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.

ANALYTICAL METHODS

Potassium-argon analyses were completed on whole-rock samples and on hornblende, biotite and potassium feldspar mineral separates. All samples were sieved to -30 to -60 mesh.

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

Apparent Age (Ma)	Rock Unit	Rock Type	Mineral	Analytical Method
†211	6	Hornblende granodiorite stock	Hornblende	K/Ar
†202	6	Hornblende granodiorite stock	Hornblende	K/Ar
195.0	2.0	Hornblende granodiorite stock	Zircon	U/Pb
194.8	2.0	Premier Porphyry dyke	Zircon	U/Pb
192.8	2.0	Hornblende granodiorite stock	Zircon	U/Pb
189.2	2.2	Hornblende granodiorite dyke	Zircon	U/Pb
186	6	Hornblende lamprophyre dyke	Hornblende	K/Ar
†130	3	Hornblende granodiorite stock	Biotite	K/Ar
†108	3	Hornblende granodiorite stock	Biotite	K/Ar
101	3	Sericite-flooded andesite tuff	Whole Rock	K/Ar
89.0	3.0	Sericite-flooded Premier Porphyry	Whole Rock	K/Ar
87.2	3.0	Sericite-flooded Premier Porphyry	Whole Rock	K/Ar
81.9	2.8	vein	K-feldspar in quartz vein	K-feldspar	K/Ar
78.5	2.8	le	Sericite-flooded andesite tuff	Whole Rock	K/Ar
62.9	2.3	tcg	K-feldspar-flooded Premier Porphyry	Whole Rock	K/Ar
54.8	1.3	hqm	Biotite granodiorite dyke	Zircon	U/Pb
†53.8	2.0	hqm	Biotite granodiorite stock	Hornblende	K/Ar
†52.2	4.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
†51.6	2.0	hqm	Biotite granodiorite stock	Hornblende	K/Ar
†50.5	2.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
†50.4	2.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
†49.9	2.0	hqm	Biotite granodiorite stock	Hornblende	K/Ar
48.4	1.7	hqm	Biotite granodiorite stock	Biotite	K/Ar
†47.3	1.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
45.2	1.6	tcg	Hornblende granodiorite stock	Biotite	K/Ar
†44.8	1.5	hqm	Biotite granodiorite stock	Biotite	K/Ar
42.7	1.5	le	Sericite-flooded andesite tuff	Whole Rock	K/Ar
25.2	1.0	dyke	Biotite lamprophyre dyke	Biotite	K/Ar

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

ARCTIC SHELF

INDEX MAP

MACKENZIE AND ROCKY

OMINECA

INTERMONTANE

ST. ELIAS

COAST AND INSULAR BELT

CASCADE BELT

INTERIOR

MOUNTAINS BELT

BELT

PROJECT AREA

MITRE MTN.

BETTY GLACIER

BIG MISSOURI RIDGE

BEAR RIVER RIDGE

AMERICAN CREEK

SALMON GLACIER

Summit Lake

Bear Lk.

Bitter Cr. Monzonite

BRITISH COLUMBIA / ALASKA

Bear Lk.

SALMON RIVER

BEAR RIVER

STEWART

HYDER

55°55'

130°00'

RYAN GLACIER

N

0   5
Kilometres

MAJOR MINERAL DEPOSITS

EAST GOLD MINE	A
SCOTTIE GOLD MINE	B
DAGO HILL DEPOSIT	C
BIG MISSOURI MINE (S–1 ZONE)	D
SILVER BUTTE DEPOSIT	E
INDIAN MINE	F
SEBAKWE MINE	G
B.C. SILVER MINE	H
SILBAK PREMIER MINE	I
RIVERSIDE MINE	J
PROSPERITY AND PORTER IDAHO MINES	K

LEGEND

hqm, bg, mhg	Eocene biotite granodiorite stocks
tcg, slg	Lower Jurassic hornblende granodiorite stocks
4	Argillite, siltstone, sandstone
3	Dacite pyroclastic formation
2	Epiclastic rocks, hematitic
1e	Andesite tuffs and flows
1d	Argillite, siltstone
1c	Andesite tuffs
1b	Argillite, siltstone
1a	Andesite tuffs

Figure 2-11-1. Geology and mineral deposits of the Stewart area (from Alldrick, 1985).

82

TABLE 2-11-2.
NEW POTASSIUM-ARGON DATES FROM THE STEWART CAMP

Sample No.	Location (Minfile No.)	Mineral or Concentrate	%K	^{40}Ar rad. 10^{-6} cc/gm	% $\frac{^{40}\text{Ar rad.}}{^{40}\text{Ar total}}$	$\frac{^{40}\text{Ar. rad.} \times 10^{-3}}{^{40}\text{K}}$	Apparent Age (Ma)
Premier G.H.[1] Lat. 56°03.1′ Long. 130°00.7′	Southeast rim of Silbak Premier gloryhole (MI 104B-54)	Whole rock, sericite flooded	6.38 ± 0.09 n = 3	22.624	93.1	5.301	89.0 ± 3.0
PM84-29-232′[1] Lat. 56°03.1′ Long. 130°00.7′	Core sample from Premier gloryhole area (MI 104B-54)	Whole rock, sericite flooded	4.92 ± 0.02 n = 3	17.079	95.2	5.189	87.2 ± 3.0
PM84-25-369′[1] Lat. 56°03.1′ Long. 130°00.7′	Core sample from Premier gloryhole area (MI 104B-54)	K-feldspar, from quartz vein	11.44 ± 0.03 n = 3	37.268	94.3	4.870	81.9 ± 2.8
81-58-25′[1] Lat. 56°06.4′ Long. 130°00.7′	Dago Hill zone, Big Missouri camp (MI 104B-45)	Whole rock, sericite flooded	4.13 ± 0.07 n = 3	16.681	89.8	6.038	101 ± 3
81-58-68′[1] Lat. 56°06.4′ Long. 130°00.7′	Dago Hill zone, Big Missouri camp (MI 104B-45)	Whole rock, sericite flooded	4.52 ± 0.03 n = 3	14.087	86.0	4.659	78.5 ± 2.8
IM-10[1] Lat. 56°04.6′ Long. 130°01.9′	Galena Cuts zone, Indian mine (MI 104B-31)	Whole rock, sericite flooded	5.68 ± 0.05 n = 5	9.542	87.4	2.511	42.7 ± 1.5
L-2[1] Lat. 56°14.8′ Long. 130°04.3′	Blueberry vein (MI 104B-133)	Hornblende, from lamprophyre dyke	0.847 ± 0.017 n = 5	6.433	90.9	11.359	186 ± 6
A84-1-8[1] Lat. 56°02.0′ Long. 129°55.0′	Roadside quarry on Stewart Hwy.	Biotite, Bitter Creek granodiorite	6.75 ± 0.06 n = 5	12.878	79.7	2.852	48.4 ± 1.7
DB-84-25[2] Lat. 56°03.3′ Long. 130°00.5′	Trench 2190 at Premier gloryhole	Whole rock K-feldspar flooded	5.92 ± 0.05 n = 2	14.721	82.2	3.717	62.9 ± 2.3
B-383[2] Lat. 55°59.3′ Long. 130°03.8′	Roadcut 2.0 km south of Riverside mine	Biotite, Texas Creek granodiorite	4.17 ± 0.02 n = 2	7.416	84.4	2.659	45.2 ± 1.6
AT84-27-5[2] Lat. 56°04.4′ Long. 130°02.4′	Roadcut on east side of Indian Lake	Biotite, lamprophyre dyke	7.22 ± 0.01 n = 2	7.133	68.0	1.477	25.2 ± 1.0

