American Mineralogist, Volume 75, pages 21–26, 1990

Single-crystal U-Pb zircon age determination of the Red Mountain pluton, Laramie Anorthosite Complex, Wyoming

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Abstract

In order to provide a precise age for the Red Mountain pluton, the youngest of the syenitic bodies of the Laramie Anorthosite Complex, Wyoming, zircons were extracted and analyzed for U-Pb isotopes. Zircon grains were selected and individually analyzed in order to minimize potential complications of inherited components. No grains with inherited cores were identified, either by microscopic examination or from the isotopic data. On a concordia diagram, the U-Pb data form a slightly discordant array. A best-fit line intersects concordia at 1439^{+7}_{-6} Ma and 102 ± 64 Ma (95% confidence level). The upper intercept is interpreted as the crystallization age of the Red Mountain pluton and provides a younger age limit for the rest of the Laramie Anorthosite Complex.

Introduction

Petrogenetic studies of Precambrian rocks rely increasingly upon precise age determinations. When the crystallization age of an intrusion is well known, calculated initial isotopic ratios of Sr, Nd, and/or Pb may provide important constraints upon its origin and evolution. U-Pb dating of zircons often yields very precise ages that provide a chronological framework and the basis for such petrogenetic modeling. Although analyses of grain-size and/or magnetically separated zircon fractions frequently provide very precise concordia-intercept ages, in some cases population studies may not always be the most successful approach. For example, if several generations of zircons are present, discordia constructed from mixed populations may yield meaningless concordia-intercept ages. An alternative approach is the analysis of single zircon crystals. Although analytically more demanding, the single-zircon approach has the advantage that grains with distinct morphological properties or grains with inherited cores will be analyzed separately, and the age of the different times of zircon growth may be established.

The goal of this study is to provide a precise age for the Red Mountain pluton, the youngest of the syenitic plutons associated with the Laramie Anorthosite Complex. The Laramie Anorthosite Complex is the subject of ongoing collaborative field, petrologic, and geochemical studies (e.g., Fuhrman et al., 1988; Kolker and Lindsley, 1989; Anderson et al., 1987, 1988). Recently, Nd and Sr isotopic studies have been initiated (see Geist et al., 1990), which require precise age data for the calculation of initial isotopic compositions. Prior to the present contribution, no age determinations of the Laramie Anorthosite Complex have been published other than as summarized in thesis and abstract form (Subbarayudu, 1975; Subbarayudu et al., 1975). Aleinikoff (1983), who dated the Sherman Granite, which is closely associated with the anorthosite complex, found that inherited radiogenic Pb complicated the U-Pb systematics of zircons. Since the zircon population of the Red Mountain pluton might exhibit similarly complex systematics, we chose to analyze single zircon crystals. With this approach we expected to determine the crystallization age, and at the same time to document the presence of any inherited components in this youngest, most geochemically evolved pluton of the Laramie Anorthosite Complex.

Geologic framework

The Laramie Anorthosite Complex is exposed over an area of approximately 800 km² in the Laramie Mountains of southeastern Wyoming. It was intruded along a major geologic boundary, the Cheyenne belt, which separates the Archean Wyoming province to the north from the Proterozoic Colorado province to the south (Houston et al., 1979; Duebendorfer and Houston, 1987). The country rocks intruded are Archean orthogneisses and metamorphosed sedimentary rocks and Proterozoic granitic rocks. The anorthosite complex is bounded on the south and east by the Sherman Granite, a regionally extensive anorogenic granite.

The Laramie Anorthosite Complex is one of the few essentially undeformed anorthosite complexes in the world. It includes the classic anorthosite triad of anorthositic rocks, a syenitic suite, and associated K- and Fe-rich granites. The anorthosites and anorthositic gabbros occupy the largest part of the surface exposure and crop out as two lobes separated by a septum of older Proterozoic gneisses and granites. The monzonitic and syenitic rocks occur principally in three satellite plutons around

