Lithos 160–161 (2013) 250–267

Contents lists available at SciVerse ScienceDirect

Lithos

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

Linking metamorphic textures to U–Pb monazite in-situ geochronology to determine the age and nature of aluminosilicate-forming reactions in the northern Monashee Mountains, British Columbia

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ARTICLE INFO

Article history:
Received 7 July 2012
Accepted 17 December 2012
Available online 23 December 2012

Keywords:
Isograds
Monazite
U–Pb geochronology
Metamorphic texture
Canadian Cordillera

ABSTRACT

The Monashee Mountains of the Canadian Cordillera are thought to expose a classic Barrovian-facies series of isograds. The timing of aluminosilicate growth in the region was determined for four pelitic schist samples by combining textural relationships with monazite compositional zoning and monazite U–Pb geochronology conducted directly on thin-sections by the laser ablation method. Three distinct phases of kyanite growth are recorded in the kyanite zone: at c. 153 Ma, between 122 and 94 Ma and between 76 and 58 Ma. For each phase, monazite and garnet grew synchronously with kyanite, probably by a reaction involving the breakdown of staurolite. In contrast, sillimanite growth by muscovite dehydration melting occurred at or before c. 104 Ma in the sillimanite zone, and retrograde sillimanite grew in schists previously metamorphosed at the kyanite grade during the first two phases by the influx of hot, acidic fluids during top-to-the-east shearing at ca. 71 Ma. These results indicate that rocks metamorphosed at different places and different times in the orogen were juxtaposed prior to being overprinted at the sillimanite grade in the Late Cretaceous–Early Paleocene during the influx of hot fluids in a structurally coherent body deforming by easterly directed shearing. This study also provides new insight into monazite petrogenesis and suggests that, at least in some circumstances, monazite formation is linked to the staurolite-out reaction that produces kyanite.

1. Introduction

Aluminosilicates are widespread in metapelitic rocks cropping out in the core zones of orogenic belts. They are essential for reconstructing pressure-temperature paths, which become a powerful tool when their timing is constrained. Indeed, derived for different structural levels of an orogen, pressure–temperature–time (P-T-t) paths can be converted into particle paths and compared with those of numerical models to discriminate between orogenic processes (e.g., Gervais and Brown, 2011). Furthermore, the core zone of orogenic belts is commonly subdivided into zones defined by index aluminosilicates and separated by isograds, the geometry of which have been used extensively for kinematic (e.g., Law et al., 2011; Vannay and Grasemann, 2001) and dynamic analyses (e.g., Ghent and Simony, 2005; Searle et al., 2007). However, prior to using isograds for such analyses it must be demonstrated that they formed during the same metamorphic event and were not the result of tectonic juxtaposition (e.g., Jamieson et al., 1998), or of local metamorphic overprint. In order to determine the nature of an isograd, it is important to document the timing of its formation because isograds of the Barrovian-facies series should have formed within less than ~10 Myr, as demonstrated by modeling (Thompson and England, 1984 their figure 9; Burg and Gerya, 2005; Ruppel and Hodges, 1994) and natural studies (Baxter et al., 2002; Burton and O'Nions, 1992; Lancaster et al., 2008).

Determining the growth age of an aluminosilicate requires linking the metamorphic reaction responsible for its formation with a geochronometer. Monazite could potentially be an ideal candidate because its growth has been linked to several stages of the metamorphic evolution of pelitic schists. For most pelitic bulk compositions, allanite is the main rare-earth-element (REE) -bearing mineral that breaks down to produce monazite, and the monazite-in isograd is commonly close to the aluminosilicate-in isograd (Corrie and Kohn, 2008; Ferry, 2000; Gasser et al., 2011; Janots et al., 2008; Smith and Barreiro, 1990; Spear, 2010; Tomkins and Pattison, 2007; Wing et al., 2003). The nature of the reaction leading to this transformation is, however, highly debated. Some studies suggested that it is related to the formation of staurolite (Corrie and Kohn, 2008; Janots et al., 2008; Kohn and Malloy, 2004; Smith and Barreiro, 1990), others that it is related to the formation of Al_2SiO_5 (Foster et al., 2004; Wing et al., 2003), and others that the spatial association of the allanite–monazite reaction and the staurolite-in or Al_2SiO_5-in reactions is not related to specific reactions involving these phases, but is rather due to their

