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Fluid inclusions in an osumilite-bearing granulite from Bunt Island in the Archean Napier Complex, East Antarctica: implications for a decompressional *P-T* path?

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Abstract: We report high-density CO_2-rich fluid inclusions in garnet, orthopyroxene, and quartz from an osumilite-bearing aluminous granulite from Bunt Island of the Archean Napier Complex, East Antarctica. The melting temperatures of fluids lie in the range of −56.8 to −57.8℃, being close to the triple point for pure CO_2 (−56.6℃). Homogenization of the CO_2-rich fluids into the liquid phase occurs at temperatures in the range of −35.4 to 24.7℃. This translates into CO_2 densities in the range of 0.788–1.084 g/cm^3. The estimated CO_2 isochore for high-density inclusions in garnet intersects the *P-T* trajectory of Bunt Island at around 10 kbar at 1050°C, which corresponds to the peak metamorphic conditions of the region derived from mineral phase equilibria. We therefore infer that CO_2 was the dominant fluid species present during the ultrahigh-temperature metamorphism in Bunt Island. CO_2 inclusions with lower density occurring in quartz and garnet provide isochores that intersect the *P-T* path at $<$7 kbar and $<$950℃, indicating density reversal of originally high-density inclusions along a decompressional exhumation path of the ultrahigh-temperature rocks in the Bunt Island.

key words: Carbonic fluid inclusion, ultrahigh-temperature granulite, Bunt Island, Archean Napier Complex, East Antarctica

1. Introduction

The Napier Complex of Enderby Land, East Antarctica, is a late-Archean high-grade terrane which has undergone granulite-facies metamorphism at temperatures exceeding 1000°C (*e.g.* Ellis, 1980; Harley, 1985; Sheraton *et al.,* 1987; Hokada *et al.,* 1999a; Yoshimura *et al.,* 2000; Hokada, 2001). The Amundsen Bay area, located in the western part of the Napier Complex, is the highest grade region of the Complex from where sapphirine-quartz and osumilite-bearing mineral assemblages have been reported

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(*e.g.* Dallwitz, 1968; Ellis, 1980; Ellis *et al.,* 1980; Grew, 1980, 1982; Motoyoshi and Matsueda, 1984; Sheraton *et al.,* 1987; Motoyoshi and Hensen, 1989; Harley and Hensen, 1990; Hokada, 1999; Harley and Motoyoshi, 2000; Osanai *et al.,* 2000, 2001). The presence of orthopyroxene-sillimanite-garnet-quartz assemblage in pelitic gneisses (*e.g.* Sheraton *et al.,* 1987; Ishizuka *et al.,* 1998; Osanai *et al.,* 1999; Hokada *et al.,* 1999b) and inverted pigeonite in meta-ironstone and mafic to intermediate granulites (Grew, 1982; Sandiford and Powell, 1986; Harley, 1987) in this area provide additional evidence for ultrahigh-temperature (UHT) metamorphism (Harley, 1998).

Stabilization of dry granulite assemblages at UHT condition, typically the presence of the index minerals such as orthopyroxene and osumilite, requires that low H_2O-activity prevailed during peak P-T conditions, since most of the crustal components (*e.g.* pelitic, psammitic, and granitic rocks) will undergo hydrous melting at elevated H_2O-activities during high-grade metamorphism. Fluid inclusions in high-grade metamorphic rocks provide one of the potential tools in obtaining direct information on the nature, composition, and density of fluids attending metamorphism, which, in conjunction with mineral phase equilibria, have been widely used to infer P-T-X conditions and exhumation paths (*e.g.* Touret, 1985; Touret and Hansteen, 1988; Santosh *et al.,* 1991). Notwithstanding the debate over the timing of entrapment of carbonic inclusions during granulite-facies metamorphism (*e.g.* Lamb *et al.,* 1987; Santosh *et al.,* 1991), CO_2-rich fluids have been demonstrated to be instrumental in effecting low H_2O-activities to stabilize the anhydrous mineral assemblages characterizing many deep continental fragments (*e.g.* Santosh, 1992). Recent fluid inclusion data from the Napier Complex indicate that high-density (0.9–1.1 g/cm^3) CO_2 dominated as the ambient fluid species during UHT metamorphism of sapphirine-bearing granulites in Tonagh Island of the Amundsen Bay area (Tsunogae *et al.,* 2002). Although this study provided new insights on the role of CO_2 in stabilizing UHT assemblages in deep crustal metamorphism, the question as to whether CO_2 infiltration occurred on a regional scale throughout the Napier Complex remains unresolved.

