

## $^{40}\text{Ar}$ - $^{39}\text{Ar}$ GEOCHRONOLOGICAL STUDIES OF GRANITIC ROCKS FROM SOUTH VICTORIA LAND, ANTARCTICA

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**Abstract:**  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  ages were obtained for two granitic rocks from the Dry Valleys region of South Victoria Land, Antarctica. One sample (biotite-rich fraction) of foliated granitoid gave three age increments of 491 Ma, 502 Ma and 506 Ma, with K/Ca ratios suggesting influence of cooling ages of biotite (younger age) and that of hornblende (older age). Granitoid emplacement is thought to have been before 506 Ma, with cooling from biotite closure temperatures about 490 Ma. A sample of unfoliated granitoid gave ages of 467-496 Ma. The similarity of ages determined for both "pre-tectonic" and "post-tectonic" samples indicate closure of isotopic systems around 490 Ma due to regional uplift/exhumation, rather than actual emplacement ages of individual plutons in South Victoria Land.

### 1. Introduction

South Victoria Land lies on the eastern margin of East Antarctica facing the Ross Sea (Fig. 1). Geochronological studies reveal that Ross Orogeny plutonism and metamorphism of basement rocks occurred within a time-span from 600 Ma to 450 Ma. The majority of ages have been determined by Rb-Sr and K-Ar techniques, with many ages determined at about 490 Ma (ALLIBONE *et al.*, 1993a). Detailed mapping indicates that a significant change in both the intrusive style and chemistry of granitoids occurred at this time, which is thought to reflect a major change in the tectonic setting Antarctic Craton margin (ALLIBONE *et al.*, 1993a, b). However, it has not yet to be established whether the Rb-Sr and K-Ar ages truly represent the emplacement and cooling of individual plutons, with significant pulse of magmatism and change in tectonic setting at about 490 Ma, or whether these ages represent the regional closure of Rb-Sr and K-Ar systems during uplift and cooling.

In this paper we present results from an  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  study of two samples from South Victoria Land: a foliated "pre-tectonic" orthogneiss, and an unfoliated "post-tectonic" granite. The purpose of the study is to determine ages using  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  techniques, and to see whether or not the  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  spectra can discriminate different thermal histories that may relate to emplacement ages, or whether they record a similar regional uplift and closure of isotopic systems. These preliminary results are part of a detailed study of the thermal

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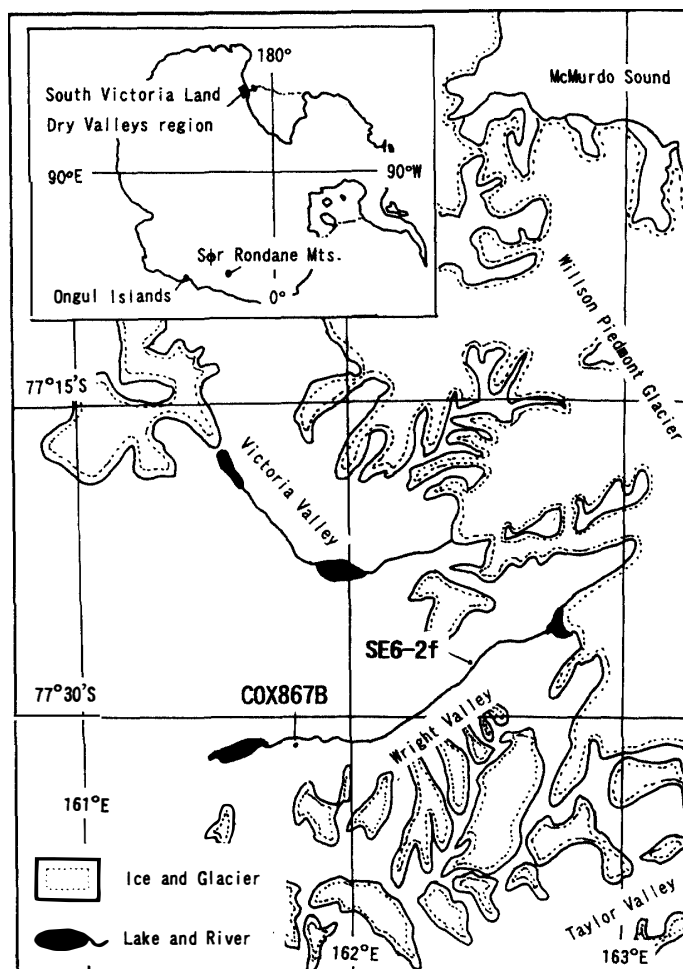


