Geothermobarometry of Garnet Amphibolites from the Indian Creek and Pony-Middle Mountain Metamorphic Suites, Tobacco Root Mountains, Montana

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INTRODUCTION

The Tobacco Root Mountains (TRM) (fig. 1) contain three Archean metamorphic suites: the Indian Creek (ICMS), Pony-Middle Mountain (PMMMS), and Spuhler Peak (SPMS) (Burger et al, 1996). The ICMS and PMMMS have very similar compositions and rock types. The ICMS is composed of quartzofeldspathic gneisses, pelitic schist, marble, quartzite, and iron formation. The PMMMS is dominated by quartzofeldspathic gneisses with lesser amounts of hornblende-plagioclase gneiss and amphibolite, but has only minor amounts of marble and quartzite. Both the ICMS and PMMMS are primarily composed of metaigneous rocks. Geochemical analysis of quartzofeldspathic gneisses and structural observations in the ICMS and PMMMS suggest that the two suites may be of single parentage (Burger et al. 1996).

Whole rock Rb/Sr and U/Pb zircon analysis of high grade basement rocks in the TRM give Archean to Proterozoic ages of ~3.3, 2.7, and 2.4 Ga (Krogh et al., 1997). Two significant metamorphic events have been documented in the rocks of the TRM. Geothermobarometry for metamorphosed mafic dikes and sills (MMDS) in ICMS and PMMMS, and amphibolites in SPMS is consistent with a clockwise P-T path with initial prograde metamorphism at >10 Kb due to a collisional event, followed by a ~5.5 Kb metamorphism due to decompression. Thus the ICMS, PMMMS, and SPMS must have been assembled before the Archean (Cheney, 1996). The last major metamorphism occurred at 1.8 Ga, at temperatures greater than 500°C, from $^{40}Ar/^{39}Ar$ ages from hornblende-amphibolites of the SPMS, ICMS, and MMDS in the ICMS (Kovaric et al, 1996).

Little detailed petrology is available for the ICMS and PMMMS. Mineral assemblages for both suites are generally consistent with those of the SPMS, but there is no data on the variation of P & T over the whole range. The ICMS and PMMMS make up most of the Archean rocks in the area. Both units contain Quartz-Garnet-Plagioclase Amphibolites that can be used to evaluate the differences in P & T within each suite as well as the systematic variation in P's & T's across the TRM. Detailed study of these amphibolites also provides a direct comparison to the well characterized amphibolites in the SPMS.

METHODS

About sixty garnet-amphibolites were collected throughout the ICMS and PMMMS. Of the sixty samples collected, thirty-five were cut into thin-sections and described for mineralogy and texture. Of those thirty-five thin-sections, six representative samples, three from the ICMS and three from the PMMMS representing a wide geographical distribution, were chosen for analysis using a Zeiss DSM 960 with a Link EDS Scanning Electron Microscope. Point analyses and garnet traverses were done in one or two areas of each slide

Representative analyses of both mineral rims and interiors were used in the program "Thermobarometry 2.0" (Kohn and Spear, 1997) to determine P's & T's of metamorphism. Graham and Powell's (1984) garnet-hornblende and Patiño-Douce et al.'s (1993) garnet-biotite models were used for geothermometers. Kohn and Spear's (1990) garnet-plagioclase-hornblende (Mg-tschermak)-quartz model was used as a geobarometer. No Fe^{3+} corrections were made.

