GEOCHRONOLOGY OF THE STEWART MINING CAMP
(104B/1)

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INTRODUCTION

This report presents a revised interpretation of the geologic history of the Stewart area based on new potassium-argon dates and all previously published geochronological data from the district. The isotopic dates from the Stewart mining camp are erratically distributed over a 186-million-year (Ma) range from Triassic to Oligocene (Table 2-11-1). Dates from samples of the same rock unit vary significantly. However, when field observations are combined with the concept of the "metamorphic veil" (Armstrong, 1966) and with closure temperatures for argon loss in minerals, a simple explanation emerges for the distribution of dates listed in Table 2-11-1.

In 1986, potassium-argon dating was completed for a suite of rock samples from the alteration envelopes surrounding three mineral deposits in the area. Other isotopic dating near Stewart has been reported by Smith (1977) and by Alldrick, Mortensen and Armstrong (1986). Additional geochronological studies in the Stewart district are in progress by R.G. Anderson at the Geological Survey of Canada and by D.A. Brown at The University of British Columbia. Potassium-argon dates have also been determined in a similar geologic setting in the nearby Alice Arm area by N.C. Carter (1981) and at the Dolly Varden mine by B.D. Devlin (Devlin and Godwin, 1986).

Detailed descriptions of rock types, their distribution, and their field relationships in the Stewart camp are provided in Alldrick (1985) and are simplified here in Figure 2-11-1.

TABLE 2-11-1.
DATES FROM THE STEWART MINING CAMP IN CHRONOLOGICAL ORDER

<table>
<thead>
<tr>
<th>Apparent Age (Ma)</th>
<th>Rock Unit</th>
<th>Rock Type</th>
<th>Mineral</th>
<th>Analytical Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>t211</td>
<td>6 tcg</td>
<td>Hornblende granodiorite stock</td>
<td>Hornblende</td>
<td>K/Ar</td>
</tr>
<tr>
<td>t202</td>
<td>6 tcg</td>
<td>Hornblende granodiorite stock</td>
<td>Hornblende</td>
<td>K/Ar</td>
</tr>
<tr>
<td>195.0</td>
<td>2.0 tcg</td>
<td>Hornblende granite porphyry</td>
<td>Zircon</td>
<td>U/Pb</td>
</tr>
<tr>
<td>194.8</td>
<td>2.0 tcg</td>
<td>Premier Porphyry dyke</td>
<td>Zircon</td>
<td>U/Pb</td>
</tr>
<tr>
<td>193.8</td>
<td>2.0 tcg</td>
<td>Hornblende granodiorite stock</td>
<td>Zircon</td>
<td>U/Pb</td>
</tr>
<tr>
<td>189.2</td>
<td>2.2 tcg</td>
<td>Hornblende granodiorite dyke</td>
<td>Hornblende</td>
<td>K/Ar</td>
</tr>
<tr>
<td>186</td>
<td>6 tcg</td>
<td>Hornblende lamprophyre dyke</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>t130</td>
<td>3 tcg</td>
<td>Hornblende granodiorite stock</td>
<td>Hornblende</td>
<td>K/Ar</td>
</tr>
<tr>
<td>t108</td>
<td>3 tcg</td>
<td>Hornblende granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>101</td>
<td>3 cle</td>
<td>Sericite-flooded andesite tuff</td>
<td>Whole Rock</td>
<td>K/Ar</td>
</tr>
<tr>
<td>89.0</td>
<td>3.0 tcg</td>
<td>Sericite-flooded Premier Porphyry</td>
<td>Whole Rock</td>
<td>K/Ar</td>
</tr>
<tr>
<td>87.2</td>
<td>3.0 tcg</td>
<td>Sericite-flooded Premier Porphyry</td>
<td>Whole Rock</td>
<td>K/Ar</td>
</tr>
<tr>
<td>81.9</td>
<td>2.8 ven</td>
<td>K-feldspar in quartz vein</td>
<td>K-feldspar</td>
<td>K/Ar</td>
</tr>
<tr>
<td>78.5</td>
<td>2.8 cle</td>
<td>Sericite-flooded andesite tuff</td>
<td>Whole Rock</td>
<td>K/Ar</td>
</tr>
<tr>
<td>62.9</td>
<td>2.3 tcg</td>
<td>K-feldspar-flooded Premier Porphyry</td>
<td>Whole Rock</td>
<td>K/Ar</td>
</tr>
<tr>
<td>54.8</td>
<td>1.3 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Zircon</td>
<td>U/Pb</td>
</tr>
<tr>
<td>t53.8</td>
<td>2.0 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Hornblende</td>
<td>K/Ar</td>
</tr>
<tr>
<td>t52.2</td>
<td>4.0 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>t51.6</td>
<td>2.0 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>50.5</td>
<td>2.0 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>50.4</td>
<td>2.0 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>49.9</td>
<td>2.0 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>48.4</td>
<td>1.7 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>47.3</td>
<td>1.0 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>45.2</td>
<td>1.6 tcg</td>
<td>Hornblende granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>t44.8</td>
<td>1.5 hqm</td>
<td>Biotite granodiorite stock</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
<tr>
<td>42.7</td>
<td>1.5 cle</td>
<td>Sericite-flooded andesite tuff</td>
<td>Whole Rock</td>
<td>K/Ar</td>
</tr>
<tr>
<td>25.2</td>
<td>1.0 dyke</td>
<td>Biotite lamprophyre dyke</td>
<td>Biotite</td>
<td>K/Ar</td>
</tr>
</tbody>
</table>

