^{40}AR/^{39}AR GEOCHRONOLOGY DATA FROM THE LADUE RIVER-MOUNT FAIRPLAY AREA, EASTERN ALASKA

Travis J. Naibert, Matthew T. Heizler, Evan Twelker, Rainer J. Newberry, and Alicja Wypych

Raw Data File 2024-32

2024
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Suggested citation:
Naibert, T.J., Heizler, M.T., Twelker, Evan, Newberry, R.J., and Wypych, Alicja, 2024, 40Ar/39Ar geochronology data from the Ladue River-Mount Fairbanks area, eastern Alaska: Alaska Division of Geological & Geophysical Surveys Raw Data File 2024-32, 16 p. https://doi.org/10.14509/31454

$^{40}Ar/^{39}Ar$ GEOCHRONOLOGY DATA FROM THE LADUE RIVER-MOUNT FAIRPLAY AREA, EASTERN ALASKA

Travis J. Naibert[1], Matthew T. Heizler[2], Evan Twelker[1], Rainer J. Newberry[1], and Alicja Wypych[1]

INTRODUCTION

During the 2019 field season, geologists from the Alaska Division of Geological & Geophysical Surveys (DGGS) conducted geologic mapping and sampling in the Tanacross Quadrangle of eastern Alaska within the Ladue River drainage and the upper Dennison Fork of the Fortymile River drainage around Mount Fairplay. The area lies northeast of the Alaska Highway between Tok, Alaska, and the Canadian border (fig. 1). A recent geologic map of the area (Twelker and others, 2021), lies within the Yukon-Tanana Uplands, which DGGS and U.S. Geological Survey (USGS) identified as having potential to host deposits of multiple critical minerals (Hammarstrom and Dicken, 2019; Kreiner and Jones, 2020; Kreiner and others, 2022), as well as gold, copper, molybdenum, lead, zinc, and silver. Most known mineralization in the region is related to Cretaceous–Paleogene magmatism. These igneous rocks intrude metamorphic rocks of the North American continental margin and the structurally overlying allochthonous Yukon-Tanana Terrane, both of which are multiply deformed and juxtaposed along low-angle faults. Samples were collected for $^{40}Ar/^{39}Ar$ geochronology to further understand the crystallization ages of igneous rocks and the exhumation history of metamorphic rocks. The 18 $^{40}Ar/^{39}Ar$ samples in this report include one volcanic crystallization age, two pluton-alteration ages, and 15 metamorphic cooling ages.

Differences in metamorphic cooling ages have been used to distinguish the allochthonous Yukon-Tanana Terrane from parautochthonous North America (Hansen, 1990; Dusel-Bacon and others, 2002; Twelker and others, 2021; Wypych and others, 2021). The 15 metamorphic samples with cooling ages reported here were collected to aid in DGGS field mapping near this major terrane boundary. Allochthonous samples include eight samples from the Ladue River assemblage with muscovite cooling ages between ca. 105 and 235 Ma; a sample from the Klondike assemblage with a muscovite cooling age of ca. 147 Ma; a sample from the Fortymile River assemblage with a muscovite cooling age of ca. 186 Ma. Parautochthonous North America samples include a sample from the Jarvis assemblage with a muscovite cooling age of ca. 149 Ma and four samples from the Lake George assemblage with muscovite cooling ages of ca. 100 and 105 Ma and hornblende cooling ages of ca. 127 and 255 Ma.

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[1] Alaska Division of Geological & Geophysical Surveys, 3354 College Road, Fairbanks, AK 99709
[2] New Mexico Bureau of Geology & Mineral Resources, 801 Leroy Pl., Socorro, NM 87801

The analytical data tables associated with this report are available in digital format as comma-separated value (CSV) files. Additional details about the organization of information are noted in the accompanying metadata file. All files can be downloaded from the DGGS website: https://doi.org/10.14509/31454.

Samples collected during the project will be stored at the DGGS Fairbanks office for the duration of the project. Once the project concludes, the samples will be stored at the Alaska Geologic Materials Center in Anchorage, and will be available for public viewing upon request.

