

Age of Platinum-Group-Element Mineralization in the Sappho Alkaline Complex, South-Central British Columbia

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INTRODUCTION

The Sappho mineral occurrence in south-central British Columbia (MINFILE 082ESE147; 49° 00' 22" N, 118° 42' 18" W) is part of the Boundary mining camp and one of a number of historical Cu-Ag-PGE(±Au) prospects associated with alkalic intrusive complexes in the province. The property is located approximately 10 kilometres south of Greenwood and 5 kilometres east of Midway (Figure 1). Between 1916 and 1918, 102 tonnes of ore with an average grade of 5.6 wt. % Cu and 61.7 g/t Ag was shipped to the smelter, followed by a further 9 tonnes in 1927-1928. Significant concentrations of platinum were detected in a grab sample of the chalcopyrite-pyrite ore which assayed 3.2 % Cu and 1.03 grams per tonne Pt (Minister of Mines Annual Report 1927). The historical record of copper production, combined with the potential for precious metals, has attracted intermittent interest from exploration companies ever since, especially over the past 40 years. The property is currently optioned to Gold City Industries Ltd. who have re-excavated the old workings and carried out geochemical analyses of soils, till and bedrock. Assays of mineralized bedrock have confirmed anomalous abundances of the platinum-group elements (PGE), and analytical data recently published by Hulbert (2001), for example, show values up to 4.34 g/t Pd, 2.26 g/t Pt, 76 g/t Ag and 0.75 g/t Au for semi-massive and disseminated sulfide-bearing samples.

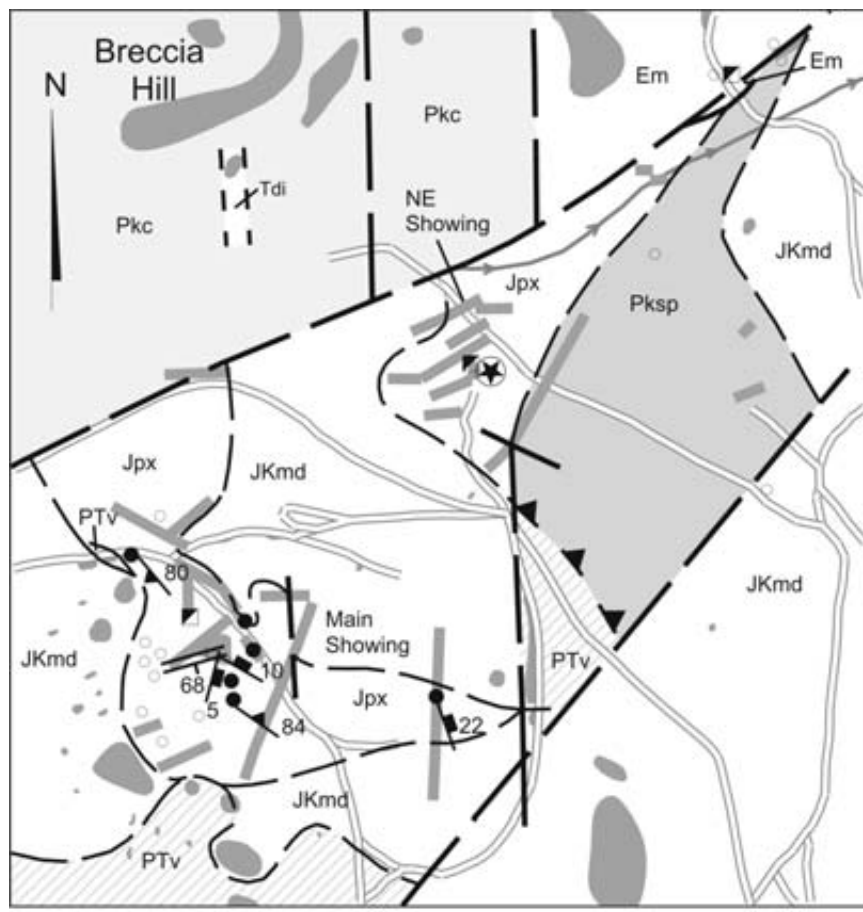
The style of mineralization at Sappho has been referred to informally as "Coryell-type" due to its association with alkaline rocks correlated with the Tertiary (Eocene) Coryell Batholith in southern British Columbia (Hulbert *et al.*, 1987; Hulbert, 2001). Another alkaline-hosted Cu-Ag-PGE occurrence originally considered to be Eocene in age is the Maple Leaf prospect (82ENE007) which was mined in the early 1900s as part of the Franklin mining camp just north of Grand Forks (Fig. 1). It has since been shown, however, that the intrusion which hosts the Maple Leaf occurrence, the Averill plutonic complex, is Jurassic in age (Keep, 1989; Keep and Russell, 1992). The purpose of this study, therefore, was to provide evidence for the age of the Cu-Ag-PGE