[1] K analyses by P.F. Ralph and B. Bhagwanani, Ministry of Energy, Mines and Petroleum Resources; D. Alldrick samples.
[2] K analyses by K. Scott, The University of British Columbia; D. Brown samples.
All Ar analyses by J.E. Harakal, 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 $LiBO_2$ at 1050°C, the glass beads were dissolved in 6 per cent HNO_3 with 3 millilitres 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-38. 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 100 per cent purity. Chemical dissolution and mass spectrometry follow the procedures of Krogh (1973). We use a mixed ^{208}Pb-^{235}U spike and measure lead and uranium on an automated Vacuum Generators Isomass 54R solid source mass spectrometer. Automation and data reduction are done with a dedicated Hewlett-Packard HP-85 computer. Errors associated with isotopic ratios and calculated ages are obtained by individually propagating all calibration and analytical uncertainties through the entire date calculation program and summing all the individual contributions to the total variance.

All the dates in this report have been calculated with the decay constants and atomic ratios recommended by the Subcommission on Geochronology of the International Union of Geological Sciences (Steiger and Jäger, 1977).

RESULTS

The results of these new potassium-argon analyses are listed 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 Alldrick, 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 illite 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,

TABLE 2-11-3.
URANIUM-LEAD ZIRCON DATA[1] (from Alldrick, Mortensen and Armstrong, 1986)

Sample No.	Location [UTM]	Sample Properties	Weight (mg)	U	Pb	Observed ^{206}Pb/^{204}Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	Concordia Age (Ma)[4]
A84-1	(130°05'55"W 56°14'00"N)	nm, 150-215µm	16.3	459	13.6	8840	0.03035±16	0.2092±11	0.04998±007	192.8±1.0	192.9±0.9	194.2± 3.3	192.8±2.0
	[09-432250E 6232320N]	m, <45µm	1.3	1908	55.6	8472	0.02952±16	0.2041±11	0.05014±009	187.5±1.0	188.6±0.9	201.4± 4.0	
		m, <45µm	1.5	887	26.2	6498	0.02962±16	0.2048±11	0.05015±013	188.2±1.0	189.2±0.9	202.0± 5.8	
A84-2	(130°03'18"W 56°05'28"N)	nm, >150µm	14.2	349	10.2	8109	0.02979±17	0.2049±11	0.04990±006	189.2±1.1	189.3±0.9	190.3± 2.8	189.2±2.2
	[09-434400E 6216475N]	m, <75µm	0.3	898	27.8	1278	0.03056±17	0.2101±73	0.04987±062	194.1±1.1	193.7±6.1	189.1±75.5	
A84-3	(130°03'18"W 56°05'28"N)	nm, >150µm	10.5	596	18.6	1838	0.03062±17	0.2113±15	0.05006±025	194.4±1.0	194.7±1.3	197.7±11.7	195.0±2.0
	[09-434400E 6216475N]	nm, >150µm, abd	4.3	510	15.6	6189	0.03072±16	0.2117±11	0.04999±009	195.0±1.0	195.0±0.9	194.4± 4.1	
		m, <45µ	1.3	1272	38.3	6639	0.03004±16	0.2078±11	0.05016±009	190.8±1.0	191.7±0.9	202.6± 4.1	
A84-5	(130°00'50"W 56°03'06"N)	nm, >150µm	5.3	343	10.84	1081	0.03020±16	0.2090±12	0.05018±017	191.8±1.0	192.7±1.0	203.5± 7.6	194.8±2.0
	[090436760E 6212240N]	nm, >150µm, abd	2.9	378	11.7	1864	0.03067±16	0.2120±13	0.05013±019	194.8±1.0	195.2±1.1	201.2± 8.9	
AT-34-3[2]	(130°01'22"W 56°03'02"N)	nm, >150µm	5.0	362.2	4.14	629	0.01064±06	0.0702±05	0.04789±002	68.2±0.4	68.9±0.5	93.7±10.1	54.8±1.3
	[09-436300E 6212130N]	m, <75µm	1.0	431.2	4.34	225	0.00853±12	0.0554±14	0.04713±093	54.8±0.8	54.8±1.3	55.6± 4.6	

[1] All analyses by J.K. Mortensen, Geological Survey of Canada, Ottawa.

[2] Data provided by R.G. Anderson, Geological Survey of Canada, Vancouver.

[3] The errors apply to the last digits of the atomic ratios.

[4] All errors shown are 1 "σ" errors, except for 2 "σ" errors in final column.

Isotopic composition of blank: 6/4:17.75, 7/4:15.57, 8/4:37.00.

Isotopic composition of common lead is based on the Stacey and Kramer (1975) model.

