Alaska Division of Geological & Geophysical Surveys

Raw Data File 2013-8

$^{40}Ar/^{39}Ar$ DATA, ALASKA HIGHWAY CORRIDOR FROM DELTA JUNCTION TO CANADA BORDER, PARTS OF MOUNT HAYES, TANACROSS, AND NABESNA QUADRANGLES, ALASKA

by
Diana N. Solie, Paul W. Layer, Melanie B. Werdon, Rainer J. Newberry,
Larry K. Freeman, and Richard R. Lessard

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$^{40}Ar/^{39}Ar$ Data, Alaska Highway Corridor from Delta Junction to Canada border, parts of Mount Hayes, Tanacross, and Nabesna quadrangles, Alaska

by

Diana N. Solie[1], Paul W. Layer[2], Melanie B. Werdon[1], Rainer J. Newberry[3], Larry K. Freeman[1], and Richard R. Lessard[1]

Abstract

$^{40}Ar/^{39}Ar$ analyses of igneous rocks from the Alaska Highway corridor between Delta Junction and the Canada border show a range of Cretaceous ages from about 68 Ma to about 112 Ma. The 25 samples fall into two broad age groups. The younger group ranges from about 68 Ma to 73 Ma; the older group ranges from a minimum age of about 84 Ma to about 103 Ma. One sample, a mafic dike, yielded an older age of about 112 Ma.

Introduction

The Alaska Division of Geological & Geophysical Surveys (DGGS) conducted a multi-year project from 2006 to 2010 studying the geology and geologic hazards along the Alaska Highway corridor. As part of the bedrock geologic mapping, samples were collected for geochronologic analyses using $^{40}Ar/^{39}Ar$, fission track, and U/Pb dating techniques. Summaries of analytical results appear on bedrock-geologic maps that are being published in three segments (Gerstle River to Dot Lake, Dot Lake to Tetlin Junction, and Tetlin Junction to the Canada border). The purpose of this DGGS Raw Data File is to present the $^{40}Ar/^{39}Ar$ age results from all three segments of the project. Analyses were done by the University of Alaska Fairbanks Geochronology Laboratory. Results for 2006 and 2007 samples were reported by Paul Layer and Jeff Drake; results for 2008 and 2009 were reported by Paul Layer and Jeff Benowitz.

The text and analytical spectra plots are being released as .pdf files; location coordinates and analytical data are being released in digital format as .csv files. A detailed description of the digital data files can be found in the associated metadata file. All are available from the DGGS website (http://dggs.alaska.gov/pubs/26841) at no charge.

Methodology

Field Methods

Field geologists collected rock samples from the surface or within 0.5 m of the surface. Care was taken to collect fresh, unweathered samples representative of igneous rock types in the map area. Locations were recorded using handheld GPS units with an estimated horizontal accuracy of approximately 10 m. Location coordinates for all dated samples are provided in an accompanying .csv file, in North American Datum of 1927 (NAD27) decimal degrees.

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ANALYTICAL METHODS

The selected rock samples were submitted to the University of Alaska Fairbanks Geochronology Laboratory. There the samples were crushed, washed, and sieved to either 100–250 or 250–500 micron size fractions, and hand-picked for datable mineral phases. The monitor mineral MMhb-1 (Samson and Alexander, 1987) with an age of 513.9 Ma (Lanphere and Dalrymple, 2000) was used to monitor neutron flux (and calculate the irradiation parameter, J). The samples and standards were wrapped in aluminum foil and loaded into aluminum cans of 2.5 cm diameter and 6 cm height. The samples were irradiated in position 5c of the uranium-enriched research reactor of McMaster University in Hamilton, Ontario, Canada, for 20 megawatt-hours.

Upon their return from the reactor, the samples and monitors were loaded into 2-mm-diameter holes in a copper tray that was then loaded in an ultra-high-vacuum extraction line. The monitors were fused, and samples heated, using a 6-watt argon-ion laser following the technique described in York and others (1981), Layer and others (1987), and Layer (2000). Argon purification was achieved using a liquid nitrogen cold trap and a SAES Zr-Al getter at 400°C. The samples were analyzed in a VG-3600 mass spectrometer at the Geophysical Institute, University of Alaska Fairbanks. The argon isotopes measured were corrected for system blank and mass discrimination, as well as calcium, potassium, and chlorine interference reactions following procedures outlined in McDougall and Harrison (1999). Interference corrections: $(^{39}Ar/^{37}Ar)Ca$ = 0.000706, $(^{36}Ar/^{37}Ar)Ca$ = 0.000279, $(^{40}Ar/^{39}Ar)K$ = 0.0297. System blanks generally were 2×10^{-16} mol ^{40}Ar and 2×10^{-18} mol ^{36}Ar, which are 10 to 50 times smaller than fraction volumes. Mass discrimination was monitored by running both calibrated air shots and a zero-age glass sample. These measurements were made on a weekly to monthly basis to check for changes in mass discrimination.

The age, Ca/K, and Cl/K spectra plots for each sample are shown in the appendices. The calcium-to-potassium ratio is determined from ^{37}Ar produced from ^{40}Ca and ^{39}Ar produced from ^{39}K and the chlorine-to-potassium ratio as determined from ^{38}Ar produced from ^{37}Cl and ^{39}Ar produced from ^{39}K. Detailed step-heating data for each sample are presented in .csv files accompanying this report. In addition, .csv files summarizing all the $^{40}Ar/^{39}Ar$ results accompany this report. These quote all ages to the ±1 sigma level and were calculated using the constants of Steiger and Jaeger (1977). The integrated age is the age given by the total gas measured and is equivalent to a potassium-argon (K-Ar) age. The spectrum provides a plateau age if three or more consecutive gas fractions represent at least 50 percent of the total gas release and are within two standard deviations of each other (Mean Square Weighted Deviation less than ~2.7). All samples showed well-defined plateaus. For some samples, two runs were done. Weighted average ages of the plateaus are reported.

SEGMENT 1: ALASKA HIGHWAY CORRIDOR, GERSTLE RIVER TO DOT LAKE

INTRODUCTION

The western segment of the Alaska Highway corridor bedrock mapping project includes part of the Mount Hayes Quadrangle (Werdon and others [2014], in press). Samples of igneous rocks were collected in summers of 2006 and 2007. Eight samples from 2006 and seven from 2007 were submitted to the University of Alaska-Fairbanks Geochronology Laboratory for $^{40}Ar/^{39}Ar$ analyses.

PRELIMINARY DISCUSSION OF 2006 RESULTS

This discussion of samples is based on interpretation of the age spectra and comments from examination of the thin sections by Rainer Newberry (University of Alaska Fairbanks). Thin section comments were included in an e-mail from Newberry to Solie on August 15, 2007, and are quoted with permission. Note that not all samples had thin sections, so Newberry did not offer comments on all samples. In general all the biotites "look good" with well-defined plateaus. For two samples, both hornblende and biotite were run, and the hornblendes are more variable and look more disturbed than the biotites. The samples are sorted from oldest apparent age to youngest.

06RL44 Biotite: Two runs of large, single biotite grains were analyzed. They have a mean plateau age of 102.2 ± 0.5 Ma, which is the oldest age in the group. These samples have very small amounts of Ar loss (less than 1 percent), with a Tertiary loss age (~30 Ma). This sample shows higher-than-expected Ca/K ratios for the last ~20 percent of ^{39}Ar release. This is a common occurrence for most biotites in this study. Newberry's comments are: "*This rock shows very little evidence for hydrothermal alteration. I estimate that ~1 percent of the biotite grains in the thin section are chloritized and the plagioclase is nearly pristine. There is no obvious hornblende in the rock or in the biotite. Minerals contained in large biotite grains include apatite, plagioclase, and allanite (an REE-rich variety of epidote).*" It is possible that the high Ca/K phase reflects these inclusions, which do not appear to significantly affect the age.

06MBW7A Biotite and Hornblende: Two runs of large, single grains of biotite yield consistent ages of about 95.0 ± 0.5 Ma. The plateaus are well defined and the biotites show evidence of slight (~1 percent) Tertiary argon loss. In contrast, the two runs on hornblendes are much more highly disturbed. For one run, no plateau or isochron could be determined. For the other, a poorly defined plateau of 97 Ma was calculated. However, the Ca/K and Cl/K spectra show that these single hornblende grains are not uniform in composition. Perhaps the hornblende is more highly altered with a chlorite component, and so gives an age younger than the biotite.

06DNS106B Biotite: One run of this biotite shows a well-defined plateau at 98.6 ± 0.5 Ma with ~1 percent Ar loss.

06RL13A biotite: Two runs of large biotite grains show well-defined plateaus with an average age of 96.6 ± 0.5 Ma. As with other biotites, there are high Ca/K fractions for the last ~20 percent of ^{39}Ar release due to inclusions in the biotite. These samples show a bit more argon loss (3–4 percent) than the older samples, but this amount of loss is generally considered to be minor and does not affect the plateau age. Newberry's comments are: *"This rock displays extensive evidence for hydrothermal alteration. Most of the magnetite grains are at least partly altered to hematite and about half of the biotite grains contain some alteration chlorite. Most of the grains in the rock show evidence of strain, e.g., most of the biotite grains are bent. There is no obvious hornblende in the rock; apatite, plagioclase, and allanite occur as inclusions in biotite."*

06RL7A biotite: Two runs of large, single biotite grains show poorly-defined pseudoplateaus (their scatter as seen in the MSWD does not permit them to be classified as true plateaus) with an average age of 95.4 ± 0.7 Ma. Modeling shows ~1.5 percent Tertiary Ar loss, while the Ca/K spectra shows evidence of inclusions. Newberry's comments are: *"Significant alteration is present. About two-thirds of the biotite grains contain some alteration chlorite and most biotite grains are strained and bent. Hornblende is present and typically contains some biotite inclusions. Hornblende grains are commonly attached to biotite, but no obvious hornblende inclusions in biotite are present. The hornblende typically contains at least a little chlorite. Apatite and allanite occur as inclusions in biotite."*

06DNS59A biotite and hornblende: One run of biotite shows a well-defined plateau with an age of 94.5 ± 0.5 Ma. There is a slight "hump" in the spectrum and higher Ca/K than in other samples, so this sample may be altered. Modeling shows less than 1 percent Ar loss. Two runs of hornblende were conducted. The first shows extremely low Ca/K and Cl/K and so probably is not hornblende. Perhaps this is a grain that was altered to chlorite (see Newberry's comments below). The second run has a more "hornblende-like" Ca/K ratio (~10). It shows evidence of some disturbance in the isotopic system, but has a well-defined isochron with an age of 99.3 ± 0.8 Ma, which probably reflects the cooling age of this sample. Note that there is a large age difference between the hornblende and biotite in this sample. Is this reflecting initial cooling over ~5 m.y. or has the biotite been reset due to alteration/shearing soon after intrusion of the pluton? Newberry's comments are: *"This rock is the most extensively altered and sheared of the group. The rock contains a distinct deformation fabric; all biotites are clearly deformed. Approximately 10–20 percent of the biotite present is as clearly secondary clumps of small crystals. About half of the magnetite grains display some alteration hematite. The hornblende typically contains inclusions of biotite; biotite is spatially associated with hornblende but doesn't obviously contain any hornblende inclusions. About one-third of the hornblende grains contain some alteration chlorite. Allanite is present, but not as inclusions in biotite."*

06DNS13A biotite: This sample is similar to 06MBW3A, with a well-defined plateau at 94.3 ± 0.5 Ma with ~3 percent loss at 0 Ma. When compared to other biotites, this sample has lower Ca/K ratios and higher Cl/K ratios. Newberry's comments are: *"The biotites in this sample are different from the others; about two-thirds of the grains are either chloritized or (most commonly) altered to pale biotite with secondary FeOxide needles. That is, although the style of alteration is different from the others, they have also experienced significant hydrothermal alteration. No obvious hornblende is present. Allanite is present, but not as inclusions in biotite."*

06MBW3A biotite: This single grain of biotite has a well-defined plateau at 92.9 ± 0.5 Ma, which could reflect a cooling age, although there is a slight "hump" in the plateau. This sample can be modeled as having 3 percent Ar loss at 0 Ma. Again this is not much loss, but given the hump shape and the slightly higher Ca/K ratio, it is possible that this age is a minimum age, reset by alteration (as seen in thin sections of other samples). Note also that this sample has a significantly lower Cl/K ratio than does 06DNS13A.

Summary

Biotites from these plutons have plateau ages spanning about 10 m.y., from 103 Ma to 93 Ma. Either this represents a real span of plutonism or reflects a period of alteration and shearing after a shorter pulse of intrusion. Based on thin sections, there is an apparent inverse relationship between degree of alteration and age for the five samples with thin sections, suggesting the latter interpretation. However, more detailed work needs to be done to confirm the hypothesis.

Preliminary Discussion of 2007 Results

Seven samples were analyzed. Four of these (07RL263A, 07MBW1097A, 07MBW1055A and 07RL379A) show well-defined plateaus with reasonable precision, and for these only one run was done. Of the three that range from 90–95 Ma, the biotite from 07MBW1097A yields a slightly younger plateau age than hornblendes from the others, perhaps due to the different closure temperatures. The biotite from 07RL263A yields the youngest age of about 68 Ma.

For sample 07RL484B, two runs were done. One shows a pattern of some excess argon, and we regard its age as being a bit too old. The second run has a plateau age of 112 Ma, making it the oldest sample in the study area.

The other two samples (07MBW793A and 07LF370A) show disturbed argon isotopic systematics such that we are unable to determine a 'true' cooling age for these samples. For each of these samples, two runs were done. Hornblende sample 07MBW793A shows significant between-grain variability and neither hornblende run has a true plateau. Both runs have very low Ca/K for the first ~20 percent of release, indicative of alteration of the hornblende. The weighted average age indicates a mid-Cretaceous age (~90 Ma), but this is probably too young due to argon loss during alteration. The two runs of hornblende 07LF370A were more consistent. Both runs show a stair-step up-pattern indicative of a complicated cooling history, or argon loss. The high temperature steps (which do not have enough gas release for a 'true' plateau), also indicate an age of ~90 Ma.

SEGMENT 2: ALASKA HIGHWAY CORRIDOR, DOT LAKE TO TETLIN JUNCTION

INTRODUCTION

During 2008, DGGS continued bedrock geologic mapping of the Alaska Highway corridor between Dot Lake and Tetlin Junction in the Tanacross Quadrangle. Four samples of igneous rocks were collected and submitted to the University of Alaska Fairbanks Geochronology Laboratory. The following discussion is derived from the laboratory report on the analytical results.

PRELIMINARY DISCUSSION OF 2008 RESULTS

08MBW708B biotite: A biotite separate from sample 08MBW708B was analyzed. The integrated age (68.9 ± 0.6 Ma), the plateau age (68.8 ± 0.6 Ma), and the isochron age (69.3 ± 0.4) are all within error. We prefer the plateau age of 68.9 ± 0.6 Ma for sample 08MBW708B based on convention and the large error on the isochron-derived initial $^{40}Ar/^{36}Ar$ related to the generally homogenous radiogenic content of the release.

08RN645A biotite: A biotite separate from sample08RN645A was analyzed. The integrated age (67.8 ± 0.3 Ma), the plateau age (68.1 ± 0.3 Ma), and the isochron age (68.1 ± 0.4) are all within error. We prefer the plateau age of 68.1 ± 0.3 Ma for sample 08RN645A based on convention.

08RN679A muscovite: A muscovite separate from sample 08RN679A was analyzed. The integrated age (102.8 ± 0.4 Ma), the plateau age (102.9 ± 0.4 Ma), and the isochron age (103.2 ± 0.5) are all within error. We prefer the plateau age of 102.9 ± 0.4 Ma for sample 08RN679A based on convention and the large error on the isochron-derived initial $^{40}Ar/^{36}Ar$ related to the generally homogenous radiogenic content of the release.

08RN785A biotite: A biotite separate from sample 08RN785A was analyzed. The integrated age (69.6 ± 0.3 Ma), the plateau age (70.0 ± 0.3 Ma), and the isochron age (70.1 ± 0.4) are all within error. We prefer the plateau age of 70.0 ± 0.3 Ma for sample 08RN785A based on convention and the large error on the isochron-derived initial $^{40}Ar/^{36}Ar$ related to the generally homogenous radiogenic content of the release.