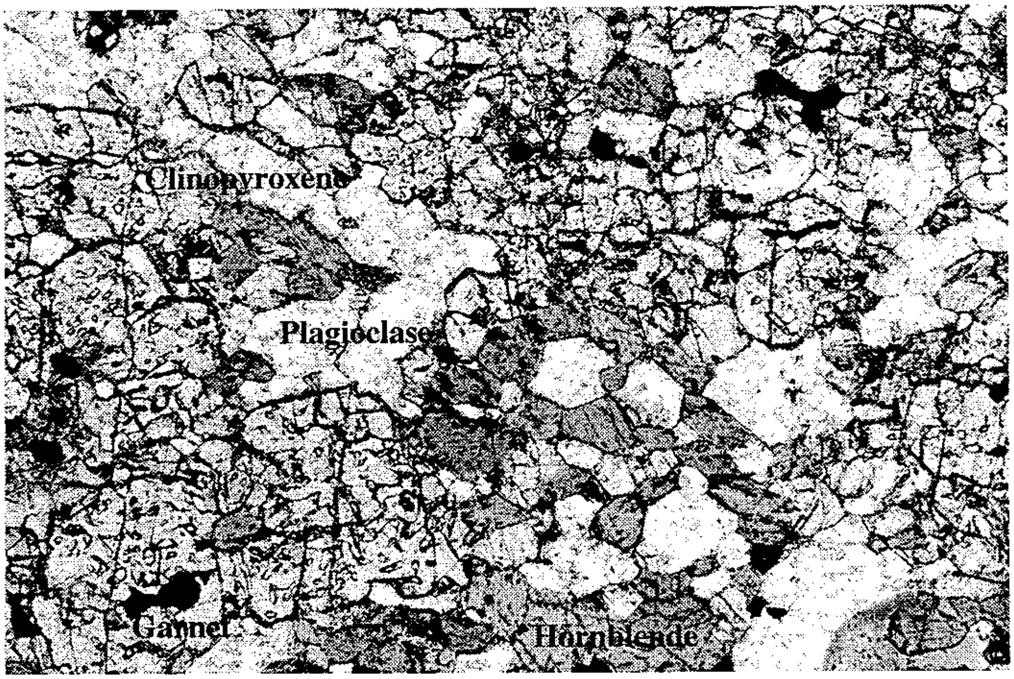

Figure 1. Typical clustered granoblastic MMD with abundant garnet inclusions, from Cataract Mountain (PMMMS).

