METAMORPHIC FLUIDS AND UPLIFT-EROSION HISTORY OF A PORTION OF THE KAPUSKASING STRUCTURAL ZONE, ONTARIO, AS DEDUCED FROM FLUID INCLUSIONS

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Introduction

Fluid inclusions can be used to determine the compositional evolution of fluids present in high grade metamorphic rocks (Touret, 1979) along with the general P-T path followed by the rocks during uplift and erosion (Hollister *et al.*, 1979). In this context, samples of high-grade gneisses from the Kapuskasing structural zone (KSZ, Fig. 1) of eastern Ontario were studied in an attempt to define the composition of syn- and post-metamorphic fluids and help constrain the uplift and erosion history of the KSZ. Recent work by Percival (1980), Percival and Card (1983) and Percival and Krogh (1983) shows that the KSZ represents lower crustal granulites that form the lower portion of an oblique cross-section through the Archean crust, which was up-faulted along a northeast- striking thrust fault. The present fluid inclusion study places constraints upon the P-T path which the KSZ followed during uplift and erosion.

Occurrence, Morphology and Composition of Fluid Inclusions

Fluid inclusions present in quartz in high-grade (700-800^{o}C, 6-8 kbar) rocks (paragneisses, amphibolite, gabbro gneiss and a tonalite dike) collected near the Shawmere anorthosite complex in the KSZ (Fig. 1), consist of three types (listed in order of decreasing abundance): (1) CO_2-rich inclusions (no visible H_2O)(generally 1 to 12 um, but up to 20 um); (2) H_2O-rich inclusions (no visible CO_2) (1-35 um); and (3) mixed CO_2 and H_2O (of variable sizes).

CO_2-rich inclusions occur along healed fractures and exhibit irregular to negative crystal morphologies with a few possessing an acicular morphology (up to 30um by 2um) (Fig. 2). At room temperature some of the CO_2 inclusions contain a birefreingent solid phase that exhibits a large variation in relief upon rotation of the microscope stage (probably carbonate). In addition, there are acicular carbonate grains associated which acicular CO_2 inclusions within the same fracture. These CO_2 inclusions have apparently developed in the casts of carbonate grains. Melting points of the CO_2 inclusions range from -61.5 to -56.6^{o}C (Fig. 3), indicating the presence of variable amounts of another component which depresses the melting temperature. Laser Raman spectroscopy performed on a CO_2-rich inclusion which posseses one of the lowest melting temperatures (-61.5^{o}C), shows the presence of CH_4 and no apparent N_2. From this data, the melting point depressions of the CO_2 are tenatively attributed to varying amounts of CH_4 in the CO_2 phase. The amount of CH_4 within CO_2-rich inclusions appears to be dependent on host rock lithology: meta-igneous rocks contain predominantly pure CO_2 (T_m = -56.8 to -57.0 ± .5^{o}C, with one trail in SH80-22A yielding a T_m of -57.7^{o}C, Fig. 3) while metasedimentary rocks contain varying proportions of CH_4 (T_m = -61.5 to -57.2 ± .5^{o}C, Fig. 3). Homogenization temperatures for the CO_2 inclusions (T_h, vapor to liquid) range from -47 to +31^{o}C (Fig. 3), with older-looking inclusions having lower T_h than younger-looking inclusions. A late-stage tonalite dike (41-D2) and a garnet gabbro gneiss (22A) contain "pseudo-secondary", negative crystal form CO_2 inclusions (cf. Roedder, 1980), which are believed to have been entrapped during initial crystallization of the host mineral. The psuedo-secondary inclusions in the tonalite dike along with planar, negative crystal form inclusions in an amphibolite (42F), exhibit the lowest T_h (highest density) of any CO_2 inclusions found in the KSZ rocks (Fig. 3). The high density inclusions in the amphibolite show significant melting point depressions, indicating the presence of CH_4, which will cause T_h to be lower than if the inclusion were pure CO_2. Consequently, the densities of these inclusions are not as high as they appear, and the corresponding isochores are not representative of the actual P and T of entrapment. The CO_2 inclusions in the tonalite dike are relatively pure CO_2 (as seen by their melting temperatures), therefore, the T_h yields an accurate density and the corresponding isochore can be used to determine the P or T of entrapment. The isochores for these high density inclusions in the tonalite pass through the lower portion of the T and P conditions of metamorphism estimated by Percival (1980, in press)(Fig. 4). This, plus the pseudo-secondary nature of the inclusions in the tonalite suggest that the CO_2 was trapped as the quartz crystallized during the granulite facies metamorphism.

