Lithostratigraphy, age and distribution of Eocene volcanic sequences on eastern King George Island, South Shetland Islands, Antarctica

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Supplementary Information file S2 - $^{40}Ar/^{39}Ar$ dating – materials, methods & data

Thin section descriptions for dated samples

Point Hennequin

Sample P.2807.6b is a crystalline andesite lava containing c. 30 % phenocrysts of plagioclase (90 %), clinopyroxene (5 %), hypersthene (< 5 %) and opaque oxide (< 1 %). Some plagioclase contains numerous inclusions. Some groundmass alteration present.

Sample P.2809.4 is an andesite lava. It contains c. 25 % phenocrysts of plagioclase (80 %), clinopyroxene and hypersthene (5 %) and opaque oxide (2 %). In the groundmass pyroxene and some plagioclase are altered, including thin carbonate rims to pyroxene crystals.

Sample P.2811.12 is a siliceous andesite lava with 15-20 % phenocrysts of fresh plagioclase (< 95 %), clinopyroxene (< 40 %), opaque oxide (< 5 %) and hypersthene (< 1 %). Some plagioclase contains inclusions. The fine groundmass contains a high proportion of glass (< 40 %).

Sample P.2811.21 is a basaltic andesite lava containing 50 % phenocrysts of plagioclase (85 %), clinopyroxene (20 %), and opaque oxide (< 1 %). C. 5 % of the clinopyroxene phenocrysts are altered. Inclusions are common in plagioclase. The matrix is very fine grained.

Sample P.2814.4b is a basaltic andesite lava from Warkocz. It is composed of 50 % phenocrysts of plagioclase (90 %), clinopyroxene (5 %), opaque oxide (< 5 %) and hypersthene (< 1 %). Plagioclase is very fresh with very few inclusions.

Vauréal Peak

Samples P. 2789.1 and P. 2792.4 are basaltic lavas of the Cape Vaureal Formation and comprise 35 % phenocrysts (< 95 % plagioclase, < 10 % clinopyroxene), 65 % matrix (< 60 % plagioclase, < 10 % cpx, < 2% opaque oxides, remaining matrix consists of extremely fine grained plagioclase). The plagioclase composition is An49.

Sample P. 2792.4 shows some groundmass alteration in thin section but the plagioclase has good crystal shapes and is generally free from inclusions. P. 2789.1 has a fresher groundmass but < 70 % inclusions of clinopyroxene and altered clinopyroxene in some plagioclase.

Sample P. 2799.1a and P.2799.12, from the Vauréal Peak lava sequence, are also a basalt lavas, comprising c. 40 % phenocrysts (< 98 % plagioclase, < 2 % opaque oxides) and 60 % groundmass (< 75 % plagioclase, < 15 % altered clinopyroxene, < 10 % of opaque oxides). The plagioclase composition is An55 and the crystals are generally fresh, although rarely crystals contain < 20 % inclusions.

$^{40}Ar/^{39}Ar$ analytical methods

The argon isotopic results are listed in Tables S2-1 and S2-2. Age spectra and inverse isochron plots are shown in Figures S2-1, S2-2. A summary of the $^{40}Ar/^{39}Ar$ ages yielded in this study is provided in Table 3 (main paper).

Leeds University:

The samples were crushed and sieved for the 250-500 μm fraction, avoiding veining and weathered surfaces. The fractions were passed through a Frantz magnetic separator to concentrate plagioclase feldspar, washed in 1M HNO_3 for 10 minutes to remove carbonates, decanted then washed in 40% HF for a further 10 minutes to remove fines, rinsed in deionised water and then dried. The samples, weighing approximately 60 mg, were then hand-picked to remove visibly altered grains and grains with inclusions. The $^{40}Ar/^{39}Ar$ analysis was carried out at the School of Earth Sciences, University of Leeds and followed the method described by Rex et al. (1993) with the following variations: Samples P. 2789.1 and P. 2792.4 were irradiated at the Riso Reactor, Roskilde Laboratory, Denmark, interference correction factors were (40/39)K = 0.048, (36/39)Ca = 0.38 and (37/39)Ca = 1492. P. 2799.1 was irradiated at the McMasters Reactor, Ontario, Canada, interference correction factors were (36/39)Ca = 0.32, (37/39)Ca = 1515 and (40/39)K = 0.02. The University of Leeds internal standard is Tinto biotite (Rex and Guise, 1995) with assigned age of 409.2 Ma and biotite LP-6 (128.9 ± 1.4 Ma; Ingamells and Engels, 1976). Isotopic analyses were performed with a modified MS10 mass spectrometer, measured atmospheric $^{40}Ar/^{36}Ar$ was 287.8 ± 0.2 and sensitivity 1.12 x 10^{-7} cm^3V^{-1}. Gas volumes are corrected to STP.

The $^{40}Ar/^{39}Ar$ ratio, age and errors for each gas fraction were calculated using formulae similar to those given by Dalrymple and Lanphere (1971). Errors in these ratios were evaluated by numerical differentiation of the equation used to determine the isotope ratios and quadratically propagating the errors in the measured ratios. J-value

uncertainty is included in the errors quoted on the total gas ages but the individual step ages have analytical errors only. All errors are quoted at the 2σ level unless otherwise stated. Ages calculated using the constants recommended by Steiger and Jäger (1977). Data for isotope correlation plots were reduced using the Isoplot/Ex program of Ludwig (1999). IsoPlot/Ex uses three separate models to regress the $^{40}Ar/^{39}Ar$ versus $^{36}Ar/^{40}Ar$ data on the isotope correlation plot. If the probability of fit of the initial regression is low, Isoplot attempts to use either a second or third model fit which weight the data-points using different criteria.

