The Geochronology of the Ayer Granite
in the Wachusetts - Marlborough Tunnel
Clinton, Mass.

by

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Abstract

The Ayer Granite, one of three granitic bodies penetrated by the Wachusetts - Marlborough Tunnel, exhibits an age of $460 \pm 150$ M.Y. The Ayer has suffered sericitization and secondary calcite enrichment producing a greater scatter in the data and a larger uncertainty in the age than is generally the case.
Fr James Skehan S.J. of Boston College generously donated the available tunnel samples of all three granites from which five Ayer Granite samples were used.

Robert Novotny of the U.S.G.S. provided one surface sample he collected from the Bolton Station Area.

The work of Lincoln Hanford concerning the Andover and Muscovite Granites (unpublished as yet) was considered in preparing the conclusion of this paper.
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Part I - Setting

Introduction

The eight mile Wachusetts - Marlborough Tunnel lies mostly in a faulted zone of schists, amphibolites, quartzites, and other meta-sediments. The tunnel also penetrates three granitic bodies: the Ayer Granite, the Muscovite Granite, and the Gospel Hill Granite Gneiss. The location of the tunnel and the entry way shaft A are in the SE portion of the map in Plate 1.

Although the tunnel was not sampled with this particular project in mind, it was deemed of sufficient interest to attempt to construct a Rb-Sr whole rock isochron for one or more of the tunnel granites. Time permitted the completion of only one isochron although preliminary X-ray work was done on all three. This work is shown in Table 1.

The Ayer was chosen for this investigation because of:
1) its accepted igneous origin (Jahns, 1942), (2) its four-fold Rb-Sr ratio (a deceptive criterion as it turned out), (3) previous age work done on the Muscovite Granite by Lincoln Hanford at M.I.T., and (4) the definition of the Gospel Hill Gneiss as a metamorphic granite by Hansen (1966).

Petrology

The Ayer has two facies, one porphyritic and the other nonporphyritic. Hansen (1956) states that the mineral composition is orthoclase, quartz, albite, accessory biotite, muscovite, chlorite, and apatite. The phenocrysts are orthoclase, commonly twinned and slightly perthitic.

The Ayer in the tunnel consists of both facies. The 50 ft
of Ayer adjacent to the contact with the Nashoba Formation is mostly the fine grained variety with a few porphyritic veins. The rest of the Ayer has large, relatively unaltered, microcline phenocrysts, and a matrix of medium grained, sericitized oligoclase or andesine, quartz, chlorite, muscovite, epidote, zircon (showing pleochroic halos), and secondary calcite.

Sampling

The Ayer is difficult to sample because all of the available outcrops have undergone fairly intense chemical weathering. The tunnel samples all appeared to be quite fresh. It proved difficult to obtain a complementary suite of surface rocks.

Five tunnel samples, two from within the porphyry and three from within the finer grained area were available. The Scredd adjacent to Shaft A contained fresh Ayer from which a few samples were taken to supplement the five tunnel samples, even though their exact location from within the tunnel was not known. A few additional surface rocks were selected in an attempt to see how compatible the data from the tunnel would be with the data from the surface samples. These were obtained from an outcrop near the Bolton Station Bench Mark shown in the NE portion of the map in Plate 1.

Previous Work

While nothing has yet been published concerning the tunnel or the age of the Ayer, Fr James Skehan, S.J. of Boston College has reported in an N.S.F. proposal unpublished K-Ar and Rb-Sr mineral ages done by the U.S.G.S. These ages of 190 M.Y. (surface samples) and 150 M.Y. (subsurface samples) indicate Mesozoic activity. Work in an adjoining area on the Andover Granite done by Lincoln Hanford at M.I.T. (unpublished) indicates igneous activity in this area during the early Ordovician.
Plate 1
Map of Clinton, Mass. Showing the Tunnel and the Bolton Station Bench Mark