SEGMENT 3: ALASKA HIGHWAY CORRIDOR, TETLIN JUNCTION TO CANADA BORDER

INTRODUCTION

The eastern segment of the Alaska Highway corridor project, from Tetlin Junction to the Canada border, in parts of the Tanacross and Nabesna quadrangles, was mapped in 2009. Six igneous rock samples were submitted to the University of Alaska Fairbanks Geochronology Laboratory for $^{40}Ar/^{39}Ar$ dating. The following sections are derived from the laboratory report on analytical results.

PRELIMINARY DISCUSSION OF 2009 RESULTS

09MBW215A biotite: A biotite separate from sample 09MBW215A was analyzed. The integrated age (95.8 ± 0.7 Ma) is significantly different than the plateau age (100.4 ± 0.8) and the isochron age (98.3 ± 2.5). We infer the sample has experienced minor loss (~4 percent) based on the "stepping-up" nature of the age spectra. We prefer the plateau age of 100.4 ± 0.8 Ma because of the documented minor loss and large error on the isochron-derived initial $^{40}Ar/^{36}Ar$.

09MBW245A biotite: A biotite separate from sample 09MBW245A was analyzed. The mineral phase analyzed was not a pure biotite, based on the Ca/K ratio greater than 1. The integrated age (76.6 ± 1.2Ma) is significantly different than the weighted mean average age (84.4 ± 1.5). We infer the sample has experienced moderate loss (~15 percent) based on the "stepping-up" nature of the age spectra. We prefer the weighted mean average age of 84.4 ± 1.5 as a minimum age for this mineral phase because of the documented moderate loss.

09MBW245 hornblende: A hornblende separate from sample 09MBW245A was analyzed. The mineral phase analyzed was not a pure hornblende, based on the Ca/K ratio less than 5 for the low-temperature steps. The integrated age (80.0 ± 0.8Ma) is significantly different than the weighted mean average age (89.7 ± 1.2). We infer the sample has experienced moderate loss (~10 percent) based on the "stepping-up" nature of the age spectra. We prefer the weighted mean average age of 89.7 ± 1.2 as a minimum age for this mineral phase because of the documented moderate loss.

09MBW269A biotite: A biotite separate from sample 09MBW269A was analyzed. The integrated age (95.8 ± 0.6) Ma) and the plateau age (97.7 ± 0.7 Ma) were within error. We prefer the plateau age of 97.7 ± 0.7 Ma because of evidence of loss in the lowest temperature steps. No isochron age determination was possible because of the homogenous radiogenic content of the release.

09LF374A biotite: A biotite separate from sample 09LF374A was analyzed. The integrated age (72.3.4 ± 0.4 Ma), the plateau age (73.3 ± 0.4 Ma), and the isochron age (73.6 ± 0.5) all were within error. We prefer the plateau age of 73.3 ± 0.4 Ma based on convention.

09LF493A Whole rock: A homogenous whole-rock separate from sample 09LF493A was analyzed. The integrated age (72.5 ± 0.5 Ma), the plateau age (70.5 ± 0.5 Ma), and the isochron age (70.0 ± 0.5) all were within broad error. We prefer the plateau age of 70.5 ± 0.5 Ma based on convention and the low amount of K in the first two steps.

ACKNOWLEDGMENTS

This project was supported by Alaska State Capital Improvement Project funding. Partial funding for mapping and $^{40}Ar/^{39}Ar$ geochronology in the Mt. Hayes C-1, C-2, D-1, and D-2 quadrangles was also provided through the U.S. Geological Survey STATEMAP program under award number 07HQAG0076. Samples in this report were collected by Larry Freeman, Melanie Werdon, Richard Lessard, and Diana Solie of DGGS, and Rainer Newberry of University of Alaska Fairbanks Department of Geology & Geophysics.

ERRATA

Users may notice sample numbering discrepancies throughout various project publications. DGGS staff have completed significant work over the duration of the project to assimilate data from various sources into comprehensive division-wide databases. In conjunction with loading the project data into the Geologic Materials Center Inventory and Alaska Geochemistry databases, staff identified and, when possible, corrected sample labeling inconsistencies. Error correction required certain assumptions, and it is possible, particularly in cases where multiple lithologies were collected from a single outcrop, that published observations tied to a given sample number may not correspond to the same rock.

BIBLIOGRAPHY

Lanphere, M.A., and Dalrymple, G.B., 2000, First-principles calibration of ^{38}Ar tracers: Implications for the ages of $^{40}Ar/^{39}Ar$ fluence monitors: U.S. Geological Survey Professional Paper 1621, 10 p.

Layer, P.W., 2000, Argon-40/Argon-39 age of the El'gygytgyn impact event, Chukotka, Russia: Meteroritics and Planetary Science, v. 35, n. 3, p. 591–599.

Layer, P.W., Hall, C.M., and York, D., 1987, The derivation of $^{40}Ar/^{39}Ar$ age spectra of single grains of hornblende and biotite by laser step-heating: Geophysical Research Letters, v. 14, n. 7, p. 757–760.

McDougall, Ian, and Harrison, T.M., 1999, Geochronology and thermochronology by the $^{40}Ar/^{39}Ar$ method, 2nd ed.: New York, Oxford University Press, 269 p.

Samson, S.D., and Alexander, E.C., 1987, Calibration of the interlaboratory ^{40}Ar-^{39}Ar dating standard, MMhb1: Chemical Geology, v. 66, p. 27–34.

Steiger, R.H., and Jaeger, E., 1977, Subcommission on geochronology—Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.

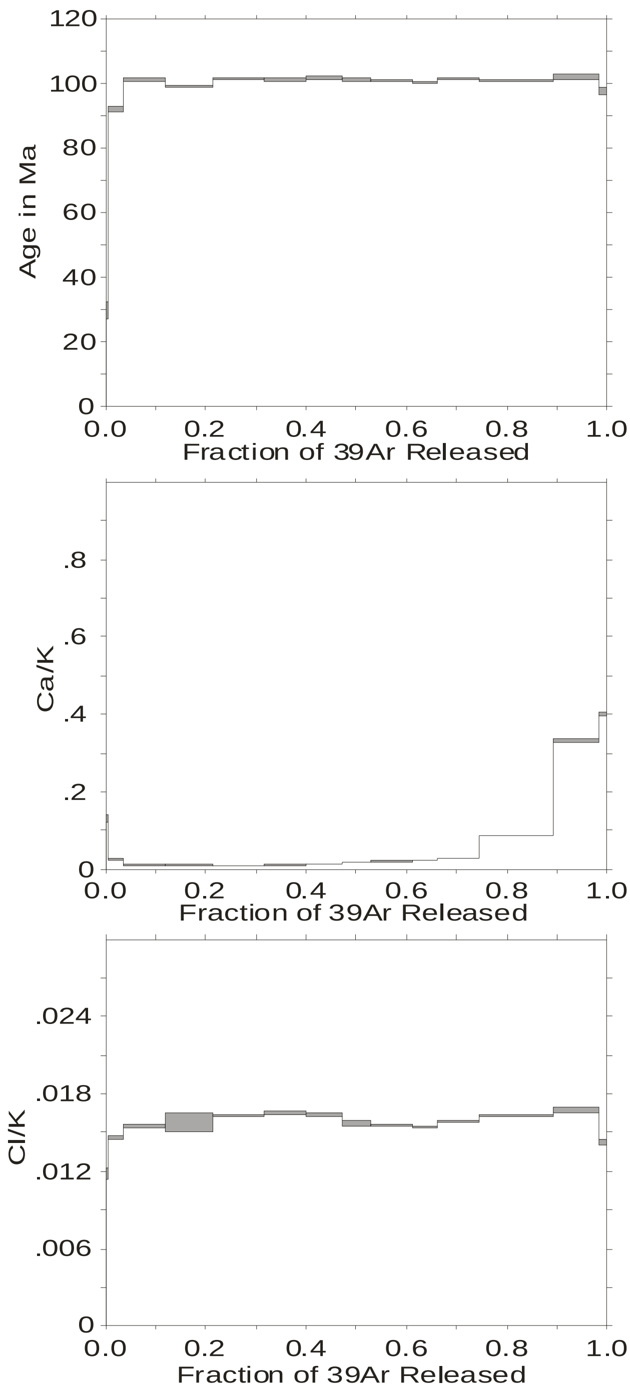
Werdon, M.B., Solie, D.N., Newberry R.J., Freeman, L.K., Elliott, B.A., and Lessard, R.R., [2014] in press, Bedrock geologic map, Alaska Highway corridor, Gerstle River to Dot Lake, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigations.

York, Derek, Hall, C.M., Yanase, Yotaro, Hanes, J.A., and Kenyon, W.J., 1981, $^{40}Ar/^{39}Ar$ dating of terrestrial minerals with a continuous laser: Geophysical Research Letters, v. 8, n. 11, p. 1,136–1,138.

APPENDIX A-1:

^{40}AR/^{39}AR AGE, CA/K AND CL/K SPECTRA PLOTS FOR 2006 SAMPLES

06RL44 Biotite #1



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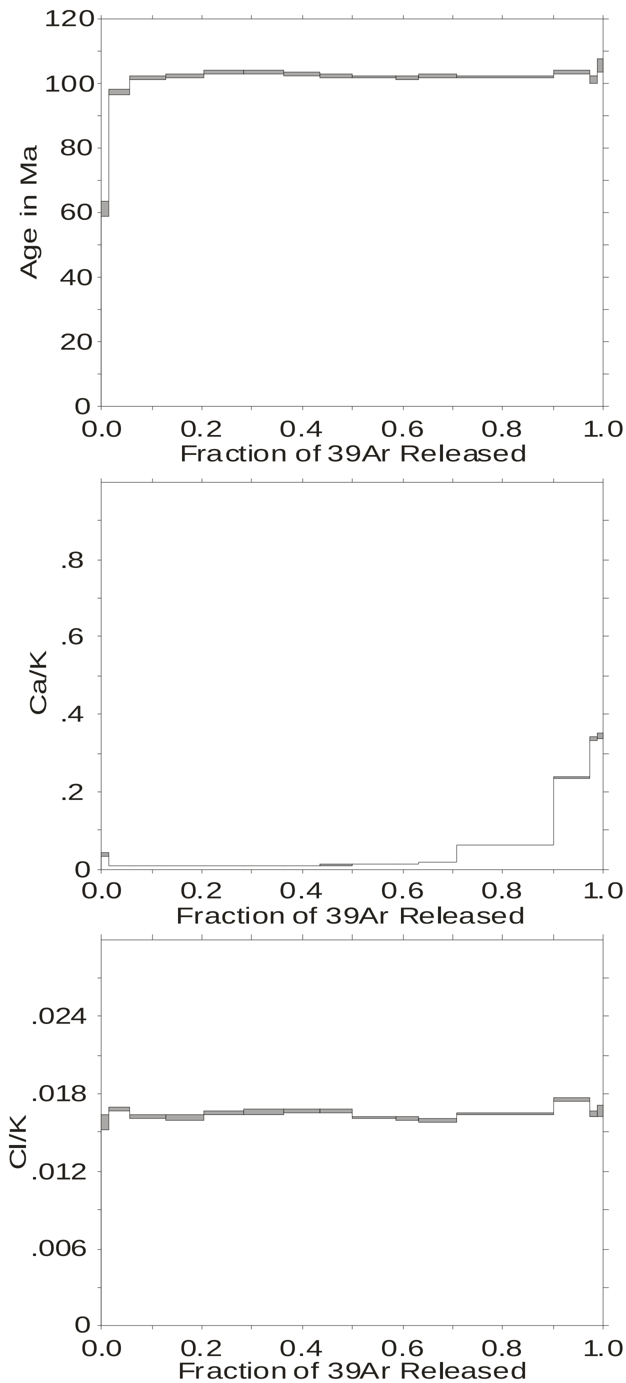

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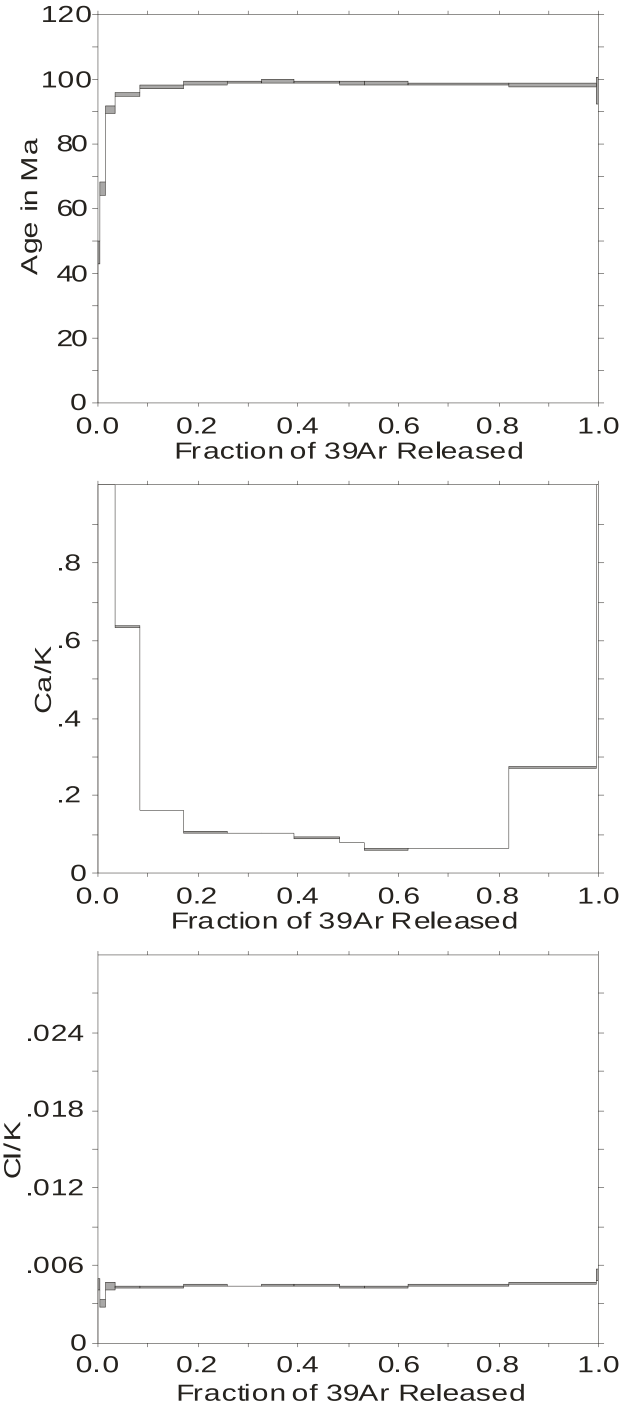

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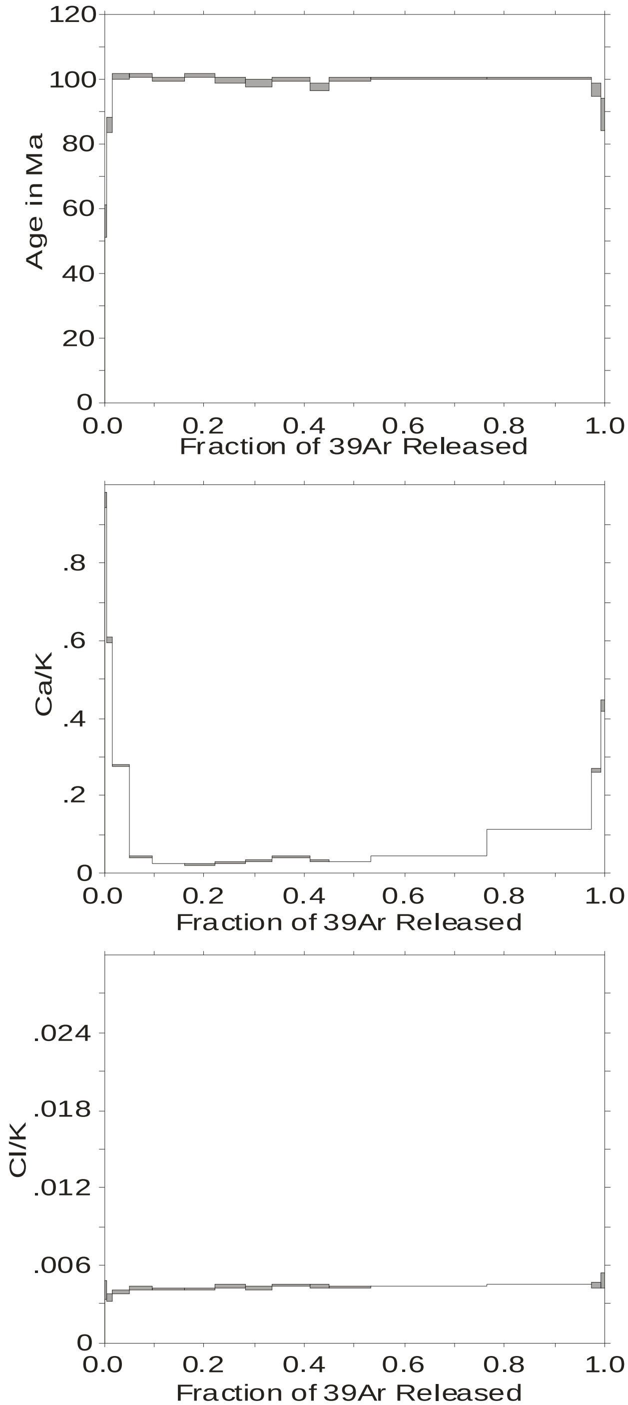