Potassium concentrations were measured using a Ciba-Corning 480 flame photometer incorporating a lithium internal standard. International and laboratory standards were analysed on a routine basis.

Argon was extracted in a glass vacuum line using a ^{38}Ar tracer from an aliquoting system. Special attention was given to the purity of the gas sample before it was analysed. A two-stage clean-up procedure was used, stage one incorporating a Ti sponge furnace and liquid nitrogen trap. The gas was then transferred to a second stage Ti/Zr sponge furnace by absorption on activated charcoal at liquid nitrogen temperature. Argon isotopes were measured on a modified AEI MS 10 mass spectrometer fitted with computer controlled peak switching. Ion beams were detected by a VG pre-amplifier with 10^{11} ohm resistor, digitized with a Solartron 7060 voltmeter and stored on computer disc for subsequent processing. International standards were analysed and atmospheric argon ratios determined on a regular basis. Ages were calculated using the decay constants and branching ratio agreed by the USGS Subcommission on Geochronology (Steiger and Jäger 1977).

New Mexico Geochronology Research Laboratory:

Two samples (P.2799.1 and P.2799.12) were analysed by the furnace incremental heating age spectrum method.

Preparation: Sieved groundmass samples were packaged and irradiated in machined Al discs for 7 hours in D-3 position, Nuclear Science Center, College Station, Texas. Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 28.201 Ma (Kuiper et al., 2008).

Instrumentation: Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system. Groundmass samples step-heated in Mo double-vacuum resistance furnace. Reactive gases from the groundmass concentrates were removed during a 15 minute reaction with 3 SAES GP-50 getters, 2 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filament operated at c. 2000°C and a cold finger operated at -140°C.

Analytical parameters: Electron multiplier sensitivity averaged $1x10^{-16}$ moles/pA. Total system blank and background for the incrementally heated samples averaged 1200, 5.2, 3.6, 2.2, 4.3 x 10^{-18} moles for the isotopes ^{40}Ar, ^{39}Ar, ^{38}Ar, ^{37}Ar and ^{36}Ar, respectively. J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from

each of 4 radial positions around the irradiation tray. Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:

Texas: $(^{40}Ar/^{39}Ar)_K$ = 0.0002±0.0003; $(^{36}Ar/^{37}Ar)_{Ca}$ = 0.00028±0.000011; and $(^{39}Ar/^{37}Ar)_{Ca}$ = 0.00089±0.00003.

Age calculations: Total gas ages and errors calculated by weighting individual steps by the fraction of ^{39}Ar released. Weighted-mean ages were calculated using data from all heating steps from each of the groundmass concentrate samples by weighting by the inverse of the variance (Taylor, 1982), with weighted mean errors multiplied by the square root of the MSWD where MSWD exceeded cutoff values recommended by Mahon (1996). MSWD values were calculated for n-1 degrees of freedom for plateau and preferred ages. Isochron ages, $^{40}Ar/^{36}Ar_i$ and MSWD values calculated from regression results obtained by the methods of York (1969). Decay constants and isotopic abundances are after Steiger and Jäger (1977). All errors reported at ±2σ unless otherwise noted.

$^{40}Ar/^{39}Ar$ results

Point Hennequin

P.2807.6b produced a slightly curved age spectrum, with lower aged steps at both low and high temperatures (Figure S2-1a). The variation correlates with the minor variations in the Ca/K ratio at low and high temperatures. The plateau age based on 100 % of the ^{39}Ar is 42 ± 2.4 Ma, and agrees with the isotope correlation plot age of 42.5 ± 5.2 Ma (Figure S2-1b). A weighted average age (at 2σ) of 44.0 ± 11 Ma, based on 62.3 % of the gas released, is obtained from the low-error, high gas-volume central steps on the age spectrum, which is more consistent with other age data from the same sequence.

P.2811.21 yielded a plateau age of 49.6 ± 4.8 Ma, based on 6 disturbed steps constituting 70.9 % of the ^{39}Ar released (Fig. S2-1c). The plateau age is comparable with the total gas age of 52.2 ± 5.6 Ma and the Model 1 isotope correlation age 48.1 ± 11.4 Ma (MSWD = 1.2) (Fig. S2-1d). Decreasing Ca/K ratios at higher temperatures are correlated with two old high-temperature steps (steps 8 and 9) suggesting incorporation of older excess Ar. However, the contemporaneous sample P.2809.4, the likely down-section equivalent of P.2811.21, yielded isotope correlation age and plateau ages which are both within error of P.2811.21 suggesting that the ages are geologically robust.

P.2809.4 gave a plateau age of 50.2 ± 2.8 Ma, with some disturbance in the low temperature steps that correlated with the Ca/K ratios, indicating minor alteration (Fig. S2-1e). The isotope correlation age of 49.1 ± 5.6 Ma (MSWD = 0.82) is well-constrained and within error of the plateau age (Fig. S2-1f). By discarding the initial three high error steps, a weighted average age is possible and reduces the age to 49.8 ± 5.7 Ma, based on 87.1 % of the ^{39}Ar released (at the 2σ interval).