† Dates from Smith (1977), recalculated with IUGS decay constants.

* Presently with the Geological Survey of Canada.

Figure 2-11-1. Geology and mineral deposits of the Stewart area (from Alldrick, 1985).
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location (Minfile No.)</th>
<th>Mineral or Concentrate</th>
<th>% K</th>
<th>$^{40}$Ar rad. $10^4$ cc/gm</th>
<th>$^{40}$Ar rad. $^{40}$Ar total</th>
<th>$^{40}$Ar rad. $\times 10^3$</th>
<th>Apparent Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premier G.H.</td>
<td>Southeast rim of Silbak Premier gloryhole (MI 104B:54)</td>
<td>Whole rock, sericite flooded</td>
<td>6.38 ± 0.09</td>
<td>22.624</td>
<td>93.1</td>
<td>5.301</td>
<td>89.0 ± 3.0</td>
</tr>
<tr>
<td>PM84-29-232</td>
<td>Core sample from Premier gloryhole area (MI 104B:54)</td>
<td>Whole rock, sericite flooded</td>
<td>4.92 ± 0.02</td>
<td>17.079</td>
<td>95.2</td>
<td>5.189</td>
<td>87.2 ± 3.0</td>
</tr>
<tr>
<td>PM84-25-369</td>
<td>Core sample from Premier gloryhole area (MI 104B:54)</td>
<td>K-feldspar, from quartz vein</td>
<td>11.44 ± 0.03</td>
<td>37.268</td>
<td>94.3</td>
<td>4.870</td>
<td>81.9 ± 2.8</td>
</tr>
<tr>
<td>81-58-25</td>
<td>Dago Hill zone, Big Missouri camp (MI 104B:5)</td>
<td>Whole rock, sericite flooded</td>
<td>4.13 ± 0.07</td>
<td>16.681</td>
<td>89.8</td>
<td>6.038</td>
<td>101 ± 3</td>
</tr>
<tr>
<td>81-58-68</td>
<td>Dago Hill zone, Big Missouri camp (MI 104B:5)</td>
<td>Whole rock, sericite flooded</td>
<td>4.52 ± 0.03</td>
<td>14.087</td>
<td>86.0</td>
<td>4.659</td>
<td>78.5 ± 2.8</td>
</tr>
<tr>
<td>IM-10</td>
<td>Galena Cuts zone, Indian mine (MI 104B:1)</td>
<td>Whole rock, sericite flooded</td>
<td>5.68 ± 0.05</td>
<td>9.542</td>
<td>87.4</td>
<td>2.511</td>
<td>42.7 ± 1.5</td>
</tr>
<tr>
<td>L-2</td>
<td>Blueberry vein (MI 104B-133)</td>
<td>Hornblende, from lamprophyre dyke</td>
<td>0.847 ± 0.017</td>
<td>6.433</td>
<td>90.9</td>
<td>11.359</td>
<td>186 ± 6</td>
</tr>
<tr>
<td>A84-1</td>
<td>Roadside quarry on Stewart Hwy. Biotite, Bitter Creek granodiorite</td>
<td></td>
<td>6.75 ± 0.06</td>
<td>12.878</td>
<td>79.7</td>
<td>2.852</td>
<td>48.4 ± 1.7</td>
</tr>
<tr>
<td>DB-84-25</td>
<td>Trench 2190 at Premier gloryhole</td>
<td>Whole rock, K-feldspar flooded</td>
<td>5.92 ± 0.05</td>
<td>14.721</td>
<td>82.2</td>
<td>3.717</td>
<td>62.9 ± 2.3</td>
</tr>
<tr>
<td>B-38</td>
<td>Roadcut 2.0 km south of Riverside mine</td>
<td>Biotite, Texas Creek granodiorite</td>
<td>4.17 ± 0.02</td>
<td>7.416</td>
<td>84.4</td>
<td>2.659</td>
<td>45.2 ± 1.6</td>
</tr>
<tr>
<td>AT84-27-5</td>
<td>Roadcut on east side of Indian Lake</td>
<td>Biotite, lamprophyre dyke</td>
<td>7.22 ± 0.01</td>
<td>7.133</td>
<td>68.0</td>
<td>1.477</td>
<td>25.2 ± 1.0</td>
</tr>
</tbody>
</table>