H_2O-rich fluid inclusions have been found in all lithologies studied. These aqueous inclusions are always in planar arrangements and have morphologies varying from irregular to ovoid to partial negative crystal form (Fig. 2). The planes of aqueous inclusions often cut across grain boundaries, indicating post-crystallization entrapment. The aqueous inclusions generally possess one or more daughter phases: several cubic, isotropic phases (NaCl plus ?), a rectangular, birefringent phase identified as $CaCO_3$ through Raman spectroscopy and, rarely, an opaque, acicular phase. In addition, many H_2O-rich inclusions contain minute amounts of CO_2, which can only be observed through the formation of a clathrate which melts around +10°C. Melting points for the H_2O-rich inclusions range from -37 to +10°C depending upon the dissolved components present, while some of the aqueous inclusions do not appear to freeze down to -190°C.

Mixed CO_2 + H_2O inclusions (with both phases visible) are rare in the KSZ rocks and generally only occur where a trail of H_2O-rich inclusions intersects a trail of CO_2-rich inclusions. The morphologies of the mixed CO_2 - H_2O inclusions vary from negative crystal form (inherited from the original CO_2 inclusions) to irregular.

Source of Fluids

The source of CO_2 in granulite facies rocks is poorly constrained. Two models are generally invoked: (1) CO_2 is derived from surrounding rocks by decarbonation reactions during metamorphism, or by oxidation of graphite, or (2) CO_2 is derived from the mantle. Either or both of these two models may apply to the CO_2 inclusions in the KSZ. The presence of CO_2 filling carbonate mineral casts suggest that some CO_2 may be derived from *in situ* decarbonation. However, the lack of extensive carbonate layers in the KSZ requires an additional source for the CO_2; either unexposed carbonate layers, oxidized graphite (graphite occurs in some of the KSZ paragneisses (Percival, 1980)), or perhaps the CO_2 is fluxed from the mantle (Newton *et al.*, 1980).

The H_2O-rich inclusions and mixed H_2O-CO_2 inclusions clearly formed after the peak metamorphism. H_2O apparently penetrated the KSZ during uplift and may be associated with minor retrograde metamorphism (which is manifested by sericitized feldspars and epidote-chlorite alteration on some of the mafic mineral phases). The mixed H_2O-CO_2 inclusions form where a trail of H_2O crosses a trail of earlier CO_2.

Interpretation of Fluid Inclusion Data

Several inferences can be made from the above data. CO_2 appears to have been the fluid phase present during the peak metamorphism. Small amounts of CH_4, present in the metasedimentary units, may have been locally derived. Two rocks, a tonalite dike and an amphibolite, possess high density CO_2 inclusions which, in the case of the tonalite dike, were trapped during crystallization of the host quartz. The corresponding isochore for these dense inclusions passes through the lower portion of the estimated P-T conditions of metamorphism of the KSZ. After entrapment of these high density CO_2 inclusions, the P-T path of the KSZ granulites is constrained to have remained within 1.5 kbar of the 1.05 g/cm^3 isochore (the shaded region in Fig. 4A). If the rocks passed below this range, the fluid inclusions would have decrepitated due to the large pressure differential thus created between the interior and exterior of the fluid inclusion (Hollister *et al.*, 1979). Therefore the KSZ was not uplifted while retaining high temperatures, as the Tertiary coast range granulites of British Columbia (path B, Fig. 4)(Hollister, 1979). Additionally, the KSZ granulites could not have cooled isobarically, producing denser, late-stage inclusions, as Swanenberg (1980) found for Precambrian granulites from southern Norway (path C, Fig. 4); the morphologically later inclusions in the KSZ invariably have lower densities. The KSZ granulites were uplifted along the path shown in Fig. 4A. As the P and T dropped, CO_2 was released and re-trapped, forming the lower density inclusions. The lowest density CO_2 inclusions present are 0.5 g/cm^3, and must have been trapped along that isochore within the shaded region (Fig. 4A). H_2O penetrated the KSZ as higher levels were reached (producing the retrograde assemblages present in some units) and was trapped, as fractures in the quartz continued to form and heal.