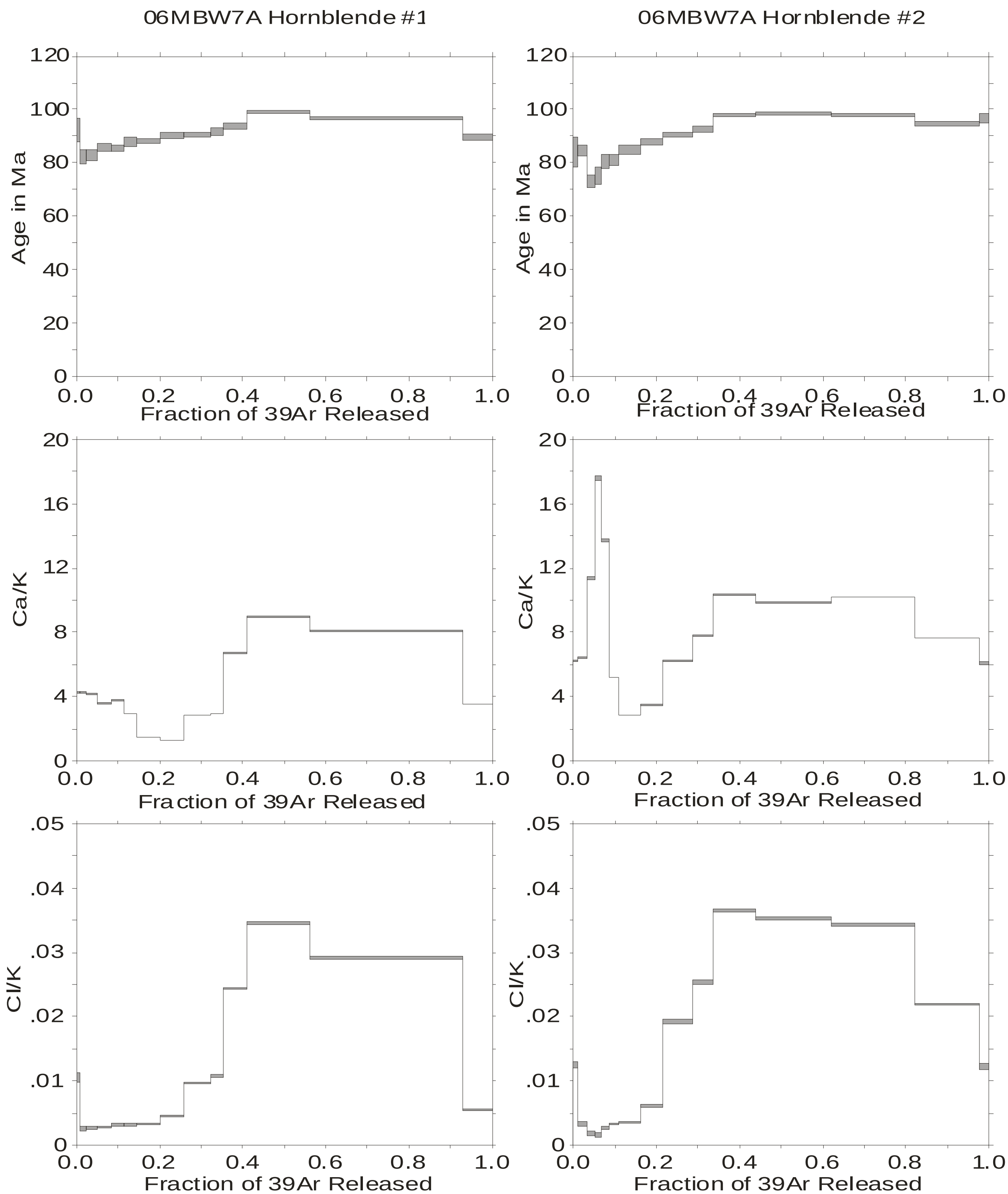
06MBW7A Hornblende #1
06MBW7A Hornblende #2
Age in Ma
120
100
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released
Ca/K
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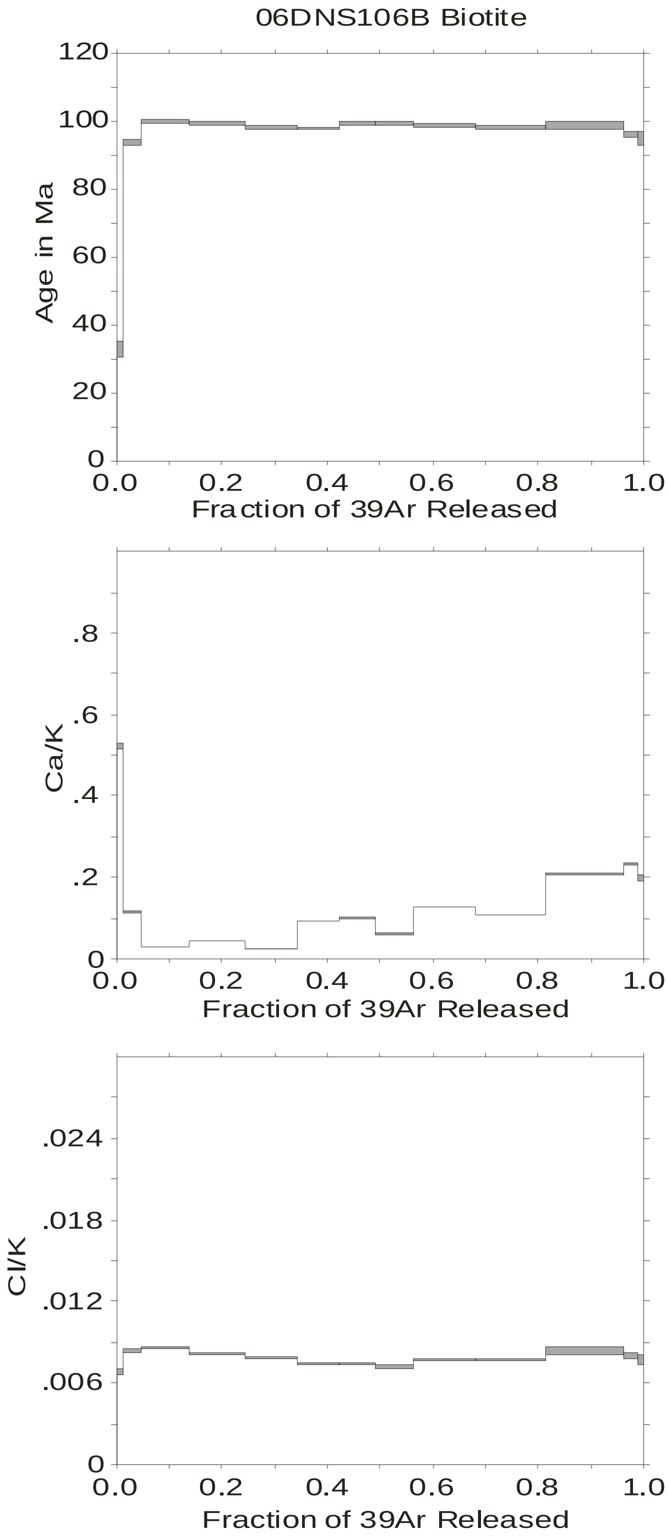
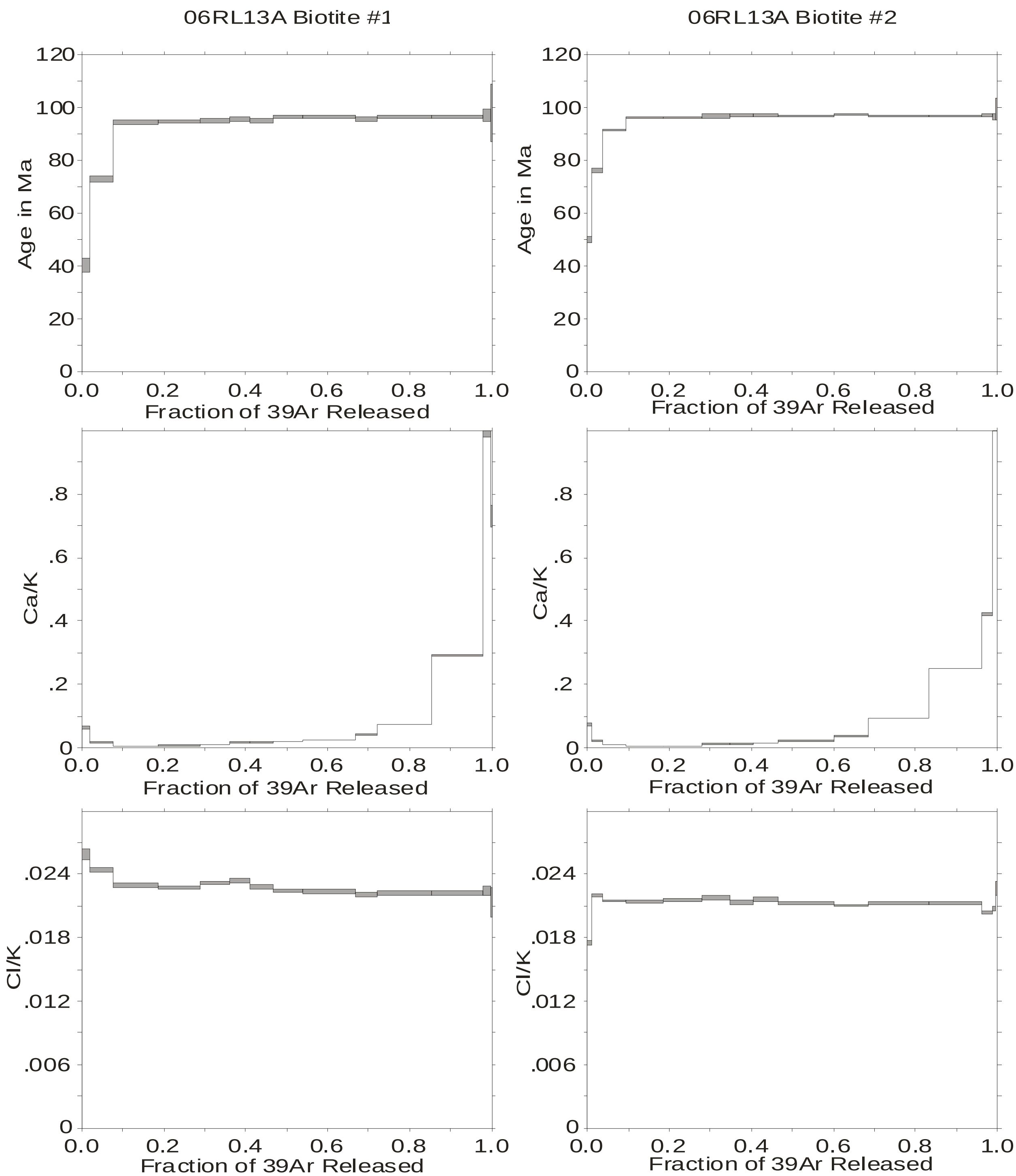
12
8
4
Cl/K
.05
.04
.03
.02
.01


06DNS106B Biotite
Age in Ma
Fraction of 39Ar Released
Ca/K
Fraction of 39Ar Released
Cl/K
Fraction of 39Ar Released


06RL13A Biotite #1
06RL13A Biotite #2
Age in Ma
120
100
80
60
40
20
0
Fraction of 39Ar Released
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0.2
0.4
0.6
0.8
1.0
Ca/K
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Cl/K
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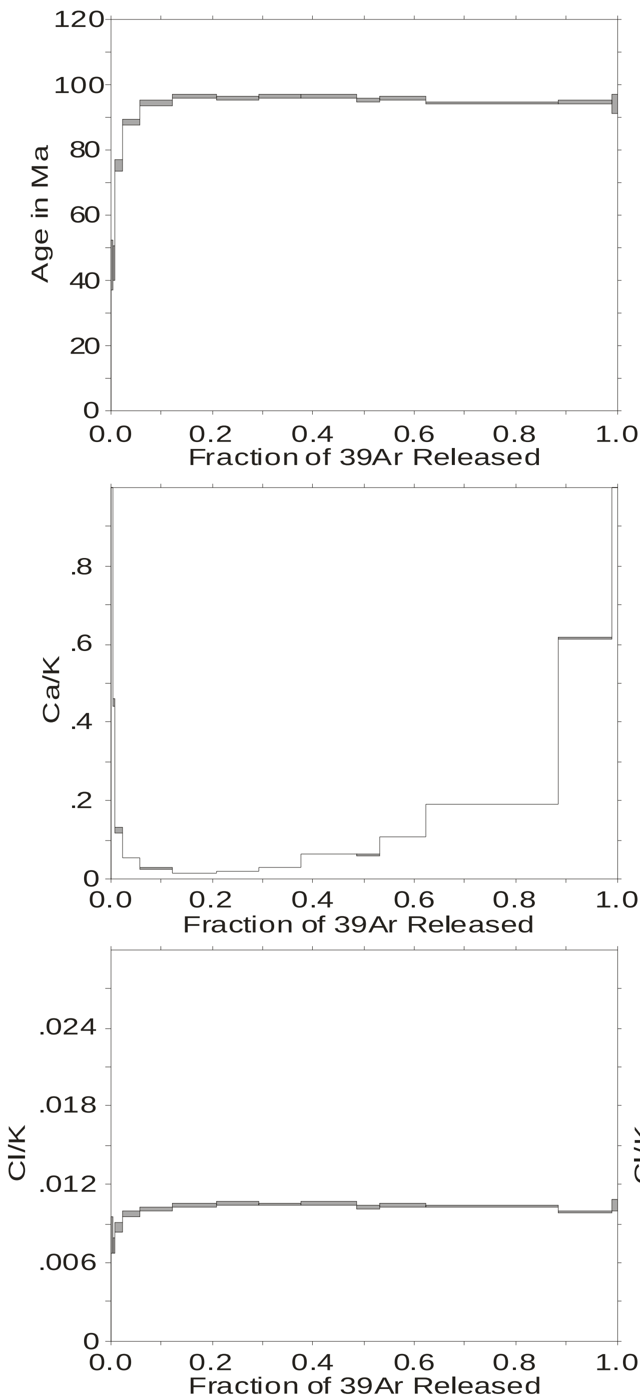
06RL7A Biotite #1