Figure 1. Location of the Sappho alkaline-hosted Cu-Ag-PGE occurrence in south-central British Columbia. Also shown are the locations of the Maple Leaf Cu-Ag-PGE prospect (Averill alkaline plutonic complex) and Shasket Creek alkaline complex in northern Washington State (*see text*).

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0 100 200
meters

Tertiary (Eocene)
Marron Formation

- Em volcanic rocks
- Tdi diorite

Jurassic or Cretaceous

- JKmd diorite-monzodiorite (minor monzonite)

Jurassic

Sappho alkaline complex

- Jpx clinopyroxenite
- syenite dike (attitude unknown)
- syenite dike (strike and dip)
- flow lamination in dike
- Cu-Ag-PGE vein

Triassic or Permo-Carboniferous

- PTv mafic volcanic rocks

Permo-Carboniferous
Knob Hill Group

- Pkc chert-argillite
- Pksp serpentinized ultramafic

- outcrop, trench
- pit, adit
- $^{40}\text{Ar}/^{39}\text{Ar}$ date
- Geological contact
- Normal fault
- Pre-Tertiary thrust fault (inferred)

Figure 2. Geology of the Sappho alkaline complex showing location of sample collected for $^{40}\text{Ar}/^{39}\text{Ar}$ dating.

mineralization at Sappho using $^{40}\text{Ar}/^{39}\text{Ar}$ dating methods. The results given below are preliminary but sufficient to show that alkaline rocks which host the mineralization are Jurassic in age, and this is also considered to be the age of the mineralization.

CAPSULE GEOLOGY

The geology of the Sappho alkaline complex, named for the mineral occurrence, is shown in Figure 2. Exposure is extremely poor, and the position and nature of contacts between map units are inferred from fieldwork conducted last summer, a compilation of previous exploration work on the property, and detailed maps by Fyles (1990) and Church (1986). This geological compilation of the Sappho alkaline complex is currently available (Nixon, 2002).

In terms of Cordilleran settings, Sappho is located within Quesnellia, an accreted magmatic-arc terrane comprising Late Paleozoic basement rocks (Harper Ranch or Okanagan subterrane) overlain by Early Mesozoic volcanic-sedimentary sequences. The oldest rocks in the area belong to the Permo-Carboniferous Knob Hill and Attwood Groups. Knob Hill lithologies represent a disrupted ocean-floor assemblage of chert, metabasalt, gabbro/diorite and serpentinized peridotite (Fyles, 1990; Dostal *et al.* 2001). The Attwood Group (south and east of the area shown in Fig. 2) comprises argillite, phyllite, limestone and lesser mafic to intermediate volcanoclastic rocks of island-arc or back-arc affinity (Dostal *et al.* 2001). Stratigraphic relationships between these sequences are unknown. These older strata are unconformably overlain by clastic, carbonate and calc-alkaline volcanic rocks of the Middle Triassic Brooklyn Formation which contains detritus derived from erosion of Knob Hill obducted ophiolite sequences and was deposited in a mature island-arc setting (Dostal *et al.*, 2001). The mafic volcanic rocks shown in Figure 2 were tentatively assigned to the Brooklyn Formation by Fyles (1990). Further contraction in late Early to Middle Jurassic time accompanied accretion of Quesnel terrane to the cratonic edge of North America (Hoy and Dunne, 1997). Renewed volcanism (Marron Formation) and dike emplacement occurred in the Tertiary (Eocene) accompanied by extensional tectonism which reactivated older structures and generated new ones. The Sappho area lies at the eastern margin of the Toroda Creek graben which is defined by an intersecting set of northeasterly to northerly trending structures (Fig. 2).

