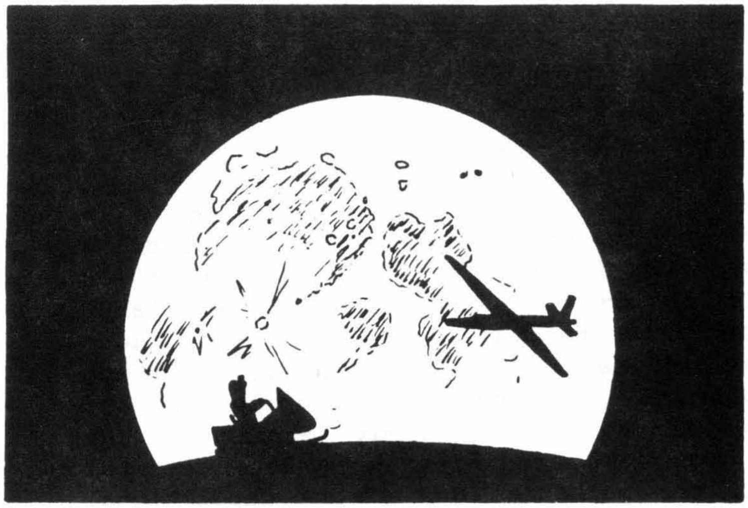

LUNAR SAMPLE NEWSLETTER

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CONTENTS — Page

WORKSHOP ON THE GEOLOGY AND PETROLOGY OF THE APOLLO 15 LANDING SITE

November 13-15, 1985
at LPI, Houston
(Co-convenors: P. Spudis (U.S.G.S.) and G. Ryder (LPI))

The geology of the Apollo 15 landing site remains poorly understood, in contrast with that of the geology and samples of the Apollo 16 and 17 landing sites. The Apollo 15 site is on the rim of the Imbrium basin, the remains of a paramount event in lunar geologic history. It encompasses a remarkably complete stratigraphic section ranging from pre-Imbrian to Copernican, unique among Apollo sites. Within the Apollo 15 samples, site photographs, surface experiments, and crew reports is recorded a variety of lunar processes and historical events, many of which are at present only dimly perceived. The petrology and stratigraphy of site materials are relevant to lunar crustal composition, formation, and origin, the mechanics and ejecta depositional processes of craters ranging from large basins to secondary clusters; and a whole gamut of volcanic processes. However, the Apollo 15 mission has often been felt to have received short shrift and to have been overshadowed by the succeeding Apollo 16 landing. It has never had a "conference of its own" at which multidisciplinary approaches could focus on its scientific opportunities. There is a perception that we have glaring deficiencies in our understanding which would be remedied by a multidisciplinary examination of the Apollo 15 landing site, especially in the light of the results from other missions.

To examine and synthesize our present knowledge, to discuss and dispute varied pertinent concepts, and to formulate research directions likely to advance our understanding of the landing site and of the moon, the Lunar and Planetary Institute, at the instigation of LAPST, is sponsoring a "Workshop on the Geology and Petrology of the Apollo 15 Landing Site." Keynote talks, contributed papers, and discussions are being arranged around eight main topics, following keynote presentations providing background (see preliminary agenda, below). Following the meeting, the contributed and invited abstracts and summaries of the discussion sessions will be published as an LIP Technical Report. Members of the prime, backup, and support crews have expressed great interest in participating in the Workshop. In the following paragraphs we summarize, in order of the Workshop topics, some of the rationale and questions which future studies might at least partly answer.

Sampling of the Apennine Front was the prime target of the Apollo 15 mission, yet its petrology remains one of the major outstanding problems. The talus deposit on the lower slopes of Hadley Delta is dominated by mare debris and mare-rich breccias; highlands materials is generally cryptic or at least small. Small samples, including coarse-fines from the regoliths, were scantily regarded in the Apollo mission days, partly because of time constraints. These small samples are now a target for study. Why was so little highlands materials found? Is the Front dominantly very friable material? A rough average composition appears to be some form of low-K Fra Mauro (LKFM, a low-KREEP basaltic composition), and there are some impact melts of this broad composition: these might represent Imbrium basin impact melt. We do not know the range of compositions in the highlands, although igneous ferroan anorthites, norites, and troctolites have been found. These cannot mix to produce the average; the LKFM composition has so far been found as non-igneous rocks and its origin is a recurring question which investigation of the Front samples might solve. The regolith throughout the site contains highlands components, mostly in a cryptic form. Up to the present, petrographic studies of particle populations and synthesis of chemistry (especially mixing models) have not been particularly directed at defining the highlands materials. Not until the terra components are identified can the events and processes which formed them be deciphered. The common pre-mission interpretation of massif materials forming the Front is of an Imbrium and Serenitatis basin origin. The sample suite is at present too poorly understood to adequately assess this interpretation, or whether other sources also provided Front material. Can material identified at the Apollo 17 site, e.g., the Serenitatis melt sheet, be identified among the Apollo 15 samples? Ejecta comprises older material: there are some deeply-derived, lower crustal (?) samples in the collection but their significance has not been adequately discussed. Basin-related rocks and ejecta can provide much information about multi-ring basin formation.

