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Preliminary petrographic characterization, $^{40}Ar/^{39}Ar$ and CRE ages of Apollo 15 regolith basaltic fragments

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Abstract

We present here preliminary results of an integrated study of nine Apollo 15 basaltic fragments found along impact ejecta of small craters in the vicinity of the landing site. The 2-4mm fragments present a wide range of compositions similar to those already defined for Apollo 15, including evidence of an assembly of at least two different lithologies that crystallized at different times. ^{40}Ar-^{39}Ar ages obtained for these 9 fragments range from 3163±9 to 3891±21 Ma Ma, tapping into older ages for samples from the Mare Imbrium.

1. Introduction

Together with the previously reported data on "new" Apollo 17 basaltic regolith fragments, here is reported preliminary work on "new" Apollo 15 basaltic regolith fragments. Like Serenitatis Basin, remote sensing data obtained from lava filled surface within Imbrium Basin presents 30 lava flows distinguished based on their spectrally different compositions [1]. The range in ages based on crater counting statistics is between 2.01 and 3.57 Ga (≥1.6 Ga activity). However, there is currently no information on the chemical diversity of lava flows below the observable ones. Thus, a complete understanding of chemical and isotopic mantle evolution beneath this basin cannot be constrained, yet. Apollo 15 basalt lithologies are divided into olivine, pigeonite, quartz and KREEP types, and green, yellow and orange glasses. The current Apollo 15 volcanic samples age range is narrow comprising about ~200 Ma between 3.16 and 3.40 Ga [2, 3], a ~7 times shorter active period than that suggested by cratering statistics. Acquiring mineralogical and chemical composition and chronological data from different lava types is needed to improve the understanding Mare Imbrium volcanic activity. Here are presented textural, mineral chemical composition and ^{40}Ar-^{39}Ar ages of 9 Apollo 15 2-4 mm regolith fragments collected from impact ejecta of small craters in the vicinity of Stations 6 and 9 & 9A, and from the rim of Spur crater at Station (Table 1). Ejecta from these small craters come from depths greater than any of the Apollo 15 drill-cores. Hence, these fragments potentially sampled material from excavated underlying lava flows and intercalated regolith that potentially included local and regional material (from other flows within Mare Imbrium).

2. Methods

A JEOL JXA 8500A with field emission EMP was used to obtain BSE images and major mineral major element compositions (11 mm working distance, 15 keV power and 15 nA current). A Thermo Scientific Argus VI mass spectrometer was used for ^{40}Ar-^{39}Ar age determination via the IR-laser step-heating technique. The present CRE-ages were calculated using the nominal ^{38}Ar production rate.

3. Samples

Table 1 shows a summary of the preliminary petrographic and chemical characterization of the Apollo 15 regolith basaltic fragments.
⇒**15243,108:** is a vitrophyre containing one large zoned pyroxene ($En_{24-60}Wo_{9-32}Fs_{28-44}$), olivine ($Fo_{60-68}$) and ubiquitous spinel and chromite.
⇒**15385,29** (Fig. 1b): is a coarse olivine basalt containing large olivine crystals (Fo_{57-63}) and large zoned pyroxene ($En_{12-57}Wo_{9-41}Fs_{15-32}$), interstitial plagioclase (An_{90-95}), minor ilmenite, FeS and K-glass.
⇒**15388,29:** resembles the last crystallization stages of a quartz basalt and is composed only of pyroxene ($En_{12-57}Wo_{9-41}Fs_{21-61}$), plagioclase ($An_{89-94}$) and minor spinel.
⇒**15433,94:** has at least two lithologies: 1) a coarser lithology composed of orthopyroxene rimmed by pigeonite ($En_{4-81}Wo_{3-32}Fs_{17-54}$), 2) a finer lithology composed of plagioclase laths (An_{71-89}) and a KREEPy component containing K-spar, K-glasss,

Table 1 Summary of Apollo 15 basaltic regolith samples showing basalt type, texture, mineralogy and major mineral chemical composition.

