EVOLUTION OF MINETTE, LAMPROITE AND MAFIC PHONOLITE MAGMAS IN THE HIGHWOOD MOUNTAINS PROVINCE, MONTANA, U.S.A.: GEOCHEMICAL AND MINERALOGICAL EVIDENCE

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INTRODUCTION

Potassic mafic volcanic and intrusive rocks of the Eocene Highwood Mountains province of north-central Montana show mineralogical, textural and chemical evidence for multiple episodes of fractional crystallization and mixing of minette and mafic phonolite magmas at low pressures. Phenocryst compositions and bulk rock REE abundances of the most primitive mafic minette magmas are consistent with their derivation by partial melting of a phlogopite-bearing garnet peridotite mantle. Despite the distinctly different phenocryst assemblages of the minettes and mafic phonolites, the bulk compositions of these two groups of rocks overlap significantly (Figure 1). The mineralogical differences evidently result from differences in volatile fugacities during crystallization, implying that low pressure degassing was important.

ROCK TYPES

The Highwood province consists of an older series of quartz-normative latite flows and dikes and a younger series of K-rich, silica-undersaturated minette and mafic phonolite flows, dikes and sills and rare lamproitic dikes. Shonkinite, the phaneritic equivalent of mafic phonolite, forms four major stocks, and fine grained phaneritic equivalents of the minettes occur in several smaller intrusive bodies. The hiatal porphyritic minettes contain phenocrysts of diopside ($\underline{mg}$ = 92, Al_2O_3 = 1 wt. %) + phlogopite ($\underline{mg}$ = 92) ± Mg-rich olivine (Fo_{89-92}) in a sanidine + biotite + salite + oxide groundmass. The seriate porphyritic mafic phonolites contain salite ($\underline{mg}$ = 76, Al_2O_3 = 4 wt. %) + pseudoleucite + olivine (Fo_{77-60}) phenocrysts in a salite + sanidine + oxide ± biotite ± nepheline ± glass matrix. The rare lamproitic rocks contain phenocrysts of phlogopite + diopside + leucite + olivine (now pseudomorphed by talc + serpentine) in a leucite + sanidine + mica + clinopyroxene + oxide matrix, and appear to form a mineralogical link between the minettes and the mafic phonolites. Cumulate xenoliths are common in all magma types, but mantle xenoliths are apparently absent.

GEOCHEMISTRY

Neither major nor trace element abundances serve to discriminate mafic phonolites from minettes. However, the most primitive minettes have slightly higher MgO contents than the corresponding mafic phonolites whereas the latter show slightly more evolved compositions (Figure 1A). The lamproitic dike is chemically indistinguishable from the primitive minettes. The syenite trend (Figure 1A) could be the product of biotite pyroxenite fractionation from primitive mafic phonolite magma, which is consistent with the large bodies of pyroxenite mapped in the field. This figure also shows two trends that converge at MgO $\sim$ 11.5 wt. %. Samples plotting on the higher CaO branch represent shonkinites enriched in salite + biotite. The lower CaO branch may represent an olivine control trend. However, even the two most magnesian Highwood samples (missourites) plot on the well defined Sc-CaO curve demonstrating the importance of clinopyroxene fractionation (Figure 1F). Na_2O is incompatible and increases with fractionation (Figure 1B) while K_2O remains essentially constant across a wide range of MgO values (Figure 1C) except for the syenites and trachytes in which sanidine is an important early phase. Ba-Ni plots (Figure 1D) show the same trends suggesting that a K,Ba-rich phase crystallized throughout the fractionation sequence. BaO increases from $\sim$ 0.5 wt. % in phlogopites from primitive minettes to $\sim$ 4.0 wt. % in biotite from more evolved shonkinites suggesting that mica + cpx fractionation was responsible for maintaining a bulk D_{Ba} value of $\sim$ 1.0. Figure 1E is also consistent with cpx + mica fractionation if the genetically unrelated syenites of Highwood Baldy and the latites are excluded. The presence of plagioclase phenocrysts in these latter rocks suggests they were derived from a distinctly different source region, possibly within the lower crust.

ROLE OF FLUIDS

Early crystallization of F-poor phlogopite and evidence of explosive eruption indicate that a fluid phase (H_2O- and CO_2-rich) played an important role in the petrogenesis of the minettes and lamproitic rocks. However, microphenocrysts of salite and F-rich biotite in minette that crystallized subsequent to dike emplacement and degassing, have the same composition as the salite phenocrysts and interstitial biotite in mafic phonolite. This indicates that conditions during the later stages of minette crystallization were similar to those during mafic phonolite crystallization, i.e., mafic phonolites are essentially outgassed equivalents of minettes.

MAGMA MIXING

The majority of the evolved mafic phonolites and evolved minettes contain mixed phenocryst assemblages which are consistent with periodic mixing between these two magma types. Colorless diopside occurs in the mafic phonolites as separate subhedral xenocrysts, as euhedral to subhedral cores in green salite and as continuous growth bands 20-100 µm wide within salite. Many mafic phonolites also contain rounded, resorbed phlogopite and/or large ($\sim$ 1 cm), rounded zoned olivine xenocrysts with Mg-rich ($Fo_{>87}$) cores. The more evolved minettes contain complexly zoned clinopyroxene, salite and olivine ($Fo_{<77}$) xenocrysts, and resorbed phlogopite rimmed by Ti, Ba-rich biotite. It is possible that mixing of the two major magma types may have initiated eruption of the Highwood volcanics. The presence of diopside and phlogopite xenocrysts in mafic phonolite flows and tuffs is consistent with injection and mixing of a pulse of fluid-rich minette magma into the subvolcanic mafic phonolite magma system causing degassing and triggering explosive eruptions. The rarity of minette flows is consistent with such a model.

