Metamorphic xenoliths in the Vinalhaven pluton, Vinalhaven Island, Maine

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INTRODUCTION

Vinalhaven Island (fig 1) is underlain by rocks that are part of the Coastal Maine Magmatic Province (CMMP), a suite of plutons grouped along the southeastern coast of Maine. Vinalhaven Island represents the southernmost exposure of the CMMP and is situated in Penobscot Bay. As shown in figure 1, the Vinalhaven Pluton is exposed over a 5-6 Km^2 area. It is bimodal in composition, combining granite with slightly less gabbro. Intrusive basalt that was chilled against the granite comprises the remaining igneous portion of the pluton. Chemical mixing is limited between the granite and gabbro, although a distinct hybridized lithology occurs locally (Mitchell & Rhodes, 1989). Both metamorphic and volcanic rocks are host to the pluton. Xenoliths from the metamorphic host are present in the Vinalhaven Pluton and presumably detached during intrusion.

This study examines the relationship of the pluton to these xenoliths. This examination leads to a depth of emplacement for the Vinalhaven pluton that is in keeping with the model being developed by R.A. Wiebe and others as part of this KECK undergraduate research project.

Geology of the CMMP

The CMMP spans the northern coast of Maine, from Penobscot bay at the southern end, to Passamaquoddy Bay, between Maine and Nova Scotia (Hogan & Sinha, 1989). The province contains over 100 bimodal plutons (Hogan & Sinha, 1989).

Fundamental to the CMMP is the recurring theme of bimodal magmatism. Most of the plutons in the province have granite and gabbro in a bimodal, commingling relationship (Seaman et al., 1995; West et al., 1992; Wiebe, 1993). As the CMMP is generally bimodal, rifting has been suggested as a mechanism for emplacement (Seaman et al., 1995). Further conclusive data, such as an accurate depth of emplacement, are needed to reinforce this hypothesis.

METHODS

Xenolith outcrops occur around the coast of the island as shown on figure 1. Sample locations illustrate availability of exposure, which is limited to coastal locations. Presumably, similar exposure is present throughout the island, but dense growth and population cover most of the island.

Seventy-four samples were collected from the 13 Vinalhaven xenoliths and from four xenoliths on Green's island (fig 1). Each xenolith was described in the field, and thin sections were made for petrographic analysis of the samples. From these data, 11 sections were chosen for quantitative mineral chemistry analysis with a Zeiss Digital Scanning Microscope with attached Link Energy Dispersive Spectrometer.

LITHOLOGICAL DESCRIPTION

Field Observations

The Vinalhaven xenoliths are exposed in areas varying from approximately three to 100 square meters. To most accurately determine the conditions of equilibrium associated with contact metamorphism, specific sample locations are in areas of contact with the surrounding granite or gabbro.

Three types of xenoliths are present within the pluton: a massive, gneissic plagioclase biotite quartzite; an amphibole-bearing calc-silicate; and a layered rock (fig 2). Each sample of the layered rock type is divided into two mineral assemblages. These assemblages are contained in dark and light areas, hereafter known as the melanosome and leucosome, respectively. This layered rock type will be the focus of this study; the quartzite and calc-silicate will not be discussed further.

The layering defined by the melanosome and leucosome is regularly spaced, from mm to cm scale (fig 2). The leucosome typically forms discreet white pods. These pods range from 2-10 cm in length. The melanosome comprises the remaining portion of the rock and surrounds the leucosome pods. It is typically dark brown and has visible biotite.

Petrography

Although both the leucosome and melanosome contain alkali and plagioclase feldspar, the assemblages in these units are different.

The melanosome contains the assemblage cordierite + plagioclase feldspar + andalusite + spinel +/- corundum +/- perthitic alkali feldspar (present in one sample). Biotite is randomly oriented throughout the melanosome. The melanosome contains no quartz. The leucosome typically consists of quartz and alkali feldspar with minimal clumped muscovite and is commonly separated from the melanosome by a biotite selvage. Garnet occurs in the leucosome assemblage at three localities.