P.2811.12 was potentially a most important sample from Point Hennequin, since it overlies the Mount Wawel plant beds, thereby constraining the minimum age of the

Mount Wawel flora. Two plagioclase size fractions from the sample yielded plateau ages of 39.1 ± 2.2 Ma and 39.9 ± 1.9 (Figs S2-1g,i), which have good isotope correlations (Figs S2-1h,j). However, a classic argon-loss profile is obtained from whole rock analysis of the sample, dated at 34.39 ± 0.68 Ma (Fig. S2-1k). High loss on ignition values from XRF analyses (Table 3) and low Ca/K ratios indicate that argon loss has occurred and that the plateau age is too young. This interpretation is supported by the isotope correlation age, which indicates a much older (c. 38 Ma) age, though imprecise (Fig. S2-1l). In addition, sample P.2811.12 has a high proportion of glass in the matrix (see above), which is a common source of argon loss during post-extrusion devitrification (McDougall and Harrison, 1999). Argon loss resulting from devitrification is therefore suggested as the cause of the variation in ages obtained by whole rock analyses, which incorporate glass, and by plagioclase separate analyses that do not.

Although the $^{40}Ar/^{39}Ar$ age spectra derived from P.2811.12 look well constrained by the isotope correlation plots, the high temperature steps may define a separate plateau (Figs S2-1h,j), possibly suggesting further argon loss. The weighted average ages (at 2σ) of the last four steps (31.4 % of ^{39}Ar) are 46 ± 11 Ma (P. 2811.12, 30-60 micron sieved sample) and 47 ± 9 Ma (P.2811.12, 60- 90 micron sieved sample; Table 3). These ages are more consistent with ages obtained from elsewhere in the formation, excepting P.2807.6b (and Dupre, 1982; Nawrocki et al., 2011) and support the field relations, which show no evidence for a major hiatus or prominent palaeosols within the sequence at Point Hennequin. The weighted average age (46-47 Ma, with high errors) is therefore adopted as closest to the age of crystallisation since argon loss affecting the plateau age has been observed in the sample and since the weighted average age is more consistent with the geology of the area.

Sample **P.2814.4b** yielded a 'noisy' spectrum, with little correlation to the Ca/K ratios (Figs S2-1m,n). Some of the age scatter relates to the large relative errors resulting from the release of very small gas volumes (e.g. steps 2 and 7). The plateau age of 46.40 ± 1.66 Ma comprises 69.3 % of the ^{39}Ar (Fig. S2-1m). Despite the high error, the total gas age of 49.4 ± 8.4 Ma is more comparable with other samples with better plateau ages. Although the latter is probably closer to the true age of the Smok Hill sequence, basal relationships with the Mount Wawel Formation (conformable or unconformable) are unexposed and a younger age (i.e. c. 46 Ma) remains possible.

Vauréal Peak

All of the samples from Vauréal Peak produced noisy release patterns (Figs S2-1o-r). Sample **P. 2789.1** has a disturbed spectra which correlates with variations in the Ca/K ratios and indicates that some minor alteration was present in the plagioclase grains (Fig. S2-1o, Table S1). The plateau age for the sample was 55.4 ± 7.6 Ma, based on 100% of the ^{39}Ar released. This is within error of the isotope correlation age of 54.6 ± 15.4 Ma, although the gradient of this plot is poorly constrained due to scatter in the age data and the large error bars resulting from low gas release volumes (Fig. S2-1p). The slight saddle in the age spectrum, particularly at higher temperatures may indicate the incorporation of excess argon in the sample (Fig. S2-1o; Table S2-1).

Sample **P.2792.4** yielded better plateau and isotope correlation ages of 49 ± 2 Ma and 48.6 ± 8.2 Ma, respectively (Figs S2-1q,r, Table S2-1). Disturbance in the low temperature step ages correlates with noise in both Ca/K and Cl/K plots and indicates that some minor alteration was present in the plagioclase grains (Fig. S2-1q). We consider that the flatter spectrum and better correlation in the isotope plot of sample P.2792.4, in addition to the freshness of plagioclase in thin section, indicates that this age is most reliable. We therefore accept an age of 49 ± 2 Ma for the Cape Vauréal Formation.

For sample **P.2799.1A**, the age spectrum is somewhat undulatory, with ages ranging from as young as 43.6 Ma to as old as 59.1 Ma (excluding the earliest, non-radiogenic heating steps). The one-sigma uncertainties on the individual heating steps are high, ranging from 3% to 28%. A weighted mean value for the flattest portion of the age spectrum yields an apparent age of 51.5 ± 3.6 Ma with a MSWD of 4.7 (Fig. S2-2a). Radiogenic yields for this sample gradually increase with increasing temperature from a minimum of zero to 25%. The K/Ca ratios for this sample are very low, never rising above 0.1. Results for the groundmass concentrate from sample P.2799.1A show the effects of alteration and ^{39}ArK recoil. The age spectrum is less precise than what would normally be expected for a basalt sample of this age. The age variability for the individual heating steps, combined with the low radiogenic yields (a factor contributing to the imprecision) suggests that alteration and/or hydration products may be influencing the argon isotopic results for P.2799.1A. Indeed, inspection of the whole-rock sample under a binocular microscope shows a significant quantity of glassy groundmass as well as a green, clay-like phase. During the groundmass concentration, most of the green contaminant was removed. However, it was not possible to remove the glassy groundmass from the P.2799.1A separate. It is this glassy phase that is the likely source of the alteration/hydration products. The combination of alteration/hydration products with the low potassium content of the basalt is responsible for the low precision ages. Despite the imprecision of this age determination, it is our interpretation that the weighted mean or plateau age of 51.5 ± 3.6 Ma represents an accurate estimate of the eruption age of this sample.