1981, page 91). From the closure temperatures listed in Table 2-11-4 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 2-11-4.
CLOSURE TEMPERATURES FOR
ARGON LOSS IN MINERALS

Mineral	Data from Parrish and Roddick (1984)
Hornblende	530° ± 40°C
Muscovite	~350°C
Biotite	280° ± 40°C
K-feldspar	130 ± 15°C
Microcline	110°C

Note that although the closure temperature for coarse-grained igneous muscovite is estimated at 350°C, fine-grained hydrothermal "sericite" that is present in the Stewart 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 sericite 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 sericite 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 sericite-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
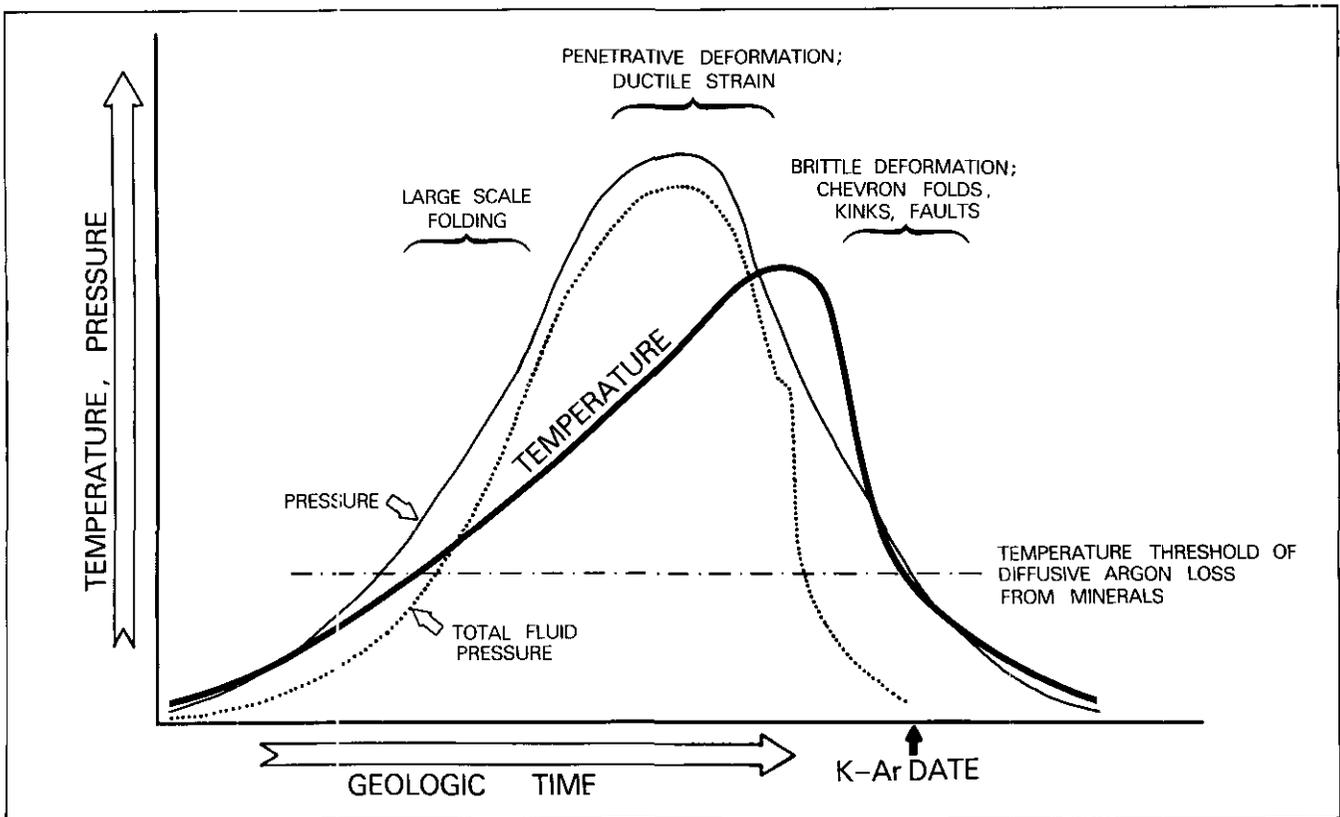

Figure 2-11-2. General relationships of temperature, pressure, deformation and argon loss from minerals in the metamorphic interior of an orogenic belt (from Armstrong, 1966).
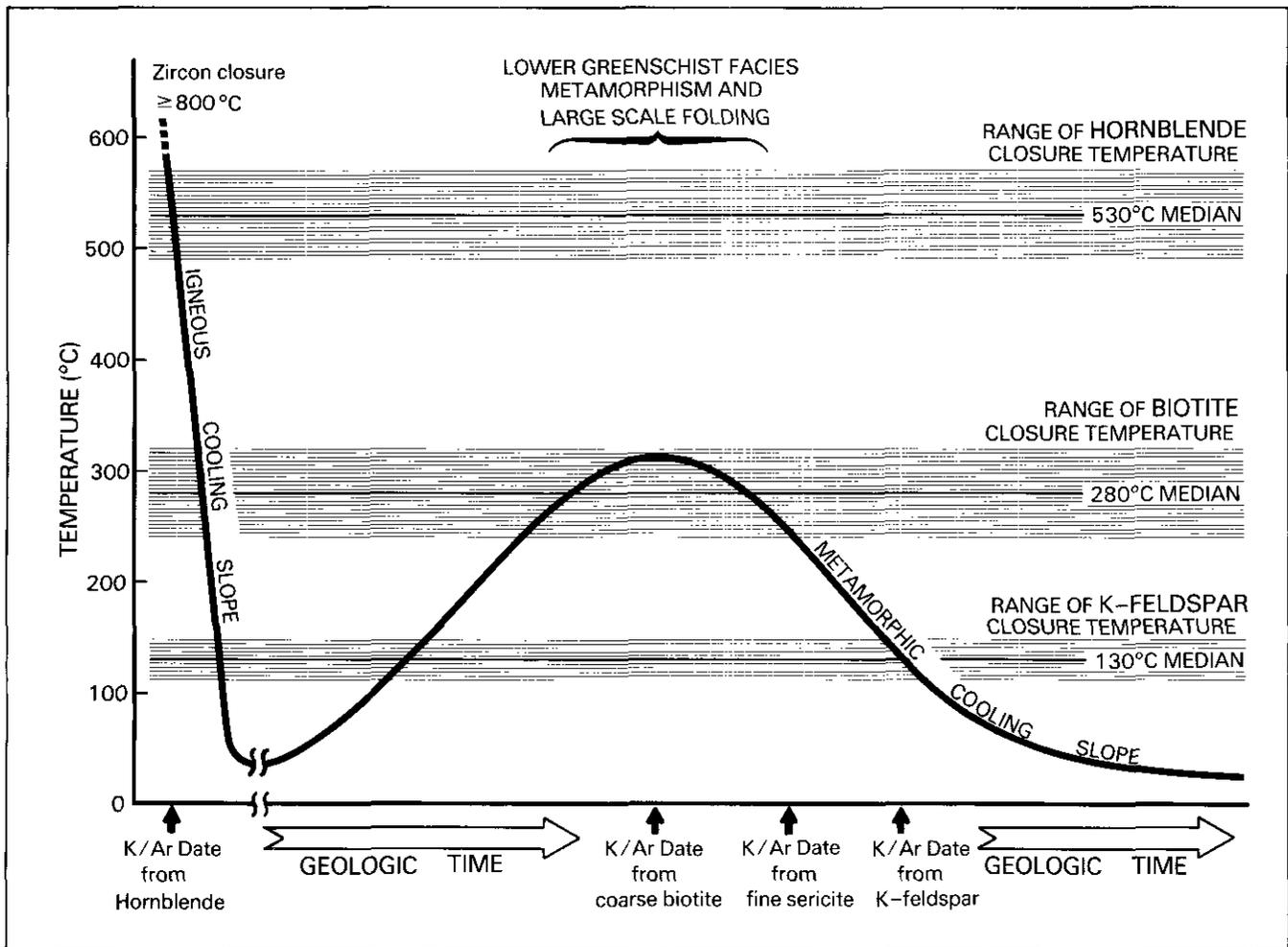
Figure 2-11-3. General relationships of temperature, deformation and argon loss for minerals dated in the Stewart mining camp.