The leucosome has an isotropic fabric and accounts for nearly 30% of the volume of each sample. Subequal amounts of undeformed quartz and non-perthitic alkali feldspar represent the majority of the leucosome. Quartz and alkali feldspar are typically equant and 1-2 mm in diameter. As the leucosome is commonly under 1 cm thick, these grains dominate the section. Between the quartz and alkali feldspar, twinned plagioclase is also present with minor quantities muscovite. Muscovite in these samples does not have a preferred orientation. Cummingtonite occurs in two samples of the leucosome. The cummingtonite is in the same habit as biotite and coexists with the biotite in the selvage of these samples.

Garnet in the leucosome is nearly euhedral and ranges in diameter from less than 1 mm to 1 cm. Various minerals are in contact with the rim of the garnet, these minerals are normally cryptocrystalline. The garnets are nearly free of inclusions, where there are inclusions, they appear to be biotite +/- plagioclase feldspar. Garnet has not been found in melanosome assemblages.

Melanosomes are differentiated on the basis of mineral content. Each melanosome has a cordierite matrix that accounts for a large percentage by volume. Cordierite in every sample has well developed, yellow pleochroic halos. The remaining minerals in this assemblage appear as inclusions in larger cordierite grains.

The weak melanosome fabric is defined by clumping of andalusite, spinel and biotite in roughly parallel layers. Each layer is dominated by one of these three minerals. Plagioclase feldspar is interspersed throughout the cordierite matrix and represents nearly 15% of the melanosome. Minerals in the melanosome, excepting cordierite, are subhedral granular and typically less than 1mm in diameter.

Reaction textures occur throughout the melanosome. Spinel commonly rims corundum where the latter is surrounded by cordierite, although in other areas of the same sections, the two appear stable. Cordierite in one sample has a distinctive crossed shape, similar to that of staurolite. These shapes may be pseudomorphs of staurolite, although staurolite is not present in any sample.

Interpretation of these data yields two important observations. (1) Despite possible minor changes in bulk composition, the assemblage of minerals does not vary significantly in either the melanosome or the leucosome throughout the map area. Lack of variation of assemblages suggests that perhaps each of these xenoliths equilibrated at the same pressure and temperature, and therefore the same depth within the magma chamber. (2) The pressure of equilibrium must be below 2 kbar. The stability field of andalusite combined with the stability of the assemblage cordierite + andalusite suggests that these minerals equilibrated at pressures below 2 Kbar. Above pressures of 2 Kbar, this assemblage is unstable and is replaced by garnet and cordierite (Spear et al., 1999).

Chemistry

Melanosome chemistry is dominated by cordierite, which has an XFe (Fe/(Fe+Mg)) of 43-60%. These values are similar both within and between samples. Plagioclase is not significantly zoned (fig 3) and has an An content ranging from 15-35% between samples. Other melanosome minerals include spinel (near pure hercynite) XFe 93-99% and biotite XFe 60-66%.

Leucosomes contain some of the same minerals, but with a different composition: biotite has a slightly lower XFe (56-64%) and plagioclase is present as Albite (ranging in these samples from An 0-0.9).

Where present in the leucosome, cummingtonite ranges in XFe from 36-38%. The XFe content of garnets in the leucosome range from 83-92%. The garnet is slightly zoned in Fe and Mg within 20 µM of the rim (fig 4).

PETROGENESIS

The origin of the leucosome remains to be determined. Leucosomes may be the result of granitic injection from the pluton or partial melting caused by dehydration reactions or injection of water released by the cooling granite. These assemblages appear to have formed by partial melting. Evidence for this includes the under-saturation of silica in melanosome assemblages (Porter, 1999), and the textural interpretation of the banding of leucosome and melanosome layers. The presence of a biotite selvage may suggest a melting event (Spear et al., 1999), although other interpretations of the selvage are possible, such as an instability between two Na + K bearing minerals.