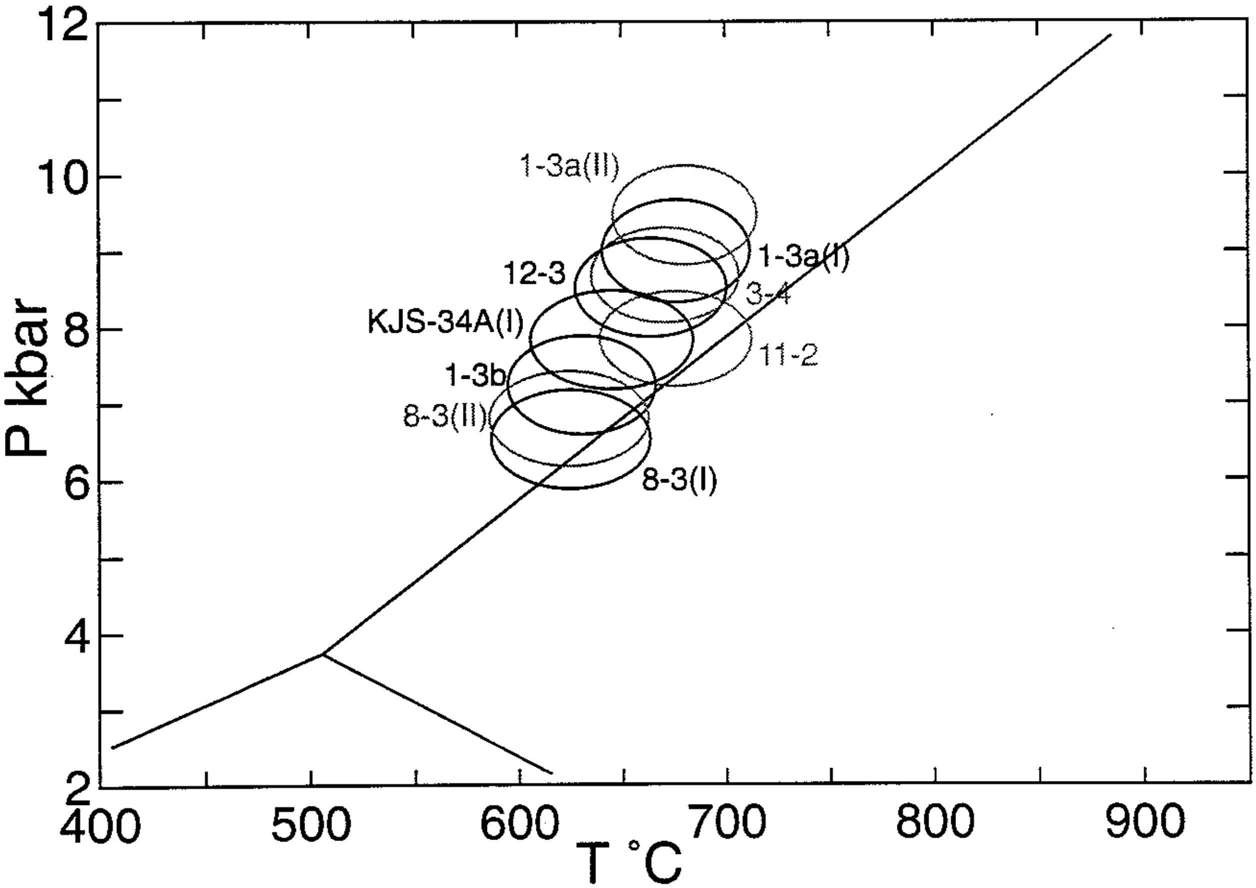

Figure 2. Pressure-temperature graph of samples from around the ICMS and PMMMS. Geothermobarometry results were calculated from near-rim compositions of garnet, hornblende, and plagioclase.

RESULTS

Amphibolite samples from both the ICMS and PMMMS are, with some exceptions, similar in terms of their texture, mineralogy, and mineral chemistry. All of the rocks studied in detail are coarse grained, foliated to massive quartz bearing garnet-plagioclase-hornblende amphibolites. Some samples contain clinopyroxene or biotite, and all contain minor amounts of either ilmenite or titanite ± epidote, apatite, sericite, chlorite, and magnetite.

Garnet crystals are anhedral to euhedral, .3-5 mm in size; modes vary from 5-40%. Garnets are slightly zoned, for example, the maximum variation of Mg/(Mg+Fe) ranges from 14-21%; most are within a 3-5% range. As shown in figures 2a and 2b, there are similar, small variations in pyrope, almandine, grossular, and spessartine contents, i.e. typically <5%. Plagioclase crystals are subhedral to euhedral, .2-5 mm in size, with the exception of a 9 mm phenocryst; modes vary from 3-40%. Plagioclase is slightly zoned, anorthite content varies by about 5% (~An_{35} to An_{40}). However, in some cases the zoning is normal (low Ca rim) and in others it is reversed (high Ca rim). There is one exception in the PMMMS--one sample has an anomalously high Ca content, An_{86} to An_{94}. Hornblende crystals are subhedral to euhedral, .2-4 mm in size; modes vary from 10-60%. Hornblendes are relatively homogeneous within each sample. No sample varies by more than 6% Mg/(Mg+Fe), with the exception of one sample that varies by 16% Mg/(Mg+Fe). Quartz crystals are subhedral to euhedral, fine to coarse grained and present in every slide; modes vary from 3-10%.

P's & T's calculated using rim and near rim (within 100 μm) compositions are nearly the same, as shown by figures 3a and 3b. Geothermobarometric results indicate temperatures of ~700°C± 50 and pressures of ~8 Kb ± 1 for both the ICMS and PMMMS (fig. 4), with the exception of one PMMMS sample that indicates pressures of 4-6 Kb. As shown in figure 1, there is no significant geographic variation of pressure or temperature throughout the Tobacco Root Mountains. The garnet-biotite thermometer yields systematically higher temperatures than the garnet-hornblende thermometer.

SUMMARY

Calculated T's & P's for both the ICMS and PMMMS are similar and consistent with ~700°C and ~8 Kb over a wide area in the Tobacco Root Mountains of Montana. Geothermobarometry for the ICMS and PMMMS, two fundamentally different rock packages, indicates that the two suites experienced a similar evolution. Moreover, results reported here are similar to those of Steffen (this volume) on SPMS and PMMMS, and Carmichael (this volume) on MMDS.

