Metamorphic History of Archean Ultramafic Pods in the Tobacco Root Mountains, Southwestern Montana

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INTRODUCTION

Pods of metamorphosed ultramafic rocks are scattered throughout the Tobacco Root Mountains of Montana and are found in all three of the metamorphic suites that comprise the Archean part of the range (the Spuhler Peak, Indian Creek, and Pony Middle Mountain). This study focused on sampling these isolated pods of ultramafic rocks and determining the metamorphic history of these rocks on the basis of their mineralogy and texture. In general, the Archean rocks of the Tobacco Root Mountains have been through at least two metamorphic events: a high pressure event, which was later overprinted by an amphibolite facies event. The mineral assemblages of most of the Archean rocks are consistent with the upper amphibolite facies, which reached pressures of 5-7 kb and temperatures of 650-700°C (Burger and others, 1996).

FIELD RELATIONS

During August, 1995, the author mapped and collected samples from ultramafic pods in each of the three metamorphic suites. The pods ranged from a couple of meters across to tens of meters across. The variation in size was independent of the location of the pod, though the largest were found near the contact between the Spuhler Peak Metamorphic Suite and the Indian Creek Metamorphic Suite.

The pods in the Spuhler Peak Metamorphic Suite are well exposed in the walls of glacial cirques, where they are generally in contact with felsic gneisses and amphibolites. The few contacts that were found showed that the ultramafic pods cross-cut the foliation in the gneiss and amphibolite. These ultramafic rocks generally contain amphibole crystals at least a centimeter long and a millimeter wide that weather green and silver. Some of these rocks also contain large pyroxenes, which form knobs up to 5 cm in diameter on the surface of the outcrop. These outcrops are not foliated, though some show a foliated blackwall, which is the reaction surface between the ultramafic pod and the surrounding unit. Such foliations tend to be parallel to the contact.

The ultramafic rocks of the Pony Middle Mountain Metamorphic Suite form two different types of outcrops. Some are resistant to weathering and stand out from the rest of the outcrops; these contain coarse grained rocks, similar to the ones seen in the Spuhler Peak. Others are fine grained and are weathered flat against the surrounding rock. In both of these cases, it was not possible to find the contact or any blackwall reaction zone.

The few ultramafic outcrops that were seen in the Indian Creek Metamorphic Suite are fine grained (< 1 mm) and weathered close to the ground on the ridges on which they were found. It was not possible to find the contact or any blackwall for these rocks.

PETROLOGY

Sixty samples were taken from the field, and from these, twenty-four thin sections were made and eight other sections were borrowed from other members of the project. Samples from all of the suites contain orthopyroxene, cummingtonite, magnesio-hornblende, anthophyllite, olivine, spinel, and magnetite (along with chlorite and serpentine alteration products). Some samples from both the Pony Middle Mountain Metamorphic Suite and the Spuhler Peak Metamorphic Suite contain euhedral crystals of chlorite up to 3 mm long. In the Spuhler Peak, talc and phlogopite were also found. Apatite and dolomite were found in small quantities in the Indian Creek Metamorphic Suite.

In the following descriptions, petrographic observation is supplemented by SEM/EDS analyses. The olivine, which is a component of many but not all of the samples, is typically surrounded by orthopyroxene or hornblende. Some of the olivine crystals are large, (~2 mm in diameter) and others are small fragments with a diameter of 0.5 mm or less. Orthopyroxene makes up the largest volume of the rock, ranging in size from crystals that cover half of the thin section (about 2.5 cm) to crystals that are only about 0.5 mm in diameter. The large orthopyroxene grains commonly contain small inclusions (< 0.5 mm) of hornblende. The amphibole itself appears zoned, with anthophyllite around the outside and hornblende in the center. In some of the samples from the region in the Spuhler Peak metamorphic Suite near Lower Branham Lake, there appear to be two generations of hornblende. In these samples, there are well defined euhedral crystals of hornblende within a groundmass of fine grained, interlocking hornblende crystals.

The similarities in the petrology of the pods suggest that they have experienced similar metamorphic conditions. There are no indications of stress or strain, however, in any of the thin sections studied. Few of the minerals appear to be oriented preferentially and the orientation of those few crystals that are aligned appears to be determined by cleavage and fracture planes rather than structural deformation.

MINERAL CHEMISTRY

Four of the samples have been analyzed with an x-ray analyzer on a scanning electron microscope. Three of the samples are from in and near lower Branham Lake, in the Spuhler Peak Formation, and the fourth is from the Indian Creek Formation. In all of the samples that have been analyzed, there is a reaction rim around the hornblende. Between the reaction rim and about 10 μm into the grain, the Mg:Mg+Fe ratio increases from 0.793 to 0.845, showing about a 15 percent increase.