Volcanic KREEP basalts were an unexpected discovery among the Apollo 15 samples. They are ubiquitous and numerous but small: only two are individually numbered rocks and the largest is 7.5 g. Their investigation is essential in shedding light on the development of KREEP on the moon. They have crystallization ages of $\geq$ 3.85 b.y. and according to Sr-isotopic studies at least two distinct extrusions have been sampled. Their age cannot yet be distinguished from that of the Imbrium impact, but there is evidence that they are derived from the Apennine Bench Formation, hence are post-Imbrium. Was pressure-release significant in their genesis? The number of flows, their fractionation, and their origin is not yet known. How did they get distributed around the site as tiny fragments? - from beneath the local mare units or delivered laterally by rays? Why are their rare earth abundances so much lower than the Apollo 14 (brecciated) KREEP? How does the much older zircon age of the quartz-monzodiorite clasts in 15405 fit in with KREEP petrogenesis? A few workers remain unconvinced of the origin of Apollo 15 KREEP as volcanic flows, suggesting instead that they are impact melts, perhaps from Imbrium itself.

The Apollo 15 highlands, once its composition and stratigraphy have been established, offers a perspective on lunar basins, especially with integration of information from other landing sites. One important potentially solvable question is the age of the Imbrium basin. Can we identify Imbrium basin ejecta at Apollos 14 and 16 and compare it with that of Apollo 15? What can cratering mechanics and remote sensing tell us about the target stratigraphy? Understanding the relationship between Apollo 15 KREEP basalts and the Imbrium basin is of fundamental importance in establishing crustal responses to large impacts and the thermal state of the moon's crust at $\geq$ 3.9 b.y. ago. How did the pronounced layering at Silver Spur form? Cratering mechanics and the lateral and vertical redistribution of crustal materials are intimately related. Understanding of Imbrium ejecta and its distribution is a profitable approach towards understanding these problems.

Hadley Rille was an important target and has been well-described, but its origin as a lava channel or tube is not undisputed. But even if it is a lava tube, the mechanism of its formation is unclear. It has not been clearly related to any of the sampled lavas. Can the features seen in its walls be adequately correlated with the known characteristics of the rocks, for instance the thickness of flows as determined from samples? The rille might expose unsampled lava types. If so, then we need to explain how Apollo 15 KREEP volcanics and the yellow volcanic glasses were distributed around the landing site without exposing them. Perhaps distinct mare volcanics do exist as small samples (e.g., coarse fines) but have not been recognized. There is a dark feature around the base of the massifs which has been disputably interpreted as a "high lava" mark. Is there an episode of lava ponding recorded within the mare basalt samples? The landing site lies upon a topographic ridge, and to the north is the raised mound of the North Complex, a planned sampling location not eventually visited. Are these features mare-related or older (e.g., Apollo 15 KREEP)? The inventory of basalt types has not necessarily been completed, because some small samples have not been adequately characterized and yet seem to be distinct. The olivine-normative and quartz-normative mare basalts are distinct in major element chemisty, yet have indistinguishable ages and isotopic systematics, and almost identical trace element patterns. The proper interpretation of this puzzling feature has never been addressed, yet surely is of deep significance for the petrogenesis of mare basalts in general. Several geochemists have suggested on the basis of small differences in trace element ratios that the two main mare basalts have sub-groups. If the existence of these sub-groups is verified, they have import for mantle processes or assimilations. Hadley Rille formation might include assimilation if it incorporated downcutting. Can recent suggestions that terrestrial komatrites assimilated older flows guide us in interpretations of Hadley Rille and the chemistry of the mare basalts? Where are the source vents for the lavas and what are they like? If the vents are some distance away, then it is quite likely that surface fractionation has occurred and that the magmas as erupted have not been sampled. If the flows came any great distance, one might not expect volatiles in sufficient abundance to have created the 30 to 40% vesicularity of many of the olivine-normative mare basalts. What were the volatiles and where did they come from? What is the basalt distribution and stratigraphy? Did the olivine-normative basalts form as a spill over from the rille? Several cooling rate studies, some rather quantitative, have been made on the mare basalts. Can these shed further light on the volcanic flooding history of the landing site?

Green glasses which are volcanic pyroclastics are common, apparently more so on the Apennine Front. On stratigraphic grounds they would appear to predate the lava flows and mantle the Apennines, although their radiometric ages are undistinguishable from the mare lavas. Green glass occurs as friable clods, some rather pure and likely to represent original deposits, yet the stratigraphy of green glass, the nature of eruptional mechanisms, depositional processes, and ultimate origin are still poorly known. Several slightly but significantly different compositions exist, but we do not yet know how they are related to each other, or whether they were deposited sequentially or simultaneously. Whether a single near-pure clod of glass contains one or more than one group has not been established; the relevant analytical work has not yet been performed. Other pyroclastic glasses, yellow and red, disseminated at the site are even more poorly understood. Relationships among glass groups and other geologic units have not been deciphered because of a lack of data on trace element chemistry, ages and radiogenic isotopic ratios, and stratigraphic context.