These results are similar to ~650°C, ~5.5 Kb reported by Cheney (1996), but in fact reflect slightly higher pressures and temperatures. This could reflect the use of different geobarometers or that the previous results were not obtained from ICMS and PMMMS rocks!

The whole range apparently reflects the same P-T conditions of metamorphism, independent of rock unit. These results confirm that this metamorphism indeed postdates assembly of the terrane and that the rocks from all units have largely reequilibrated during the 1.8 Ga event.

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Tobacco Root Mountains

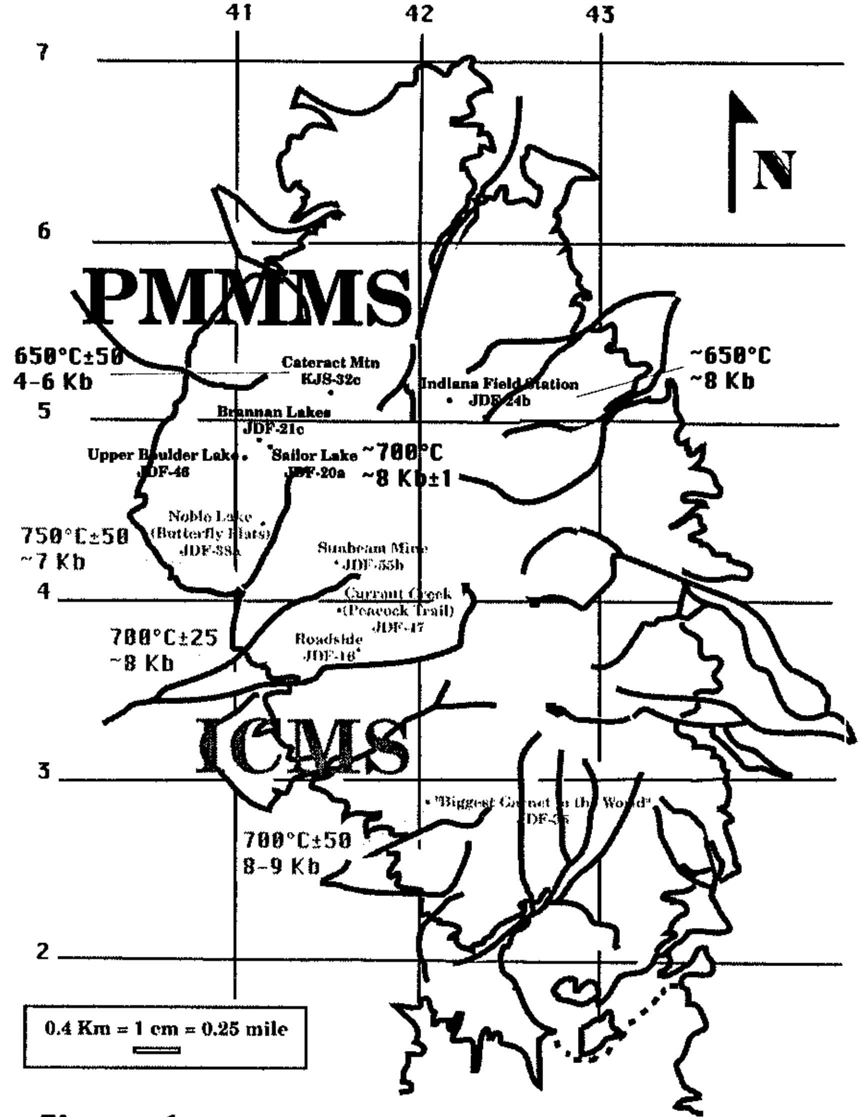


Figure 1.
Sample location map. Includes G-H thermometer temperatures and pressures for both rims and cores.

Figure 2.
Representative garnet traverses from the ICMS and PMMMS.

Figure 2a.