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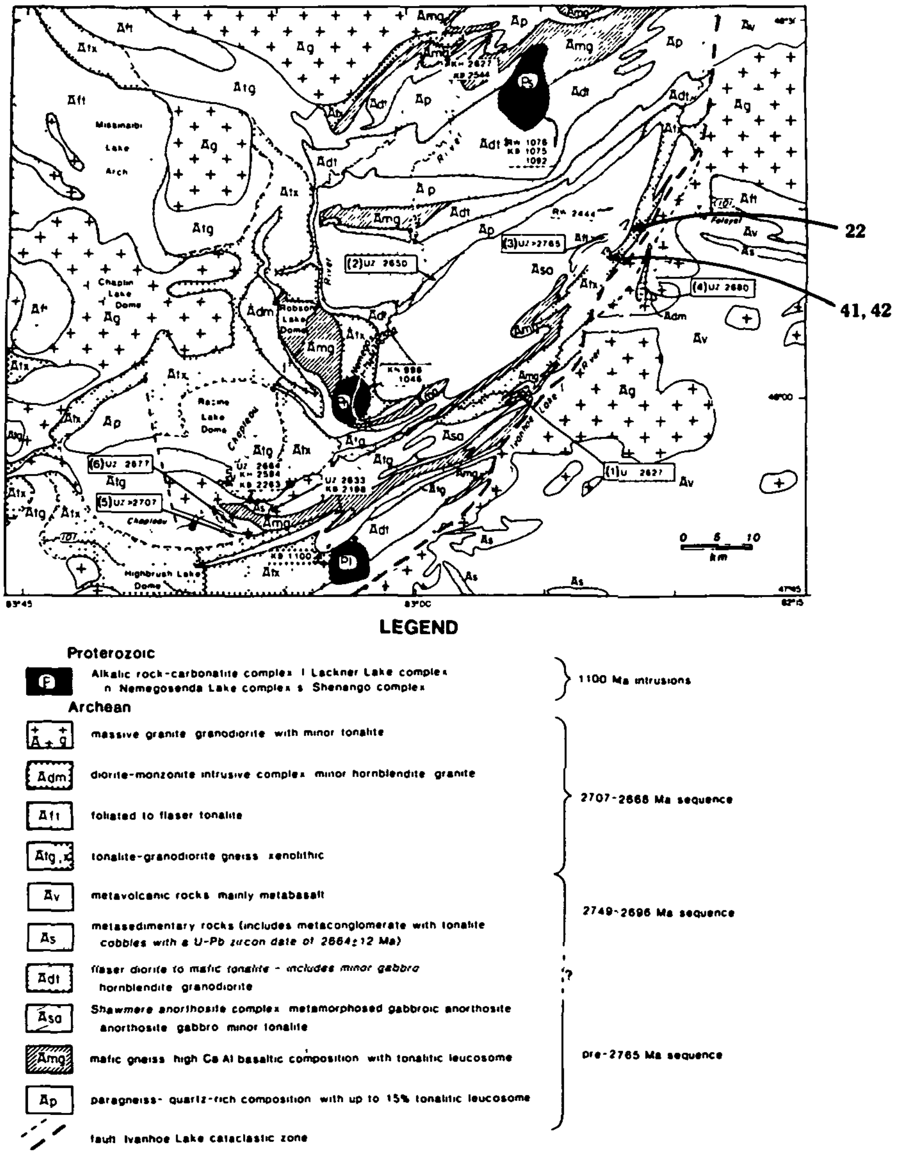

Fig. 1, Geologic map of the Kapuskasing structural zone showing sample localities for this study (from Percival and Krogh, 1983).