Lavas are probes of the lunar interior, but how so is subject to interpretation. The pyroclastic glasses would appear to be the magma as extruded, hence the most primitive and more direct probes. However, even their interpretation requires assumptions about multiple or single phase saturation, fractionation during ascent, and wall-rock interactions. Their chemical and trace element chemistries can be and are being studied to place constraints on interior processes and mantle melting. Volatile species within the glasses are currently under investigation as guides to the lunar interior and lunar formations. Volatiles on the surfaces contain primitive lead and indicate the presence of primitive volatile reservoirs within the moon. For lavas, the problem is compounded in that they are more fractionated and the lava even as it first arrived at the lunar surface cannot be unequivocally established. But a wide variety of mantle derived materials is present at the Apollo 15 landing site and in synthesis can provide a useful guide to the composition, variation, and origin of the lunar mantle at a single spot.

The conjunction of the older steep highlands and younger flat mare makes the Apollo 15 site particularly appropriate for examining post-mare regolith development, the roles of lateral and vertical mixing, and talus development. This requires a critique and comparison of geochemical mixing models and their reality, and input from remotely-sensed data of areas further afield. Drill cores can be especially useful; one drive-tube, collected at Spur Crater, has not yet been opened. Regolith at the lip of Hadley Rille is very thin, and this may be the only site on the moon where bedrock blocks have been sampled almost in situ. What can compositional chemistry of regolith glasses tell us about the target and the glass-forming process?

A number of "recent" cratering events may be studied at the Apollo 15 site. Specific ray materials can possibly be identified among samples, if adequate criteria can be developed. Do exotic rocks (e.g., 15405) record major impact events, perhaps related to Aristillus or Autolycus? If ray deposits within core and drill sections are identifiable, perhaps we can use this information to decipher the mechanisms of ray deposition. The geology of the South Cluster has the potential to tell us about the formation of large secondary craters.

Apollo 15 is an important lunar site, at which a remarkably complete lunar stratigraphic section may be studied. Aspects of all major lunar processes may be profitably studied from this single location. The Workshop should stimulate the kind of high-quality work that the Apollo 16 Workshop induced a few years ago. With it, an improved understanding of lunar geologic processes and history will be achieved.

Workshop on the Geology and Petrology of the Apollo 15 Landing Site
Preliminary Agenda
(K = Keynote Talk)

Day 1 - Wednesday, Nov. 13, 1985

Overview of the Apollo 15 Landing Site
Chairmen: To be announced

	Introduction	G. Ryder and P. Spudis
K.	Geologic Setting of the Apollo 15 Landing Site	D. Wilhelms
K.	Remote-sensing of the Hadley-Apennine Region	R. Hawke
K.	Apollo 15 Field Geology	G. Swann
K.	Types and Distributions of the Apollo 15 Samples	G. Ryder
K.	Crew Observations	D. Scott, J. Irwin, J. Allen

- Lunch -

Topic 1. Apennine Front Rocks and Their Sources
Chairman: O. James; Summarizer: J. Papike

K.	Petrology and Geochemistry of Highland Samples from the Apennine Front	M. Lindstrom

Contributed Papers and Discussion.

Topic 2. Apollo 15 KREEP Basalt
Chairman: R. Dymek; Summarizer: P. Warren

K.	Geology and Petrogenesis of Apollo 15 KREEP Basalts	G. McKay

Contributed Papers and Discussion.

- end Day 1 -

Evening: Keg Session and Videotapes of Apollo 15 EVAs.

Day 2 - Thursday, Nov. 14, 1985

Topic 3. Apollo 15 Perspective on Lunar Basins

Chairmen: R. Grieve; Summarizer: J. Taylor

K. The Formation and Materials of the Imbrium Basin — P. Spudis

Contributed Papers and Discussion.

Topic 4. Mare Volcanism at the Apollo 15 Landing Site

Chairman: G. Lofgren; Summarizer: L. Taylor

K. Morphology of Volcanic Landforms at the Hadley-Apennine Region — R. Greeley

K. Apollo 15 Volcanic Rocks and Their Relation to Stratigraphic Units — T. Grove (?)

Contributed Papers and Discussion.

- Lunch -

Topic 5. Mare Rocks and Their Implication for the Mantle Beneath the Apollo 15 Site

Chairman: M. Drake; Summarizer: To be announced

K. Pre-eruption History of Apollo 15 Magmas — J. Delano

Contributed Papers and Discussion.

Topic 6. Post-mare Cratering and Apollo 15 Regolith Evolution

Chairman: D. Morris; Summarizer: A. Basu

K. Geochemistry of the Apollo 15 Regolith — R. Korotev

K. Regolith Dynamics at the Apollo 15 Site — D. McKay

K. Ray Emplacement, Secondary Cratering and Apollo 15 Exotic Samples — P. Schultz

Contributed Papers and Discussion.

- end Day 2 -

Day 3 - Friday, Nov. 15, 1985

Topic 7. Utilization of the Apollo 15 Site
Chairman: M. Duke

K. Lunar Base Potential of the Apollo 15 Site — H. Schmitt

Contributed Papers and Discussion.