2 K analyses by K. Scott, The University of British Columbia; D. Brown samples.
All Ar analyses by J.E. Hantik, The University of British Columbia.
P.F. Ralph and B. Bhagwanani carried out sample preparation and potassium analysis at the laboratory of the British Columbia Ministry of Energy, Mines and Petroleum Resources. Following sample fusion with LiBO$_3$ at 1050°C, the glass beads were dissolved in 6 per cent HNO$_3$ with 3 milliliters of 50 per cent HF; a small amount of CsCl was added as a buffer. Potassium abundance was measured on a Perkin Elmer Model 107 single-beam atomic absorption spectrophotometer.

Argon analysis was completed at the Department of Geological Sciences, The University of British Columbia. Samples were fused using a Phillips radiofrequency induction heater and spiked with high purity argon-36. The gas mixture was purified by passing over titanium "getter" furnaces. Argon isotopic ratios were measured in an Associated Electrical Industries MS-10 mass spectrometer equipped with a Carey model 31 vibrating reed electrometer. Analyses of standards indicate potassium and argon accuracy better than 2 per cent. Estimated precision of the analyses is given in Table 2-11-2.

Zircons were separated from 20 to 40-kilogram rock samples using a standard Wilfley table, heavy liquids and magnetic separation techniques. They were sized using nylon mesh screens and hand picked to 200 mesh. Analyses of standards indicate potassium and argon accuracy better than 2 per cent. Estimated precision of the analyses is given in Table 2-11-2.

Potassium-argon dates from Smith (1977) have been recalculated and are listed in Table 2-11-1. Uranium-lead dates reported in Allèdric, Mortensen and Armstrong (1986) are presented with analytical data in Table 2-11-3.

**DISCUSSION**

It was hoped that the new potassium-argon analyses would reveal the age of mineralization at the Silbak Premier mine (MI 104B-054), the Dago Hill deposit (MI 104B-045) near the Big Missouri mine, and the Indian mine (MI 104B-031). However, significantly different dates were obtained from two samples of altered wallrock from a single diamond-drill hole at the Dago Hill deposit. These results indicate that a simple interpretation of the dates, as direct measurements of the age of alteration and mineralization, cannot be valid. In addition, contrasting dates obtained by Smith (1977) for hornblende and biotite separates from samples of Texas Creek granodiorite suggest that there has been argon loss from at least some mineral phases in these rocks. A brief review of the vulnerability of minerals to argon loss follows.

Early experimental and geochronometric studies have shown that minerals will lose argon gas from their crystal lattices when heated to moderate temperatures over geologically short periods of time (reviewed in Armstrong, 1966; Dodson, 1973; York, 1984). The lowest temperature at which minerals rapidly lose argon has been termed the "threshold temperature" (Armstrong, 1966), "closure temperature" (Dodson, 1973), and "blocking temperature" (York, 1984). Closure temperature is largely dependent on grain size and mineral type. Parrish and Roddick (1984) have compiled closure temperatures for mineral phases and mineral groups (Table 2-11-4).