Fig. 1. Dry Valleys region in the South Victoria Land and sampling localities (modified after ALLIBONE *et al.*, 1993a).

and intrusive history of granitoids in South Victoria Land.

## 2. Regional Geology

The oldest rocks of southern Victoria Land are multiply deformed, upper amphibolite facies Koettlitz Group metasediments (GUNN and WARREN, 1962; GRINDLEY and WARREN, 1964; FINDLAY *et al.*, 1984; ALLIBONE, 1992), of possible late-Proterozoic age (ADAMS and WHITLA, 1991). At least two phases of deformation have affected Koettlitz Group metasediments during the Ross Orogeny. During the later stages of deformation, Koettlitz Group metasediments were intruded by granitoids of the Granite Harbour Intrusives (GRINDLEY and WARREN, 1964; COX, 1993).

On the basis of field relations and geochemistry, granitoids in the Dry Valleys region of South Victoria Land were subdivided into three petrogenetically distinct suites (ALLIBONE *et al.*, 1993a, b). The DV1a (Dry Valley 1a) suite consists of Cordilleran I-type granitoids including the batholithic-scale Bonney Pluton and at least four other major plutons of hornblende-biotite granitoid, and hornblende-biotite orthogneisses (Cox and

ALLIBONE, 1991). The DV1b suite comprises several large plutons of biotite granodiorite and granite, and younger plugs of biotite granite, as well as biotite orthogneisses. Both the DV1a and DV1b suites were time transgressive, and emplacement of older orthogneisses in each suite overlapped. Field relationships and limited Rb/Sr dating indicate plutonism before about 500 Ma was dominated by the DV1a suite, which predated a major pulse of DV1b plutons with Rb/Sr ages all around 490 Ma. Overlapping plutonism has resulted in complicated mutually crosscutting relationships between granitoids of the DV1a and DV1b suites. Younger DV2 alkali-calcic, Caledonian I-type plutonism is inferred to have formed in response to uplift and extension between about 486 Ma and 455 Ma. K-Ar dating of granitoids yields a range of uplift ages, mostly 480–420 Ma (ANGINO *et al.*, 1962; JONES and FAURE, 1967; FAURE and JONES, 1974; MCDUGALL and GHENT, 1970). Isotopic dates from Antarctica were compiled by STUIVER and BRAZIUNAS (1985).

Emplacement of granitoids was followed by uplift and erosion of the regionally extensive Kukri Erosion Surface. Deposition of the Devonian to Triassic Beacon Supergroup followed, consisting primarily of texturally mature sandstones, siltstones, and minor coal measures, with a total thickness of about 2 km (BARRETT *et al.*, 1986). Sills and dykes of tholeiitic Ferrar Dolerite intruded all of the above rocks during the Jurassic (KYLE *et al.*, 1981). There is little evidence of geological activity until development of the Royal Society Range (part of the Transantarctic Mountains) during rifting in the Ross Sea in the middle Cenozoic (GLEADOW and FITZGERALD, 1987). Apatite fission track ages from Wright Valley granitoids vary from 66–154 Ma with altitude, recording the period since uplift from temperatures about 100–125°C (GLEADOW *et al.*, 1984). Sparse but widespread veins cut both basement and overlying sediments, and are thought to result in part from hydrothermal activity associated with both Ferrar Dolerite intrusion, and later uplift (CRAW and FINDLAY, 1984; CRAW *et al.*, 1992). The youngest rocks of the Dry Valleys region are Miocene-Recent moraines and small alkali basanite flows and scoria cones of the McMurdo Volcanics.