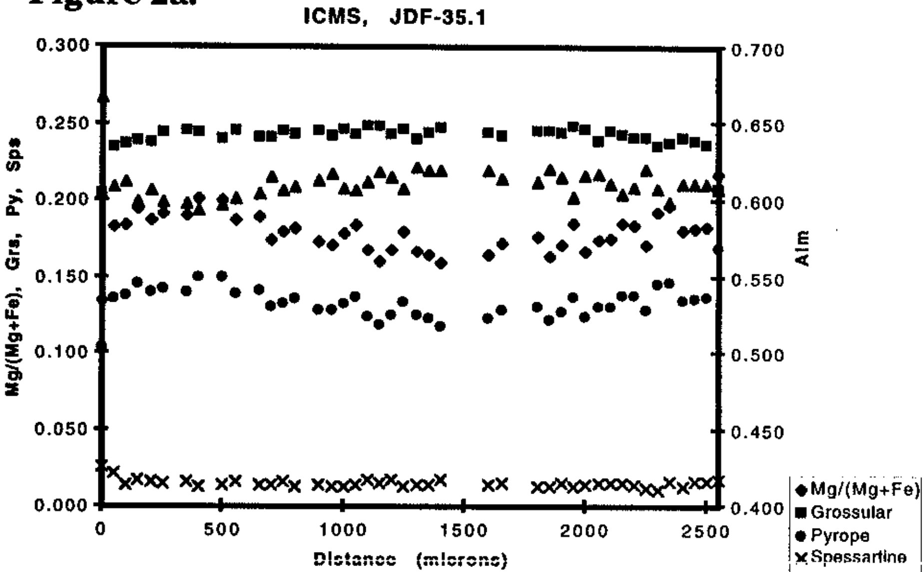


Figure 2b.