The Sappho alkaline complex comprises biotite-hornblende clinopyroxenite, the dominant lithology, minor melanocratic monzonite and dikes of potassium-feldspar porphyritic syenite which cut the pyroxenite. The feldspathic phases of the complex contain melanitic garnet (titanian andradite) with igneous textures, and the syenite dikes locally exhibit a planar alignment of feldspar phenocrysts. Church and Robertson (1983) described the clinopyroxenite as "shonkinite" which, according to Le Maitre *et al.* (1989), requires the presence of essential feldspathoid minerals and none have been observed. The pyroxenite commonly contains veins and disseminations of

calcite locally accompanied by epidote, chlorite and white mica; the dikes are typically sericitized. The alkaline rocks are in contact with a larger dioritic intrusion which appears to be younger based on its lesser degree of alteration and lack of syenite dikes. A sample of this intrusion is currently being dated by U-Pb techniques.

The Cu-Ag-PGE mineralization occurs in semi-massive to massive veins, blebs and pods of chalcopyrite-pyrite-magnetite ore and as sulfide disseminations hosted by pyroxenite and syenite dykes. The sulfide veins are predominantly controlled by gently dipping fractures and shears in the pyroxenite (Fig. 2). Thin leucocratic melanite-bearing syenite veins, apophyses of the dikes, have been observed occupying some of these fractures and are found locally at the margins of sulfide-oxide assemblages. The intimate structural and textural relationships between the mineralization and the felsic dykes imply a genetic relationship. Furthermore, the alkalic nature of the pyroxenite and feldspathic phases, underscored by the presence of primary melanite garnet, support previous inferences of a common magmatic lineage (Gilmour, 1981; Church and Robertson, 1983). The Cu-Ag-PGE mineralization is therefore considered to be late magmatic or magmatic-hydrothermal in origin and bears mineralogical traits commonly assigned to the alkalic porphyry deposit-type (Barr *et al.*, 1976).

SAMPLE DESCRIPTION

The sample submitted for dating is a biotite-hornblende clinopyroxenite collected from outcrop at the entrance to an adit at the north-east showing (Fig. 2). The rock is a dark grey-green, medium-grained, moderately magnetic clinopyroxenite that is extensively fractured and locally stained by malachite and azurite. The rock contains dark greenish-black hornblende and minor amounts of fresh biotite; hornblende also occurs in localized segregations of coarse subhedral crystals (5-10 mm) intergrown with minor feldspar. The outcrop is cut by numerous white carbonate veinlets several millimetres to a centimeter wide, and calcite also occurs as poikilitic replacements enclosing relatively fresh hornblende. Chlorite, minor epidote and hematitic alteration are locally conspicuous. The copper carbonate stains are derived from local sulfide disseminations (trace to 4 vol. %) and thin veins of chalcopyrite-pyrite-magnetite (≤ 6 cm in width) which cut the clinopyroxenite and dip shallowly to the north.

In thin section, the rock is a hornblende clinopyroxenite carrying minor amounts of biotite, feldspar, apatite, magnetite and sphene. Colourless to pale green diopsidic pyroxene (2-4 mm) displays mutual intergrowths with primary hornblende and is partially altered to secondary amphibole (?actinolitic) and calcite. Primary hornblende (≤ 5 mm) exhibits brownish green to deep green pleochroism and may poikilitically enclose magnetite and apatite. The coarser hornblende segregations are observed to contain minor alkali feldspar and rare biotite. The alkali feldspar occurs as anhedral interstitial grains with patchy extinction or perthitic texture and rarely encloses subhedral sodic

plagioclase. Biotite (≤ 2 mm) exhibits dark greenish brown to nearly colourless pleochroism and is partially altered along cleavages to chlorite and secondary granular sphene. Small amounts of apatite (≤ 0.4 mm; ~ 2 vol. %) forms euhedral to subhedral grains commonly intergrown with subhedral to anhedral magnetite (≤ 1.5 mm; ~ 3 vol. %); and primary sphene forms brownish grey anhedral crystals (≤ 0.4 mm; < 1 vol. %).

ANALYTICAL METHODS

Mineral separates and flux-monitors (standards) are wrapped in Al-foil and the resulting disks are stacked vertically into a 11.5 cm long and 2.0 cm diameter container, and then irradiated with fast neutrons in position 5C of the McMaster Nuclear Reactor (Hamilton, Ontario) for a duration appropriate for the expected age of the sample. Groups of flux monitors (typically 12 in total) are located at ca. 1 cm intervals along the irradiation container and J-values for individual samples are determined by second-order polynomial interpolation between replicate analyses of splits for each position in the capsule. Typically, J-values are between ca. 0.003 and 0.03 and vary by $< 10\%$ over the length of the capsule. No attempt is made to monitor horizontal flux gradients as these are considered to be minor in the core of the reactor.

