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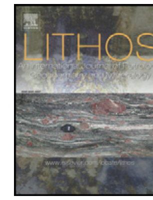

Migmatites formed by water-fluxed partial melting of a leucogranodiorite protolith: Microstructures in the residual rocks and source of the fluid

E.W. Sawyer *

Département des Sciences Appliquées, Université du Québec à Chicoutimi, Chicoutimi, Québec, Canada G7H 2B1

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ABSTRACT

The Opatica Subprovince in the Canadian Shield is a late Archaean (2761–2702 Ma) plutonic arc formed above a north-dipping subduction zone. Anatexis (2690–2677 Ma) of leucogranodiorite and leucotonalite orthogneisses in the Opatica generated migmatites in an area of north-vergent back thrusts visible at the surface and in LITHOPROBE seismic profile 48. Schollen diatexite migmatites occur in the thrusts and metatexite migmatites between them.

The modal mineralogy, microstructure, and whole rock major, trace and oxygen isotope compositions of the protolith and migmatites were investigated to; 1) determine the melting reaction, 2) find microstructural criteria for identifying residual rocks in leucocratic systems where there is no melanosome, and 3) to determine the source of the fluid involved in anatexis.

Partial melting of the protolith did not change the mineral assemblage, but the abundance of quartz and microcline both declined and plagioclase and biotite increased in the residual rocks. Quartz, plagioclase and microcline show evidence for dissolution and biotite does not. Thus, water-fluxed melting of quartz + plagioclase + microcline occurred. A mass balance indicates 25–30% partial melting. The melting reaction consumed the microcline and created essentially monomineralic domains of plagioclase. Extraction of 80–90% of the melt left a thin film of melt on the grain boundaries, and crystallization of these in the plagioclase domains created diagnostic microstructures. Microcline fills the last remaining pore space and forms high-aspect ratio crystals between plagioclases or triangular crystals at grain junctions. Quartz shows a range of morphologies, from high-aspect ratio films through the “string of beads” to isolated rounded grains, as the microstructure progressively equilibrated after crystallisation.

Most accessory phases, including zircon, remained in the residuum. However, almost all the schollen migmatites have high contents of Th, U, Nb, Ta and REE relative to the protolith, due to contamination by accessory phases derived from mafic rocks. Disaggregation of the mafic rocks may have been facilitated by the high strain in the back thrusts where the schollen diatexites formed.

Average whole rock $\delta^{18}O$ for the protolith and migmatites are similar (ca 8.2‰), and the small difference between melt-rich (8.6‰) and residuum-rich rocks (8.0‰) is consistent with fractionation. Thus, the fluid that caused melting was probably of metamorphic origin with $\delta^{18}O$ similar to the protolith. The seismic profile shows several reflectors extending to a present depth of 20 km (ca. 40 km in the late Archaean) under the migmatites; these are the paths along which the metamorphic fluid migrated and generated the migmatites now at the surface. A new type of neosome reported in this study may have formed along fractures that the fluids migrated along, however, these are peripheral pathways in the metatexites adjacent to the back thrusts and schollen diatexites.

1. Introduction

Metapelitic and metapsammitic rocks commonly contain 30 modal percent, or more, of biotite + muscovite. Incongruent melting reactions in which micas break down at temperatures between 800 and 900 °C can generate large volumes of granitic melt from these rocks, and complementary residual assemblages with garnet, cordierite, K-feldspar or orthopyroxene. Examples of extensive anatexis from this type of hydrate break down reaction (also known as dehydration melting) are numerous (e.g. Waters and Whales, 1984; Otamendi and Patiño Douce, 2001; White et al., 2003; Guernina and Sawyer, 2003). Some (Clemens, 1990; Clemens and Watkins, 2001) have suggested that such reactions occurring at temperatures of the granulite facies are the only way that large volumes of granitic magma can be generated in the continental crust.

Recent studies (Jung et al., 2000; Genier et al., 2008; Ward et al., 2008) of migmatites formed from metapelitic rocks have noted that

* Tel.: +1 418 545 5011 5636; fax: +1 418 545 5012.
E-mail address: ewsawyer@uqac.ca.

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large volumes of granitic melt have been produced at low temperatures (ca.700 °C) and, therefore, that anatexis must have been caused by an ingress of aqueous fluid into hot, subsolidus rocks; a process variously termed water-added, water-assisted, or water-fluxed melting. Evidence for the influx of an aqueous fluid has also come from changes in the isotopic composition of oxygen between protolith and migmatite (Wickham and Taylor, 1985; Scaillet et al., 1990; Jung et al., 1999, 2000).

The anatexis of granitic rocks presents a challenge to our concepts of how melting occurs in the continental crust because of the far smaller proportion of hydrous minerals that they contain; leucogranites are particularly problematic. Many workers (Slagstad et al., 2005) have noted that the amount of granitic melt that can be produced from the hydrous minerals present is determined by their H_2O content, and that the ratio of biotite in the protolith to granitic melt produced is about 1. Because the amount of melt produced in migmatites derived from granitic protoliths commonly far exceeds that which can be derived from the breakdown of the mica (or hornblende) in them, and the absence of garnet, cordierite or orthopyroxene in the residuum, it is now widely believed that partial melting of granite, granodiorite and trondhjemite protoliths occurs because of the influx of an aqueous fluid (McLellan, 1988; Mogk, 1992; Slagstad et al., 2005; Burri et al., 2005; Berger et al., 2008). Petrogenetic modelling, irrespective of whether the protolith is granitic (Schulmann et al., 2008), granodioritic (Berger et al., 2008) or metagranite (Hasalová et al., 2008), also shows that only a few percent of melt can be generated from the breakdown of micas in a closed system, and at temperatures in excess of 800 °C.