We therefore attempted a preliminary fluid inclusion study on an ultrahigh-temperature metamorphic assemblage from Bunt Island, which is located about 25 km ESE of Tonagh Island (Fig. 1). Granulites in this crustal segment are characterized by typical UHT mineral assemblages such as sapphirine + quartz, orthopyroxene + sillimanite + quartz, and osumilite (Osanai *et al.,* 2001). This paper is the first report to present the petrography and microthermometric data of fluid inclusions in an osumilite-bearing aluminous granulite. The results are particularly important in the light of evaluating the nature and role of fluids involved in ultrahigh-temperature metamorphism of the Archean deep continental crust. Based on the new results, we also attempt to reconstruct the P-T path and the exhumation history of Bunt Island.

2. General geology

Since geological framework and structural characteristics of Bunt Island are discussed in Osanai *et al.* (2001), only a brief summary will be given here. The island is underlain by layered gneisses containing garnet-bearing and orthopyroxene-bearing quartzo-feldspathic gneisses, mafic and ultramafic granulites, and garnet-sillimanite

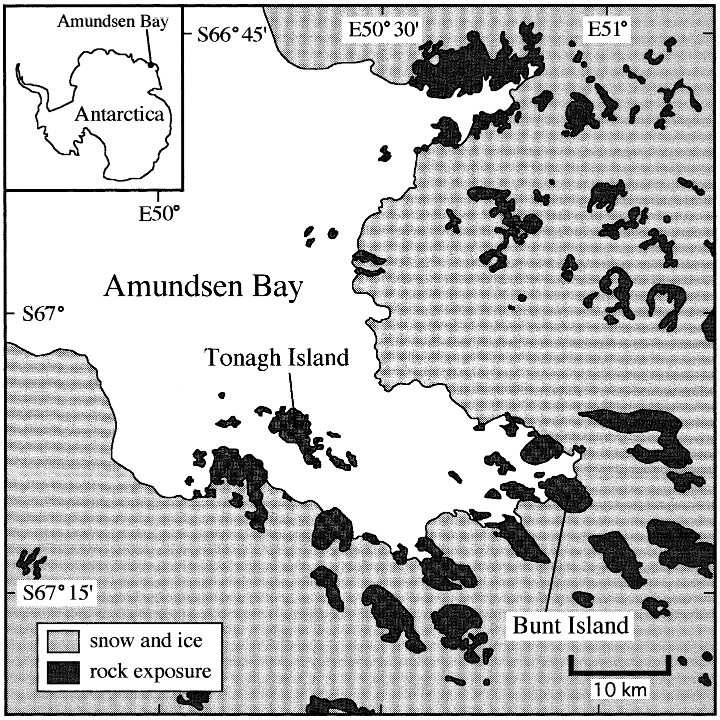

Fig. 1. Simplified location map of Bunt Island in the Napier Complex, East Antarctica (after Sheraton et al., 1987).

(pelitic) gneiss. The osumilite-bearing aluminous granulite discussed in this paper was collected by the geology team of the 39th Japanese Antarctic Research Expedition (JARE-39) during 1997–1998 as a part of the Japanese earth science project "SEAL" (Structure and Evolution of east Antarctic Lithosphere). The osumilite-bearing granulite occurs between boudinaged ultramafic granulite and sillimanite-garnet-sapphirine gneiss, which in turn is surrounded by garnet- and orthopyroxene-bearing quartzo-feldspathic gneisses.

Osanai *et al.* (2001) estimated the UHT peak metamorphic condition of Bunt Island as $T>1034$°C and $P<9.78$ kbar by using a petrogenetic grid and the THERMOCALC program (Holland and Powell, 1998). On the basis of detailed petrographic observations and thermodynamic considerations in the KFMAS system, they proposed that the garnet-K-feldspar-sillimanite assemblage is replaced by sapphirine-garnet-K-feldspar assemblage due to a pressure drop at almost constant temperature. Application of Harley's (1998) FMAS petrogenetic grid also suggests that the isothermal decompression history of Bunt aluminous granulite proceeds from the stability field of orthopyroxene+sillimanite+quartz to the garnet+cordierite+sillimanite+quartz field through sapphirine+quartz field. These observations led Osanai *et al.* (2001) to suggest a decompressional P-T path for the Bunt Island granulites.

3. Fluid Inclusion Studies

3.1. Analytical procedure

Fluid inclusions were studied in doubly polished thin wafers of the osumilite-bearing granulite. The thickness of the wafers prepared is about 130 microns as measured by a micrometer. The nature and occurrence of inclusions, their distribution pattern, shape, size and phase categories were carefully studied and documented under the petrological microscope following the techniques outlined by Roedder (1984), Touret (2001), and Van den Kerkhof and Hein (2001). Figure 2 is an example of a rock wafer used for the fluid inclusion analysis (sample BI-1), where compositional banding of Opx-Qtz-Osm and Spr-Grt-Osm-Opx layers are clearly seen. The fluid inclusions examined in this study occur in quartz and orthopyroxene within the Opx-Qtz-Osm layer and garnet in the Spr-Grt-Osm-Opx layer. Mineral abbreviations used in this study are after Spear (1993).