Topic 8 Major Problems for Future Research
Chairmen: G. Ryder and P. Spudis

- Summarizers review and identify outstanding problems and approaches to their solution

- Open Forum for all Workshop attendees

- Potential Consortia approaches and formation

- adjourn, 12:00 p.m. -

LPSC XVI LUNAR SAMPLE FIELD TRIPS A BIG SUCCESS

The lunar sample field trips offered by the Lunar Sample Curator and his staff during the Lunar and Planetary Science Conference were very well attended. More than 70 individuals visited the Lunar Sample Preparation Laboratory during seven tours: a rehearsal with a Space Science class from the University of Houston, one trip each day during LPSC XVI, and a post-Conference trip for JSC employees. The attendees included scientists from Austria, France, Germany, Japan, Spain, and the USSR, in addition to the United States. Many had studied samples from the laboratory.

Cut surfaces of five lunar breccias (14303, 60016, 60019, 72255, and 72275) were displayed in the nitrogen filled processing cabinets. One or two new slabs had been cut from each sample. Each NSI Lunar Sample Processor who prepared maps and clast descriptions of a breccia presented a brief description of the sample. Participants in the lunar sample field trip then had an opportunity to observe the displayed surfaces and discuss the rocks with the processor who had worked with it. Binocular microscopes were available for detailed observations.

Collections of 1 to 2 mm particles sieved from two lunar soils were displayed in another cabinet. An investigator had sorted the particles into groups of similar lithology while searching for rocklets that supported his investigation. These were displayed as examples of another resource available to support the search for new types of lunar rock.

NEXT LAPST MEETING WILL BE NOVEMBER 16-18, 1985

The Lunar and Planetary Sample Team (LAPST) met at the Lunar and Planetary Institute June 7-9, 1985. LAPST reviewed ten requests for lunar samples and recommended allocation of 129 samples weighing 100.4 grams and 40 thin sections to eight investigators. LAPST endorsed the Curator's recommendation for allocation of 13 samples weighing 5.5 grams and 52 thin sections to eight investigators in response to lunar sample requests received between the February and June meetings.

Investigations related to the Apollo 15 workshop and the Highland Initiative requested signficant allocations. Samples supporting two new studies, (1) germanium in lunar basalts and (2) spectral reflectance of lunar material, account for more than half of the pristine sample mass recommended for allocation.

Two additional slabs will be sawed to support consortium studies of two Apollo 14 rocks; two other rocks were identified as candidates for sawing in the continuing program of opening new surfaces to support the search for new rock types in the lunar samples. The continuing search for zircon crystals that are suitable for age dating and the search for additional types of lunar glass accounted for all of the recommended allocations of returned samples.

Other requests supported:

- o determination of Be10 distribution in the Apollo 17 regolith
- o studies of the abundance of Ni in lunar olivine
- o upgrade of the educational thin section packages.

LAPST will next meet November 16-18, 1985; the following meeting is tentatively scheduled for February 22-24, 1986. We encourage you to submit requests well ahead of the meeting so that adequate background materials can be assembled to support the LAPST deliberations. Your requests are welcome at any time; some allocations can be recommended by the Curator between LAPST meetings.

STUDY OF NEW BRECCIA SURFACES CONTINUES

Breccias are objects of active study by several investigators because breccia clasts include types of rock that are not represented as large rocks in the Apollo collection. LAPST supports a program of sawing large breccia samples to expose new clasts for study. Descriptions of representative clasts and maps of the new surfaces of four rocks (60016, 60019, 72255, and 72275) have been published in recent newsletters. These four and breccia 14303 were available for observation by Lunar Sample Field Trip participants during Lunar and Planetary Science Conference XVI.

Descriptions of the new surfaces of breccia 14303 have been completed since the Lunar and Planetary Science Conference. Several types of clasts are distinguishable with the aid of a binocular microscope. R. Martinez has mapped the distribution of each type of clast on the new surfaces and has described typical examples. His report "Mapping of Breccia 14303" is Appendix I of this newsletter.

At the June meeting, LAPST recommended sawing an additional slab from each of four rocks. Two of these (14305 and 14321) are allocated for consortium studies. The other two (15459 and 15498) are being cut to support the Apollo 15 studies.

Breccias 14303, 60016, 60019, and 72255 are available for study. Requests for consortium study will receive priority; but requests from individual investigators are encouraged, also.

UPCOMING DATES OF INTEREST

1985

July 11-13	Antarctic Meteorite Workshop, Mainz, West Germany
July 16-19	Annual Meeting, Meteoritical Society, Bordeaux, France
August 5-9	Symposium: Microbeam Analysis Techniques in the Study of Lunar, Meteorite and Cosmic Dust, Louisville, KY
August 31	Deadline for receipt at the LPI of proposals to the Planetary Materials and Geochemistry and Planetary Geology and Geophysics Programs
October 10-12	LPI Conference on Heat and Detachment in Crustal Extension on Continents and Planets, Sedona, AZ
October 28-31	GSA Annual Meeting, Orlando, FL
November 13-15	Workshop on the Geology and Petrology of the Apollo 15 Landing Site
November 16-18	LAPST Meeting, Lunar and Planetary Institute
December 9-13	AGU Fall Meeting, San Francisco, CA

1986

February 22-24	(tentative) LAPST Meeting, Lunar and Planetary Institute
March 17-21	Lunar and Planetary Science Conference, JSC