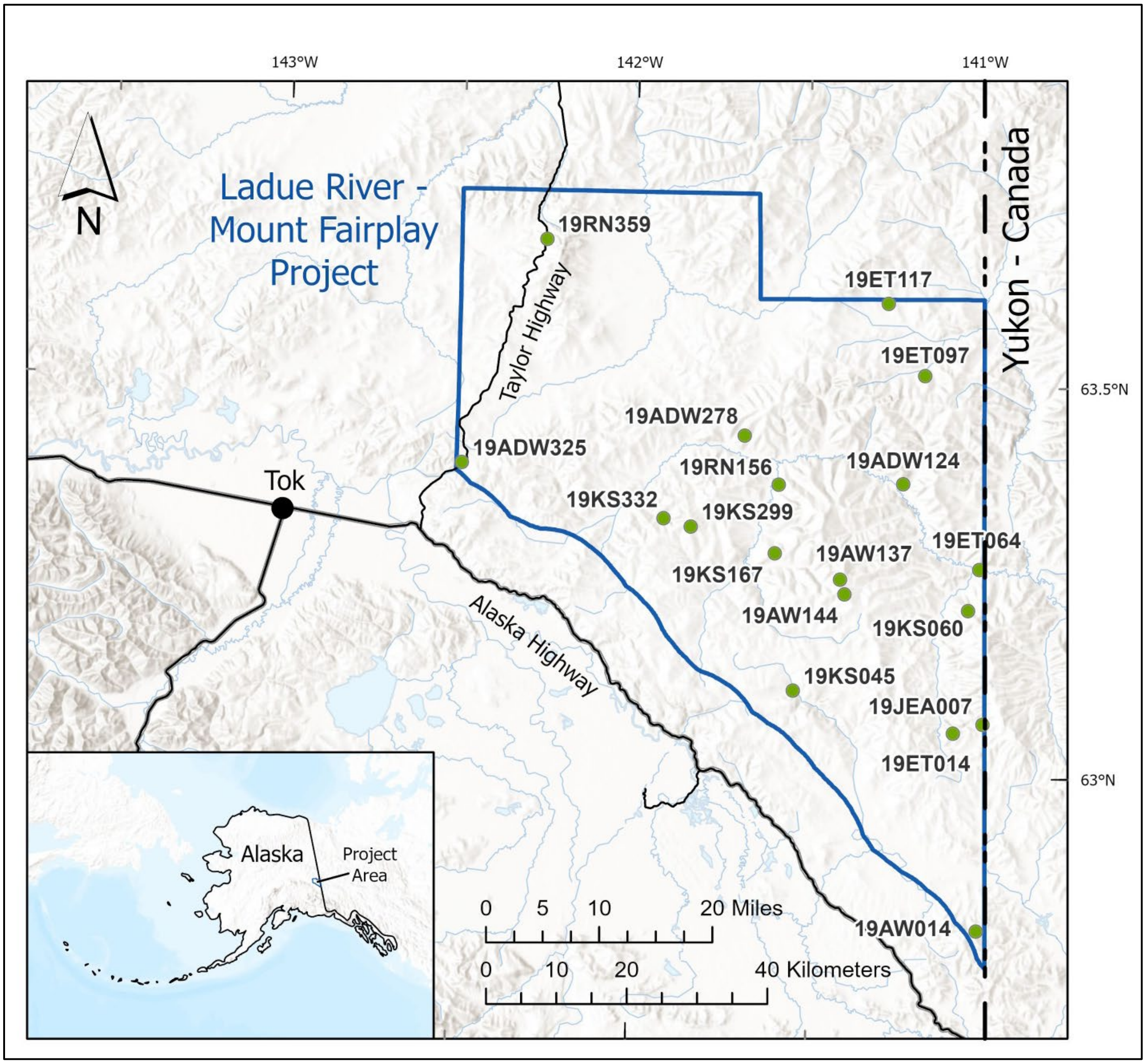

Figure 1. Map showing location of samples in this report (green circles) within the Ladue River-Mount Fairplay area.

DOCUMENTATION OF METHODS

Sample Collection

Fresh, unweathered samples from surface outcrops were collected by DGGS field geologists for dating. Sample location coordinates (in WGS84 datum) were obtained using GPS-enabled field tablets with a typical reported accuracy of ± 10 meters. Samples were examined under a binocular microscope and/or in thin section to select unaltered mineral phases before sample preparation.

Sample Preparation

Twenty-four samples were submitted to the New Mexico Geochronological Research Laboratory (NMGRL) in Socorro, New Mexico. Nineteen samples yielded acceptable mineral separates for $^{40}Ar/^{39}Ar$ geochronology. Muscovite and/or hornblende were separated from rock samples using standard magnetic, heavy liquid, and hand-picking procedures. The samples were loaded into machined aluminum discs and irradiated for 16 hours at the USGS reactor in Denver, Colorado (NM-316), or for 14 hours at the Oregon State University reactor in Corvallis, Oregon (NM-312), along with the Fish Canyon Tuff sanidine standard (FC-2; assigned age—28.201 Ma; Kuiper and others, 2008) as a neutron flux monitor.

Analytical Methods

After irradiation, the samples and monitors were analyzed by step-heating with a 75W 810 nm diode laser. The samples were step-heated using between 12 and 16 increments. Reactive gases were removed by a 60-second reaction with a SAES GP-50 getter at 450°C, and gas was also exposed to a cold finger at -140°C. The samples were analyzed in a Thermo-Fisher Scientific Helix MC-plus mass spectrometer at NMGRL. Total system blanks were 3.5×10^{-17} mol ^{40}Ar, 8×10^{-18} mol ^{39}Ar, 5×10^{-19} mol ^{38}Ar, 3×10^{-18} mol ^{37}Ar, and 5×10^{-19} mol ^{36}Ar. Isotopic ratios were corrected for blank, radioactive decay, and mass discrimination but were not corrected for interfering reactions.

RESULTS AND SAMPLE DESCRIPTIONS

Nineteen samples were analyzed, but due to a probable sample number mix-up (discussed below), eighteen sample ages are reported. One sample, 19ET064, was analyzed twice. A summary of the $^{40}Ar/^{39}Ar$ results is provided in table 1, with ages quoted at the ± 2-sigma level. See the accompanying digital data tables for more detailed results, with ages quoted at the ± 1-sigma level. The integrated age is the age given by the total gas measured and is equivalent to a potassium-argon (K-Ar) age. Age spectra plots are included in the appendix. The spectra provide plateau ages 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 [MSWD] less than 2.5). When spectra did not provide a plateau age under the above definition, a weighted mean age was calculated, or the integrated age was used as the preferred age for the sample. Below we provide sample descriptions and additional discussion of the results of each age analysis, noting our preferred age determination.

19ADW124 – Orthogneiss from the Ladue River assemblage

Muscovite biotite feldspar quartz orthogneiss with distinct bands of biotite and quartz at multiple scales. A muscovite separate was analyzed, and the weighted mean age (224.09 ± 0.63 Ma) and the integrated age (218.06 ± 0.16 Ma) are within uncertainty. The preferred age for this sample is the weighted mean age of **224.09 ± 0.63 Ma** calculated from seven heating steps representing 23 percent of total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19ADW278 – Metasediment from the Ladue River assemblage

Biotite chlorite muscovite feldspar quartz porphyroclastic paragneiss. Upper greenschist to lower amphibolite facies. A muscovite separate was analyzed, and the age spectrum yields an undulatory pattern. Due to the undulatory age spectrum, neither a plateau nor weighted mean age was calculated and the preferred age for this sample is the integrated age of **109.69 ± 0.06 Ma**, which is interpreted to record cooling of the sample through the closure temperature of muscovite.

19ADW325 – Schist from the Fortymile River assemblage

Calcite albite chlorite muscovite epidote quartz schist. A muscovite separate was analyzed, and the integrated age is 181.13 ± 0.10 Ma. The age spectrum yields a climbing pattern, with younger ages for the initial heating steps. Due to the climbing age spectrum, the preferred age is a weighted mean age of **185.60 ± 0.10 Ma** calculated from two heating steps representing 49 percent of the total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19AW014 – Paragneiss from the Lake George assemblage

Magnetite-bearing muscovite biotite feldspar quartz paragneiss. Thin, 1- to 2-mm-thick layers of quartz and feldspar parted by 1- to 2-mm-thick biotite-magnetite layers. A muscovite separate was analyzed, and the integrated age is 100.37 ± 0.06 Ma. The age spectrum is flat, and the preferred age for this sample is the weighted mean age of **100.06 ± 0.34 Ma** calculated using nine heating steps representing 62 percent of the total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19AW137 – Felsic schist from the Ladue River assemblage