Scale 1: 24000
Part II- Rb-Sr Whole Rock Age Measurement

Physical and Mathematical Basis

The equation used to calculate Rb-Sr whole rock ages is derived in Appendix I. It is:

\[ \frac{\text{Sr}^{87}}{\text{Sr}^{86}} = \left( \frac{\text{Sr}^{87}}{\text{Sr}^{86}} \right)_0 + \frac{\text{Rb}^{87}}{\text{Sr}^{86}} (e^{\lambda t} - 1) \]

This is a linear equation of the form:

\[ y = a + bx \]

where:

- \( y = \frac{\text{Sr}^{87}}{\text{Sr}^{86}} \) and is a measured quantity.
- \( a = \left( \frac{\text{Sr}^{87}}{\text{Sr}^{86}} \right)_0 \) and is the unmeasurable ratio that existed at the time the rock formed and is called the initial ratio.
- \( b = (e^{\lambda t} + 1) \) and is the slope of the equation. \( \lambda \), the decay constant, = \((\ln2)/T\) where \( T \) is the half life.
- \( x = \frac{\text{Rb}^{87}}{\text{Sr}^{86}} \) and is a measured quantity.

\( \frac{\text{Sr}^{87}}{\text{Sr}^{86}} \) and \( \frac{\text{Rb}^{87}}{\text{Sr}^{86}} \) of several samples with a significant variation of the Rb to Sr ratio are measured on a mass spectrometer and an x-ray fluorescent spectrometer. The results are plotted on a graph, and if the data are compatible, the points fall on a straight line with an intercept \( a = \frac{\text{Sr}^{87}}{\text{Sr}^{86}} \) and a slope \( = e^{\lambda t} + 1 \). If the points fall on a straight line, it is assumed that the rock has remained a closed system since consolidation. If the points do not fit a straight line, it is presumed that metasomatism has altered the chemistry or isotopic balance over a greater volume than that sampled. Secondary veins of alkali feldspars or calcite too small to be seen in hand specimen may cause discrepancies.

The age of the rock is obtained from the slope:

\[ t = \frac{(\ln(1+b))}{\lambda} \]

The value of \( \lambda \) used is \( 1.39 \times 10^{-11} \text{yr}^{-1} \).

While only \( \text{Sr}^{87} \) and \( \text{Rb}^{87} \) need enter into the equation, the \( \text{Sr}^{86} \) denominator eliminates machine and operator bias.
Sr$^{86}$ is neither radioactive nor radiogenic. Another normalization is used that does not enter into the equation, but it is used to correct for mass fractionation in the mass spectrometer.

The ratio Sr$^{86}$ - Sr$^{88}$ has been established as 0.1194. Any deviation from this value is assumed to be due to mass fractionation. Since Sr$^{87}$ is half way between Sr$^{86}$ and Sr$^{88}$, it is also assumed that Sr$^{87}$ is fractionated half as much as Sr$^{88}$ is fractionated with respect to Sr$^{86}$. Therefore Sr$^{88}$ is measured and the Sr$^{87}$ - Sr$^{88}$ ratio is used to normalize the Sr$^{87}$ - Sr$^{86}$ ratio accordingly:

$$\frac{(\text{Sr}^{87}/\text{Sr}^{86})}{(\text{Sr}^{86}/\text{Sr}^{88})} = \frac{\text{Sr}^{86}/\text{Sr}^{88}}{\frac{1}{2}(\text{Sr}^{86}/\text{Sr}^{88} - 0.1194) + 0.1194}$$

Rb and Sr are measured on an x-ray spectrometer using both a Rb and a Sr dunite standard. The x-ray intensity of the Rb and the Sr of the sample is compared to that of the dunite for which the Rb-Sr weight ratio has been established as 1.20. The Rb-Sr ratio of the sample is multiplied by the ratio 1.20 divided by the dunite ratio for Rb-Sr:

$$\frac{(\text{Rb/Sr})_{\text{ppm}}}{(\text{Rb/Sr})_{\text{cps sample}}} = \frac{(\text{Rb/Sr})_{\text{ppm}}}{(\text{Rb/Sr})_{\text{cps standard}}}$$