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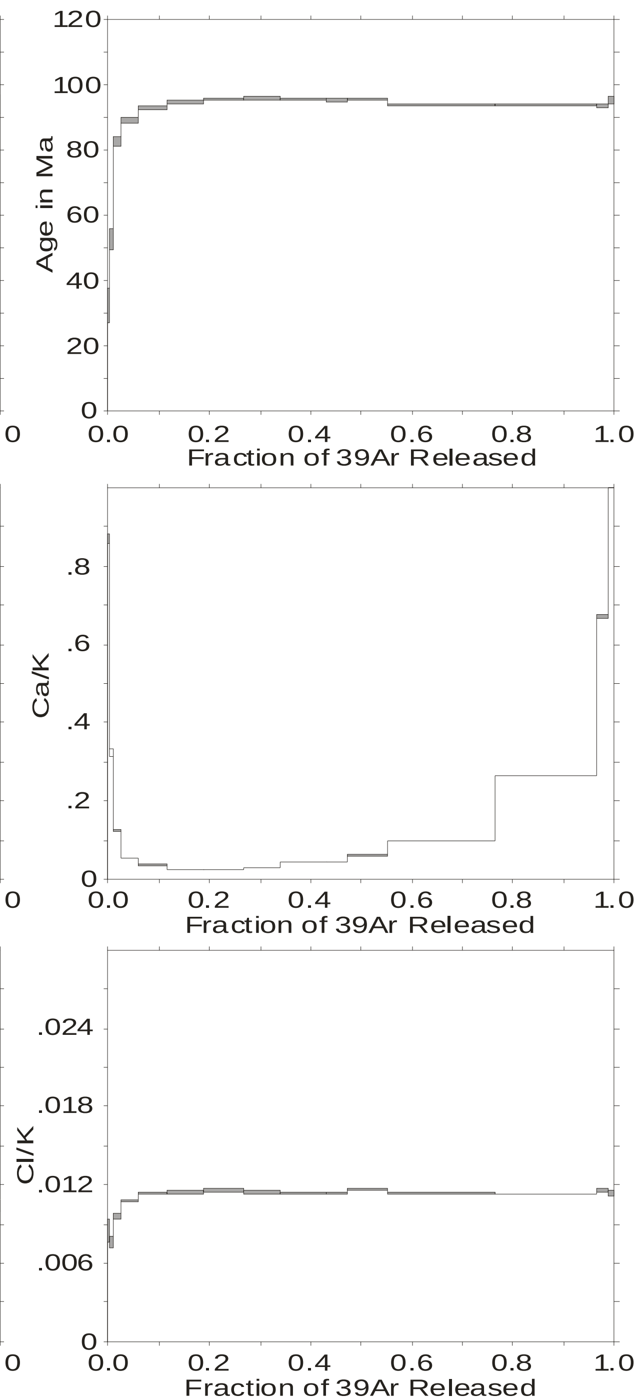

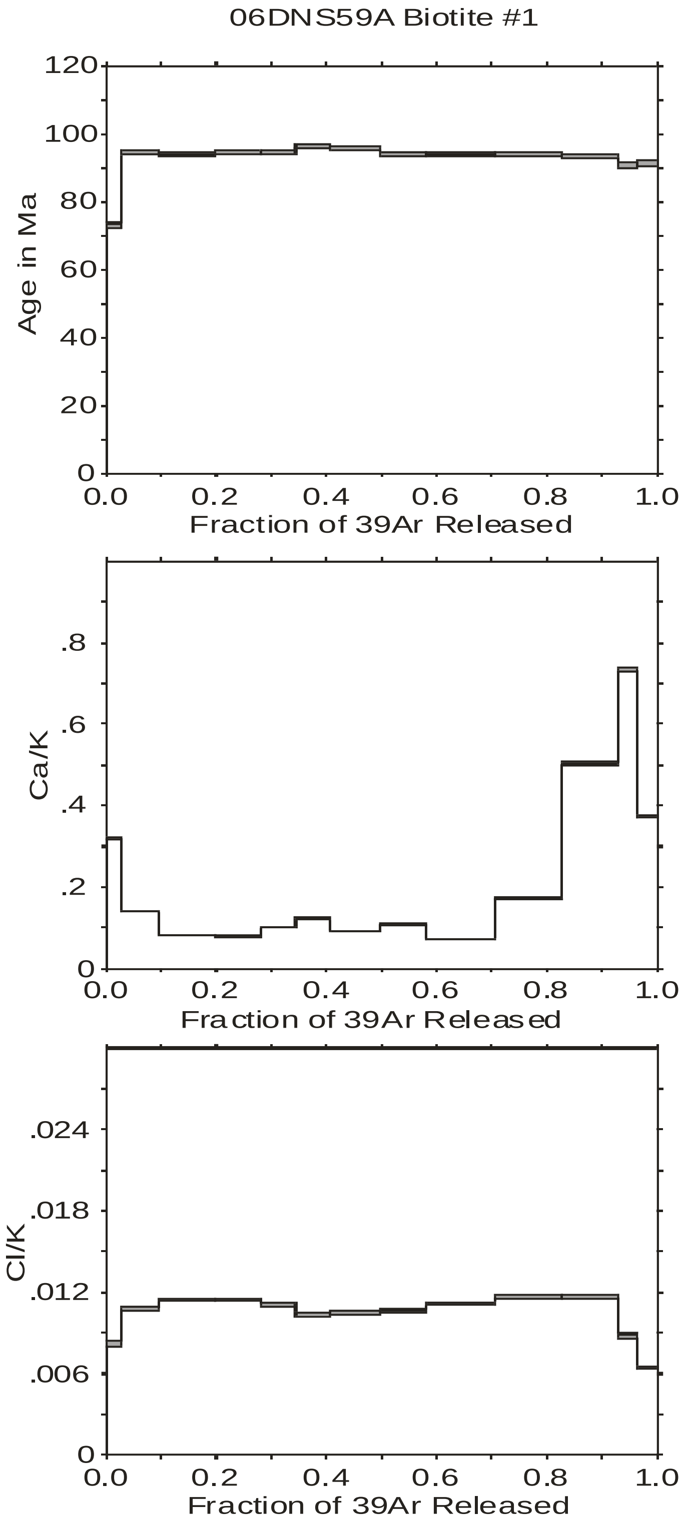
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80
60
40
20
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Age in Ma
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0.4
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0.8
1.0
Fraction of 39Ar Released
.8
.6
.4
.2
0
Ca/K
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released
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Cl/K
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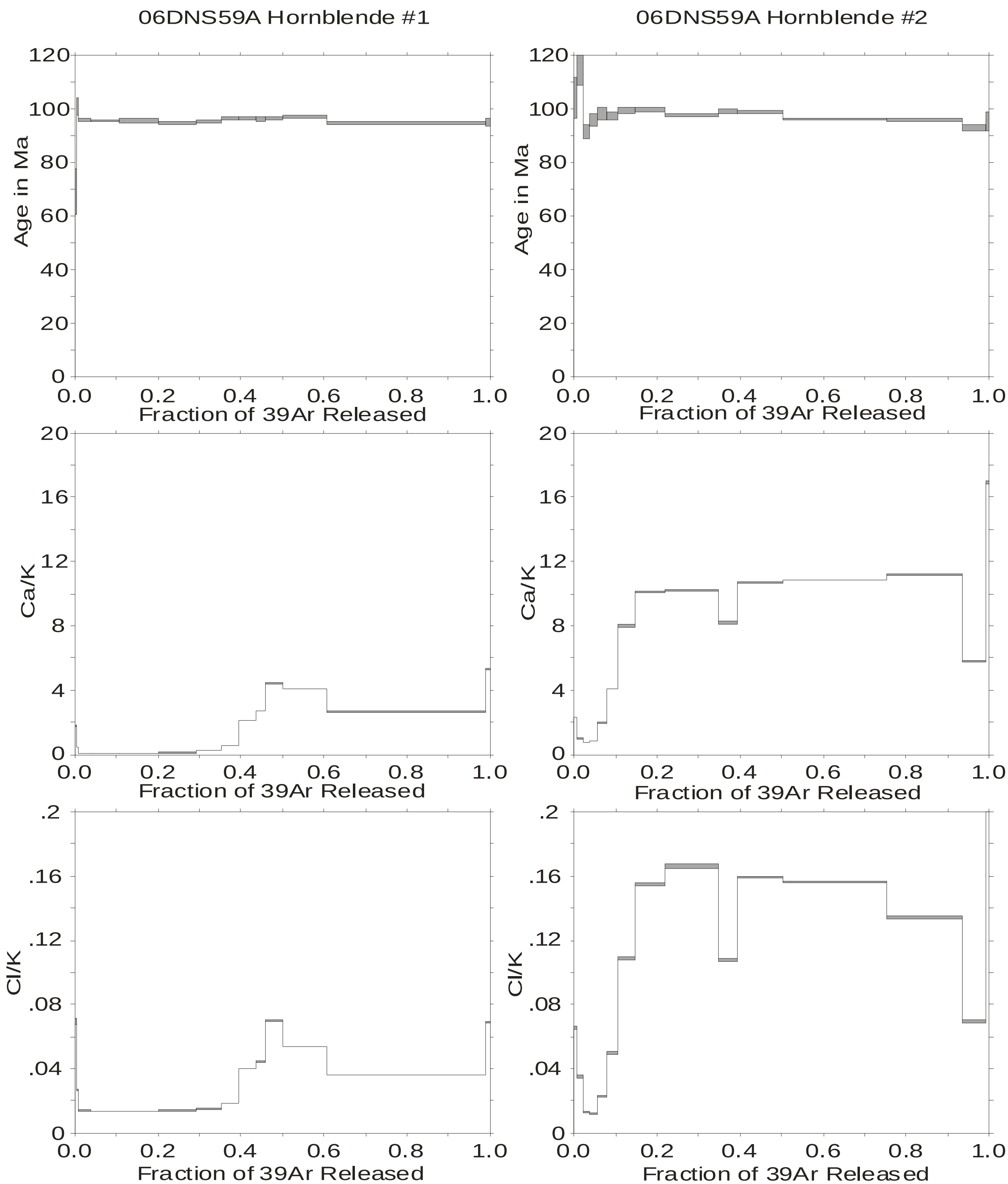
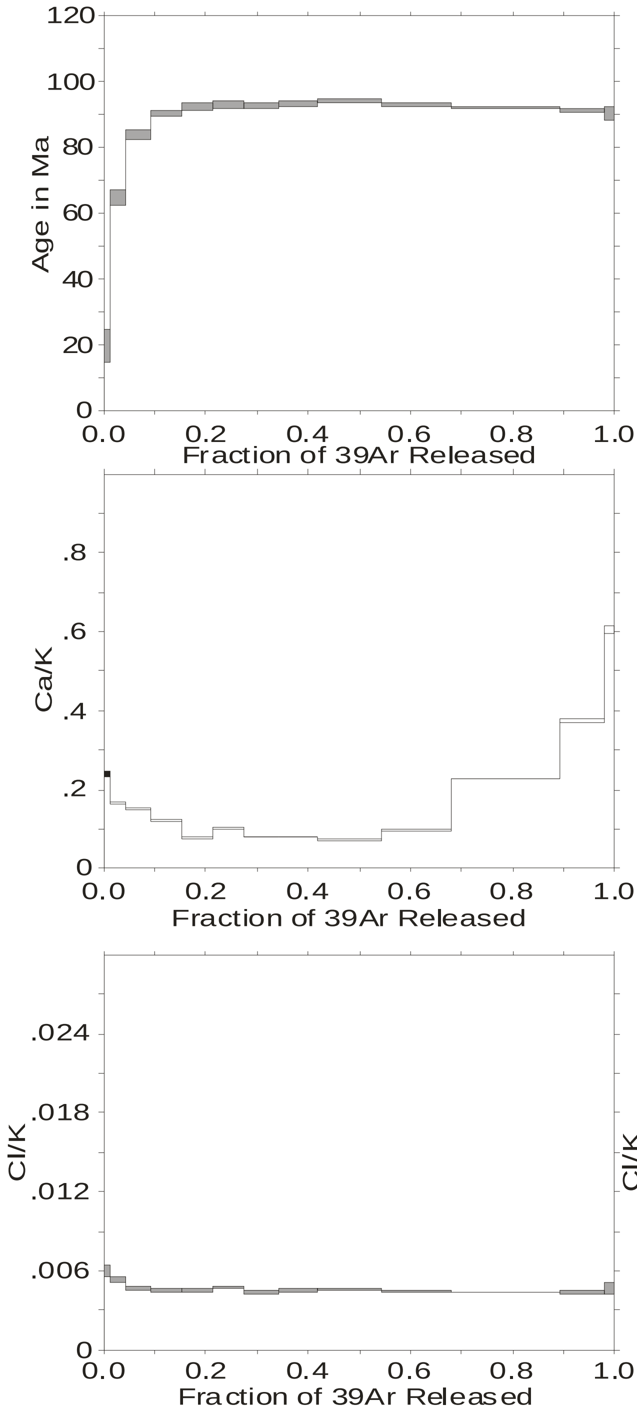
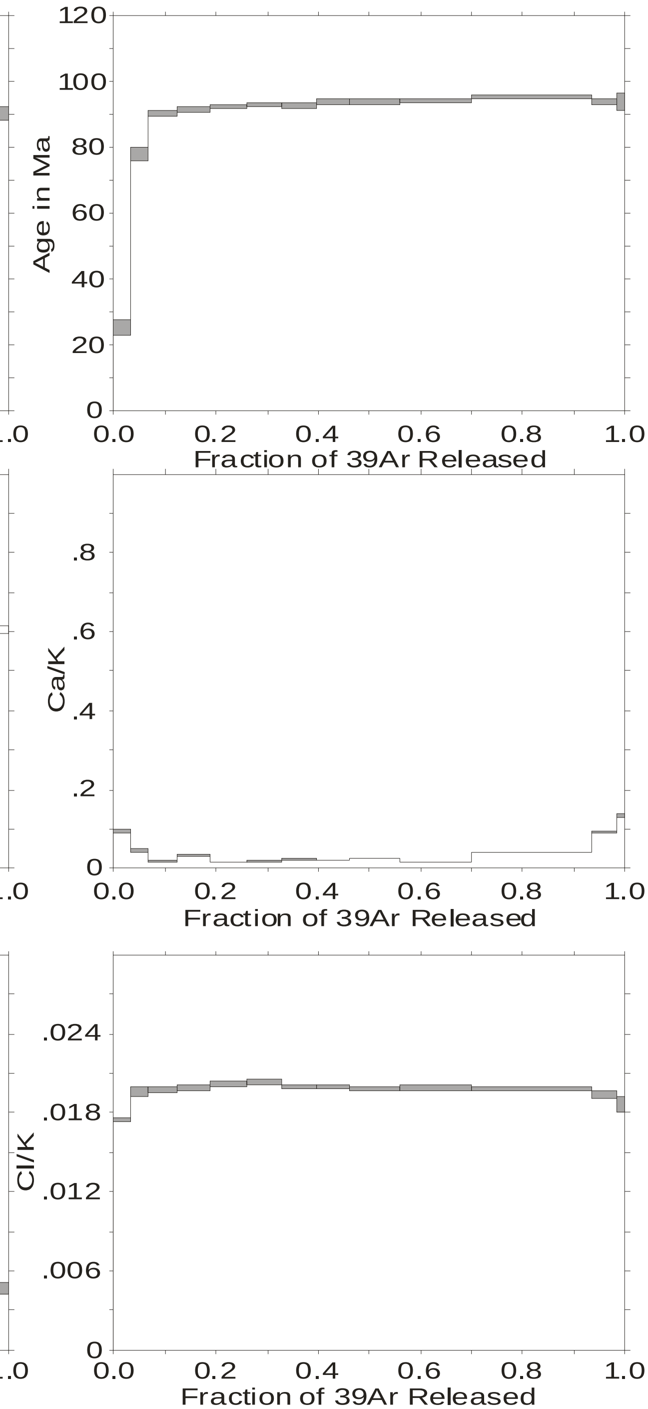
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


06DNS59A Hornblende #1
06DNS59A Hornblende #2
Age in Ma
Ca/K
Cl/K
Fraction of 39Ar Released