Microthermometric measurements were performed with a U.S.G.S. Gas-Flow Heating/Freezing System (Werre *et al.*, 1979) at the University of Tsukuba. The stage is equipped with a Nikon microscope (Optiphot) with maximum magnification of 400×. The thermocouple was calibrated with synthetic standard materials supplied by Fluid Inc., Denver. The calibrations were performed at 0°C (triple point of H_2O), -56.6°C (triple point of CO_2), and the critical point of pure H_2O with density of 0.317 g/cm^3 (374.1°C). Heating rates of the samples are 0.05°C/s for melting and 0.1°C/s for homogenization temperatures. The precision of microthermometric results reported in this study is within ±0.1°C and ±0.2°C for melting and homogenization temperatures,

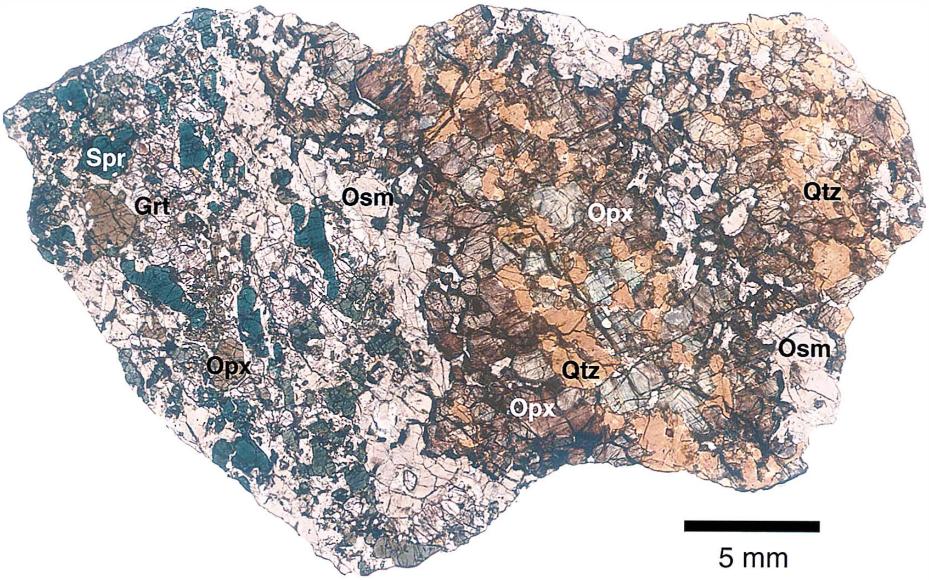

Fig. 2. Photomicrograph of a wafer used for fluid inclusion analyses (sample BI-1). It is composed mainly of Osm-Opx-Qtz and Spr-Grt-Osm-Opx layers.

respectively.

3.2. *Inclusion petrography*

Fluid inclusions are present in quartz, garnet, and orthopyroxene in the sample. Those in other minerals such as osumilite, sapphirine, and cordierite are sparse and too small to analyze. The quartz in which fluid inclusions were studied occurs as Opx-Qtz-Osm layers of the rock. It is medium to coarse-grained (0.1–2.2 mm) and lacks any discernible deformation effects such as wavy extinction or internal cracks. Fine-grained quartz occurs in equilibrium with sapphirine, although fluid inclusions are rare in this. Garnet in the sample is subhedral, medium- to coarse-grained (0.3–4.3 mm), and occurs mainly in Spr-Grt-Osm-Opx layers. Often, garnet is closely associated with sapphirine and cordierite. Fine-grained and anhedral garnet coexisting with sapphirine was not examined in this study because of its post-peak origin and lack of fluid inclusions. Fluid inclusions in both garnet and quartz have ovoid cavities ranging in size from 2–10 microns (Figs. 3a and 3b). They form random clusters composed of 10 to 30 inclusions. Orthopyroxene in Opx-Qtz-Osm layers is subhedral, medium- to coarse-grained (0.4–3.6 mm), and contains numerous fibrous minerals that cannot be identified under the microscope (see Fig. 3c). Fluid inclusions in the orthopyroxene have ovoid cavities ranging in size from 3–13 microns. They form planar arrays which pinch out within individual grains (Fig. 3c).