The conversion factor $K$ used to change Rb-Sr weight ratios to Rb$^{87}$/Sr$^{86}$ atomic ratios has been calculated and plotted as a function of Sr$^{87}$/Sr$^{86}$. The factor is:

$$K = 0.003255 \frac{\text{At. Wt. Sr}}{\text{At. Fraction Sr}^{86}}$$
Analytical Procedure

The samples were washed and broken with a sledge until the pieces fitted into a steel mortar. These were then crushed in the steel mortar with a steel pestle and put into sample boxes. A portion was selected from each box by cutting out alternate quarters with a spatula. This portion was ground for ten minutes in a Pica blending mill. At least ten grams, and up to fifty grams, of sample was powdered. All implements were washed and dried before the crushing or powdering of each sample.

The standard laboratory procedure for putting silicates into solution was followed. It is given in Appendix II. The alequots of the tunnel samples contained 300 micrograms; those of the surface samples 100 micrograms. The procedure for separating the Rb and the Sr in the resin columns is also reported in Appendix II.

An attempt was made to use uniform settings on the mass spectrometer. The magnet current was set at 325 m.a. and 83 v. It oscillated slowly over a week from 320 m.a. to 330 m.a. The high voltage was set between 2.10 to 2.15 kilovolts. Measurements were recorded only when the pressure was less than $1.0 \times 10^{-6}$ m.m.Hg. Resolution was a problem in certain instances despite otherwise adequate pressures. This was attributed to excess sample on the filament producing background from nitrate liberation even after twelve hours of conditioning.

The Rb-Sr ratios of the samples were determined on the x-ray unit using an alequot of the same sample used for mass analysis. The standards were run at the beginning, between each sample, and at the end of each run. The sample holders were washed and dried with acetone before they were used.
Results

The scatter of the points on the graph demonstrates that the Ayer has not remained a closed system. The secondary calcite and extreme sericitization of the plagioclase seen in thin section provide evidence of this.

The three samples within 50 ft of the Nashoba - Ayer contact (R5755, R5756, R5757) showed the most secondary calcite and the least sericitization in thin section. They are plotted as crossed circles. The sample R5784 taken from the scree at shaft A also showed a high calcite content; these four fall above the least square isochron. Sample R5784 had enough Rb to absorb the calcite without as large a change in the Rb-Sr ratio as the others showed.

One surface sample showed more weathering than the other two surface samples chosen for analysis, and it falls significantly below the isochron. It is marked by a solid circle.

The three crossed circles and the solid circle were not used in calculating the least squares isochron. The remaining five points used gave a slope of 0.0065. Because of the scatter and short length of the isochron, further statistics were not employed. Rather lines connecting the three points yielding the highest slope and those three yielding the lowest slope were used to estimate the extreme age possibilities. This resulted in a 25% bracket on an age of 460 M.Y. The initial ratio value of 0.710 is certain to lie below the 0.7175 value obtained on the sample with only 15ppm Rb that was intensely enriched in calcite. It is also fairly certain to lie above the value of 0.705, a low value for granites.

Table 1 shows the preliminary x-ray work on the Rb-Sr contents of all three bodies. Tables 2 and 3 give a synopsis
of the raw data and the calculations. Plate II shows the results compared to the Andover isochron by L. Hanford.

Precision

The precision of both the mass spectrometric and x-ray analyses exceeds the natural scatter of the data. The mass-spectrometer is capable of reproducing replicate values to less than ± 0.001, and the x-ray spectrometer Rb-Sr ratios have a precision of about 3%. The standard deviations of the x-ray data are shown in Table 2. Values less than 0.01 are shown as 0.01. The standard deviations of the mass spectrometer data for one run were below the standard deviation for replicate analyses. The standard deviation given in Table 3 is the standard deviation for replicate analyses.

The scatter does not greatly exceed these limits. The main cause of the inaccuracy is the shortness of the isochron. Although the Rb-Sr ratios cover a ten-fold range, all of the values are lower than is customarily the case. Many isochrons have points above Rb$^{87}$/Sr$^{86} = 50$. The highest point on this isochron is Rb$^{87}$/Sr$^{86} = 2.38$.

