Lithos 208–209 (2014) 21–33

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Graphite thermometry in a low-pressure contact aureole, Halifax, Nova Scotia

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ARTICLE INFO

Article history:
Received 9 June 2014
Accepted 21 August 2014
Available online 30 August 2014

Keywords:
Contact metamorphism
RSCM thermometry
Graphite
Conductive cooling model

ABSTRACT

Intrusion of the late Devonian South Mountain Batholith, southern Nova Scotia, produced a low-pressure contact metamorphic aureole in its metasedimentary host rocks. The effects of contact metamorphism are particularly well developed in pelitic rocks of the Halifax Group on the eastern margin of the batholith. Contact metamorphic isograds and mineral assemblages suggest low-pressure metamorphism, with P–T conditions at the contact estimated at 2.5–3.0 kbar and ca. 650 °C. In this study, Raman spectroscopy of carbonaceous material (RSCM) was used to obtain temperatures from graphite, which is common throughout the contact aureole. Temperature estimates range from ca. 360 °C just outside the cordierite-in isograd to ca. 640 °C in the sillimanite–K-feldspar zone near the contact, the latter consistent with the temperature estimated from the corresponding silicate mineral assemblage. Three different RSCM calibrations produced very similar results except at the high-temperature end of the observed range. A thermal profile constructed from the RSCM data was used to constrain a 2D numerical model for post-intrusion conductive cooling of the batholith along its eastern margin. Comparison of RSCM vs model thermal profiles suggest that observed differences between the thermal structure of the inner and outer aureole were controlled by the subsurface geometry of the pluton contact. The model predicts that peak temperatures in country rocks within 1 km of the contact were reached within 50 ka of intrusion, but that the outer part of the aureole took 250–500 ka to reach peak temperatures. The results confirm the utility of RSCM thermometry for acquiring temperature data over a range of metamorphic grades.

1. Introduction

The South Mountain Batholith, the largest plutonic complex in the Appalachian orogen, intruded late Proterozoic to early Paleozoic rocks of the Meguma Supergroup, southern Nova Scotia, at about 380 Ma (Fig. 1a; MacDonald, 2001; Kontak et al., 2004). A low-pressure contact metamorphic aureole was superimposed on *ca*. 400 Ma greenschist-facies regional metamorphic assemblages (e.g., Hicks et al., 1999; Jamieson et al., 2005, 2012; Mahoney, 1996; White and Goodwin, 2011). Jamieson et al. (2012) documented mineral assemblages and isograds within the contact aureole in the city of Halifax (Figs. 1b, 2) and demonstrated contrasting low-pressure mineral assemblages in pelitic rocks of different bulk compositions, including the unusual appearance of cordierite and andalusite (chiastolite) before biotite in aluminous graphitic slates.

Jamieson et al. (2012) estimated pressure–temperature (P–T) conditions in the vicinity of the pluton–host rock contact at 2.5–3.0 kbar and ca. 650 °C, based on silicate mineral assemblages. However, quantitative assessment of temperatures during progressive metamorphism within the contact aureole has been hampered by uncertainties in the thermodynamic parameters of cordierite and retrogression of low-grade silicate assemblages. Here we report the results of a study using Raman spectroscopy of carbonaceous material (RSCM) to obtain temperatures from graphite throughout the contact aureole. Three different RSCM calibrations (Aoya et al., 2010; Beyssac et al., 2002a) produced essentially identical results over the temperature range 350–550 °C, with minor differences at higher temperature. While the RSCM method has been widely applied in regional metamorphic and subduction zone settings (Angiboust et al., 2009; Beyssac et al., 2004; Rahl et al., 2005), this consistency confirms the robustness of the method for estimating metamorphic temperatures in rocks from low-pressure settings such as contact aureoles, as suggested by Aoya et al. (2010). It also suggests that RSCM thermometry is potentially useful for estimating temperatures of ore mineralisation in similar settings.

Finally, we compare the RSCM data with a numerical model for conductive cooling of the eastern margin of the South Mountain Batholith, and conclude that the thermal profile across the contact aureole was largely controlled by the geometry of the upper contact of the pluton. The combination of graphite thermometry and thermal modelling offers an opportunity to investigate the thermal structure of the shallow crust, in this case at the margin of a large batholith.

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http://dx.doi.org/10.1016/j.lithos.2014.08.015
0024-4937/