### 3. Samples

Two samples of hornblende-biotite granitoids with contrasting lithofacies were selected for  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  dating. The samples are from Wright Valley, with one sample (SE6-2f) from an outcrop of orthogneiss (162°5.6'E, 77°7.1'S) and the other (COX867B) from an undeformed granitic dyke (161°2.5'E, 77°1.8'S) (Fig. 1). Biotite-rich fractions were separated from each sample by isodynamic separator for analysis. Although coarse grained hornblende was separated from the analysed samples, some of fine grained hornblende included in the biotite aggregates was not successfully separated. Preparation of very fine grained biotite sample (less than 200 mesh) is required for a further precise dating study.

Sample SE6-2f was collected by Mr. S. ELLERY from the Mt. Theseus area, Lower Wright Valley (ELLERY, 1989). The sample has a weak foliation represented by hornblende-biotite alignment, which is parallel to foliation in the highly deformed Koettlitz Group metasediments it intrudes. The sample is composed of potassium feldspar, plagioclase, quartz, biotite and hornblende as main constituent minerals. Granular subgrain texture in quartz suggests recrystallization and amalgamation of pre-existing finer

grained quartz as a result of deformation.

Sample COX867B was collected by Dr. S.C. Cox near Lake Bull in Wright Valley, from a leucocratic granitic dyke lying within the Bonney Pluton (ALLIBONE *et al.*, 1993a). The sample is massive and unfoliated, with biotite, potassium feldspar, plagioclase and quartz as the main constituent minerals. Hornblende and titanite are minor constituents, and are typically associated with in biotite aggregates. Some biotite in the sample shows minor oxidation.

#### 4. Experiments

Biotite-rich fractions of two samples were wrapped in Al foils and sealed in a quartz tube (70 mm × 10 mm  $\phi$ ) in vacuum condition. JG1-biotite (biotite separated from JG-1 standard sample of granite by the Japan Geological Survey,  $K_2O = 7.64 \pm 0.05$  wt%, Age =  $90.8 \pm 1.7$  Ma), were sealed together with  $K_2SO_4$  and  $CaF_2$  as the age standard and collection standards of K- and Ca-derived interference Ar isotopes, respectively. The quartz tube was wrapped in Cd foil in order to decrease the thermal neutrons in the reactor. They were irradiated with fast neutrons for 24 hours in Japan Material Testing Reactor, receiving about  $10^{18}$  total neutrons.

After about 8 months, Ar gas was extracted from the each irradiated sample in a Mo crucible using an induction heater at Radio Isotope Center, University of Tokyo. Temperature of the top of Mo crucible was controlled by the output power of the induction heater with the aid of an optical pyrometer. Temperature was increased stepwisely for every 60 min.

Ar gas was purified by heated Ti and introduced to the Quadrupole Mass Spectrometer (MSQ-400; ULVAC Corp.) for isotopic analysis. Data were corrected for mass discrimination and are listed in Table 1. Ages were calculated from ratios of radiogenic  $^{40}Ar$  over K-derived  $^{39}Ar$  using the age standard data of JG-1 biotite after further correction of K- and Ca-derived interference isotopes. Calculated ages are also listed in Table 1.

#### 5. Results and Discussion

Results are shown in Table 1, Fig. 2a and Fig. 2b.

*Sample SE6-2f*: Age spectrum of this sample shows slight increase stair type. Ages of about 488–513 Ma for each step are similar to Rb-Sr ages determined for the pulse of DV1b plutons at 490 Ma (ALLIBONE *et al.*, 1993a). However, until petrochemical data is available, we prefer not to assign the sample to either of the synkinematic DV1a or DV1b granitoid suites of ALLIBONE *et al.* (1993b).