Conclusions

The major contribution from this work is the fair certainty that the Ayer was not emplaced during the Jurassic as indicated by the mineral ages mentioned by Fr Skehan in his proposal. Rather the age agrees well with the more precise, early Ordovician age obtained by L. Hanford on the Andover, a large body twenty miles to the northeast. Also a single analysis done by Hanford on the Muscovite Granite lies above the isochron of the Andover Granite as does the isochron of the Ayer (see Plate II0
Either both the Ayer and the Muscovite Granites have high initial ratios when compared to the Andover, or the Muscovite Granite is older than the Andover.

These three bodies indicate a period of activity in this area during the Ordovician, probably their emplacement from magma; the younger mineral ages are related to post-crystallization metamorphic events.

The difficulties encountered with the Ayer do not permit any conclusion regarding the differences between surface samples and tunnel samples.

Suggestions for Further Work

Besides completing the geochronology of the other two granites in the tunnel, it is suggested that further sampling of the Ayer might produce data that would lengthen the isochron and reduce the uncertainty in its age. It may also be possible to leach the calcite from the powdered samples with glacial acetic acid and reanalyze those that have shown a high calcite content.
Table 1
Rb - Sr Content of the Tunnel Granites

<table>
<thead>
<tr>
<th></th>
<th>Rb (ppm)</th>
<th>Sr (ppm)</th>
<th>Rb / Sr</th>
</tr>
</thead>
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<tr>
<td><strong>Ayer Granite</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tunnel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5753</td>
<td>90</td>
<td>300</td>
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</tr>
<tr>
<td>R5754</td>
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</tr>
<tr>
<td>R5756</td>
<td>30</td>
<td>750</td>
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</tr>
<tr>
<td>R5757</td>
<td>15</td>
<td>1730</td>
<td>0.008</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5781</td>
<td>115</td>
<td>280</td>
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</tr>
<tr>
<td>R5782</td>
<td>115</td>
<td>335</td>
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</tr>
<tr>
<td>R5783</td>
<td>85</td>
<td>335</td>
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</tr>
<tr>
<td>R5784</td>
<td>75</td>
<td>335</td>
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<tr>
<td>R5785</td>
<td>135</td>
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</tr>
<tr>
<td>R5786</td>
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<td>240</td>
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<td><strong>Muscovite Granite</strong></td>
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<tr>
<td>R5762</td>
<td>450</td>
<td>30</td>
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</tr>
<tr>
<td>R5765</td>
<td>460</td>
<td>25</td>
<td>18.</td>
</tr>
<tr>
<td><strong>Gospel Hill Gneiss</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5766</td>
<td>180</td>
<td>160</td>
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<tr>
<td>R5768</td>
<td>230</td>
<td>130</td>
<td>2.</td>
</tr>
<tr>
<td>R5769</td>
<td>230</td>
<td>125</td>
<td>2.</td>
</tr>
<tr>
<td>Sample</td>
<td>Intensity</td>
<td>Weight</td>
<td>Rb / Sr</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>R5753</td>
<td>0.264</td>
<td>0.313</td>
<td>0.266</td>
</tr>
<tr>
<td>R5754</td>
<td>0.127</td>
<td>0.146</td>
<td>0.126</td>
</tr>
<tr>
<td>R5755</td>
<td>0.051</td>
<td>0.060</td>
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</tr>
<tr>
<td>R5756</td>
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<td>0.033</td>
<td>0.029</td>
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<tr>
<td>R5757</td>
<td>0.009</td>
<td>0.011</td>
<td>0.009</td>
</tr>
<tr>
<td>R5781</td>
<td>0.388</td>
<td>0.460</td>
<td>0.404</td>
</tr>
<tr>
<td>R5784</td>
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<td>0.240</td>
<td>0.233</td>
</tr>
<tr>
<td>R5785</td>
<td>0.723</td>
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<td>0.754</td>
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<tr>
<td>R5786</td>
<td>0.487</td>
<td>0.582</td>
<td>0.479</td>
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Table 3
Mass Spectrometer Results on the Ayer Granite