APPENDIX I

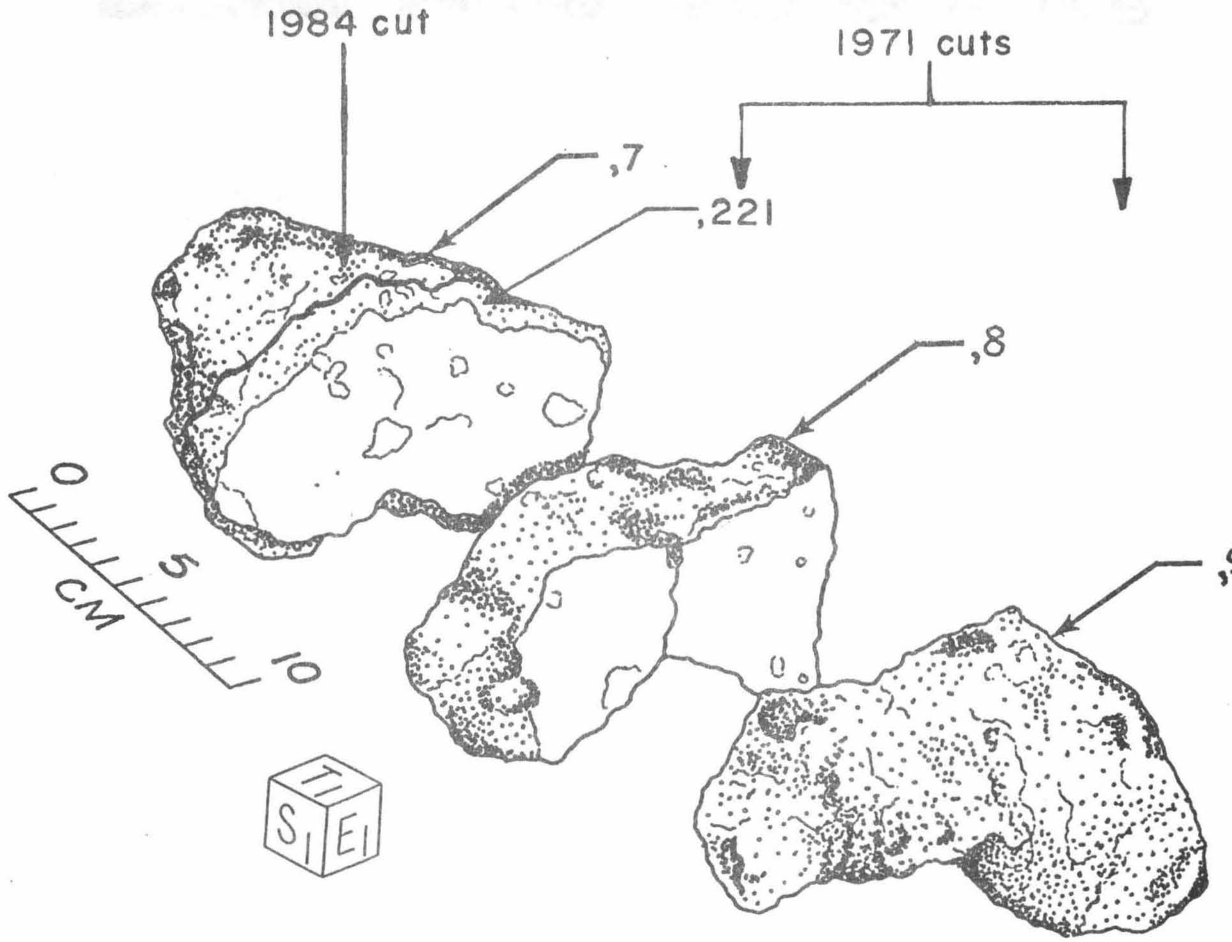
MAPPING OF BRECCIA 14303

Sample 14303 is one of two pieces (14303 and 14304) collected as a single rock. Both have been extensively subdivided and sampled. The rock is friable, subrounded, and has zap pits on all sides except on its fresh broken surface. It is a strongly annealed, (thermally metamorphosed) shocked breccia with a holocrystalline matrix.

The matrix intrudes fractured clasts often making clast boundaries indistinct. The majority of clasts are grey, very fine-grained micro-breccias. One to two percent are light colored, subrounded feldspar clasts and a few are basaltic rocks.