The results are separated to three parts from ages and K/Ca ratios (Table 1 and Fig. 2a) as follows;

- 1) 800–920°C fractions; released  $^{39}Ar = 38.4\%$ ;  $491.2 \pm 6.5$  Ma; K/Ca = 70–94,
- 2) 980–1100°C fractions; released  $^{39}Ar = 12.2\%$ ;  $502.0 \pm 6.6$  Ma; K/Ca = 15–18,
- 3) 1200–1500°C fractions; released  $^{39}Ar = 43.9\%$ ;  $506.0 \pm 7.6$  Ma; K/Ca = 2.5.

Microscope observations and high K/Ca values indicate that the 800–920°C fractions

Table 1. Analytical data of  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  age results.  
Sample SE6-2f (biotite-rich fraction; 193.4 mg)  $J=0.003091\pm 0.000066^{(1)}$

Step No.	Temperature (°C)	$^{40}\text{Ar}$ ( $\times 10^{-6}\text{ cm}^3/\text{g}$ )	$^{36}\text{Ar}/^{40}\text{Ar}^{(2)}$ ( $\times 10^{-5}$ )	$^{37}\text{Ar}/^{40}\text{Ar}^{(2)}$ ( $\times 10^{-3}$ )	$^{39}\text{Ar}/^{40}\text{Ar}^{(2)}$ ( $\times 10^{-2}$ )	$^{39}\text{Ar}$ (%)	$^{40}\text{Ar}^*/^{39}\text{Ar}_K^{(3)}$	Age <sup>(3)</sup> (Ma)	K/Ca <sup>(3)</sup>
1	600	0.196	75.46 $\pm 3.52$	3.480 $\pm 0.292$	2.433 $\pm 0.047$	2.0	31.94 $\pm 0.75$	169.8 $\pm 5.1$	6.99 $\pm 0.60$
2	700	0.791	10.76 $\pm 0.63$	0.2577 $\pm 0.0413$	1.045 $\pm 0.016$	3.5	92.56 $\pm 1.43$	453.9 $\pm 10.5$	40.6 $\pm 6.5$
3	800	4.60	2.686 $\pm 0.174$	0.1039 $\pm 0.0088$	0.9806 $\pm 0.0080$	19.4	101.1 $\pm 0.8$	490.8 $\pm 9.8$	94.4 $\pm 8.0$
4	860	3.18	0.5856 $\pm 0.2092$	0.1156 $\pm 0.0134$	0.9811 $\pm 0.0137$	13.4	101.7 $\pm 1.5$	493.2 $\pm 10.9$	84.9 $\pm 9.9$
5	920	1.31	1.608 $\pm 0.265$	0.1409 $\pm 0.0209$	0.9907 $\pm 0.0118$	5.6	100.4 $\pm 1.2$	487.8 $\pm 10.4$	70.3 $\pm 10.5$
6	980	0.817	0.8472 $\pm 0.4858$	0.5304 $\pm 0.0410$	0.9721 $\pm 0.0171$	3.4	102.6 $\pm 1.8$	497.0 $\pm 12.0$	18.3 $\pm 1.5$
7	1040	0.827	5.910 $\pm 0.798$	0.6326 $\pm 0.0975$	0.9303 $\pm 0.0156$	3.3	105.6 $\pm 1.8$	509.6 $\pm 12.0$	14.7 $\pm 2.3$
8	1100	1.33	2.382 $\pm 0.270$	0.6179 $\pm 0.0409$	0.9599 $\pm 0.0105$	5.5	103.4 $\pm 1.1$	500.5 $\pm 10.4$	15.5 $\pm 1.0$
9	1200	6.60	1.849 $\pm 0.123$	3.755 $\pm 0.090$	0.9364 $\pm 0.0106$	26.5	106.3 $\pm 1.2$	512.7 $\pm 10.7$	2.49 $\pm 0.07$
10	1500	4.21	5.701 $\pm 0.401$	3.882 $\pm 0.441$	0.9619 $\pm 0.0086$	17.4	102.3 $\pm 0.9$	495.8 $\pm 10.0$	2.48 $\pm 0.28$
Total		23.86	1.236	1.903	0.9871	100.0	100.3	487.1	

reference age ( 800~ 920 °C; released  $^{39}\text{Ar}$  38.4%)  $491.2\pm 6.5$  Ma