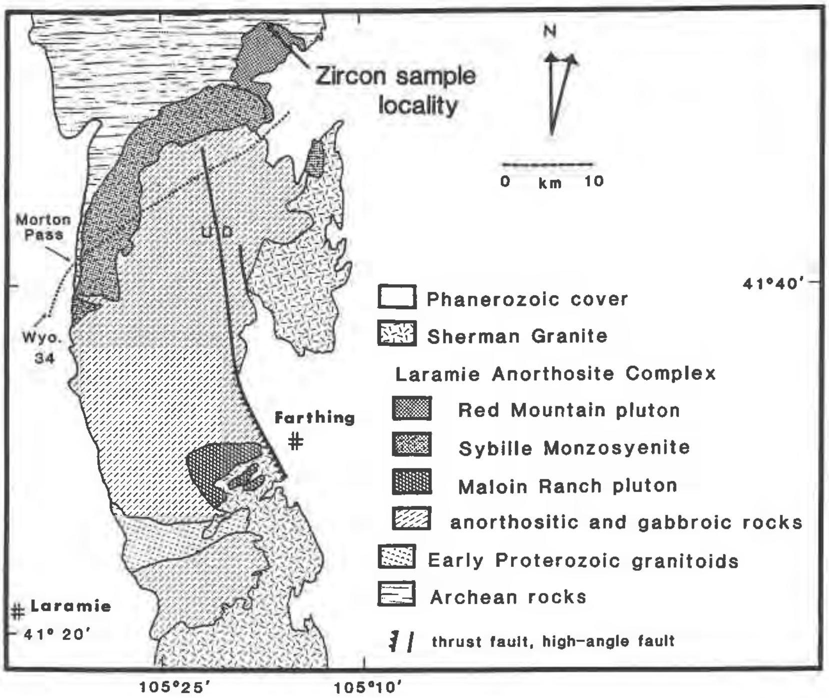

Fig. 1. Generalized geologic map of the Laramie Anorthosite Complex, southeastern Wyoming, showing location of zircon sample from the Red Mountain pluton.

the margins of the anorthosite: the Maloin Ranch pluton to the southeast, the Sybille pluton in the northwest, and the Red Mountain pluton in the northeast (Fig. 1). All of the syenitic rocks have intruded anorthosite, and the Red Mountain pluton has intruded the Sybille pluton. The Red Mountain pluton (30 km^2) is distinguished by extreme Fe enrichment and high REE contents. The pluton is composed of three main units, interpreted as oldest to youngest: a peripheral fayalite monzonite facies, which forms a discontinuous border around the margin of the pluton; a clinopyroxene-quartz monzonite, which is found as a rim inside of the fayalite monzonite; and a biotite-hornblende-quartz syenite, which makes up the central 90% of the body. On the basis of textural relations, Anderson (1990) has interpreted the fayalite monzonite and clinopyroxene-quartz monzonite as cumulates. Monzonite dikes crosscut the pluton. Granite dikes peripheral to the pluton are mineralogically, chemically, and isotopically similar to the Sherman Granite (Anderson, 1990; Geist et al., 1989) and appear to represent Red Mountain pluton magmas contaminated by partial melts from the country-rock pelitic gneisses (Anderson, 1990). Zircon is abundant (up to 0.5 modal percent) in the fayalite monzonite and the clinopyroxene-quartz monzonite, decreasing in abundance in the syenite and granite. Allanite appears in the clinopyroxene-quartz monzonite, in which it makes up to 4% of the rock, and is the main REE-bearing mineral in both the clinopyroxene-quartz monzonite and the biotite-hornblende-quartz syenite. Differentiation index Si/3 − Mg − Ca + K and Fe/Mg ratio increase throughout this sequence. REE contents rise from $[La] = 300 \times [La]_{chondrites}$ in the fayalite monzonite to $[La] = 3000 \times [La]_{chondrites}$ in the clinopyroxene-quartz monzonite, then fall to $[La] = 400 \times [La]_{chondrites}$ in the Red Mountain

Table 1. U-Pb isotopic data

Sample	Size (μm)	Mass (μg)	U (ppm)	Pb_{rad} (ppm)	Pb_{com} (ppm)	^{238}U	^{208}Pb	^{207}Pb	^{206}Pb	^{204}Pb
						(10^{-12} mol corrected for analytical blank)				
2	140 × 70	13.3	61.71	14.50	0.3	3.423	0.0982	0.0754	0.7837	0.00033
8	500 × 100	19.4	79.32	16.53	0.3	6.418	0.1530	0.1234	1.307	0.00042
9	700 × 80	19.2	54.69	13.73	0.4	4.380	0.1489	0.1043	1.063	0.00057
10	380 × 130	22.1	139.24	32.68	0.1	12.835	0.4986	0.2506	2.759	0.00013
11	850 × 140	22.9	49.25	11.68	0.2	4.704	0.1528	0.1016	1.068	0.00038
12	370 × 100	18.3	73.03	17.75	2.0	5.575	0.2259	0.1590	1.362	0.00255

* Measured ratio corrrected for mass fractionation and tracer contributions.
† Analytical uncertainties (95% confidence level) refer to last significant digits of corresponding ratio.
‡ Correlation coefficient $^{207}Pb/^{235}U$ vs. $^{206}Pb/^{238}U$.

granite (Anderson et al., 1988). Zircons analyzed in this study are from the fayalite monzonite facies of the Red Mountain pluton.