<table>
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<tr>
<th></th>
<th>Sr$^{87}$/Sr$^{86}$</th>
<th>Sr$^{87}$/Sr$^{86}$</th>
<th>Ave</th>
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<td>R5753</td>
<td>0.7140</td>
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<td></td>
<td>0.7156</td>
<td>0.7139</td>
<td></td>
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<td></td>
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<td>R5754</td>
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<tr>
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<td>R5755</td>
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<td></td>
<td>0.7146</td>
<td>0.7134</td>
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<tr>
<td></td>
<td>0.7119</td>
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<td>R5757</td>
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<td>0.7071</td>
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<td>R5784</td>
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<td>0.7118</td>
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<tr>
<td></td>
<td>0.7151</td>
<td>0.7137</td>
<td>0.7142</td>
</tr>
</tbody>
</table>

Each Sr$^{87}$/Sr$^{86}$ is the average of 6 consecutive scans.
AYER GRANITE
CLINTON MASS.

460 M.Y. ANDOVER GRANITE
FROM LINCOLN HANFORD 1965

\[
\frac{\text{Rb}^{87}}{\text{Sr}^{87}} - \frac{\text{Rb}^{86}}{\text{Sr}^{86}} = 5.0
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.7200
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.7100
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.7000
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6900
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6800
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6700
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6600
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6500
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6400
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6300
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6200
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6100
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.6000
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5900
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5800
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5700
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5600
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5500
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5400
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5300
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5200
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5100
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.5000
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4900
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4800
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\[
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\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4500
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4400
\]

\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4300
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4200
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4100
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.4000
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3900
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3800
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3700
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3600
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3500
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3400
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3300
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3200
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3100
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.3000
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2900
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2800
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2700
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2600
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2500
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2400
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2300
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2200
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2100
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.2000
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1900
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1800
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\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1700
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1600
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1500
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1400
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1300
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1200
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1100
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\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.1000
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\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0900
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0800
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0700
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0600
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0500
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0400
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0300
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0200
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0100
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\frac{\text{Sr}^{87}}{\text{Sr}^{86}} - 0.0000
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\[
\frac{\text{Sr}^{87}}{\text{Sr}^{86}} = 0.7100 \pm 0.005
\]

FOR $\lambda = 1.39 \times 10^{-11}$ yr$^{-1}$
Appendix I

Hand Specimen (1) and Thin Section (2) Descriptions


R5754: WMT 1+86  (1) Large, shiny microcline phenocrysts. Green mafics foliated but very little plagioclase orientation. Lots of bluish quartz. (2) Large crystals of clean microcline. Small to fair amount of sericitization in plagioclase; albite twins show clearly. Accumulations of medium sized quartz crystals. Small amount of calcite. Chlorite showing good pleochroic halos around zircons.


R5757: WMT 4+56 (1) Gneissic. Feldspar stringers a mechanical mixture of ivory plagioclase and shiny microcline. Dark green mafics give rock a green color. (2) Mildly sericitized plagioclase. Lots of calcite, little quartz. Microcline losing its structure, cross twinning is very faint or absent in some clear crystals of feldspar.

R5781: Novotny #361 (1) & (2) not available.

R5784: Scree at shaft A (1) Gneissic. Fewer amount of mafics give rock a bluish color. (2) Few clean microcline fragments. Strongly sericitized plagioclase. Lots of quartz and calcite, quartz crystals small but in large accumulations.

R5785: Bolton Station. (1) Slightly weathered. Feldspars slightly lineated and mechanically mixed with quartz. Mafics are brown. (2) Some feldspar heavily sericitized except its plagioclase; other is mildly sericitized expect it is microcline that lost its structure. Quartz crystals within accumulations are lineated.