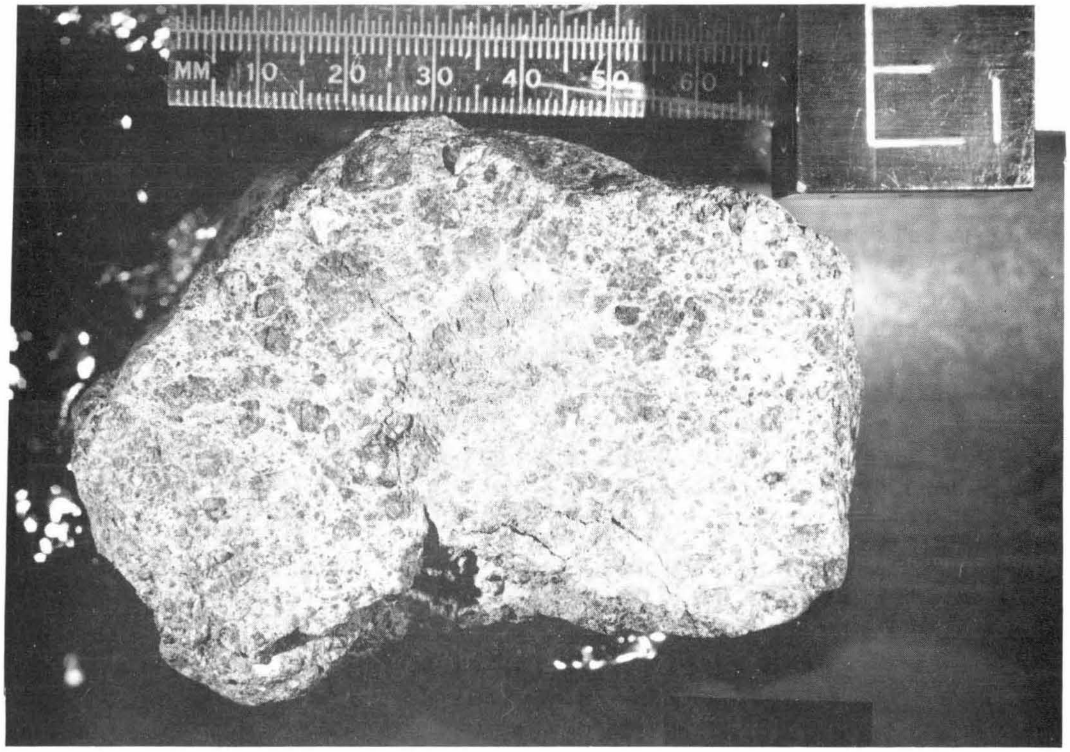
The weight of 14303,7 before slabbing was 461.8g. The cuts that produced slab ,8 and butt end ,9 were made in 1971. Recently, a second slab was cut parallel to the East face of ,7. Maps of the newly exposed faces have been drawn from photographs and laboratory observations in order to document the character and distribution of clasts and to facilitate their identification for sample requests.

THE CUTTING OF 14303



APPENDIX I

,221 EAST FACE



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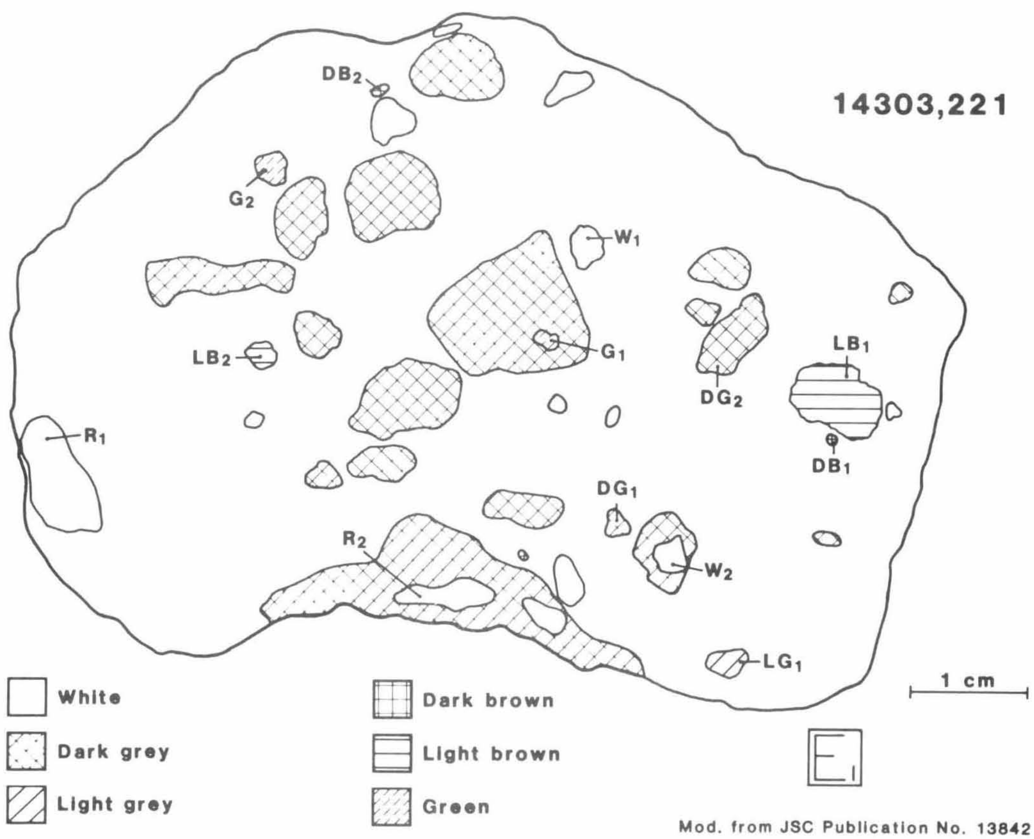


Mod. from JSC Publication No. 13842

APPENDIX I

MODIFIED MAP OF ,221 EAST FACE

The face now referred to as ,221 E face was mapped as ,7 in 1978. See JSC Publication No. 13842 "Lithological Maps of Selected Ap. 14 Breccia Samples" page 40.

The map has been modified to reflect changes resulting from allocations and other processing operations.