The petrographic observation suggests that fluid inclusions of all the genetic types —primary, secondary, and pseudosecondary—as defined by Roedder (1984) are present in the studied sample. Fluid inclusion clusters in quartz and garnet represent the "primary" type as classified by Roedder (1984), or group of synchronous inclusions according to the scheme of Touret (2001). The primary inclusions are defined as isolated inclusions or local clusters, totally contained within a grain and not focused along identifiable cracks. Planar array inclusions in orthopyroxene correspond to the

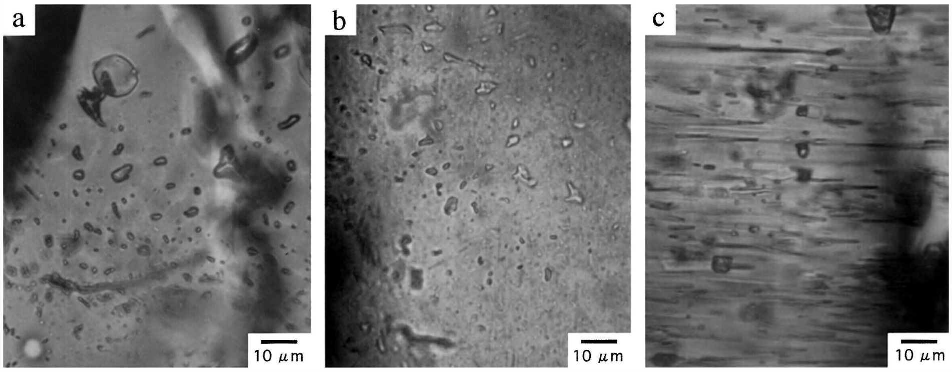

Fig. 3. Photomicrographs of fluid inclusions in an osumilite-bearing granulite discussed in this study (sample BI-1). (a) Primary fluid inclusions in garnet forming a cluster of about twenty inclusions. (b) Primary fluid inclusions in quartz. (c) Pseudosecondary fluid inclusions in orthopyroxene. They are distributed along a healed crack perpendicular to the orthopyroxene cleavage.

"pseudosecondary" type as classified by Roedder (1984), or intergrain trails according to the scheme of Van den Kerkhof and Hein (2001). The pseudosecondary inclusions form along microcracks that develop during the partial growth of the crystal and form arrays that pinch out within grains. It must be noted, however, that in the case of CO_2 inclusions, the array-bound nature need not necessarily indicate late entrapment. Primary CO_2-rich inclusions occurring along intergrain trails are known from several high-grade terranes (*cf.* Santosh, 1992). This is due to the wetting properties of CO_2, wherein carbonic fluids propagate by microfracturing and do not form an interconnected grain boundary fluid like H_2O (Watson and Brenan, 1987). Late secondary inclusions are also present, but they are not discussed further because they are too small to observe the phase changes during microthermometry, and are also relatively less abundant.

3.3. *Microthermometry*

The microthermometric results of fluid inclusions in quartz, garnet, and orthopyroxene in the osumilite-bearing aluminous granulite are summarized in Table 1 and compiled in histograms in Fig. 4.

The dominant category of inclusions in the sample is monophase at room temperature, being filled with a dense fluid phase. On supercooling, they freeze into a solid aggregate and on slow warming, abrupt melting occurs at temperatures (T_{m}) around -57.8 to -56.8°C, which is close to the triple point of pure CO_2 (-56.6°C; Fig. 4a). The slight depression in the melting temperatures below -56.6°C suggests the probable presence of traces of additional fluid components such as CH_4 and N_2, which are known to depress the melting temperature of pure CO_2 (*cf.* Roedder, 1984) because of the lower critical temperatures of these fluids (-82.6°C and -147.0°C for CH_4 and N_2, respectively). We also observed slightly varying melting temperatures for CO_2 inclusions depending on the host mineral. As shown in Fig. 4a, the melting temperatures are higher for inclusions in quartz as compared to those in garnet and orthopyroxene. Whether this difference is a true reflection of the slightly varying fluid compositions as a consequence of the change in fluid composition at different stages of trapping remains to be investigated through Laser Raman spectrosocopy in a future study.

Table 1. Summary of microthermometric measurements of fluid inclusions in an aluminous granulite from Bunt Island.

Host mineral	Melting temperature			Homogenization temperature			Density (g/cm^3)	Type of inclusions[2]	Inclusion size (micron)
	min	max	average[1]	min	max	average[1]			
Grt[3]	−57.7	−57.3	−57.5±0.1	−35.4	−24.6	−29.5±2.3	1.064–1.084	P	2–8
Grt[4]	−57.8	−56.8	−57.5±0.2	−12.0	10.8	−5.1±4.5	0.932–0.982	P	4–10
Grt[3]	−57.3	−57.0	−57.2±0.1	−4.8	1.1	−1.7±2	0.926–0.950	P	2–7
Grt[4]	−57.4	−57.2	−57.3±0.1	6.3	24.7	14.6±4.1	0.788–0.858	P	2–7
Opx	−57.6	−57.6	−57.6	−23.6	11.5	−1.0±13.4	0.843–1.006	PS	3–13

