A geochemical and petrographic analysis of the meta-ultramafic rocks in the Tobacco Root Mountains, Southwest Montana

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INTRODUCTION

Small pods of meta-ultramafic rock 10 to 100m in length lie scattered throughout the three Archean metamorphic suites of the Tobacco Root Mountains. These dull brown and grey unfoliated rocks are concentrated in the area around Branham Lakes in the Spuhler Peak Metamorphic Suite (SPMS) as well as near the Indiana University Field Camp in the Pony Middle Mountain Metamorphic Suite (PMMS), but isolated pods also lie in the Indian Creek Metamorphic Suite (ICMS). 30 samples were collected from 20 of these pods in order to investigate the geochemistry and petrography of these ultramafic rocks.

FIELD RELATIONS

The ultramafic rocks in the Tobacco Root Mountains occur as small sub-rounded to lens-shaped pods. These bodies are separate and distinct from the surrounding rocks, and no ultramafic to mafic sequences occur within the pods. Most of the ultramafic rocks are unfoliated, but strongly foliated gneisses and amphibolites surround them. Many ultramafic outcrops that are adjacent to the contact show a weak foliation defined by the alignment of metamorphic minerals. The foliation of the surrounding rocks often wraps around the elongated pods, but is sometimes sharply truncated by the pods. Relationships with the surrounding rocks were not observed in the PMMS due to poor outcrop.

Blackwall rocks often lie on the margins of the ultramafic pods, but are found only in the SPMS. These well-defined one to ten meter wide zones consist of sequences of hornblendite, anthophyllite and hornblende, chlorite-rich rocks, biotite, and biotite-rich rocks. The composition of the blackwall zones is variable, and there is often very little outcrop due to the weathered nature of these rocks. These zones appear to have been formed during metamorphic episodes by metasomatic processes that occurred between the adjacent, but chemically dissimilar ultramafic rocks and amphibolites or felsic gneisses.

PREVIOUS WORK

The metamorphic histories of these ultramafic rocks is unclear, but several possible mechanisms may have emplaced these rocks within these sequences of gneisses and amphibolites. It is unlikely that they were emplaced as dikes or sills before the first episode of high-grade metamophism in the region 2.7Ga because the ultramafic rocks are unfoliated, while the surrounding gneisses and amphibolites are strongly foliated. The emplacement of these rocks as cold ultramafic bodies late in the 2.7Ga metamorphic episode was suggested by Cummings and McCulloch (1992). This would explain the alignment of these elongated pods with the foliation, but the lack of serious deformational fabrics within the pods.

It is possible that these rocks were originally komatiites or ultramafic lavas, but the coarse-grained mineral textures and a lack of any evidence of extrusive characteristics argue against this hypothesis. Other suggested protoliths include cumulates of a mafic magma chamber (Tendall, 1978), ultramafic plugs intruded during the 2.7Ga metamorphic event (Friberg, 1976), or solid diapiric serpentinites that were emplaced along faults during this metamorphic event (Desmarais, 1981).

PETROGRAPHY

Most of these ultramafic rocks were originally orthopyroxenites to harzburgites, and the original ultramafic mineralogy consists of orthopyroxene, olivine, clinopyroxene, and spinel. These minerals are preserved within variable amounts of metamorphic replacement minerals that overgrow the original minerals. Actinolite is the most prominent replacement mineral in these rocks and normally comprises a majority of these rocks, while anthophyllite occurs in only a few samples. Chlorite, talc, and serpentine are widespread low-grade metamorphic minerals that occur in all samples to various degrees. Magnetite is also present in all samples, and biotite is found in a few.

Most ultramafic rocks from the SPMS are dull brown-colored, and orthopyroxene, the dominant original mineral, often occurrs as large megacrysts or pseudomorphs replaced by talc and serpentine. Clinopyroxene is also sometimes present, and olivine is usually a minor consituent. Moderate amounts of actinolite are present, and anthophyllite occurs in large concentrations in some of these rocks, appearing as large white spots in outcrop. Fresh ultramafic samples from the ICMS appear dark grey to green colored and are usually dominated by actinolite, which is a replacement product of the original orthopyroxene. A small amount of orthopyroxene and clinopyroxene, as well as olivine, remain in these rocks, and most of these samples contain abundant green spinel. Rocks from the PMMS are dark grey, green, and black colored and contain greater amounts of highly serpentinized olivine grains than samples in the other two suites. Fresher grains of orthopyroxene and spinel are also present in these rocks.

