supported by an age of $4.58 \pm 0.09 \times 10^9$ years for St. Severin, which is obtained by combining Podosek's (*9*) observation that St. Severin began to retain ^{129}Xe $7.5 \pm 1.0 \times 10^6$ years after the Bjurbole chondrite with Bjurbole's ^{40}Ar-^{39}Ar age of $4.59 \pm 0.09 \times 10^9$ years [calculated from the data for 580° through 1000°C given in Turner (*10*)]. Therefore, we have assumed the Rb-Sr age of 4.56×10^9 years (*8*) as the age of the monitor and assign an error of $\pm 0.05 \times 10^9$ years (1 S.D.) to allow for the uncertainties involved. Any change in the age assigned to the monitor will propagate to the sample age by a factor of $\delta T_s / \delta T_m = 0.914$.

Figure 2 is a plot of $^{40*}Ar/^{39*}Ar$ and apparent age against the fraction of $^{39*}Ar$ released. Argon-39* is the ^{39}Ar derived from potassium and is given by

$$^{39*}Ar = {}^{39}Ar - ({}^{39}Ar/{}^{37}Ar)_{Ca}\,{}^{37}Ar \quad (3)$$

Sample 15555 has lost 19.7 percent of its $^{40*}Ar$, and the St. Severin monitor has lost 2.2 percent. However, the temperature fractions $\geq$ 900°C define good "plateaus" in both cases.

Our age of $3.33 \pm 0.05 \times 10^9$ years (relative to an assumed monitor age of $4.56 \pm 0.05 \times 10^9$ years) for sample 15555 is in good agreement with an age of $3.30 \pm 0.05 \times 10^9$ years determined by the same method (*11*). A conventional K-Ar age of $3.32 \pm 0.05 \times 10^9$ years from a plagioclase separate and a Rb-Sr internal isochron age of $3.36 \pm 0.07 \times 10^9$ years also agree (*12*). It should be noted that the K-Ar ages were calculated with slightly different decay constants of ^{40}K, and part of the scatter may be due to this. For instance, when our data for sample 15555 are recalculated with $1/\lambda = 1.90 \times 10^9$ years [which is the value Husain *et al.* (*13*) used for their Apollo 14 work] the age of sample 15555 becomes $3.29 \pm 0.05 \times 10^9$ years, which is almost exactly the value obtained by Husain (*11*) for sample 15555.

If sample 15555 does represent the local bedrock at the edge of Hadley Rille, then $3.33 \pm 0.05 \times 10^9$ years represents an upper limit to the age of the rille. The age of sample 15555 overlaps the older ages reported (*14, 15*) for the Apollo 12 samples from Oceanus Procellarum. The result for sample 15555 tends to support the prediction and interpretation of Soderblom and Lebofsky (*16*), according to whom "the major mare unit at the Apollo 15 landing site is expected to have a crystallization age of $3.5 \pm .1$ billion years." They indicate that the major mare unit at the Apollo 15 site is part of the same spectroscopically "red" (*17*) formation as the Apollo 12 site but is slightly older by their crater-morphology dating technique. However, with only one sample dated the agreement may be coincidental.

If the Fra Mauro samples from Apollo 14 do date the formation of the Imbrium basin (*3, 13, 17*) and if sample 15555 is representative of the basalts filling the Imbrium basin, then the basalts postdate the formation of the basin by at least 500×10^6 years. Therefore, the mare basalts cannot be simple impact melts but must represent igneous activity that occurred long after basin formation.

The age of sample 15555 contrasts sharply with the value of $4.15 \pm 0.2 \times 10^9$ years reported (*11*) for the anorthosite rock 15415 from the mountain-front at the Apollo 15 site. With only two samples dated, it is already apparent that the Apollo 15 astronauts did an excellent job of obtaining samples with a wide range of ages at the Hadley site.