The successful identification of the rocks from which melt has been extracted is critical to understanding the process of anatexis. This is commonly done using field, mineralogical or geochemical criteria. However, the past decade there has been significant progress in understanding the microstructure of migmatites and, consequently, new criteria are now available for recognising the residual parts of migmatites (Sawyer, 1999; Holness and Clemens, 1999; Sawyer, 2001; Marchildon and Brown, 2002; Holness and Watt, 2002; Holness and Isherwood, 2003; Holness et al., 2005; Guernina and Sawyer, 2003; Holness and Sawyer, 2008), but these have not yet been applied to leucocratic systems that have undergone water-fluxed melting.

This contribution examines migmatites derived from leucocratic igneous protoliths, and has three objectives. 1) To compare the microstructures in the protolith to those in migmatites in order to find microstructural criteria that can be used to better identify the residual rocks in leucocratic systems where there is residuum, but no melanosome. 2) To determine the origin of the aqueous fluids which caused anatexis by comparing the oxygen isotopic compositions of the protolith with that of the anatectic rocks. 3) To use the morphology of the neosomes in the metatexite migmatites, and the regional tectonic setting of the Opatica Subprovince to investigate how the fluid may have entered the rocks to cause anatexis.

2. Regional geology

The Opatica Subprovince is a 1000 km long belt of plutonic rocks located in the southeastern part of the Superior Province. It is bordered to the north (Fig. 1) by upper amphibolite to granulite facies metasedimentary rocks belonging to the Nemiscau, Opinaca and Ashuanipi Subprovinces; except for one small area where a nappe of tonalites belonging to the Lac Rodayer Pluton lies over the contact with the Nemiscau. The Abitibi Subprovince lies to the south, and the Opatica is truncated by the Grenville Front in the east.

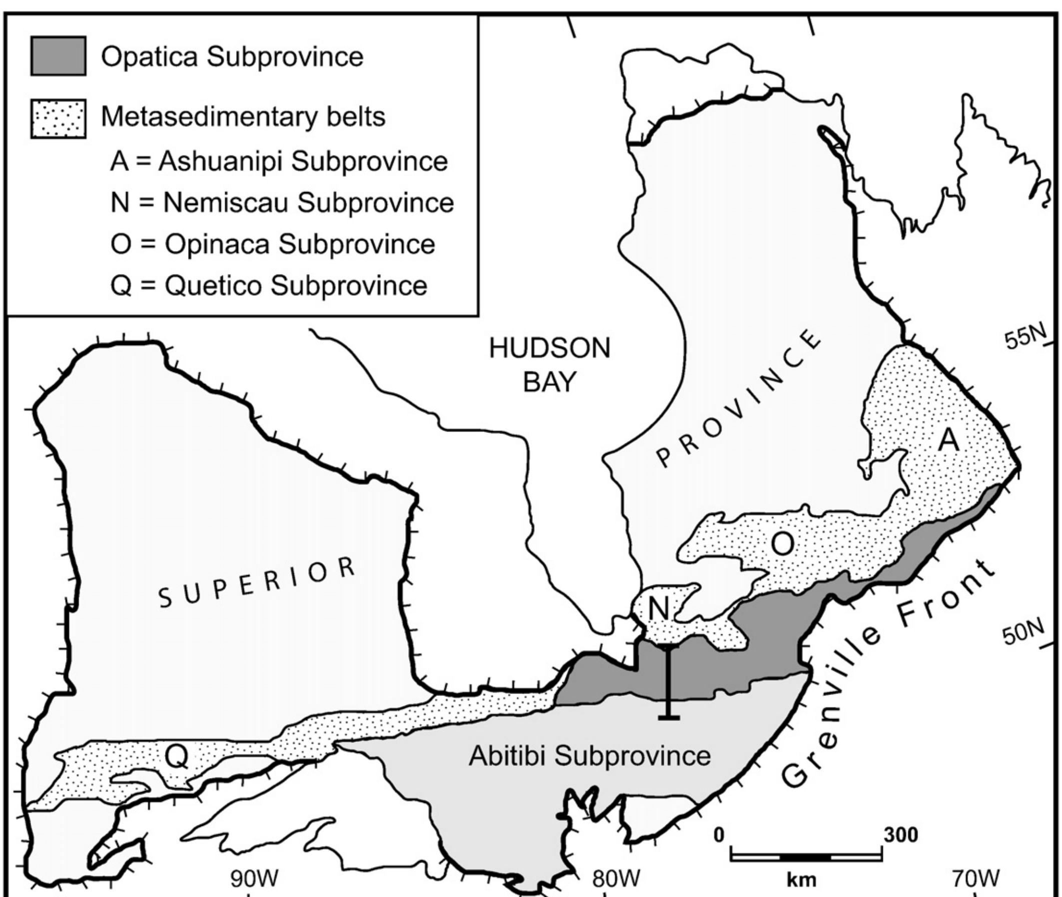

Fig. 1. Map showing the location of the Opatica Subprovince within the southeastern Superior Province of the Canadian shield. The black line shows the location LITHOPROBE reflection line 48 and the study area.