Chemical Geology 384 (2014) 120–134

Contents lists available at ScienceDirect

Chemical Geology

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

Geochemical variation of amphiboles in A-type granites as an indicator of complex magmatic systems: Wentworth pluton, Nova Scotia, Canada

Angeliki Papoutsa [a,*], Georgia Pe-Piper [b]

[a] Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada
[b] Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada

ARTICLE INFO

Article history:
Received 22 July 2013
Received in revised form 22 May 2014
Accepted 4 July 2014
Available online 12 July 2014

Editor: L. Reisberg

Keywords:
A-type granite
Amphibole
Coeval magmas
Geochemistry

ABSTRACT

The Wentworth pluton is the most complex intrusion among a series of A-type granitic plutons, emplaced along an active shear zone in the Cobequid Highlands of Nova Scotia during the latest Devonian–earliest Carboniferous. This pluton consists of A-type granites of different generations and a large gabbroic body. Among all late Paleozoic plutons in the Cobequid Highlands, only the Wentworth granites contain both primary calcic (edenite, hornblende) and sodic amphiboles (arfvedsonite). Whole-rock, and mineral chemical data were examined along with estimated magmatic parameters, such as temperature, emplacement pressure, oxygen fugacity and volatile contents, in order to understand the geological factors responsible for this mineralogical variation. The granites with calcic amphiboles show systematically lower ε_{Nd} values, magmatic temperatures, and F-in-melt contents and appear geochemically less evolved, compared to the granites with the sodic amphiboles. All granites, however, appear geochemically homogeneous with limited evidence of fractionation. Specific chemical differences between these two types of granites indicate the presence of two coeval but distinct granitic systems in the Wentworth pluton. The granites with the calcic amphiboles were formed from a geochemically less evolved, hydrous, relatively calcic melt, whereas the granites with sodic amphiboles were emplaced at structurally deeper levels and were derived from a relatively drier sodic melt, which had a larger mantle component and was enriched in fluorine. Coexistence of these two magmas is indicated by the presence of interstitial sodic–calcic amphiboles in a late granitic dyke. This study provides evidence that in A-type granites, where fractional crystallization is limited, extreme variation in the type of amphibole can be the result of a very complex magmatic history.

1. Introduction

Amphiboles are the major ferromagnesian phase in many igneous rocks. In A-type granites, the presence of amphiboles not only indicates derivation from hydrous melts but also is considered to play an important role in the geochemical evolution of the parent magma (Martin, 2007). Compositional variation of amphiboles has been observed in felsic rocks and has been interpreted as the result of either magmatic crystallization or oxidative re-equilibration (Strong and Taylor, 1984). In peralkaline rocks, in particular, the magmatic trend of amphiboles is represented by a continuous change from barroisite through richterite to arfvedsonite, whereas the post-solidus oxidative trend is from actinolite towards riebeckite (Table 1).

Even though sodic amphiboles appear to be the dominant ferromagnesian minerals in many A-type granites (Wang et al., 2001; Schmitt et al., 2002; Ogunleye et al., 2005; Kynicky et al., 2011), calcic amphiboles are also present in several A-type granites (Han et al., 1996; Dall'Agnol et al., 1999; Wu et al., 2002). The presence of both sodic and calcic amphiboles in A-type granites, in the same area, has been reported in the literature (Han et al., 1996; Wu et al., 2002). In most cases the sodic amphiboles are found either in different plutons than the calcic amphiboles and belong to different ages and tectonic regimes or they are found in the same intrusion as the result of fractionation of the calcic-amphibole-bearing syenites (Han et al., 1996; Gualda and Vlach, 2007).

The Wentworth pluton in the Cobequid Highlands, in mainland Nova Scotia, belongs to a series of plutonic bodies, which were emplaced along an active shear zone in the late Paleozoic (Pe-Piper and Piper, 2002). All late Paleozoic granites of the Cobequid Highlands have A-type affinities and similar chemical composition of major oxides. The Wentworth pluton, however, is the only composite intrusion hosting both primary sodic and calcic amphiboles in different granitic bodies within the pluton (Pe-Piper, 2007). Previous mapping (Koukouvelas et al., 2002) showed that coeval sodic amphibole-bearing and calcic amphibole-bearing granites do not show a systematic distribution within the pluton.