Armstrong (1966) argued that temperature increases during regional metamorphism would drive off argon from many minerals whose potassium-argon dates would then be reset to record only the time of the final cooling of the orogen. If the temperatures were high enough all potassium-argon dates relating to the pre and syn-metamorphic history of the rocks would be lost or degraded to younger values. This concept of a "metamorphic veil" is illustrated schematically for a high-grade region in Figure 2-11-2. In the case of high-grade regional metamorphism, all mineral groups would have their potassium-argon "clocks" reset because the temperature peak during metamorphism far exceeds the closure temperatures of all minerals.

Regional metamorphic grade in the Stewart area was at most lower greenschist facies based on the ilelite and chlorite mineralogy of both sedimentary and tuffaceous rocks, and the absence of regionally distributed garnet and biotite. Lower greenschist facies metamorphism indicates a thermal peak of 300°C to 350°C (Smith, 1986).

**TABLE 2-11-3.**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location [UTM]</th>
<th>Sample Properties</th>
<th>Concentration (ppm)</th>
<th>Observed Ratio</th>
<th>Atomic Ratios$^3$</th>
<th>Model Age (Ma)$^4$</th>
<th>Concordia [Ma]$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A84-1</td>
<td>(130°05'35&quot;W 56°14'00&quot;N)</td>
<td>nm. 150-215μm</td>
<td>459 13.6</td>
<td>8840</td>
<td>0.03035 ± 16</td>
<td>0.2092 ± 11</td>
<td>0.04998 ± 007</td>
</tr>
<tr>
<td></td>
<td>[09-432250E 6212320N]</td>
<td>m, &lt;45μm</td>
<td>1.3</td>
<td>1008 55.6</td>
<td>8472</td>
<td>0.02952 ± 16</td>
<td>0.2041 ± 11</td>
</tr>
<tr>
<td>A84-2</td>
<td>(130°03'18&quot;W 56°05'28&quot;N)</td>
<td>nm. &gt;150μm</td>
<td>349 10.2</td>
<td>1099</td>
<td>0.02973 ± 17</td>
<td>0.2034 ± 11</td>
<td>0.04900 ± 006</td>
</tr>
<tr>
<td></td>
<td>[09-434350E 6216475N]</td>
<td>m, &lt;75μm</td>
<td>0.9</td>
<td>898 27.8</td>
<td>1278</td>
<td>0.03076 ± 17</td>
<td>0.2101 ± 73</td>
</tr>
<tr>
<td>A84-3</td>
<td>(130°03'18&quot;W 56°05'28&quot;N)</td>
<td>nm. &lt;150μm</td>
<td>596 18.6</td>
<td>1088</td>
<td>0.03087 ± 17</td>
<td>0.2113 ± 13</td>
<td>0.05089 ± 023</td>
</tr>
<tr>
<td></td>
<td>[09-434450E 6216275N]</td>
<td>m, &gt;150μm, Ab</td>
<td>4.3</td>
<td>510 15.6</td>
<td>6319</td>
<td>0.03702 ± 16</td>
<td>0.2187 ± 11</td>
</tr>
<tr>
<td>A84-4</td>
<td>(130°00'50&quot;W 56°03'06&quot;N)</td>
<td>nm. &gt;150μm</td>
<td>343 10.8</td>
<td>1081</td>
<td>0.03020 ± 16</td>
<td>0.2090 ± 12</td>
<td>0.05100 ± 017</td>
</tr>
<tr>
<td></td>
<td>[09043560E 6212280N]</td>
<td>m, &lt;150μm, Ab</td>
<td>2.9</td>
<td>378 11.7</td>
<td>1884</td>
<td>0.03066 ± 17</td>
<td>0.2120 ± 11</td>
</tr>
<tr>
<td>A84-5</td>
<td>(130°07'22&quot;W 56°03'02&quot;N)</td>
<td>nm. &gt;150μm</td>
<td>362 4.1</td>
<td>629</td>
<td>0.01064 ± 06</td>
<td>0.0702 ± 05</td>
<td>0.04789 ± 002</td>
</tr>
<tr>
<td></td>
<td>[09-436350E 6212130N]</td>
<td>m, &lt;75μm</td>
<td>1.0</td>
<td>431.2 4.3</td>
<td>225</td>
<td>0.00853 ± 12</td>
<td>0.0954 ± 14</td>
</tr>
</tbody>
</table>

$^1$ All analyses by J.K. Mortensen, Geological Survey of Canada, Ottawa.