For **P.2799.12**, the groundmass concentrate yields individual heating steps with more precise ages than P.2799.1A. However, the P.2799.12 age spectrum does exhibit decreasing apparent ages with increasing temperature. The initial temperature steps (excluding the earliest, non-radiogenic heating steps) yield ages older than 65 Ma while the final, highest temperature heating step yields an age of 41 Ma. A weighted mean age for the flattest portion of the spectrum (steps E through H) yields an apparent age of 53.1 ± 1.6 Ma (two sigma) with a high MSWD of 14.3 (Fig. S2-2b). The radiogenic yields for P.2799.12 are considerably higher than those yielded by P.2799.1A, ranging from 0 to 85.5%. Excluding the final heating step, the radiogenic yields are generally inversely correlated to age (i.e. high radiogenic yields correspond to the youngest age). The K/Ca ratios for P.2799.12 are slightly higher than those observed for P.2799.1A, but also fail to increase above 0.1. The age spectrum for the sample is probably influenced more by ^{39}ArK recoil than by alteration, in contrast to sample P.2799.1A. The case

against significant alteration products (compared to the previous sample) is the higher radiogenic yields and more precise ages of individual steps. The ^{39}ArK recoil is manifested in the P.2799.12 age spectrum as the old initial ages, slightly decreasing ages in the intermediate temperature steps (E through H), and the young age for the final step. Age spectra displaying similar shapes were observed by Foland et al (1993) for samples from the Kirkpatrick Basalt, Antarctica. The explanation for the shape of the P.2799.12 age spectrum is the recoil of ^{39}ArK out of a relatively high potassium, low temperature phase (e.g. glass) and into a low potassium, high temperature phase (e.g. pyroxene). The loss of ^{39}ArK from the high potassium phase increases the apparent age because the daughter/parent isotope ratio is increased. Inversely, the ^{39}ArK being implanted into the low potassium phase lowers the apparent age because the daughter/parent ratio is decreased. Based on the appearance of the P.2799.12 age spectrum, it is likely that the intermediate heating steps (E through H) are not significantly affected by ^{39}ArK recoil. The plateau age of 53.1 ± 1.6 Ma is inferred to be the most accurate assessment of the eruption age of the P.2799.12 basalt.

Inverse isochron analyses were conducted on groundmass concentrates for both P.2799 samples (Figures S2-2a,b). Isochron ages for the groundmass samples are concordant with the plateau ages and yield trapped initial ^{40}Ar/^{36}Ar compositions within error of the atmospheric value (295.5). The possibility that samples P.2799.1A and P.2799.12 contain excess ^{40}Ar that is increasing their apparent ages cannot be entirely ruled out. However, the isochrons for both samples, although not well defined, do not suggest that significant excess ^{40}Ar is present. Although the age spectra of these two samples are somewhat disturbed, we consider it unlikely that their actual eruption ages are significantly less than 50 Ma.

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Table S2-1. Summary of new $^{40}Ar/^{39}Ar$ step heating data for samples analysed by Leeds University. Batch 1 (B1): J-Value = 0.00514 ± 0.5 %. Batch 2(B2): J-Value = 0.0112 ± 0.5 %. Errors quoted are 1σ. *^{40}Ar = volume of radiogenic ^{40}Ar, gas volumes corrected to STP. PH = Point Hennequin, VP = Vauréal Peak. WR = whole rock age; plagioclase = plagioclase separate age.

Sample	Locality	Run No	Weight	Weight %K	*40Ar cm^3g^{-1}	Temp °C	$^{39}Ar_K$	$^{37}Ar_{Ca}$	$^{38}Ar_{Cl}$	Ca / K	$^{40}Ar / ^{39}Ar_K$	%Atm ^{40}Ar	Age Ma	Error Ma	$\%^{39}Ar_K$	Total gas age Ma
							{Vol. $x10^{-9}$ cm^3}									
P2789.1	VP	2496	0.07935g	0.06	1.2×10^{-7}	660	0.33	23.3	0.57	140	2.287	99.6	25.0	33.5	18.8	50.9 ± 7.3Ma
Plagioclase						749	0.30	35.2	0.02	232	6.120	85.8	59.8	7.1	17.2	
B1						797	0.18	14.5	0.00	163	6.505	57.9	63.2	14.9	10.1	
						880	0.35	29.7	0.01	168	4.547	64.7	45.6	6.9	20.1	
						950	0.17	11.9	0.01	144	6.146	75.4	60.0	8.1	9.4	
						1000	0.09	5.4	0.01	124	4.681	87.0	46.8	24.4	5.0	
						1060	0.09	4.2	0.01	99	6.238	80.3	60.8	18.9	4.9	
						1150	0.14	8.2	0.02	120	6.220	82.4	60.7	26.1	7.7	
						1240	0.12	7.8	0.02	128	7.167	85.3	69.1	21.3	6.9	
P2792.4	VP	2495	0.06861g	0.29	5.9×10^{-7}	540	0.13	0.9	0.40	14.1	2.266	99.8	24.9	109.4	1.8	50.7 ± 2.3Ma
Plagioclase						650	0.16	1.4	0.01	17.2	3.466	91.4	35.8	21.1	2.2	
B1						750	0.16	1.7	0.00	21.1	8.752	95.0	83.2	21.9	2.2	
						855	0.46	4.5	0.01	19.8	5.241	57.5	51.9	9.6	6.3	
						950	1.38	13.7	0.02	19.7	4.991	30.5	49.6	2.2	19.0	
						1025	1.09	10.9	0.02	19.8	5.229	36.8	51.7	1.9	14.9	
						1070	0.85	8.5	0.01	19.9	4.468	40.3	44.9	2.3	11.7	
						1127	0.83	8.2	0.01	19.8	4.726	43.6	47.2	3.1	11.3	
						1190	1.20	12.0	0.02	19.9	4.715	57.7	47.1	2.4	16.4	
						1290	1.03	10.9	0.02	20.9	6.695	60.6	64.9	3.6	14.2	
P2809.4	PH	2498	0.06973g	0.24	4.7 x 10-7	660	0.35	4.9	0.64	28.0	2.572	99.7	27.6	50.7	5.8	49.4 ± 3.3Ma
Plagioclase						710	0.21	3.5	0.01	33.9	6.785	94.3	65.7	13.0	3.4	
B1						780	0.22	3.8	0.00	34.3	6.440	55.3	62.6	10.9	3.7	
						848	0.44	6.9	0.01	31.3	5.161	44.1	51.1	7.0	7.3	
						910	1.28	20.3	0.02	31.6	4.886	8.8	48.6	3.5	21.3	
						958	0.85	14.5	0.01	34.1	4.496	32.3	45.1	3.6	14.1	
						1020	0.51	8.6	0.01	33.7	5.064	20.3	50.3	4.4	8.5	
						1100	0.84	14.7	0.01	35.0	5.072	20.8	50.3	2.5	13.9	
						1217	0.79	14.2	0.02	35.7	5.519	51.3	54.4	3.7	13.2	
						1300	0.54	9.5	0.01	35.2	4.963	74.5	49.3	6.5	8.9	

