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THERMAL AND TECTONIC HISTORY OF THE MINERAL MOUNTAINS INTRUSIVE COMPLEX

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ABSTRACT

Study of the Mineral Mountains intrusive complex was undertaken to decipher interrelationships of intrusion, uplift rate and structural control as related to the Roosevelt Hot Springs geothermal system. Results of fission track and K-Ar dating show that different units of the intrusive complex underwent similar cooling histories. Uplift rates calculated for the north (0.25 mm/yr) and central (0.5 mm/yr) portions differ substantially. This difference in uplift rate may have accounted for the development of faulting which has been important as structural controls on the geothermal system.

INTRODUCTION

Portions of the Mineral Mountains intrusive complex serve as host rocks for the Roosevelt Hot Springs geothermal system (Nielson et al., 1978). During our studies of the Roosevelt system it has become evident that thermal events which predate the present geothermal system have reset K-Ar dates of much of the intrusive complex as well as Precambrian rocks which also host portions of the geothermal reservoir. In addition, geologic evidence suggests that the intrusive complex has experienced very rapid uplift during its emplacement history. Faults developed during this rapid uplift are responsible for forming the structural controls of the geothermal reservoir.

This study was initiated to assess the interrelationships of intrusion, uplift rate, and structural development to better understand the genesis of the Roosevelt Hot Springs geothermal system.

The samples chosen for the present study represent the spectrum of rocks which are contained within the Mineral Mountains intrusive complex. These lithologies are shown in Figure 1. The northernmost unit sampled is also one of the oldest phases of the intrusive complex. Aleinikoff et al. (in press) have shown that this unit has a complex history but probably was emplaced 25 ± 4 m.y. ago. The second unit to be discussed is a quartz monzonite (Tqm) which forms a large pluton in the central portion of the Mineral Mountains. Most data indicate that the age of this unit is 20-22 m.y. The southernmost unit sampled for this study (Tbg) is a biotite granite from the southern portion of the intrusive complex. Its age is perhaps as young as 12 m.y.

ANALYTICAL TECHNIQUES

A number of samples from the Mineral Mountains were dated using both potassium-argon and fission track techniques. Mineral separates of hornblende, biotite, zircon and apatite were obtained using heavy liquid and magnetic separator techniques. Purity of separates was usually better than 98-99 percent.

Potassium-argon dating was accomplished using the standard ultra-high vacuum fusion method described in Dalrymple and Lanphere (1969). Argon isotopic composition was determined on a Reynolds-type mass spectrometer. Potassium analyses were done on a flame photometer using natural mineral standards. Uncertainties in the potassium-argon ages were calculated by the technique of Dalrymple and Lanphere (1969). Constants used in calculating ages were $\lambda_\varepsilon=0.581^{-10}$ yr^{-1}, $\lambda_\beta=4.962x10^{-10}$ yr^{-1} and $^{40}K/K=1.167x10^{-4}$ mole/mole (Steiger and Jäger, 1978). Results of potassium-argon dating are given in Table 1.

Table 1. Potassium-argon dates from the Mineral Mountains, Utah

Sample Number	Mineral	Unit	Weight(g)	%K	$^{40}Ar^*$, Mol/gm ($x10^{11}$)	% $^{40}Ar_{at}$	T m.y.	±S m.y.
79-1	Biotite	Tbg	0.40065	7.21	13.082	62	10.4	0.5
79-1	Hornblende	Tbg	2.00465	0.77	1.588	69	11.8	0.6
79-153	Biotite	hd	0.50100	7.40	17.473	57	13.6	0.6
79-153	Hornblende	hd	2.50158	0.79	3.744	33	27.2	0.9
79-154	Biotite	Tqm	0.61965	7.00	14.777	49	12.1	0.5

Zircon and apatite separates were dated using techniques described by Naeser (1978). Samples were irradiated in the lazy susan of the TRIGA research reactor of the U.S. Geological Survey at

