Available online at www.sciencedirect.com

ScienceDirect

Geochimica et Cosmochimica Acta 70 (2006) 4977–4996

Geochimica

www.elsevier.com/locate/gca

Oxygen isotopic studies of the interaction between xenoliths and mafic magma, Voisey's Bay Intrusion, Labrador, Canada

J. Mariga, E.M. Ripley *, C. Li

Department of Geological Sciences, Indiana University, Bloomington, IN 47405, USA

Received 6 December 2005; accepted in revised form 18 July 2006

Abstract

Sulfide mineralization in the Voisey's Bay Intrusion, Labrador, Canada, is closely associated with country rock xenoliths that have extensively reacted with basaltic magma. In order to better understand the processes that control the assimilation of country rocks by mafic magma, a detailed study of oxygen isotope systematics related to magma-country rock interaction in the Voisey's Bay area was undertaken. Protracted interaction of the xenoliths with magma produced refractory mineral assemblages in the xenoliths (2–10 cm in diameter) composed of Ca-rich plagioclase, corundum, hercynite, and minor magnetite. Overgrowth rims of plagioclase and biotite that surround most xenoliths separate the restites from the enclosing igneous matrix. The $\delta^{18}O$ values of minerals from regionally metamorphosed pelitic and quartzofeldspathic protoliths are: plagioclase (8.7–12.3‰), orthoclase (9.5–9.8‰), biotite (5.2–8.7‰), garnet (8.3–10.8‰), pyroxene (8.0–10.1‰), and quartz (9.6–14.0). The $\delta^{18}O$ values of minerals from the hornfels in the contact aureole of the intrusion are consistent with modeling which indicates that as a result of essentially closed system contact metamorphism oxygen isotope values should differ only slightly from those of the protoliths. Hercynite, plagioclase, and corundum separates from the xenoliths have $\delta^{18}O$ values that vary from 2.9‰ to 10.5‰, 5.6‰ to 10.9‰, and 2.0‰ to 6.8‰, respectively. Although a siliceous ^{18}O-enriched melt has been lost from the xenoliths, corundum, and feldspar $\delta^{18}O$ values are significantly lower than expected through melt loss alone. The relatively low $\delta^{18}O$ values of minerals from the xenoliths may be a function of incomplete isotopic exchange with surrounding mafic magma which had a $\delta^{18}O$ value of ~5.5‰ to 6.0‰. The high-^{18}O melt that was released from the xenoliths is partially recorded in the plagioclase overgrowth on the margin of the xenoliths ($\delta^{18}O$ values from 6.2‰ to 10.7‰), and in hercynite that replaced corundum. However, mass balance calculations indicate that a portion of the partial melt must have been transferred to magma that was moving through the conduit system. $\delta^{18}O$ and δD values of biotite surrounding the plagioclase overgrowth range from 5.0‰ to 6.2‰ and −58‰ to −80‰, respectively. These data suggest that the outermost rim associated with many xenoliths has closely approached isotopic equilibrium with uncontaminated mafic magma. The current gabbroic to troctolitic matrix of the xenoliths shows no evidence for contamination by the high-^{18}O partial melt from the xenoliths. The feldspar and biotite overgrowths on the xenoliths that formed after the motion of the xenoliths relative to the magma had stopped prevented further isotopic exchange between the xenoliths and final magma. The minerals within the xenoliths are not in oxygen isotopic equilibrium with each other, due in part to rapid thermal equilibration, partial melting, and partial exchange with flow through magma.

1. Introduction

The interaction of mantle-derived mafic magmas with crustal country rocks is a process that may be essential for the generation of many world-class Cu–Ni–PGE deposits (e.g., Naldrett, 1999). Previous studies have provided evidence for the attainment of sulfide saturation as a result of the addition of crustal sulfur to magma (e.g., Grinenko, 1985; Ripley, 1999). The contamination of mafic magma with siliceous country rocks can also lead to a decrease in the solubility of sulfur in the magma, and trigger the formation of an immiscible sulfide liquid (Irvine, 1975; Li and Naldrett, 1993; Li and Ripley, 2005).

---

* Corresponding author. Fax: +1 812 855 7961.
E-mail address: ripley@indiana.edu (E.M. Ripley).

0016-7037/$ - see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1016/j.gca.2006.07.018

In the Voisey's Bay Ni–Cu–Co deposit in Labrador, Canada, abundant xenoliths of country rocks are found in close association with sulfide mineralization, and provide petrological evidence for the link between magma contamination and ore formation. Xenoliths can often be utilized to evaluate the poorly understood mechanisms of mass transfer between magmas and country rock. In dynamic magma conduit systems, where large amounts of magma may have passed through the conduit-magma chamber network, little or no evidence of the assimilation process may remain in the igneous rock. For this reason an understanding of the evolution of the country rock xenoliths is essential.

