JSC# 24035

The Apollo 15 Coarse Fines (4-10 mm)

NASW-4066

Graham Ryder
Sarah Bean Sherman
Lunar and Planetary Institute

Solar System Exploration Division
Planetary Science Branch Publication #81

December 1989

NASA
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Introduction:

In 1972 Benjamin N. Powell made a particle-by-particle examination of all of the Apollo 15 4-10 mm fines samples that had been sieved from bulk regolith samples. He classified and grouped the particles according to their observable lithologic features in order to provide a basis for sample allocations and study. The results of his study were published as "Apollo 15 Coarse Fines (4-10 mm): Sample Classification, Description, and Inventory" by the National Aeronautics and Space Administration, Manned Spacecraft Center document MSC 03228 (91 pp., February 1972), by Benjamin N. Powell.

Since Powell's publication, many of the particles were thin sectioned, and petrographic and other studies, particularly chemical analyses, have been performed (some by Powell himself). These studies are thinly spread through the lunar literature, and some data was not published. Since then a greater understanding of the lunar rock types has also developed. For instance, KREEP basalts were recognized among the Apollo 15 samples (particularly among these coarse fines), and new, more useful names for particular rock types have supplanted older names (e.g., most of Powell's "microbreccias" are now "regolith breccias". It is clear that Powell's publication, while providing descriptions of the particles, is inadequate as a basis for planning new studies of the Apollo 15 coarse fines particles or for understanding the nature of the materials in the collection. Therefore, we have made this new catalog of the Apollo 15 coarse fines particles, relying on Powells macroscopic descriptions and retaining his groupings, but incorporating petrographic, chemical, and other data to better characterize individual particles and describe the groups. There remain a large number of particles for which no characterization has been made further than Powell's original catalog. In this catalog, the name "Powell" is commonly used and refers to the original catalog.

Numbering system, particle designations, and descriptions:

Apollo 15 samples numbered 15xx0 are unsieved regolith samples, except for some rake samples (153x0 and 156x0). Portions of some of these regolith samples were sieved, and the sieve fractions in the size range 4-10 mm are designated 15xx4. (Particles larger than 1 cm are numbered as individual rocks; 2-4 mm fractions are 15xx3, 1-2 mm are 15xx2, and <1 mm are 15xx1). Powell subdivided the 15xx4 coarse fines fractions according to their macroscopic appearance; thus 15024,1 was 10 microbreccia (now regolith breccia) particles. Some groups consist of only one particle.

In this catalog, where possible, an individual particle has been designated by an individual number. Ideally this is the number first given to a single particle when it was separated from its parent group; for instance, 15024,11 was a single particle separated from the group of particles 15024,4, and subdivisions are easily traced with 15024,11 as a parent particle. However, processing numbering was not always so simple: in some cases, several split numbers for a particle were produced simultaneously, and in others a chip of a particle was allocated but the particle not removed (and hence usually not identified) from the parent group. In these cases, the lowest split number used on a particular particle is used in this catalog as the particle designation.

At the beginning of each bulk coarse fines sample description in this catalog there is a generic tree for the sample. This is divided into four columns: group, individual particle, subsamples of individual particles, and thin sections of individual particles.

These differ in several details from the generic listings available in the Curatorial files, mainly because the processing documentation frequently jumped steps i.e. ascribed a subsample to the group (or even to the parent ,0) instead of to an individual particle. In other cases these curatorial trees are merely in error because of typographical or recording mistakes. We have derived the trees in this catalog from a detailed search of the processing records available in the Curatorial Data Center at the Johnson Space Center and consider them to be the most accurate. These generic trees should make tracing the relationships among subsamples and allocation requests comparatively simple.

In the descriptions of groups, the heading line gives the group number designation, a name for the group, the number of particles that are in the group (some may since have been removed as individual particles), and the mass of the group as it now exists under that particular designation. If there is a mass given in parentheses, that is the mass that the group originally was prior to any subdivisions.

The descriptions of individual particles are indented 10 spaces compared with the descriptions of the groups. The heading line similarly gives the particle specific number, a name for the particle (usually more precise than the group name, because most specific particles have been at least thin-sectioned), and the mass of the split that bears the particle number. If there is a mass given in parentheses, that is the mass that the particle orginally had, prior to any subdivisions.

We have attempted to provide fairly complete descriptions of the particles in this catalog, with all known references included. For almost all of those that have been sectioned, a photomicrograph is included. All published chemical data is included, and we are grateful to those colleagues who provided us with unpublished information. Some work on some of these particles is currently being performed and some is planned. Most of the work in this catalog referred to as Ryder (unpublished) is intended to be published in the near future. The catalog is intended to be used by researchers requiring sample allocations, and thus has a planned obsolescence. It also is intended to be useful to those interested in finding out what is known about the rock types collected by Dave Scott and Jim Irwin in the Hadley-Appenine region.

Acknowledgements:

Sarah Bean Sherman worked on this catalog under the Summer Intern Program of the Lunar and Planetary Institute, as an undergraduate student from Boston University, Massachusetts. The Lunar and Planetary Institute is operated by the Universities and Space Research Association under contract # NASW-4066 with the National Aeronautics and Space Administration.

We are grateful for the support of personnel in the Curatorial Data Center at the Johnson Space Center, particularly Jenny Selzer and Lee Smith, in thin section library, data pack research, and photograph retrieval work. We are also grateful for those colleagues (listed in the text) who provided unpublished data.

APOLLO 15 COARSE FINES (4-10 mm)

15024 Station LM 3.6g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (0.36g)			
,1 (2.64g)			
,2 (0.28g)			
,3 (0.15g)			
,4 (0.19g)	,4 (0.19g)	,14 (0.02g, Geiss)	
	,11 (0.127g, RSV)	,12 (ES, Powell)	,18 (15999,98)
		,19 (CONS, Powell)	
		,13 (CONS, Haskin)	

15024,0 Fines and friable clods 0.36g

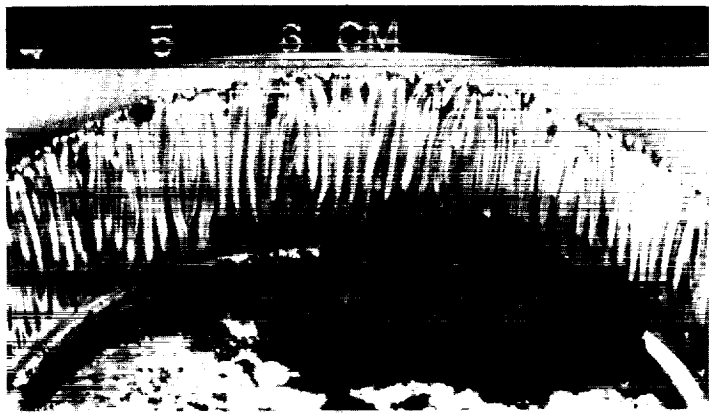


Fig. 1 15024,0 S-72-15960

15024,1 Regolith breccias 10 particles 2.64g

The particles are friable medium gray regolith breccias lacking conspicuous white clasts. They are subrounded to rounded. They do not appear to be identical. They have never been allocated.