P. 2807.6b	PH	2528	0.07419	0.22	3.6×10^{-7}	690	0.8	8.4	-	21.6	99.2	99.2	29.9	12.8	5.9	40.8 ± 1.6 Ma
B2						795	0.9	12.8	-	27.0	92.3	92.3	38.1	8.9	7.3	
						856	1.6	23.2	-	29.5	70.4	70.4	38.3	5.5	12.0	
						914	2.2	34.3	-	30.5	53.2	53.2	42.5	2.9	17.2	
						960	1.9	28.7	-	29.9	60.8	60.8	45.7	2.2	14.6	
						1010	1.1	16.1	-	29.3	67.2	67.2	41.9	4.4	8.4	
						1060	1.2	17.2	-	29.1	70.1	70.1	41.0	5.3	9.0	
						1110	1.7	25.0	-	29.2	73.3	73.3	44.2	3.0	13.1	
						1160	0.9	13.3	-	28.6	85.0	85.0	36.6	3.2	7.1	
						1220	0.7	9.9	-	28.1	85.8	85.8	38.3	5.8	5.4	
						1104	1.8	3.3	0.40	3.6	3.843	85.2	39.2	1.5	8.2	
						1250	1.7	6.8	0.36	8.0	4.099	88.2	41.5	1.1	7.7	
P.2811.12	PH	2492	0.05252	1.1	14.3×10^{-7}	560	2.5	1.7	0.94	1.4	0.929	98.4	12.6	1.3	11.3	31.5 ± 0.4 Ma
W.R						625	1.3	0.9	0.43	1.4	1.983	91.0	22.3	1.0	6.0	
B1						720	3.0	2.5	0.59	1.7	3.364	85.6	34.9	0.5	13.7	
						770	2.2	2.1	0.36	2.0	3.208	80.6	33.5	1.1	9.9	
						824	2.2	2.5	0.40	2.3	3.308	81.8	34.4	0.7	10.3	
						870	1.7	2.1	0.34	2.4	3.227	83.4	33.6	0.9	7.9	
						926	1.5	1.9	0.29	2.6	3.217	83.0	33.5	1.8	6.7	
						970	1.4	2.0	0.31	2.8	2.713	85.2	28.9	1.2	6.6	
						1023	2.6	3.3	0.59	2.5	3.132	84.0	32.8	0.9	11.8	
						1104	1.8	3.3	0.40	3.6	3.843	85.2	39.2	1.5	8.2	
						1250	1.7	6.8	0.36	8.0	4.099	88.2	41.5	1.1	7.7	
P. 2811.12	PH	2530	0.07392	0.26	4.1×10^{-7}	615	0.49	3.0	-	12.2	1.573	93.6	31.5	13.6	3.2	40.3 ± 1.5 Ma
30-60						750	0.79	9.0	-	22.8	1.710	97.8	34.2	8.1	5.2	
B2						842	1.62	22.8	-	28.0	2.088	76.0	41.7	3.0	10.7	
						895	2.21	32.4	-	29.2	1.788	65.2	35.8	2.5	14.6	
						955	1.90	27.6	-	28.9	1.907	58.7	38.1	2.6	12.5	
						1005	1.48	21.0	-	28.2	1.789	66.3	35.8	4.6	9.7	
						1055	1.85	26.0	-	27.9	1.881	65.5	37.6	2.5	12.2	
						1100	1.87	26.5	-	28.2	2.337	73.1	46.6	3.8	12.3	
						1150	1.62	23.4	-	28.8	2.218	87.8	44.3	5.4	10.6	