Previous age determinations

Age determinations of rocks from the Laramie Anorthosite Complex itself are restricted to U-Pb zircon results reported by Subbarayudu (1975) and Subbarayudu et al. (1975) on zircons separated by F. A. Hills and analyzed by R. E. Zartman. Zircon fractions from two samples of Sybille monzosyenite were nearly concordant and yielded $^{207}Pb/^{206}Pb$ ages of 1432 ± 15 Ma. Zircons from a sample of the Red Mountain pluton gave a $^{207}Pb/^{206}Pb$ age of 1424 ± 15 Ma. The Laramie Anorthosite Complex is older than the Sherman Granite, which intrudes it. The Sherman Granite has been dated at 1430 ± 20 by the Rb-Sr whole-rock method (Zielinski et al., 1981). Aleinikoff (1983) obtained a U-Pb upper-intercept age of 1412 ± 13 Ma on zircons separated from different host minerals of the Sherman Granite. Because of possible Pb loss, he interpreted this as a minimum age.

Analytical procedures

All analytical work was done at the Laboratory for Isotope Geochemistry at the ETH, Zurich. Fresh specimens of Red Mountain fayalite monzonite were collected from a blasted outcrop near the northern margin of the pluton (Fig. 1), and zircons were extracted using conventional heavy liquid and magnetic separation techniques. The zircon separate was mounted in glycerine for microscopic morphological characterization and selection for U-Pb analysis.

The six single crystals chosen for isotopic analysis were cleaned ultrasonically in acetone, then rinsed in distilled water. Each zircon crystal was immersed in cold 1*M* HNO_3 for 5 min, then leached for 30 min in 4.5*M* HCl. To determine if any radiogenic Pb or U was lost from the crystals during the leaching process, the leachates from samples 2, 8, 10, and 11 were analyzed. Amounts of U leached were 0.04% and 0.07% of the U content of samples 2 and 11, respectively, and 0.4% for samples 8 and 10. Contents of radiogenic ^{206}Pb in the leachates of samples 2 and 11 were relatively small (approximately 0.1% of the sample Pb contents), whereas 0.7% and 0.8% were removed from samples 8 and 10, respectively. U and Pb in these leach solutions may have been derived in part from other mineral phases intergrown with the zircon, as suggested by the relatively high apparent Th/U ratios of 2.1 to 4.1 calculated from radiogenic $^{208}Pb/^{206}Pb$ of these leachates. In the case of samples 8 and 10, considerable amounts of common Pb (1.8 and 1.3 ppm, respectively) were removed.

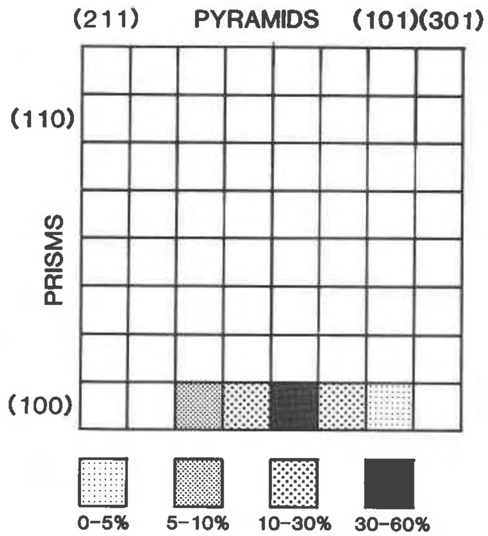

Fig. 2. Typological representation of morphology of the zircons from the fayalite monzonite of the Red Mountain pluton, using the classification diagram of Pupin (1980). The frequency distribution of the zircons is shown by stippled squares. All zircons have only one prism {100}, but the dominance of the two pyramid types varies within the population.