For total fusion of monitors and step-heating using a laser, the samples are mounted in an aluminum sample-holder, beneath the sapphire view-port of a small, bakeable, stainless-steel chamber connected to an ultra-high vacuum purification system. An 8W Lexel 3500 continuous argon-ion laser is used. For total-fusion dating the beam is sharply focused; for step-heating the laser beam is defocused to cover the entire sample. Heating periods are ca. 3 minutes at increasing power settings (0.25 to 7 W). The evolved gas, after purification using an SAES C50 getter (ca. 5 minutes), is admitted to an on-line, MAP 216 mass spectrometer, with a Baur-Signer source and an electron multiplier (set to a gain of 100 over the Faraday). Blanks, measured routinely, are subtracted from the subsequent sample gas-fractions. The extraction blanks are typically $< 10 \times 10^{-13}$, $< 0.5 \times 10^{-13}$, $< 0.5 \times 10^{-13}$, and $< 0.5 \times 10^{-13}$ cm⁻³ STP for masses 40, 39, 37, and 36, respectively.

Measured argon-isotope peak heights are extrapolated to zero-time, normalized to the ⁴⁰Ar/³⁶Ar atmospheric ratio (295.5) using measured values of atmospheric argon, and corrected for neutron-induced ⁴⁰Ar from potassium, ³⁹Ar and ³⁶Ar from calcium (using production ratios of Onstott and Peacock, 1987), and ³⁶Ar from chlorine (Roddick, 1983). Dates and errors are calculated using formulae given by Dalrymple *et al.* (1981), and the constants recommended by Steiger and Jaeger (1977). Isotope correlation analysis used the formulae and error propagation of Hall (1981) and the regression of York (1969). Errors shown in the tables and on the age spectra and isotope correlation diagrams represent the analytical precision at 2σ , assuming that the errors in the ages of the flux-monitors are zero. This is suitable for comparing within-spectrum variation and determining which steps form a plateau (McDougall and Harrison, 1988,

p. 89). A conservative estimate of this error in the J-value is 0.5% and can be added for inter-sample comparison. The dates and J-values for the intralaboratory standard (*e.g.*, MAC-83 biotite at 24.36 Ma) are referenced to TCR sanidine at 28.0 Ma (Baksi *et al.*, 1996) for young samples and to Hb3Gr hornblende at 1071 Ma for old samples.

RESULTS

The material analyzed consisted of ca. 25 fine-grained, hand-picked crystals of green hornblende. Some grains are intergrown with a small amount of alkali feldspar along grain boundaries and may have had thin overgrowths of a clear to pale green, optically zoned biotite.

The analytical data are given in Table 1 and the age spectrum is shown in Figure 3A. The spectrum is complex and typical of samples that are mixtures of more than one phase. The variation in the calculated Ca/K ratio (Table 1) shows that the low- and high-temperature parts of the spectrum are dominated by Ar release from a K-rich phase whereas the mid-temperature steps (3.75 to 4.25 W) record Ar release from a more Ca-rich phase (with a Ca/K ratio ≥ 5.6).

The first four, low-temperature steps have high atmospheric contamination and large errors but plot on an argon isotope correlation diagram as a linear array with a near-atmospheric ⁴⁰Ar/³⁶Ar ratio (Fig. 3B). The y-intercept yields a date of 100 ± 9 Ma for these steps. The significance of this date is not known. It may reflect argon re-distribution during post-emplacement tectonothermal events (see discussion).

The 4.25 W step yielded 28% of ³⁹Ar and the maximum date in the spectrum (156 ± 3 Ma at the 2σ level of confidence). The calculated Ca/K ratio of 5.6 for this step is typical of many hornblendes. However, because biotite and alkali feldspar release argon over a wider temperature range and fuse at a higher temperature than hornblende both the Ca/K ratio and the date for this step should be taken as minimum estimates. Accordingly, this spectrum shows that the Sappho clinopyroxenite is older than 156 Ma and most likely Jurassic in age.