In another sample from the same area, a euhedral crystal of hornblende is surrounded by smaller interlocking crystals of hornblende. The smaller crystals of hornblende have an average Mg:Mg+Fe ratio of 0.788. This ratio remains the same into the center of the euhedral crystal, where the ratio jumps up to 0.820. The quantity of Ca in the crystal also changes; in this case, the center of the crystal has a stoichiometry of 0.917 Ca, but about 200 μm out, the quantity of Ca increases to 0.940. This small change is still great enough to fall outside the limit of error which the analyzer estimated. About 50 μm from the outside of the crystal, the chemistry of the euhedral crystal reaches equilibrium with the groundmass.

DISCUSSION

A typical ultramafic igneous rock would be primarily composed of olivine, orthopyroxene and clinopyroxene. Since these are anhydrous minerals, extremely high temperatures and pressures are required to metamorphose them. The ultramafic rocks that the author has been studying are composed of orthopyroxene, olivine and hornblende, with minor amounts of other amphiboles and spinel. This means that in order to metamorphose these rocks to the upper amphibolite facies, as suggested by their mineralogy and the mineralogy of the units in which the ultramafic pods are found, they must first undergo retrograde metamorphism to incorporate water into the mineral system (Evans, 1977). The presence of amphiboles in the author's samples is the only evidence that remains of the first retrograde event.

The event that is most evident in the samples from the various ultramafic pods corresponds to the younger, 650°C, 6 kb event. In the samples that the author has been studying, it is possible to see evidence for the second, decompression event. As will be shown in the following examples, it is possible to trace a small part of the reaction on Figure 1, a P-T diagram for the system SiO_2-MgO-CaO-H_2O (Spear, 1993). This is a diagram for a perfect system, but it is sufficient for making the estimates that I am trying to make.

Most of the textures and mineralogy that can be seen in these samples indicate various reactions taking place. In all of the samples studied, orthopyroxene crystals seem to be growing and replacing the olivine. All of these crystals are larger than any other mineral in the sample, and they are commonly engulfing other minerals. Hornblende crystals, along with magnetite-rimmed spinel, can be found inside the larger orthopyroxene crystals.

Hornblende, however, also engulfs and grows over orthopyroxene, as can be seen in Figures 2 and 3. These are backscattered electron images, in which minerals with more iron and magnesium (in this case), such as olivine and orthopyroxene, appear brighter than minerals with a lower percentage of iron and magnesium, like the hornblende. In Figure 2, there is a subhedral hornblende grain with two spots that are a lighter grey, corresponding to orthopyroxene (confirmed by EDS analysis). Immediately around this is hornblende which is slightly Ca-poor compared to the rest of the crystal (the stoichiometry is 0.02 less for Ca, near the orthopyroxene).

This seeming discrepancy between orthopyroxene overgrowing hornblende, and hornblende overgrowing orthopyroxene was resolved in another slide, which contained hornblende overgrowing hornblende, as described in the Mineral Chemistry section of this paper. In this slide, there are two generations of hornblende. Thus, the first generation could have grown before the orthopyroxene engulfed them, and the second generation could have engulfed the orthopyroxene.

The mineral reactions involving anthophyllite, one of which has just been described, can help to estimate some of the pressure/temperature conditions. This can be done using Figure 1 and the textures that have been described. The author has assumed that since the olivine is found in small fragments and is typically engulfed by other minerals, the olivine is being consumed by the reactions described. On Figure 1, reaction (2) is talc + enstatite yields anthophyllite. The samples from the inner part of the disturbed zone contain talc, as mentioned earlier, which could be from a retrograde reaction. Considering the metamorphic history of the surrounding rocks, and the fact that the orthopyroxene is never completely converted to anthophyllite, it is possible that the all of the original talc was consumed in this reaction. Once the talc was consumed, there was nothing left to react. One of the possible stable mineral assemblages that would be produced would be tremolite (hornblende with the addition of iron, as in my system), anthophyllite and orthopyroxene (see Figure 1B). This is the mineral assemblage shown in Figure 3.

Reaction (7) in Figure 1 is another possibility. This is the reaction enstatite + water yields anthophyllite + olivine. The problem here is that olivine is supposed to be produced, yet it looks like it is being consumed in all of the author's samples. Olivine, however, is easily altered, so it may not be possible to preserve a texture in which olivine is engulfing other minerals. Water is the limiting reagent however, and the reaction could have produced only a minor amount of anthophyllite before the water was consumed. The attractive thing about this region of the P-T diagram (Figure 1) is that in this region, olivine would not be associated with orthopyroxene because serpentine interferes (see Figure 1C). This corresponds to the texture and mineralogy shown in Figure 2, which contains olivine, serpentine and hornblende.

