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THERMAL AND TECTONIC HISTORY OF THE MINERAL MOUNTAINS INTRUSIVE COMPLEX

Stanley H. Evans, Jr. and Dennis L. Nielson
Earth Science Laboratory Division
University of Utah Research Institute
Salt Lake City, Utah 84108

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 southermost 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 separation 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 $\lambda_e = 0.581 \times 10^{-10}$ yr$^{-1}$, $\lambda_a = 4.962 \times 10^{-10}$ yr$^{-1}$ and $40\text{K}/K = 1.167 \times 10^{-4}$ mole/mole (Steiger and Jäger, 1978). Results of potassium-argon dating are given in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Number</th>
<th>Mineral</th>
<th>Unit</th>
<th>Weight (g)</th>
<th>$%K$ ($\times 10^{-1}$)</th>
<th>Age (m.y.)</th>
<th>U (m.y.)</th>
<th>T ($\times 10^{-1}$)</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>79-1</td>
<td>Biotite</td>
<td>Tbg</td>
<td>0.40065</td>
<td>7.21</td>
<td>13.082</td>
<td>62</td>
<td>10.4</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>79-1</td>
<td>Hornblende</td>
<td>Tbg</td>
<td>2.00465</td>
<td>0.77</td>
<td>1.588</td>
<td>69</td>
<td>11.8</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>79-153</td>
<td>Biotite</td>
<td>hd</td>
<td>0.50100</td>
<td>0.79</td>
<td>3.744</td>
<td>33</td>
<td>27.2</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>79-153</td>
<td>Hornblende</td>
<td>hd</td>
<td>2.50158</td>
<td>0.79</td>
<td>3.744</td>
<td>33</td>
<td>27.2</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>79-154</td>
<td>Biotite</td>
<td>Tqm</td>
<td>0.61965</td>
<td>7.00</td>
<td>14.777</td>
<td>49</td>
<td>12.1</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

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

EXPLANATION
Siliceus Sinter Deposits
Alluvium
Pyroclast Flows
Rhyolite Lovo Flows
Basalt Flows
Cones
Lovo Flow
Porphyrltic Rhyolite Dikes
Fine -Groinad Gronite
Leueocratic Granite
Syenite
Biotite Granite
Porphyritic Quartz Monzonite
big Pass Mine
Denver View Mine
Garnet Mine
Map Symbols
a) Fault dashed where inferred
dotted where covered
b) Fault mapped from
photo lines
WNC Wild horse Canyon Fault
MNP Negro Mog Fault
c) Mine shaft
La) Geothermal well
F) Fumarole
e) B-1 Sample Location
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 238U 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 tem-
peratures 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 17525°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 approx-
imately 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 consid-
erable 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