$^3$ The errors apply to the last digits of the atomic ratios.

$^4$ All errors shown are 1σ errors, except for 2σ errors in final column.

Isotopic composition of blank: 64.17.5, 74.15.7, 84.37.00.

Isotopic composition of common lead is based on the Stacey and Kramers (1975) model.
only certain mineral groups should show argon loss during lower greenschist facies metamorphism. Figure 2-11-3 shows a schematic diagram which predicts the effects of lower greenschist facies temperatures on potassium-argon dates for a variety of minerals.

TABLE 2.1-1-4.
CLOSURE TEMPERATURES FOR ARGON LOSS IN MINERALS

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Data from Parrish and Rodrick (1984)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hornblende</td>
<td>530°C ± 40°C</td>
</tr>
<tr>
<td>Muscovite</td>
<td>~350°C</td>
</tr>
<tr>
<td>Biotite</td>
<td>280°C ± 40°C</td>
</tr>
<tr>
<td>K-feldspar</td>
<td>130°C ± 15°C</td>
</tr>
<tr>
<td>Microcline</td>
<td>110°C</td>
</tr>
</tbody>
</table>

Note that although the closure temperature for coarse-grained igneous muscovite is estimated at 300°C, fine-grained hydrothermal “sercite” that is present in the Stevart samples will be some variety of muscovite, paragonite, hydromuscovite, illite or phengite, and may even be a mixed, layered aggregate of a few of these minerals (Deer et al., 1963, pages 215-216). The closure temperature for sercite is not known, but the fine-grained, hydrous mineral aggregate would be particularly susceptible to water loss and argon diffusion during heating. Therefore the closure temperature for hydrothermal sercite is probably below 300°C and thus similar to biotite.

INTERPRETATION

All dates from Table 2-11-1 are displayed on Figure 2-11-4. Note that this figure includes uranium-lead dates from zircons which are estimated to have closure temperatures of >500°C and thus are not easily susceptible to thermal resetting at greenschist facies temperatures. As illustrated in Figures 2-11-2 and 2-11-3, the “date” of a mineral represents the last time the mineral cooled down through its closure temperature, whether the temperature drop resulted from original cooling of an igneous magma or from cooling after a metamorphic event.

The broad grey band on Figure 2-11-4 represents the interpreted regional thermal history for the Stewart mining camp. The black lines represent the interpreted thermal history of discrete igneous bodies such as dykes and stocks. The cooling curve after each thermal “peak” is drawn through the data points. The temperature rise of each thermal peak and details of any prior cool interval cannot be exactly reconstructed. For igneous bodies the temperature rise can be considered virtually instantaneous — a vertical line, but for the regional metamorphic event the temperature rise is hidden behind the metamorphic veil and must be strictly hypothetical — a dashed grey band.

The dates for two mineral groups, biotites from the Texas Creek granodiorite and sercite-rich rocks from the Silbak Premier, Dago Hill (Big Missouri) and Indian deposits, require further comment.

The biotite separates from the Texas Creek granodiorite are clearly reset since their potassium-argon dates do not match those for hornblende separates from the same samples (Table 2-11-1; Smith, 1977)). Also, the potassium-argon dates for the reset biotites differ by 22 million years even though the dates for the two hornblende separates lie within analytical error of each other. This is interpreted to be the result of only partial argon loss from the older biotite (sample 3S-008 of Smith, 1977). Partial argon loss occurs either when the thermal peak is short lived, such as country rock intruded by a narrow dyke, or when the thermal peak barely reaches