Pale green chlorite muscovite quartz albite schist. A muscovite separate was analyzed, and the integrated age is 234.02 ± 0.12 Ma. The age spectrum is undulatory. The preferred age for this sample is the weighted mean age of **234.80 ± 1.24 Ma** calculated from 13 heating steps representing 94 percent of the total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19AW144 – Orthogneiss from the Ladue River assemblage

Biotite muscovite orthogneiss with up to 10-mm-thick boudinaged felsic layers parted by less than 1-mm-thick layers of coarse-grained mica. A muscovite separate was analyzed, and the integrated age is 230.06 ± 0.15 Ma. The age spectrum yields a climbing pattern where the higher temperature heating steps have older ages. Due to the climbing age spectrum pattern, the preferred age for this sample is the weighted mean age of **231.77 ± 0.86 Ma** calculated from five heating steps representing 87 percent of the total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19ET014 – Granite near the Goodrich (Shady Ridge) prospect

Equigranular, biotite granite with grain size from 1 to 4 mm in diameter cut by iron-oxide-stained quartz veinlets up to 10 mm thick at various orientations. The granite is partially altered to a sericite-bearing assemblage. Sample assay yielded 61 ppm Mo (Wypych and others, 2019). A sericite separate was analyzed, and the integrated age is 72.43 ± 0.05 Ma. The age spectrum yields a flat pattern. A weighted mean age of **72.65 ± 0.90 Ma** was calculated from all 16 heating steps and is the preferred age for this sample. The weighted mean age is interpreted to record post-crystallization alteration of the granite.

19ET064 – Orthogneiss from the Ladue River assemblage

Muscovite biotite albite potassium feldspar quartz orthogneiss. Two muscovite separates were analyzed. The first analysis resulted in an integrated age of 112.82 ± 0.08 Ma. The age spectrum is saddle-shaped with older ages in the initial and later heating steps. Due to the saddle-shaped age spectrum, the preferred age for this subsample is the weighted mean age of **117.91 ± 2.32 Ma** calculated from six heating steps representing 32 percent of the total gas release, which is interpreted to record cooling of the subsample through the closure temperature of muscovite. The second analysis resulted in an integrated age of 105.10 ± 0.05 Ma. The age spectrum is relatively flat. A weighted mean age was calculated using all 16 heating steps. The preferred age for this subsample is the weighted mean age of **105.07 ± 1.23 Ma**, which is interpreted to record cooling of the subsample through the closure temperature of muscovite.

19ET097 – Quartz schist from the Klondike assemblage

Pale green chlorite muscovite quartz schist. A muscovite separate was analyzed, and the integrated age is 130.42 ± 0.07 Ma. The age spectrum is hump shaped. Due to the hump-shaped age spectrum, the preferred age for this sample is the weighted mean age of **146.53 ± 1.49 Ma** calculated from three heating steps representing 40 percent of the total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19ET117 – Metamafic rock from the Lake George assemblage

Fine-grained garnet diopside hornblende plagioclase metamafic rock. A hornblende separate was analyzed, and the integrated age is **254.51 ± 0.86 Ma**. Due to the complex age spectrum, the preferred age for this sample is the integrated age, which is interpreted to record cooling of the sample through the closure temperature of hornblende. The complex age spectrum does not appear to be related to complex mineralogy based on the consistent K/Ca ratio for the sample.

19JEA007 – Granodiorite near the Honks prospect

Altered granodiorite. Mineralogy includes 75 percent quartz, 20 percent sericite, 5 percent pyrite, and 0.1 percent arsenopyrite. A sericite separate was analyzed, and the integrated age is 90.87 ± 0.06 Ma. The age spectrum has a flat shape. The preferred age for this sample is the weighted mean age of **91.14 ± 0.29 Ma** calculated from twelve heating steps representing 92 percent of total gas release. The weighted mean age is interpreted to record sericite alteration of the granodiorite.

19KS045 – Orthogneiss from the Jarvis belt

Porphyroclastic biotite muscovite orthogneiss. Feldspar augen up to 10 mm make up 1–10 percent of the sample. Minor chlorite replacement of biotite. A muscovite separate was analyzed, and the integrated age is 152.51 ± 0.10 Ma. The age spectrum has a complex pattern. The preferred age for this sample is the weighted mean age of **149.29 ± 2.84 Ma** calculated from four heating steps representing 40 percent of total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19KS060 – Amphibolite from the Lake George assemblage

Medium-grained foliated amphibolite. A hornblende separate was analyzed, and the integrated age is 132.84 ± 0.39 Ma. The age spectrum has a generally flat pattern. The preferred age for this sample is the weighted mean age of **126.86 ± 0.94 Ma** calculated from nine heating steps representing 85 percent of total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of hornblende.

19KS167 – Porphyroclastic orthogneiss from the Ladue River assemblage

Fine-grained, foliated tan orthogneiss with 2 mm porphyroclasts. A muscovite separate was analyzed, and the integrated age is 144.68 ± 0.09 Ma. The age spectrum is variable. The preferred age for this sample is the weighted mean age of **164.59 ± 3.82 Ma** calculated from four heating steps representing 59 percent of total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19KS299 – Orthogneiss in the Ladue River assemblage

Biotite chlorite muscovite quartz feldspar orthogneiss. A muscovite separate was analyzed, and the integrated age is 204.19 ± 0.11 Ma. The age spectrum has a climbing pattern with the oldest ages from the highest temperature heating steps. Due to the climbing age spectrum, the preferred age for this sample is the weighted mean age of **206.81 ± 1.37 Ma** calculated from 13 heating steps representing 90 percent of total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19KS332 – Orthogneiss in the Lake George assemblage

Biotite-bearing foliated muscovite orthogneiss. Muscovite is observed as mica fish and in pressure shadows around plagioclase porphyroblasts up to 3 mm. Quartz is recrystallized into fine-grained elongate ribbons. A muscovite separate was analyzed, and the integrated age is 105.30 ± 0.06 Ma. The age spectrum is flat. The preferred age for this sample is the weighted mean age of **105.50 ± 0.09 Ma** calculated from seven heating steps representing 41 percent of the total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19RN156 – Paragneiss in the Ladue River assemblage

Muscovite chlorite feldspar quartz paragneiss. A muscovite separate was analyzed, and the integrated age is 225.37 ± 0.10 Ma. The age spectrum has a climbing pattern with younger ages from lower temperature heating steps. Due to the climbing age spectrum, the preferred age for this sample is the weighted mean age of **230.83 ± 2.79 Ma** calculated from four heating steps representing 14 percent of the total gas release. The weighted mean age is interpreted to record cooling of the sample through the closure temperature of muscovite.