[1] error indicates standard deviation

[2] P: primary, PS: pseudosecondary

[3] high-density inclusions

[4] low-density inclusions

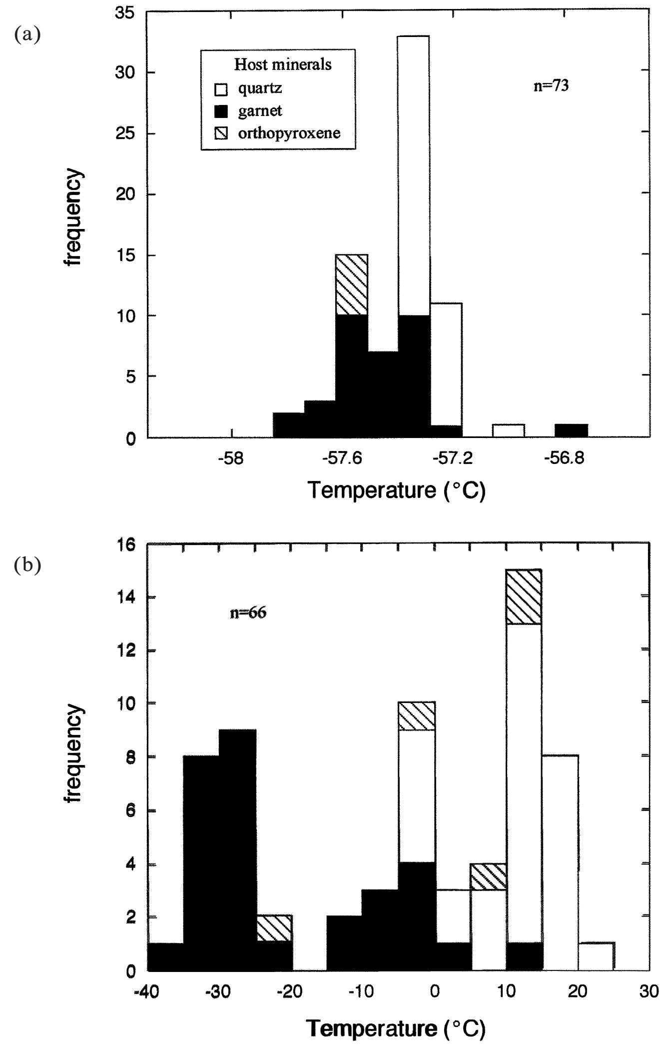

Fig. 4. Histograms showing the distribution of melting and homogenization temperatures (a: T_m and b: T_h, respectively) of fluid inclusions in garnet, quartz, and orthopyroxene in an aluminous granulite of Bunt Island.

Following melting of the carbonic inclusions, on continued heating, the fluid trapped within the inclusions homogenizes by the gradual dissolution of the gas phase into the liquid phase. In all cases, the CO_2 homogenizes into the liquid phase. Homogenization temperatures (T_h) are compiled in Fig. 4b, and show a relatively broad distribution from −35 to 25°C. Generally, inclusions in garnet and orthopyroxene show lower homogenization temperatures as compared to those in quartz. As shown in Fig. 4b, the homogenization temperatures of fluid inclusions in garnet define two peaks, around -29.5 ± 2.3°C and -5.1 ± 4.5°C. Such a feature could arise either from density reversal of originally high- (or low-) density inclusions or entrapment of subsequent pulses of lower (or higher) density fluids during the post-peak metamorphic history (Santosh and Tsunogae, 2003). In the present case, the latter model is not realistic because fluid inclusions with different homogenization temperatures occur within the same group of synchronous inclusions in garnet. Obviously, the texture suggests that they were probably trapped at the same stage, reflecting capture of fluids from a single fluid infiltration event. In order to examine this aspect further, we attempted a correlation between the homogenization temperatures and inclusion size within synchronous group of inclusions in garnet (Fig. 5). Interestingly, it was revealed that inclusions with larger cavities show higher homogenization temperature as compared to those with smaller cavities. Clearly, fluids in some of the inclusions with large cavities have suffered post-trapping density reversal. Santosh *et al.* (1991) described an identical scenario from a train of CO_2 inclusions in quartz that showed varying homogenization temperatures with the smallest inclusions preserving the original (high) densities. We therefore infer that the inclusions showing lower homogenization temperature (high-density) may record the history of early (probably peak) stage of metamorphism. Although some inclusions in garnet show anomalously high homogenization temperatures (~10.8°C) compared with the others, we regard them to be the result of local fluid leakage and those inclusions are therefore discarded for quantitative isochore calculations.

The homogenization temperatures of fluid inclusions in quartz indicate a peak at around -1.7 ± 2.0°C. The range is nearly consistent with the low-density fluid inclusions in garnet. On the other hand, some inclusions show very high homogenization temperatures compared with the others, showing a broad peak at around 14.6 ± 4.1°C.

