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Labrador massif anorthosites: Chasing the liquids and their sources

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Abstract

Bulk analyses of plagioclase megacrysts in massif anorthosites contain enough information on the 11 major element oxides of common igneous rocks to retrieve their complete parent magma compositions. The necessary partition coefficients for this inversion process are generated from a core-drilled trapped liquid and a pure anorthosite autolith in the Anorthosite–Norite–Troctolite (ANT) Nain Plutonic Suite (NPS) of Labrador. When applied to plagioclase megacrysts from five anorthositic intrusions in the NPS, the CIPW norms of the derived liquids correctly classify the parent liquids of dark plagioclase as olivine-normative and those of pale plagioclase as quartz-normative. Dark plagioclase megacrysts have higher An, lower K and some tetrahedral ferrous iron, compared to pale megacrysts. Experimental melts considered parental to the Lower Zone troctolites of the Kiglapait Layered Intrusion plot closely among the calculated olivine-normative liquids from the Nain anorthosites, lending further credibility to the inversions.

The coupled nature of silica activity and oxygen fugacity for these and other anorthosite magma types permits a classification of massif anorthosites from melatroctolite to andesine norite based on silication and redox state, with potential for quantitative treatment. This treatment may also scale with the degree of crustal contamination experienced by ponded anorthositic magmas.

Experimentally determined linear partitioning of plagioclase confirms a narrowing of the binary loop with high pressure, and allows retrieval of one unknown among pressure, temperature and liquid composition. These principles can be used for modeling the plagioclase component of liquids at their source, their intermediate storage sites, during ascent and at emplacement conditions.

Experiments on a model Kiglapait bulk composition at high pressure suggest the separation of magma at 11 kbar from a spinel harzburgite source, with crystallization of olivine on ascent to saturation with plagioclase. Ponding of such high-temperature liquids in the lower or middle crust allows assimilation and silication leading to the noritic trend. Felsic suspensions leaving mafic crystals behind can account for anorthosite intrusions at upper levels. Lithospheric extension permits uplift of mantle melting regions to shallower depths, not to be confused with crust, as inferred for the Central North American Rift. Crustal melting appears to be neither necessary nor viable as a source of ANT (perhaps excluding monzonite) magmas.

Origins and ideas: The array of anorthosite massifs in eastern North America is of a length scale equal to the volcanic Cameroon Line, which also has a heterogeneous distribution of ages on a very much shorter time scale. Precursor anorthosites far older than the commonly recognized Mesoproterozoic massifs must reflect a deep and revisited root cause of the anorthosite epoch, which may have begun near the time of origin of the Earth's inner core. A tectonically related superplume origin of massif anorthosite magmatism is appealing and has some credibility in paleogeographic reconstructions of Laurentia. It can also explain the apparent Al–Fe-rich nature of the ANT mantle source. The Mg#–An trends of two vastly different layered mafic intrusions, Bushveld and Kiglapait, are uncannily parallel, suggesting a fundamental, scale-independent, physicochemical behavior of large magma systems.

Keywords: Anorthosite; Magmas; Source rocks; Origins; Partitioning; Major elements

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1. Introduction

Like its precursor abstract (Morse, 2004), this paper is a mixture of an outrageous numerical experiment, developed in some detail, and a potpurri of comments on matters pertinent to the origin of massif anorthosites. Some of these matters are new laboratory experiments, both recently published and in progress, and others are scrounged from the geophysical literature of the day in an effort to bring together tectonic, seismic and geochemical news possibly bearing on the origins of massif anorthosites.

I write origins, plural, above, for I am persuaded that the massif anorthosites of northern Labrador, including more than two dozen identified layered mafic intrusions near Nain (e.g., Berg et al., 1994) and farther inland, bear only passing resemblance to the more Na,K-rich bodies in the Grenville Province to the south so ably described and differentiated by Robert Dymek (2004). Nevertheless, there are sure to be many issues in common as to their ultimate origin and age distribution. As to these deeper roots of cause and source, it is perhaps helpful to view the ~ 1.2 Ga epoch of massif anorthosites in the context of an evolving Earth and to wonder whether such matters as the evolution of continental lithosphere and the birth of the Earth's inner core should claim our attention, as I suspect they should. It is these larger matters that occupy the final parts of this paper.

The paper proceeds in five parts after this one, beginning with the numerical experiment (Section 2), continuing through (Section 3) a silica-redox classification of anorthosites, (Section 4) melting experiments and theory of binary solutions, through high-pressure experiments (Section 5) relevant to the source regions of troctolitic magmas, to (Sections 6.1–6.5) matters of scale and lithospheric extension, convective partial melting, the bizarre discoveries of ancient precursors among familiar younger anorthosites, the difficulties that such time gaps present to our concepts of anorthosite generation, and then on to some arm-waving about superplumes, the geoid, the paleogeographic history of Laurentia, the inner core and the uncanny resemblance of some aspects of Laurentia to the Kaapvaal craton of southern Africa.

2. Plagioclase gets the liquid

2.1. Introduction

Two suites of petrographically and geographically distinct anorthositic rocks occur in the Nain Plutonic Suite of Labrador (NPS; Ryan, 1990; Berg et al., 1994). Rocks of the western region (Fig. 1) are largely noritic (*hy*- or *q*-normative), whereas in the eastern region they have a troctolitic (*ol*-normative) heritage even if the more differentiated rock type is noritic (Xue and Morse, 1993, 1994). These classifications are general and not exclusive; there may be some western troctolites, and some eastern norites may lack an olivine heritage. The generalized boundary between the two classes is shown as an "Olivine Line" in Fig. 1. This classification is also approximately the geographic boundary between the dark and pale facies of anorthosite as defined by Wheeler (1960). Wheeler noted that the darker feldspars were commonly associated with olivine-bearing anorthosites and that the paler ones were noritic, with hypersthene as the major mafic silicate. The whole-rock geochemical studies of five plutons in the NPS by Xue and Morse (1993) also showed these characteristics. The color of the plagioclase is a function of the abundance of opaque inclusions, primarily of Fe–Ti oxide minerals.

2.2. Plagioclase color and chemistry

The plagioclase feldspars of massif anorthosites, and in particular the large megacrysts among them, contain, in measurable quantity, all 11 of the usual components of igneous rocks. They even contain significant amounts of Ti, ferric and ferrous iron, Mn, Mg and P. Morse and Xue (1992), in an unusual and provocative result, showed that the chemical composition of plagioclase itself carries all the information needed to classify the parent liquids of the two facies or classes of NPS anorthosite. This distinction is also evident in the compositions of the plagioclase megacrysts alone (Fig. 2), which range systematically from low-K, high-An, darker-colored varieties to low-An, high-K, paler-colored varieties. At least five other chemical indicators also discriminate between these petrographic and color varieties (Xue and Morse, 1994). These chemical characteristics bear out the importance of Wheeler's (1960) classification of these anorthosites into dark and pale facies.

Here I show how the chemical distinction is successfully translated into the complete, major-element, parent magma compositions obtained by inversion. The parent liquids are correctly classified according to their normative silica saturation and redox state. Although the demonstration is local and limited in the number of examples, it does serve to make such an exercise an important target of further research.

The overriding reason for any success at all in this enterprise is the availability of highly precise *bulk*