R1 White clast removed in January of 1981 as sample no. 14303,204. This was entirely subdivided as follows:
,205 0.054g clast material allocation for thin section ,209
,206 0.072g clast material allocation
,207 0.229g in stock of which 0.046g is estimated to be clast material.
Approximately 0.05 to 0.10g clast material remains in ,221 East face.

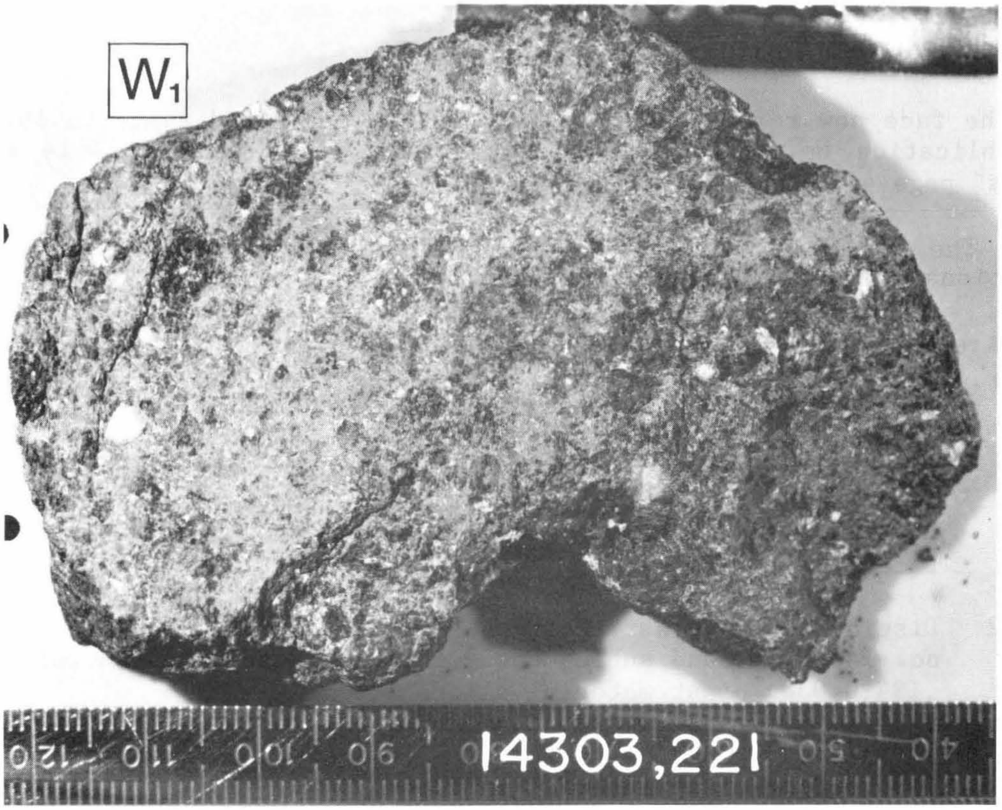
R2 Distinct white clast. Most was removed in April of 1979 as sample no. 14303,193 and subsequently entirely subdivided as follows:
,194 0.038g clast material allocation
,195 0.029g clast material allocation for thin sections ,198 and ,199
,196 0.015g clast material in stock.
The remainder of host micro-breccia crumbled out during most recent sawing of ,7 and is part of chips and fines from that operation.

W1 Most of this white clast was extracted in October of 1982 and allocated as ,217 (0.016g) . About 0.015g remains in ,221.

W2 This white clast within a grey micro-breccia was extracted and split as follows:
,218 0.017g clast material allocation
,220 0.065g grey micro-breccia host matrix remains in stock.

APPENDIX I

,221 WEST FACE



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APPENDIX I

,221 WEST FACE

W1 2x2 mm. White clast with distinct boundary. Mode is approximately 70% chalky white plagioclase and 30% comparatively vitreous plagioclase or pyroxene.

W2 4x4 mm. White clast with distinct boundary. Very fine-grained plagioclase with mafic silicate "vein" and what appears to be a reaction rim along contact with matrix.

W3 2x2 mm. White clast within grey breccia clast GB1. Appears monomineralic, slightly translucent to white, euhedral plagioclase.

W4 3x2 mm. Same as W3.

G1 2x2 mm. Green clast with indistinct boundary. Small and incoherent. Mode is approximately 90% green vitreous mineral (olivine?) and the remainder may be plagioclase with black flakes of opaque mineral (ilmenite?).

