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Implications of a preliminary fluid-inclusion study of giant quartz veins of the southern Great Bear magmatic zone, Northwest Territories[1]

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Abstract: Giant quartz veins occur along brittle faults in the ca. 1865 Ma Great Bear magmatic zone. They comprise two or more generations of subparallel veins and stockworks in zones as much as 100 m wide and 10 km long. They contain local concentrations of hematite/specularite, pyrite, copper sulphides, and pitchblende.

Fluid inclusions in the veins at two uranium showings, Crowfoot and Ted, were examined. The homogenization temperatures (Th) range from 96 to 217°C for Type I (2-phase liquid-rich) inclusions at Crowfoot, and from 122 to 169°C for Types I and III (3-phase liquid-rich) inclusions at Ted. Type II (2-phase vapour-rich) inclusions yield grossly different Th (228–445°C range), which do not represent true Th, but do suggest fluid mixing, as does the wide salinity range from 0.18 to 31.6 weight per cent NaCl equivalent. These data are consistent with the formation of the veins in a tensional epizonal environment.

Résumé : Des filons de quartz géants se rencontrent le long de failles cassantes dans la zone magmatique du Grand lac de l'Ours (environ 1 865 Ma). Ils comportent deux générations ou plus de filons subparallèles et de stockwerks dans des zones de jusqu'à 100 m de largeur et 10 km de longueur. Ils contiennent des concentrations locales d'hématite/spécularite, de pyrite, de sulfures de cuivre et de pechblende.

On a examiné des inclusions liquides dans les filons à deux indices d'uranium (Crowfoot et Ted). Les températures d'homogénéisation (Th) varient de 96 à 217 °C pour les inclusions de type I (deux phases, riches en liquide) à l'indice Crowfoot, et de 122 à 169 °C pour les inclusions de type I et III (trois phases, riches en liquide) à l'indice Ted. Les inclusions de type II (deux phases, riches en gaz) fournissent des températures d'homogénéisation très différentes (de 228 à 445 °C), qui ne représentent pas de véritables températures d'homogénéisation, mais suggèrent un mélange de liquides, comme le suggère également la plage étendue de salinités de 0,18 à 31,6 % d'équivalent NaCl en poids. Ces données sont compatibles avec une formation des filons dans un environnement épizonal en tension.

[1] Contribution to Canada–Northwest Territories Minerals Initiative Program 1991–1996

INTRODUCTION

A distinctive group of giant quartz veins characterize the Great Bear magmatic zone in the northwestern Canadian Shield (Fig. 1, 2). They are topographically conspicuous, and have attracted the attention of geologists and explorationists since the early part of this century (Furnival, 1935). During the first uranium exploration boom in the 1950s, uranium was mined from one of the veins, namely the Rayrock deposit in the southern part of the magmatic zone, and numerous smaller occurrences of uranium and copper sulphides hosted by the veins of this type were discovered (Fig. 3; Lang et al., 1962; Gandhi, 1994). The Rayrock mine produced 150 t of uranium from 1956 to 1958. Another noteworthy occurrence is the Rah prospect, where uranium is associated with significant amounts of gold, platinum, and palladium (Gandhi and Paktunc, 1989).

This paper presents results of the first study of fluid inclusions in the giant quartz veins in the Great Bear magmatic zone. The samples studied are from the Crowfoot and Ted uranium showings, located 20 km to the north and 5 km to the northwest of the Rayrock mine, respectively (Fig. 2, 3). The two showings were mapped and sampled during 1992 and 1995, respectively, by the first and third authors. The laboratory studies were carried out by the second author.