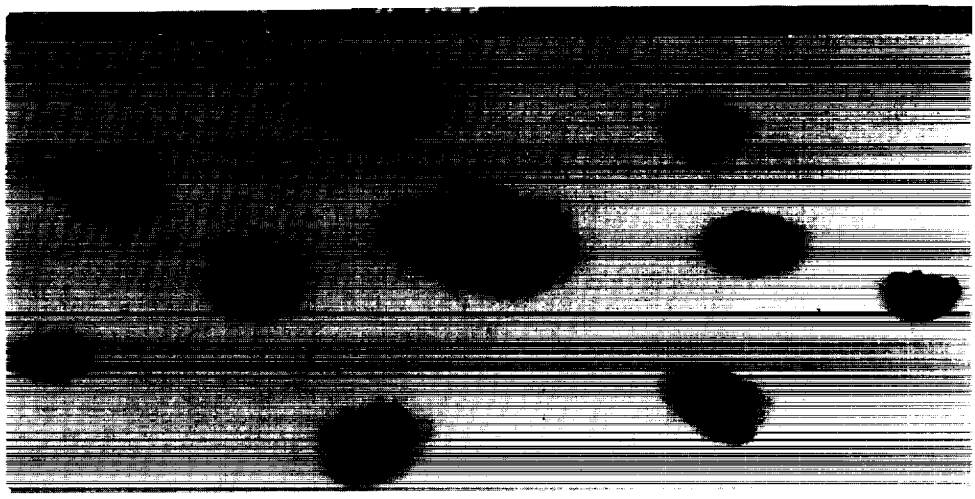
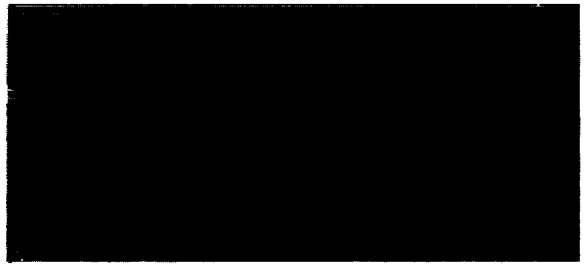


Fig. 2 15024,1 S-72-16208

15024,2 Non-mare crystalline breccias (?) 2 particles 0.28g

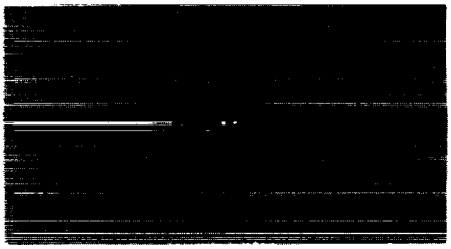
These two particles are subangular to subrounded, tough, and fine-grained crystalline rocks. They are medium- to light-gray and rather granular. They may be impact melts or granulitic breccias; no thin sections have been cut or other allocations made.

Fig. 3 15024,2 S-72-16207



15024,3 Agglutinate/Glass 1 particle 0.15g

15024,3 Agglutinate/Glass 1 particle .15g



The particle is dominantly a vesicular dark glass, probably with some regolith breccia attached. It has never been allocated.

Fig. 4 15024,3 S-72-16206

15024,4 Mare basalt and KREEP basalt 2 particles 0.19g (0.41g)

Powell described the two particles as being olivine basalts (i.e. mare basalts), macroscopically similar to particles in 15604,3 (at least some of which are mare basalts, as expected from their St. 9a location). However, the particle taken from ,4 and numbered ,11 is a KREEP basalt fragment; the other remaining as ,4 probably is a mare basalt.

15024,4 Mare basalt (?) 1 particle 0.19g (0.21g)

The particle is dark and quite different macroscopically from ,11. It contains obvious prismatic dark crystals, probably pyroxenes, in a much finer-grained groundmass. It is probably a quartz-normative mare basalt. The only allocation was a small fragment for radiogenic isotope studies and no data have been reported.

Fig. 5 15024,4, from S-71-60185. Scale bar about 5 mm.

15024,11 KREEP basalt 1 particle 0.127g (.21)g

The particle is shown in Fig. 6. It is a KREEP basalt, as shown by its petrography (Fig. 7) and its partial chemical analysis (Table 1, Fig. 8; Helmke et al.,1973). Powell et al. (1973) described the fragment as a highly-degraded glass-rich material, apparently confusing it with 15404,3,17. In reality it is a coarse KREEP basalt; the thin section is poor and most of the mesostasis patches have been plucked (Fig. 7). No microprobe data have been reported.

Fig. 6 15024,11, prior to dissection. From S-71-60185. Scale bar about 5mm.

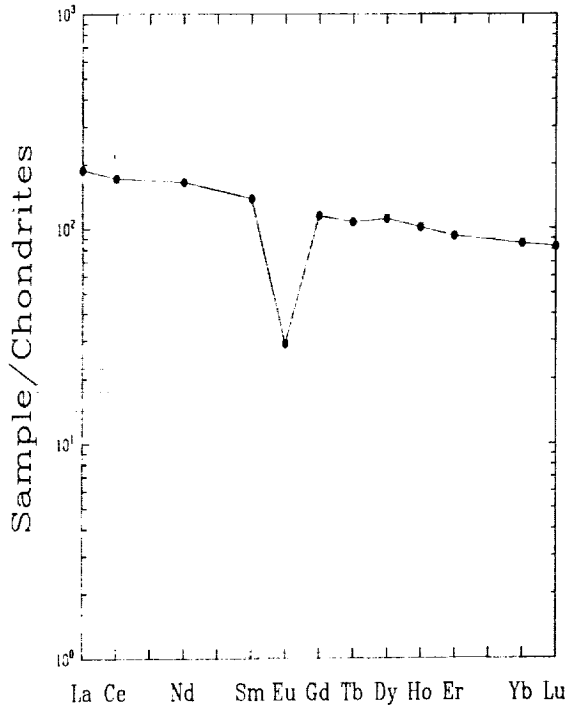
Fig. 7 Photomicrograph of 15024,11,18, compounded on 15999,98. Plane light, field of view ~ 1 mm wide.

Table 1. Helmke et al. (1973), Helmke and Haskin (1972); RNAA. ppm 15024,11,13 (25 mg).

Sc	22.4
Co	21.4
Hf	19
La	69
Ce	164
Nd	117*
Sm	31.8
Eu	2.53
Gd	35
Tb	6.16
Dy	42.6
Ho	8.6
Er	23
Yb	21.1
Lu	3.14

* incorrectly listed as 177 ppm by Helmke et al. (1973).

Fig. 8 Chondrite-normalized plot of rare-earths in 15024,11,13. Data of Helmke and Haskin (1972), Helmke et al. (1973).



15034 Station 8 7.0g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (3.5g)			
,1 (0.73g)	,1 (0.73g)	,16 (ES, Powell)	,22 (15999,97)
		,23 (CONS, Powell)	
		,17 (0.015g, RSV)	
		,18 (0.02g, Turner)	
,2 (1.0g)			
,3 (1.47g)			

15034,0 Fines and several undescribed particles. 3.5g

15034,1 Olivine-normative mare basalt 1 particle 0.73g (0.78g)

15034,1 Olivine-norm mare basalt 1 particle 0.73g (0.78g)

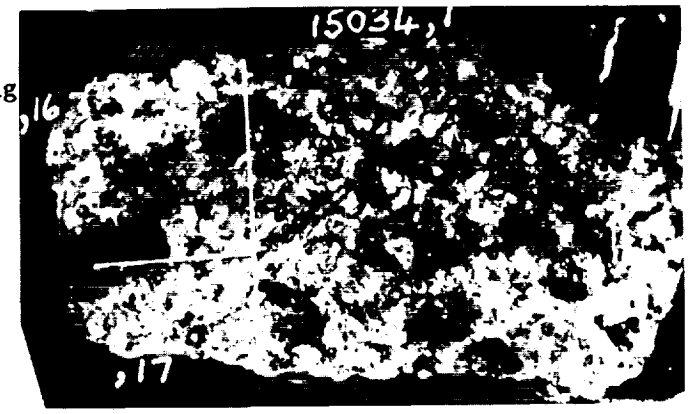


Fig. 1 Initial splitting of 15034,1 (data pack photo). Lines are schematic.