06MBW3A Biotite #1



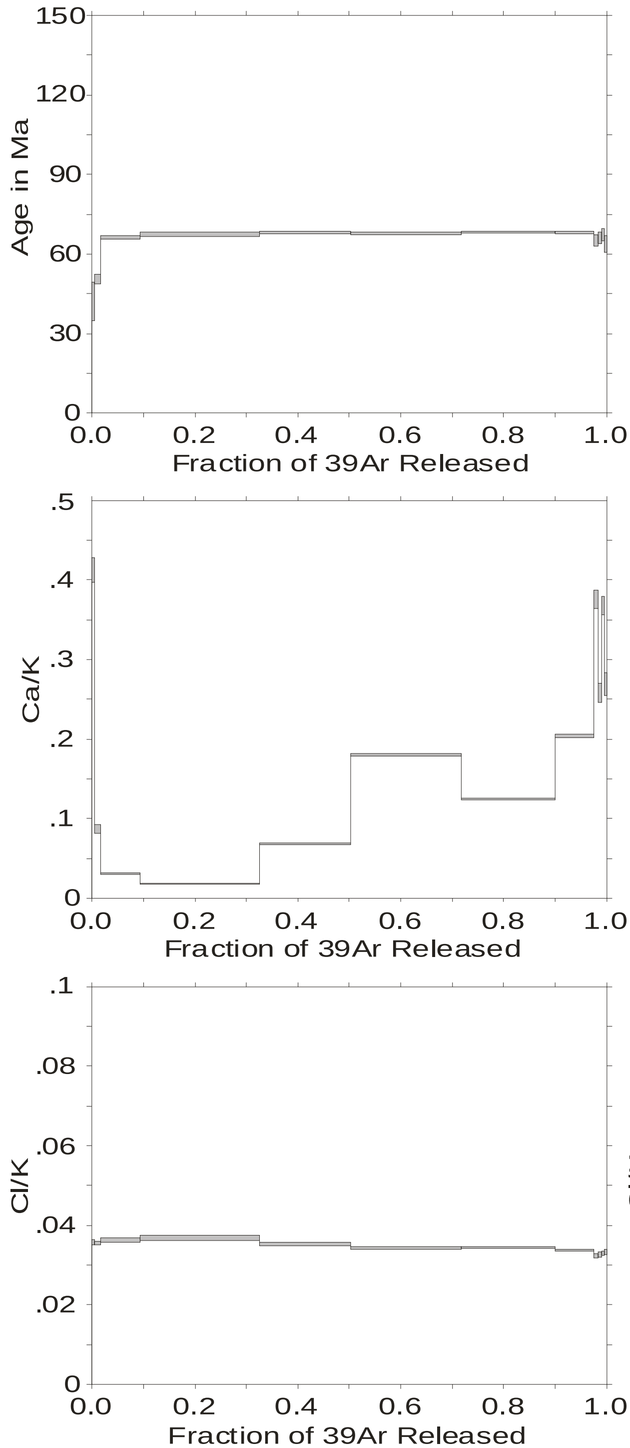
06DNS13A Biotite #1



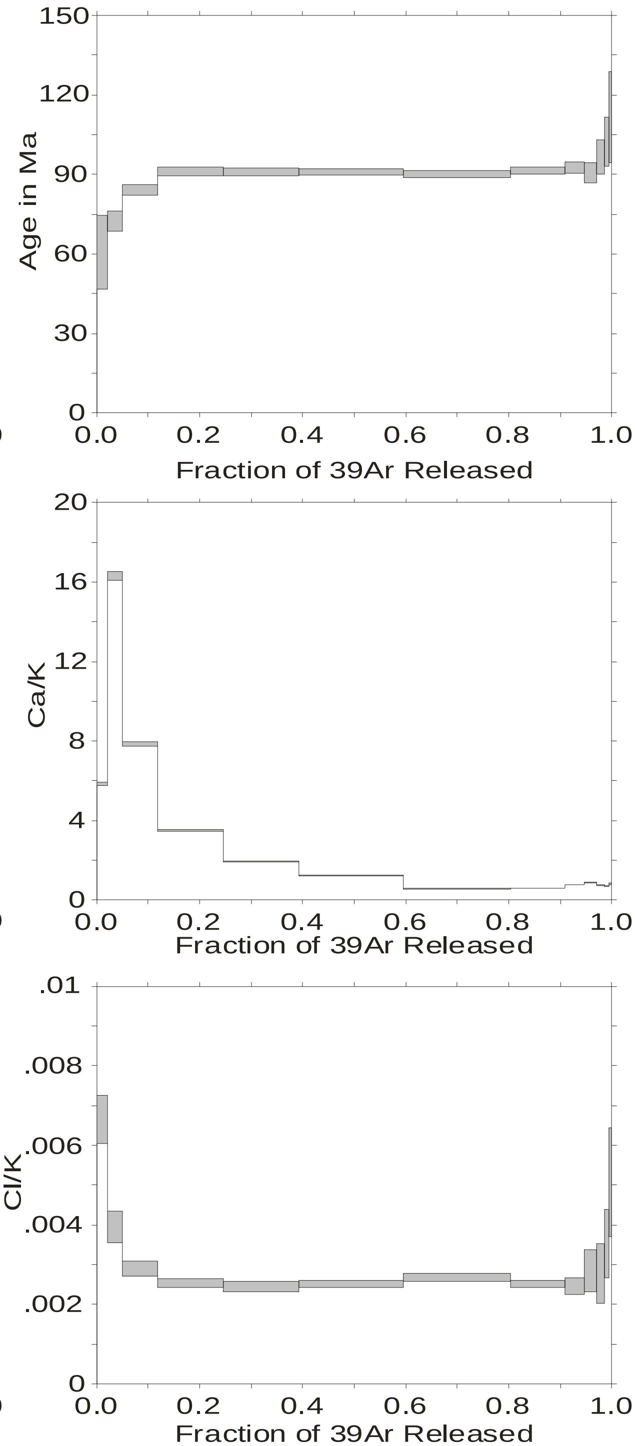
APPENDIX A-2:

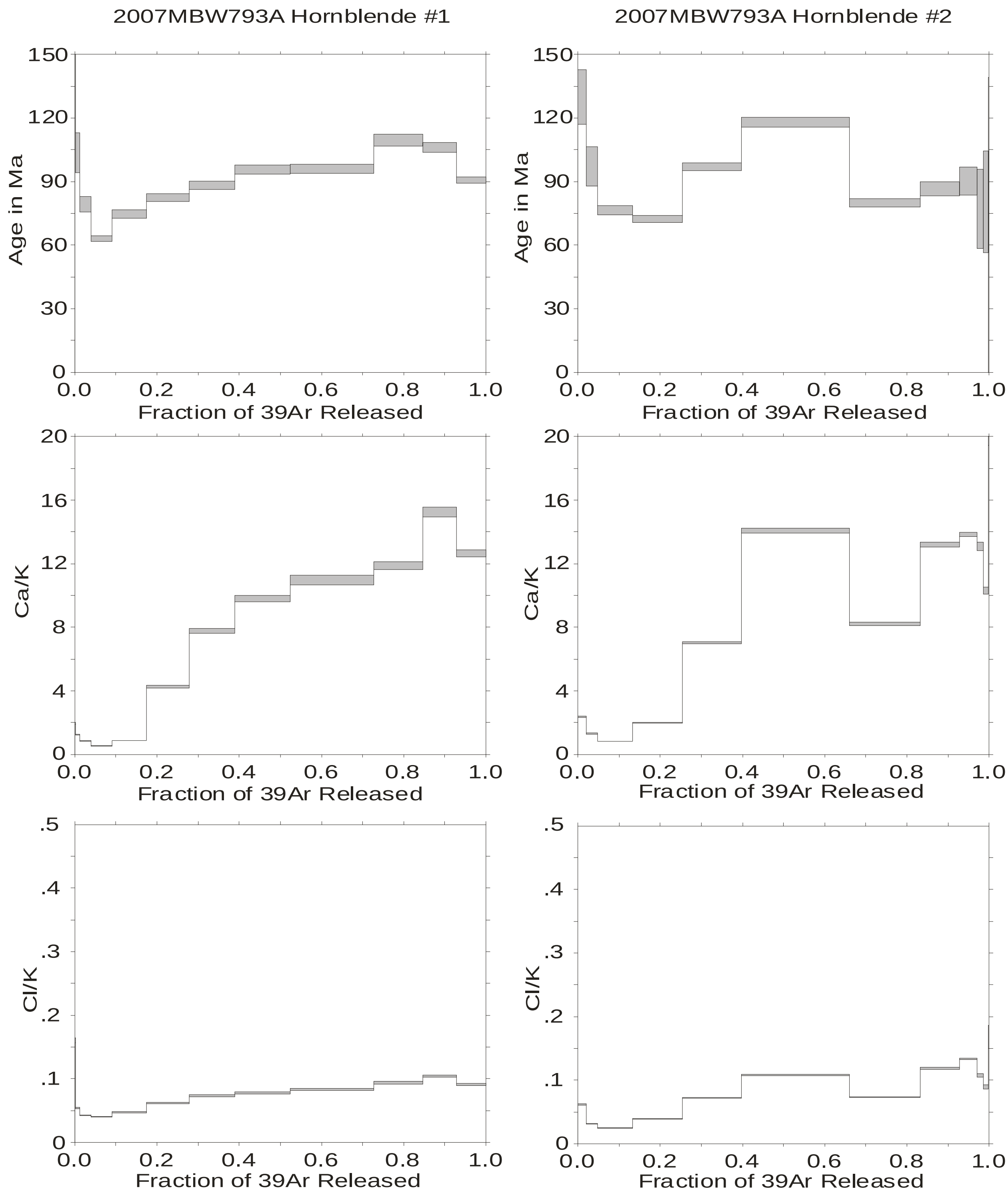
^{40}Ar/^{39}Ar Age, Ca/K and Cl/K spectra plots for 2007 samples