These mineral assemblages provide evidence for two episodes of metmorphism. During a high grade metamorphic event, actinolite, anthophyllite, and talc replaced orthopyroxene and clinopyroxene megacrysts. During a lower grade metamorphic event, serpentine, talc, and chlorite replaced olivine, orthopyroxene, actinolite, and anthophyllite. Magnetite overgrowths on spinel and a few large biotite grains also formed during this event.

GEOCHEMISTRY

Major, trace, and rare earth element whole-rock geochemistry was determined by XRF and INAA analyses. The results were used to characterize ultramafic samples from the three suites, determine degrees of metamorphic replacement and metasomatism, and help determine the metamorphic histories and protoliths of these rocks. A large amount of metasomatism has occurred in many of these samples, causing wide variations in the major element concentrations, especially SiO_2 (Figure 1). Due to the variable degrees of metamorphic replacements in these rocks, the major element concentrations may be inaccurate representations of the original geochemistries of these rocks.

Most binary diagrams that plot the major elements provide a fairly well-defined grouping of the ultramafic samples. Several samples consistently fall outside of this grouping due to great variations in the mineralogy. Large amounts of talc, chlorite, and serpentine produce low SiO_2 and high MgO concentrations, and anthophyllite-rich rocks have high SiO_2 concentrations. For all ultramafic samples, SiO_2 concentrations generally lie between 44% and 55%, Al_2O_3 concentrations lie between 2% and 10%, Mg numbers lie between 83 and 74 with MgO between 20% and 32% and FeO between 9% and 15%, and CaO concentrations lie between 2% and 10%. TiO_2 concentrations generally lie between 0.1% and 0.5%. Alkali elements are very scarce, almost always below 1%, and P_2O_5 concentrations are always below 0.1%.

Trace elements concentrations may be more useful for determining a protolith for these rocks. Cr and Ni are the most abundant, with Cr concentrations between 1700 and 4100ppm (Figure 2), and Ni concentrations between 540 and 1320ppm. Other important trace elements include Co, between 82 and 153ppm, V, between 54 and 171ppm, Zn, between 60 and 145ppm, and Zr, between 17 and 52ppm.

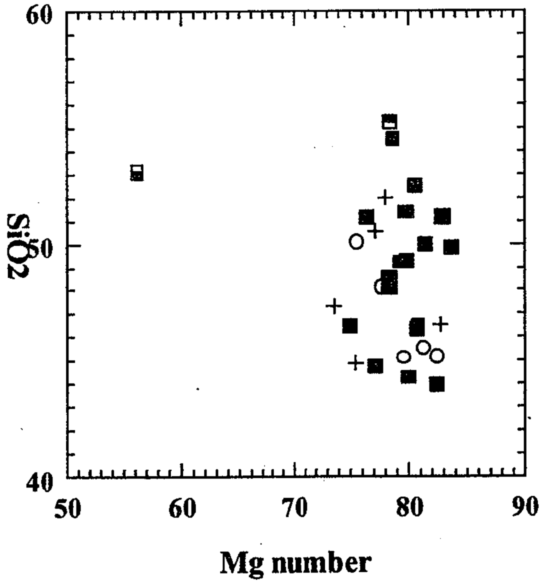


Figure 1: Plot of Mg# versus SiO_2 for ultramafic samples from the SPMS (■), ICMS (+), and PMMS (○), as well as one blackwall (◧) and one amphibolite (▣) sample from the SPMS.