Using the textures of the samples and Figure 1, it can be estimated that at some point these rocks were at temperatures between 650 - 800°C and pressures from 6 - 12 kb. They then underwent a decompression reaction and ended up at temperatures between 600 and 700°C and pressures no greater than 6 kb. These sets of conditions correspond to the decompression of the Archean units of the Tobacco Root Mountains from the 10kb event to the 6 kb, 650°C event.

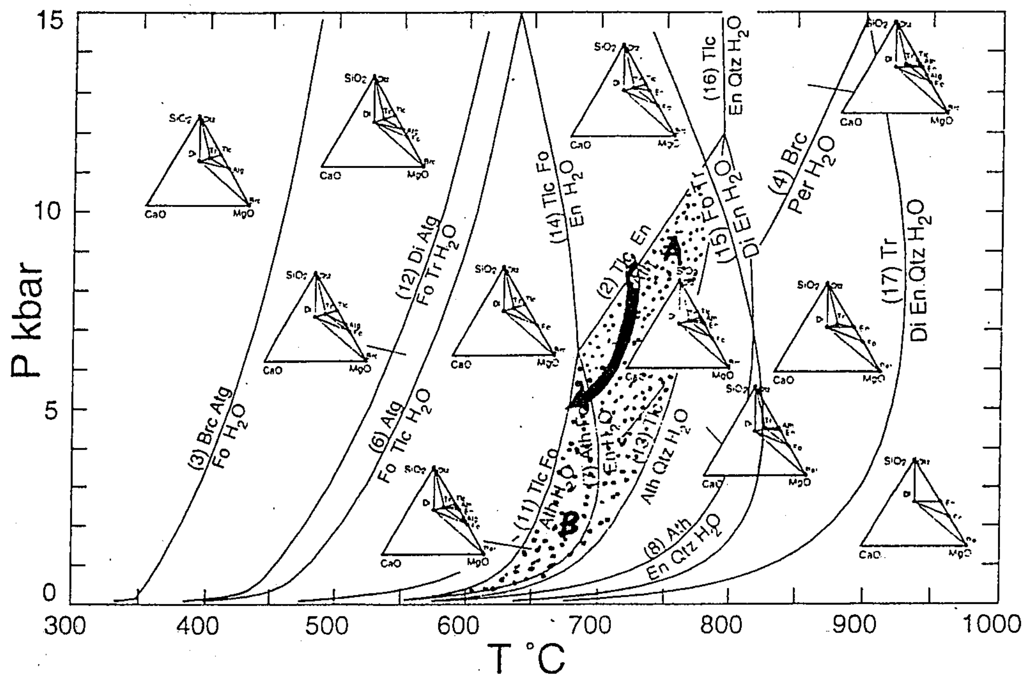

Figure 1. Pressure-Temperature Diagram for ideal SiO_2-MgO-CaO-H_2O system.

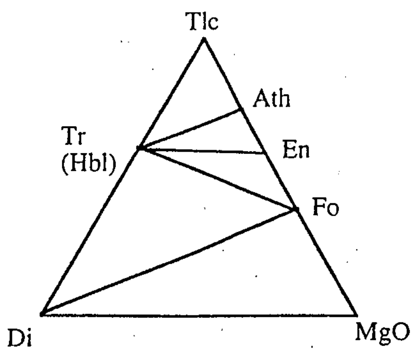

Figure 1B. Magnified Triangular Phase Diagram for Area A, Looking Specifically at the Talc, Diopside, and MgO end members.

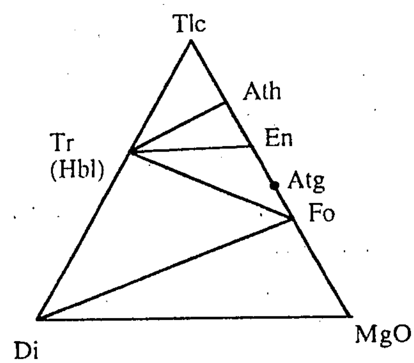

Figure 1C. Magnified Triangular Phase Diagram for Area B, Looking Specifically at the Talc, Diopside, and MgO end members.