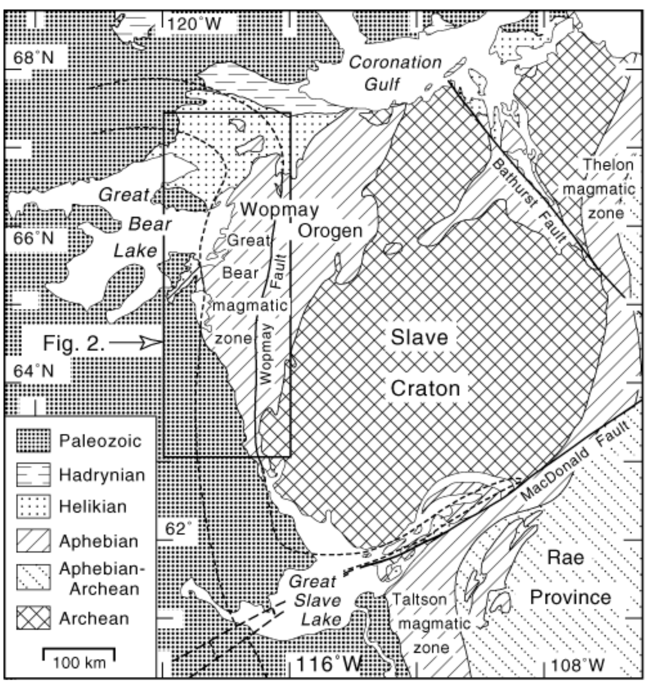


__Figure 1.__ Location map of the Great Bear magmatic zone.

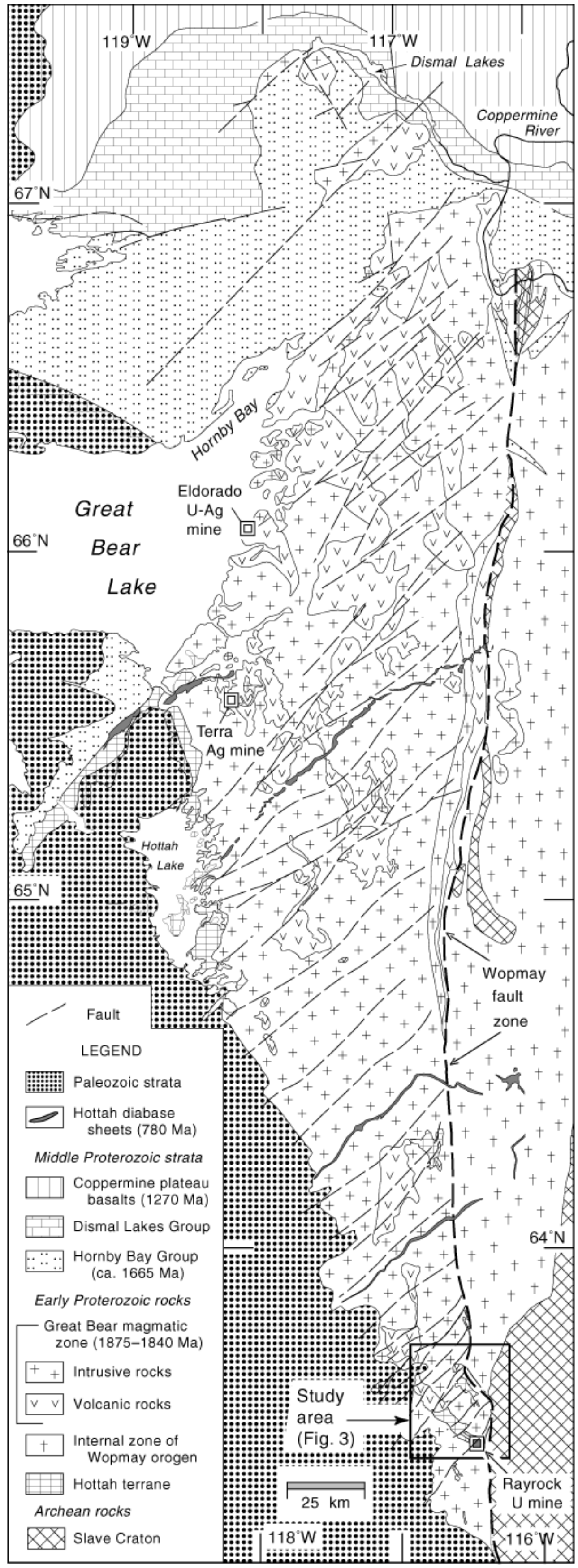


__Figure 2.__ General geology of the Great Bear magmatic zone, northwestern Canadian Shield.

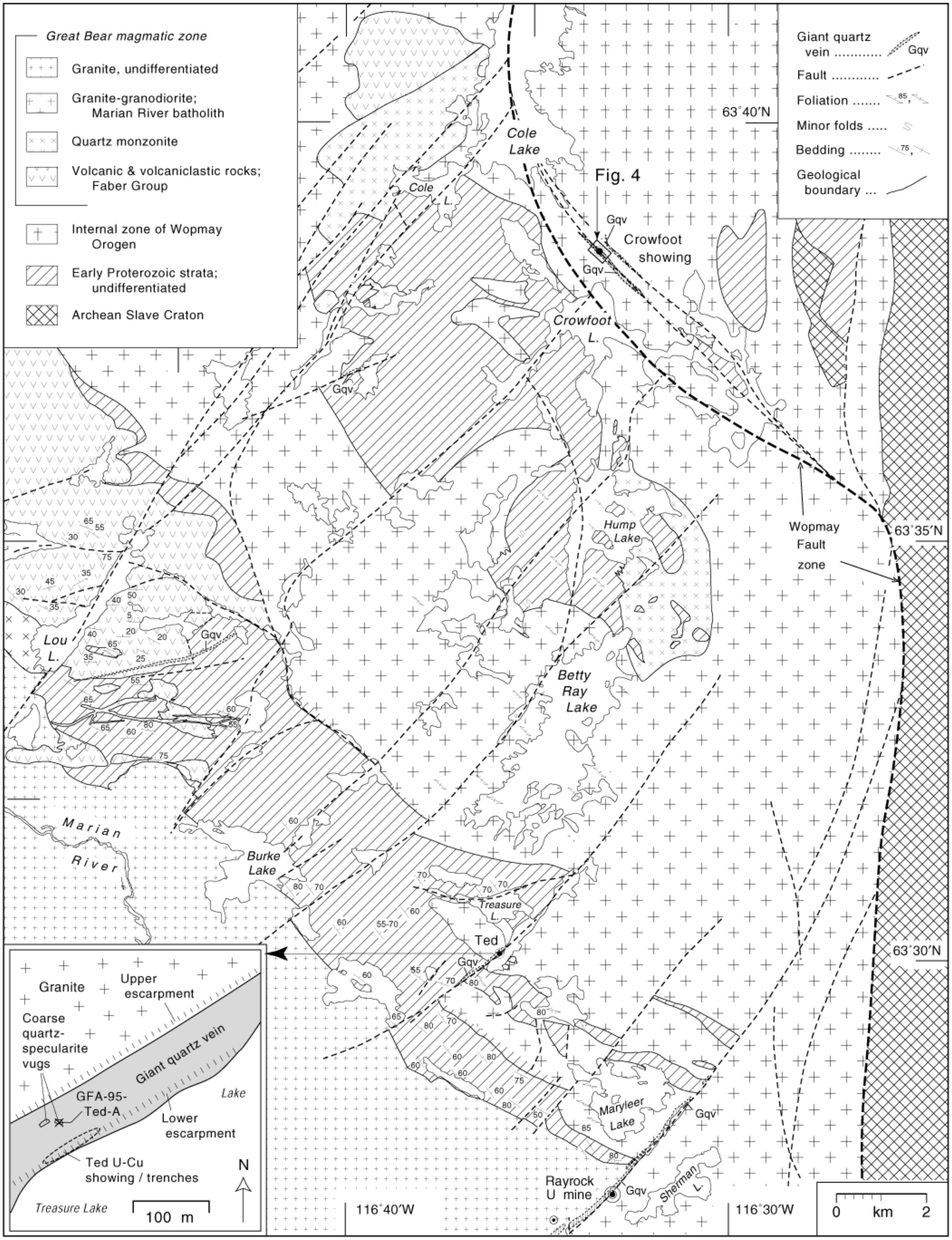


Figure 3. *Geological map of the Rayrock Mine–Crowfoot Lake area, Northwest Territories; inset — geological map of the Ted uranium showing.*

REGIONAL GEOLOGICAL SETTING

The Great Bear magmatic zone is a postcollisional, continental, dominantly felsic, calc-alkaline magmatic arc on the western margin of the ca. 1900 Ma Wopmay Orogen (Fig. 1; Hoffman, 1988). The magmatic arc was developed ca. 1875–1840 Ma on older Proterozoic basement rocks, which are exposed in the Hottah Lake region in the north and in the study area to the south (Fig. 2, 3; Hildebrand et al., 1987; Gandhi, 1994). The eastern margin of the Great Bear magmatic zone with the internal zone of the orogen marked by the structurally complex Wopmay fault and fold zone or the 'median zone'. The fault zone is covered in some places in the north by the volcanic rocks of the Great Bear magmatic zone. Flat-lying Proterozoic and Paleozoic strata conceal the magmatic zone to the north, west and south (Hoffman, 1988; Ross and Kerans, 1989). Continuity of the magmatic zone to the north and south beneath these strata can, however, be inferred from the regional magnetic patterns. A linear belt of quartz monzonitic intrusions forms an eastern extension of the magmatic zone in the Great Slave Lake area (Fig. 1).

The early stages of the Great Bear magmatic activity were dominated by volcanism and related subvolcanic intrusions. The volcanic rocks and associated volcaniclastic sediments have an aggregate thickness in the order of 10 km in the north and 5 km in the south. The lower volcanic strata in the north were gently folded about northeast axes and intruded by quartz monzonite plutons. Large granite batholiths were emplaced during the late stage of magmatic activity. Uranium-lead zircon data show that the volcanic activity occurred mainly during the period 1870 to 1865 Ma, and the granite batholiths were emplaced ca. 1865–1840 Ma. The sequence of events has been interpreted to be the result of eastward subduction of oceanic lithosphere (Hildebrand et al., 1987; Hoffman, 1988).

After the cessation of magmatic activity, brittle faults developed, which are attributed to the collision of a microcontinent in the west (Hildebrand et al., 1987). The most prominent of these form a set of northeast-trending right-lateral faults, which have movements in the order of a few hundred metres to a few kilometres (Fig. 2, 3). Some northwest-trending complementary faults and north-south brittle faults were also developed in the Great Bear magmatic zone. It is noted that the faults existed, and/or were reactivated, during the sedimentation of the ca. 1680 Ma Hornby Bay Group in the north (Ross and Kerans, 1989; Gandhi and Paktunc, 1989). Giant quartz veins occur intermittently along the brittle faults. The region has been tectonically stable since, except for the intrusion of diabase dykes (Fig. 2).

The topography of the magmatic zone is characterized by low relief in granitic areas and hills as much as 150 m high formed by volcanic units. The brittle faults are marked by topographic lows except for the giant quartz veins, which are relatively more resistant to erosion. The region has been affected by recent glaciers moving from east to west.