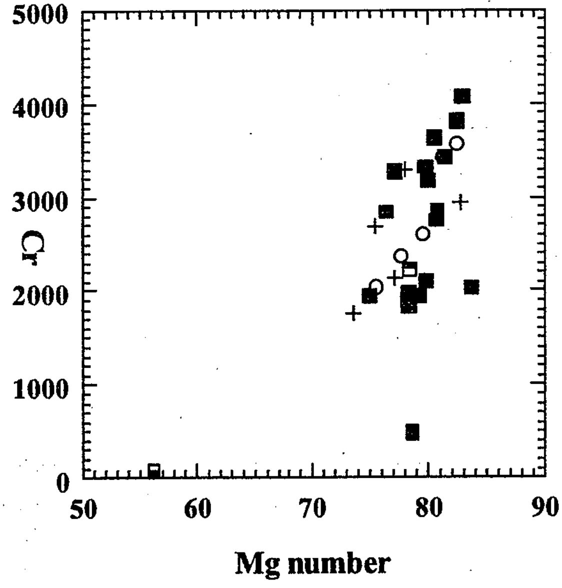


Figure 2: Plot of Mg# versus Cr for same samples.

Rare earth element plots indicate that ultramafic rocks from all three suites are enriched in light rare earth elements and have a flat heavy rare earth element profile compared to chondritic values (Figure 3). Trace element spider plots indicate that these rocks are slightly enriched in incompatible elements compared to primitive mantle values, with low concentrations of Rb and Sr (Figure 4).

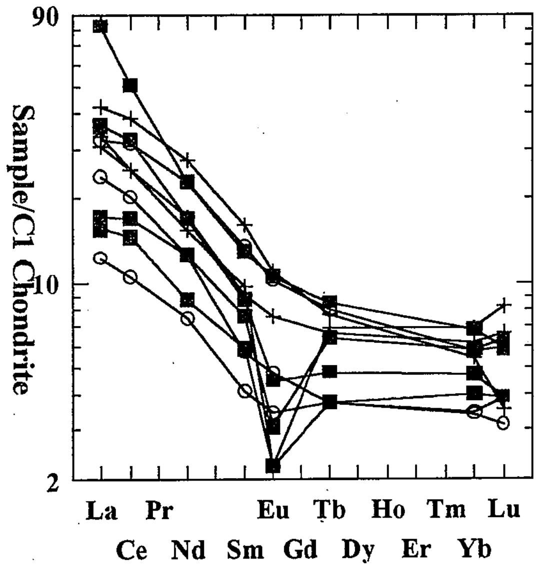


Figure 3: Rare earth element spider plot for 4 SPMS, 3 ICMS, and 3 PMMS ultramafic samples.

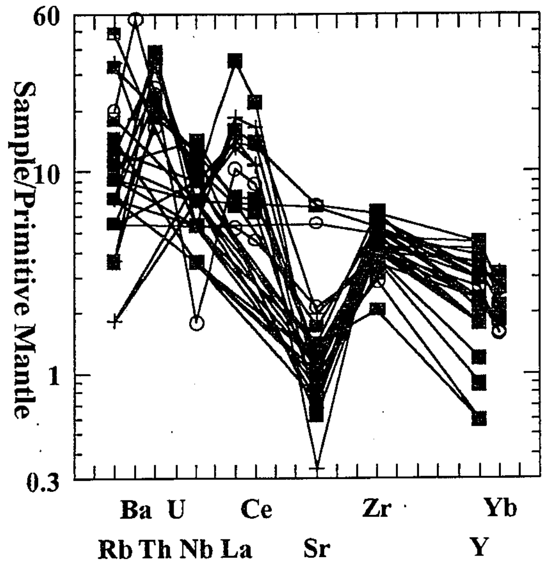


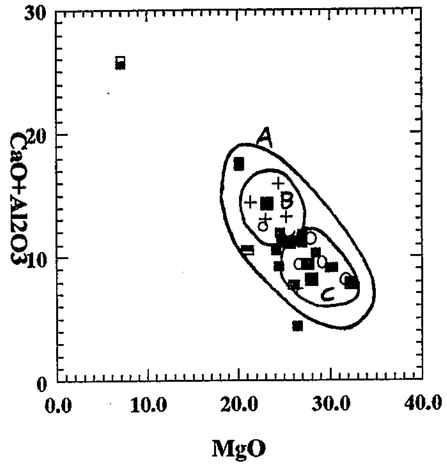
Figure 4: Trace element spider plot for ultramafic and blackwall samples.