Because of the large differences that may exist between the oxygen isotopic compositions of metasedimentary rock types and mafic magma, oxygen isotopic values can be sensitive indicators of magma contamination. At the Voisey's Bay deposit, earlier studies of the intrusive rocks showed little or no oxygen isotopic evidence of contamination, even though the xenoliths are in many cases refractory and suggest a prolonged history of interaction with magma (Ripley et al., 1999, 2000). As part of a detailed investigation of contamination processes that occurred in the Voisey's Bay Intrusion, we initiated a study of the oxygen isotopic systematics of gneissic country rocks, contact hornfels, xenoliths, and igneous matrix surrounding the xenoliths. The objectives of this study were to quantify the oxygen isotopic fractionation that accompanied mineral transformations in the xenoliths and to utilize the isotopic variations to better understand the mechanisms of magma-country rock interaction. Hydrogen isotopic measurements of biotite were also undertaken to better evaluate the role of fluid in magma–xenolith interaction.

2. Geological background

2.1. Regional and local geology

The Voisey's Bay Ni–Cu–Co sulfide deposit is located in Northern Labrador, Canada, approximately 30 km southwest of the town of Nain (Fig. 1). Details of the geology of the Nain area have been given by several authors (e.g., Berg and Docka, 1983; Wardle, 1983; Lee, 1987; Wardle et al., 1990a,b; Ryan et al., 1995; Ryan, 2000; McFarlane et al., 2003). A brief description of regional and local geology is presented here. The Voisey's Bay deposit occurs near

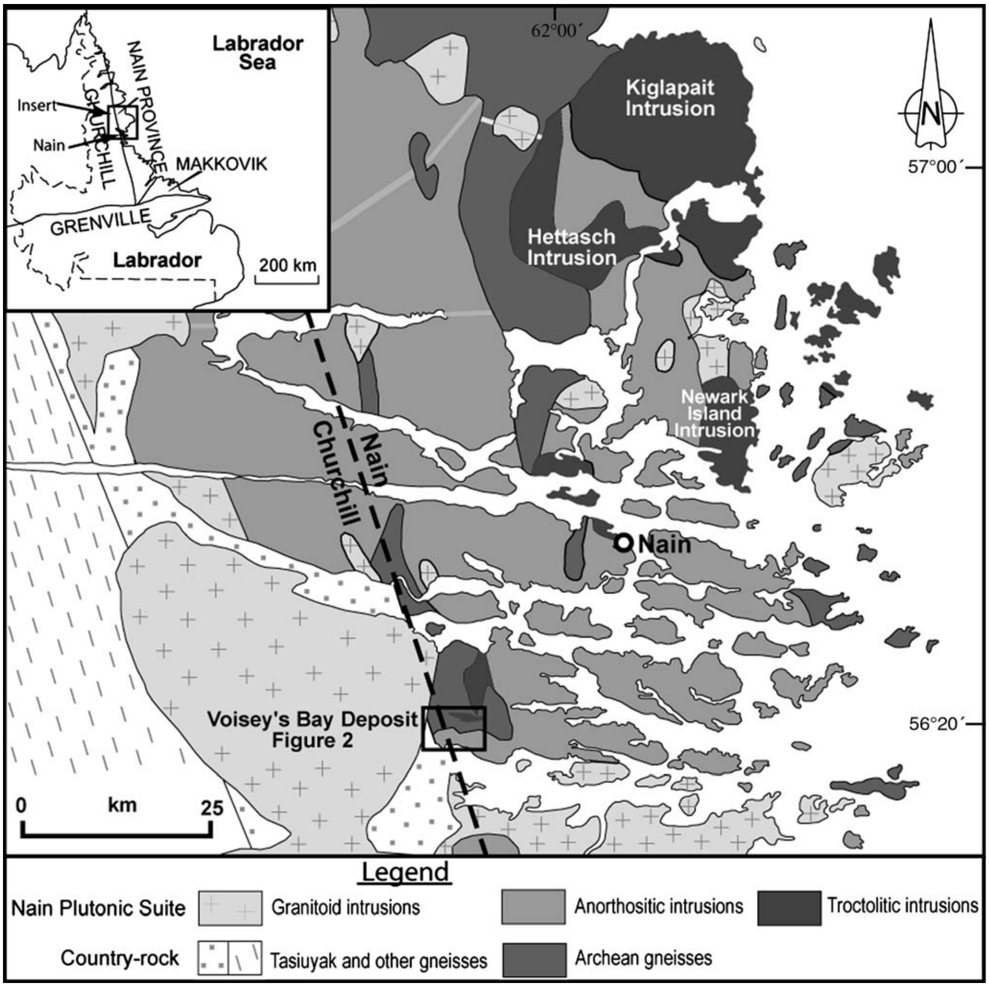

Fig. 1. Regional geology of the area around the Voisey's Bay deposit (adapted from Ryan et al., 1995).