Figure 2-11-2. General relationships of temperature, pressure, deformation and argon loss from minerals in the metamorphic interior of an orogenic belt (from Armstrong, 1966).
a temperature equal to the closure temperature for the mineral. Coarse-grained igneous biotites are estimated in general to have closure temperatures of 240 to 320°C and, since the thermal peak of regional metamorphism was probably not a short lived event, the temperatures during regional metamorphism are inferred to have reached but not exceeded 300°C. It is also possible that the two biotite separates had slightly different closure temperatures, or that the maximum temperature during regional metamorphism varied between the sample locations, which were 3 kilometres apart (Smith, 1977). A third biotite separate from the Texas Creek granodiorite, sample B-383 in Table 2-11-2, has been dated at 45.2 Ma. This sample was collected near the northern contact of the Hyder stock and the potassium-argon ratio of the biotite has been thermally reset by the Tertiary intrusion.

Two dates for sericite-rich altered dyke rock from the Silbak Premier mine, 87.2 and 89.0 Ma, fall within analytical error of each other and are considered the most representative values for thermally reset sericite dates. The potassium feldspar date from the Silbak Premier mine, 82 Ma, gives a reasonable additional control for the cooling curve after regional metamorphism.

The dates for two sericite-rich altered andesite samples from a single drill hole at Dago Hill are quite different, 78.5 Ma and 101 Ma. Thin section study of these two samples shows that the deeper core sample, which yields the younger date, is composed of sericite and carbonate-altered andesitic ash tuff (Plate 2-11-1). The shallower core sample is similarly altered andesitic crystal tuff containing large laths of hornblende that have been extensively altered to coarse sericite (Plate 2-11-2). The closure temperature for hornblende is well above the thermal peak reached during regional metamorphism (Figure 2-11-3) so the small amount of remnant hornblende would probably retain some of the radiogenic argon generated since its original magmatic crystallization prior to metamorphism. The older date is thus attributed to a mixture of argon from older (Jurassic) hornblende and younger (reset to Cretaceous) sericite.

The whole-rock sample of sericite and carbonate-altered andesite from the Indian mine has a potassium-argon date of 42.7 million years. From Figure 2-11-4, two interpretations might explain this date:

1. The alteration and the associated ore deposit formed in Eocene time, about 43 Ma.
2. The alteration and the associated ore deposit formed prior to Eocene time but the potassium-argon "clock" has been reset by Eocene igneous or hydrothermal activity.

The geology of the Indian mine is well described by McGuigan (1985) and Grove (1971). New lead isotope data (Alldrick, Gabites and Godwin, this volume) show that galena from the Galena Cuts open stope has an isotopic composition identical to that of the Porter Idaho mine (MI 103P-089). The lead isotope compositions of galena from the Indian and Porter Idaho mines suggest that this mineralization is significantly younger than that of the Silbak Premier mine, the Scottie Gold mine (MI 104B-034), the Big Missouri deposits and the Silver Butte deposit (MI 104B-150).
Figure 2-11-4. Isotopic dates versus closure temperatures for the Stewart mining camp, with interpreted thermal, igneous and metamorphic histories.
Plate 2-11-1. Photomicrograph of sericite and carbonate-altered andesitic ash tuff, with fine rounded lithic grains. DDH 81-58, 70 feet; crossed nicols; 40x; length of total field, 0.6 millimetre.