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).
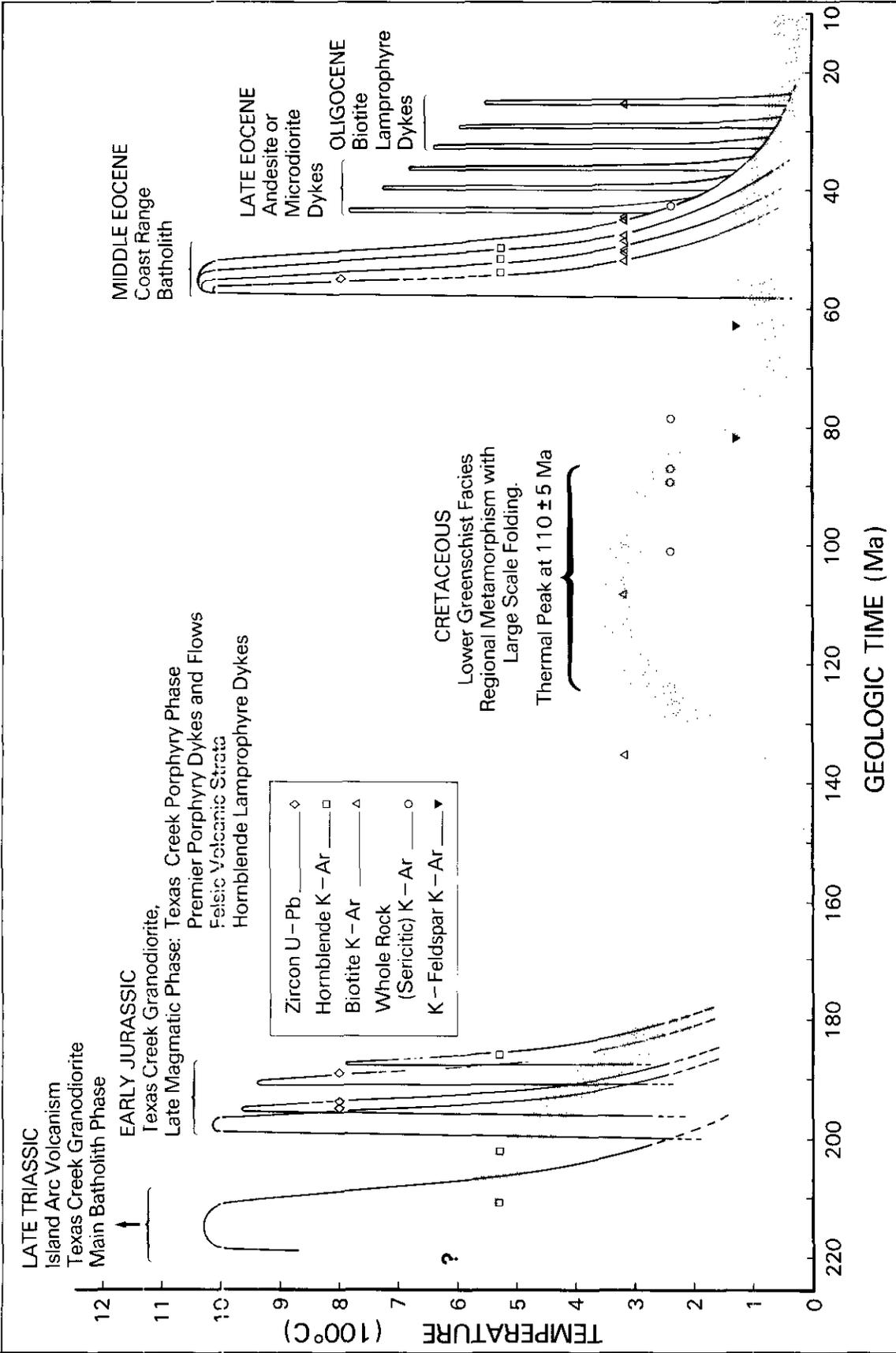
86