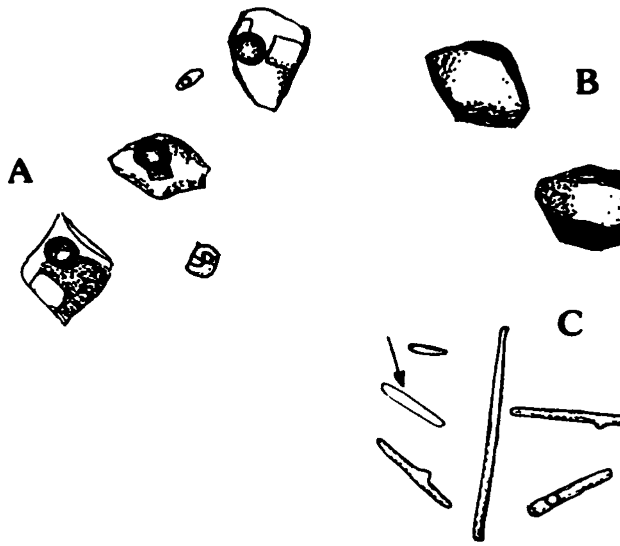

Figure 2, A: morphology of H_2O-NaCl fluid inclusions, B: negative crystal form CO_2 fluid inclusions, C: acicular CO_2 fluid inclusions, arrow points to acicular carbonate grain.