GIANT QUARTZ VEINS AND STOCKWORKS

The giant quartz-vein zones and stockworks are widely distributed in the Great Bear magmatic zone. They occur along or close to the brittle faults, a majority of which are northeast-trending, right-lateral faults. They are localized mainly by subsidiary faults and tensional fractures, especially where the main faults have a gentle curvature in trend (Fig. 3). Some of the main faults have more than one vein zone along their strike. Some of the veins and stockworks also trend northwest, east, or north. The north-trending veins are mainly along the Wopmay fault zone and represent a late stage tensional phenomenon in this complex zone of tight folding and mylonitization.

The quartz vein zones and stockworks are as much as 100 m wide and 10 km long. They include two or more generations of quartz. The main component of the system is commonly a massive vein zone, a few metres to a few tens of metres wide, of fine- to medium-grained milky quartz, dipping steeply or vertical. These veins are cut by one or more generations of coarser veins, which form stockworks or sets of subparallel veins that are commonly less than 1 m wide and randomly oriented. Concentrations of hematite or specularite, pyrite, copper sulphides, and pitchblende occur locally in the younger, coarse-grained, vuggy veins. The steeply dipping, main massive veins have gentle undulations along strike and dip. At the Rayrock mine, these undulations are recognized as the controlling structure for the later metallic mineralization (Lang et al., 1962; McGlynn, 1968, 1971; Gandhi, 1994).

Crowfoot uranium showing

A northwest-trending giant quartz vein, 4 km long, occurs near the northeast shore of Crowfoot Lake in the Wopmay fault zone (Lord, 1942; Fig. 3). It was explored for uranium from 1953 to 1955. Its northwestern part was staked as the 'Will' group of six claims (McGlynn, 1971, p. 98–99; Thorpe, 1972, p. 65; Donaldson, 1955) and the southeastern part as the 'A' group of six claims (Byrne and MacPherson, 1955). Surface exploration located several small radioactive occurrences distributed widely along the length of the vein, some of which were marked by yellow uranium stain and visible pitchblende. The showings on the 'Will' claim group were trenched (Fig. 4), and in 1955, Iso Uranium Mines Ltd. drilled 636 m (2087 ft) in 10 holes (Donaldson, 1955; Thorpe, 1972). The claims were restaked as the 'IRA' group and some surface examination was done in 1967 (Thorpe, 1972, p. 65). The area covering all of the Crowfoot vein zone was staked again as the 'OUR' claim group in 1995 by Noront Resources Ltd., following the release of an airborne multiparameter survey of the region by the Geological Survey of Canada (Gandhi et al., 1996).

The host rock is gneissic granodiorite with well developed coarse crystals of plagioclase and microcline (Fig. 4). It is fractured and altered at, and in the vicinity of, the quartz vein zone. The giant quartz vein pinches and swells along its 4 km strike length. The quartz vein zone in the trenched and drilled area (Fig. 4) comprises six generations of veins as noted below, although relative ages in some cases are not certain:

1. The oldest quartz veins are massive, fine to medium grained, milky white, dip steeply and are as much as 5 m thick. The granitic wall rock has chlorite, hematite, and silica alteration. Sample GFA-92-CL-1 (Fig. 5) is representative.

2. The second generation is of coarse crystalline quartz veins. They dominate in the trenched and drilled section (Fig. 4). They are relatively more abundant on the southwest side than on the northeast side of the older, massive vein zone, and have little wall-rock alteration associated with them. Quartz crystals, as much as 5 cm long, have well developed terminations in the vuggy cores of the veins. Coarse crystalline pyrite aggregates occur locally, and traces of chalcopyrite are found with pyrite.

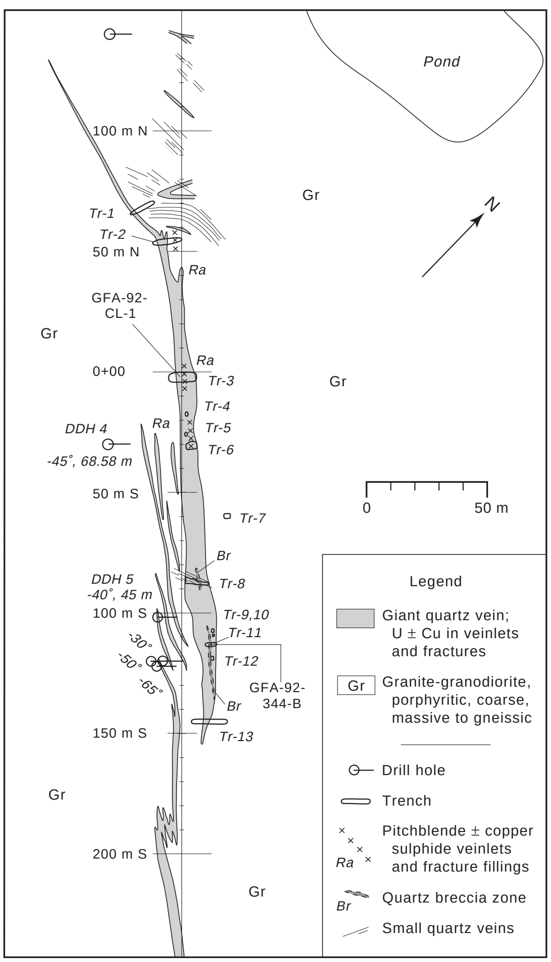


Figure 4. Geological map of the Crowfoot uranium showing, Northwest Territories.

3. Breccia zones comprise fragments of the first two generations of quartz veins, in a red, hematite-stained (rusty), fine-grained quartz matrix. This relationship is observed at several localities. Sample GFA-92-344b