19RN391 – Trachyandesite

Amphibole-bearing porphyritic trachyandesite. Mineralogy includes 10 percent clinopyroxene, 3 percent hornblende, 25 percent plagioclase, and 62 percent feldspar-rich groundmass. A hornblende separate was analyzed, and the integrated age is 69.90 ± 0.13 Ma. A plateau age was calculated from nine heating steps representing 80 percent of total gas release. The preferred age for this sample is the plateau age of **69.01 ± 0.09 Ma**, which is interpreted to record crystallization of hornblende during eruption.

Mineral separate probably mislabeled as 19RN359

A muscovite separate was analyzed, and the integrated age is 218.66 ± 0.14 Ma. The age spectrum is complex. A weighted mean age of 226.82 ± 2.69 Ma was calculated from three heating steps representing 65 percent of the total gas release. The separate was labeled as 19RN359; however, this sample, an altered felsic dike, yielded a U-Pb zircon age of 70.5 ± 1.6 Ma (Wildland and others, 2021). Wildland and others (2021) note aphanitic texture, tourmaline aggregates, and disseminated pyrite in the sample description but do not note biotite. The crushed sample remnants contain partly chloritized biotite, coarse-grained quartz and feldspar, and 1 mm white mica. No sulfides or tourmaline were noted in the crushed sample. We conclude that the crushed sample was not sample 19RN359 and that it was mislabeled prior to mineral separation. After examining the other samples, we suggest it is unlikely that the sample was switched with another sample in this report. It is probable that the sample was switched with one of the five samples that did not yield acceptable mineral separates, most likely sample 19TJN128, a biotite muscovite orthogneiss from the Ladue River assemblage in the eastern Tanacross Quadrangle.

Table 1. Age results, including integrated age, plateau or weighted mean age, and interpretive details. MSWD = Mean Square Weighted Deviation.

Sample	Mineral	Integrated Age (Ma)	Plateau or Weighted Mean Age (Ma)	Preferred Age Information
19ADW124	Muscovite	218.06 ± 0.16	**224.09 ± 0.63***	7 out of 16 fractions; 23.2 percent ^{39}Ar release; MSWD = 9.9
19ADW278	Muscovite	**109.69 ± 0.06**		No plateau calculated
19ADW325	Muscovite	181.13 ± 0.10	**185.60 ± 0.10***	2 out of 15 fractions; 48.5 percent ^{39}Ar release; MSWD = 0.2
19AW014	Muscovite	100.37 ± 0.06	**100.06 ± 0.34***	9 out of 14 fractions; 61.5 percent ^{39}Ar release; MSWD = 47
19AW137	Muscovite	234.02 ± 0.12	**234.80 ± 1.24***	13 out of 16 fractions; 93.6 percent ^{39}Ar release; MSWD = 584
19AW144	Muscovite	230.06 ± 0.15	**231.77 ± 0.86***	5 out of 13 fractions; 86.6 percent ^{39}Ar release; MSWD = 183
19ET014	Sericite	72.43 ± 0.05	**72.65 ± 0.90***	16 out of 16 fractions; 100 percent ^{39}Ar release; MSWD = 628
19ET064	Muscovite	112.82 ± 0.08	**117.91 ± 2.32***	6 out of 12 fractions; 32.3 percent ^{39}Ar release; MSWD = 1283
19ET064	Muscovite	105.10 ± 0.05	**105.07 ± 1.23***	16 out of 16 fractions; 100 percent ^{39}Ar release; MSWD = 5753
19ET097	Muscovite	130.42 ± 0.07	**146.53 ± 1.48***	3 out of 14 fractions; 39.8 percent ^{39}Ar release; MSWD = 2325

Sample	Mineral	Integrated Age (Ma)	Plateau or Weighted Mean Age (Ma)	Preferred Age Information
19ET117	Hornblende	**254.51 ± 0.86**		No plateau calculated
19JEA007	Sericite	90.87 ± 0.06	**91.14 ± 0.29***	12 out of 16 fractions; 91.7 percent ^{39}Ar release; MSWD = 48
19KS045	Muscovite	152.51 ± 0.10	**149.29 ± 2.84***	4 out of 16 fractions; 40.1 percent ^{39}Ar release; MSWD = 1293
19KS060	Muscovite	132.84 ± 0.39	**126.86 ± 0.94***	9 out of 13 fractions; 84.5 percent ^{39}Ar release; MSWD = 9.5
19KS167	Muscovite	144.68 ± 0.09	**164.59 ± 3.82***	4 out of 16 fractions; 59.0 percent ^{39}Ar release; MSWD = 5814
19KS299	Muscovite	204.19 ± 0.11	**206.81 ± 1.37***	13 out of 16 fractions; 89.7 percent ^{39}Ar release; MSWD = 947
19KS332	Muscovite	105.30 ± 0.06	**105.50 ± 0.09***	7 out of 15 fractions; 41.1 percent ^{39}Ar release; MSWD = 1.7
19RN156	Muscovite	225.37 ± 0.10	**230.83 ± 2.79***	4 out of 16 fractions; 14.0 percent ^{39}Ar release; MSWD = 145
19RN391	Hornblende	69.90 ± 0.13	**69.01 ± 0.09**	9 out of 14 fractions; 79.6 percent ^{39}Ar release; MSWD = 1.3
19RN359	Sample probably mislabeled. See text for explanation.			

Samples analyzed with standard FC-2 with an age of 28.201 Ma.
*Did not meet all the criteria for a plateau age, hence a weighted mean age determination is presented.
All errors reported are 2σ. Preferred age in **bold**.