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Rubidium-Strontium and Potassium-Argon Age of Lunar Sample 15555

Abstract. *The lunar mare basalt 15555 from the edge of Hadley Rille has been dated at 3.3 × 10⁹ years by both rubidium-strontium and potassium-argon techniques. Age and trace element abundances closely resemble those of the Apollo 12 mare basalts. Data from lunar basalts obtained thus far indicate that they cannot be derived by simple fractionation from a homogeneous source.*

We report here the age and the abundances of some trace elements for lunar sample 15555. As described in the Lunar Sample Preliminary Examination Team (LSPET) report (*1*), this 9.6-kg rock, collected from the edge of Hadley Rille, is a coarse-grained porphyritic olivine mare basalt and may be related to the layered sequence exposed in the wall of the rille. We received two chips of this sample, chips 15555,12 and 15555,15, weighing 1.04 and 0.52 g, respectively, as part of the early allocation scheme adopted for the distribution of Apollo 15 samples. The samples we received were coarse-grained rocks exhibiting the mineralogy reported by LPSET (*1*), but, contrary to their sample description, they were extremely friable and suffered considerable disintegration during shipment.

Analytical procedures related to sample handling, mineral separations, and mass-spectrometric procedures for Rb-Sr internal isochron age measurement have been described elsewhere (*2*). From sample 15555,12 a plagioclase fraction was handpicked from a fraction with a density $\rho < 2.89$ g/cm^3 of $-100 + 125$ mesh size. Aliquots of this handpicked fraction were used both for the Rb-Sr and for the K-Ar dating described below. For the fraction with $\rho > 3.33$ g/cm^3 magnetic separation methods were used to obtain moderately pure (~ 90 percent) olivine and pyroxene

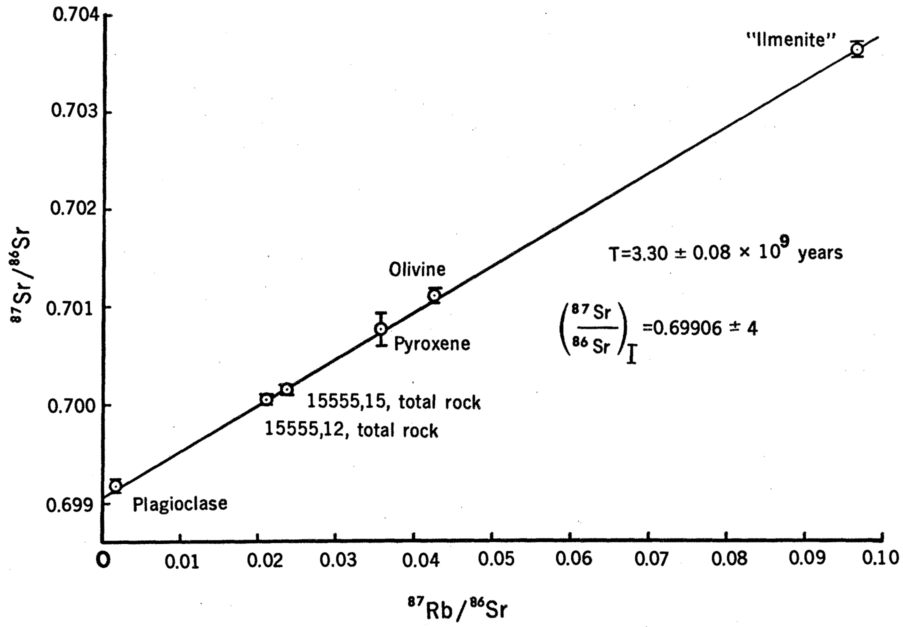

Fig. 1. Rubidium-strontium evolution diagram for rock 15555. Isochron parameters shown were calculated by the double regression method (*3*). Error bars shown are 95 percent confidence limits. All points deviate from the best-fit isochron by less than 1 part in 10^4.

fractions. Ilmenite constitutes about 1 percent of the rock (*1*), and it was therefore not feasible to obtain a sufficient sample size of pure ilmenite separate. However, a highly magnetic fraction containing olivine, pyroxene, and ilmenite yielded the highest Rb/Sr ratio observed in our work. Total rock analyses were performed on aliquots from both chips we received.

The results of the chemical and isotopic analyses are shown in Table 1. A total range of 0.6 percent in $^{87}Sr/^{86}Sr$ was obtained for the mineral separates from this basalt. In a Rb-Sr evolution diagram these data points describe a precise linear relationship. From the parameters of a best-fit line determined by the double regression method of York (*3*), we obtained an internal isochron age of $3.30 \pm 0.08 \times 10^9$ years and an initial $^{87}Sr/^{86}Sr$ ratio of 0.69906 $\pm$ 0.00004 at the 95 percent confidence level (Fig. 1).