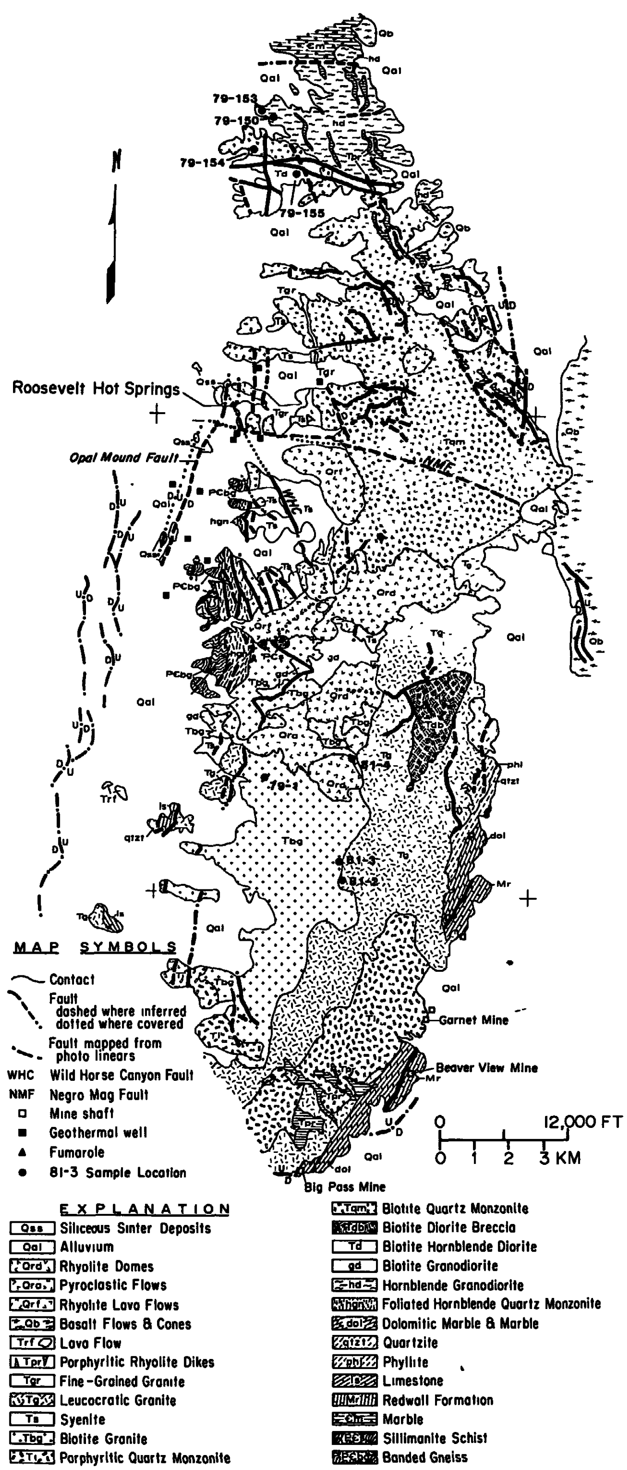

Figure 1. Geologic map of the Mineral Mountains intrusive complex, Utah. Sample locations for dating indicated by solid circles.

Denver, Colorado. Zircons were dated using the external detector method while apatites were dated by the population method. The decay constant used for spontaneous fission of ^{238}U was $\lambda_F = 7.03 \times 10^{-17}$ yr^{-1} (Naeser, 1979). The uncertainty for each fission track date was derived by the method given by Johnson et al. (1979). Results of fission track dating are given in Table 2.

RESULTS OF MINERAL DATING

Mineral dating of various units of the Mineral Mountains intrusive complex shows cooling histories which bear the effects of both simple cooling and tectonic uplift. The technique employed here is that of Harrison et al. (1979) and Harrison and McDougall (1980). Mineral ages are plotted against estimates of closure temperatures for the particular mineral in question. Estimates of closure temperatures are taken from Harrison and McDougall (1980). The closure temperatures used are: hornblende 530±40°C, biotite 280±40°C, zircon 175±25°C and apatite 105±10°C. It is important to note that these closure temperatures are dependent on the cooling history of a sample. Cooling rates on which the above estimates are based are: hornblende 100°C/m.y. and the other minerals 10°C/m.y. Justification for selection of these closure temperatures may be found in Harrison et al. (1979) and Harrison and McDougall (1980).