Fig. 2 Photomicrograph of 15034,16,22, compounded on 15999,97. Plane light, field of view ~ 1mm wide.

15034,1 is a light brown vesicular mafic basalt (Fig. 1). The only thin section (,16,22; in 15999,97) is very poor, being badly plucked and wedged (Fig. 2). It is a pyroxene-rich basalt with a grain-size of about 0.5mm, with some plagioclase laths, minor opaque minerals including chromite, and at least one equant olivine core to a pyroxene. Grain boundaries are sharp and smooth, and little silica or mesostasis is present, giving the basalt a granular or microgabbroic texture. This sample was listed as studied by Powell et al. (1973), but they provided no specific information. It is presumably a medium-grained olivine-normative mare basalt.

Powell described the particle as a medium- to coarse-grained granular basalt with an equigranular xenomorphic-granular texture, containing anhedral cinnamon-brown pyroxene (~60%), subhedral to anhedral white plagioclase (~40%), greenish-yellow olivine (~1%), and minor opaques. He also noted the vugs into which euhedral prisms of brown pyroxene and white blades of plagioclase projected. He stated the grain size as 0.25-0.5 mm. Although he listed 15034,1 as having two particles, it consisted only of one particle, which was chipped as shown in Fig. 1.

15034,2	Regolith breccias	5 particles	1.00g

Powell described 15034,2 as friable to coherent, medium gray microbreccias consisting of lithic, mineral, and glass fragments of varied size and shape in a very fine-grained matrix. The lithic fragments are not abundant, and include granular basalts and feldspar-rich materials. One of the particles contains a 3x5mm lithic clast rich in pale green material, either olivine or glass. No allocations of ,2 have been made.

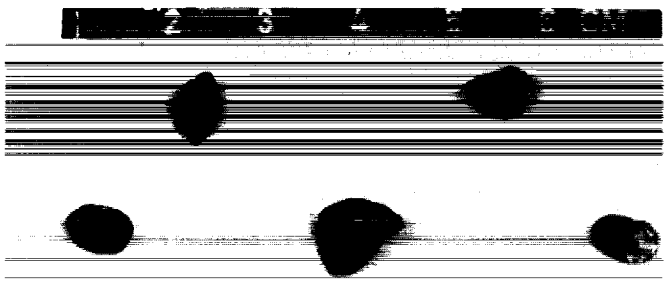


Fig. 3 15034,2
S-72-15486

15034,3 Glass-coated regolith breccias 6 particles 1.47g

Powell described 15034,3 as particles essentially similar to those in 15034,2, except that they have thin splash glass as partial coats. The glasses are vesicular and dark brownish-gray to yellowish-brown. Although Powell listed ,3 as five particles, there are six (Fig. 4). No allocations of ,3 have been made.

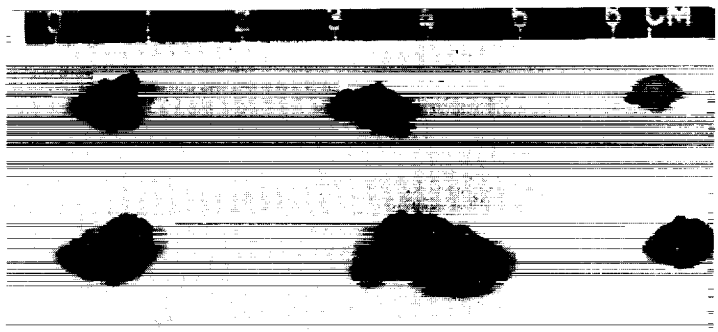


Fig. 4 15034,3
S-72-15488

15044 Station 8 1.5g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (0.33g)			
,1 (0.84g)			
,2 (0.18g)	,2 (0.18g)		

15044,0 Fines 0.33g

15044,1 Glass-coated regolith breccias 4 particles 0.84g

These particles are subangular to subrounded, friable to coherent regolith breccias which all have some splash glass coating. The breccias are medium to dark grey; the glasses are darker. They have never been allocated for study.

Fig. 1 15044,1. S-72-16204

15044,2 Mare(?) basalt 1 particle 0.18g

15044,2 Mare(?) basalt 1 particle 0.18g

The particle is a medium- to coarse-grained granular basalt with about 60% cinnamon brown pyroxene and 40% white plagioclase. A trace amount of a green mineral (olivine?) might be present. The sample has not been sectioned or allocated for study.

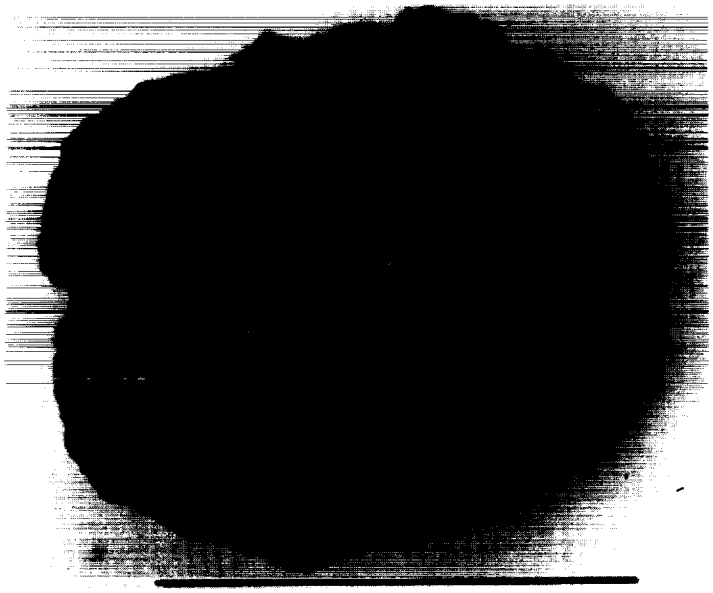
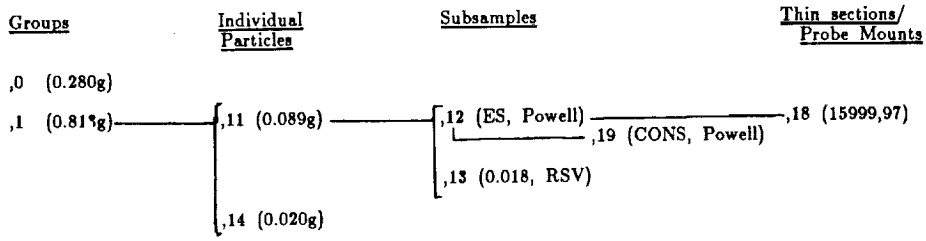


Fig. 1. 15044,2. S-71-60186. Scale bar is 5mm.