Figure 2-11-4. Isotopic dates versus closure temperatures for the Stewart mining camp; with interpreted thermal, igneous and metamorphic histories.
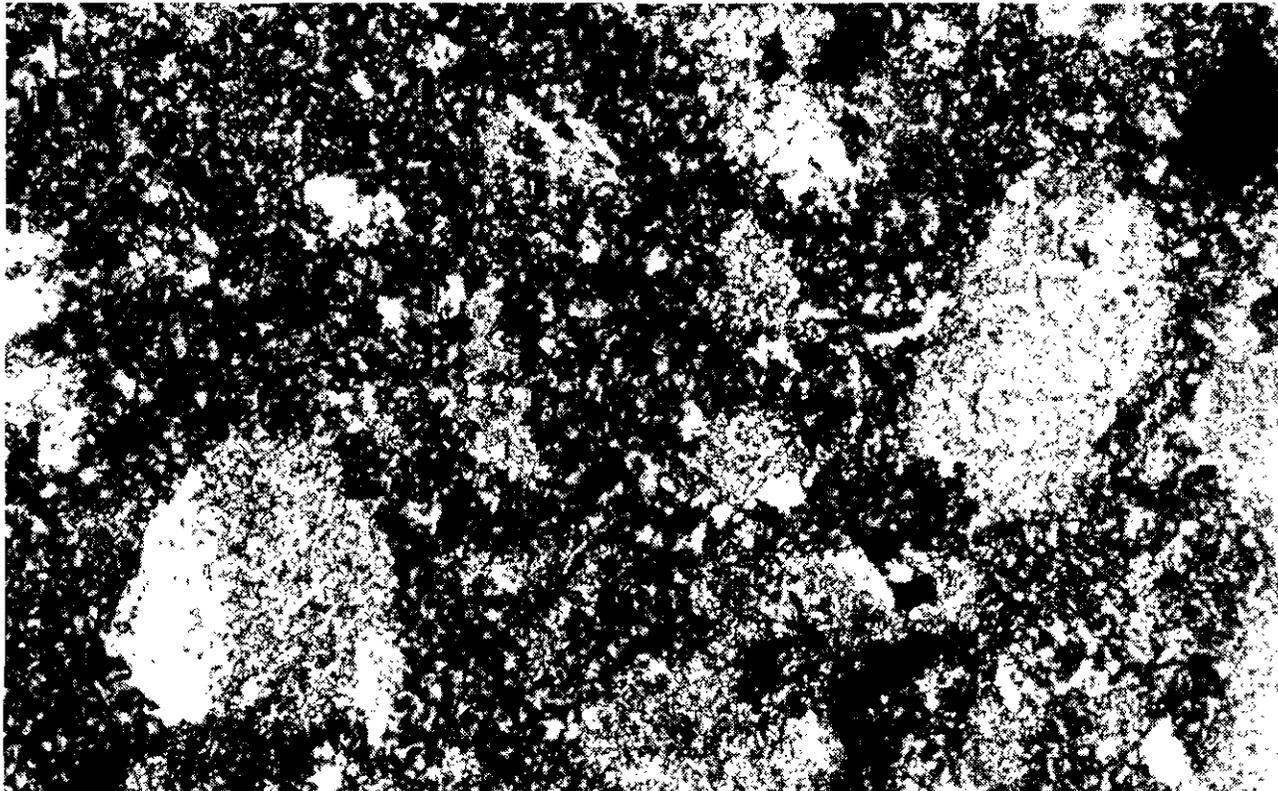
Plate 2-11-1. Photomicrograph of sericite and carbonate-altered andesitic ash tuff, with fine rounded lithic grains. DDH 81-58, 70 feet; crossed nicols; 40×; length of total field, 0.6 millimetre.
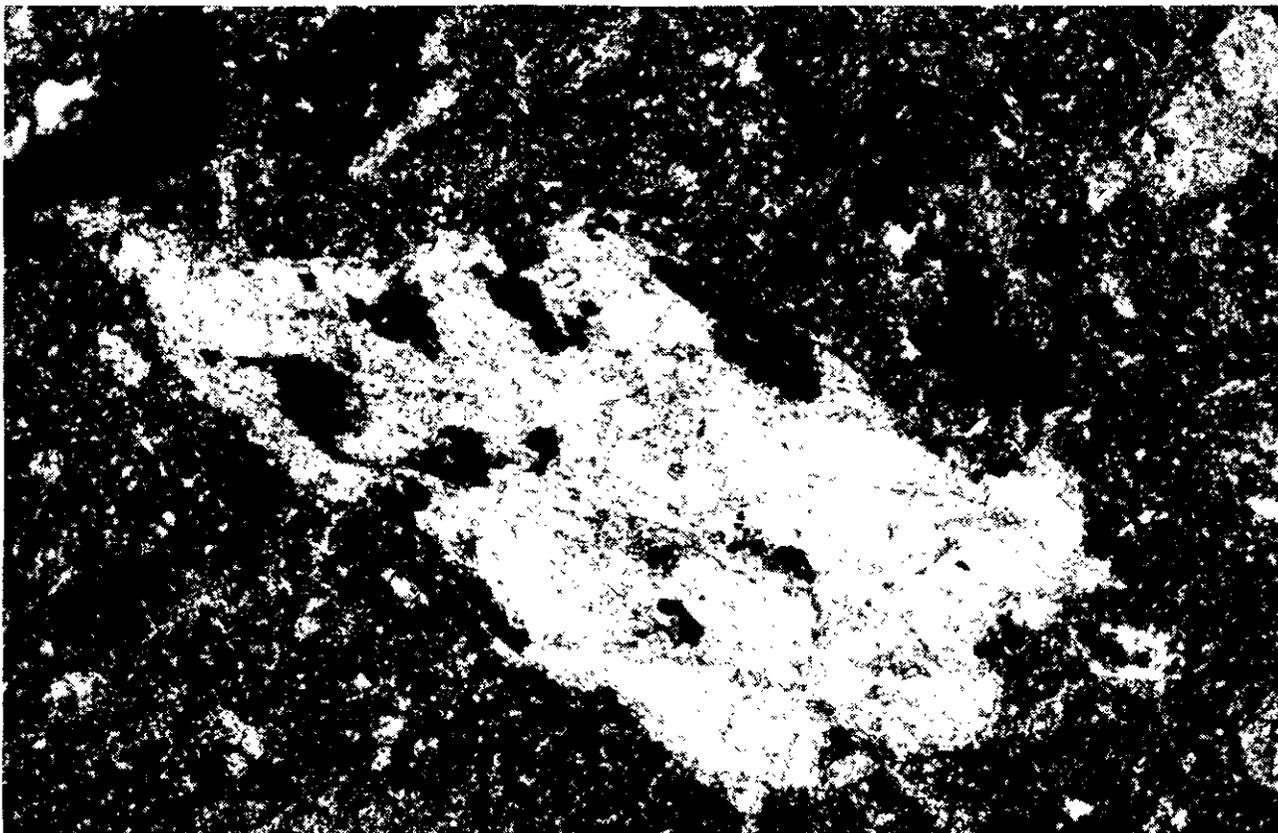

Plate 2-11-2. Photomicrograph of sericite and carbonate-altered andesitic crystal tuff. Rhombic hornblende fragment is extensively altered to coarse sericite. DDH 81-58, 25 feet; crossed nicols; 40×; width of fragment, 0.5 millimetre.