Contrasting types of granites have been described in the literature for alkaline provinces. Gualda and Vlach (2007) reported the two mineralogically different, alkaline and aluminous associations of the felsic rocks in the Graciosa Province in Brazil. In the alkaline association, calcic amphibole occurs only in the alkali-feldspar and alkali-feldspar quartz syenites, whereas peralkaline alkali-feldspar granites present a wide

* Corresponding author. Tel.: +1 902 449 4907.
E-mail address: angeliki_papoutsa@hotmail.com (A. Papoutsa).

http://dx.doi.org/10.1016/j.chemgeo.2014.07.001
0009-2541/© 2014 Elsevier B.V. All rights reserved.

Table 1
Ideal chemical formulae of the types of amphibole mentioned in this work.

Amphibole mineral name	Type	Chemical formula
Ferro-edenite	Calcic	$NaCa_2Fe^{2+}{}_5Si_7AlO_{22}(OH)_2$
Ferrohornblende	Calcic	$\square Ca_2(Fe^{2+}{}_4(Al,Fe^{3+}))Si_7AlO_{22}(OH)_2$
Magnesiohornblende	Calcic	$\square Ca_2(Mg_4(Al,Fe^{3+}))Si_7AlO_{22}(OH)_2$
Ferro-actinolite	Calcic	$\square Ca_2Fe^{2+}{}_5Si_8AlO_{22}(OH)_2$
Actinolite	Calcic	$\square Ca_2(Mg,Fe^{2+})_5Si_8AlO_{22}(OH)_2$
Richterite	Sodic–calcic	$Na(Ca,Na)Mg_5Si_8O_{22}(OH)_2$
Ferro-richterite	Sodic–calcic	$Na(Ca,Na)Fe^{2+}{}_5Si_8O_{22}(OH)_2$
Ferro-winchite	Sodic–calcic	$\square(Ca,Na)Fe^{2+}{}_4(Al,Fe^{3+})Si_8O_{22}(OH)_2$
Katophorite	Sodic–calcic	$Na(Ca,Na)Fe^{2+}{}_4(Al,Fe^{3+})Si_7AlO_{22}(OH)_2$
Barroisite	Sodic–calcic	$\square(Ca,Na)Mg_3AlFe^{3+}Si_7AlO_{22}(OH)_2$
Arfvedsonite	Sodic	$NaNa_2(Fe^{2+}{}_4Fe^{3+})Si_8O_{22}(OH)_2$
Ferro-eckermannite	Sodic	$NaNa_2(Fe^{2+}{}_4Al)Si_8O_{22}(OH)_2$
Riebeckite	Sodic	$\square Na_2(Fe^{2+}{}_3Fe^{3+})Si_8O_{22}(OH)_2$

Notes: □ = vacancy in crystalographic site.

range of amphibole compositions, from sodic–calcic to sodic, and are related to the syenites through magmatic differentiation. The aluminous petrographic association contains metaluminous biotite granites with only calcic amphiboles in the less evolved varieties and with a narrow compositional range, suggesting contrasting sources between the two associations.

The amphiboles of the Wentworth pluton were studied by Pe-Piper (2007). The magmatic amphiboles include arfvedsonite (sodic) and edenite (calcic), whereas secondary amphiboles are represented by riebeckite (sodic) and actinolite (calcic). Even though there is a compositional variation in the amphiboles of this pluton, these minerals are not zoned. The lack of zoning was considered as evidence of limited fractionation of the parental magma (Pe-Piper, 2007).

It is not clear why the Wentworth granites present such an extreme chemical variation of magmatic amphiboles, in a pluton with limited evidence of magmatic differentiation. Several factors can control the type of amphibole that will form, such as the composition of the magma, oxygen fugacity, temperature, pressure and the presence of volatiles (Martin, 2007). The purpose of this study is to examine and evaluate the role of each of these factors on the composition of the amphiboles present, and thereby provide an insight to the geological history of this distinct and complex magmatic system.