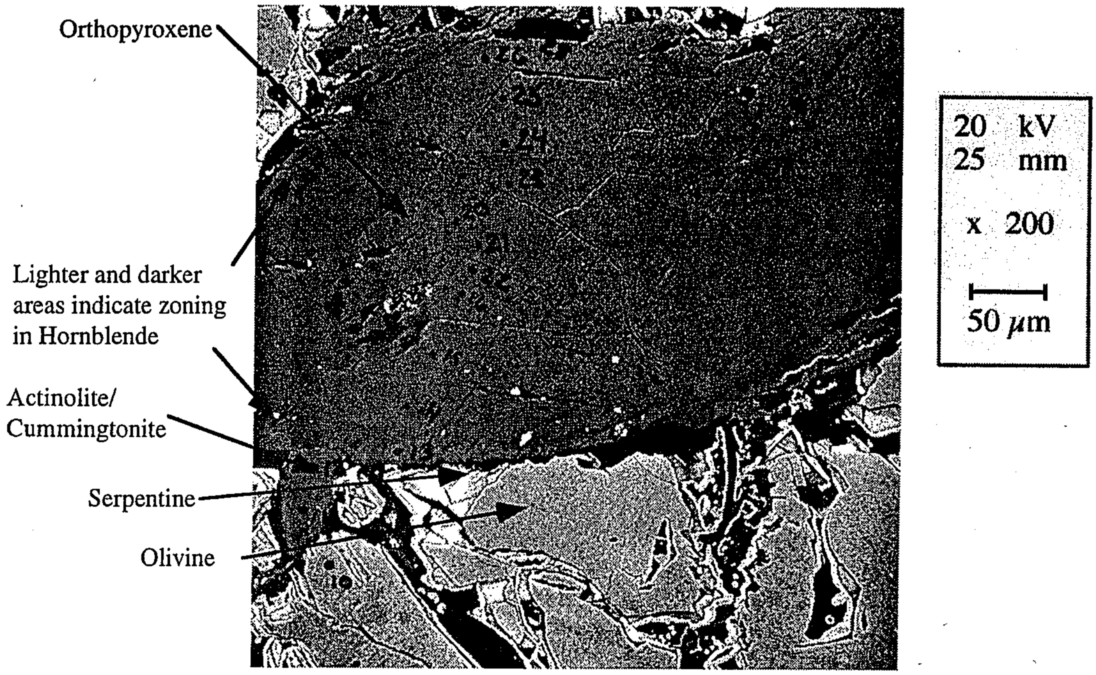

Figure 2. Backscattered Electron Image of Zoned Hornblende and Olivine

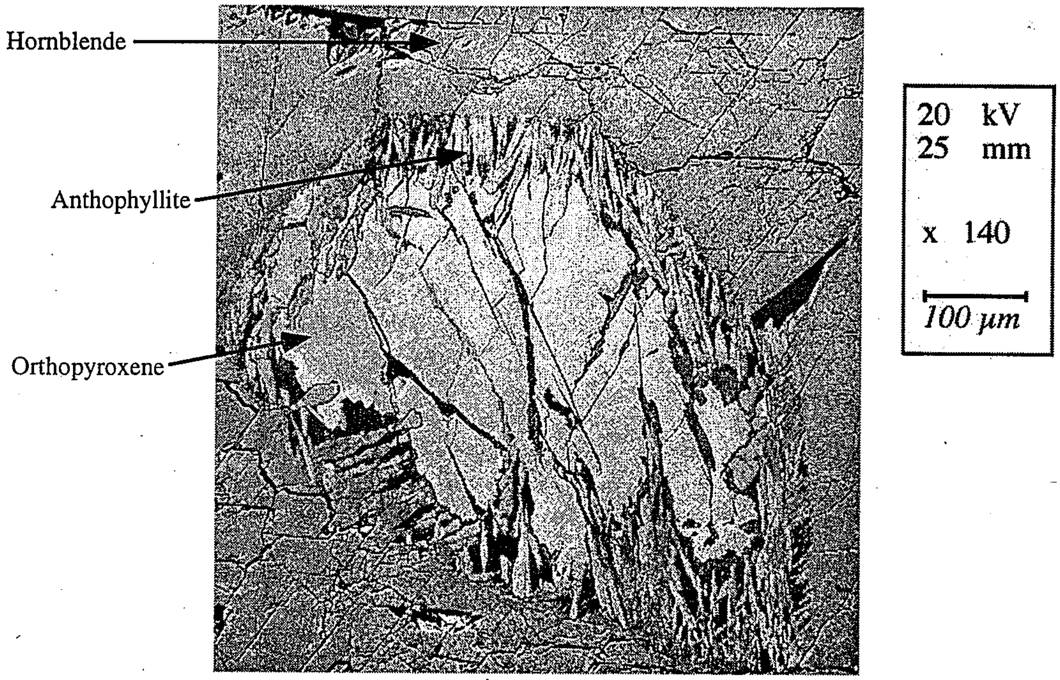

Figure 3. Backscattered Electron Image of Orthopyroxene Reacting With Hornblende

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