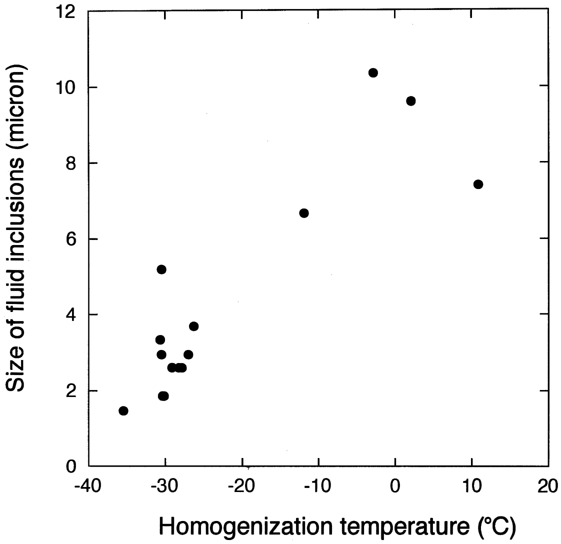

Fig. 5. Homogenization temperature (T_h) vs. fluid inclusion size diagram showing a positive correlation between the two. The inclusions are present in garnet and form a cluster of about twenty fluid inclusions. Note that larger inclusions show higher T_h (low density). See text for discussion.

These inclusions were obviously trapped at a later stage of the exhumation history of the rock and do not preserve the peak metamorphic history. The homogenization temperatures of fluid inclusions in orthopyroxene show a wide variation, from −23.6 to 11.5°C, although only a limited number of inclusions were analyzed. Clearly, fluid inclusions in garnet and orthopyroxene suggest at least two distinct stages of fluid capture—one at peak or near peak metamorphic conditions and the other during subsequent exhumation. Both minerals contain two groups of CO_2 inclusions, a high-density variety and a low-density variety. A better understanding of the fluid regime in the rock requires a more precise textural correlation of the different varieties to various stages of metamorphic equilibration of the mineral assemblages which was beyond the scope of the present study.

The composition of the fluid, and the temperature and phase of homogenization, allow precise estimation of the density of the fluid. The wide range of homogenization temperatures attributes CO_2 densities in the range of 0.788–1.084 g/cm^3 (Table 1). The effect of slight depression in melting temperatures of some of the CO_2-rich fluid inclusions, which could imply small amounts of N_2 or CH_4, was not taken into consideration for density calculations and the density values reported assume the fluid to be pure CO_2. The implications for compositional variation within such inclusions, if any, shall be addressed in a future study involving Laser Raman spectroscopy.

Knowledge of the composition of a fluid phase and its density value constrain it to lie along an "isochore" (line of constant volume) in *P-T* space. The underlying assumption that fluid inclusions have remained closed systems and the size of the cavities have remained constant since entrapment (*cf.* Roedder, 1984) allows the interpretation that the density of the fluid captured within the inclusion remained unchanged from its value at the time of entrapment. Thus, those inclusions which we infer to have undergone density reversal are not further considered for isochore calculations. In this study the isochores were calculated using a computer program "FLINCOR" developed by Brown (1989), which computes isochores of pure CO_2 inclusions. The FLINCOR enables us to estimate isochores using several equations and thermodynamic data. In this study we adopted the equation of Brown and Lamb (1989) for computing isochores from the microthermometric data. The isochores for the analyzed samples are shown in Fig. 6.

4. Discussion

4.1. High-density CO_2-rich inclusions from Bunt Island

Our preliminary fluid inclusion study on an osumilite-bearing aluminous granulite from Bunt Island indicates the ubiquitous presence of CO_2-rich fluids trapped within various minerals (quartz, garnet, and orthopyroxene) in the rock. The probable presence of traces of additional fluid phases (*e.g.* N_2 and CH_4) is indicated from the depression of CO_2 melting temperatures. It has to be noted that a recent fluid inclusion study on Antarctic anorthosites indicated that dense CO_2-rich fluid inclusion is not a primary feature. Kleinefeld and Bakker (2002) noted that interactions between the host mineral and enclosed CO_2-H_2O binary fluid could consume water to form hydrous minerals in the inclusions, leaving CO_2-rich fluid. However, such later enrichment of