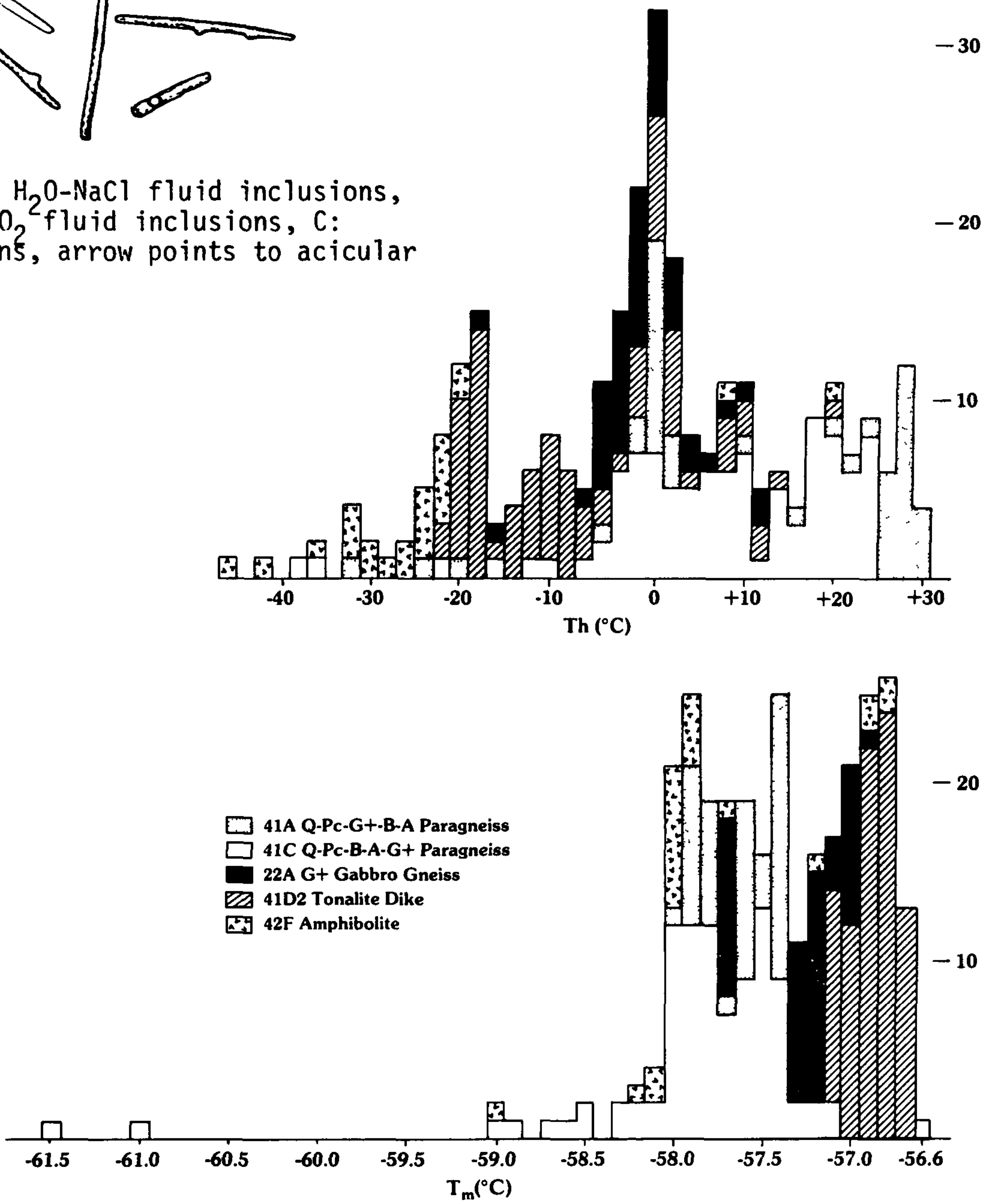

Fig. 3, Temperature of homogenization (T_h) and temperature of melting (T_m) for CO_2-rich fluid inclusions from high-grade rocks from the Kapuskasing structural zone, Ontario. Q = quartz, Pc = plagioclase, Gt = garnet, B = biotite, A = amphibole.

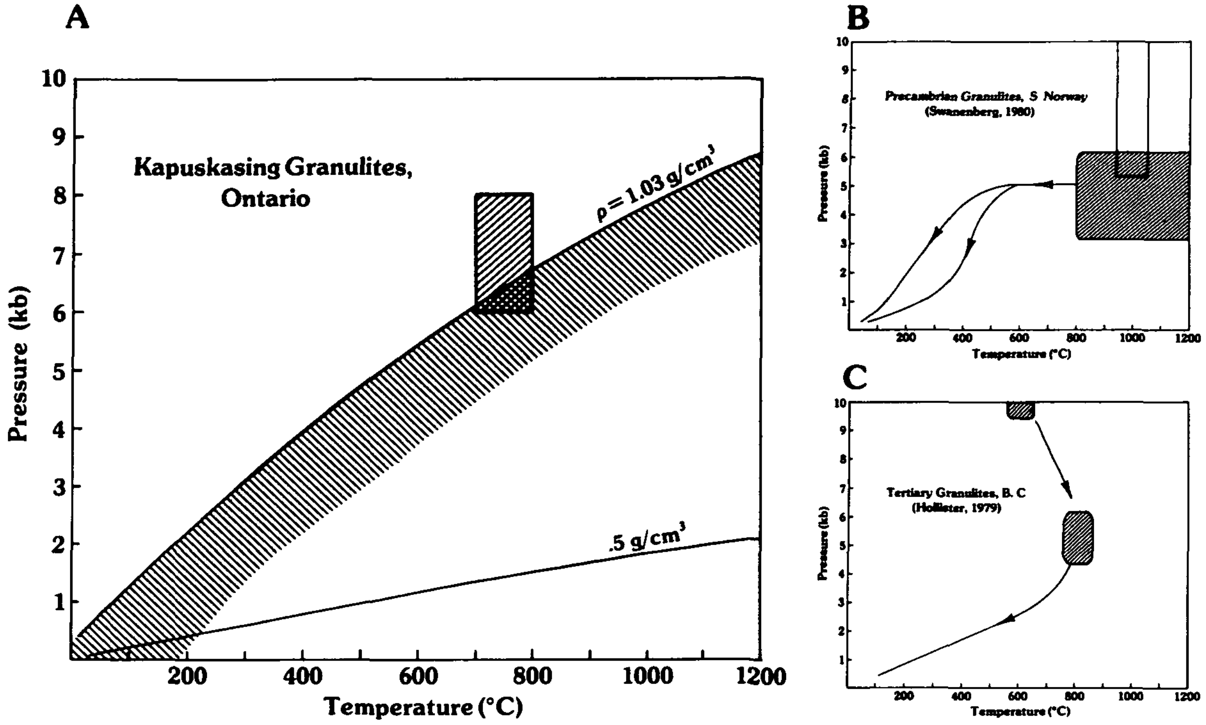

Fig. 4, A: P and T of metamorphism of the KSZ (from Percival and Card, 1983) and uplift path deduced by high density fluid inclusions (1.03 g/cm^3). Isochore with ρ = .5 g/cm^3 represents least dense CO$_2$ inclusions in KSZ. These lower density inclusions must have been trapped along the .5 g/cm^3 isochore within the shaded region. B: conditions of metamorphism and uplift path for S. Norway granulites from Swanenberg (1980). C: conditions of metamorphism and uplift path for Tertiary Granulites from the Coast Range, British Columbia from Hollister, 1979.