Table with columns (reading left to right): AGE (MA), METALLOGENIC ASSOCIATIONS, KETCHIKAN AREA (Smith et al., 1979 and Smith, 1973), STEWART AREA (this study), SOUTHEAST ALASKA (Brew & Morrell, 1983), CANADIAN CORDILLERA (Armstrong, in press) — NUMBER OF MAGMATIC DATES.

CANADIAN CORDILLERA (Armstrong, in press) — NUMBER OF MAGMATIC DATES (0, 50, 100, 150)

SOUTHEAST ALASKA (Brew & Morrell, 1983)
- Behm Canal Belt: alkali granite, gabbro, granodiorite
- Coast Plutonic Complex: Belt II
- Migmatite and Orthogneiss reset to this date
- Coast Plutonic Complex: Belt I
- Coast Plutonic Complex: Sill Belt
- Admiralty–Revillagigedo Belt: granodiorite, quartz diorite, diorite
- Klukwan – Duke Island Mafic / Ultramafic Belt: dunite, pyroxenite, gabbro
- Bokan Mountain granodiorite (Armstrong, 1986)
- Texas Creek granodiorite

STEWART AREA (this study)
- Basaltic volcanism (Carter, 1981)
- Biotite lamprophyre dykes
- Microdiorite or Andesite dykes
- Coast Plutonic Complex: biotite granodiorite to biotite quartz monzonite
- Crustal extension: granodiorite dykes and onset of emplacement of stocks at depth
- Thermal Peak
- Regional deformation and greenschist metamorphism
- Sedimentation continues?
- Subsidence; regional flysh sequence; Bowser Lake Group
- Coeval Texas Creek: subvolcanic granodiorite, late dykes and flows
- Hazelton Group: Volcanics and sediments

KETCHIKAN AREA (Smith et al., 1979 and Smith, 1973)
- Regional lamprophyre dyke swarm
- Epizonal granites
- Regional biotites reset to this date
- Granite and granodiorite
- Regional hornblendes reset to this date
- Garnetiferous granodiorite and tonalite
- Tonalite and granodiorite
- Migmatite and Gneiss reset to this date
- Texas Creek granodiorite

METALLOGENIC ASSOCIATIONS
- Porphyry Mo (Quartz Hill in epizonal granites)
- Porphyry Mo – Ag (Kitsault) Poly metallic Skarns (Ajax, Molly B)
- Au–quartz veins (Juneau) Base metal sulphide lenses and pods (Sill Belt)
- U–Th–REE (Bokan Mtn.)
- Cumulate Magnetite (Duke Island)
- Au–Ag veins (Scottie Gold) Polymetallic veins (Silbak Premier, Big Missouri)
- Ag–Barite–Jasper (Dolly Varden, Torbrit)

AGE (MA): 0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220
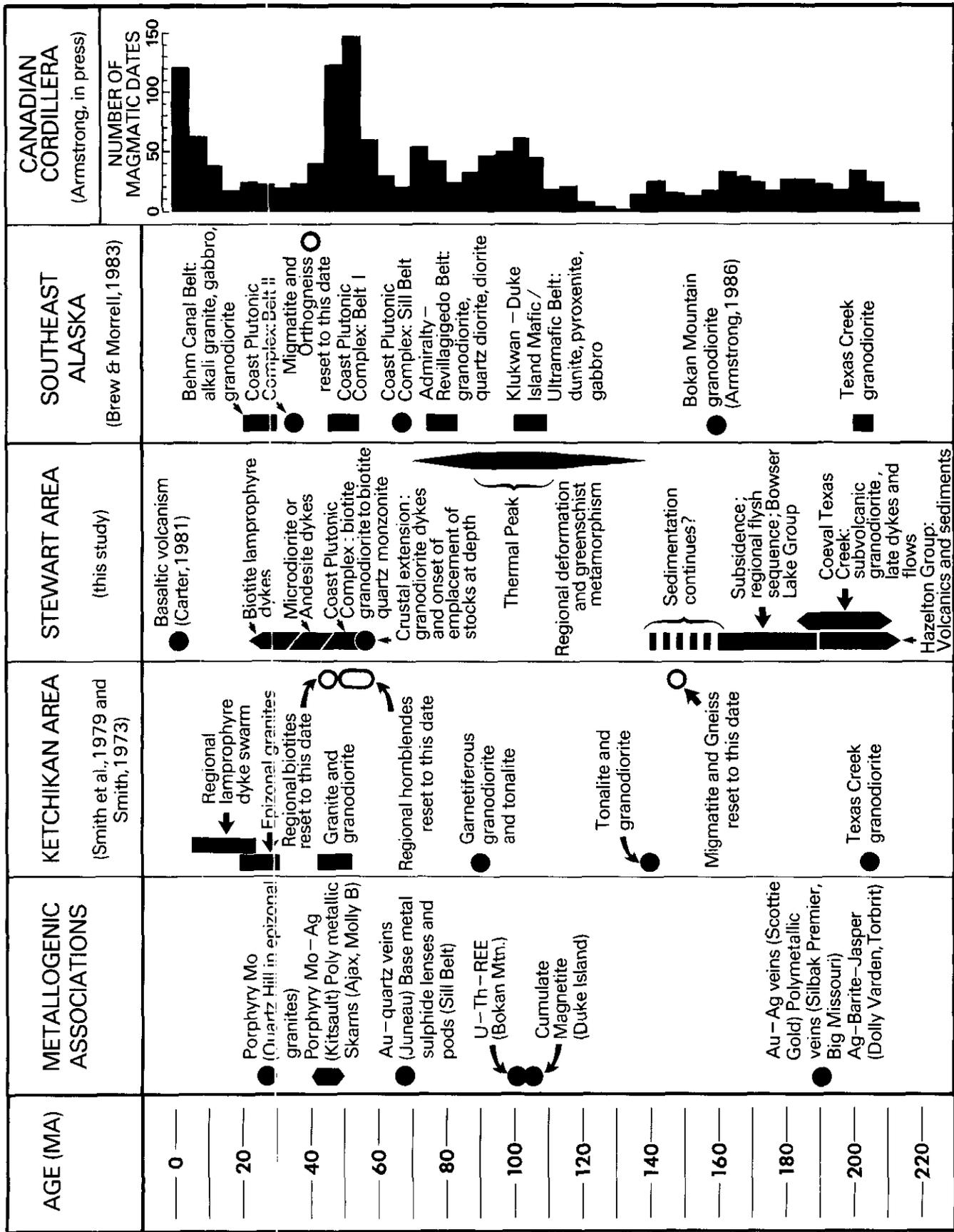
Table 2-11-6. Comparison of geologic histories for Stewart, southeast Alaska and the Canadian Cordillera. Bar = significant timespan, solid circle = short timespan or limited dating, open circle = minimum date only.