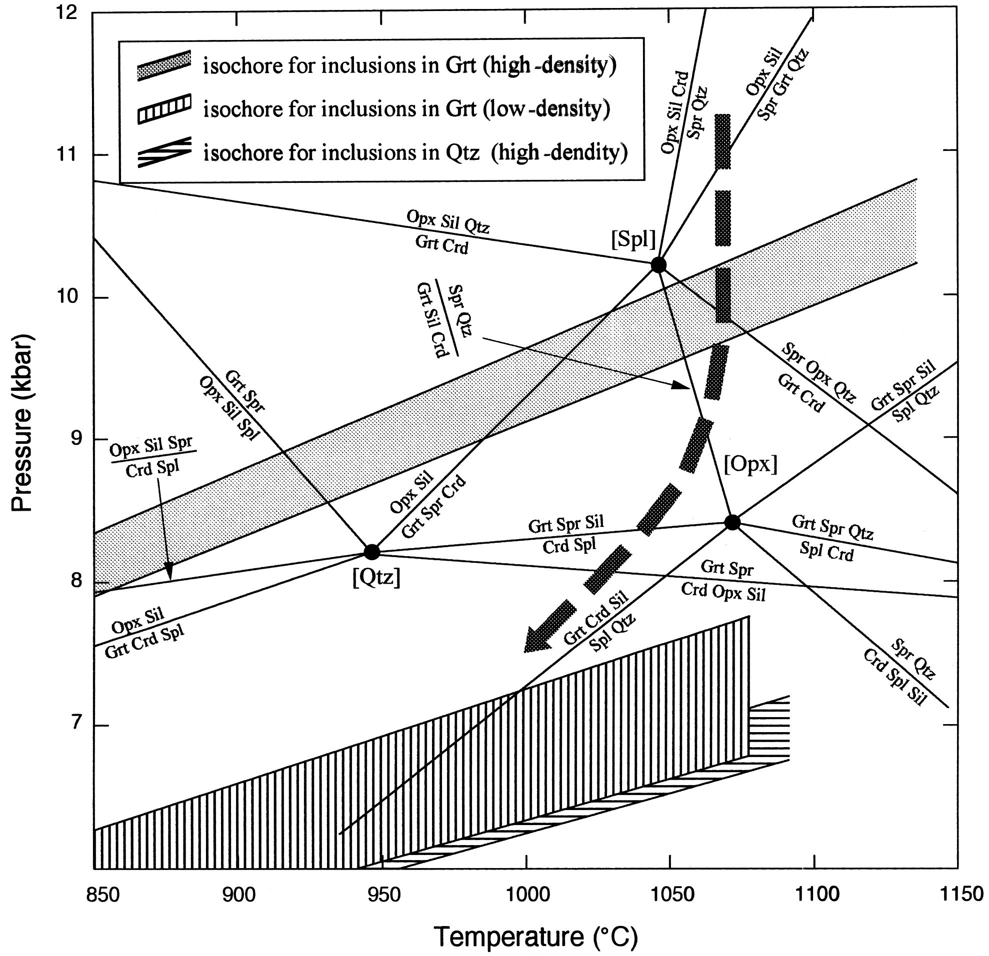

Fig. 6. Petrogenetic grid in the FMAS system (modified after Hensen and Harley, 1990; Harley, 1998) with isochores for fluid inclusions in garnet and quartz in an aluminous granulite. Gray arrow indicates an approximate P-T trajectory of granulites from Bunt Island after Osanai et al. (2001). See text for further discussion.

CO_2 did not occur in the osumilite-bearing rock because of the lack of daughter minerals such as pyrophyllite and paragonite in our sample.

A recent fluid inclusion study of ultrahigh-temperature granulites from Tonagh Island in the Napier Complex revealed the occurrence of very high-density CO_2-rich fluids (Tsunogae *et al.,* 2002). Carbonic fluid inclusions commonly present in sapphirine, garnet, orthopyroxene and quartz from Tonagh Island granulites have melting temperatures in the range of −56.3 to −57.2°C, and homogenization occurs into the liquid phase at temperatures between −34.9 and −4.2°C. The T_h values translate into high densities in the range of 0.9–1.1 g/cm^3. The estimated CO_2 isochores for sapphirine-granulite intersect the counterclockwise *P-T* trajectory of Tonagh Island rocks at around 6–9 kbar at 1100°C, which corresponds to the peak metamorphic conditions of the island derived from mineral assemblages, suggesting that the carbonic fluids are traces of syn-metamorphic CO_2 trapped during UHT metamorphism. In another recent study on ultrahigh-temperature granulites from the Eastern Ghats Belt in India, Sarkar *et al.* (2003) reported very high-density CO_2-rich inclusions and showed that these were trapped at peak metamorphic conditions. Thus, the role of nearly pure CO_2 as the ambient fluid species which buffered water activities and generated the dry granulite assemblages that characterize UHT rocks is emerging as an important theme in understanding extreme crustal metamorphism within the deep crust.