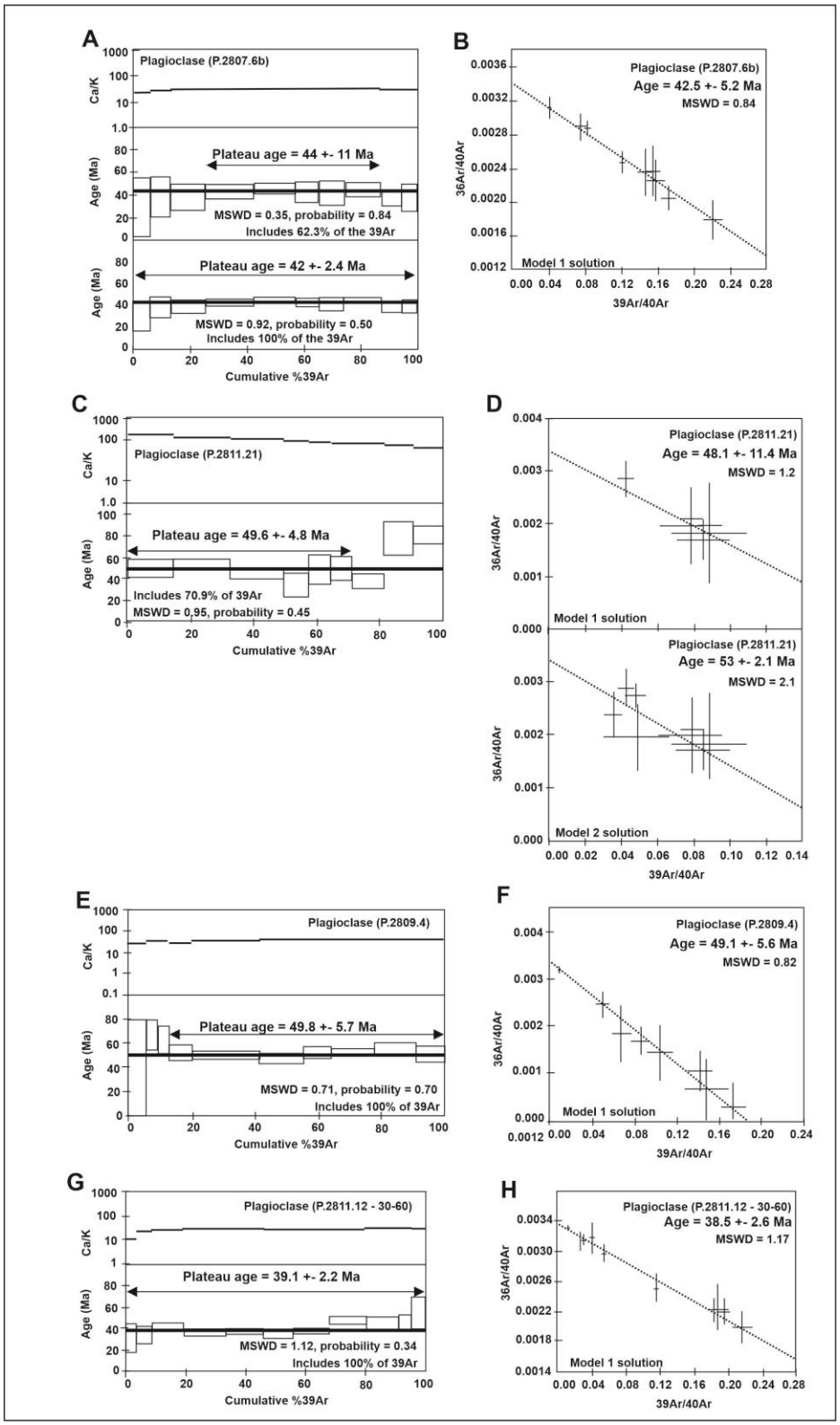
						1200	0.66	9.6	-	28.8	2.274	93.0	45.4	6.6	4.3	
						1250	0.70	10.1	-	28.7	2.756	92.4	54.8	14.0	4.6	
P. 2811.12	PH	2532	0.07521	0.29	4.8×10^{-7}	726	1.20	10.3	-	17.1	1.886	96.7	37.7	4.5	6.9	42.0±1.1 Ma
60-90						825	1.29	16.4	-	25.3	2.092	79.8	41.8	3.3	7.5	
B2						866	2.29	32.5	-	28.2	2.005	61.2	40.1	2.5	13.3	
						920	2.93	41.6	-	28.3	2.048	51.5	40.9	2.5	17.0	
						975	2.02	28.2	-	27.7	1.926	59.3	38.5	2.1	11.7	
						1026	2.10	28.9	-	27.4	1.864	64.4	37.3	1.9	12.2	
						1075	1.91	25.9	-	27.0	2.338	63.4	46.6	3.5	11.1	
						1125	1.63	21.8	-	26.6	2.244	75.4	44.8	3.7	9.5	
						1175	1.17	15.7	-	26.7	2.498	84.7	49.8	6.1	6.8	
P2811.21	PH	2494	0.06622g	0.11	2.3 x 10-7	705	0.40	34.0	0.36	172	4.973	98.7	49.4	8.1	14.7	52.2 ± 2.8Ma
Plagioclase						806	0.48	29.7	0.01	123	5.436	52.0	53.6	3.3	18.0	
						900	0.46	23.2	0.01	101	4.422	64.0	44.5	4.9	17.0	
						970	0.21	8.9	0.00	86	3.231	86.1	33.7	10.8	7.7	
						1035	0.19	6.5	0.01	69	4.811	55.8	48.0	13.3	6.9	
						1090	0.18	5.5	0.00	62	4.912	60.1	49.9	11.2	6.6	
						1160	0.28	9.0	0.01	64	3.643	82.3	37.4	6.8	10.5	
						1250	0.25	6.3	0.01	52	8.039	71.0	76.9	15.3	9.1	
						1290	0.26	5.0	0.01	39	8.391	58.5	80.1	8.3	9.5	
P2814.4B	PH	2497	0.07095g	0.20	3.9 x 10-7	690	0.44	6.9	0.91	30.8	2.041	99.7	22.8	46.3	8.6	49.4 ± 4.2Ma
Plagioclase						760	0.20	3.6	0.01	36.4	6.504	80.3	63.2	10.6	3.8	
						820	0.34	6.2	0.01	35.8	3.275	64.7	34.1	6.4	6.7	
						896	0.75	13.4	0.01	35.7	4.575	29.5	45.8	2.6	14.5	
						1008	1.54	28.6	0.02	36.9	4.657	20.3	46.6	0.9	29.9	
						1063	0.30	5.5	0.01	35.9	5.002	47.1	49.7	14.5	5.9	
						1120	0.20	3.6	0.01	35.4	8.459	37.8	80.6	7.0	3.9	
						1205	0.49	8.8	0.01	35.6	5.649	72.7	55.5	5.3	9.6	
						1308	0.89	15.8	0.01	35.5	6.433	73.8	62.6	2.4	17.2	