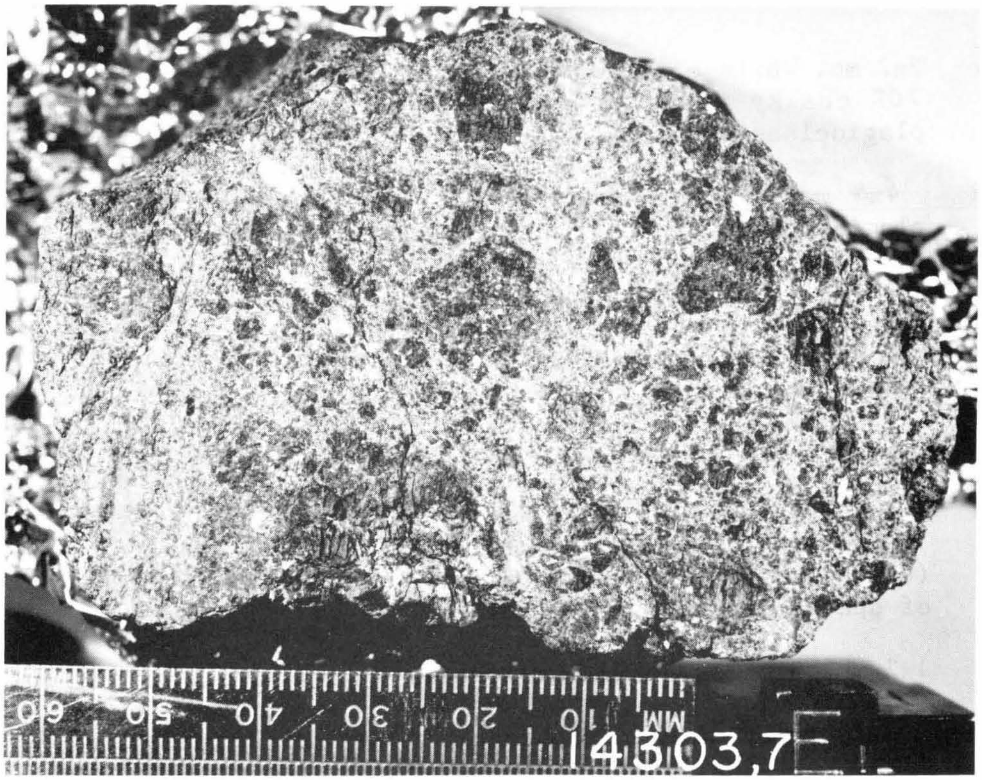
G2 1x2 mm. Similar to G1 but lighter in color, almost yellow.

GB1 10x15 mm. Grey microbreccia clast with indistinct boundary. Clasts of plagioclase and plagioclase with pyroxene up to 3mm.

LB1 2x3 mm. Light brown clast with indistinct boundary. Approximately 60% white plagioclase and 40% light-brown pyroxene. Appears brecciated.

LB2 3x2 mm. Same as LB1.

,7 EAST FACE



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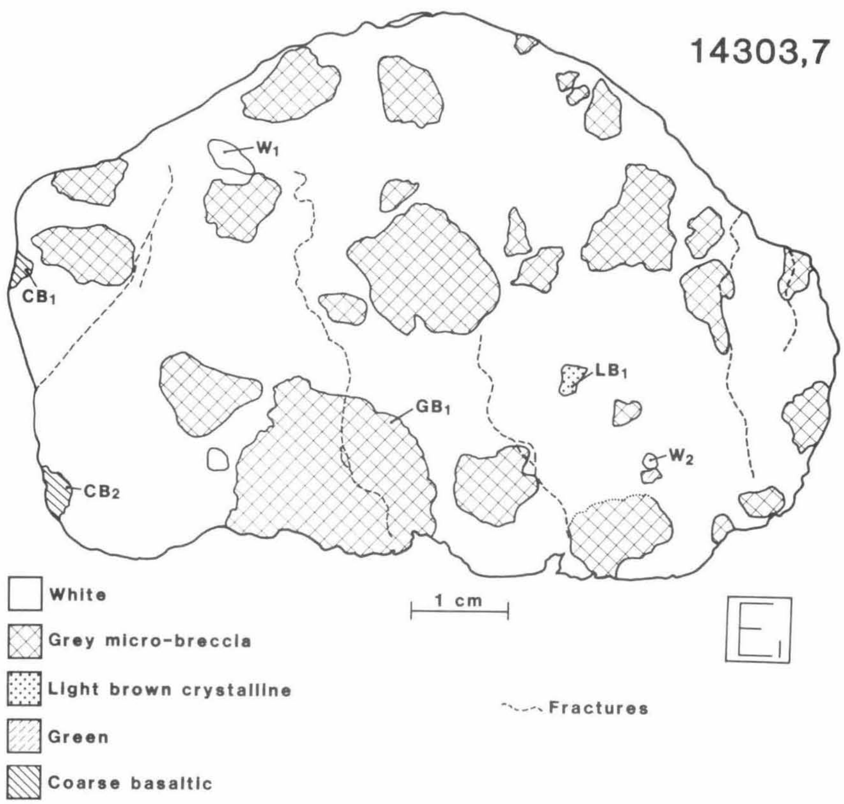

APPENDIX I

,7 EAST FACE

CB1 4x4 mm. Distinct, light-colored clast. Coarse grained (1mm.) Mode is about 50% honey-brown to grey mafic silicate (probably pyroxene), 45% chalky white plagioclase, and 5% dark grey material (opaque mineral grains?).

CB2 5x5 mm. Same as CB1.

W1 5x3 mm. Distinct ovoid white clast. Mostly white milky plagioclase with approximately 30% relatively vitreous, translucent mineral, possibly pyroxene. One zone of segregated mafic silicate grains along clast-matrix boundary. Also, one small (<1mm.) metallic bleb with white, lustrous sheen in plagioclase.

W2 2x2 Granular, fine grained, plagioclase rich.

LB1 2x4 Light brown clast with indistinct boundary. Approximately 60% light brown pyroxene, 30% grey plagioclase or pyroxene and 10% opaque mineral grains. Very fine grained.

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