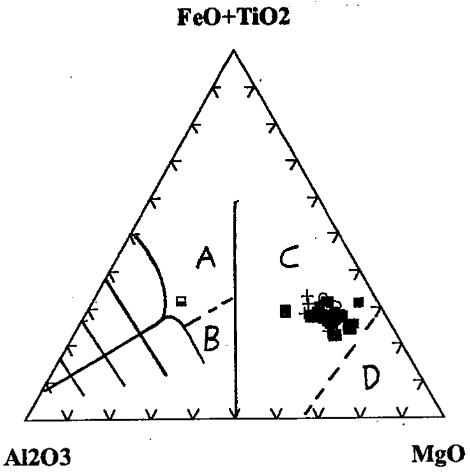
DISCUSSION

Ultramafic rocks from the three metamorphic suites can not be easily distinguished geochemically. In major element binary plots, analyses from the SPMS cover a large range, while those of the ICMS and PMMS are distinct but overlap those of the SPMS (Figure 5). Generally, ultramafic samples from the ICMS have higher concentrations of SiO_2, $Al2O_3$, and TiO_2, and lower concentrations of MgO. These samples are more similar to an amphibolite collected from the surrounding rocks in the SPMS. Ultramafic samples from the PMMS have lower SiO_2 and Al_2O_3, but higher MgO and plot on the opposite side of the grouping. In addition, samples from the ICMS are more enriched in rare earth elements compared to those from the PMMS, but samples from the SPMS cover the whole range of values.

Various degrees of metamorphic replacement also produce geochemical trends. Individual samples that are highly replaced by talc, chlorite, and serpentine plot further from the amphibolite composition and have higher MgO and lower SiO_2 concentrations, while amphibole-rich samples are higher in SiO_2. Much of this is due to metasomatism between these small pods and the surrounding rocks. The analysis of one blackwall sample suggests that it represents an exoskarn that was originally an amphibolite. MgO migrated into this rock from the ultramafic rock, while SiO_2 migrated from the amphibolite into the ultramafic rock. The resulting blackwall sample has a very similar geochemistry to an ultramafic sample, but is high in SiO_2 like the amphibolite. Those blackwall zones that lie further from the pod may be more similar to the surrounding amphibolites and gneisses.

Discrimination diagrams show that these rocks are not truly komatiitic in composition, but may be classified more as a basaltic komatiite (Figures 6 and 7). They do not display any features of komatiitic lavas such as spinifex textures, chill zones, or associated tuffs and breccias, although these features may have been erased during metamorphism. The MgO concentrations are too high for komatiitic basalts, and there are no volcanic sequences within these rocks. It is unlikely that these represent cumulates of a mafic magma chamber because there is no compositional layering in the pods. It is more likely that the protolith of these rocks is a series of deep ultramafic magma chambers, which may have been the source of Archean komatiitic lavas. Small pods and slivers of these chambers may have been incorporated into nearby rocks during intense isoclinal folding and faulting late in the 2.7Ga metamorphic event, causing them to be aligned with the dominant foliation but not foliated themselves.





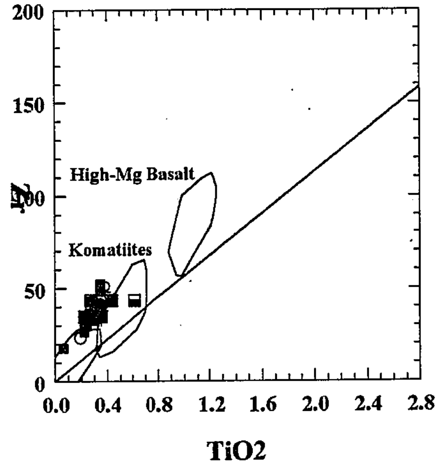


Figure 5: Plot of $CaO+Al_2O_3$ versus MgO to show how ultramafic analyses from the SPMS (A), ICMS (B), and PMMS (C) generally relate to each other.

Figure 6: Jensen Cation plot (Jensen, 1976) of ultramafic, amphibolite, and blackwall samples. Fields are A: high-Fe tholeiite, B: high-Mg tholeiite, C: basaltic komatiite, D: ultramafic komatiite.

Figure 7: Discriminant diagram for komatiites (Hallberg, 1985), showing that the ultramafic samples fall outside of the komatiitic field.

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