GEOTHERMOBAROMETRY

Mineral compositions were used in the program GTB (Kohn & Spear, 2001) to obtain equilibrium pressures and temperatures from garnet bearing assemblages. Various assemblages were used to calculate pressures and the garnet-biotite assemblage was used to calculate temperatures.

SUMMARY

Xenoliths found on Vinalhaven and its surrounding islands provide the bulk of available information about contact metamorphism from the pluton. Geothermobaromerty data from garnet assemblages have shown an anticipated temperature of 750˚C and unexpected pressures exceeding 4 Kbar. These pressures are not consistent with the melanosome assemblage. It is possible that the garnets did not react when in contact with the magma, but are rather precursors to this metamorphism, but if so, why did they not react? Interpretation of the garnet reaction history is a primary goal of this study.

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Figure 1: Geologic Map of Vinalhaven Island, Maine

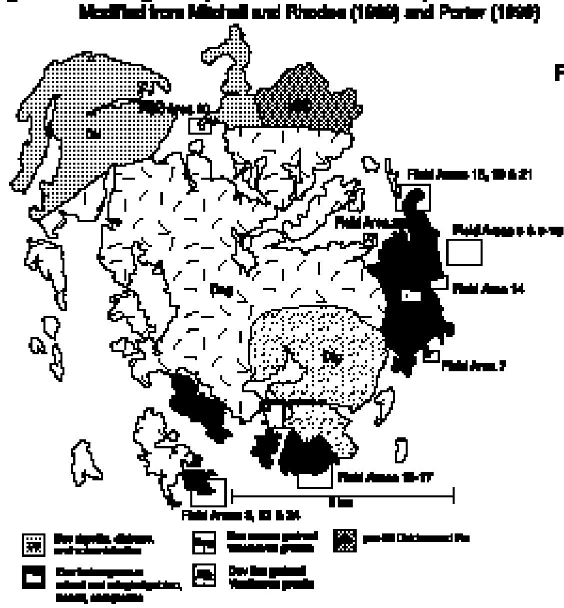


Figure 2: Typical leucosome-melanosome relationship

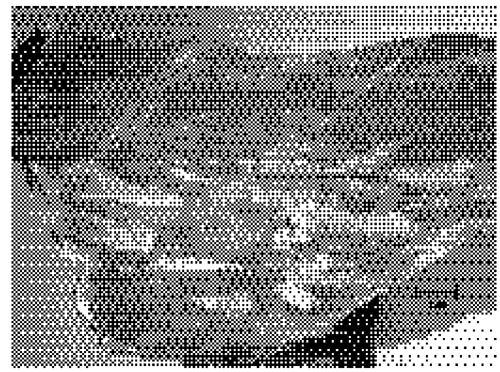


Figure 3: Garnet Diffusion Profile, Rim to Core

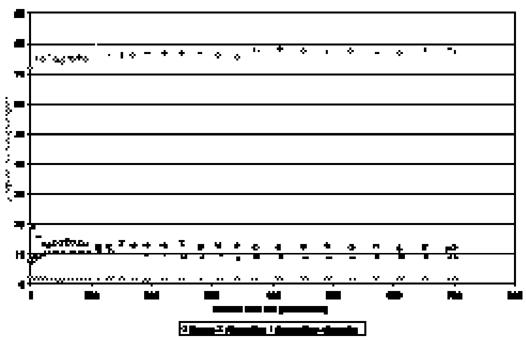
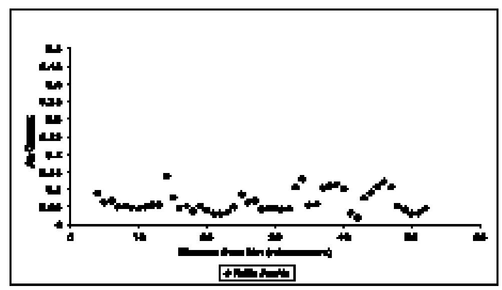


Figure 4: Plagioclase Zonation Profile, Rim to Core



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