15074 Station 1 1.3g



15074 Fines 0.28g

15074,1 Mare basalts 3 particles 0.813g (1.03g)

Powell described the three particles as mottled light brown, subangular porphyritic olivine diabases (however, the only thin section lacks olivine, see below). The yellowish-green phenocrysts are tabular and subhedral and range in size from 3 to 5 mm. They constitute about 20% of the sample. The groundmasses are fine-grained (mean ~0.5mm) with subhedral to euhedral lath-like plagioclases (~40%), anhedral equidimensional reddish-brown pyroxenes (~40%), and anhedral ilmenite. The textures are intergranular to subophitic. One particle (,11) was subdivided (Fig. 2). From one of the others (without documentation) a chip (,14) was removed and allocated, but later returned unopened.

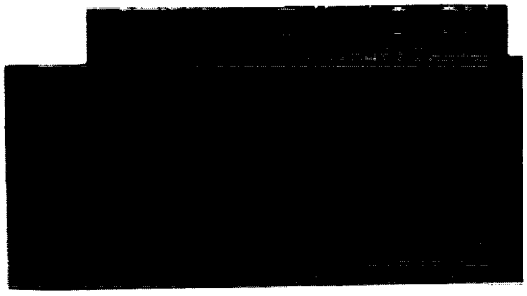


Fig. 1 15074,1 Original three particles.

Fig. 2 Initial splitting of 15074,11. Lines are schematic.

15074,11 Quartz-normative mare basalt 1 particle 0.089g (~0.145g)

15074,11 is a coarse-grained mare basalt with abundant reddish-brown zoned and twinned pyroxenes (Figs. 2 and 3). Larger grains of plagioclase are stubby/bladed, and smaller ones are euhedral laths. The texture is subophitic with little mesostasis material. In the thin section (,12,18 in 15999,97), minor tridymite and cristobalite are present with rare mesostasis glass(?) and a few opaque minerals. Powell identified yellowish-green phenocrysts of olivine but in thin section all the phenocrysts are pyroxenes. Powell et al. (1973) listed the sample in their group III olivine-cristobalite basalts; however, the thin section contains tridymite and lacks olivine. 15074,11 is probably a coarse-grained quartz-normative mare basalt.

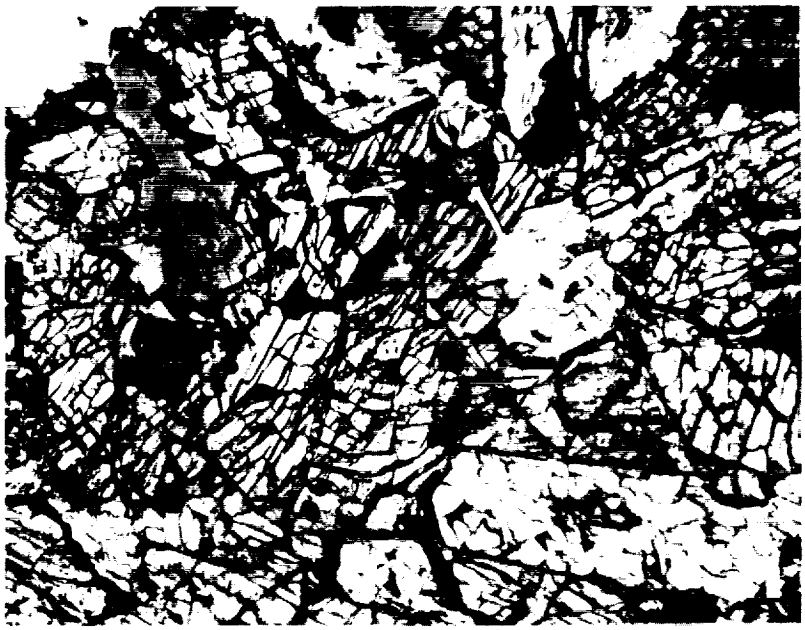


Fig. 3 Photomicrograph of 15074,11,12, compounded on 15999,97. Plane light, field of view ~1mm wide.

15074,14 Mare? basalt 1 particle 0.02g

15074,14 was split and allocated from one of the two particles remaining in 15074,1. There is no documentation of this processing, and no data were reported for the split, which was returned unopened.

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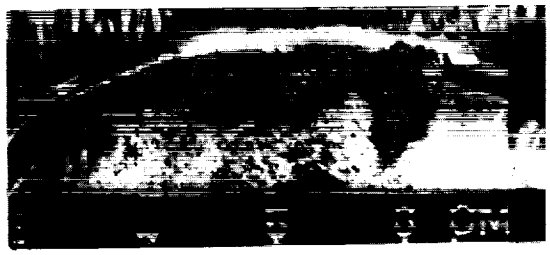
15084 Station 1 1.1g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (0.30g)			
,1 (0.33g)	,1 (0.33g)		

15084,0 Fines and fragments 0.30g

The sample appears to consist of a friable rounded regolith breccia and a few crystalline or glassy fragments, as well as degraded fines.

Fig. 1 15024,0 S-72-15958

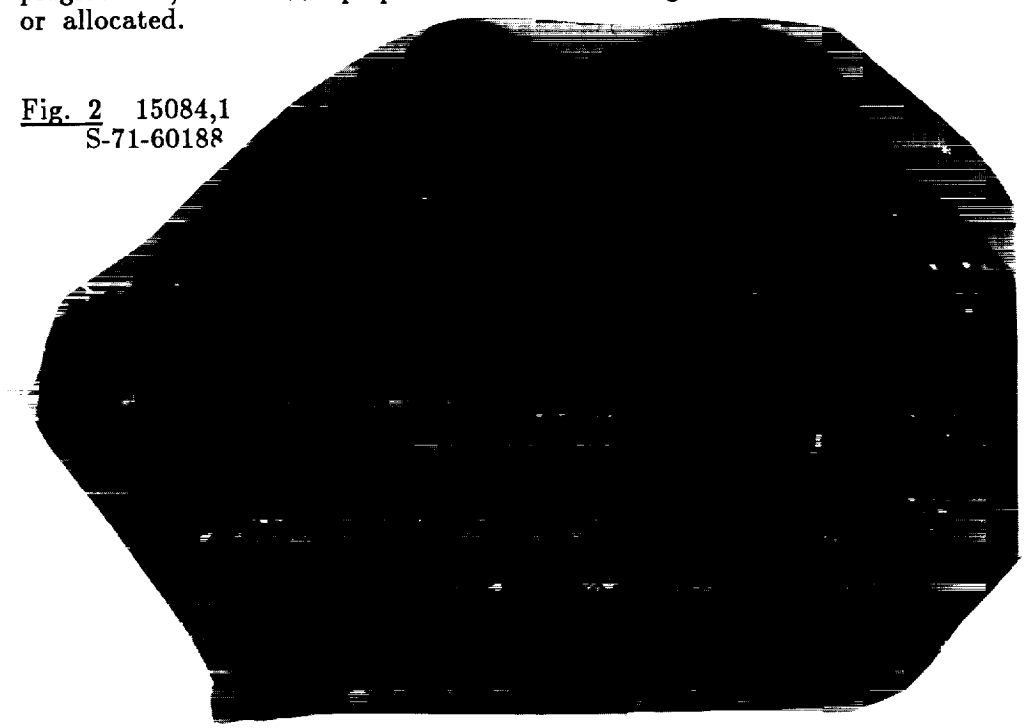


15084,1 Mare basalt 1 particle 0.33g

15084,1 Mare basalt 1 particle 0.33g

The fragment is tough and subangular. It is coarse-grained, with euhedral prismatic cinnamon-brown to orange-brown pyroxenes up to 5 mm in length, and plagioclases less than 2 mm long. The mean grain size of all silicates is 2-3 mm. Powell estimated 10% olivine, 50% pyroxene, 40% plagioclases, and ~1% opaque minerals. The fragment has not been sectioned or allocated.