Previous fluid inclusion studies on high-grade rocks suggest that garnet, which is a relatively robust mineral, can preserve inclusions that record the history of fluids around the peak metamorphic stage, particularly when it is a product of prograde to peak metamorphism, as in this case (*e.g.* Santosh and Yoshida, 1992; Santosh and Tsunogae, 2003). It is therefore not surprising that in the UHT granulite of this study, the garnet-bound primary inclusions possess the lowest homogenization temperatures (-29.5 ± 2.3°C), and, therefore, the highest-density CO_2 within the rock. Figure 6 is a *P-T* diagram showing the available *P-T* path of Bunt Island after Osanai *et al.* (2001). Isochores for inclusions in garnet and quartz in the osumilite-bearing granulite are also plotted in the diagram. Isochores for high-density carbonic inclusions in garnet intersect the *P-T* path of Bunt Island at around 1050°C and 10 kbar, which corresponds to the peak *P-T* condition of the Island (Osanai e*t al.,* 2001). This provides strong evidence to infer that the high-density carbonic fluids in the rock were captured during the peak *P-T* conditions and that the inclusions preserve traces of the syn-metamorphic fluid (*cf.* Touret, 1985; Santosh and Tsunogae, 2003). Although high-density CO_2 inclusions can also be trapped at relatively lower temperature and pressure conditions in some rocks that underwent isobaric cooling, both primary textures and the correspondence of isochores of high-density fluid inclusions with the peak *P-T* conditions derived from mineral phase equilibria in this case are consistent with entrapment of these fluids at peak metamorphic conditions. Our results suggest that a CO_2-rich fluid was present during the peak UHT metamorphism of Bunt Island. The textural characteristics of the high-density inclusions as primary, isolated clusters within the cores of mineral grains are consistent with their entrapment during the growth or textural equilibration of the peak mineral phases. Occurrence of primary CO_2-rich fluid inclusions from more than one locality of the Napier Complex probably suggests that carbonic fluid played an important role in the origin of the UHT rocks in the Napier Complex. The presence of carbonic fluids could have aided in buffering H_2O-activity and stabilizing the anhydrous mineral assemblages that characterize the UHT granulite-facies metamorphism of the Napier Complex.

Our observations of CO_2-rich inclusions in the Napier rocks are comparable with similar reports of carbonic fluid inclusions in granulites from other crustal fragments of the Gondwana to which the East Antarctic fragment was juxtaposed (*e.g.* Santosh, 1986, 1992; Hansen *et al.,* 1987; Touret and Hansteen, 1988; Bolder-Schrijver *et al.,* 2000; Santosh and Tsunogae, 2003; Sarkar *et al.,* 2003). These observations have important implications on potential sources in the sublithospheric mantle underlying the East Gondwana crustal fragment from where high-density CO_2 was tapped during deep crustal and crust-mantle interaction processes associated with deep crustal metamorphism.

4.2. Implications for a decompressional P-T path

CO_2 inclusions reported from various granulite terranes of the world in different studies generally show a wide range of homogenization temperatures in individual areas (Santosh, 1992). This usually results in a large spread of Th data in histograms from the same locality, or even from a single host mineral. A similar observation was also made in the present study (*cf.* Fig. 4b), with distinct variation in the homogenization temperatures of CO_2 inclusions within different host minerals. Even apparently single generation inclusions in garnet show a wide range of homogenization temperatures (-35.4 to 10.8°C). It is obvious from Fig. 5 that coarse-grained inclusions in garnet show higher homogenization temperatures, suggesting density reversal of originally high-density inclusions, rather than entrapment of lower density fluids during retrograde fluid influx.

Primary inclusions in quartz show higher homogenization temperatures (lower densities) than those in garnet. As quartz is easily stretched or deformed compared to garnet and orthopyroxene, isochores obtained from quartz-hosted inclusions may preserve a retrograde event. It is interesting to note that (*cf.* Fig. 6) the estimated isochores for fluid inclusions in quartz are consistent with those obtained from low-density inclusions in garnet. The two categories of inclusions are therefore regarded to have undergone volume and density reversal during retrograde metamorphism. Isochores estimated from the low-density fluid inclusions intersect the *P-T* trajectory of Bunt Island at about <7 kbar and <950°C. A pressure estimate from this lower intersect provides a control point for the exhumation history of the Bunt Island granulites, and defines a decompressional *P-T* path.

In contrast, fluid inclusion data from Tonagh Island show that primary fluid inclusions in garnet have lower densities than intra-grain trails of very high-density inclusions in quartz. This is because Tonagh Island granulites were exhumed along a counterclockwise *P-T* path which is characterized by isobaric cooling from the stability field of sapphirine + quartz. The close correspondence between diverse exhumation paths defined from mineral phase equilibria and fluid inclusion studies further confirm the use of fluid inclusions to determine the style of *P-T* paths in high-grade metamorphic rocks. Combined petrologic and fluid inclusion studies on a regional extent in the Napier Complex is therefore imperative to understand the nature and role of fluids in UHT granulites and their implications on the evolution of the Archean crust. Tectonic implications of the two contrasting *P-T* paths obtained from a small area in the Amundsen Bay area (see Fig. 1) remain to be evaluated in a future study.

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