DISCUSSION

The ⁴⁰Ar/³⁹Ar date reported above for primary igneous amphibole in Sappho pyroxenite places a minimum age of 156 ± 3 Ma (2σ) (Late Jurassic) on emplacement of the alkalic complex and hence the Cu-Ag-PGE mineralizing event with which it is genetically associated. Interestingly, this date is concordant with a conventional K-Ar date of 150 ± 10 Ma (2σ) obtained on an impure mineral separate (hornblende + biotite + clinopyroxene) from the Averill alkaline complex which hosts the Maple Leaf Cu-Ag-PGE occurrence (Keep, 1989). Also of note is the age of the Shasket Creek alkaline intrusive complex situated just across the International Boundary near Danville (Fig. 1) which may also be Jurassic. Syenite porphyry dikes from this complex cut Permian and Triassic limestones and, at the historic Comstock Mine, are intimately associated with copper ores

TABLE 1
RESULTS OF $^{40}\text{Ar}/^{39}\text{Ar}$ LASER STEP-HEATING EXPERIMENTS

01GNX1-2-2 Hornblende

J Value: 0.007650±0.000058

Maximum Date: 156±3

Initial $^{40}\text{Ar}/^{39}\text{Ar}$ Ratio: 312.03±63.15 (MSWD: 1.54)

Volume ^{39}ArK : 123.16

% ^{39}ArK for MD: 27.75

Integrated Date: 137.7±2.3

Isotope Correlation Date: 100.1±8.5

% ^{39}ArK for CD: 17.48

	Laser Power (Watts)	Isotope Volumes					Isotope Ratios			
		^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{36}\text{Ar}/^{39}\text{Ar}$
1	0.75	9.915±0.101	0.068±0.003	0.021±0.003	0.012±0.002	0.031±0.002	145.551±0.041	0.306±0.140	0.175±0.173	0.453±0.078
2	1.50	5.655 0.028	0.257 0.003	0.015 0.003	0.079 0.003	0.015 0.002	22.039 0.014	0.057 0.178	0.308 0.034	0.057 0.149
3	2.25	7.099 0.046	0.517 0.004	0.016 0.003	0.050 0.002	0.013 0.002	13.725 0.010	0.030 0.163	0.096 0.046	0.026 0.154
4	3.00	11.598 0.060	1.335 0.006	0.043 0.003	0.291 0.004	0.008 0.002	8.684 0.007	0.032 0.075	0.218 0.014	0.006 0.265
5	3.75	20.788 0.078	1.895 0.008	0.109 0.004	0.725 0.006	0.004 0.002	10.970 0.006	0.058 0.039	0.383 0.010	0.002 0.507
6	4.25	40.689 0.141	3.441 0.010	0.219 0.007	1.384 0.010	0.006 0.002	11.826 0.005	0.064 0.034	0.402 0.008	0.002 0.391
7	4.75	11.329 0.037	1.043 0.005	0.056 0.003	0.227 0.146	0.002 0.002	10.857 0.006	0.054 0.062	0.217 0.645	0.002 1.141
8	5.50	15.389 0.098	1.511 0.007	0.074 0.004	0.328 0.212	0.003 0.002	10.187 0.008	0.049 0.054	0.217 0.646	0.002 0.782
9	7.00	23.190 0.148	2.348 0.010	0.104 0.004	0.459 0.330	0.003 0.002	9.878 0.008	0.044 0.039	0.196 0.719	0.001 0.720

Isotope Correlation Data									
	$^{36}\text{Ar}/^{40}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	r	Ca/K	Cl/K	% ^{40}Ar atm	% ^{39}Ar	$^{40}\text{Ar}/^{39}\text{ArK}$	Age
1	0.002883±0.000221	0.006567±0.000329	0.180	2.235	0.046	85.18	0.53	22.54±9.58	287.0±112.8
2	0.002247 0.000387	0.044824 0.000657	0.014	4.229	0.006	66.31	2.05	7.50 2.55	100.6 33.3
3	0.001584 0.000293	0.072422 0.000752	0.023	1.292	0.002	46.70	4.15	7.35 1.20	98.6 15.7
4	0.000461 0.000183	0.114747 0.000804	0.010	3.001	0.004	13.57	10.75	7.53 0.48	101.0 6.2
5	0.000033 0.000107	0.090674 0.000514	0.003	5.293	0.010	0.95	15.27	10.92 0.35	144.8 4.5
6	0.000019 0.000055	0.084089 0.000386	0.005	5.568	0.011	0.54	27.75	11.83 0.20	156.3 2.5
7	0.000004 0.000370	0.091664 0.000950	0.661	3.000	0.009	0.09	8.40	10.90 0.69	144.5 8.8
8	0.000015 0.000332	0.097750 0.001105	0.635	3.000	0.008	0.41	12.17	10.19 0.42	135.4 5.4
9	0.000003 0.000321	0.100859 0.001102	0.661	2.700	0.007	0.07	18.93	9.91 0.32	131.8 4.0