Fig. 2 15084,1
S-71-60188



15104 Station 2 1.5g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (0.32g)			
,1 (0.79g)			
,2 (0.148g)	,2 (0.148g)	,4 (0.035g, Laul)	
		,5 (0.017g, PB)	,6

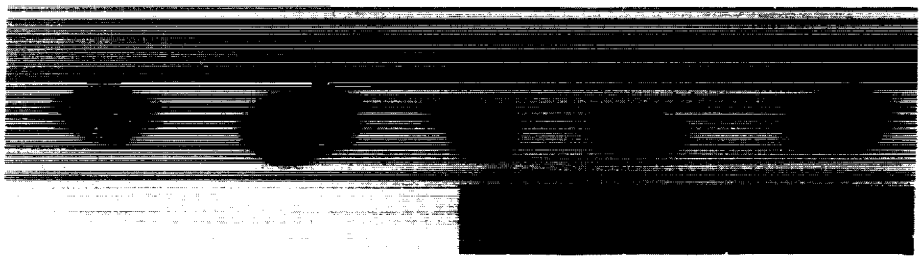
15104,0 Fines and undescribed particles 0.32g

Fig. 1 15104,0
S-72-15968

15104,1 Regolith Breccias 5 particles 0.79g

The particles are friable, subrounded to rounded regolith breccias. Some of them have partial coats of glass. Powell listed the particles as being similar to 15244,2 and 15244,6.

Fig. 2 15104,1
S-72-16200



15104,2 Olivine-normative mare basalt 1 particle 0.148g (0.21g)

15104,2 Olivine-norm mare basalt 1 particle 0.148g (0.21g)

15104,2 is a fine-grained olivine-normative mare basalt. It is a tough, subangular to rounded medium to light gray or tan crystalline rock. Powell listed it as being similar to 15434,5, but that is a collection of disparate particles. The particle has been subdivided (Fig. 3).

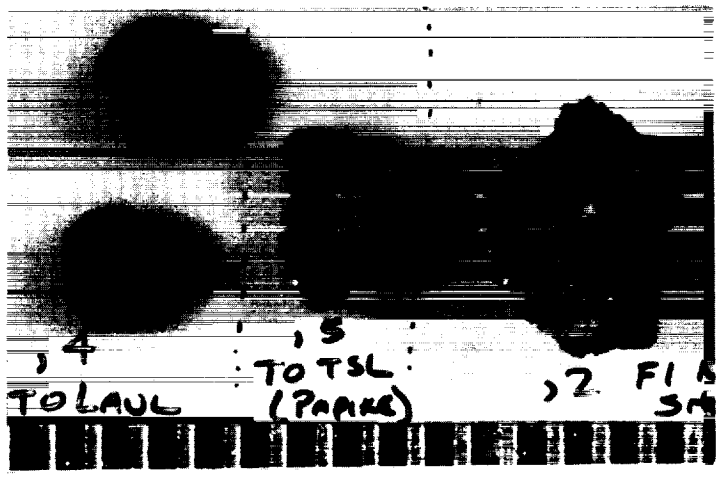


Fig. 3 Subdivision of particle 15104,2. (Data pack photo).

The thin section 15104,6 has an intergranular, subpoikilitic texture with a groundmass of pyroxenes (Fig. 4). Tabular, twinned plagioclase with irregular grain boundaries, and subhedral to anhedral olivines and opaques are dispersed throughout the thin section. The plagioclases range from laths to anhedral shapes with sharp contacts, some of which contain inclusions. There is a large zoned olivine phenocryst which has an embayment filled with the pyroxene groundmass and inclusions of opaques. A spherulite composed of elongate plagioclase laths has pyroxene filling in the spaces between the plagioclases. The sample is listed as being studied by Powell et al. (1973) but there is no published data; no chemical data has been reported.

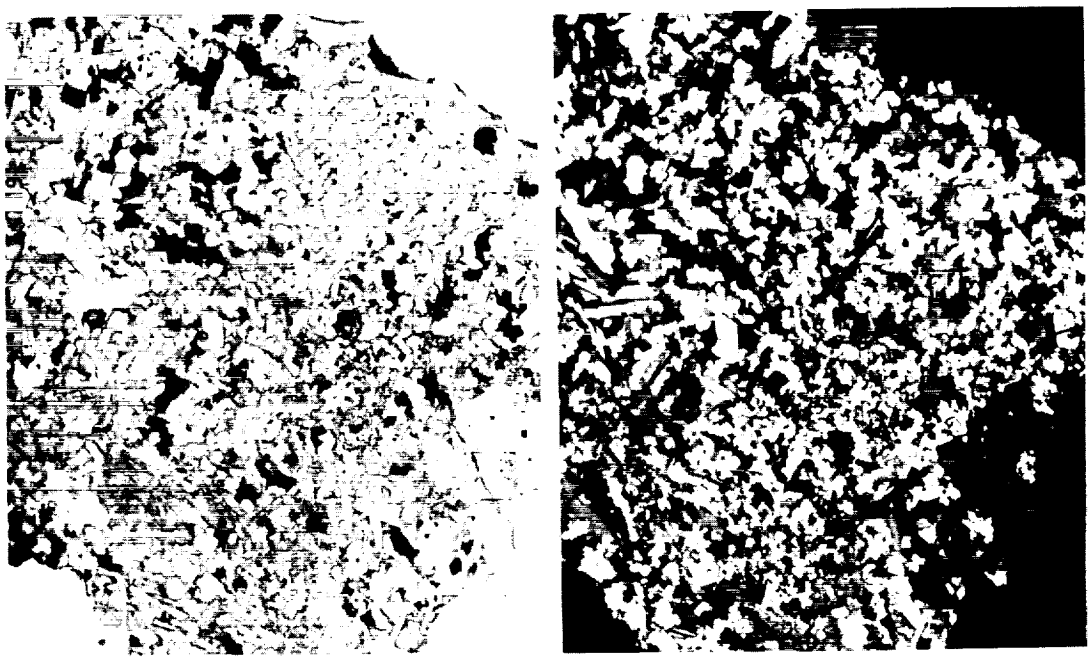


Fig 4. Paired photomicrographs of 15104,2,6, fields of view about 1mm wide. Left, plane light; right, crossed polarizers.

15204 Station 2 0.10g

Groups	Individual particles	Subsamples	Thin sections/ Probe mounts
,1 (0.08g)——	,1 (0.08g)		

15204,1	Regolith breccia	1 particle	0.08g

The fragment is a subrounded fine-grained breccia that is similar to those identified as regolith breccias. It is medium gray with tiny white clasts visible. It is similar to 15244,2 but slightly more coherent. It has never been sectioned or allocated.