CONSTRAINTS ON MANTLE SOURCES

The primitive minettes show marked light REE enrichment (Figure 2), and have relatively high contents of Ba (2000-5000 ppm), Sr (850-1200 ppm), Ni (250-330 ppm) and Cr (500-725 ppm). These features are consistent with residual garnet, mica and clinopyroxene in the source. Furthermore, the compositions of olivine, diopside and phlogopite phenocrysts in the most primitive minettes are very similar to those in phlogopite-garnet lherzolite xenoliths in minettes from The Thumb, NM (Ehrenberg, 1982). Thus, we suggest that the Highwood parental minette magmas were derived by small degrees of partial melting of phlogopite-bearing garnet peridotite mantle.

References

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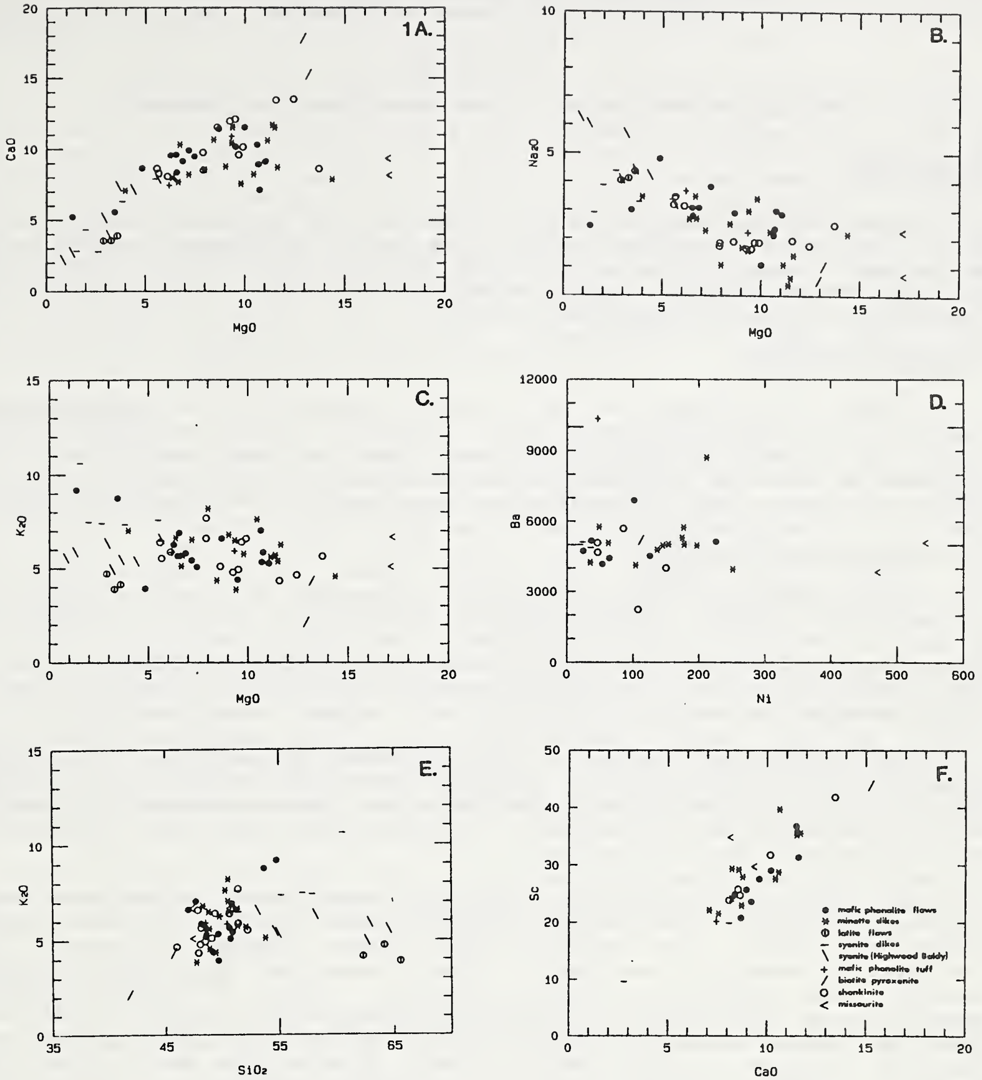

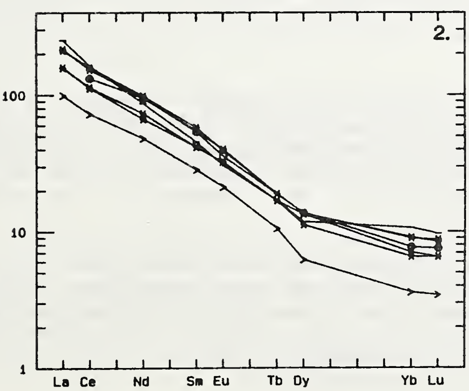

Fig. 1. (A-E) Variation diagrams for selected Highwood whole-rock samples. Compositions determined by ICP emission spectroscopy. Key to symbols for all figures given in 1F.

Fig. 2. Chondrite-normalized REE abundances for 7 Highwood samples (data for one mafic phonolite from Schnetzler & Philpotts, 1970).