Plate 2-11-2. Photomicrograph of sericite and carbonate-altered andesitic crystal tuff. Rhombic hornblende fragment is extensively altered to coarse sericite. DDH 81-58, 25 feet; crossed nicols; 40x; width of fragment, 0.5 millimetre.
<table>
<thead>
<tr>
<th>AGE (MA)</th>
<th>METALLOGENIC ASSOCIATIONS</th>
<th>KETCHIKAN AREA</th>
<th>STEWART AREA (this study)</th>
<th>SOUTHEAST ALASKA (Brew &amp; Morrell, 1983)</th>
<th>CANADIAN CORDILLERA (Armstrong, in press)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Porphyry Mo (Quartz Hill in epizonal granites)</td>
<td>Regional lamprophyre dyke swarm</td>
<td>Basaltic volcanism (Carter, 1981)</td>
<td>Behm Canal Belt: alkali granite, gabbro, granodiorite</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Porphyry Mo- Ag (Kitsault) Polymetallic Skarns (Ajax, Molly B)</td>
<td>Regional granites reset to this date</td>
<td>Biotite lamprophyre dykes</td>
<td>Coast Plutonic Complex: Belt II</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Au-quartz veins (Juneau) Base metal sulphide lenses and pods (Sill Belt)</td>
<td>Regional biotites reset to this date</td>
<td>Microdiorte or Andesite dykes</td>
<td>Migmatite and Orthogness reset to this date</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>U-Th-REE (Bokan Mtn.)</td>
<td>Garnetiferous granodiorite and tonalite</td>
<td>Coast Plutonic Complex: biotite</td>
<td>Coast Plutonic Complex: Belt I</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>Cumulate Magnetite (Duke Island)</td>
<td>Granodiorite and granodiorite</td>
<td>Crustal extension: granodiorite dykes and onset of emplacement of stocks at depth</td>
<td>Coast Plutonic Complex: Sill Belt</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>Tonalite and granodiorite</td>
<td>Thermal Peak</td>
<td>Admiralty-Revillagigedo Belt: granodiorite, quartz diorite, diorite</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td></td>
<td>Regional deformation and gneisschist metamorphisms</td>
<td>Klukwan - Duke Island Mafic / Ultramafic Belt: dunite, pyroxenite, gabbro</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>Au-Ag veins (Scottie Gold) Polymetallic veins (Silbak Premier, Big Missouri)</td>
<td></td>
<td></td>
<td>Bokan Mountain granodiorite (Armstrong, 1986)</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>Ag-Barite-Jasper (Dolly Varden, Torbrit)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td></td>
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<tr>
<td>200</td>
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<tr>
<td>220</td>
<td></td>
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</tbody>
</table>

Table 2-11-6. Comparison of geologic histories for Stewart, southeast Alaska and the Canadian Cordillera. Bar = significant timespan, solid circle = short timespan or limited dating, open circle = minimum date only.
Alldrick (1985) interpreted the Porter Idaho mine as an Eocene deposit related to emplacement of the 50 Ma Hyder stock, based on field relationships (Alldrick and Kenyon, 1984). The lead isotope data support this Eocene age for the Porter Idaho deposit and indicate that sulphides at the Indian mine were precipitated at the same time. Thus the 43 Ma potassium-argon date for the altered wallrock at the Indian mine probably represents the age of emplacement of the sulphides along the controlling fault structure. Three varieties of Tertiary dykes have been identified on the Indian mine property (McGuigan, 1985), but the nearest major body of Eocene intrusive rock crops out on the summit and the northern slope of Mineral Hill, 3 kilometres south-southwest of the Indian mine.

The formation of the Dago Hill and Silbak Premier deposits must predate the >90 Ma regional metamorphic event, since the isotopic ratios of the alteration envelopes surrounding these deposits are thermally reset by the metamorphism. Black stylolites of insoluble residue are common within the coarse crystalline carbonate gangue at several mineral deposits in the Big Missouri camp (Plate 2-11-3). These stylolites are pressure-solution features that also suggest the deposits predated regional deformation. Fine to medium-grained euhedral pyrite crystals associated with the alteration envelopes at the Big Missouri deposits exhibit well-developed pressure shadows in thin section (Plate 2-11-4), also indicating that the mineralization and alteration predate metamorphism. The age of ore deposition at the Big Missouri, Silbak Premier, Silver Butte, Scottie Gold and similar deposits is estimated at ~190 million years based on field relationships reviewed in Alldrick (1985).

Late biotite lamprophyre dykes crosscut all other rock types, alteration, and mineralization in the Stewart area. These dykes are part of the Tertiary lamprophyre dyke province defined by Smith (1973) who interpreted a Miocene age of emplacement based on field relationships. In the Alice Arm district Carter (1981) reported late Eocene dates from two of these dykes. In separate studies underway at The University of British Columbia, D.A. Brown (Table 2-11-2) and B.D. Devlin (Devlin and Godwin, 1986) have obtained Oligocene dates on biotite lamprophyre dykes in the Stewart and Alice Arm districts respectively. The age range for these dykes is schematically illustrated on Figure 2-11-4 which suggests that Smith's (1973) Tertiary lamprophyre dyke province is dominantly Oligocene in age. These dates contrast with the early Jurassic hornblende potassium-argon date from a hornblende lamprophyre dyke sampled near the Granduc millsite (Table 2-11-2 and Figure 2-11-4).