( 980~1100 °C; released  $^{39}\text{Ar}$  12.2%)  $502.0\pm 6.6$  Ma

(1200~1500 °C; released  $^{39}\text{Ar}$  43.9%)  $506.0\pm 7.6$  Ma

are biotite, whereas the lower K/Ca fractions contain both biotite and minor hornblende. Thus,  $491.2\pm 6.5$  Ma may indicate an exhumation of the granitic rocks from a level at temperatures less than the closure temperature of biotite (approximately 300°C). Exhumation from levels at the hornblende closure temperature (approximately 500°C, see FAURE, 1986) is considered to be older than 506 Ma.

*Sample COX867B*: Age spectrum also shows a slight increase stair type spectrum. Young ages of temperature fractions less than 760°C may be due to minor biotite alteration (oxidation). Fractions at temperature above 840°C give 467–496 Ma. Though these ages are considered to come from mainly Ar in biotite from the microscope observation, the effect of hornblende contamination should be examined carefully in future.

## 6. Conclusions

A granitic rock containing a weak foliation developed during metamorphism and deformation of the Ross Orogeny, sample SE6-2f, was dated by  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  technique. A biotite-rich separate records a low temperature age about 490 Ma, whereas higher temperature fractions record ages up to 506 Ma. K/Ca ratios suggest higher temperature fractions have a greater component of Ar derived from hornblende. The data suggest exhumation of the sample occurred about 490 Ma from temperatures above biotite closure (about

Table 1. (Continued).

Sample COX867B (biotite-rich fraction; 181.0 mg)  $J = 0.003416 \pm 0.000074$ 

Step No.	Temperature (°C)	$^{40}\text{Ar}$ ( $\times 10^{-7}\text{cm}^3/\text{g}$ )	$^{36}\text{Ar}/^{40}\text{Ar}$ ( $\times 10^{-4}$ )	$^{37}\text{Ar}/^{40}\text{Ar}^{(4)}$ ( $\times 10^{-3}$ )	$^{39}\text{Ar}/^{40}\text{Ar}$ ( $\times 10^{-2}$ )	$^{39}\text{Ar}$ (%)	$^{40}\text{Ar}^*/^{39}\text{Ar}_K$	Age (Ma)	K/Ca <sup>(4)</sup>
1	500	0.303	30.22 $\pm 0.68$	5.361 $\pm 5.230$	0.3463 $\pm 0.0051$	0.6	31.39 $\pm 5.85$	183.8 $\pm 32.8$	0.64 $\pm 0.63$
2	600	0.442	17.14 $\pm 1.07$	14.46 $\pm 10.89$	2.886 $\pm 0.056$	1.6	17.23 $\pm 1.15$	103.2 $\pm 7.0$	2.0 $\pm 1.5$
3	680	2.24	12.41 $\pm 0.36$	2.535 $\pm 4.031$	1.310 $\pm 0.013$	2.9	48.38 $\pm 0.95$	275.9 $\pm 7.5$	5.2 $\pm 8.2$
4	760	4.65	6.513 $\pm 0.251$	0.094 $\pm 2.235$	0.9619 $\pm 0.0148$	3.5	83.93 $\pm 1.50$	454.8 $\pm 11.3$	100 $\pm 2400$
5	840	24.9	1.137 $\pm 0.033$	0.3083 $\pm 0.3915$	1.116 $\pm 0.010$	18.2	86.58 $\pm 0.76$	467.4 $\pm 9.6$	36 $\pm 46$
6	920	23.2	0.2722 $\pm 0.0243$	1.908 $\pm 0.534$	1.134 $\pm 0.009$	16.8	87.50 $\pm 0.70$	471.8 $\pm 9.6$	140 $\pm 1.7$
7	1000	11.0	0.4449 $\pm 0.0707$	0.075 $\pm 1.562$	1.065 $\pm 0.016$	7.5	92.62 $\pm 1.42$	496.0 $\pm 11.5$	140 $\pm 2900$
8	1100	28.3	0.4200 $\pm 0.0300$	2.721 $\pm 0.653$	1.110 $\pm 0.013$	20.2	89.03 $\pm 1.60$	479.1 $\pm 10.4$	4.1 $\pm 1.0$
9	1200	37.4	0.2524 $\pm 0.0264$	6.462 $\pm 0.585$	1.089 $\pm 0.009$	25.9	91.40 $\pm 0.74$	490.2 $\pm 9.9$	1.7 $\pm 0.2$
10	1500	3.85	1.755 $\pm 0.295$	24.94 $\pm 3.63$	1.101 $\pm 0.019$	2.8	87.30 $\pm 1.85$	470.9 $\pm 12.6$	0.44 $\pm 0.06$
Total		141.1	1.236	3.538	1.114	100.0	86.79	468.5	