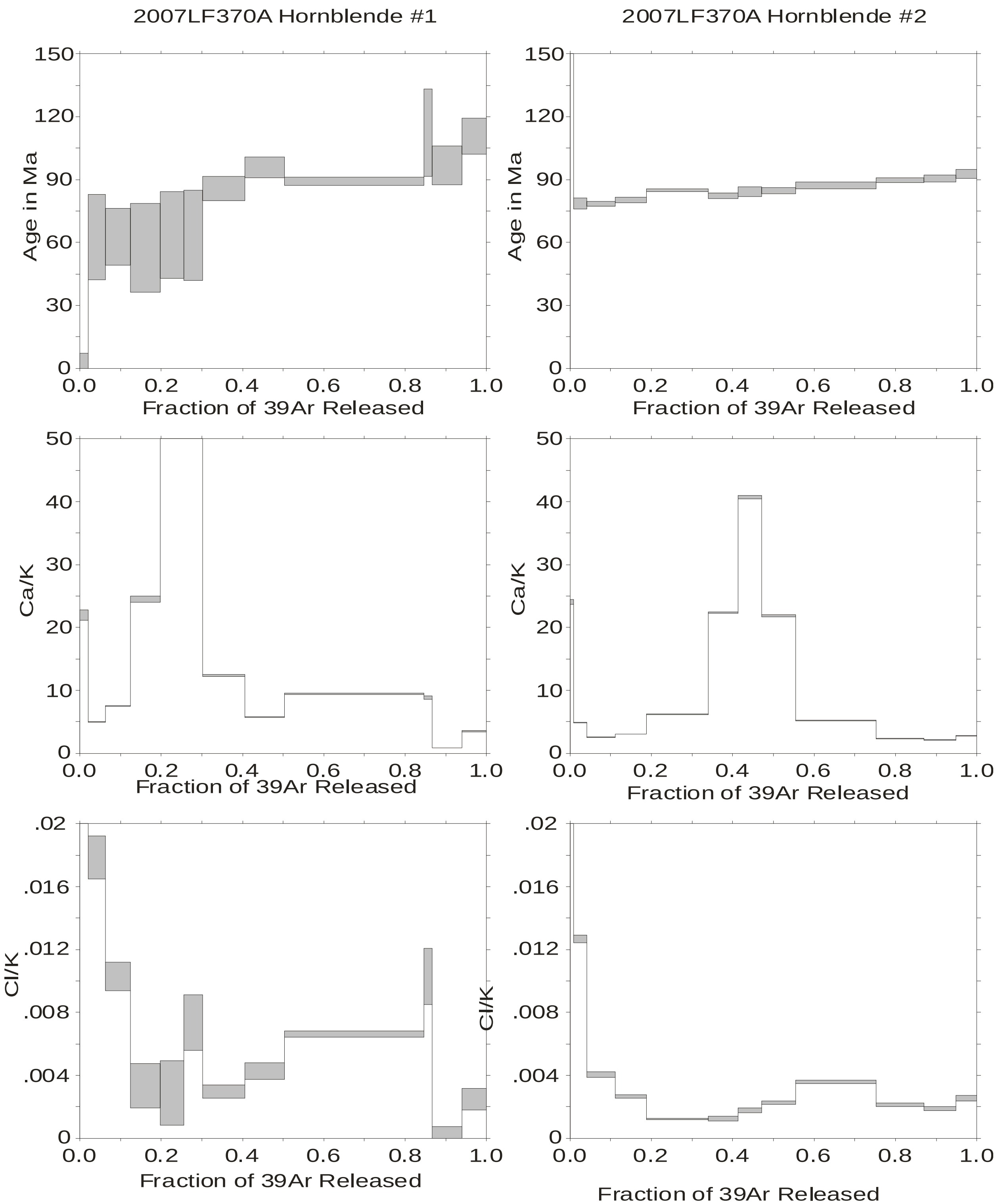
2007RL263A Biotite



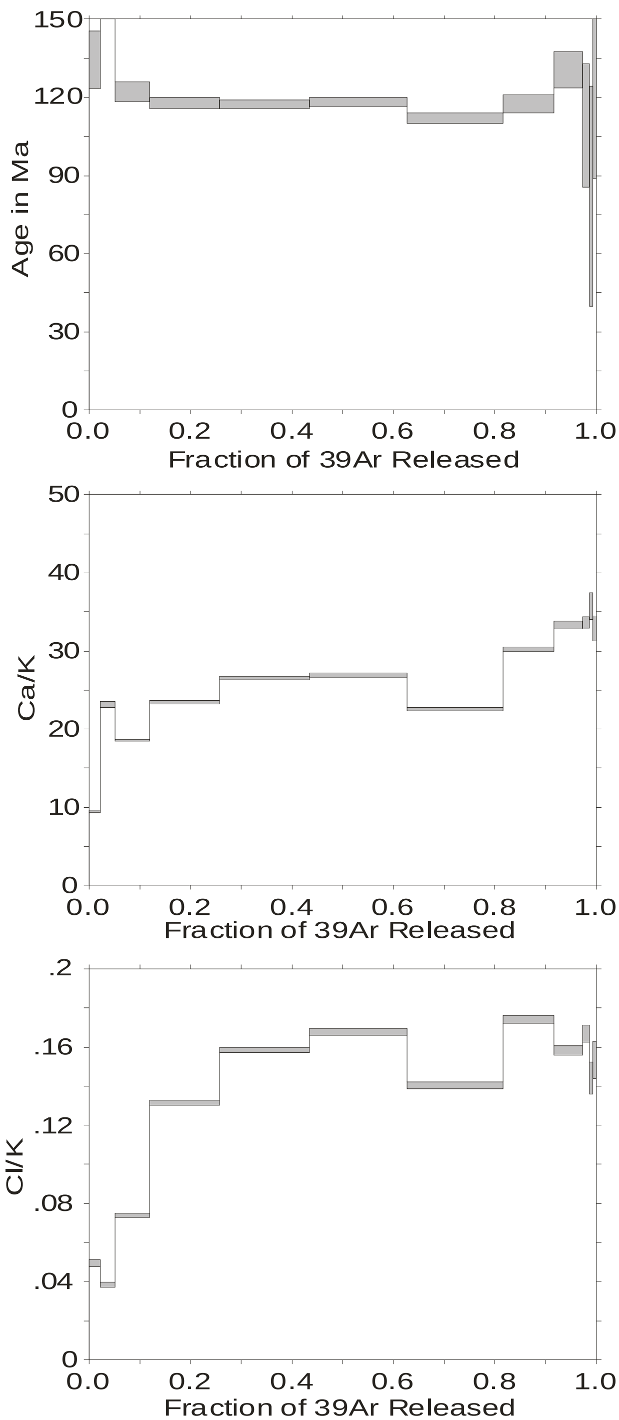
2007MBW1097A Biotite



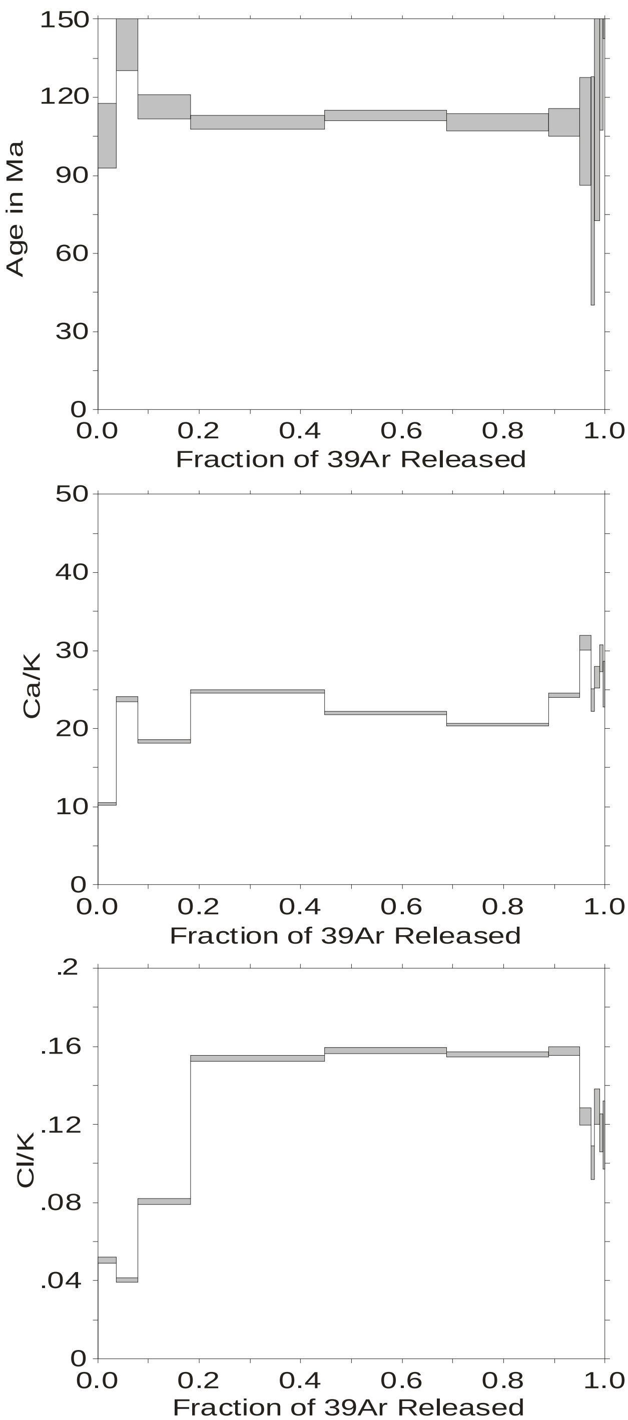

2007MBW793A Hornblende #1
2007MBW793A Hornblende #2
Age in Ma
Ca/K
Cl/K
Fraction of 39Ar Released


2007LF370A Hornblende #1
2007LF370A Hornblende #2
Age in Ma
Fraction of 39Ar Released
Ca/K
Cl/K
0
30
60
90
120
150
10
20
40
50
.004
.008
.012
.016
.02
0.0
0.2
0.4
0.6
0.8
1.0

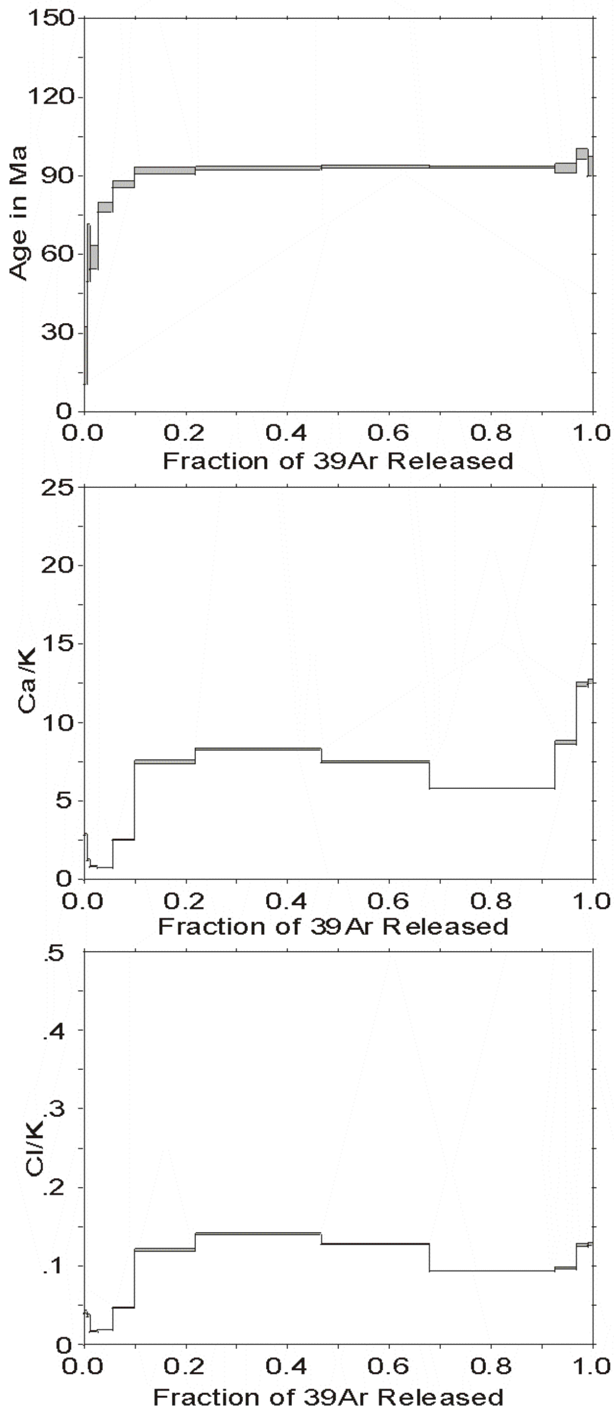
2007RL484B Hornblende #1



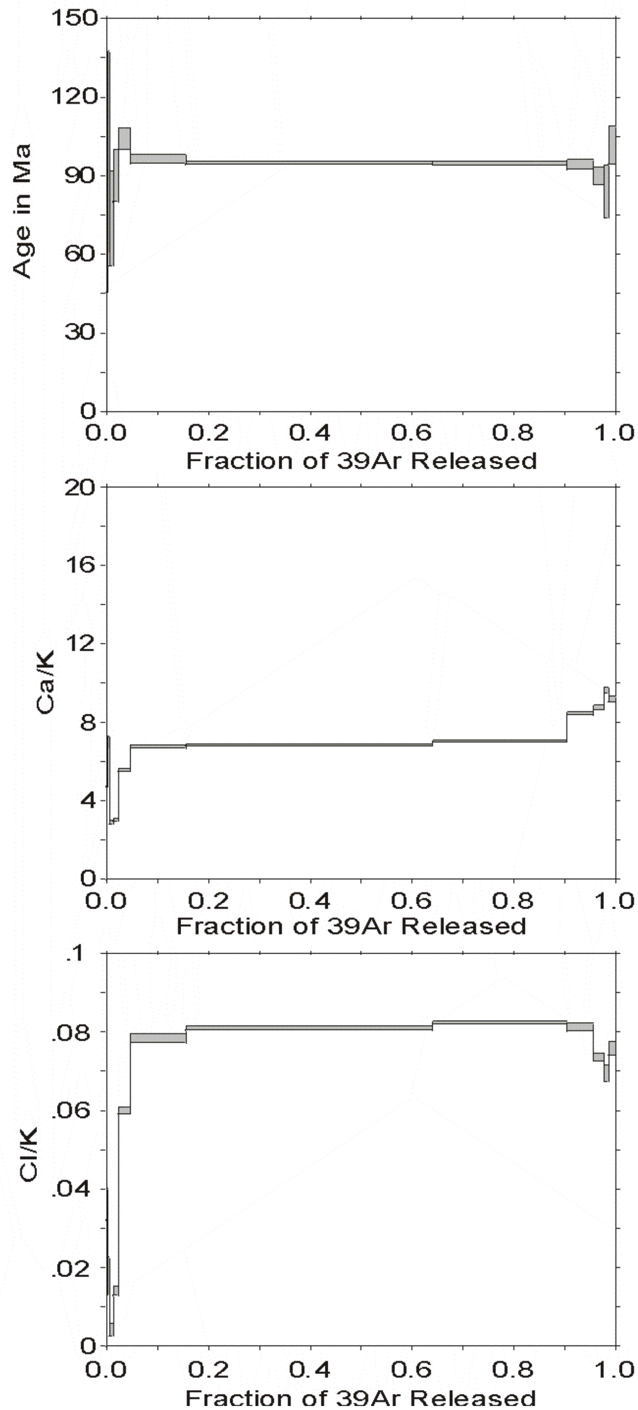
2007RL484B Hornblende #2



2007MBW1055A Hornblende

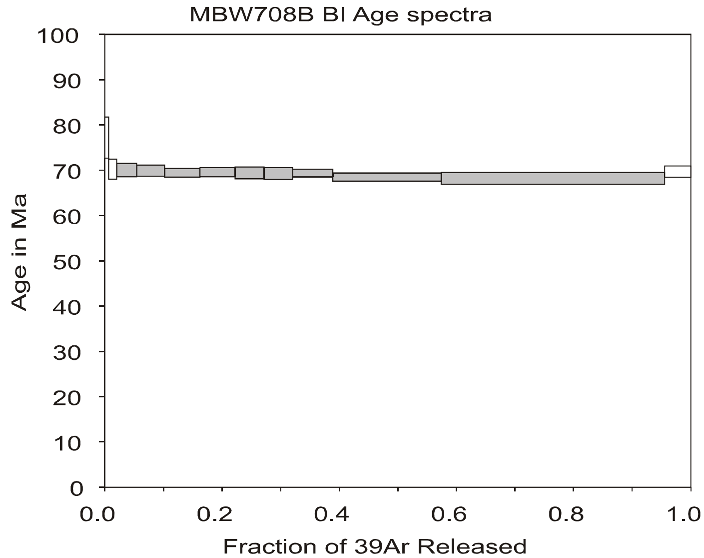


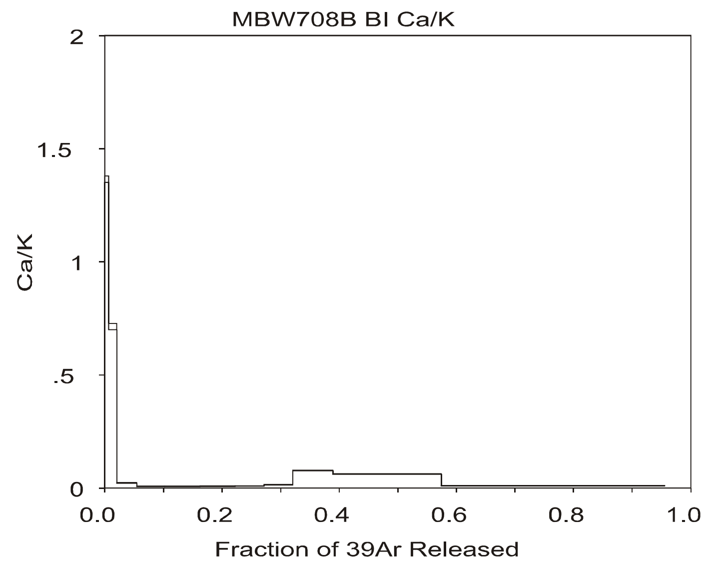
2007RL379A Hornblende

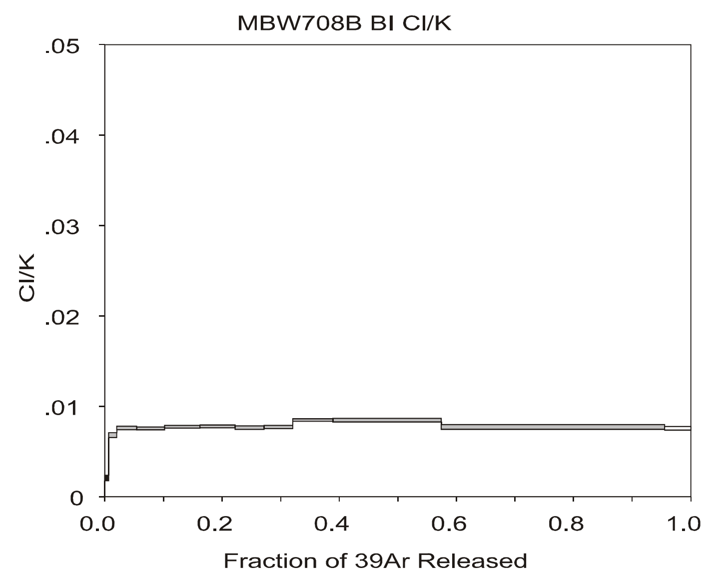


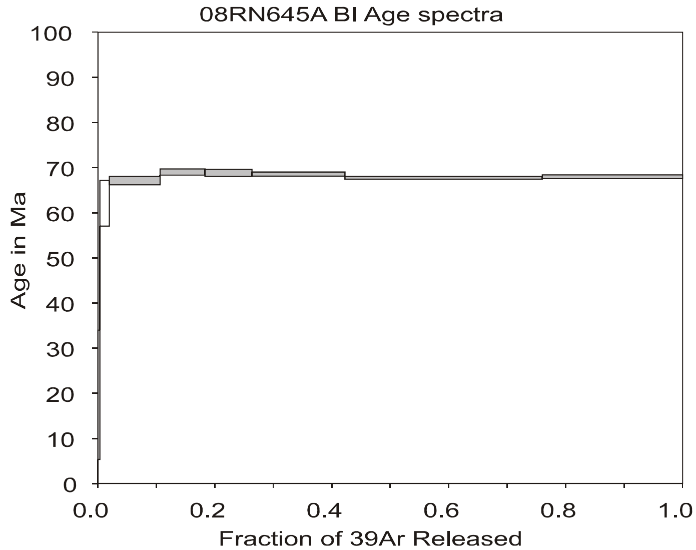
APPENDIX A-3:

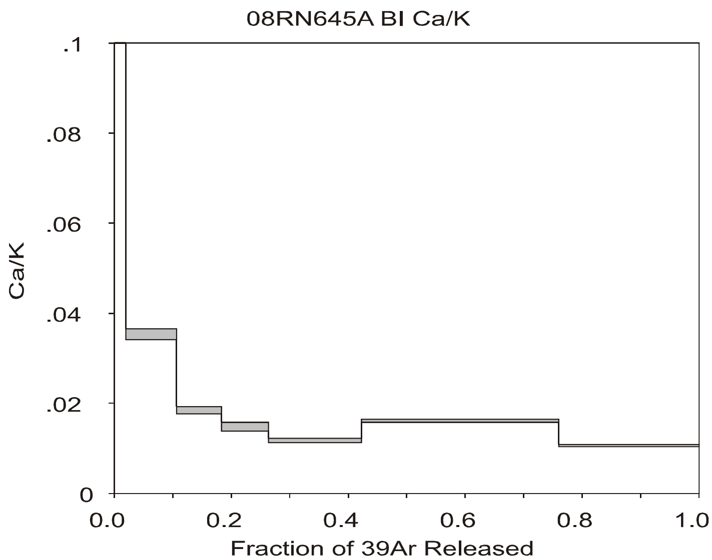
$^{40}Ar/^{39}Ar$ AGE, CA/K AND CL/K SPECTRA PLOTS FOR 2008 SAMPLES