Cooling histories for three units of the Mineral Mountains intrusive complex are plotted in Figure 2 (sample locations are given on Figure 1). Sample 79-153, a hornblende granodiorite thought to be the northernmost unit of the intrusive complex, shows emplacement at 27 m.y. followed by slow cooling at a rate of approximately 18°C/m.y. until 9 m.y. ago. At this time cooling rapidly increased. After this interval of rapid cooling the rate slowed considerably up to the present.

Sample 79-1 shows a markedly different cooling history than sample 79-153. Here after initial emplacement at 12 m.y., rapid cooling took place followed by slower cooling until around 9 m.y. at which time cooling rate increased. After this interval of rapid cooling the rate decreased again as with sample 79-153.

The cooling history of a third sample is included here for comparison. Sample 79-154 is from the quartz monzonite that makes up a considerable portion of the intrusive complex. No emplacement date is available for this unit but cooling from the biotite closure temperature is similar to the two previously cited samples.

Apparent uplift rates for the northern and central parts of the intrusive complex may be obtained from samples collected along traverses designed for this purpose. The location of these traverses is given in Figure 1. Apparent uplift rates derived from both zircon and apatite ages are given in Table 3. It is clear that the

Table 2. Fission track dates from the Mineral Mountains, Utah

Sample Number	Mineral	ρ_S tracks/cm^2	ρ_S tracks	ρ_I tracks/cm^2	ρ_I tracks	Φ neutrons/cm^2	Φ tracks	T m.y.	±S m.y.	Number of Grains Counted	U,ppm
79-1	Zircon	$1.37x10^6$	92	$8.84x10^6$	297	$8.99x10^{14}$	1290	8.4	0.6	4	260
79-1	Apatite	$3.26x10^4$	75	$2.10x10^5$	483	$8.90x10^{14}$	1290	8.3	1.0	100/100	5
79-150	Apatite	$7.38x10^4$	85	$4.58x10^5$	366	$8.84x10^{14}$	1280	8.5	1.0	50/50	15
79-153	Zircon	$1.05x10^6$	64	$6.58x10^6$	200	$8.70x10^{14}$	1280	8.3	0.7	5	195
79-153	Apatite	$8.15x10^4$	94	$5.24x10^5$	604	$8.78x10^{14}$	1280	8.2	0.9	50/50	15
79-154	Zircon	$2.38x10^6$	178	$15.3x10^6$	573	$9.06x10^{14}$	1290	8.4	0.5	4	450
79-154	Apatite	$5.57x10^4$	128	$3.66x10^5$	841	$8.95x10^{14}$	1280	8.1	0.8	100/100	10
79-155	Zircon	$1.23x10^6$	172	$8.03x10^6$	560	$9.45x10^{14}$	1290	8.7	0.7	5	240
79-155	Apatite	$3.96x10^4$	91	$2.40x10^5$	553	$8.78x10^{14}$	1280	8.7	1.0	100/100	5
81-2	Zircon	$2.94x10^6$	329	$16.97x10^6$	950	$8.60x10^{14}$	1280	8.9	0.4	5	500
81-2	Apatite	$3.52x10^4$	18	$2.13x10^5$	109	$8.83x10^{14}$	1280	8.7	2.2	50/50	5
81-3	Zircon	$2.94x10^6$	165	$17.48x10^6$	492	$8.63x10^{14}$	1280	8.7	0.5	5	510
81-3	Apatite	$4.04x10^4$	93	$2.34x10^5$	538	$8.87x10^{14}$	1280	9.1	1.0	100/100	5
81-4	Zircon	$1.58x10^6$	189	$9.81x10^6$	590	$8.67x10^{14}$	1280	8.3	0.5	5	285
81-4	Apatite	$3.34x10^4$	77	$2.19x10^5$	504	$8.93x10^{14}$	1280	8.2	1.0	100/100	5

Neutron fluence, Φ, calculated using NBS glass standard 962 calibrated against Cu radiation.
For both spontaneous (ρ_S) and induced (ρ_I) track-densities both the density and actual number of tracks counted is given.
Uranium contents are rough estimates only.

apparent uplift rates derived from zircon data are twice those of apatites. This is attributable to the responsiveness of the two minerals to the combined effect of uplift and downward relaxation of isotherms. In order for an apparent uplift rate to equal the true uplift rate of a block of rock, isotherms must remain at a fixed level in the crust and denudation must equal uplift. Uplift data from apatite ages do match quite closely true uplift rates whereas uplift rates from zircon data are influenced strongly by relaxation of isotherms. This phenomenon has been demonstrated clearly by the incisive theoretical study of Parrish (1981). It is also apparent from Table 3 that the central portion of the Mineral Mountains has experienced more rapid apparent uplift than the northern portion. This is reflected in the more rugged topography of the central portion of the range.