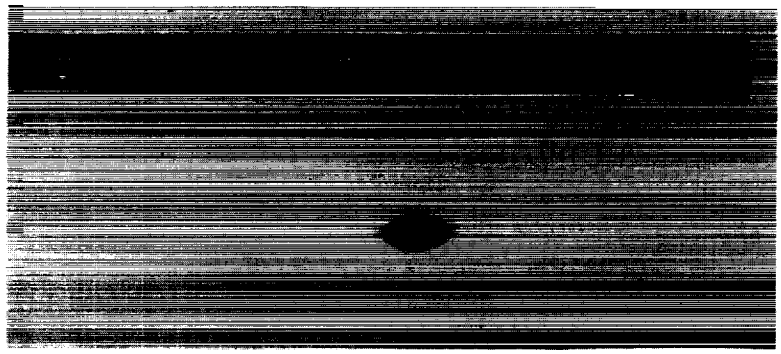


Fig. 1 15024,1
S-72-15498

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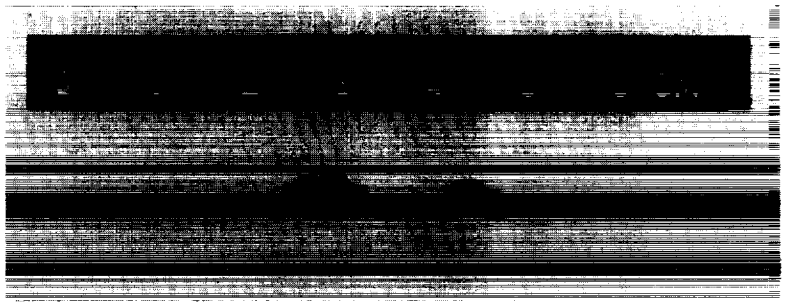
15214 Station 2 0.20g

Group	Individual Particles	Subsamples	Thin section/ Probe Mounts
,1 (0.140g)			

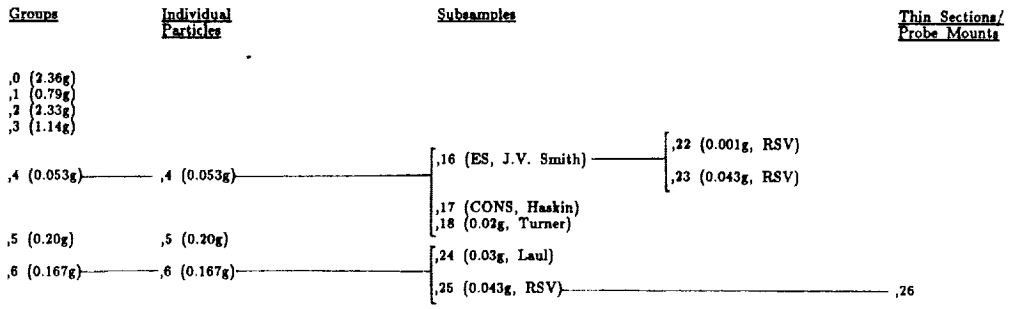
15214,1 Impact melts(?) 2 particles 0.140g

Powell described the two fragments as tough, subangular, and light gray. They contain lithic and mineral clasts in a fine-grained, apparently crystalline, matrix. One particle contains fragments of a subophitic basalt as well as granular clasts of pale greenish yellow olivine(?). Plagioclase is the dominant clast-type in both fragments. One particle has adhering dark glass on one corner, but glass within the fragments was not unequivocally identified. The fragments are probably crystalline impact melt breccias. They have never been sectioned or allocated.

Fig. 1 15214,1
S-72-15482



15224 Station 2 7.00g



15224,0 Fines 2.36g

The sample consists largely of very fine material but some small particles or clods are included (Fig. 1).

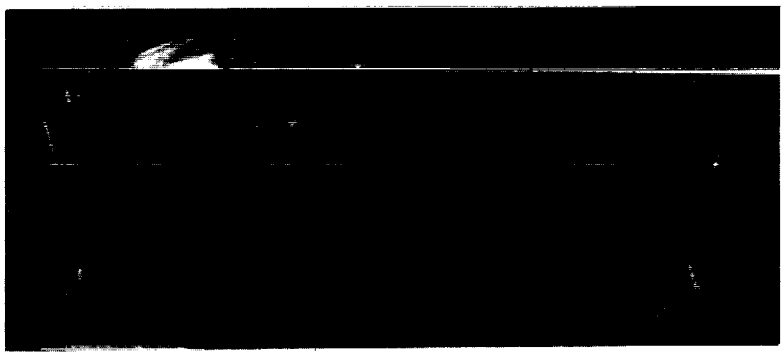


Fig. 1 15224,0
S-72-16210

15224,1 Regolith breccias 6 particles 0.79g

Powell described 15224,1 as friable, subrounded to rounded microbreccias, similar to 15224,1. The breccias are very finely granular and are regolith breccias. Powell listed 5 particles where there are 6 shown in the photograph (Fig. 2); one appears to be distinct and possibly crystalline.

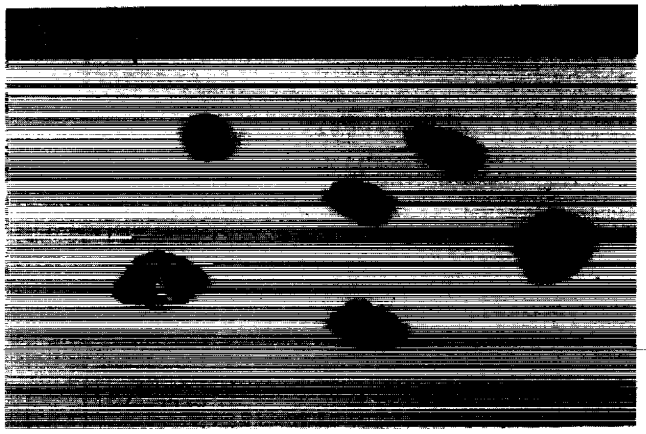
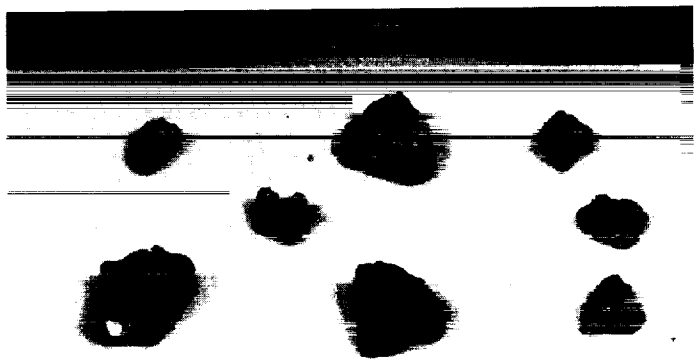


Fig. 2 15224,1
S-72-15185

15224,2 Glass-coated regolith breccias 8 particles 2.33g

The particles in 15224,2 are friable, partially glass-coated regolith breccias. According to Powell they are subangular to subrounded, medium gray, and have surfaces which are finely-granular to smooth (Fig. 3), and they are essentially identical to 15244,6. Except for the glass coats they are similar to 15224,1. There are 8 particles, although Powell listed only 7.