Table S2-2. Summary of new $^{40}Ar/^{39}Ar$ step heating data for samples analysed at the New Mexico Geochronology Research Laboratory.

ID		Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
P.2799.1A, 48.35 mg groundmass concentrate, J=0.0007093±0.10%, NM-137, Lab#=52285-01											
A	†ø	*625*	*n.a.*	*19.08*	*n.a.*	*0.024*	*0.027*	*-2.7*	*0.1*	*n.a.*	*n.a.*
B	†	*700*	*6154*	*5.532*	*21029*	*0.570*	*0.092*	*-1.0*	*2.0*	-79.5	339.5
C	†	*750*	*685.7*	*7.221*	*2164.7*	*1.21*	*0.071*	*6.8*	*6.0*	59.8	*16.6*
D		800	308.1	10.66	929.8	1.74	0.048	11.1	11.7	44.2	7.3
E		875	233.7	18.42	672.3	5.88	0.028	15.6	31.2	47.5	2.0
F		975	171.1	16.33	439.5	7.02	0.031	24.9	54.5	55.2	1.7
G		1075	194.5	15.54	532.5	3.32	0.033	19.8	65.5	49.8	2.9
H		1250	177.7	36.17	461.7	4.69	0.014	24.9	81.1	58.3	2.2
I		1650	143.1	47.60	374.6	5.71	0.011	25.4	100.0	48.6	1.4
total gas age				n=9		30.2	0.028			49.3	>700*
plateau			MSWD=4.7**	n=6	steps D-I	28.4	0.025		94.0	**51.5**	3.6*
isochron			MSWD=4.5**	n=8		$^{40}Ar/^{36}Ar$=294±32*				52.6	19.0*
P.2799.12, 55.14 mg groundmass concentrate, J=0.0007098±0.10%, NM-137, Lab#=52284-01											
A	†ø	*625*	*n.a.*	*2.065*	*n.a.*	*-0.008*	*0.25*	*-1.6*	*0.0*	*n.a.*	*n.a.*
B	†	*700*	*5715*	*5.848*	*19075*	*0.506*	*0.087*	*1.4*	*0.8*	99.7	277.1
C	†	*750*	*208.5*	*4.982*	*530.0*	*1.35*	*0.10*	*25.1*	*3.1*	66.9	*4.9*
D	†	*800*	*81.89*	*6.027*	*118.6*	*3.26*	*0.085*	*57.8*	*8.6*	60.7	*1.5*
E		875	72.31	10.23	101.3	11.2	0.050	59.8	27.5	55.7	0.5
F		975	53.76	8.983	44.66	21.7	0.057	76.8	64.2	53.2	0.3
G		1075	47.38	6.241	24.96	10.9	0.082	85.5	82.5	52.1	0.5
H		1250	50.68	16.36	41.87	6.67	0.031	78.3	93.8	51.5	0.5
I	†	*1650*	*69.56*	*76.83*	*154.8*	*3.68*	*0.007*	*43.4*	*100.0*	*41.5*	*1.5*
total gas age				n=9		59.3	0.057			53.6	4.4*
plateau			MSWD=14.3**	n=4	steps E-H	50.5	0.057		85.2	**53.1**	1.6*
isochron			MSWD=28.7**	n=8		$^{40}Ar/^{36}Ar$=317±44*				51.6	3.3*

Notes: n = number of heating steps; † = analyses excluded from plateau weighted mean; Ø- analyses excluded from inverse isochron age; K/Ca = molar ratio calculated from reactor produced $^{39}Ar_K$ and $^{37}Ar_{Ca}$. * = 2σ error; ** = MSWD outside of 95 % confidence interval.

Figure S2-1. $^{40}Ar/^{39}Ar$ step-heating spectra, Ca/K and Cl/K profiles, and isotope correlation plots for lavas from Point Hennequin and Vauréal Peak dated at Leeds University. Arrows indicate steps used to calculate plateau age. 1σ errors.