ACKNOWLEDGMENTS

Sample collection and analyses for the Eastern Tanacross project was jointly funded by the State of Alaska and the U.S. Geological Survey's Earth Mapping Resources Initiative (EarthMRI) through cooperative agreement G19AC00262. We are grateful to have had access to Doyon Limited lands within the study area. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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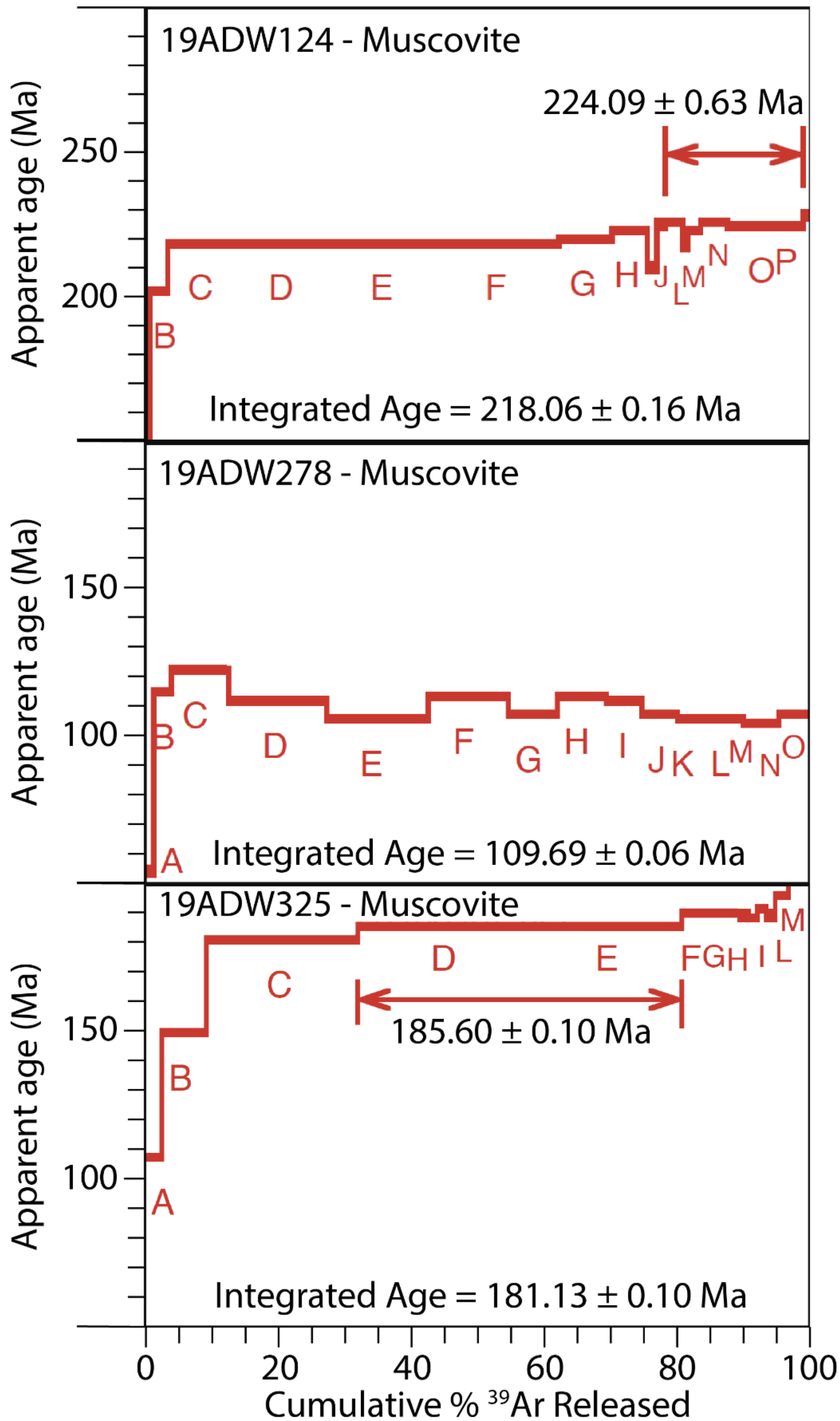
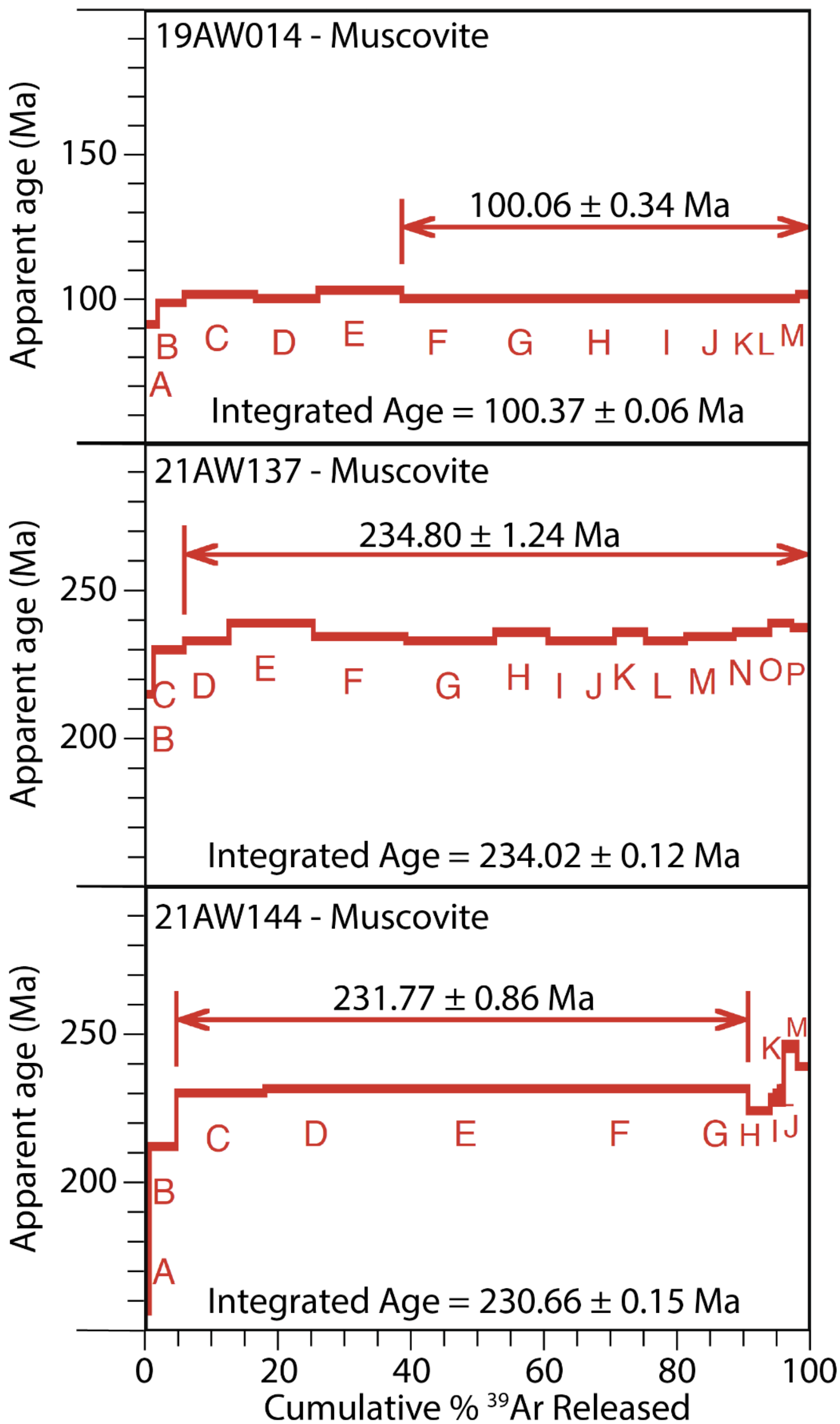
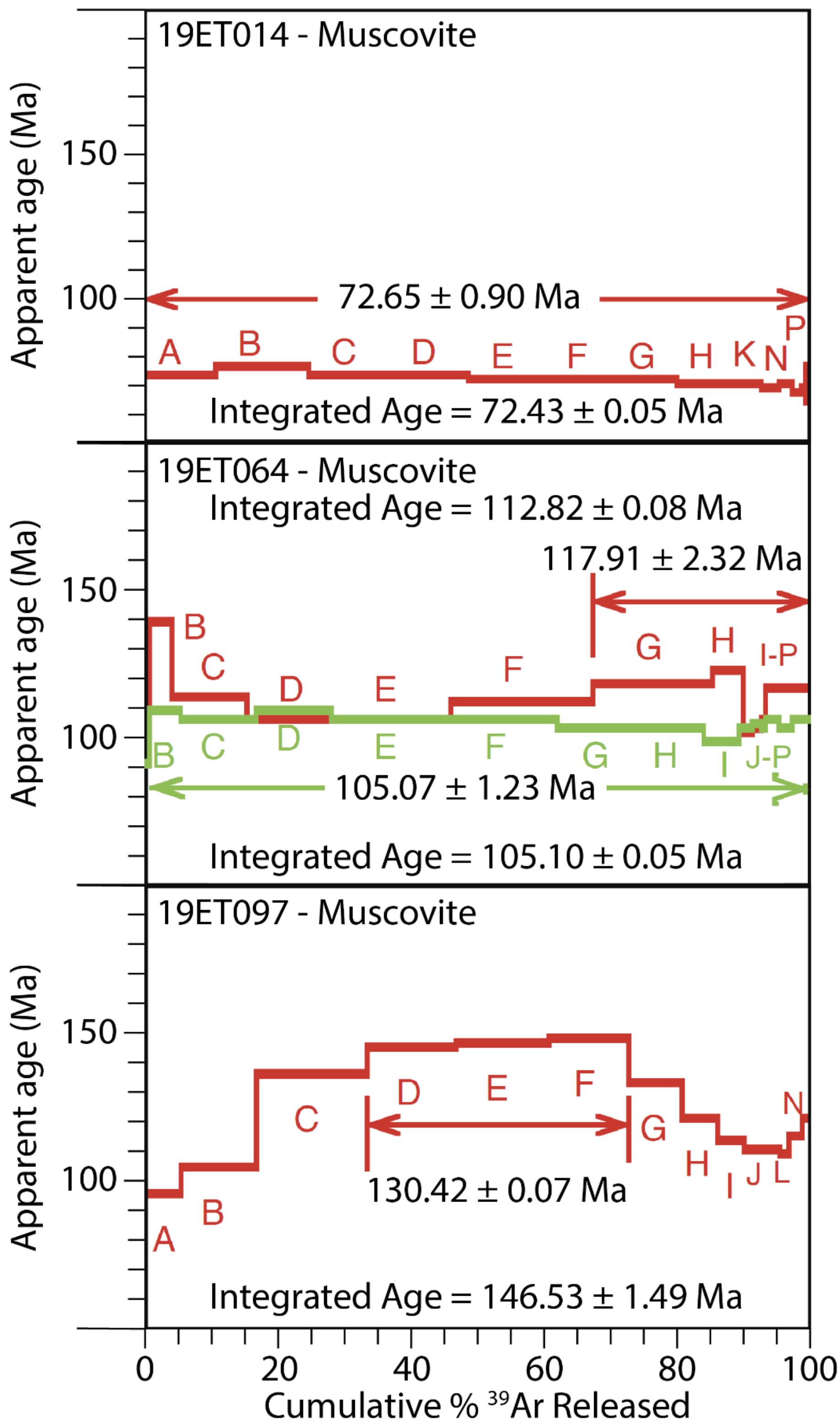
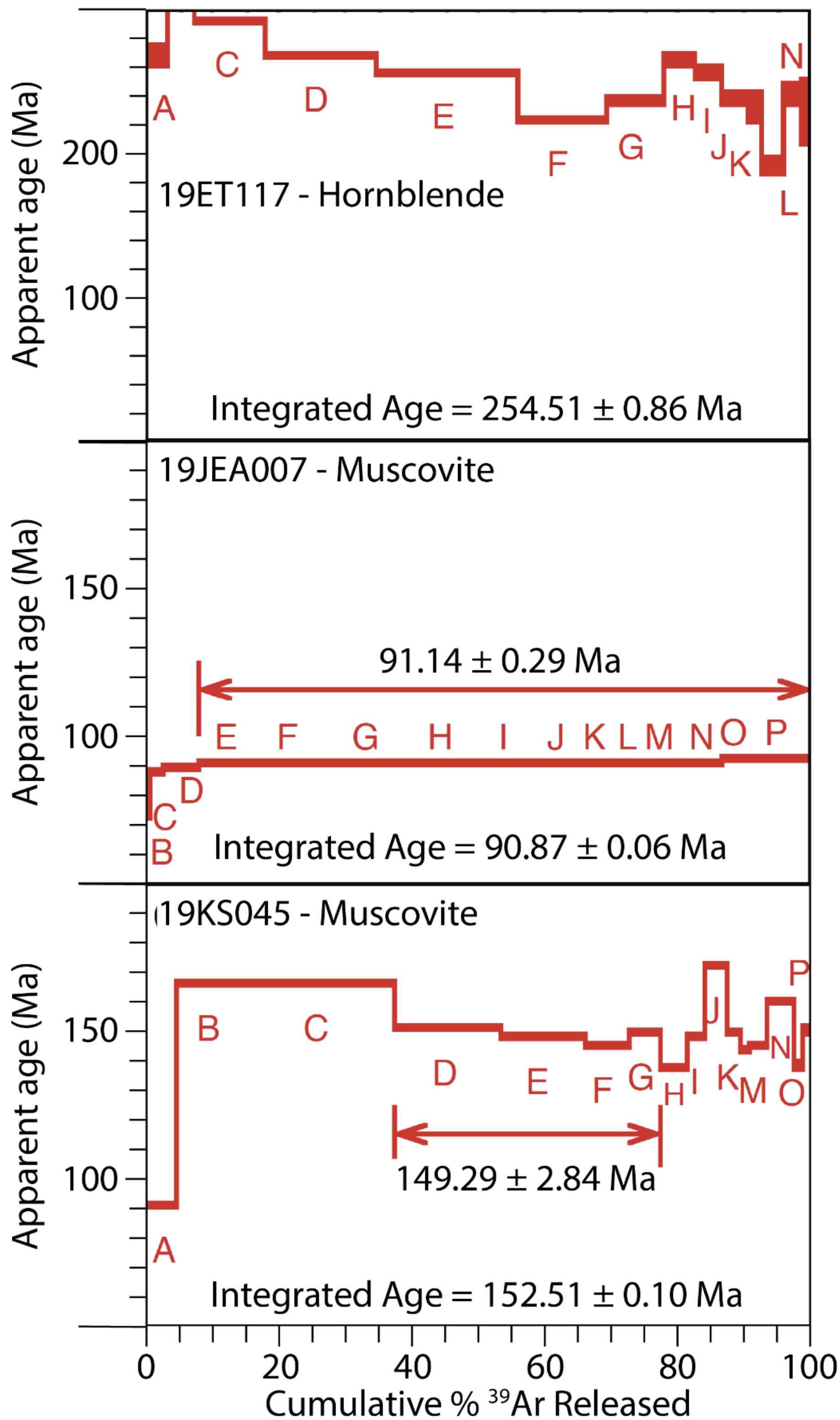
APPENDIX: PLOTS OF ^{40}AR/^{39}AR AGE SPECTRA