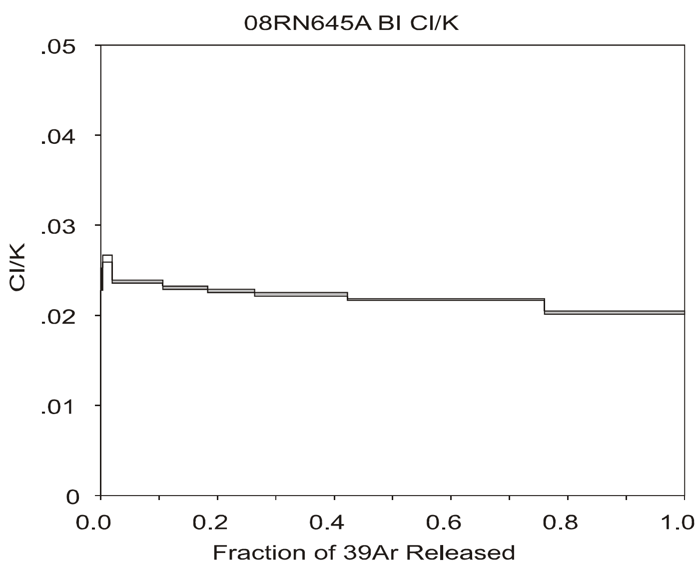

MBW708B BI Age spectra
Age in Ma
Fraction of 39Ar Released

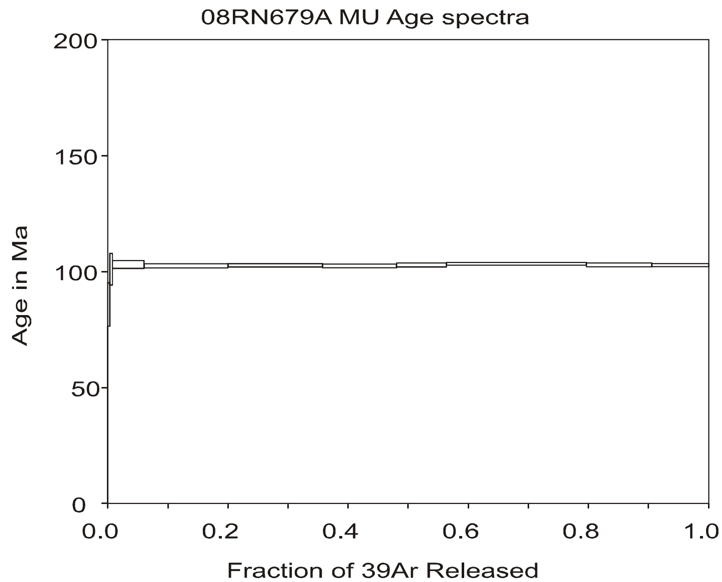

MBW708B BI Ca/K
Ca/K
Fraction of 39Ar Released

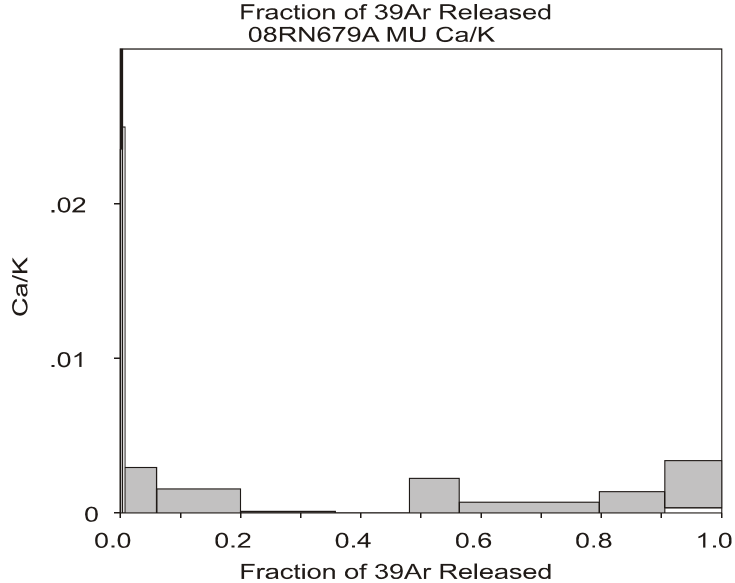

MBW708B BI Cl/K
Cl/K
Fraction of 39Ar Released

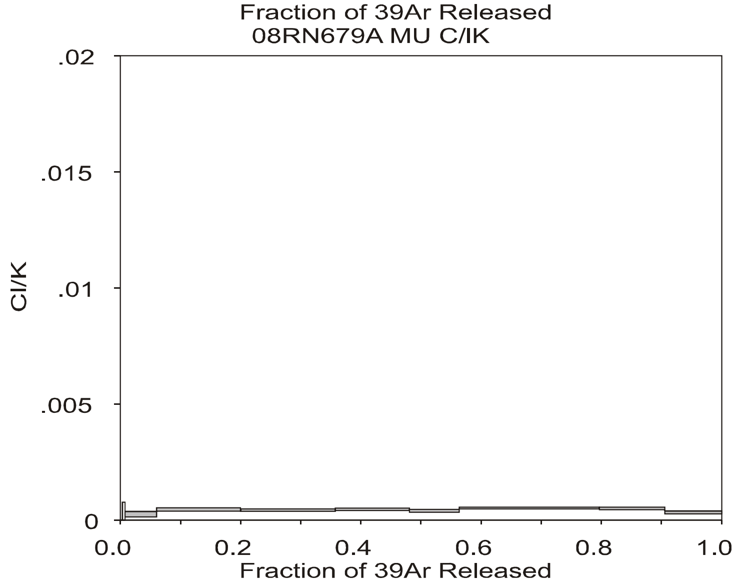

08RN645A BI Age spectra
Age in Ma
100
90
80
70
60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

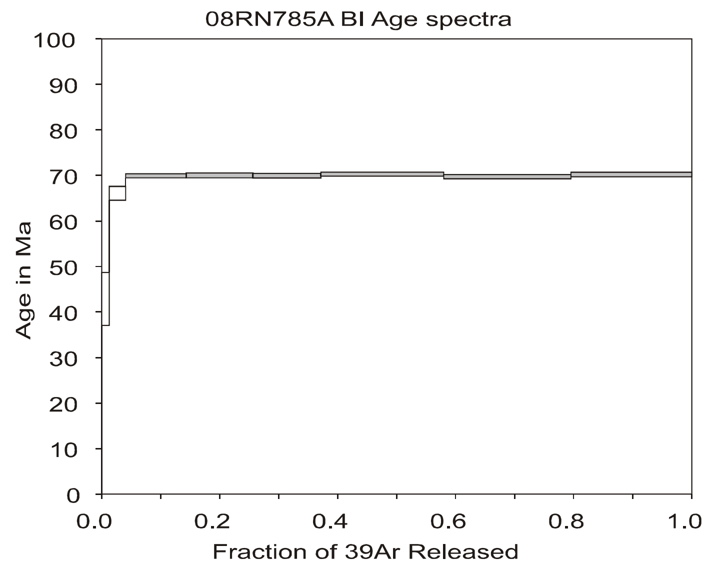

08RN645A BI Ca/K
Ca/K
.1
.08
.06
.04
.02
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

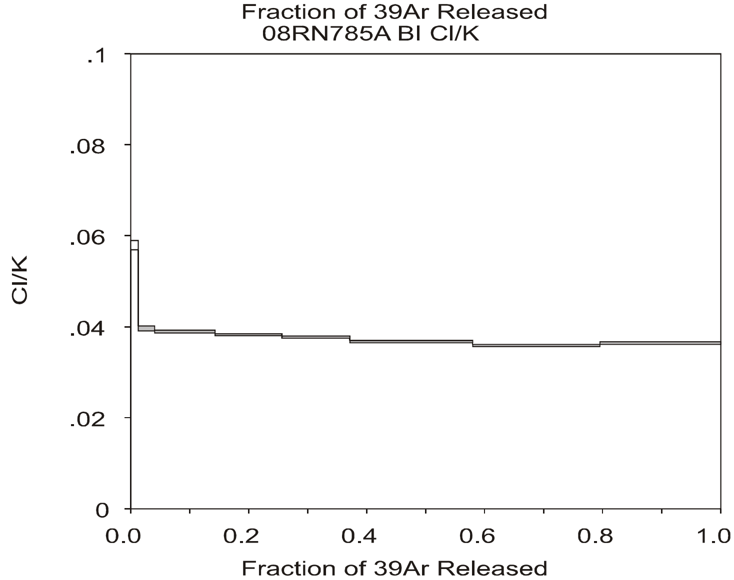

08RN645A BI Cl/K
Cl/K
.05
.04
.03
.02
.01
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

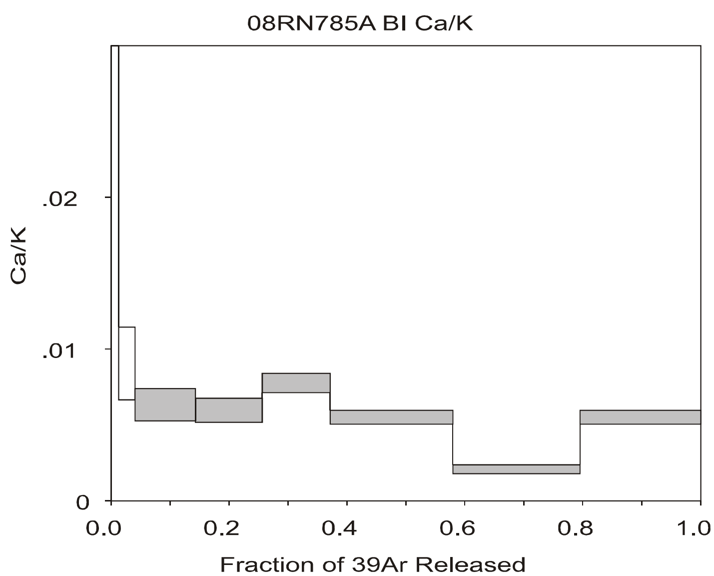

08RN679A MU Age spectra
Age in Ma
200
150
100
50
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


08RN679A MU Ca/K
Ca/K
.02
.01
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


08RN679A MU C/IK
Cl/K
.02
.015
.01
.005
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

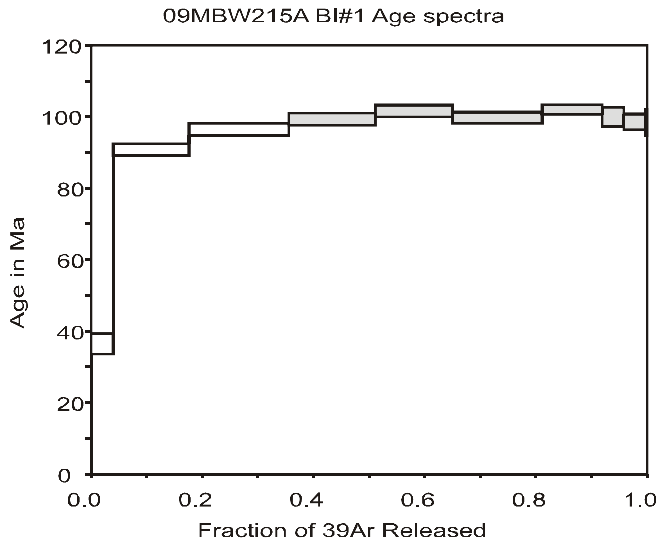

08RN785A BI Age spectra
100
90
80
70
60
50
40
30
20
10
0
Age in Ma
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

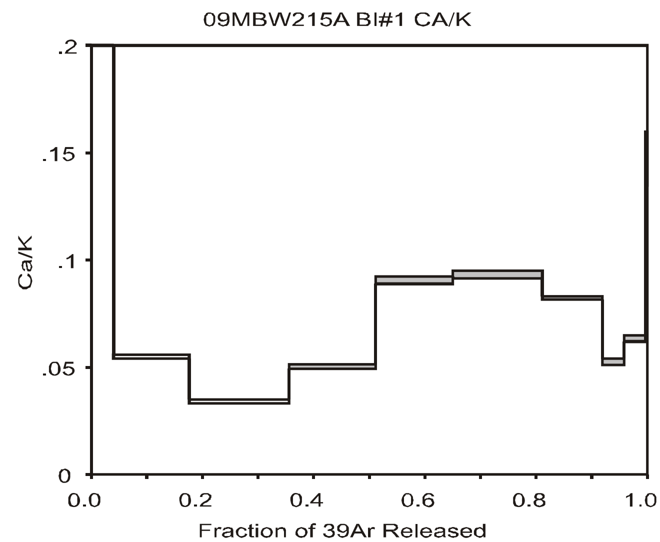

08RN785A BI Cl/K
.1
.08
.06
.04
.02
0
Cl/K
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

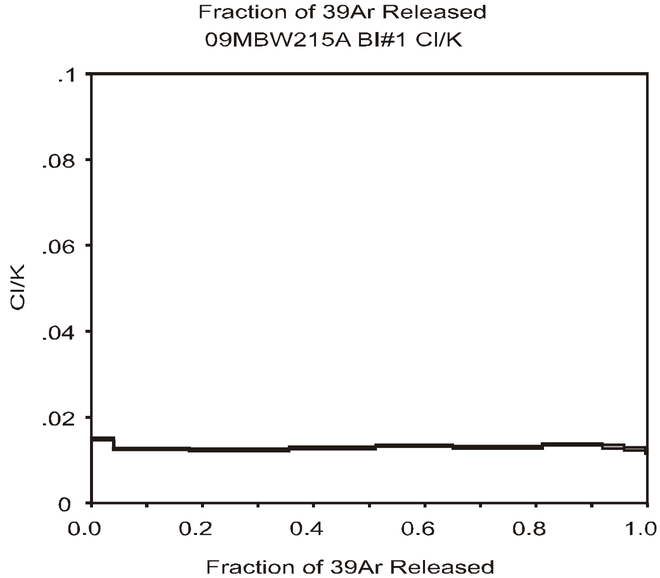

08RN785A BI Ca/K
.02
.01
0
Ca/K
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

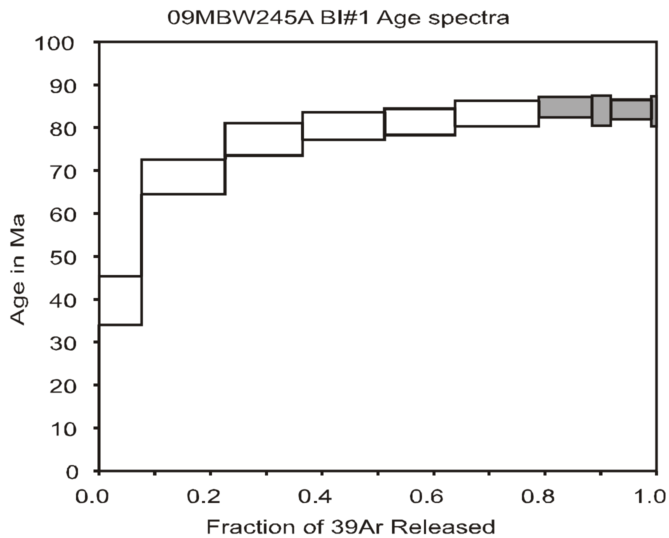
APPENDIX A-4:

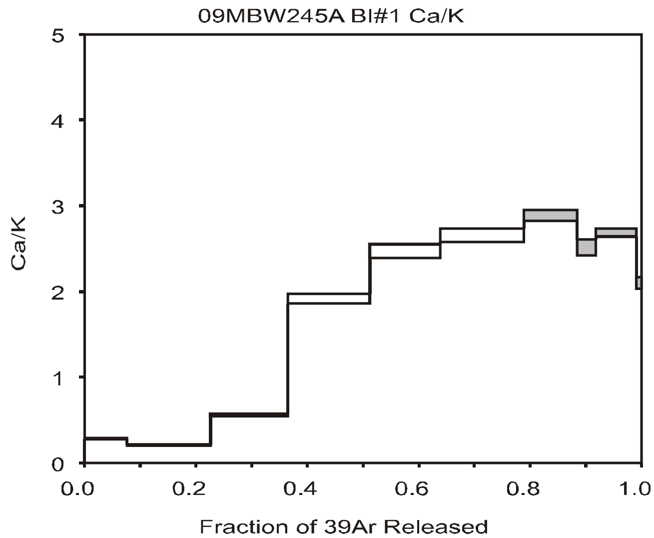
$^{40}Ar/^{39}Ar$ AGE, CA/K AND CL/K SPECTRA PLOTS FOR 2009 SAMPLES