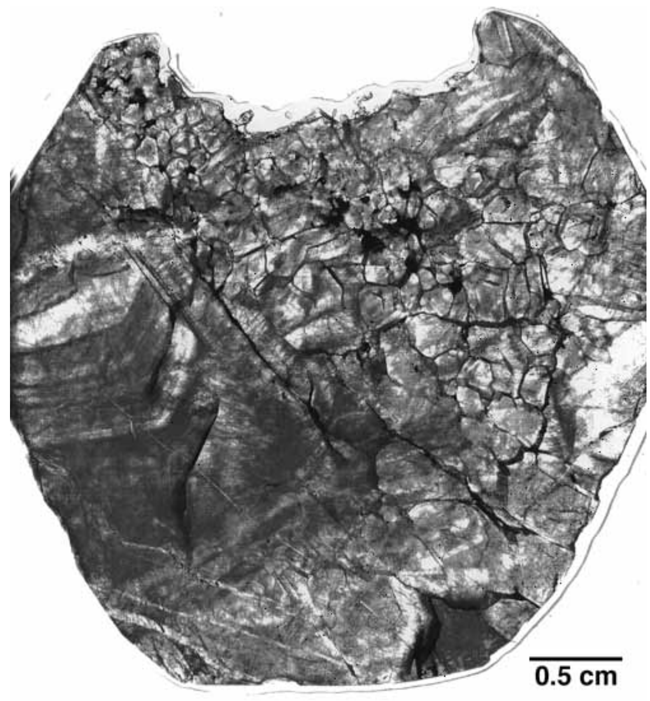


Figure 5. *Xerox image of fluid inclusion section GFA-92-CL-1.*

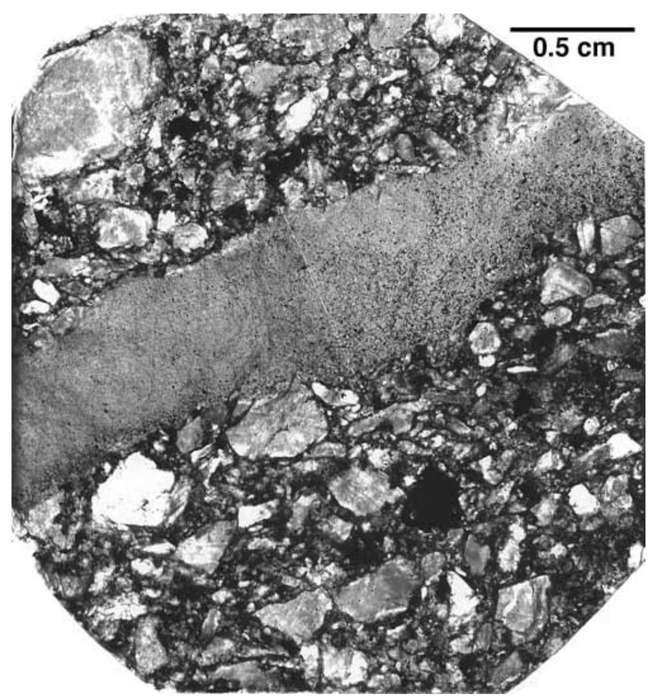


Figure 6. *Xerox image of fluid inclusion section GFA-92-344B from a brecciated zone (Fig. 4).*

(Fig. 6) represents this generation. It is noteworthy that it has a fine-grained granitic dykelet that contains fragments of the quartz vein, and is in turn cut by younger quartz veins. This field relationship is not seen in other giant quartz veins.

4. A generation of quartz-specularite veins forms a minor part of the whole system. The relationships of these veins with 3) and 5) are not certain. Some agate-like quartz veins may be related to this phase.

5. Fine-grained massive to crystalline (medium grained) quartz veins constitute a set that hosts uranium mineralization. Pitchblende (uraninite) occurs as stringers and veins as much as 2 cm wide in the section 30 m S to 55 m N (Fig. 4). These are erratically distributed along the quartz vein zone, and trend northwest and dip steeply or vertically. Their strike length ranges from < 1 m to several tens of metres. Pitchblende also occurs in subsidiary fractures and cross fractures. Black pitchblende is visible at several places, and yellow uranium oxide stains are common at these veins. Pyrite and traces of chalcopyrite occur locally in these veins. Some rusty hematitic zones and fractures along the system are notably radioactive. Hematite and/or specularite also occur independently as veins, fracture fillings, and local aggregates.

6. Thin quartz veins of a younger set transect veins of stages 1), 2), and 3), but their relationship to 4) and 5) is not certain.

Ted uranium showing

This was the first uranium occurrence discovered in the southern Great Bear magmatic zone. It was reported in 1934 by a Geological Survey of Canada party that found yellow uranium stain at this locality (Lang et al., 1962; McGlynn, 1971). The showing occurs in a northeast-trending giant quartz vein, which extends discontinuously for 3 km along the south arm of Treasure Lake (Fig. 3 and inset). The vein is well exposed along a steep, southeast-facing cliff on the shore of the lake. In 1949, pitchblende and a mineral resembling thucolite were reported along the sheared contact between the giant quartz vein and the host granodiorite. The reports led to the staking of the area as the 'Ted' claim group in the early 1950s by Yellowknife Volcanic Gold Mines Ltd. Some trenching was done later. The claims were acquired by New Athona Mines Ltd. in 1954, and the company drilled 12 holes totalling 1208 m and intersected erratic uranium and copper mineralization (Byrne and McMorland, 1955; McGlynn, 1971, p. 97). The area was staked again in 1994 as part of the 'Treasure-Island' claim group by Fortune Minerals Ltd. and GMD Resource Corp., following the release of the airborne geophysical survey by the Geological Survey of Canada mentioned above.

The quartz vein zone on the cliff face at the shore is dominated by milky white, equigranular, medium-grained quartz. It cuts a highly chloritic, amorphous, pale green mass, most likely representing highly altered host rock. The massive equigranular quartz vein zone is approximately 10 m wide and nearly vertical. It is cut by coarse comb-quartz veins, commonly with specular hematite coating the terminations of quartz crystals in vuggy zones. Aggregates of pyrite and coarse crystalline quartz are common, and impart large rusty weathered surfaces to the cliff face. Yellow uranium stains, and green and blue copper stains, are observed at a few places in the crystalline veins. Earlier reports recognized the erratic distribution of mineralization in two main fractures zones at the cliff. One trends northeast and the other to the east, and both are steep or vertical (McGlynn, 1971, p. 97). A 50 m wide zone on the northwest side of the cliff is characterized by numerous veins and stockworks in porphyritic, massive to gneissic granite, which contains lensoid xenoliths of metasedimentary rocks. The trend of foliation in granite and of the bedding in xenoliths is west-northwest, and their dips are steep. The veins include some vuggy zones that have well formed coarse quartz crystals. One of them has coarse radiating blades of specularite as much as 5 cm long associated with equally long, zoned quartz crystals, which were examined in this study (sample GFA-95-Ted-A, Fig. 7).

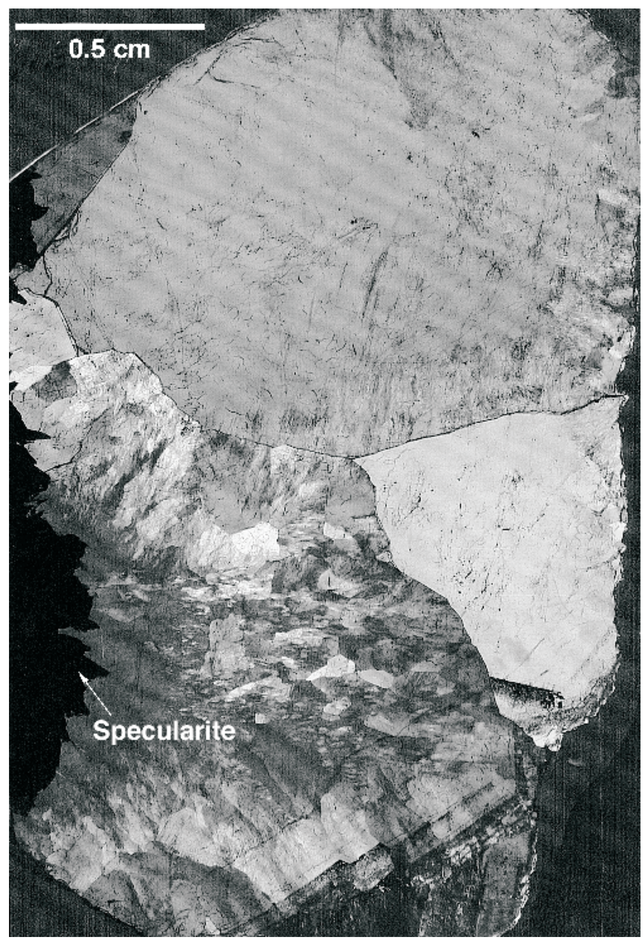


Figure 7. *Xerox image of fluid inclusion section GFA-95-Ted-A taken under crossed nicols. Note the different microtextures within the different quartz grains, described as 'grey' quartz (lower left), 'blue' quartz (top), and 'yellow' quartz (centre right).*

FLUID INCLUSION STUDY

Methodology and results

Doubly polished fluid-inclusion sections (100–150 µm thick) were prepared from ten samples from the giant quartz-vein zones of the Crowfoot and Ted showings. A preliminary petrographic study of these revealed a dense population of fluid inclusions, with widely variable gas/liquid ratios. The inclusions were grouped into types I (2-phase liquid rich), II (2-phase vapour rich), and III (3-phase liquid-rich) (Table 1). Their identification as primary, pseudosecondary, or secondary was based on the criteria defined by Roedder (1984), as discussed in the section on petrographic observations.