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0024-4937/$ – see front matter
http://dx.doi.org/10.1016/j.lithos.2012.12.007

occurrence within the same temperature range (Spear, 2010; Tomkins and Pattison, 2007). Nevertheless, the spatial coincidence of the two isograds strongly suggests that, for such terrains, the age of the oldest monazite in pelitic schist provides a close estimate for the age of the aluminosilicate-in reaction. Furthermore, because it crystallizes during cooling of granitic melt (Kelsey et al., 2008; Spear and \Pyle, 2010), monazite has the potential to provide the maximum age of partial melting and its associated aluminosilicate formation. Finally, in the presence of fluid, monazite can dissolve and reprecipitate as a second generation phase elsewhere (e.g. Wawrzenitz et al., 2011) or be modified in-situ by coupled dissolution–reprecipitation that leads to its pseudomorphic replacement and partial to total resetting of the U–Th–Pb isotopic system. (Crowley et al., 2008; Harlov et al., 2011; Hetherington et al., 2010; Seydoux-Guillaume et al., 2003, 2012; Williams et al., 2011).

The Mica Creek–Blue River area of the Canadian Cordillera (Fig. 1) is an ideal natural laboratory in which to investigate these issues. This area is characterized by the sequence of index minerals garnet → staurolite → kyanite → sillimanite, which is typical for a Barrovian-facies series. Extensive fieldwork and metamorphic studies pointed towards a model involving the formation of five isograds at the end of a second penetrative deformation event in the Early Cretaceous (Digel et al., 1998; Ghent and Simony, 2005; Ghent et al., 1980; Raeside and Simony, 1983; Simony and Carr, 2011; Simony et al., 1980; Tinkham and Ghent, 2005). Although these data imply one regional-scale metamorphic event in a structurally coherent body, a second metamorphic event was recognized as an overprint of the earlier metamorphic sequence caused by the infiltration of hot fluids (Digel et al., 1998; Stout et al., 1986). However, a geochronological transect across the area indicated that the area can be divided into three domains with distinct timing of deformation and metamorphism (Crowley et al., 2003). This could in principle be compatible with the prevalent "*overprinted Barrovian*" model if the younger ages reflected localized metamorphism, but it could also indicate that the Barrovian sequence is only apparent and that cryptic shear zones juxtaposed packages of rocks metamorphosed and deformed at different times and places in the orogen (Crowley et al., 2003). In the Selkirk Mountains further southeast, Gibson et al. (2004) linked the chemical composition and the age of monazite extracted from a kyanite-bearing pelitic schist to infer metamorphic reactions. Their results (see below) are different from those of Crowley et al. (2003) and point towards a complex and protracted metamorphic