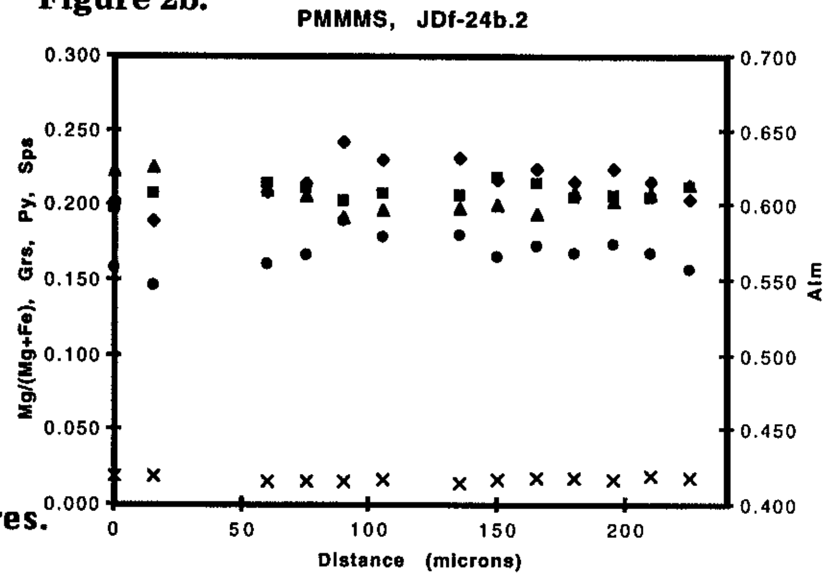


Figure 3a.
Summary Diagram of ICMS Geothermobarometry

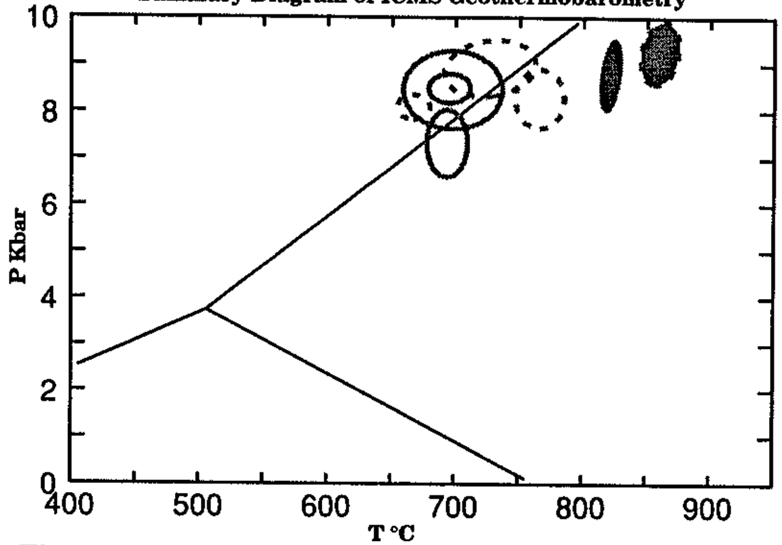


Figure 3b.
Summary Diagram PMMMS Geothermobarometry

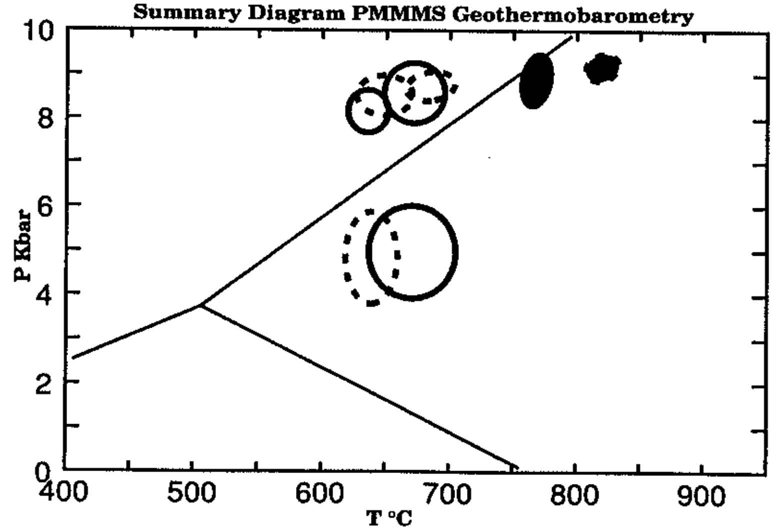
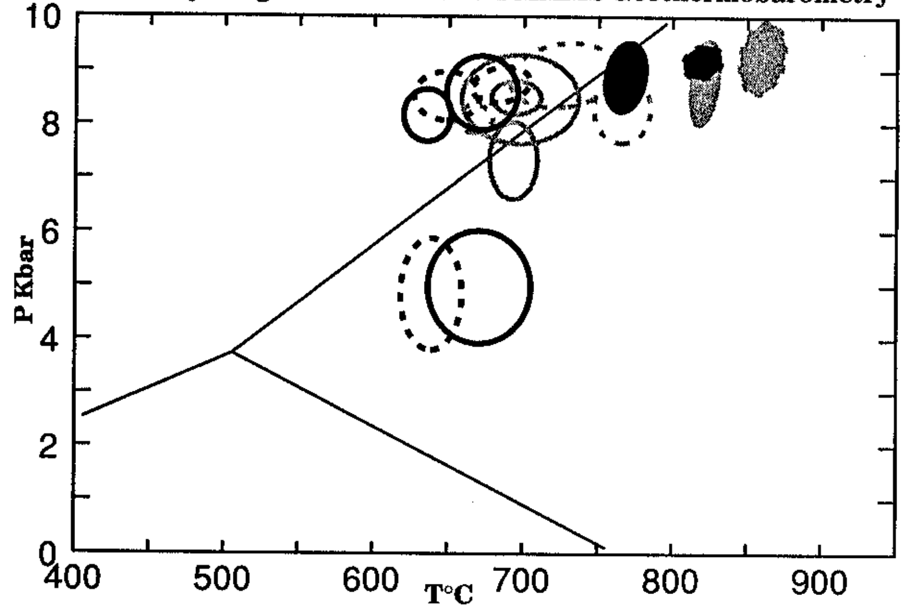


Figure 4.
Summary Diagram of ICMS and PMMMS Geothermobarometry



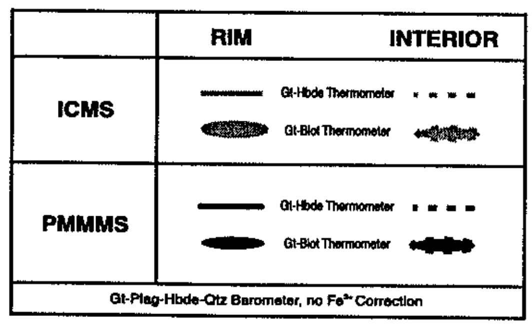


Figure 3c (bottom right). Legend for Figures 3a, 3b, & 4.