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).
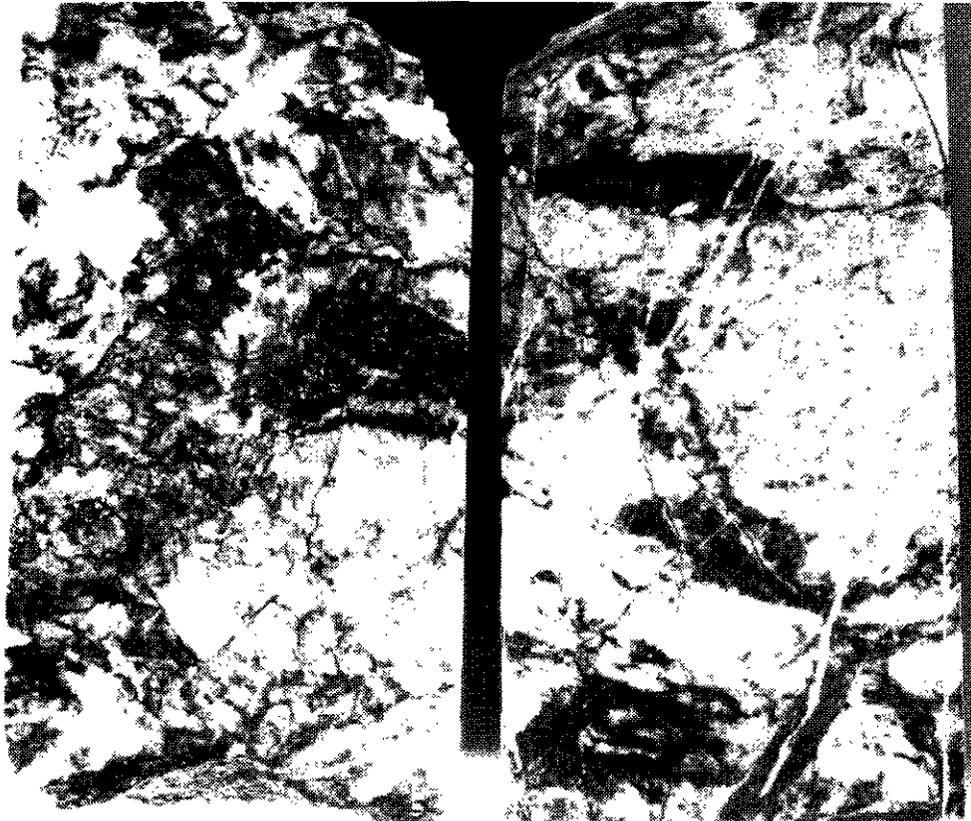

Plate 2-11-3. Coarse calcite-quartz gangue in Dago Hill mineral deposit shows stylolites and fractures lined with black insoluble residue. Scale bar in centimetres; BQ drill core; DDH 81-58.
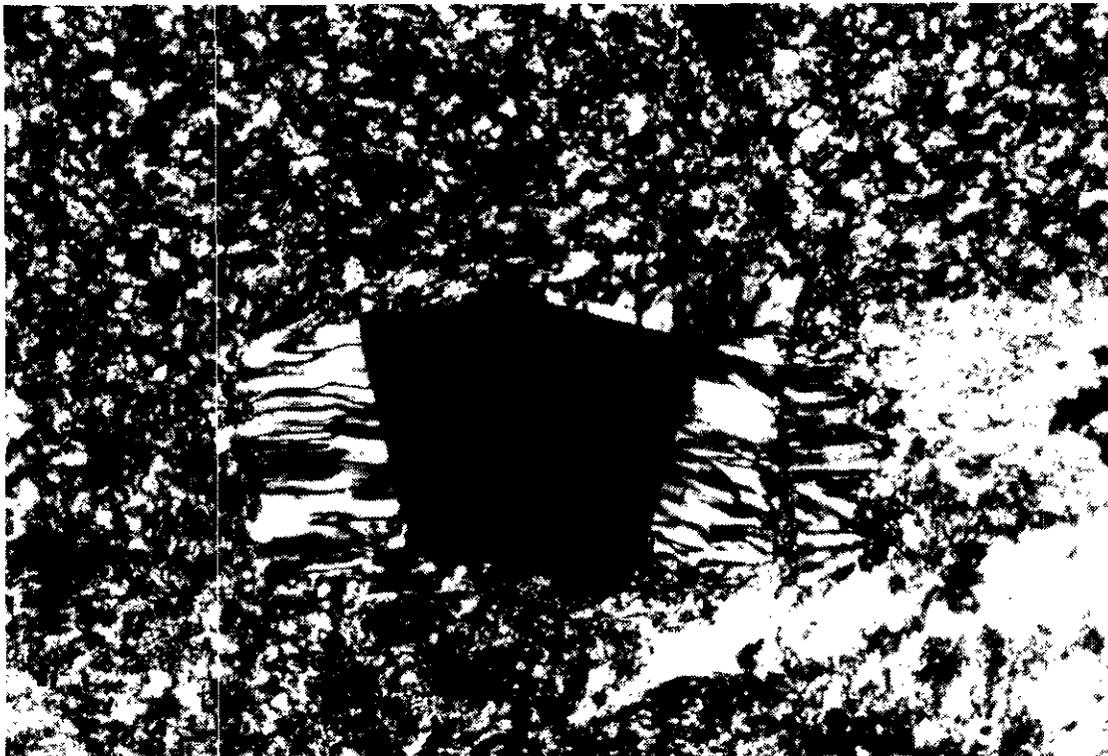
Plate 2-11-4. Pressure shadows of fibrous quartz around euhedral pyrite. DDH 81-58, 22 feet; crossed nicols; 100×; width of pyrite crystal, 0.3 millimetre.