Analytical procedures followed closely those given by Bossart et al. (1986), using Krogh's (1973) techniques. Zircons were spiked with approximately 70 μL of a tracer enriched in ^{205}Pb (1 ng ^{205}Pb/g) and ^{233}U and ^{235}U (100 ng each, allowing control of mass-fractionation bias for U). The total Pb blank is 17 ± 5 pg; blank ratios are $^{208}Pb/^{206}Pb = 2.066 \pm 0.023$, $^{207}Pb/^{206}Pb = 0.853 \pm 0.016$, and $^{204}Pb/^{206}Pb = 0.0551 \pm 0.0011$, and correlation coefficients of $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ vs. $^{204}Pb/^{206}Pb$ are 0.64 and 0.56, respectively (uncertainties correspond to the 95% confidence level). Isotopic measurements were performed on a Varian MAT Tandem mass spectrometer.

Table 1—*Continued*

$^{206}Pb/^{204}Pb$* (observed)	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	Rho‡
	(isotopic ratios corrected for blank and common Pb)†				
539	0.1111(12)	0.09036(47)	2.833(17)	0.22737(60)	0.54
838	0.10613(75)	0.08994(31)	2.512(16)	0.2026(10)	0.84
624	0.1219(14)	0.09064(56)	3.007(21)	0.24060(50)	0.53
2148	0.17920(37)	0.09018(16)	2.6712(72)	0.21482(39)	0.74
704	0.13102(84)	0.09016(33)	2.807(14)	0.22578(64)	0.66
372	0.1016(12)	0.09053(51)	2.958(23)	0.2370(11)	0.69