Microthermometric analyses were conducted on three selected sections: two from the Crowfoot showing, viz., samples GFA-92-344B and GFA-92-CL1 (Fig. 4), and one from the Ted showing, sample GFA-95-TED-A (Fig. 3). Determinations of homogenization temperature (Th) and melting temperature (Tm) were carried out on a Linkam heating/freezing stage. The stage was calibrated before measurements using SYNFLINC Synthetic Standards ranging from -56.6° to 0°C. Due to the preliminary nature of this study only temperatures below 0°C have been adjusted.

The accuracy with which fluid chemistries may be determined from heating and freezing studies depends on, among other factors, the correct identification of major components, and the proper interpretation of observable phase transitions. Hence, only inclusions from one field of view per chip were measured during a heating/freezing run. Attempts were made to isolate fluid inclusion assemblages, viz., a group of petrographically associated inclusions that resulted from the same, most finely discernible event, of fluid inclusion entrapment. Data have been collected from primary inclusions in individual growth zones or pseudosecondary inclusions, of different sizes and shapes, in individual planes. In most cases, inclusions were subjected to freezing measurements first to avoid stretching and false homogenization temperatures. All homogenization runs were repeated and results were replicated within 4°C; those exceeding this error limit were not recorded. Replication is a repetition of temperature measurements collected under the same experimental conditions without removal of the sample from the stage between measurements (Goldstein and Reynolds, 1994). Freezing runs were also repeated and results were replicated within 0.5°C. Average estimated accuracy was ± 2°C on readings above, and ± 0.5°C on readings below 0°C.

The sections selected for the detailed study (Fig. 5, 6, 7) are characterized by a dense population of fluid inclusions with variable liquid/vapour ratios. Individual inclusions formed from heterogeneous systems can be expected to trap different ratios of the phases present (Roedder, 1984). Two situations occur in nature in which two phases are present and may be trapped as inclusions; one is boiling, in which the low-density fluid is the vapour of the liquid, and the other is effervescence, in which the low-density fluid is compositionally different from the high-density fluid. The trapping of primary gas, either from boiling or effervescence, can cause particularly large errors in determination of temperature of homogenization (e.g. Th > Tt, temperature of entrapment). H_2O and CO_2 are common phases in the fluid inclusions of quartz in vein-type uranium deposits, and have been identified in this study. Whether effervescence occurred has not been verified, but if an inclusion has trapped both phases, it will give erroneous temperature, pressure, and density data.

Petrographic observations

The classification of the inclusions as primary, secondary, or pseudosecondary in this study was not obvious. Type I inclusions often occurred in a random, three-dimensional distribution throughout the crystal, and sometimes in trails; and ranged in size from 4 x 3 µm to 68 x 23 µm. Inclusions in the Crowfoot samples are smaller than those in the Ted sample. The vapour bubbles were relatively small, and occupied from 5 to 10 volume per cent of the inclusion. Type I inclusions were interpreted to be primary or pseudosecondary. Type II inclusions often occurred in trails abutting or crossing grain boundaries, which would suggest they are secondary in origin. Inclusions in some trails did not have the same characteristics from one grain to the other, suggesting a pseudosecondary origin. They ranged in size from 3 x 2 µm to 45 x 25 µm, and the vapour bubble occupied from 60 to 80 volume per cent of the inclusion. Type III inclusions occurred with a random, three-dimensional distribution throughout the crystal, or as single inclusions associated with Type I inclusions. Type III inclusions, found only in the Ted sample, are often large in size, ranging from 7 x 6 µm to 40 x 27 µm, with the vapour bubbles occupying from 5 to 10 volume per cent of the inclusion. The daughter mineral was approximately the same size as the vapour bubble. Type III inclusions were interpreted to be primary or pseudosecondary. The microthermometric data were recorded separately for the three inclusion types (Table 1, 2) and are discussed later.

Table 1. Three types of fluid inclusions and their phases.

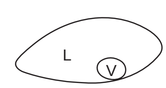
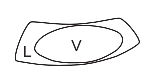
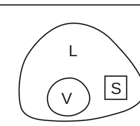
Inclusion type	Phases	Illustration (L: Liquid, V: Vapour, S: Solid)
Type I	2-phase liquid-rich H_2O inclusions ($\pm CO_2$)	
Type II	2-phase vapour-rich H_2O inclusions	
Type III	3-phase liquid-rich H_2O inclusions with a cubic daughter mineral; presumably halite	

Table 2. Summary of microthermometric data for Type I, II and III inclusions from Ted uranium showing.

Quartz type/ characteristics	'Grey' quartz	'Blue' quartz	'Yellow' quartz
Type I inclusions:			
Th	129–156° (182°) (n=25 + 1)	122–154°C (n=11)	123–161°C (n=17)
Tm(ice)	excessively low (n=8)	excessively low (n=2)	excessively low (n=6)
Evidence for presence of CO_2	- low Tm(ice) - most bubbles expanded or became deformed on freezing - presence of CO_2 clathrate	- low Tm(ice)	- low Tm(ice) - most bubbles expanded or became deformed on freezing - bubbles returned to normal size and shape between -60 and -45° (CO_2 melts at -56.6°)
Comments		most ice invisible	
Type II inclusions:			
Th	Th > 450°C (n=20)	none observed	Th = 228–445°C (n=13)
Tm(ice)	-27.0 to -32.4° (n=9)		-16.5 to -20.6° (n=6)
Evidence for presence of CO_2	none		none
Comments	- low Tm, but not excessive - no inclusions near Th or Td (decrepitation)		- less saline, normal range - not true Th, fluid mixing suggested or phase separation.
Type III inclusions:			
Th	122–169°C (n=4)	122–164°C (n=22)	128–150°C (n=2)
Tm(ice)	165–185°C (n=4)	137–191°C (n=21)	128–141°C (n=2)
Evidence for presence of CO_2	low Tm(ice)	low Tm(ice)	low Tm(ice)
Comments	few in number compared to Type I	very abundant	few in number compared to Type I

Notes: Th = homogenization temperature; Tm(ice) = melting temperature of ice; Tm(dm) = melting temperature of daughter mineral; L/V = liquid/vapour ratio.

Temperature and salinity determinations

Crowfoot samples

Sample GFA-92-CL-1 represents the older milky quartz veins (Fig. 5) and sample GFA-92-344B represents a younger generation (Fig. 6). A frequency distribution diagram (Fig. 8) of homogenization temperatures (Th) for Type I and Type II inclusions (Fig. 9), and the corresponding salinity plot (Fig. 10), show the data are skewed. A temperature-salinity plot (Fig. 11) illustrates the variability of the data. The fact that these data are not consistent suggests that they must be regarded with caution. The trapping of both liquid and primary gas during boiling or effervescence, as discussed above, would result in inclusions that give erroneous temperature, pressure, and density data. Other processes, as noted below, could modify primary inclusions and result in a dispersion of homogenization temperatures. The most reliable data are the salinity determinations. The plot includes the fields of data points for the Ted sample discussed below.