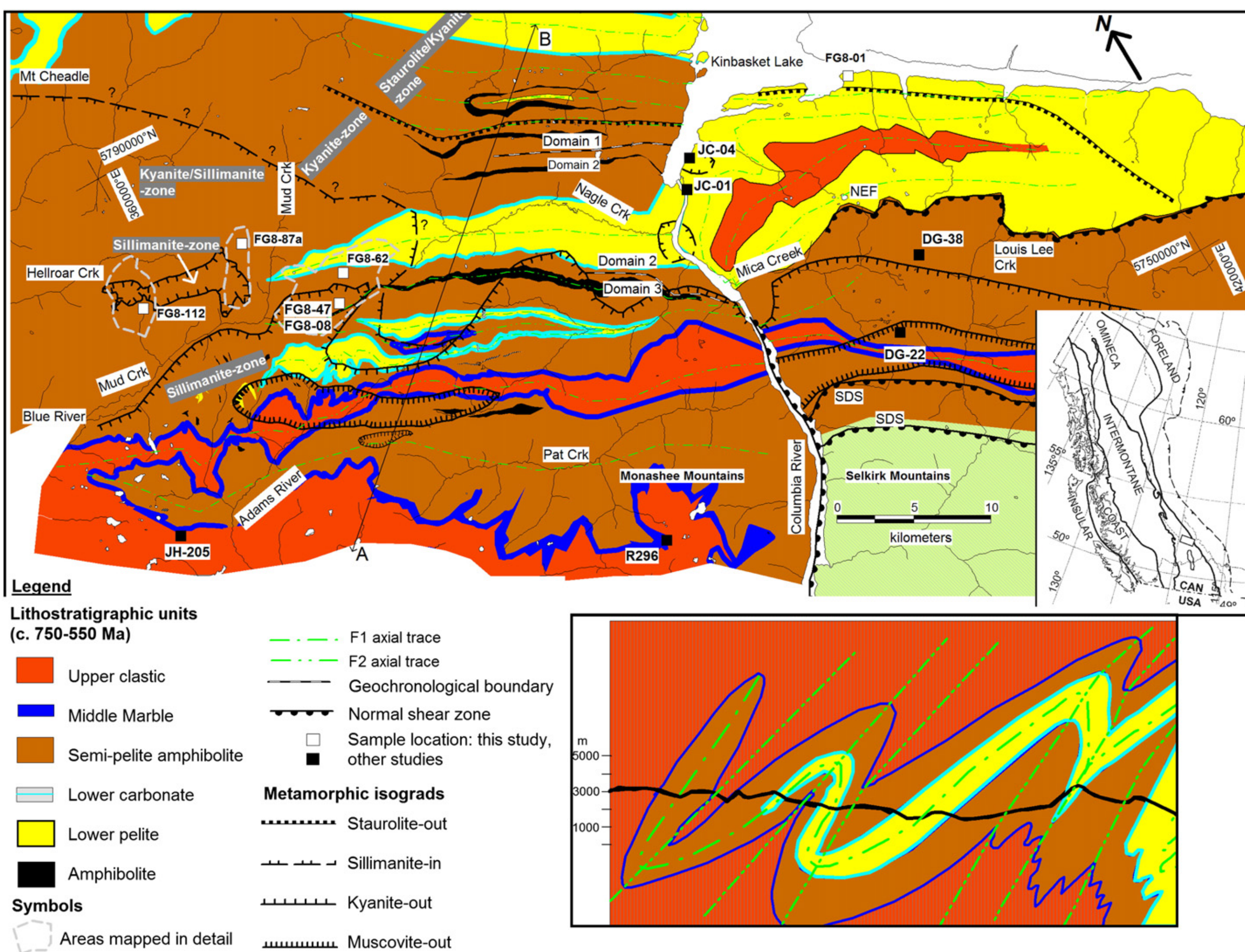

Fig. 1. Geological map of northern Monashee and Selkirk mountains (modified from McDonough et al., 1992; Scammell, 1993; Gibson, 2003) with isograds modified from original maps, locations of samples discussed in the text, areas mapped in detail. Note that the oval geometry of the newly mapped kyanite-out isograd north of Mudcreek results from the intersection of the subhorizontal isogradic surface with the topography. Top-right inset: shows the morphogeologic belts of the Canadian Cordillera (modified from Monger et al., 1982). Bottom-right inset shows cross-section of area interpreted as a folded coherent body (modified from Murphy, 2007). The trace of the new shear zone proposed herein is parallel to the kyanite-out isograd from Blue River to the eastern limit of the mapped area in the vicinity of sample FG8-47.