.5°C within this region. Average T_{CO2} values are 21.4° to 30.5°C at sites relatively distal to the McGerrigle pluton. Average T_{CO2} values decrease with decreasing distance from the McGerrigle pluton within the zone of Type 1, 2, 2B, 2A and 3A veins that extends from Petit Lac Ste-Anne to the Candego mine.

CHAPTER 5

DISCUSSION

Since fluid inclusion data collection and investigation of the relations between T_H, m.p. and mineral zones will continue in the coming months, only a brief analysis of some salient points of the data presented in this report is given here.

5.1 REGIONAL HEAT SOURCES

Hydrothermal centres defined by vein-type (Fig. 8) and thermal (Fig. 19) zonations radiate outward from the contact of the McGerrigle Mountains. This observation suggests that the heat sources which drove the fluids responsible for vein-deposition lay in or below the region presently occupied by the McGerrigle Mountains.

5.2 HYDROTHERMAL CENTRES IN THE CANDEGO/MADELEINE MINES AREA

The observations that the Type 1-2-2B-2A-3A vein zones occupy a central position in the vein-type zoning patterns (Fig. 8), and that the T_{134}>270°C zones of Fig. 19 occur in the parts of the axial portions of the Type 1-2-2B-2A-3A vein zones nearest to the McGerrigle Mountains suggest that these parts of the Type 1-2-2B-2A-3A vein zones were the thermal centres of hydrothermal activity within the map area. Further away from the McGerrigle Mountains, the Type 1-2-2B-2A-3A vein zones were mineralogical centres of hydrothermal activity.

Type 4 inclusions occur only in the parts Type 1-2-2B-2A-3A vein zones nearest to the McGerrigle Mountains and average sample-site m.p.ice values are <-5°C mainly in these same regions. These two observations suggest that in general fluid salinities were highest in the parts of the Type 1-2-2B-2A-3A vein zones nearest to the McGerrigle Mountains.

Thermal centres defined by average $T_{H2O + CO2}$ values are more closely associated with the Type 1-2-2B-2A-3A vein type zones than are the thermal centres defined by the average T_{H2O} values (compare Figs. 20, 21). This suggests that in general the Type 3 inclusion fluids were more closely associated with vein-formation than were the Type 1 inclusion fluids.

5.3 RELATION BETWEEN METAMORPHIC AUREOLE DEVELOPMENT AND VEIN DEPOSITION

The thermal and vein-type zoning centres of Figs. 19 and 8 respectively occur in areas in which the McGerrigle metamorphic aureole mapped by Lachance (Lachance and Duquette, 1977) bulges outward further than usual from the McGerrigle Mountains contact (compare Figs. 19, 8 and 3). The McGerrigle aureole was the object of a detailed study by Van Bosse (1986). Van Bosse's (1986) data indicate an out-bowing of the aureole which may extend across the entire map sheet covered by the present investigation; her data do not indicate whether there is an in-bowing of the aureole between two regions of out-bowing, as mapped by Lachance. Van Bosse (1986) interpreted the aureole out-bowing phenomenon as having resulted from higher than usual degrees of convective heat transfer away from the McGerrigle pluton in the regions where this phenomenon is observed.

The data of Lachance (1977) and Van Bosse (1986), in conjunction with the evidence for hydrothermal centres of vein mineralization which radiate out from the McGerrigle Mountains presented in this report, suggest strongly that aureole-development and vein-formation were commonly or completely contemporaneous in the Candego/Madeleine mines map area.

CHAPTER 6

CONCLUSIONS

The conclusions of this report are:

1) Veins containing one or more of Cu-sulphide, Cu-Fe-Sulfide, Fe-sulphide, Fe-oxide or gangue minerals comprising quartz + 0-5% carbonates (Type 1,2 or 2B veins) and veins containing (quartz + 0-15% carbonates), Zn-sulphide and/or Pb-sulphide, ± Cu-Fe-sulphide ± Fe-sulphide (Type 2A or 3A veins) occur in a northern zone which strikes northwest from the McGerrigle Mountains contact and in a southern zone which strikes west from the McGerrigle Mountains contact. Within each of these two zones, Type 2A and 3A veins are commonest relatively distal to the McGerrigle pluton contact. Veins containing a gangue of carbonates + 0-84% quartz, ± Zn-sulphide ± Pb-sulphide ± Cu-Fe-sulphide ± Fe-sulphide (vein Types 3, 3B, 4, 4A, 4B) occur within and without the Type 1-2-2B-2A-3A zones described above.

2) Type 1, 2 and 2B veins persist to greater depths than Type Type 3, 3B, 4, 4A, 4B veins and perhaps also Type 2A and 3A veins.

3) Homogenization temperatures of aqueous inclusions range from 110° to 550°C; final melting temperatures are typically -14° to -2°C and rarely as high as 6° to 7°C.

4) Homogenization and final melting temperatures of pure CO_2 inclusions are 18° to 26°C and -55° to -56°C respectively.

5) Total homogenization or decrepitation temperatures of mixed aqueous/carbonic inclusions are 160° to 500°C. Homogenization and final melting temperatures of the CO_2-rich portion of these inclusions are -74° to +31°C and $\leq$-70° to -55°C, respectively. Clathrate final melting temperatures in these inclusions range from 3° to 12°C.

6) Total homogenization or decrepitation temperatures of daughter-crystal-bearing inclusions are 235° to 335°C.

7) The parts of the axial portions of the Type 1-2-2B-2A-3A vein zones which are nearest to the McGerrigle Mountains were the thermal centres of hydrothermal activity. Further away from the McGerrigle Mountains, the Type 1-2-2B-2A-3A vein zones were mineralogical centres of hydrothermal activity.

8) Fluid inclusion salinities are highest in the parts of the axial portions of the Type 1-2-2B-2A-3A vein zones which are nearest to the McGerrigle Mountains.

9) X_{CH_4} in the CO_2-rich portion of aqueous/carbonic inclusions increases with decreasing distance from the McGerrigle Mountains.

10) Metamorphic aureole-formation and vein deposition were commonly or completely contemporaneous in the Candego/Madeleine mines area.

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