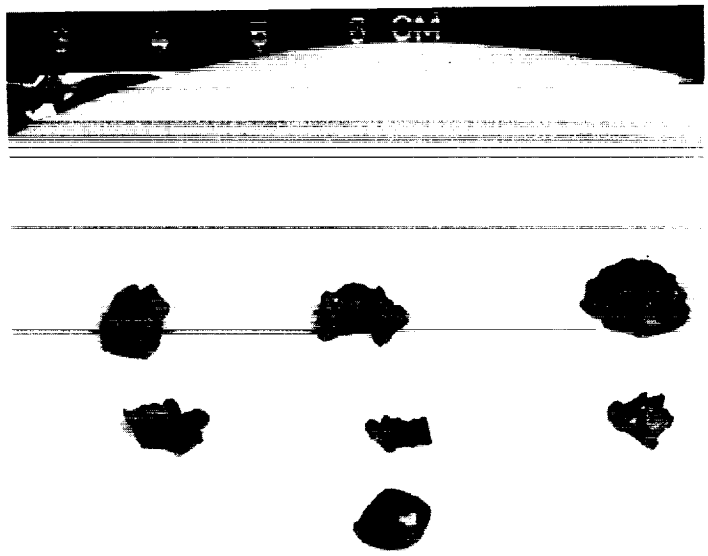
Fig. 3 15224,2
S-72-15183



15224,3 Agglutinates 7 particles 1.14g

Powell described these particles as irregularly shaped, medium to dark gray, and varied from friable breccias to tough glasses. The breccias appear to be regolith breccias. The breccia surfaces are finely-granular and the glass surfaces are smooth. The vesicular glass bonds to the breccias (Fig.4). The particles are identical with those in 15244,5; they differ from 15224,2 in that the glass in ,2 is only surficial, and in ,3 it penetrates or bonds the breccias. Powell listed 15224,3 as having 8 particles but it has 7.

Fig. 4. 15224,3
S-72-15184



15224,4	Olivine-normative mare basalt	1 particle	0.053g (0.16g)

15224,4 Olivine-normative mare basalt 1 particle 0.053g (0.16g)

The fragment is tough, subangular, and medium to dark gray (Fig. 5); it has a hackly surface. Powell identified it as ultrabasic, but the sample is a fine-grained olivine-normative mare basalt. 15224,22 is a polished butt about 4 x 2 mm from which no thin section was cut. Steele and Smith (pers. comm. in Helmke et al., 1973) described it as a porphyritic basalt with megacrysts of olivine and pyroxene in a variolitic matrix of plagioclase and pyroxene. More correctly, the butt shows an olivine-porphyritic basalt with a variolitic groundmass (Figs. 6,7). Olivine phenocrysts (0.5 to 1 mm) are rare, and there are no pyroxene phenocrysts. The olivine does not appear to be resorbed. Apart from pyroxene and plagioclase, the groundmass contains minor cristobalite, ilmenite needles (~50 microns long), ulvospinel, Fe-metal, and troilite. Helmke et al. (1973) made an analysis for trace elements in a 27 mg split (,4,17). These data are shown as Table 1 and the rare earths are plotted as Fig. 8. The incompatible trace elements are much lower than in typical Apollo 15 olivine-normative basalts, and Helmke et al. (1973) interpreted the sample to be an olivine-pyroxene cumulate from an olivine-normative basalt. However, such an origin is inconsistent with the petrography, unless the split they analyzed contained a much higher abundance of phenocrysts than does ,22.

Fig. 5 15224,4
S-72-15182. Particle is about 6 mm long.

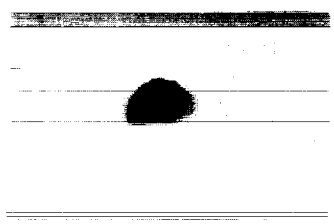
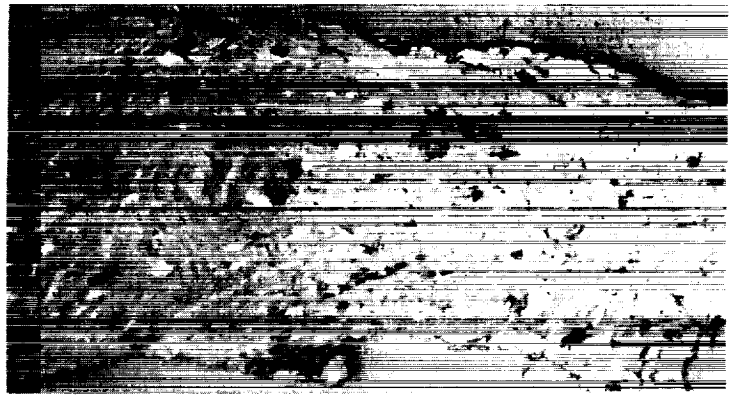


Fig. 6 Photomicrograph of 15224,4,22. Reflected light, field of view ~ 2mm wide.



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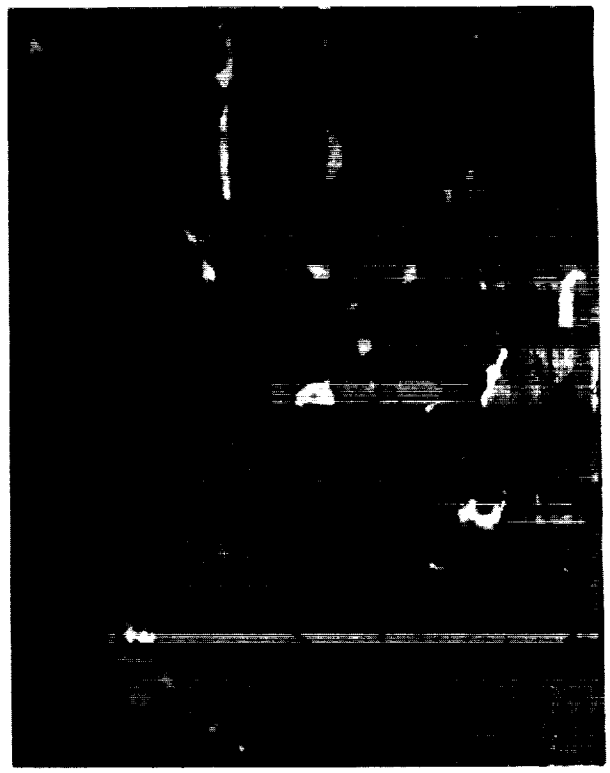
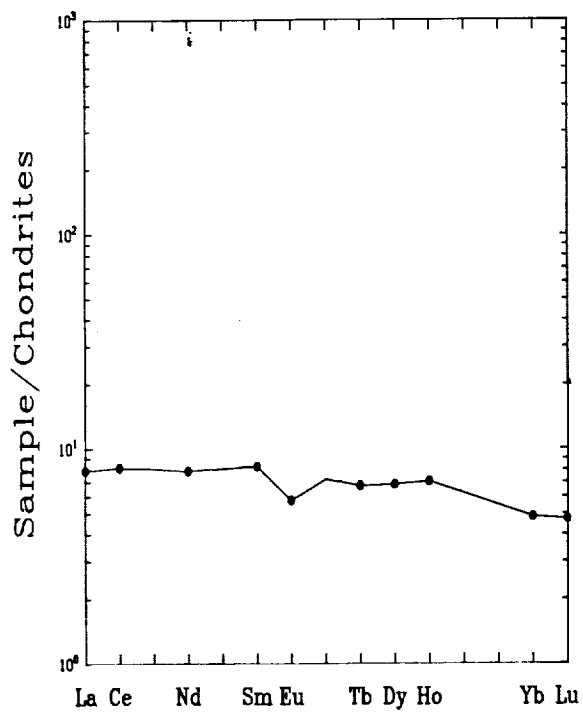


Fig. 7 Photomicrograph of 15224,4,22. Reflected light, field of view ~ 500 microns wide. Image shows variolitic groundmass and olivine phenocryst.

Table 1. Helmke et al. (1973); RNAA. ppm 15224,4,17 (27 mg).