The new data and interpretations presented in this report allow significant revisions to the geologic history of the district (Table 2-11-5). Recent compilations of isotopic dates for southeast Alaska (Smith et al., 1979 and Brew and Morrell, 1983) and for the whole of the Canadian Cordillera (Armstrong, in press) provide a regional and continent-scale context for the geologic history of the Stewart area (Table 2-11-6).

CONCLUSIONS

When isotopic dates from the Stewart mining camp are plotted against closure temperatures for argon loss in minerals, a simple thermal history can be deduced:

1. Late Triassic to early Jurassic volcanism and coeval emplacement of subvolcanic magma (211 to 190 Ma) was followed by late dyke emplacement (190 to 185 Ma) and by quiescent flysch sedimentation (Toarcian to Callovian, 190 to 160 Ma).

Plate 2-11-3. Coarse calcite-quartz gangue in Dago Hill mineral deposit shows stylolites and fractures lined with black insoluble residue. Scale bar in centimetres; BQ drill core; DDH 81-58.
Plate 2-11-4. Pressure shadows of fibrous quartz around euhedral pyrite. DDH 81-58, 22 feet; crossed nicols; 100×; width of pyrite crystal, 0.3 millimetre.

TABLE 2-11-5.
GEOLOGIC HISTORY OF THE STEWART MINING CAMP

<table>
<thead>
<tr>
<th>Age (Ma)</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-25</td>
<td>Emplacement of biotite lamprophyre dykes.</td>
</tr>
<tr>
<td>45-35</td>
<td>Emplacement of microdiorite or &quot;andesite&quot; dykes along NNW trend, locally deflected by biotite granodiorite dykes.</td>
</tr>
<tr>
<td>55</td>
<td>Crustal extension and intrusion of major WNW-trending biotite granodiorite dyke swarms marked onset of emplacement of stocks at depth.</td>
</tr>
<tr>
<td>110-90</td>
<td>Lower greenschist facies regional metamorphism reaches a thermal peak. Moderate deformation along north-trending fold axes. Major folds and slaty cleavage formed.</td>
</tr>
<tr>
<td>190-160</td>
<td>Marine transgression, flysch sedimentation with minor intraformational conglomerates (Unit 4). Relative quiescence.</td>
</tr>
<tr>
<td>190-185</td>
<td>Waning magmatic activity marked by emplacement of hornblende lamprophyre dykes at depth.</td>
</tr>
<tr>
<td>~190</td>
<td>Subaerial felsic volcanism (Unit 3). Emplacement of dykes at depth. Formation of gold-silver vein and breccia deposits. Deposition of barren pyrite around fumarolic centres at surface.</td>
</tr>
<tr>
<td>195-199</td>
<td>Deposition of subaerial epiclastic sediments and interbedded andesitic to dacitic tuffs and flows (Unit 2). (Emplacement of minor dykes at depth?)</td>
</tr>
<tr>
<td>195</td>
<td>Intrusion of porphyry phase of Texas Creek granodiorite, Premier Porphyry dykes, and extrusion of Premier Porphyry flows and tuff breccias.</td>
</tr>
<tr>
<td>215-199</td>
<td>Andesitic volcanic activity (Unit 1), predominantly subaerial with two periods of marine transgression; coeval intrusion of main phase of Texas Creek granodiorite.</td>
</tr>
</tbody>
</table>

(2) Moderate deformation associated with lower greenschist facies regional metamorphism during Cretaceous time reached its thermal peak about 110 to 90 Ma.

(3) Stocks and dykes of the Coast Range batholith intruded the deformed rocks in early to middle Eocene time, 55 to 45 Ma, followed by a 20-million-year period of microdiorite dyke and biotite lamprophyre dyke emplacement.

A worthwhile field for further studies would be ⁴⁰Ar/³⁹Ar age spectra analysis for mineral separates from andesitic crystal tuffs and from phases of the Texas Creek granodiorite.

ACKNOWLEDGMENTS
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REFERENCES