 $\pm$  in values are errors of one standard deviation.

- (1)  $J = (\exp(\lambda \cdot t_s) - 1) (^{40}\text{Ar}^*/^{39}\text{Ar}_K)_{\text{standard}}$ ;  $t_s = 90.8 \pm 1.7$  Ma.
- (2) The correction of the K- and Ca-derived interference Ar isotopes is not taken to these values.
- (3)  $^{40}\text{Ar}^*$ ; radiogenic  $^{40}\text{Ar}$ ,  $^{39}\text{Ar}_K$ ; K-derived  $^{39}\text{Ar}$  due to neutron irradiation.  
Age =  $\ln((^{40}\text{Ar}^*/^{39}\text{Ar}_K) \cdot J + 1) / \lambda$ ,  $\lambda = 5.543 \times 10^{-10}/\text{y}$  (STEIGER and JÄGER, 1977).  
The uncertainties in  $^{40}\text{Ar}^*/^{39}\text{Ar}_K$ , ages and K/Ca do not include those of correction factors for K- and Ca-derived interference isotopes. Correction factors are as follows;  $(^{40}\text{Ar}/^{39}\text{Ar})_K = 0.03$ ,  $(^{39}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = 0.002496$ ,  $(^{36}\text{Ar}/^{37}\text{Ar})_{\text{Ca}} = 0.00005156$ .
- (4) Large uncertainties of  $^{37}\text{Ar}/^{40}\text{Ar}$  and K/Ca for sample COX867B depend on the problem of mass spectrometer by measuring small amount of  $^{37}\text{Ar}$ .

300°C), and intrusion of the granitoid before 506 Ma.

A sample of massive unfoliated granite, COX867B, has textural and field relations indicating emplacement after the bulk of deformation occurred in South Victoria Land. Biotite-rich separate from this sample gives ages of 467–496 Ma. The ages are also thought to relate to exhumation of the basement rocks.

Our preliminary  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  study has shown that both “syntectonic” and “post-tectonic” granitoids in South Victoria Land record overlapping ages around 490 Ma. Cooling below the biotite Ar closure temperature appears to have occurred in relation to regional uplift at this time. It suggests that previous interpretations of Rb/Sr ages, which cluster around 490 Ma, probably also represent exhumation and closure of isotopic systems at 490 Ma, rather than a pulse of plutonism (ALLIBONE *et al.*, 1993a, b). The study outlines the potential in using  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  spectra to outline differences in the exhumation/thermal history of granitoids in South Victoria Land. Investigations are currently underway to determine whether different thermal histories can be observed between different