Geochemistry of metamorphosed mafic dikes, Tobacco Root Mountains, southwestern Montana

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INTRODUCTION

Metamorphosed mafic dikes (MMD's) in the Tobacco Root Mountains of southwestern Montana are found in the Indian Creek Metamorphic Suite (ICMS) and Pony Middle Mountain Metamorphic Suite (PMMMS), which are composed largely of quartzofeldspathic and amphibolite gneisses (Fig. 1, Vitaliano et al, 1979). They have not been found in the Spuhler Peak Metamorphic Suite (SPMS), although abundant MMD's have been intruded in the ICMS and PMMMS near their contact with the SPMS. MMD's range from 1/3 - 25m in estimated thickness. Outcrops appear blocky and weathered brown, and exhibit foliation parallel to the margins. In most cases MMD's cross-cut gneiss foliation at low angles, but in some cases dikes are parallel to foliation or cross-cut foliation at high angles. A fresh surface may or may not be foliated, and is typically dark gray in color. Grain sizes range from fine (<1mm) to coarse (>3mm). Minerals visible in hand sample and thin section consist mainly of plagioclase, hornblende, garnet and biotite.

The Tobacco Root Mountains are part of the Wyoming Province, which is believed to represent several amalgamated terranes. The resulting landmass collided with the Superior Province in the early Proterozoic to become the western margin of North America (Wooden et al., 1988). The geochemistry of the MMD's can provide information about the tectonic environment of the terranes in which they were emplaced, thereby constraining formational theories of the Wyoming Province.

METHODS

Sixty-one MMD samples were collected during the field study. Fifteen of these were analyzed for rare earth, major, and trace elements (REE, major/TEL) using the INAA and XRF facilities at the University of Oregon Radiation Laboratory and Franklin & Marshall College, respectively (Table 1). Thin sections were examined for these samples as well. Samples chosen for analyses are intended to represent MMD distribution throughout the map area; more MMD's from the PMMMS were analyzed than from the ICMS, as the dikes are more abundant in the PMMMS. Samples were also chosen to compare the lithologies of margin vs. core samples, younger versus older dikes, concordant dikes vs. cross-cutting, thinner vs. thicker dikes, dikes containing vs. those not containing garnet, and fine-granied vs. coarse-grained dikes.

RESULTS/DISCUSSION

Major element data are considered insufficient to constrain petrogenesis (Wilson, 1989), due to the mobility of major elements in hydrothermal fluids. Hydrothermal alteration is evident in all MMD thin sections by the presence of sericitization and chloritization. Therefore, the mobility of Mn (Rollinson, 1993) and alkali elements should be considered when evaluating the MnO-TiO_2-P_2O_5, TiO_2-K_20-P_2O_5, and major element discrimination function diagrams (Figs. 1-3). Moreover, the instability of K_20 may influence results in Figure 4.

Trace elements and REEs are considered less mobile and thus are more useful in determining the protolith for altered samples. REEs are relatively immobile even under low-grade metamorphism. However, heavily altered or metamorphosed rocks can cause REE mobility, affecting the accuracy of discrimination graphs (Humphries, 1984).

A spider diagram analysis characteristic of the MMD's exhibits negative anomalies for Sr and Cr (Fig. 5). The light rare earth elements (LREE) and Ba show positive anomalies. Eu remains relatively constant, indicating lack of significant substitution in plagioclase crystallization. The compatibility of Sr in plagioclase (Rollinson, 1993) therefore is an unlikely cause of Sr depletion, since its ionic potential is nearly identical to that of Eu. It is more probable that the negative Sr trend reflects its mobility during leaching (Rollinson, 1993).

Hydrothermal alteration may be the source of anomalous behavior in samples 4-2b and 9-4b in the discrimination diagrams. Both are located near the PMMMS/SPMS contact; juxtaposition of the SPMS may have