As noted earlier, the inclusions in the vein quartz have widely variable gas/liquid ratios, i.e. they are visibly divergent inclusions which have grossly different homogenization temperatures. Such inclusions are problematic because it is difficult to decipher whether they are valid samples of pre-existing fluids (e.g. formed from rapidly changing, inhomogeneous, or immiscible fluids) or samples that have been made divergent by some later (secondary) process such

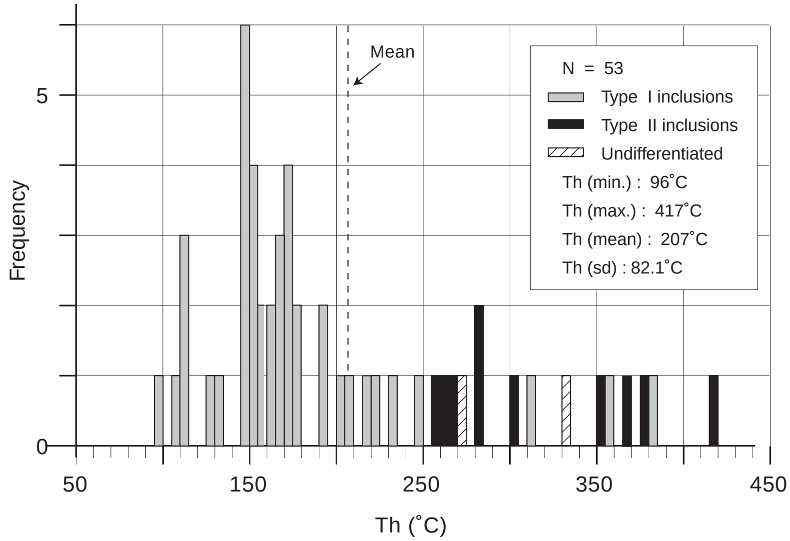


Figure 8.

Frequency distribution of homogenization temperatures (Th) for inclusions in the samples GFA-92-344B and GFA-92-CL-1 from the Crowfoot uranium showing.

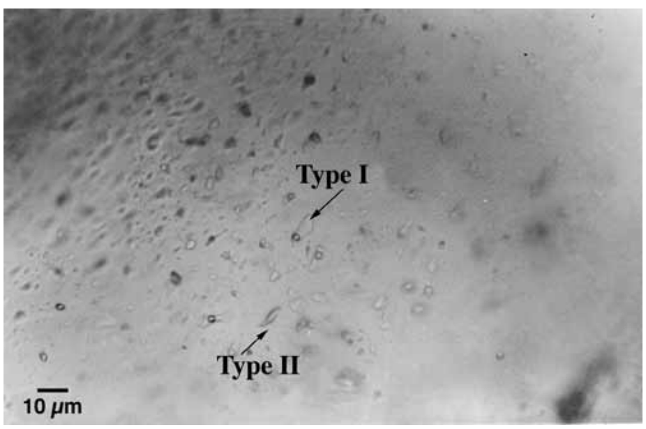


Figure 9. *Photomicrographs of fluid inclusions showing Type I and Type II inclusions of variable gas/liquid ratios from Crowfoot sample GFA-92-344B.*

as leakage and stretching, later refilling, and necking down. Variable gas/liquid ratios can also be caused by trapping at different times from fluids under different P-T conditions.

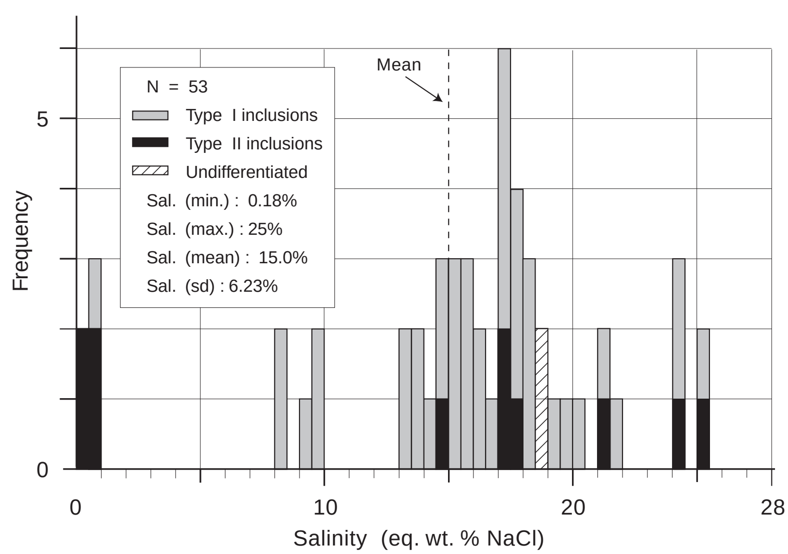
Ted sample

Sample GFA-95-TED-A from the Ted deposit represents the younger, coarser generation of quartz vein. The fluid inclusion section (Fig. 7) shows that there are three kinds of quartz crystals distinguishable under crossed nicols by their colour and texture, viz., ‘grey’ quartz, ‘blue’ quartz, and ‘yellow’ quartz.

The homogenization temperatures are consistent among these different varieties of quartz crystals (Fig. 12, Table 2). They range from 123 to 161°C (one value at 182°C), with a mean of 145°C for the Type I inclusions (Fig. 13), and from 122 to 169°C for Type III (Fig. 14), with a mean of 151°C. These data indicate that the three varieties of quartz crystals all formed under similar conditions. Some differences were

Figure 10.

Frequency distribution of salinities for samples GFA-92-344B and GFA-92-CL-1 from the Crowfoot uranium showing.



noted, however. 'Blue quartz', for example, appeared to contain many more Type III inclusions, but no Type II inclusions were observed in it.

The microthermometric behaviour of Type I inclusions (Table 2) suggested a NaCl-H_2O-CO_2 system. The excessively low Tm(ice) resulted when CO_2 reacted with the water isothermally to form CO_2 hydrate, and in doing so withdrew some of the water from the liquid, leaving the remaining water excessively saline. The resulting Tm(ice) values were low and yielded too great a value for NaCl weight per cent equivalent. The CO_2 hydrate formation resulted in volume reduction and a bubble size increase. In these inclusions the H_2O was in excess (compared to CO_2) because ice was still present after the hydrate formed and Tm(ice) could be determined, but could not be used to accurately determine salinity. Even if no hydrate formed, the CO_2 was just another solute in solution that also acted to depress the freezing point. $TmCO_2$ hydrate can be determined, if the crystals can be seen. In this study, two $TmCO_2$ hydrate values of 1.5° and 12.8°C were determined. In some inclusions, even though the crystals