Appendix II

Sample Preparation

Chemistry for solution of silicates

1. Weigh out a sample containing at least 100 micrograms of Sr for an I.R. analysis. Use a minimum of reagents for samples low in Sr. HF is the chief contaminant.
2. Wet sample with several mls. of distilled water.
3. Add 10 ml. of HF and 1.5 ml. HClO₄ for each 0.5 gm. of sample.
4. Put on steam bath and stir frequently. Use rubber gloves. If left overnight turn to low.
5. When HF has evaporated, add another portion of HF and evaporate while stirring often.
6. Add 150 ml of 2N HCl to dish (Pt) and evaporate to 20 ml.
7. Add 50 - 150 ml 2N HCl and evaporate to 20 ml again.
8. Add H₂O until sample volume is 20 - 50 ml. For most silicate rocks this treatment achieves perfect solution.
9. Pour sample into a small polyethylene bottle and let stand for one or two days to let Rb salts precipitate.
10. Filter and put on column.

Column Separation of Rb and Sr.

1. Level the resin (Dowex 50W-X8).
2. Do not disturb the resin surface when adding sample.
3. Be sure the sample is dissolved in acid of less than 2N. This is indicated by the Fe forming a well defined band.
4. Make sure that the sample contains no insoluble chemical residue. Such a residue is undoubtedly KClO₄ and RbClO₄, and being highly insoluble in HCl, the Rb will dribble through the column and contaminate the Sr.
5. In washing the sample into the resin, do so carefully so as not to disturb the resin surface. Volumes of 2N HCl equal to the volume of the sample should be added until the Fe emerges.
6. Then add a head of about 50 ml. to the column and put on auto.
Appendix III

Age Equation Derivation

$^{87}\text{Rb}$ decays to $^{87}\text{Sr}$ by emitting a beta minus. In a closed system $^{87}\text{Rb}$ decreases exponentially from its initial value $^{87}\text{Rb}_o$. The present amount of $^{87}\text{Rb}$ is expressed as:

$$^{87}\text{Rb} = ^{87}\text{Rb}_o e^{-\lambda t}$$

Conversely the initial amount of $^{87}\text{Rb}_o$ is:

$$^{87}\text{Rb}_o = ^{87}\text{Rb} e^{\lambda t}$$

The amount of radiogenic $^{87}\text{Sr}$ is obtained from the difference:

$$^{87}\text{Sr}_{\text{rad.}} = ^{87}\text{Rb} - ^{87}\text{Rb}_o = ^{87}\text{Rb} (1 - e^{-\lambda t})$$

But since the measured quantity is $^{87}\text{Rb}_o$, this is expressed as:

$$^{87}\text{Sr} = ^{87}\text{Rb} e^{\lambda t} (1 - e^{-\lambda t}) = ^{87}\text{Rb} (e^{\lambda t} - 1)$$

The present amount of $^{87}\text{Sr}$ is the sum:

$$^{87}\text{Sr} = ^{87}\text{Sr}_{\text{rad.}} + ^{87}\text{Sr}_{\text{initial}}$$

$$^{87}\text{Sr} = ^{87}\text{Rb} (e^{\lambda t} - 1) + ^{87}\text{Sr}_{\text{initial}}$$

Rearranging and dividing by stable, nonradiogenic $^{86}\text{Sr}$ gives:

$$\frac{^{87}\text{Sr}}{^{86}\text{Sr}} = \frac{^{87}\text{Sr}_{\text{rad.}}}{^{86}\text{Sr}} + \frac{^{87}\text{Rb}}{^{86}\text{Sr}} (e^{\lambda t} - 1)$$

$$\frac{^{87}\text{Sr}}{^{86}\text{Sr}} = \frac{^{87}\text{Sr}}{^{86}\text{Sr}}_0 + \frac{^{87}\text{Sr}}{^{86}\text{Sr}} (e^{\lambda t} - 1)$$
References


Hansen, W.R., "Geology and Mineral Resources of the Hudson and Maynard Quadrangle Massachusetts." Geological Survey Bull. 1038