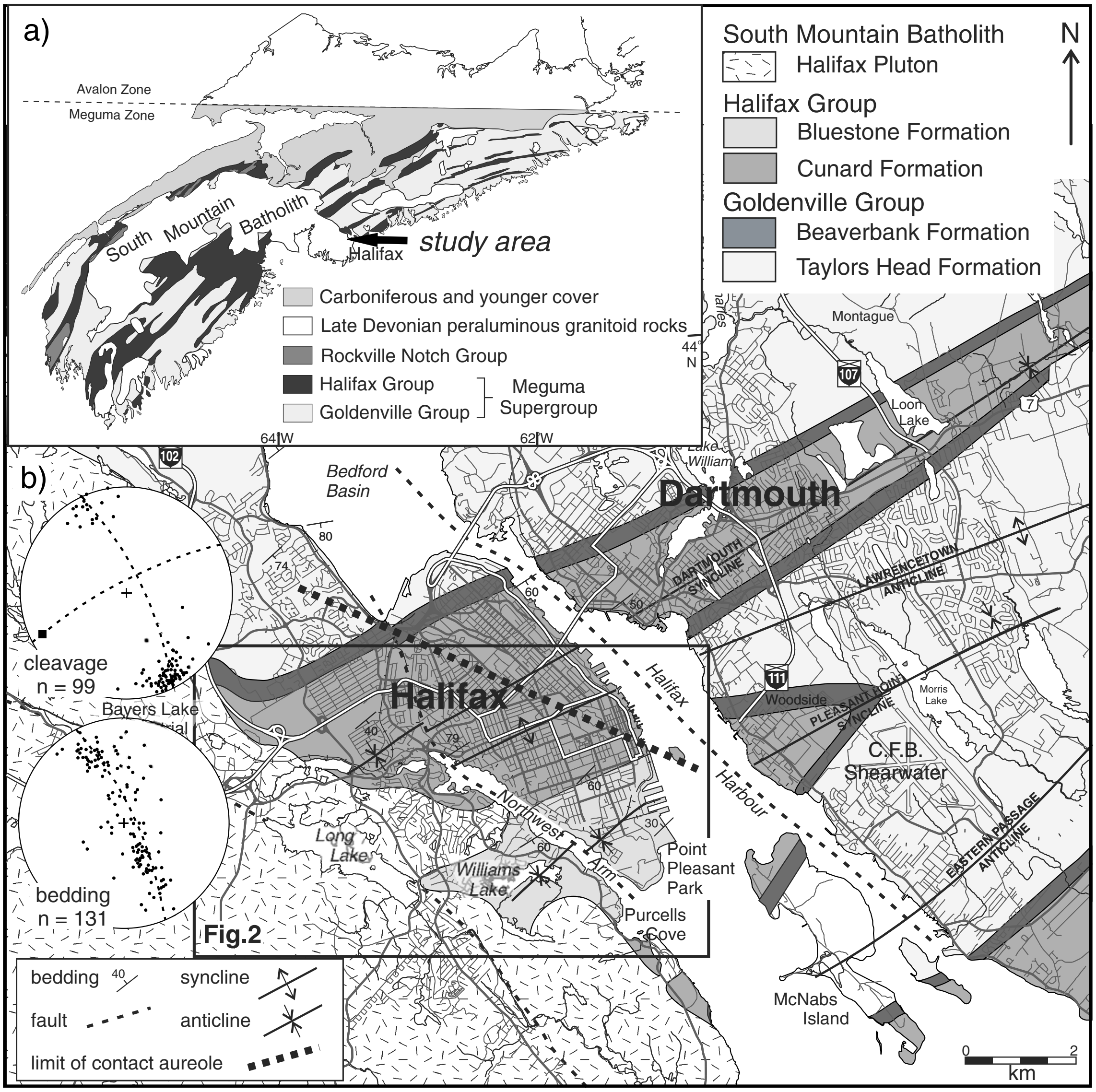

Fig. 1. Location and general geology of the study area. a) Generalised geology of the Meguma zone (after White, 2010), showing distribution of late Devonian intrusions and their Paleozoic host rocks; study area is located at the southeastern margin of the South Mountain Batholith. b) Geology of Halifax and vicinity (after White et al., 2008; Jamieson et al., 2012), showing the structure and stratigraphy of the Meguma Supergroup host rocks and their contact with the eastern edge of the Halifax Pluton. The mapped outer limit of contact metamorphic assemblages is shown by a heavy dotted line.

2. Geological Setting

2.1. Meguma Supergroup

Metasedimentary rocks of the Meguma Supergroup (Fig. 1a; Schenk, 1995; White, 2010) include the turbiditic late Neoproterozoic to Cambrian Goldenville Group, dominated by metasandstone (psammite) with subordinate metasiltsone, slate, and argillite, and the overlying late Cambrian to early Ordovician Halifax Group, dominated by metamorphosed mudrock (pelite), interlayered with fine-grained metasandstone and metasiltstone. In the study area, the Halifax Group can be divided into two lithological units (Jamieson et al., 2005, 2011; White, 2010; White et al., 2008) with contrasting bulk compositions. The Cunard formation (Figs. 1b, 2) consists of graphitic black slate with sparsely interlayered fine-grained metasandstone and metasiltstone horizons, and contains abundant sulphide minerals, mainly pyrrhotite (e.g., White and Goodwin, 2011). The overlying Bluestone formation (Fig. 1b, 2) consists of blue-grey slate interlayered with abundant metasiltstone and metasandstone horizons containing spectacular ripple marks and other well preserved primary sedimentary structures (Jamieson et al., 2005, 2011; White et al., 2008).

On a regional scale, the Meguma Supergroup is deformed into a series of NE–SW-trending, chevron- and box-style, upright folds with wavelengths of 1–2 km (Fig. 1b; Horne and Culshaw, 2001; Culshaw and Lee, 2006; White et al., 2008). Folding was accompanied by the development of a strong, axial–planar, slaty cleavage (S1) in fine-grained slate and metasiltstone and a spaced (disjunctive) solution cleavage in metasandstone. Both map-scale structures and meso- and microscopic textures indicate that regional folding mainly pre-dated intrusion and contact metamorphism, although there is evidence for post-intrusive flexural slip folding coaxial with the earlier folds (Horne and Culshaw, 2001). Variations in fold orientations, lineations, and metamorphic textures in the country rocks suggest that the style of intrusion and orientation of the Halifax pluton contact varied somewhat along its eastern margin from shallower in the south to steeper in the north (Culshaw and Bhatnagar, 2001). Jamieson et al. (2012) documented progressive annealing of the slaty cleavage within the contact aureole.