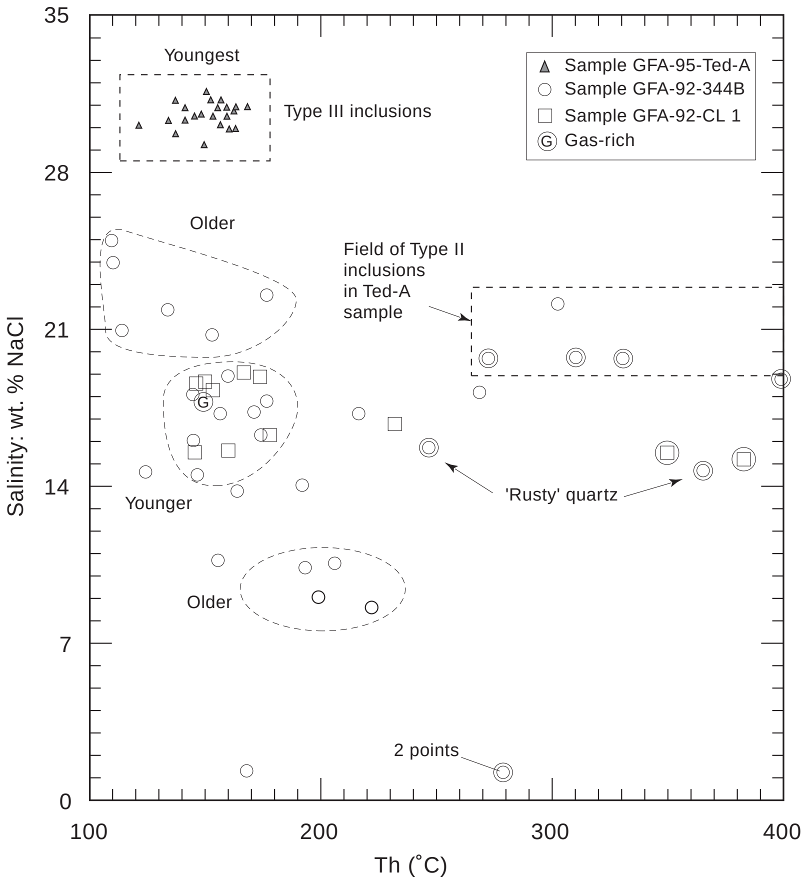


Figure 11.

Temperature (Th)-salinity plot of the Crowfoot and Ted data.

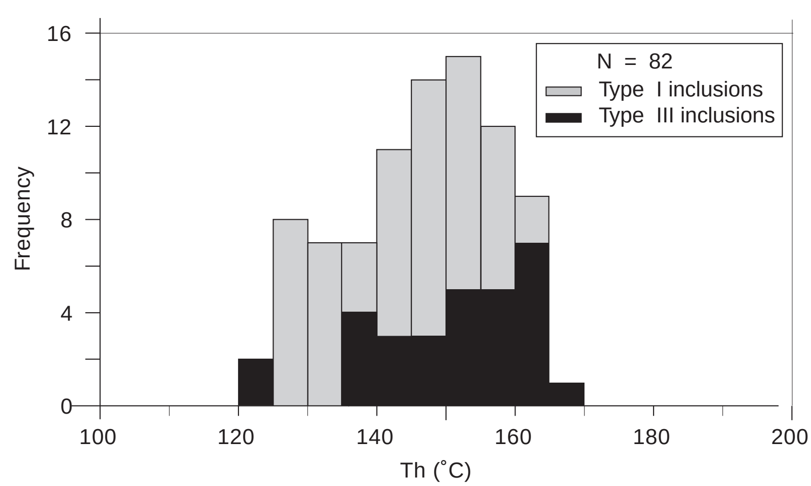


Figure 12.

Frequency distribution of homogenization temperatures (Th) in sample GFA-95-Ted-A.

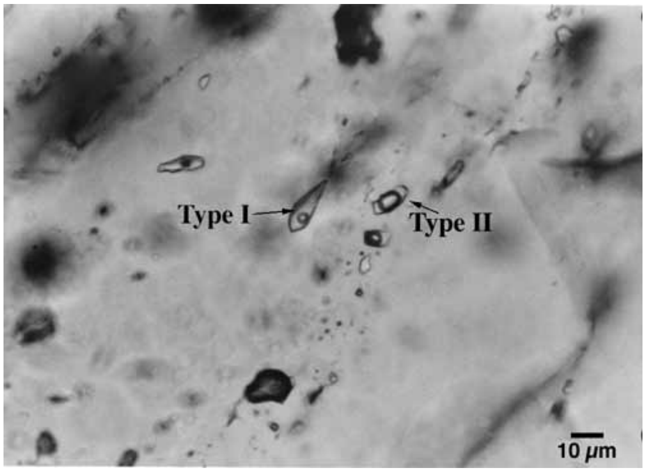


Figure 13. *Photomicrographs of fluid inclusions showing Type I and Type II inclusions of variable gas/liquid ratios from Ted sample GFA-95-Ted-A.*

were invisible, an irregular or jagged meniscus between solution and vapour indicated the presence of the crystals (Roedder, 1984). The homogenization data for Type I and Type III inclusions are shown in Figure 12.

The microthermometric behaviour of Type II inclusions (Fig. 13, 15; Table 2) suggested the H_2O-NaCl (or equivalent) system. There was no evidence of CO_2 in these inclusions. These inclusions showed varied liquid/vapour ratios, and occurred in the same plane with some Type I inclusions. The behaviour of these inclusions was not fully understood. The inclusions in the 'grey' quartz did not change noticeably even after being heated to 454°C. None of the inclusions decrepitated. Some of the inclusions in the 'yellow' quartz did homogenize, but over a wide range of temperatures.

The microthermometric behaviour of Type III inclusions (Table 2) suggested a NaCl-H_2O-CO_2 system. When daughter salts are present within fluid inclusions, the salinity may be determined (Sterner et al., 1988) by noting the temperature at which the last bit of salt finally dissolves Tm(dm). The

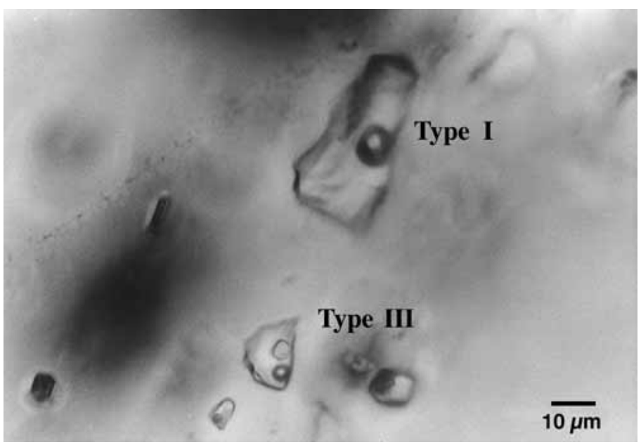


Figure 14. *Photomicrographs of fluid inclusions showing Type III of 3-phase liquid-rich inclusions from Ted sample GFA-95-Ted-A.*

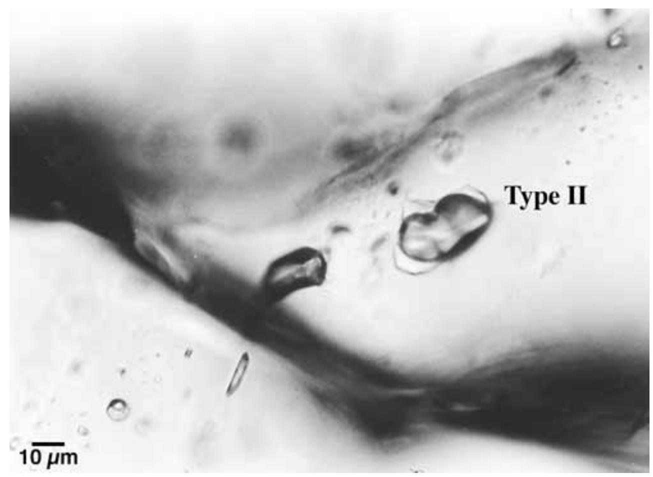


Figure 15. *Photomicrographs of fluid inclusions showing Type II inclusions of variable gas/liquid ratios from Ted sample GFA-95-Ted-A.*