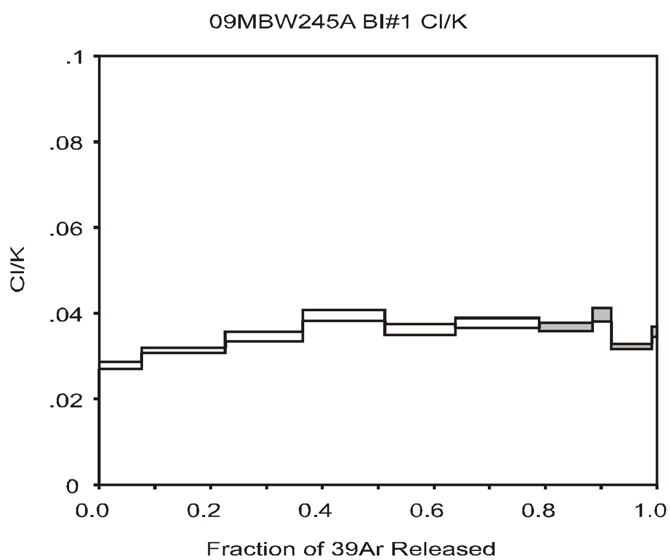

09MBW215A BI#1 Age spectra
Age in Ma
120
100
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

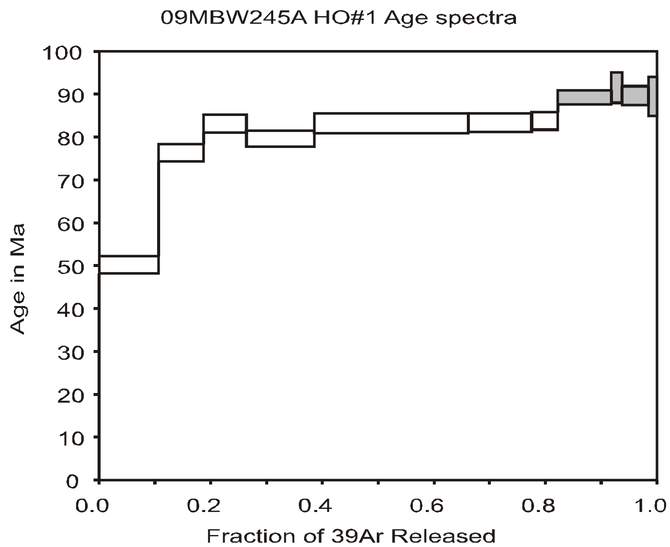

09MBW215A BI#1 CA/K
Ca/K
.2
.15
.1
.05
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

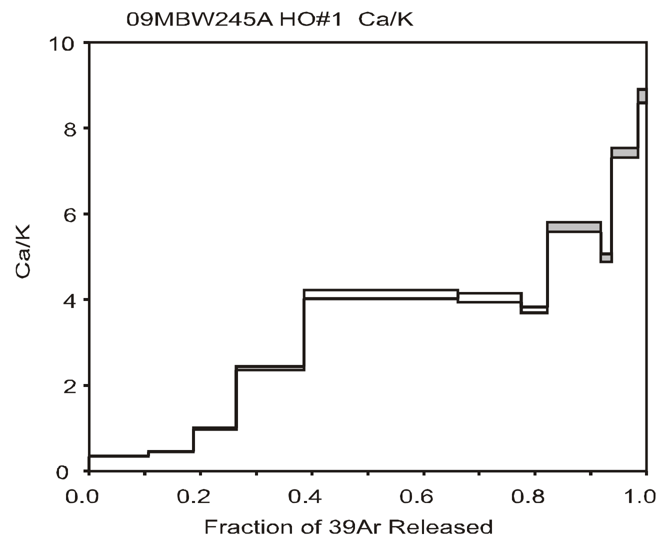

09MBW215A BI#1 Cl/K
Cl/K
.1
.08
.06
.04
.02
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

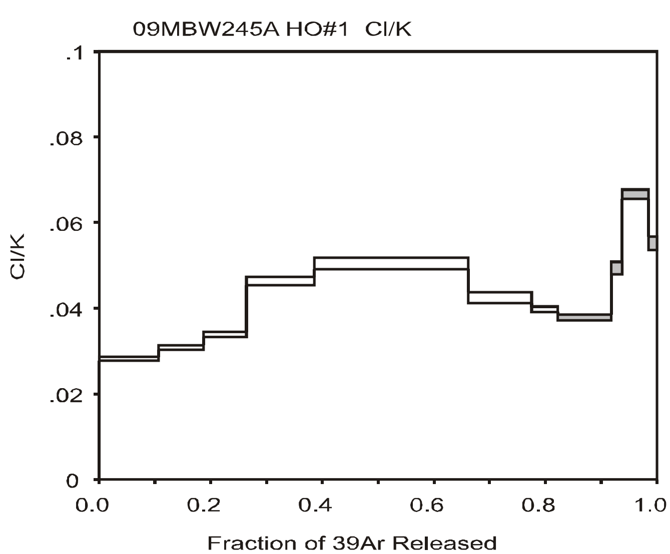

09MBW245A BI#1 Age spectra
Age in Ma
Fraction of 39Ar Released

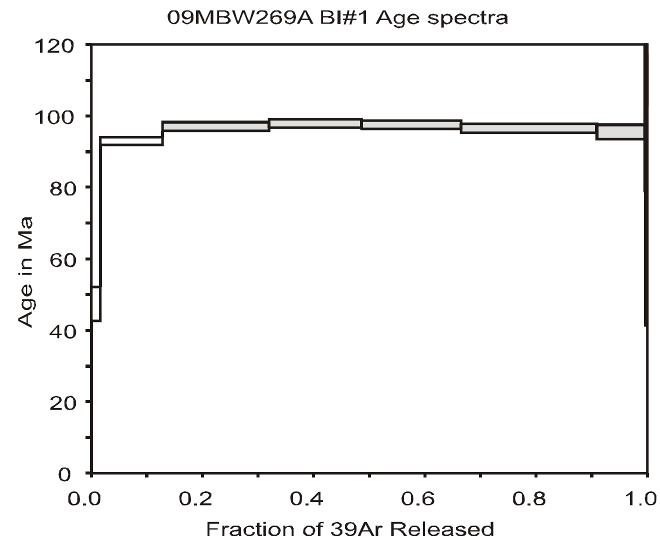

09MBW245A BI#1 Ca/K
Ca/K
Fraction of 39Ar Released

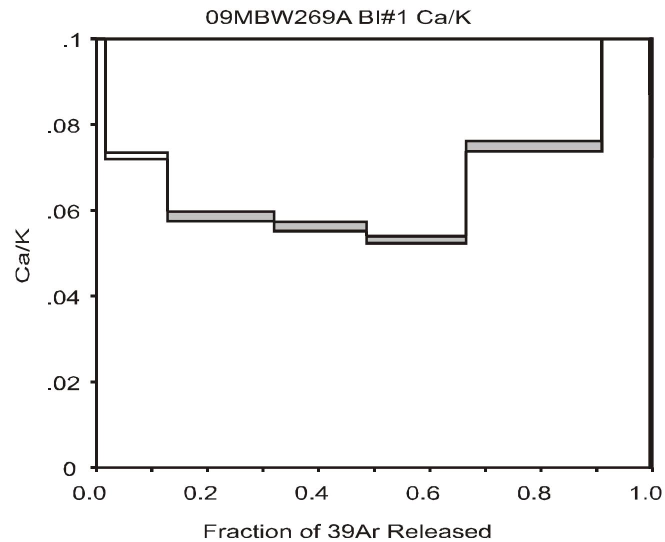

09MBW245A BI#1 Cl/K
Cl/K
Fraction of 39Ar Released

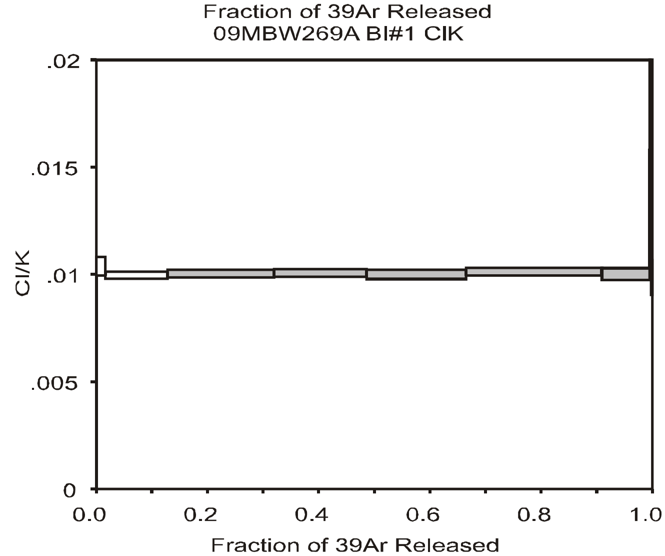

09MBW245A HO#1 Age spectra
Age in Ma
100
90
80
70
60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


09MBW245A HO#1 Ca/K
Ca/K
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

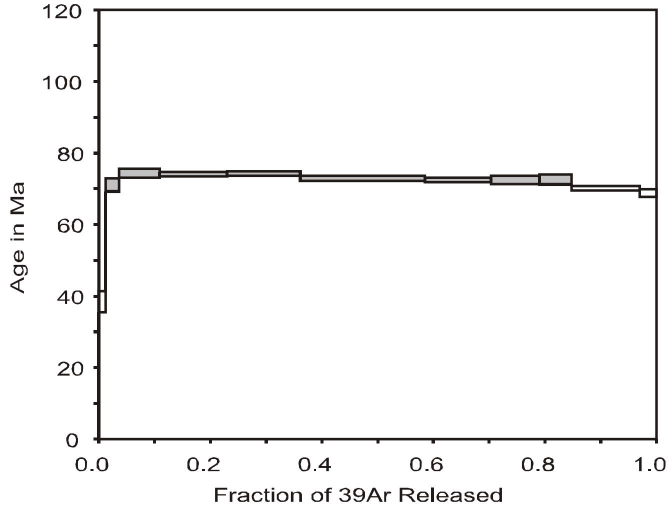

09MBW245A HO#1 Cl/K
Cl/K
.1
.08
.06
.04
.02
0
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


09MBW269A BI#1 Age spectra
120
100
80
60
40
20
0
Age in Ma
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

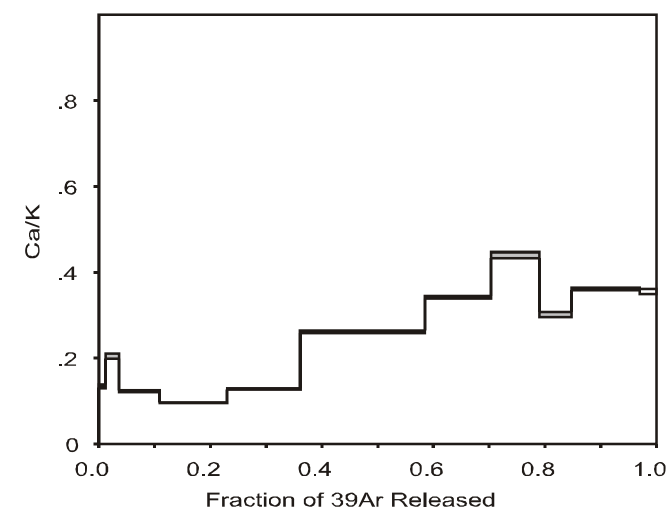

09MBW269A BI#1 Ca/K
.1
.08
.06
.04
.02
0
Ca/K
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


09MBW269A BI#1 CIK
.02
.015
.01
.005
0
Cl/K
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released

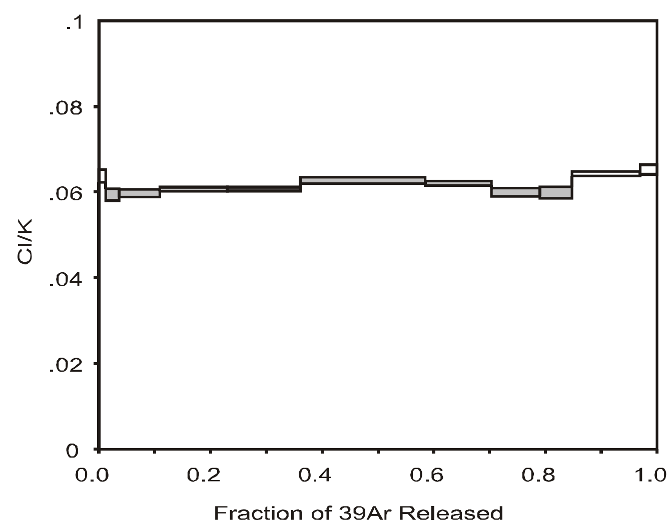
09LF374A BI#1 Age spectra

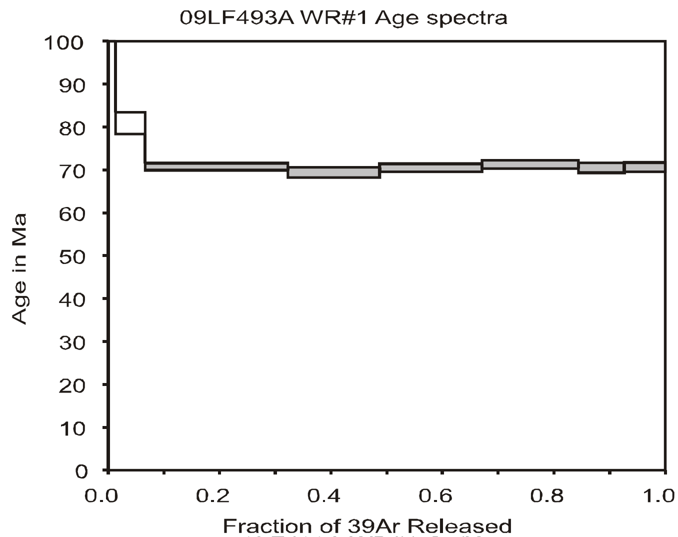


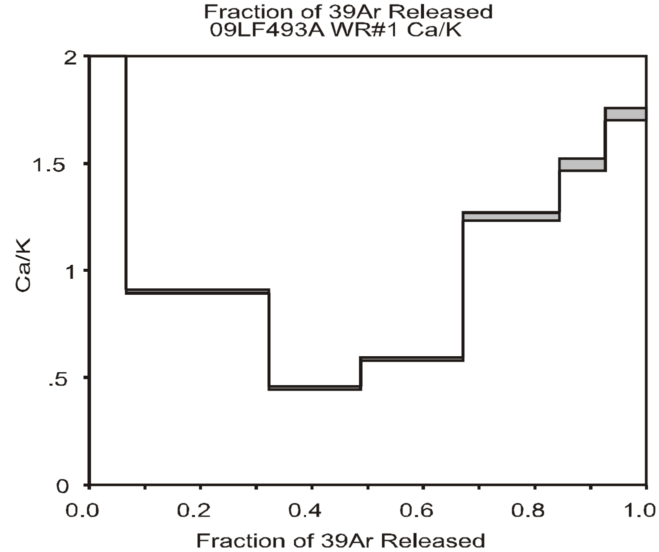
09LF374A BI#1 Ca/K

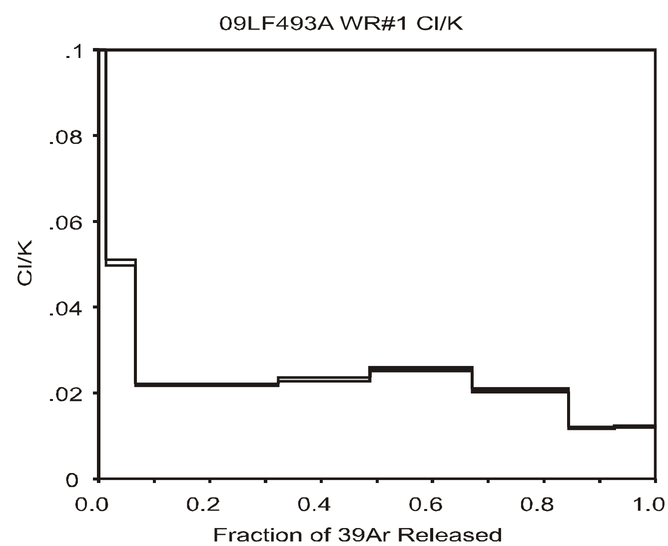


09LF374A BI#1 Cl/K




09LF493A WR#1 Age spectra
Age in Ma
0
10
20
30
40
50
60
70
80
90
100
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


09LF493A WR#1 Ca/K
Ca/K
0
.5
1
1.5
2
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released


09LF493A WR#1 Cl/K
Cl/K
0
.02
.04
.06
.08
.1
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of 39Ar Released