Measurements of K and Ar were made on aliquots of a plagioclase separate from sample 15555,12 (details of the analysis will be published later). Potassium-argon age determinations reported by Eberhardt *et al.* (*4*) indicate that diffusive loss of radiogenic ^{40}Ar from lunar rock feldspars can be very small, and that the K-Ar technique, when applied to plagioclase separates from lunar rocks, can therefore yield a lower age limit very close to the crystallization age given by the Rb-Sr internal isochron technique or by the high-temperature ^{40}Ar-^{39}Ar method. In this sample the Ar concentration was measured mass spectrometrically by the ion-beam calibration method. Corrections of the radiogenic ^{40}Ar concentration due to contributions from lunar trapped and spallation ^{40}Ar were less than 1 percent. Using the measured plagioclase K and Ar concentrations (Table 1) and the decay constants $\lambda_\beta = 4.72 \times 10^{10}$ per year and $\lambda_e = 0.584 \times 10^{10}$ per year, we found the K-Ar age of the plagioclase to be $3.31 \pm 0.07 \times 10^9$ years. This value is in quite satisfactory agreement with the Rb-Sr isochron age. It is clear that radiogenic Ar is retained quantitatively in the plagioclase.

The age of 3.3×10^9 years obtained for the mare basalt from the Hadley Rille site is in the range of ages of several basaltic rocks from the Ocean of Storms (*2, 5*); this result suggests that volcanism and flooding by lava flows occurred in widely separated regions in the moon at this time. The low initial content of Sr in sample 15555, as in the case of mare basalts from the Sea of Tranquillity and Ocean of Storms, once again demonstrates the presence of source regions in the lunar interior with extremely low Rb/Sr ratios caused by the depletion of alkalies in these regions early in the moon's history. In contrast, the high initial Rb/Sr ratios in the nonmare basalts collected in the Apollo 14 mission (*6, 7*) show that somewhere on the moon there must exist environments that in the past contained high Rb/Sr ratios, providing the radiogenic Sr-, K-, Rb-, and Ba-rich component in the lunar soils and Apollo 14 basalts. This component is ubiquitous in various size ranges of lunar soil

Table 1. Analytical results for lunar sample 15555; "Ilmenite," highly magnetic fraction with $\rho > 3.33$ g/cm^3 consisting of ilmenite, pyroxene, and olivine; STP, standard temperature and pressure.

Sample	Weight (mg)	K (μg/g)	Rb (μg/g)	Sr (μg/g)	Ba (μg/g)	^{40}Ar [10^{-8} cm^3/g (STP)]	$^{87}Rb/^{86}Sr$* ($\times 10^2$)	$^{87}Sr/^{86}Sr$†	$^{40}Ar/^{36}Ar$	$^{38}Ar/^{36}Ar$
15555,15, total rock	39.25	352	0.700	85.32	41.61		2.375	0.70009 ± 6		
15555,12, total rock	23.87		.538	74.11			2.102	.70005 ± 5		
Pyroxene	36.10		.167	13.50			3.575	.700076 ± 13		
Olivine	46.50		.166	11.29			4.265	.70110 ± 5		
"Ilmenite"	41.10		.982	29.23			9.730	.70362 ± 9		
Plagioclase‡	29.78	431	.198	319.8	36.71		0.180	.69917 ± 7		
Plagioclase‡	36.95					+1558 −35			+168.5§ −1.4	+1.18§ −0.01

* Errors are ±2 percent for 2σ limits. † Errors refer to the fifth decimal place and are 2σ limits. ‡ Two plagioclase samples are aliquots from the same handpicked fraction. § Errors are 1σ limits.

14149, suggesting local provenance (*7*). If this exotic component is transported over long distances on the moon and mixed with the soils, it should preferentially occur in the smaller size ranges of the soils from the Apollo 11 and Apollo 12 missions.

