Isotopic and chemical constraints on the crustal evolution and source signature of Ferrar magmas, north Victoria Land, Antarctica

Abstract Isotopic (Nd and Sr) and chemical compositions of the 177 Ma Kirkpatrick Basalt and Ferrar Dolerite from north Victoria Land, Antarctica, are examined in order to address the role of crustal assimilation and the characteristics of their mantle source. Results for the Scarab Peak chemical type (SPCT) that constitutes the flow unit capping the lava sequence (Mg-number = 24, MgO = 2.4%, SiO$_2$ = 57.1%, initial $\delta^{18}$O = 0.7087–0.7097, $\varepsilon_{Nd} = -4.3$) confirm previous reports that attribute variations in the concentrations of the more mobile elements and calculated initial $\delta^{18}$O to low-temperature interaction with meteoric water. The underlying lavas and the sills that are of the Mt. Fazio chemical type (MFCT) display a much wider range of both chemical and isotopic compositions (Mg-number = 40–65, MgO = 3.7–7.5%, SiO$_2$ = 52.6–58.3%, initial $\delta^{18}$O = 0.7087–0.7117, $\varepsilon_{Nd} = -5.6$ to $-4.8$). The effects of rock alteration on apparent initial $\delta^{18}$O are demonstrated by large differences between the initial ratio of mineral separates or leached fractions and whole rocks. Cretaceous alteration produced Rb and Sr redistribution within the lava sequence that results in erroneous calculated initial $\delta^{18}$O ratios. These effects are responsible for the large initial $\delta^{18}$O variations previously proposed which combined with the large range in whole-rock $\delta^{18}$O, were purported to show very large degrees of crustal assimilation. The variations in $\varepsilon_{Nd}$ are restricted and indicate much smaller degrees of assimilation. The least altered of the MFCT rocks show good chemical and isotopic correlations that can be integrated into a model involving fractionation of pyroxene and plagioclase coupled with assimilation of material similar to early Paleozoic basement. The lower $\delta^{18}$O and higher $\varepsilon_{Nd}$ of the SPCT suggest that they were derived by extensive fractionation of a more primitive, less contaminated, precursor of the MFCT. The most isotopically primitive Ferrar rocks from the region still have a high initial $\delta^{18}$O and low initial $\varepsilon_{Nd}$; this may reflect either earlier assimilation or an enriched source. The chemical and isotopic similarities, as well as the close geographic correspondence of the Ferrar Group to granitoids produced during the early Paleozoic Ross Orogeny suggest that in either case Ross-type material may have been involved in the development of the enriched isotopic signature.

Introduction

The compositions of continental basalts provide important constraints on the nature and history of their underlying mantle sources. However, to interpret the constraints it is essential to understand the processes by which magmas evolve and interact with the crust as well as the influence of different mantle and lithospheric reservoirs on composition. Indeed, considerable uncertainty surrounds the crustal history of magmas of the Ferrar Group of Antarctica (Fig. 1) which extends along the Transantarctic Mountains for > 3000 km with a minimum volume of > 5 × 10$^9$ km$^3$ (Kyle et al. 1981). This province represents a large volume of continental basaltic magma that differs significantly from most oceanic basalts, especially in enrichment of large-ion lithophile elements (LILE) relative to high-field-strength elements (HFSE) (e.g., Ba/Nb ~ 35, Ce/Pb ~ 4) and high initial $\delta^{18}$O ( > 0.708). Models explaining the anomalous compositions of the Ferrar Group have ranged widely, from large-scale crustal assimilation (e.g., Faure et al. 1974; Hoefs et al. 1980) to derivation almost entirely from an LILE-enriched...
The Ferrar Group consists of lavas (Kirkpatrick Basalt), sills (Ferrar Dolerite), a large mafic intrusion (Dufek Gabbro), and minor pyroclastics. Compston et al. (1968) demonstrated that Ferrar Dolerites in South Victoria Land had what were considered anomalous Sr isotopic and trace element compositions. Subsequently, Faure et al. (1974, 1982) showed that lavas in the Beardmore Glacier region also have elevated $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and found significant correlations between Sr isotopic and chemical compositions that were attributed to assimilation of continental crust by a mantle-derived magma having $^{87}\text{Sr}/^{86}\text{Sr}$ of about 0.704. Kyle (1980), on the other hand, attributed the isotopic and chemical compositions of the Ferrar Group to the mantle source and suggested that crustal assimilation played a much less significant role. The $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic variations were attributed mainly to alteration and analytical uncertainties whereas chemical variations were attributed primarily to fractional crystallization.

Hoefs et al. (1980) found that calculated initial $^{87}\text{Sr}/^{86}\text{Sr}$ correlated positively with $\delta^{18}\text{O}$ for basalts in the Beardmore Glacier region and modeled this for bulk assimilation. The correlation was extrapolated down to a “mantle” $\delta^{18}\text{O}$ value of $+5.5^{\circ}\text{c}$ to imply a $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of $\approx 0.710$ for the mantle source. A similar correlation between Sr and O isotopes was reported by Kyle et al. (1983) for basalts in south Victoria Land. These authors suggested, however, that the chemical variations require a more complex model than simple mixing and reiterated that the composition of the Ferrar Group reflects its mantle source, which may have been affected by subduction along the Pacific margin of Gondwana. Hergt et al. (1989a), in conjunction with a more detailed study of the related Tasmanian Dolerites (Hergt et al. 1989b), showed that the isotopic and trace element composition of Ferrar Dolerite could be explained by 3% subducted sediment added to a depleted mantle source. Brewer et al. (1992) also argued against significant crustal contamination affecting the composition of Ferrar magmas and inferred an origin involving partial melting of hydrous lithospheric mantle containing a subducted sediment component. Menzies and Kyle (1990) suggested that the enriched isotope composition may have had a deeper origin and formed as part of a global system of sediment recycling which is related to the southern hemisphere DUPAL anomaly.

The magmatic evolution of the basalts in north Victoria Land (NVL), where the present study is focused (Fig. 2), has received considerable attention. Mensing et al. (1984, 1991) found correlations between $\delta^{18}\text{O}$ and calculated initial $^{87}\text{Sr}/^{86}\text{Sr}$ and modeled these values for coupled assimilation and fractional crystallization (AFC) assuming a primary magma with

Fig. 1 Geologic sketch map of Antarctica showing the distribution of the Ferrar Group. The Kirkpatrick Basalts are found in the central Transantarctic Mountains (CTM Grosvenor Mountains, Queen Alexandra Range, south Victoria Land (SVL Carapuu Nunataks and Prince Albert Mountains) and north Victoria Land (NVL Mesa Range and Litell Rocks).