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

Age (Ma)	Event
35-25	Emplacement of biotite lamprophyre dykes.
45-35	Emplacement of microdiorite or "andesite" dykes along NNW trend, locally deflected by biotite granodiorite dykes.
48-43	Formation of argentiferous galena-sphalerite-freibergite vein deposits and spatially associated MoS_2 and WO_3 deposits.
55-45	Intrusion of Hyder, Boundary, Davis River, Bitter Creek and Mineral Hill stocks of the Coast Range batholith. Biotite granodiorite to biotite quartz monzonite. Continuing dyke intrusion.
55	Crustal extension and intrusion of major WNW-trending biotite granodiorite dyke swarms marked onset of emplacement of stocks at depth.
110-90	Lower greenschist facies regional metamorphism reaches a thermal peak. Moderate deformation along north-trending fold axes. Major folds and slaty cleavage formed.
190-160	Marine transgression, flysch sedimentation with minor intraformational conglomerates (Unit 4). Relative quiescence.
190-185	Waning magmatic activity marked by emplacement of hornblende lamprophyre dykes at depth.
~190	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.
195-190	Deposition of subaerial epiclastic sediments and interbedded andesitic to dacitic tuffs and flows (Unit 2). (Emplacement of minor dykes at depth?)
195	Intrusion of porphyry phase of Texas Creek granodiorite, Premier Porphyry dykes, and extrusion of Premier Porphyry flows and tuff breccias.
215-195	Andesitic volcanic activity (Unit 1), predominantly subaerial with two periods of marine transgression; coeval intrusion of main phase of Texas Creek granodiorite.

(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 $^{40}Ar/^{39}Ar$ age spectra analysis for mineral separates from andesitic crystal tuffs and from phases of the Texas Creek granodiorite.

REFERENCES

Alldrick, D.J. (1985): Stratigraphy and Petrology of the Stewart Mining Camp (104B/1), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1984, Paper 1985-1, pages 316-341.

Alldrick, D.J. and Kenyon, J.M. (1984): The Prosperity/Porter Idaho Silver Deposits (103P/13), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1983, Paper 1984-1, pages 165-172.

Alldrick, D.J., Mortensen, J.K. and Armstrong, R.L. (1986): Uranium-Lead Age Determinations in the Stewart Area (104B/1), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 217-218.

Armstrong, R.L. (1966): K/Ar Dating of Plutonic and Volcanic Rocks in Orogenic Belts, *in* Potassium-Argon Dating, O.A. Schaeffer and J. Zahringer, editors, pages 117-133, *Springer-Verlag*, Berlin.

——— (1986): Rb-Sr Dating of the Bokan Mountain Granite Complex and Its Country Rocks: Reply, *Canadian Journal of Earth Sciences*, Volume 23, pages 744-745.

——— (*in press*): Mesozoic and Early Cenozoic Magmatic Evolution of the Canadian Cordillera, *Geological Society of America*, Memoir, Rogers Symposium Volume.

Berger, G.W. and York, D. (1981): Geothermometry from $^{40}Ar/^{39}Ar$ Dating Experiments, *Geochimica et Cosmochimica Acta*, Volume 45, pages 795-811.

Brew, D.A. and Morrell, R.P. (1983): Intrusive Rocks and Plutonic Belts of Southeastern Alaska, U.S.A., *in* Circum-Pacific Plutonic Terranes, *Geological Society of America*, Memoir 159, pages 171-194.

Carter, N.C. (1981): Porphyry Copper and Molybdenum Deposits of West-central British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 64.

Deer, W.A., Howie, R.A. and Zussman, J. (1963): Rock Forming Minerals, Volume 3, *Longman's*, London, 270 pages.

Devlin, B.D. and Godwin, C.I. (1986): Geology and Genesis of the Dolly Varden Silver Camp, Alice Arm Area, Northwestern British Columbia, *in* Geoexpo '86, Program with Abstracts, *Geological Association of Canada*, page 34.

Dodson, M.H. (1973): Closure Temperature in Cooling Geochronological and Petrological Systems, Contributions, *Mineralogy and Petrology*, Volume 40, pages 259-274.

Grove, E.W. (1971): Geology and Mineral Deposits of the Stewart area, British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 58.

Krogh, T.E. (1973): A Low-contamination Method for Hydrothermal Decomposition of Zircon and Extraction of U and Pb for Isotopic Age Determinations, *Geochimica et Cosmochimica Acta*, Volume 37, pages 485-494.

McGuigan, P.J. (1985): Summary Report of 1985 Exploration Program on the Indian Property, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 14111.

Parrish, R. and Roddick, J.C. (1984): Geochronology and Isotope Geology for the Geologist and Explorationist, *Geological Association of Canada*, Cordilleran Section, Short Course Number 4, 71 pages.

Smith, D.G. (editor) (1981): The Cambridge Encyclopedia of Earth Sciences, *Prentice-Hall*, Scarborough, 496 pages.

Smith, J.G. (1973): A Tertiary Lamprophyre Dike Province in Southeastern Alaska, *Canadian Journal of Earth Sciences*, Volume 10, pages 408-420.

——— (1977): Geology of the Ketchikan D-1 and Bradfield Canal A-1 Quadrangles, Southeastern Alaska, *United States Geological Survey*, Bulletin 1425, 49 pages.

Smith, J.G., Stern, T.W. and Arth, J.G. (1979): Isotopic Ages Indicate Multiple Episodes of Plutonism and Metamorphism in the Coast Mountains near Ketchikan, Alaska, *Geological Society of America*, Program with Abstracts, Volume 11, page 519.

Stacey, J.S. and Kramers, J.D. (1975): Approximation of Terrestrial Lead Isotope Evolution by a Two-stage Model, *Earth and Planetary Science Letters*, Volume 26, pages 207-221.

Steiger, R.H. and Jager, E. (1977): Subcommission on Geochronology — Convention on the Use of Decay Constants in Geo- and Cosmochronology, *Earth and Planetary Science Letters*, Volume 36, pages 359-362.

York, D. (1984): Cooling Histories from $^{40}Ar/^{39}Ar$ Age Spectra, Annual Review, *Earth and Planetary Sciences Letters*, Volume 12, 1984, pages 383-409.