Sample	Station	Basalt type	Sub-sample	Olivine Fo	Pyroxene En	Pyroxene Wo	Pyroxene Fs	Plagioclase An	Oxide	Other phases	Groundmass
15243,108	6	Olv-vitrophyre	10B	60-68	24-60	9-32	28-44	-	spn, chr	-	✓
15385,29	7	Olivine	11B	57-63	44-63	9-40	15-32	90-95	ilm	tr, K-glass	-
15388,29	7	Pigeonite	7B	-	12-57	9-41	21-61	89-94	spn	-	-
15433,94*	7	Coarse Opx&Plag + KREEP	17B	-	4-81	3-32	17-54	71-89	ilm, spn	bad, trq, K-spar, K-glass, apatite, SiO_2	-
15433,98	7	?	2B	72	47-80	2-39	13-27	82-95	ilm, spn	bad, zir, apt, tr,	-
15533,12	9	Olivine	14B	12-47	22-58	10-34	23-60	87-92	ilm, spn	K-glass, trq	-
15533,14	9	Pigeonite	4B	-	17-68	6-37	25-53	-	chr	-	✓
15534,29	9	Olivine	21B	48-54	43-59	9-34	23-40	89-93	chr, spn	-	-
15639,6	9A	Coarse Olv	6B	32-53	30-59	9-35	21-54	89-91	chr, spn	trq, apt, K-glass, SiO_2	-

apt=apatite; bad=baddeleyite; chr=chromite, ilm=ilmenite; SiO2=silica polymorph; spn=spinel; tr=troilite; trq=tranquiityite; zir=zircon

tranquilityite, baddeleyite, apatite and SiO_2. ⇒**15433,98:** partly resembles olivine fractionate basalt 15676, contains relatively coarser plagioclase (An_{82-95}) and pyroxene ($En_{47-80}Wo_{2-39}Fs_{13-27}$), one having lamellae. The groundmass is composed of equant pyroxene and few olivines surrounded by interstitial plagioclase. Minor phases observed were baddeleyite, zircon, apatite and troilite. ⇒**15533,12:** is a coarse texture basalt resembling the olivine cumulates 15641 and 15663. Zoned pyroxene ($En_{22-58}Wo_{10-34}Fs_{23-60}$), few scattered olivines (Fo_{12-47}), and interstitial plagioclase (An_{87-92}). Minor phases include K-glass and tranquilityite. ⇒**15533,14:** is a vitrophyre composed of quenched groundmass, zoned euhedral pyroxene ($En_{17-68}Wo_{6-37}Fs_{25-53}$), and minor subhedral chromite. ⇒**15534,29:** is a coarse texture basalt resembling olivine cumulates 15641 and 15663. Zoned pyroxene ($En_{43-59}Wo_{9-34}Fs_{23-40}$), scattered olivines ($Fo_{48-54}$), and interstitial plagioclase (An_{89-93}). Minor phases observed are chromite and spinel. ⇒**15639,6:** a coarse texture basalt resembling olivine cumulate 15663. Zoned pyroxene ($En_{30-59}Wo_{9-35}Fs_{21-54}$), scattered olivines ($Fo_{32-53}$), interstitial plagioclase (An_{89-91}), and minor phases are chromite, spinel, tranquilityite, apatite, K-glass and SiO_2.

4. ^{40}Ar-^{39}Ar and CRE age

All data corrected for blank, discrimination, decay of short-lived nucleogenic nuclides (^{37}Ar &^{39}Ar), and where necessary cosmogenic and/or trapped Ar corrections were applied. Ages were obtained from Ar-release spectra, inverse or normal isochrones. ^{40}Ar-^{39}Ar ages (Table 2) range from 3891±21 Ma and 3163±45 Ma, extending the previous age range for Apollo 15 samples by ~200 Ma. and agrees with recently reported older ages from volcanic glasses by [4]. CRE-ages define a range between 101 and 770 Ma suggesting different gardening histories for Apollo 15 regolith samples.

Table 2: Summary table for the ^{40}Ar-^{39}Ar age determinaiton measurements including Cosmic-ray Exposure Age. Ages reported at 2σ.

Sample	Weight (mg)	Age Spectra (Ma)	Age Spectra %^{39}Ar	Age Spectra low-T reset	3-isotope plots Norm. Iso (Ma)	3-isotope plots Inv. Iso (Ma)	Nominal CRE-age
15243,108	3.27	3407±15	74	-	3409±23	3390±18	611
15385,29	4.44	3414±26	83	-	3423±33	3428±49	433
15388,29	4.48	3288±500	46	-	-	3353±76	770
15433,94*	4.37	-	-	-	2049±10 3136±10 - 3596±32	low-T interm-T high-T last 6	140
15433,98	4.21	3854±20	32	≤3731	-	3891±21	583
15533,12	4.17	3410±420	68	-	-	3289±48	212
15533,14	4.10	3308±22	85	-	3307±33	-	101
15534,29	3.79	3260±25	88	-	3232±42	3258±23	197
15639,6	3.25	3168±35	62	-	3163±45	3163±9	299

***This sample is composed of at least 2 distinct lithologies: 1) an older coarse texture of opx and plag, and 2) a younger finer texture of KREEPy material, resulting in a multi-Ar domain release.**

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