Isotope Production Ratios: ($^{40}\text{Ar}/^{39}\text{ArK}$ = 0.0302; ($^{37}\text{Ar}/^{39}\text{ArCa}$) = 1416.4306; ($^{36}\text{Ar}/^{39}\text{ArCa}$) = 0.3952; Ca/K = 1.83 x ($^{37}\text{ArCa}/^{39}\text{ArK}$)

All volumes are x10⁹ cm³ NTP; all errors are x2 standard error

CD = Correlation date; MD = Maximum date

(chalcopyrite-bornite) which are known to carry anomalous concentrations of PGE (Parker and Calkins, 1964; Mutschler and Mooney, 1993). The only reported isotopic age for these rocks appears to be a $^{40}\text{Ar}/^{39}\text{Ar}$ date of 168 ± 0.4 Ma obtained on white mica associated with a “mineralizing alkalic intrusion” (Berger *et al.*, 1991). The thermal-release spectra of white mica in both this sample and altered pre-Cretaceous metavolcanic rocks and serpentinites in the area indicate thermal disturbances at $\leq 118.5 \pm 1.5$ Ma (mid-Early Cretaceous), 103-104 Ma (late Early Cretaceous) and 50-60 Ma (Late Paleocene – Early Eocene). It is possible, therefore, that the inverse isochron date of 100 ± 9 Ma obtained in this study for Sappho hornblende relates to one or more of these events.

In view of the Jurassic age for the Sappho alkaline complex and its associated Cu-Ag-PGE sulfides, it is recommended that use of the term “Coryell-type” be discontinued when referring to this style of mineralization.

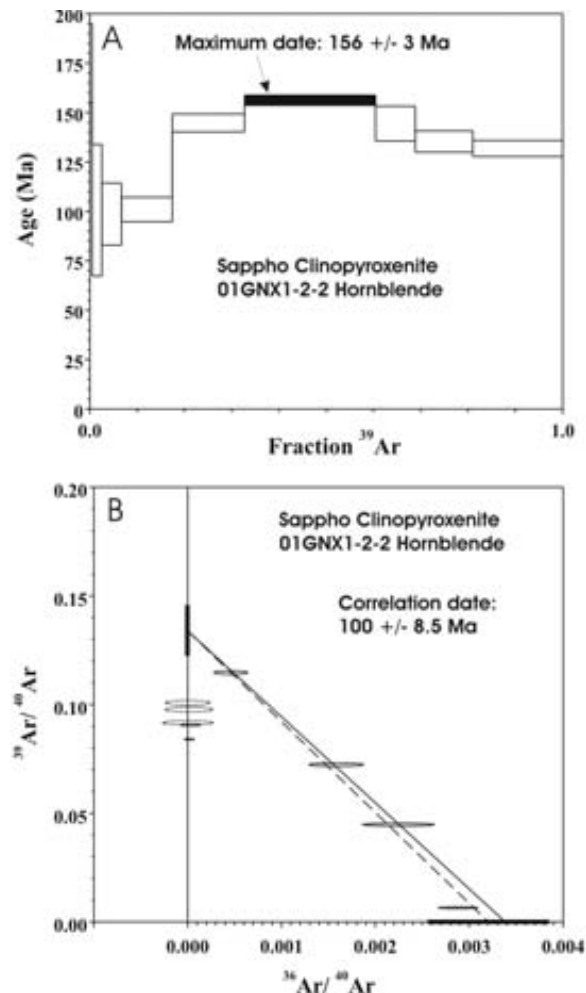


Figure 3. A. Plot of the age spectrum; the solid step indicates the fraction of ^{39}Ar released for the maximum date.

Figure 3. B. Inverse isochron plot. The dashed line is the best-fit line through the solid error ellipses; the size of the ellipse is an indication of the 2σ error associated with the ratios for each step. Ellipses on the ordinate were not included in the age calculation. The solid line connects the best-fit inverse $^{40}\text{Ar}/^{39}\text{Ar}$ ratio to the inverse atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ ratio. The near correspondence of the two lines indicates that the low-temperature steps do not contain excess argon. All quoted errors are given at the 2σ level of confidence.

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