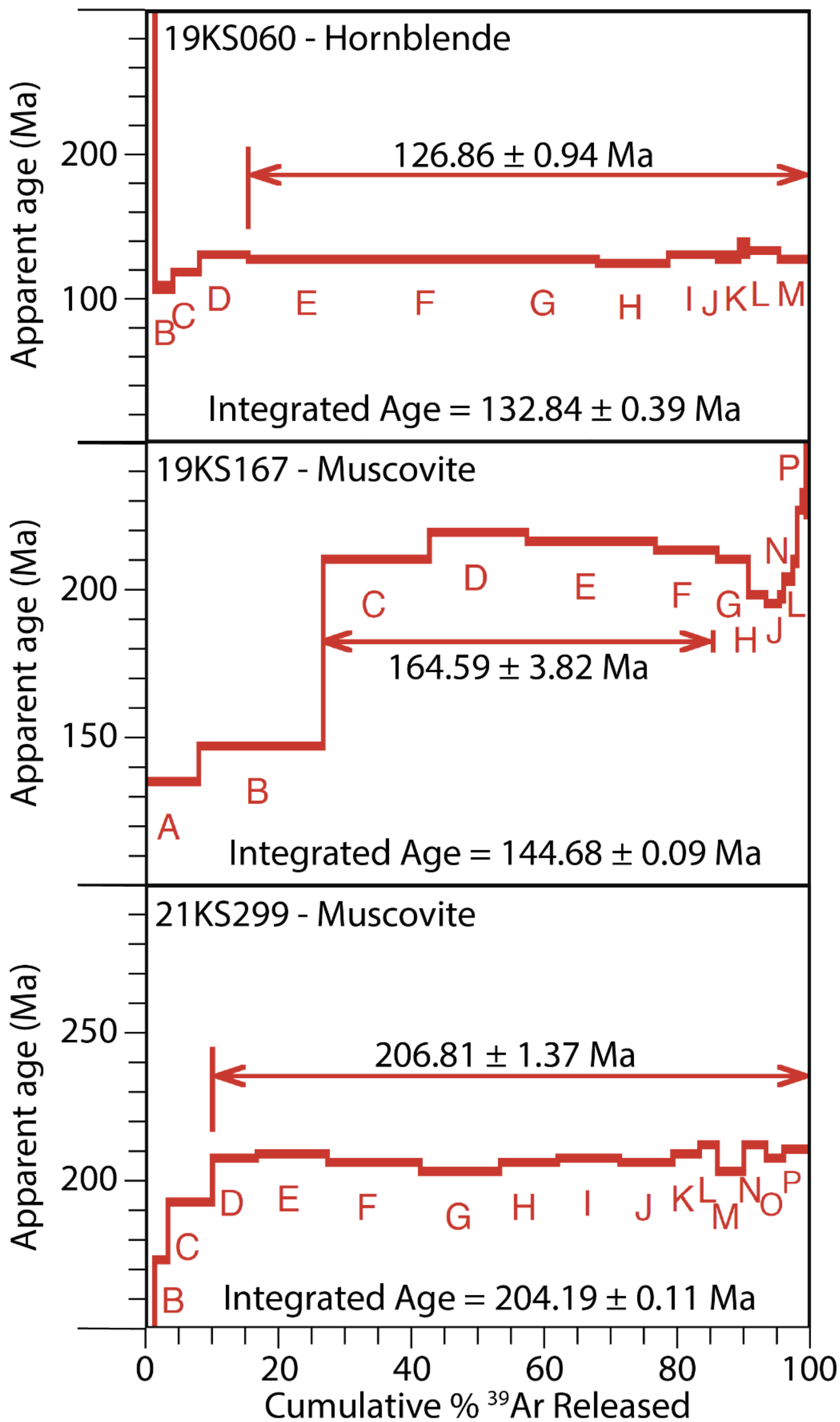


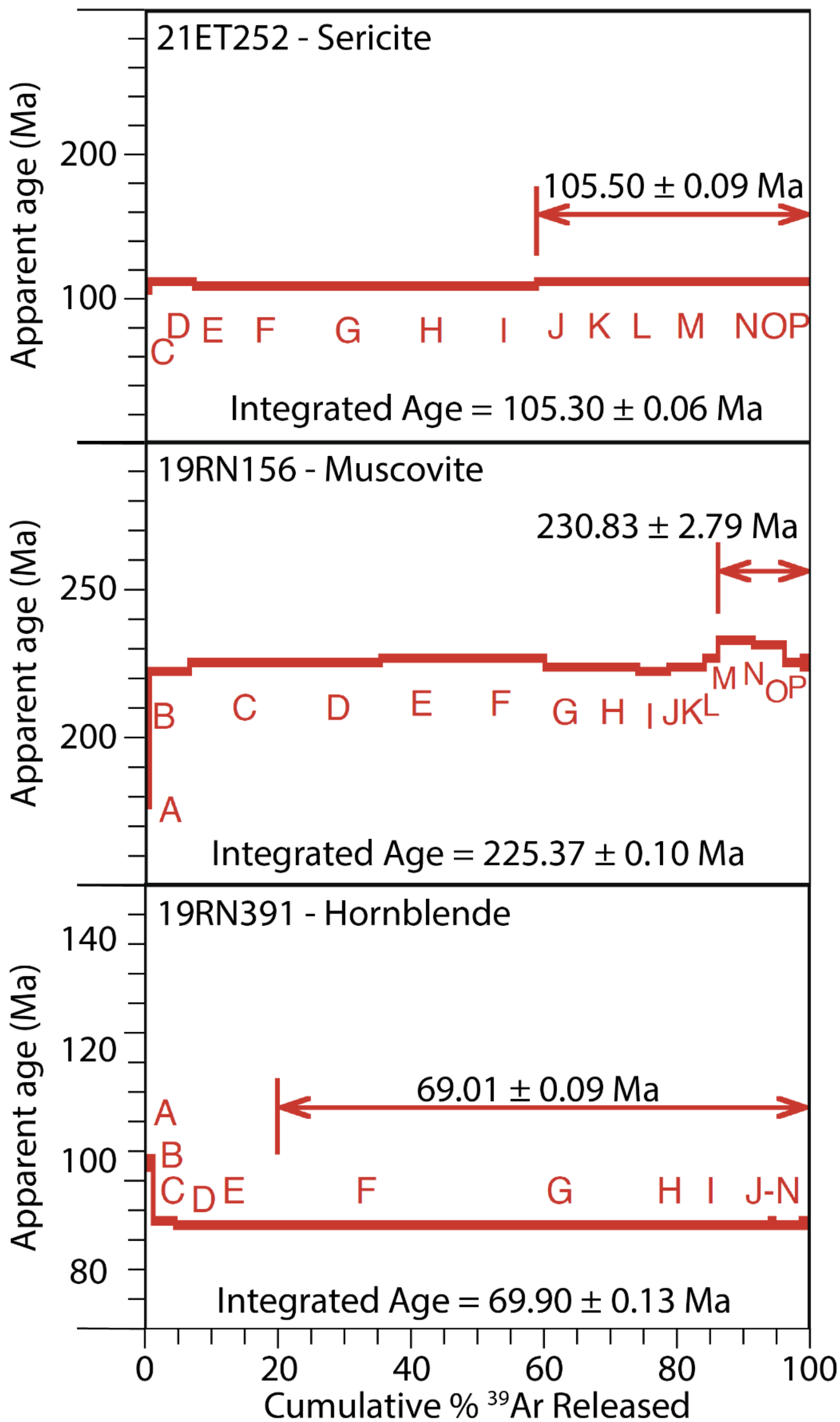

19AW014 - Muscovite
Apparent age (Ma)
150
100
100.06 ± 0.34 Ma
A B C D E F G H I J K L M
Integrated Age = 100.37 ± 0.06 Ma
21AW137 - Muscovite
Apparent age (Ma)
250
200
234.80 ± 1.24 Ma
B C D E F G H I J K L M N O P
Integrated Age = 234.02 ± 0.12 Ma
21AW144 - Muscovite
Apparent age (Ma)
250
200
231.77 ± 0.86 Ma
A B C D E F G H I J K L M
Integrated Age = 230.66 ± 0.15 Ma
0
20
40
60
80
100
Cumulative % ³⁹Ar Released


19ET014 - Muscovite
72.65 ± 0.90 Ma
A B C D E F G H K N P
Integrated Age = 72.43 ± 0.05 Ma
19ET064 - Muscovite
Integrated Age = 112.82 ± 0.08 Ma
117.91 ± 2.32 Ma
B C D E F G H I-P
B C D E F G H I J-P
105.07 ± 1.23 Ma
Integrated Age = 105.10 ± 0.05 Ma
19ET097 - Muscovite
A B C D E F G H I J L N
130.42 ± 0.07 Ma
Integrated Age = 146.53 ± 1.49 Ma
Apparent age (Ma)
150
100
0 20 40 60 80 100
Cumulative % 39Ar Released



Apparent age (Ma)
200
100
A
C
D
E
F
G
H
I
J
K
L
N
19ET117 - Hornblende
Integrated Age = 254.51 ± 0.86 Ma