The abundances of K, Rb, Sr, and Ba in sample 15555 resemble, but are slightly lower, than those in the low-K mare basalts from the Sea of Tranquillity. Striking similarities are apparent between this sample and the basalts returned from the Ocean of Storms (*2, 5*), not only in age and initial Sr content, as mentioned earlier, but also in elemental abundances anl elemental ratios (*2*). The elemental abundances of K, Rb, Sr, and Ba are quite low, however, relative to those of the Apollo 14 basalts. The range in elemental abundances observed in the basaltic rock samples thus far returned from the moon could result from differences in the composition of the source region, differentiation processes, degree of contamination with previously differentiated material, or a combination of these. It is clear, however, that simple fractionation alone from a homogeneous source is not adequate to explain the data. If a homogeneous source exists, fractionation in combination with contamination must be invoked.

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Rare Gas Record in the Largest Apollo 15 Rock

Abstract. *The spallation krypton data from rock chip 15555,23 indicate a well-shielded location during most of the time during which the rock was exposed to cosmic rays. A krypton-krypton exposure age of* $81^{+17}_{-7} \times 10^6$ *years is calculated, and the gas retention ages are estimated. No evidence for the presence of products from plutonium-244 or iodine-129 was found.*

Results obtained from rare gas isotopic abundances in a large lunar rock may provide us with data on the depth dependence of cosmic-ray induced spallation yields, as well as information about ages and irradiation history, whenever the rock had a simple one-stage irradiation history. This information is required for an understanding of lunar surface processes and turnover rates. Estimates of the depth of the lunar regolith are crucially dependent on the spallation and neutron record in the soil and core samples. We have analyzed by mass spectrometry the noble gases He, Ne, Ar, Kr, and Xe in a 182-mg chip of rock 15555. This is a chip from a fragment that broke off in transit and whose orientation relative to the rock and to the lunar surface is unfortunately not known.

Microscopic inspection has shown that fine dust was adhering to one side of the chip. Since we were mainly interested in the spallation gas record, we attempted to remove dust and surface material containing solar wind components by a short HF etching and ultrasonic cleaning. The analytical techniques used have been reported (*1*). A technique of stepping the magnetic field was employed. The errors given include, in general, errors from all sources, quadratically added. Errors in Kr and Xe data reflect both the limited sample size available for this study and the relatively low abundances of the major target elements Sr, Y, Zr, Ba, and the rare earth elements (REE). The ^{81}Kr content in our sample was only 0.012×10^{-12} cm^3 at standard temperature and pressure (STP). The ^{81}Kr and ^{78}Kr mass peaks were resolved from the interfering isobaric hydrocarbon background.

The relatively small ^{131}Xe/^{126}Xe spallation ratio (Table 1) might indicate a fairly hard irradiation, and, therefore, a close-to-surface irradiation of the analyzed chip. A closer inspection of the data, however, revealed that this was not the case. The relative spallation Kr yields (Table 2) are compatible only with a shielded location. In the diagram of P_{81}/P_{83} versus ^{78}Kr/^{83}Kr (Fig. 1), the data point for rock 15555 falls on or close to the correlation line of the Apollo 12 rocks, which indicates similar abundance ratios of the major target elements Zr and Sr for Apollo 12 rocks and rock 15555. The position of this data point in this diagram requires an effective shielding similar to those of rocks 12009 and 12052, corresponding to a model depth of ~ 150 g/cm^2 (*2*). From the preliminary description of the Apollo 15 lunar

Table 1. Concentrations and isotopic compositions of Xe in rock 15555,23. The isotopic composition of Xe in the 800°C fraction of sample 10084,29 (*1*) was used for the trapped component.

Lunar rock	^{131}Xe [$\times 10^{-12}$ cm^3/g (STP)]	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{132}Xe	^{134}Xe	^{136}Xe
15555,23	12.6 ± 1.8	6.37 ± 0.14	11.48 ± 0.27	20.8 ± 0.3	80.2 ± 1.8	18.9 ± 0.5	100	66.2 ± 0.9	23.7 ± 0.4	18.8 ± 0.5
Spallation Xe*	^{126}Xe = 1.45	0.546	1.00	1.431	1.81	0.851	4.74	0.763	0.135	≡ 0.028
Spallation Xe†	^{126}Xe = 1.45	0.546	1.00	1.423	1.72	0.836	4.66	0.670	0.100	≡ 0

* A spallation ratio for ^{136}Xe/^{131}Xe of 0.0059 is assumed, which represents an upper limit for this spallation ratio (*2*). † A spallation ratio for ^{136}Xe/^{131}Xe of 0 is used.