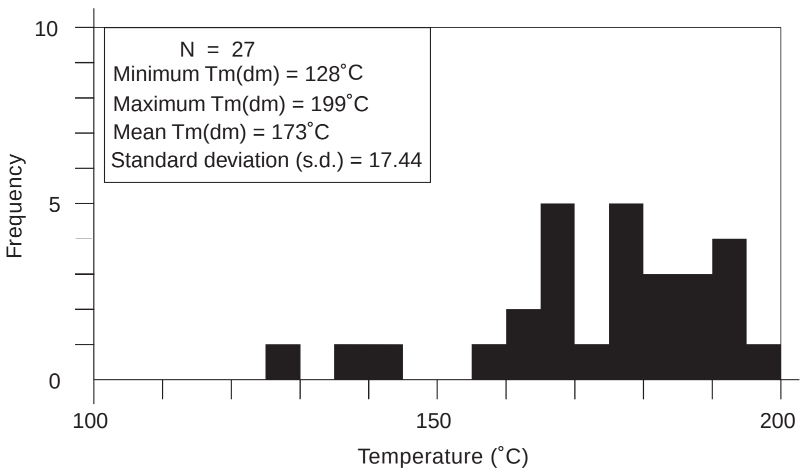


Figure 16.

Frequency distribution of final melting temperatures for salt daughter minerals in 27 Type III inclusions in Sample GFA-95-Ted-A.

Table 3. Summary of microthermometric data from samples from Crowfoot and Ted uranium showings, Northwest Territories.

Sample number	Number of fluid inclusions	Type of fluid inclusions	Th (°C) range	Th (°C) average	Tm (ice) (°C) range	Number of fluid inclusions	Salinity wt.% NaCl eq./range	Salinity average
Crowfoot uranium showing								
GFA-92-CL-1	11	I (P/PS)	146°–383°	na	–11.3 to –15.6°	12	14.4–18.2	16.4
	8	II (PS/S)	408°–434°	na	no data	–	–	–
GFA-92-344-B	33	I (P/PS)	96°–217°	na	–5.1 to –23.4°	28	8.0–25.0	15
	13	II (PS/S)	247°–434°	na	–0.1 to –27.7°	13	0.18–25.0	
Ted uranium showing								
GFA-92-Ted-A	53	I (P/PS)	123°–161°	145°	na	–	–	–
	7	II (PS/S)	228°–445°	na	–15.3 to –19.3°	5	18.9–21.9	20.8
	27	III (P/PS)	122°–169°	151°	na	27	29.2–31.6	30.4
Total	152					58		

Notes: Th: Temperature of homogenization; Tm: Temperature of melting; wt.% NaCl eq.: weight per cent NaCl equivalent; P: primary; S: secondary; PS: pseudosecondary; na: not applicable. Locations of the showings and the samples are in Figures 2, 3, and 4.

temperatures of melting of the halite daughter mineral have been plotted in Figure 16. The temperature versus salinity plot for Type III inclusions is shown in Figure 11.

DISCUSSION

Data for the Crowfoot and Ted samples are summarized in Table 3. It is apparent from the table and the temperature-salinity plot (Fig. 11) that there is a tight distribution for the Type I and III inclusions of the Ted sample, whereas the Type II inclusions and those in the two Crowfoot samples show wide ranges of temperature values. This difference in the two groups is regarded here as significant and a reflection of the multistage development history of the giant quartz veins apparent from the field observations. It also follows that the older generations of quartz veins (e.g. Crowfoot) would show relatively greater variability than the younger generations (e.g. Ted). From this perspective the Ted sample, which represents a younger generation, if not the youngest, provides a consistent set of temperature and salinity data (122–169°C and 29.2–31.6 eq. wt % NaCl) for the coarse crystalline veins, from Type III inclusions. Because the younger and coarser quartz veins are also the main carriers of metallic minerals, they reflect the physico-chemical conditions of the mineralization.

The most reliable data gathered in this study are the salinity determinations. The majority of the determinations for both giant quartz veins are in the range of 15 to 30 weight per cent NaCl equivalent. Thus both the Crowfoot and Ted giant quartz veins were formed mainly from saline fluids or have been altered by them. Inclusion fluids are, in this regard, comparable with warm diagenetic basin fluids, which are believed to play an important role in uranium deposition.

It may be noted that effervescence can play an important part in ore deposition in this environment. True effervescence is recorded when a primary gas (low-density phase) is trapped in the same fluid inclusion with a liquid-like (high-density phase) of a different composition. The presence of CO_2 gas (vapour bubble) and H_2O liquid has been indicated by the microthermometric behaviour of Type I inclusions from the Ted showing. The presence of CO_2-bearing inclusions in the Crowfoot showing is not as obvious, and crushing studies (Roedder, 1970) are required to reveal both the internal pressure of the inclusions and the possible composition of the gas present. Such studies are strongly recommended in further research on the giant quartz veins of the Great Bear magmatic zone.

The brittle fault structures that localized the giant quartz veins have been interpreted as part of a regionally extensive conjugate set of faults that resulted from the collision of the Slave-Hottah craton with another magmatic arc or microcontinent to the west, some time after the cessation of the Great Bear magmatic activity, viz., after 1840 Ma (Hildebrand et al., 1987; Hoffman, 1988). The faulting occurred most likely after the downfaulting of the Great Bear magmatic zone along the Wopmay fault zone, and some erosion. The pristine volcanic textures preserved in the Great Bear volcanic rocks show that they have not been subjected to major deformation or deep burial. Hence the giant quartz veins were formed in a relatively shallow tectonic environment. The fluid-inclusion data are consistent with this environment. Within this framework, however, there may have been considerable variations locally and/or regionally, from time to time, as adjustments occurred among the fault blocks for various reasons, e.g. erosion, uplift, seismic activity, and sedimentation. These movements certainly affected the deposition of the Hornby Bay Group ca. 1680 Ma (Ross and Kerans, 1989). Multistage development of the giant quartz veins is consistent with this tectonic setting, and would be reflected in the fluid inclusions. The age constraints on the formation of the veins are poor. Some isotopic ages are available for pitchblende in the veins (Miller, 1982; Gandhi and Paktunc, 1989), but these all tend to be much younger (<1200 Ma) than ages deduced from their tectonic setting.

This is likely because the mineralization occurs in an open system permissive of later introduction of the metals, and/or due to the loss of radiogenic daughter products, as well as the mobilization and redeposition of uranium.

CONCLUSIONS

The fluid-inclusion data indicate that the multistage development of the giant quartz veins occurred, for the most part, in the temperature range 125 to 200°C from generally saline solutions ranging from 15 to 30 weight per cent NaCl equivalent. Mixing of two or more fluids is indicated by the range in homogenization temperatures to as great as 430°C, and salinities as low as a fraction of one per cent. These data are consistent with the tectonic setting at the time of their formation, ca. 1840–1700 Ma.

The fluid-inclusion data can be reconciled with the field observations, which indicate multistage development of the Crowfoot giant quartz vein. The host faults and fractures were likely reactivated several times (Gandhi, 1994). This long history would favour 'healing' of the tensional openings by the episodic deposition of quartz derived from circulating groundwaters. Considering the complex tectonic history of these veins, the trapping of inclusions at different times from fluids under different P-T conditions, even within a single generation of the quartz veins, must be regarded as a possibility.

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