Table 3. Apparent uplift rates for the north and central portions of the Mineral Mountains intrusive complex, Utah.

Sample	Apatite Age (m.y.)	Zircon Age (m.y.)	Elevation (Meters)
Northern Mineral Mountains			
79-150	8.5	--	1890
79-153	8.2	8.3	1830
79-154	8.1	8.4	1840
79-155	8.7	8.7	1990
Uplift Rate:	0.25 mm/yr	0.42 mm/yr	
Central Mineral Mountains			
79-1	8.3	8.4	2120
81-2	9.0	8.9	2760
81-3	9.1	8.7	2440
81-4	8.2	8.3	2130
Uplift Rate:	0.56mm/yr	1.08 mm/yr	

Uplift rates calculated from linear least squares regression of the data.

It is of interest that the apparent uplift rates are in reasonable agreement with sedimentation rates of 0.024 mm/yr to 0.132 mm/yr calculated by Hulen (1978) for the Roosevelt Hot Springs area.

DISCUSSION

This study has demonstrated that rapid but differential uplift rates have affected the Mineral Mountains intrusive complex. These data support field observations which suggest that the entire complex has ascended through the crust in a diapiric fashion throughout its evolution. The abrupt increase in rates at about 8-8.5 m.y. ago is thought to be the cause of low-angle denudation faulting which is responsible for much of the structural controls on the geothermal reservoir. The difference in uplift rates within the range may be responsible for east-west faulting, such as the Negro Mag Fault (Fig. 1), which is also an important reservoir control.

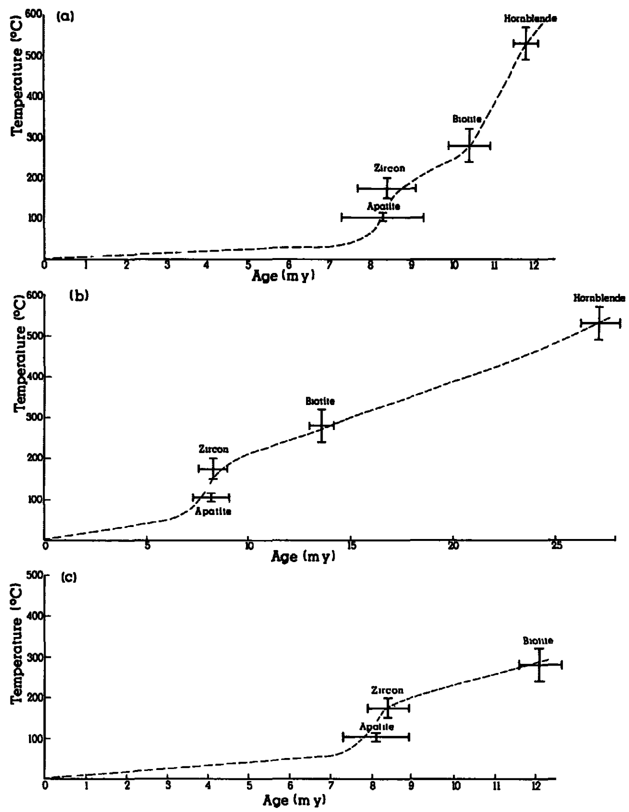

Figure 2. Cooling histories for three samples from the Mineral Mountains intrusive complex, Utah. K-Ar and fission track dates from Table 1 and Table 2 are plotted against closure temperature discussed in text. (a) sample 79-1 Biotite granite (Tbg); (b) sample 79-153 Hornblende granodiorite (hd); (c) 79-154 Quartz monzonite (Tqm). Error bars are those quoted in Tables 1, 2 and text. Dashed lines represent hypothetical cooling curve followed by each sample.

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