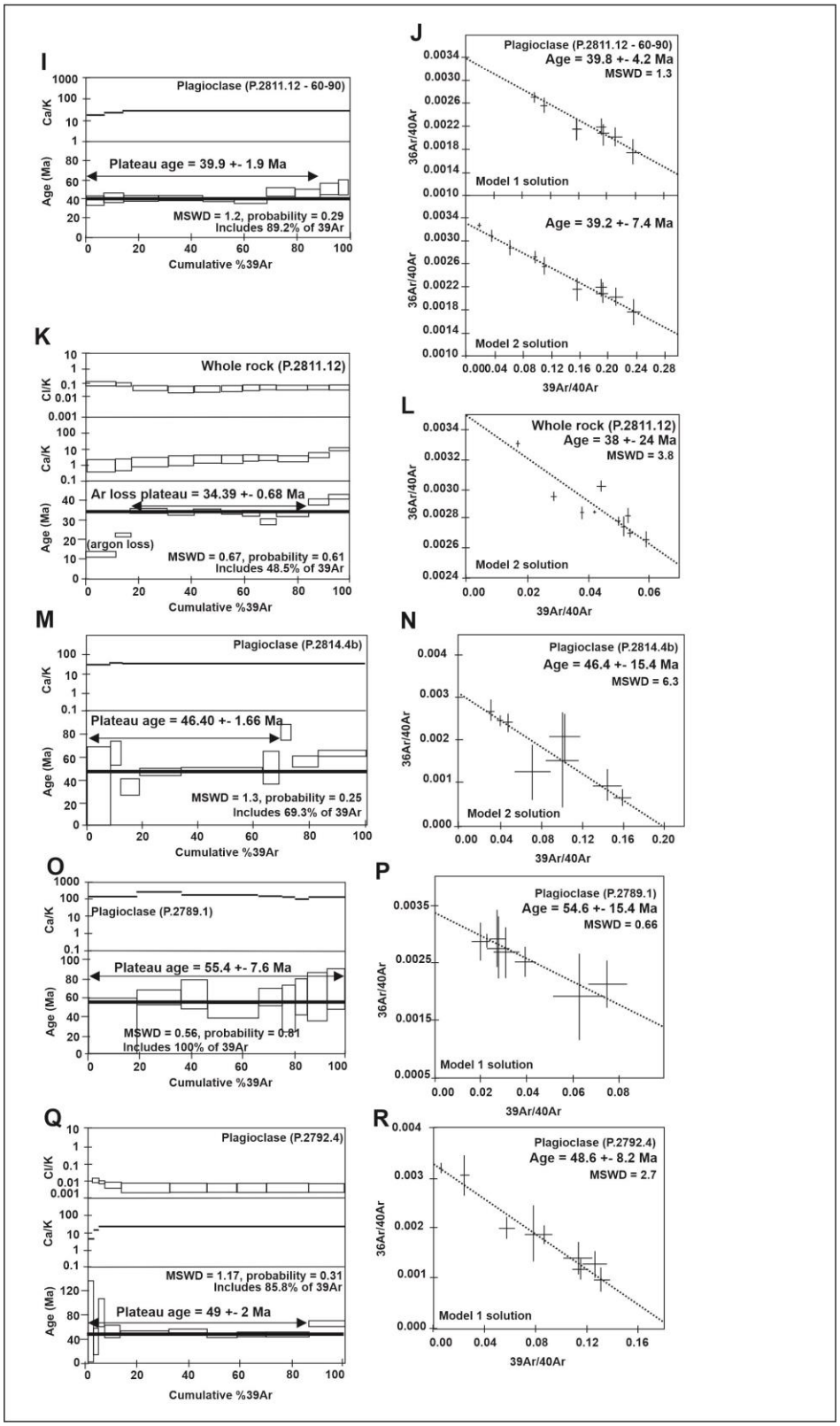

I
Plagioclase (P.2811.12 - 60-90)
Ca/K
Age (Ma)
Plateau age = 39.9 +- 1.9 Ma
MSWD = 1.2, probability = 0.29
Includes 89.2% of 39Ar
Cumulative %39Ar
J
Plagioclase (P.2811.12 - 60-90)
Age = 39.8 +- 4.2 Ma
MSWD = 1.3
Model 1 solution
Age = 39.2 +- 7.4 Ma
Model 2 solution
36Ar/40Ar
39Ar/40Ar
K
Whole rock (P.2811.12)
Cl/K
Ca/K
Age (Ma)
Ar loss plateau = 34.39 +- 0.68 Ma
(argon loss)
MSWD = 0.67, probability = 0.61
Includes 48.5% of 39Ar
Cumulative %39Ar
L
Whole rock (P.2811.12)
Age = 38 +- 24 Ma
MSWD = 3.8
Model 2 solution
36Ar/40Ar
39Ar/40Ar
M
Plagioclase (P.2814.4b)
Ca/K
Age (Ma)
Plateau age = 46.40 +- 1.66 Ma
MSWD = 1.3, probability = 0.25
Includes 69.3% of 39Ar
Cumulative %39Ar
N
Plagioclase (P.2814.4b)
Age = 46.4 +- 15.4 Ma
MSWD = 6.3
Model 2 solution
36Ar/40Ar
39Ar/40Ar
O
Plagioclase (P.2789.1)
Ca/K
Age (Ma)
Plateau age = 55.4 +- 7.6 Ma
MSWD = 0.56, probability = 0.81
Includes 100% of 39Ar
Cumulative %39Ar
P
Plagioclase (P.2789.1)
Age = 54.6 +- 15.4 Ma
MSWD = 0.66
Model 1 solution
36Ar/40Ar
39Ar/40Ar
Q
Plagioclase (P.2792.4)
Cl/K
Ca/K
Age (Ma)
MSWD = 1.17, probability = 0.31
Includes 85.8% of 39Ar
Plateau age = 49 +- 2 Ma
Cumulative %39Ar
R
Plagioclase (P.2792.4)
Age = 48.6 +- 8.2 Ma
MSWD = 2.7
Model 1 solution
36Ar/40Ar
39Ar/40Ar

Figure S2-2. $^{40}Ar/^{39}Ar$ step-heating spectra and Ca/K profiles, and isotope correlation plots for lava samples (a) P.2799.1A and (b) P.2799.12, from Vauréal Peak dated at New Mexico Geochronology Research Laboratory. Arrows indicate steps used to calculate plateau age. 2σ errors.