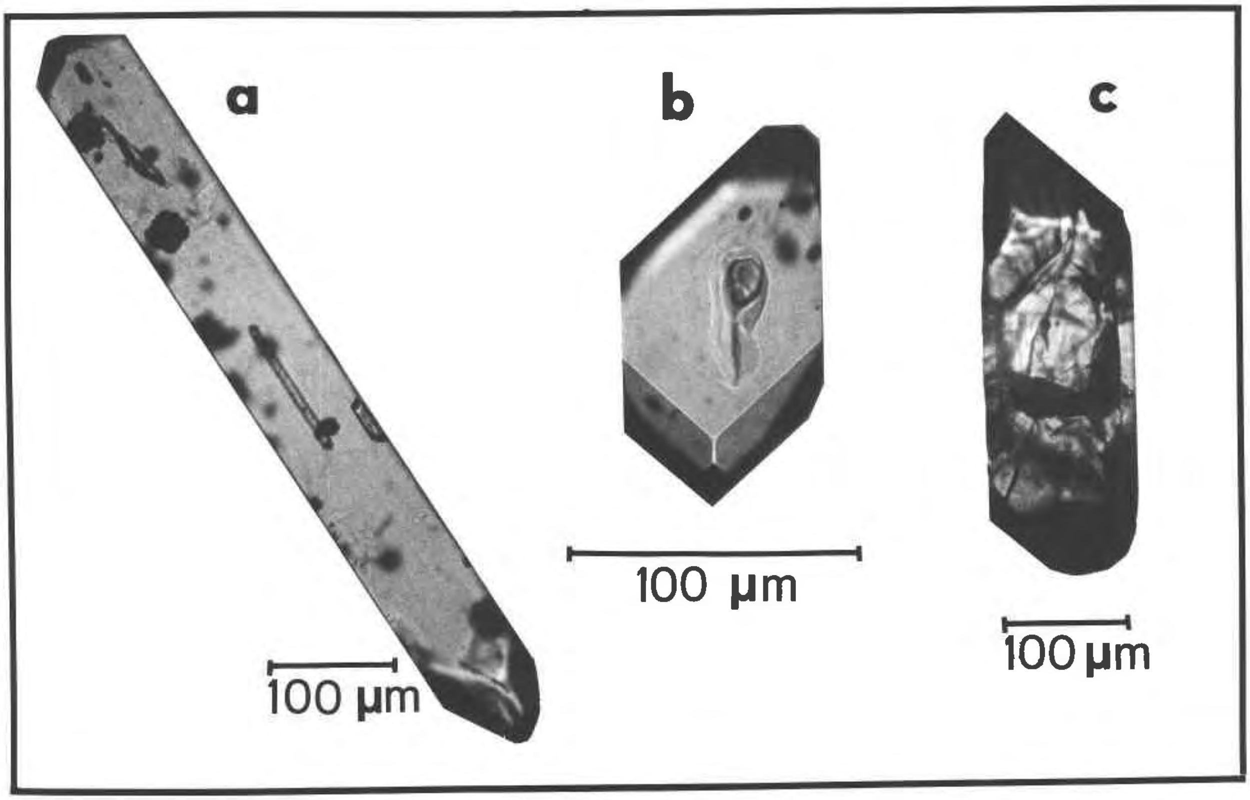

Fig. 3. Photomicrographs of three of the six zircon crystals analyzed isotopically. The bar in all photographs is 100 μm long. (**a**) Grain 9. This elongate zircon is typical of most of the population. Grains 8, 11, and 12 are similar in shape and size. (**b**) Grain 2. (**c**) Grain 10. This crystal was the only one of the population examined that had prominent zoning and a darker yellow color. It has a much higher U content than the other crystals analyzed.

U and Pb were loaded separately with silica gel–H_3PO_4. Overall analytical uncertainties given on Table 1 correspond to the 95% confidence level.

Corrections for common Pb content are based on model III of Cumming and Richards (1975); adopting an age of 1.44 Ga, the model yields isotopic ratios of $^{208}Pb/^{204}Pb = 35.93$, $^{207}Pb/^{204}Pb = 15.44$, and $^{206}Pb/^{204}Pb = 16.23$.

Results

Zircon morphology

All zircon crystals are euhedral and colorless. Most are elongate, and no cores were seen in any of the grains. Apatite mineral inclusions and fluid inclusions were present in nearly all of the crystals. The inclusions commonly had negative zircon morphology. Electron-microprobe analysis of polished grains revealed apatite and trace components of pyrrhotite, but no other mineral phases were identified.

The zircon crystals were of similar morphology, all having one {100} prism and two pyramids ({101} and {211}) of approximately equal dominance. According to Pupin's (1980) scheme (Fig. 2), zircons of this morphology are characteristic of crystallization at temperatures of approximately $\geq$900 °C and of magmas of monzonite, syenite, and alkali granite composition. This estimate of crystallization temperature agrees strikingly with the results of feldspar geothermometry reported by Anderson et al. (1987) of 900 $\pm$ 30 °C.

The lack of zircon crystals with inherited cores in the Red Mountain fayalite monzonite contrasts with the abundance of inherited cores documented in Sherman Granite zircons by Aleinikoff (1983). This lack may be explained either as the result of dissolution of any zircon incorporated into Red Mountain magmas from the country rock or by the absence of crustal contamination of the magma. Hot, mafic magmas may dissolve considerable amounts of zircon (Watson and Harrison, 1983), and the liquid that generated the fayalite monzonite cumulate probably was undersaturated with respect to Zr. Nd and Sr isotopic data for the Red Mountain pluton place limits on the amount of country rock assimilated. Geist et al. (1990) have demonstrated that the Red Mountain, Sybille, and Maloin plutons have distinct initial Sr and Nd isotopic characteristics, and they concluded that each pluton evolved independently of the other syenitic bodies. The Red Mountain fayalite monzonite has the most radiogenic Nd-isotope ratio and one of the least radiogenic Sr-isotope ratios of any sample from these syenitic plutons. These results suggest that the Red Mountain pluton

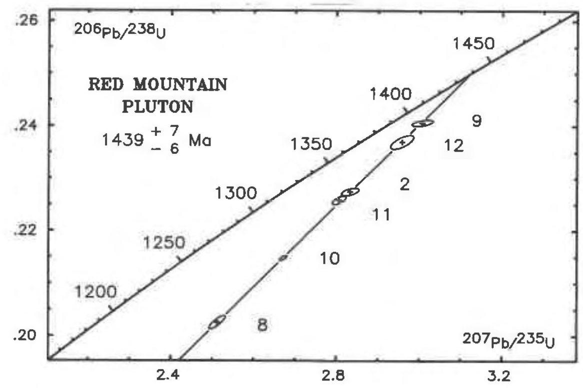

Fig. 4. Concordia representation of the Red Mountain zircon crystals analyzed. The discordia intersects the concordia at 1439^{+7}_{-6} Ma and 102 ± 64 Ma. The error ellipses and uncertainties of the ages obtained by the intercepts of the error envelopes with the concordia curve are at the 95% confidence level.

was emplaced at its present level without having assimilated as much continental crust as the other syenitic plutons; hence it should display minimal zircon inheritance.