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Mineral</th>
<th>$N_s$ tracks/cm²</th>
<th>$P_s$ tracks</th>
<th>$N_I$ tracks/cm²</th>
<th>$P_I$ tracks</th>
<th>Neutrons/cm²</th>
<th>Tracks/m.y.</th>
<th>Tracks m.y.</th>
<th>Counted U ppm</th>
<th>$N_s$ Number of Grains</th>
</tr>
</thead>
<tbody>
<tr>
<td>79-1</td>
<td>Zircon</td>
<td>1.37 x 10⁶</td>
<td>8.84 x 10⁶</td>
<td>297</td>
<td>8.99 x 10⁴</td>
<td>1290</td>
<td>8.4</td>
<td>0.6</td>
<td>4</td>
<td>260</td>
</tr>
<tr>
<td>79-1</td>
<td>Apatite</td>
<td>3.26 x 10⁷</td>
<td>2.10 x 10⁷</td>
<td>483</td>
<td>8.90 x 10⁴</td>
<td>1290</td>
<td>8.3</td>
<td>1.0</td>
<td>100/100</td>
<td>5</td>
</tr>
<tr>
<td>79-150</td>
<td>Apatite</td>
<td>7.38 x 10⁴</td>
<td>4.58 x 10⁵</td>
<td>366</td>
<td>8.84 x 10⁴</td>
<td>1280</td>
<td>8.5</td>
<td>1.0</td>
<td>50/50</td>
<td>15</td>
</tr>
<tr>
<td>79-153</td>
<td>Zircon</td>
<td>1.05 x 10⁴</td>
<td>6.58 x 10⁴</td>
<td>200</td>
<td>8.70 x 10⁴</td>
<td>1280</td>
<td>8.3</td>
<td>0.7</td>
<td>5</td>
<td>195</td>
</tr>
<tr>
<td>79-153</td>
<td>Apatite</td>
<td>8.15 x 10⁴</td>
<td>5.24 x 10⁵</td>
<td>604</td>
<td>8.78 x 10⁴</td>
<td>1280</td>
<td>8.2</td>
<td>0.9</td>
<td>50/50</td>
<td>15</td>
</tr>
<tr>
<td>79-154</td>
<td>Zircon</td>
<td>2.38 x 10⁶</td>
<td>15.3 x 10⁴</td>
<td>573</td>
<td>9.06 x 10⁴</td>
<td>1290</td>
<td>8.4</td>
<td>0.5</td>
<td>4</td>
<td>450</td>
</tr>
<tr>
<td>79-154</td>
<td>Apatite</td>
<td>7.38 x 10⁴</td>
<td>5.24 x 10⁵</td>
<td>604</td>
<td>8.78 x 10⁴</td>
<td>1280</td>
<td>8.2</td>
<td>0.9</td>
<td>50/50</td>
<td>15</td>
</tr>
<tr>
<td>79-155</td>
<td>Zircon</td>
<td>1.23 x 10⁶</td>
<td>8.03 x 10⁵</td>
<td>560</td>
<td>9.45 x 10⁴</td>
<td>1290</td>
<td>8.7</td>
<td>0.7</td>
<td>5</td>
<td>240</td>
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<tr>
<td>79-155</td>
<td>Apatite</td>
<td>3.96 x 10⁴</td>
<td>2.40 x 10⁵</td>
<td>553</td>
<td>8.78 x 10⁴</td>
<td>1280</td>
<td>8.7</td>
<td>1.0</td>
<td>100/100</td>
<td>10</td>
</tr>
<tr>
<td>81-2</td>
<td>Zircon</td>
<td>2.94 x 10⁶</td>
<td>16.97 x 10⁵</td>
<td>950</td>
<td>8.60 x 10⁴</td>
<td>1280</td>
<td>8.9</td>
<td>0.4</td>
<td>5</td>
<td>500</td>
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<tr>
<td>81-2</td>
<td>Apatite</td>
<td>3.52 x 10⁷</td>
<td>2.13 x 10⁷</td>
<td>109</td>
<td>8.83 x 10⁴</td>
<td>1280</td>
<td>8.7</td>
<td>2.2</td>
<td>50/50</td>
<td>5</td>
</tr>
<tr>
<td>81-3</td>
<td>Zircon</td>
<td>2.94 x 10⁷</td>
<td>17.48 x 10⁵</td>
<td>492</td>
<td>8.63 x 10⁴</td>
<td>1280</td>
<td>8.7</td>
<td>0.5</td>
<td>5</td>
<td>510</td>
</tr>
<tr>
<td>81-3</td>
<td>Apatite</td>
<td>4.04 x 10⁷</td>
<td>2.34 x 10⁷</td>
<td>538</td>
<td>8.87 x 10⁴</td>
<td>1280</td>
<td>9.1</td>
<td>1.0</td>
<td>100/100</td>
<td>5</td>
</tr>
<tr>
<td>81-4</td>
<td>Zircon</td>
<td>1.58 x 10⁷</td>
<td>9.81 x 10⁶</td>
<td>590</td>
<td>8.67 x 10⁴</td>
<td>1280</td>
<td>8.3</td>
<td>0.5</td>
<td>5</td>
<td>285</td>
</tr>
<tr>
<td>81-4</td>
<td>Apatite</td>
<td>3.34 x 10⁷</td>
<td>2.19 x 10⁷</td>
<td>504</td>
<td>8.93 x 10⁴</td>
<td>1280</td>
<td>8.2</td>
<td>1.0</td>
<td>100/100</td>
<td>5</td>
</tr>
</tbody>
</table>

Neutron fluence, $\phi$, calculated using NBS glass standard 962 calibrated against Cu radiation. For both spontaneous ($P_s$) and induced ($P_I$) 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.

<table>
<thead>
<tr>
<th>Northern Mineral Mountains</th>
<th>Apatite Age (m.y.)</th>
<th>Zircon Age (m.y.)</th>
<th>Elevation (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 79-150</td>
<td>8.5</td>
<td>--</td>
<td>1890</td>
</tr>
<tr>
<td>Sample 79-153</td>
<td>8.2</td>
<td>8.3</td>
<td>1830</td>
</tr>
<tr>
<td>Sample 79-154</td>
<td>8.1</td>
<td>8.4</td>
<td>1840</td>
</tr>
<tr>
<td>Sample 79-155</td>
<td>8.7</td>
<td>8.7</td>
<td>1990</td>
</tr>
<tr>
<td>Uplift Rate: 0.25 mm/yr</td>
<td>0.42 mm/yr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Central Mineral Mountains</th>
<th>Apatite Age (m.y.)</th>
<th>Zircon Age (m.y.)</th>
<th>Elevation (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 79-1</td>
<td>8.3</td>
<td>8.4</td>
<td>2120</td>
</tr>
<tr>
<td>Sample 81-2</td>
<td>9.0</td>
<td>8.9</td>
<td>2760</td>
</tr>
<tr>
<td>Sample 81-3</td>
<td>9.1</td>
<td>8.7</td>
<td>2440</td>
</tr>
<tr>
<td>Sample 81-4</td>
<td>8.2</td>
<td>8.3</td>
<td>2130</td>
</tr>
<tr>
<td>Uplift Rate: 0.56 mm/yr</td>
<td>1.08 mm/yr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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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REFERENCES