19JEA007 - Muscovite
150
100
91.14 ± 0.29 Ma
E F G H I J K L M N O P
B C D
Integrated Age = 90.87 ± 0.06 Ma
19KS045 - Muscovite
150
100
A B C D E F G H I J K M N O P
149.29 ± 2.84 Ma
Integrated Age = 152.51 ± 0.10 Ma
0 20 40 60 80 100
Cumulative % 39Ar Released


19KS060 - Hornblende
126.86 ± 0.94 Ma
Integrated Age = 132.84 ± 0.39 Ma
B C D E F G H I J K L M
19KS167 - Muscovite
164.59 ± 3.82 Ma
Integrated Age = 144.68 ± 0.09 Ma
A B C D E F G H J L N P
21KS299 - Muscovite
206.81 ± 1.37 Ma
Integrated Age = 204.19 ± 0.11 Ma
B C D E F G H I J K L M N O P
Apparent age (Ma)
100
200
150
250
0
20
40
60
80
100
Cumulative % 39Ar Released


21ET252 - Sericite
105.50 ± 0.09 Ma
Integrated Age = 105.30 ± 0.06 Ma
C D E F G H I J K L M NOP
19RN156 - Muscovite
230.83 ± 2.79 Ma
Integrated Age = 225.37 ± 0.10 Ma
A B C D E F G H I JKL M N OP
19RN391 - Hornblende
69.01 ± 0.09 Ma
Integrated Age = 69.90 ± 0.13 Ma
A B C D E F G H I J-N
Apparent age (Ma)
200
100
250
200
140
120
100
80
0 20 40 60 80 100
Cumulative % 39Ar Released