Age determination

Six crystals were chosen for single-grain U-Pb analysis. They varied in weight from 13 to 23 μg and included 5 clear, unzoned zircons and 1 yellow, zoned crystal (Fig. 3). The U-Pb results obtained are listed on Table 1. In the conventional concordia representation (Fig. 4), the U-Pb results form a slightly discordant array. As is commonly observed, those zircons with the highest U contents are the most discordant. A best-fit line (York, 1969) intersects the concordia curve at 1439^{+7}_{-6} Ma and 102 ± 64 Ma (external errors at 95% confidence level; MSWD = 0.34). Combining data from leached zircon samples and their leach solutions, or using Stacey and Kramers (1975) Pb-evolution model for initial-Pb correction, does not significantly alter the intercept ages. The upper-intercept age is interpreted as the crystallization age of the Red Mountain pluton. The less precise lower intercept reflects loss of radiogenic Pb during one or several episodes after crystallization. The lower-intercept age is compatible with Pb loss during Laramide uplift at approximately 60 Ma (Blackstone, 1975), but could also have been influenced by the uplift of the ancestral Rocky Mountains at ca. 310 Ma (Mallory, 1972).

The inferred crystallization age of 1439 Ma is within error of the U-Pb ages for the Sybille and Red Mountain plutons reported by Subbarayudu (1975) and is only slightly older than the 1412 ± 13 Ma minimum age suggested for the Sherman Granite (Aleinikoff, 1983), confirming a close temporal association of the syenitic rocks and the Sherman Granite (Fig. 5).

The U content of the zircons is low, ranging between 49 and 139 ppm. Similarly low U contents were documented for zircons from monzonoritic rocks associated with anorthosite bodies of the South Rogaland area of Norway (Duchesne et al., 1987). It is possible that low-U zircons are characteristic of syenitic rocks associated with anorthosites. They may arise either by melting of a U-poor source or by crystallization of a U-bearing phase during earlier stages in the evolution of these magmas. If the latter case applies to the Red Mountain pluton, its high REE contents suggest that whatever phase or phases depleted the magma in U, they did not produce a similar depletion in REE content.

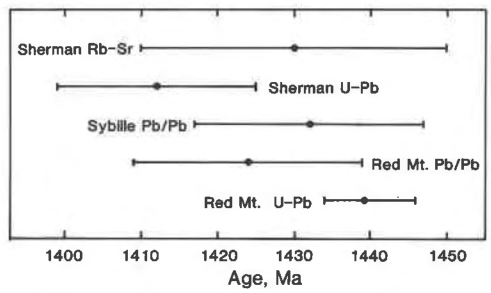

Fig. 5. Comparison of age determinations for the Sherman Granite and the Sybille and Red Mountain plutons of the Laramie Anorthosite Complex. Sources of data are Sherman Rb-Sr whole-rock age, Zieliniski et al. (1981); Sherman U-Pb zircon minimum age, Aleinikoff (1983); Sybille and Red Mountain Pb-Pb ages, Subbarayudu (1975) and Subbarayudu et al. (1975); and Red Mountain U-Pb zircon age, this study.

Conclusions

The U-Pb single-zircon upper-concordia intercept age of 1439^{+7}_{-6} Ma for the Red Mountain pluton not only establishes the crystallization age of that pluton, but also provides a younger age limit for the rest of the syenitic and anorthositic rocks of the Laramie Anorthosite Complex. The lack of inherited cores and the low U contents of the Red Mountain zircons distinguishes them from zircons from the Sherman Granite, which is spatially and temporally associated with the anorthosite complex. Although geochemically the most evolved pluton of the Laramie Anorthosite Complex, the petrogenesis of the Red Mountain fayalite monzonite appears to have been different from that of the Sherman Granite.

Acknowledgments

We are very grateful to Professor R. H. Steiger, who kindly arranged a visiting position for C.D.F. at the ETH during autumn 1987 and made this research possible. Kathleen Simmons and Ken Ludwig are thanked for their helpful reviews of this manuscript. Partial funding of this project was provided by a University of Wyoming Arts and Sciences Basic Research Grant and by NSF EAR-8617812 and EAR-8816604.

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Manuscript received February 1, 1989
Manuscript accepted September 29, 1989