1.1. Regional geology

The late Paleozoic Cobequid Highlands provide a record of a large scale, alkaline magmatic event, which is spatially associated with strike-slip motion on the main faults of the synchronous Cobequid Shear Zone (Pe-Piper and Piper, 2002). Underplating of mafic melts beneath the Magdalen Basin during the late Paleozoic has been inferred

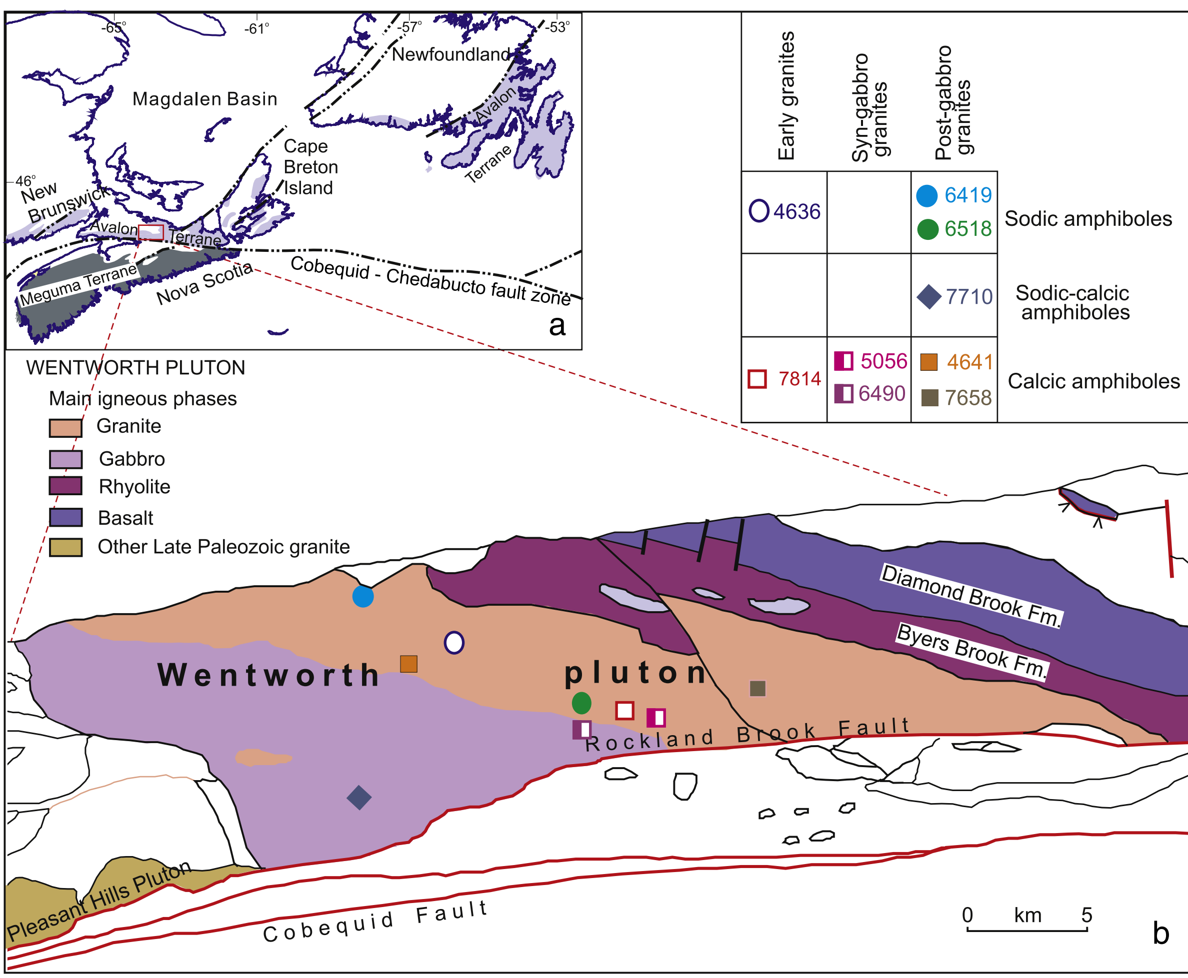

Fig. 1. Simplified maps (a) of eastern Canada showing the location of the Avalon and Meguma terranes and the Cobequid–Chedubucto fault zone and (b) the distribution of igneous phases and sample locations in the Wentworth Pluton. Open symbols represent early granites, half-filled symbols are used for syn-gabbro granites, and post-gabbro granites are shown in filled symbols.
Modified from Koukouvelas et al. (2002).