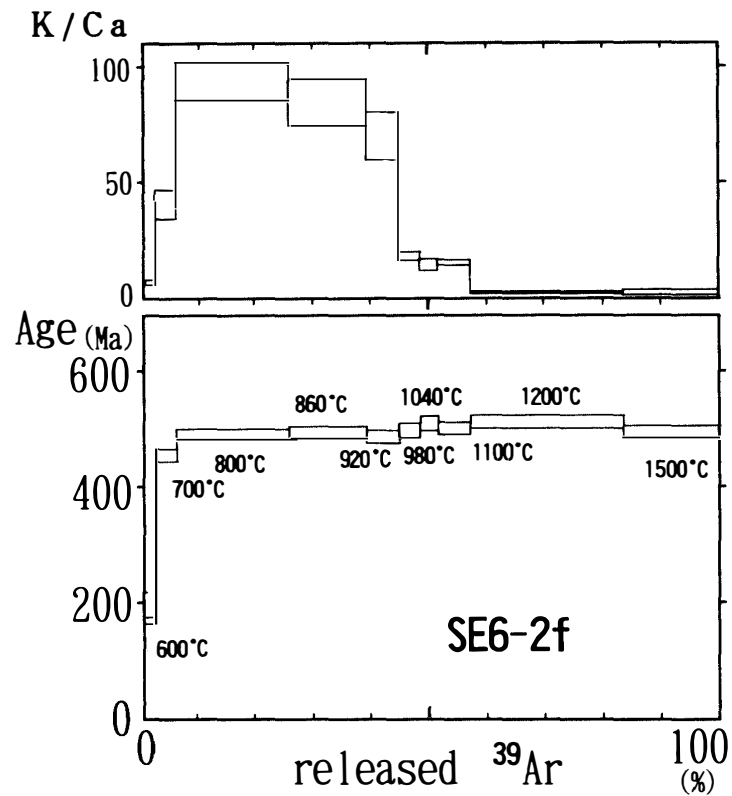


Fig. 2a.  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  age spectrum (lower) and  $\text{K}/\text{Ca}$  (upper) for sample SE6-2f. Vertical and horizontal axes indicate the apparent age and  $\text{K}/\text{Ca}$  ratio and the released  $^{39}\text{Ar}$  (%). The bands in the figures represent errors of one standard deviation. 600°C, 700°C, ... indicate temperatures of the Mo crucible at the Ar gas extraction.

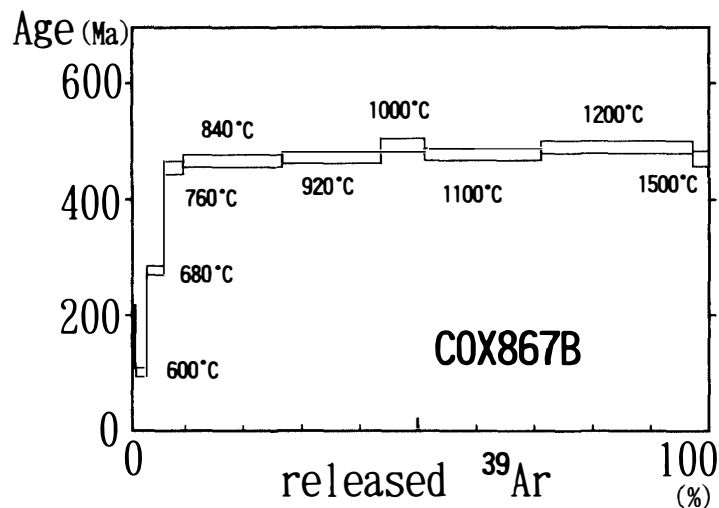


Fig. 2b.  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  age spectrum for sample COX867B.  $\text{K}/\text{Ca}$  plot is not illustrated due to the large uncertainties.

petrogenetic suites of the Dry Valleys region.

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