Sc	58
Co	75
Hf	3.9
La	2.9
Ce	7.8
Nd	5.6
Sm	1.91
Eu	0.50
Gd	-
Tb	0.39
Dy	2.6
Ho	0.6
Er	-
Yb	1.2
Lu	0.18

Fig. 8. Chondrite-normalized plot of rare-earths in 15224,4,17. Data of Helmke et al. (1973).



15224,5	Very fine-grained basalt(?)	1 particle	0.20g

15224,5 Very fine-grained basalt(?) 1 particle 0.20g

Powell described 15224,5 as a dark gray, tough, subangular particle, essentially the same as those in 15434,7. (15434,7 consists of varied fine-grained melt fragments, including KREEP basalts).

15224,6	Anorthositic breccia	1 particle	0.167g (0.25g)

15224,6 Anorthositic breccia 1 particle 0.167g (0.25g)

15224,6 is a white crystalline fragment (Fig. 9). Powell described it as a non-mare crystalline rock with 5-10% olivine; a thin section shows that more precisely 15224,6 is a brecciated anorthositic that lacks olivine but contains some pyroxene.

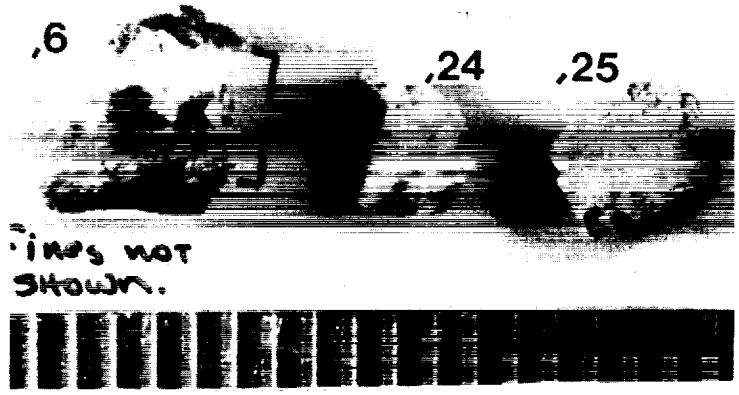


Fig. 9 Splitting of 15224,6. Scale in millimeters.

The thin section 15224,26 is a monomict breccia with cataclastic texture (Fig. 10). The largest grains are plagioclases that are approximately 500 microns across, and the matrix consists of smaller grains of plagioclase, pyroxene, and some glass. The section contains some silica, which contains needle-like inclusions. 15224,6,26 was described a a feldspathic cataclastic rock by Simon et al. (1987). They provided microprobe information (Figs. 11,12). The plagioclase is slightly less calcic than that of ferroan anorthosites and it has shock fractures, kink bands and oscillatory extinction. The pyroxene is Mg-rich orthopyroxene with a limited compositional range, and shows no exsolution or twinning. No bulk chemical data has been reported.

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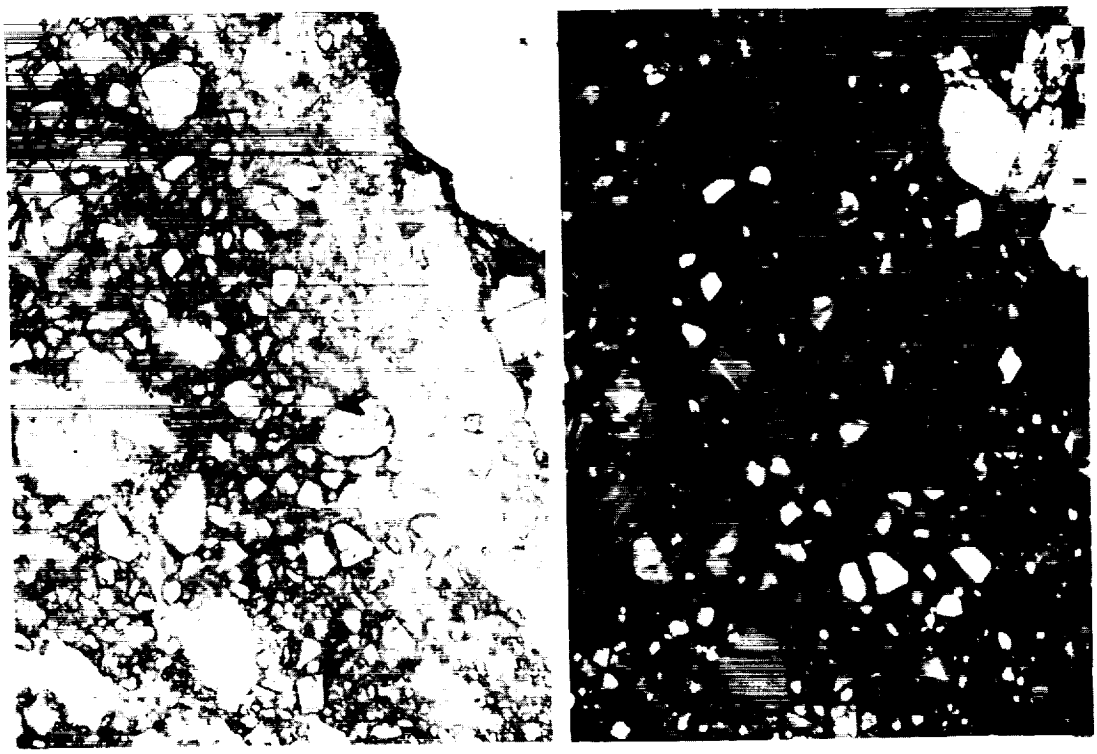


Fig. 10. Photomicrographs of 15224,6,26. Width of views about 2mm. Left is plane light, right is crossed polarized light.

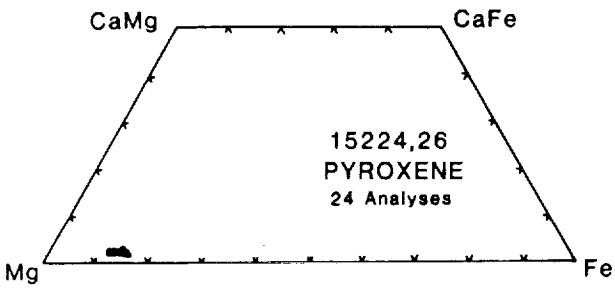


Fig. 11 Compositions of pyroxenes in 15224,6,26 (Simon et al., 1987)

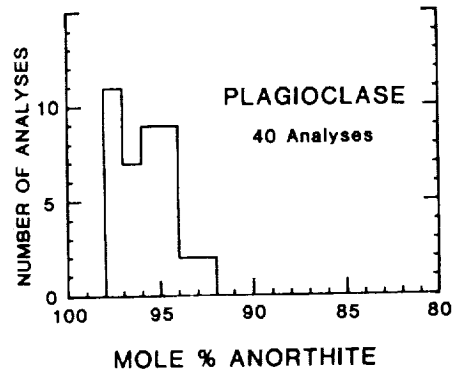


Fig. 12 Compositions of plagioclases in 15224,6,26 (Simon et al., 1987)

15234 Station 2 1.8g

Groups	Individual particles	Subsamples	Thin sections/ Probe mounts
,0 (0.60g)			
,1 (0.85g)			
,2 (0.106g)	,2 (0.106g)		
	,4 (0.035g, Laul)	,5 (0.009g, RSV)	,6

15234,0 Fines and undescribed particles 0.6g

15234,0 consists mainly of fines, but includes some small particles that have not been described (Fig. 1).

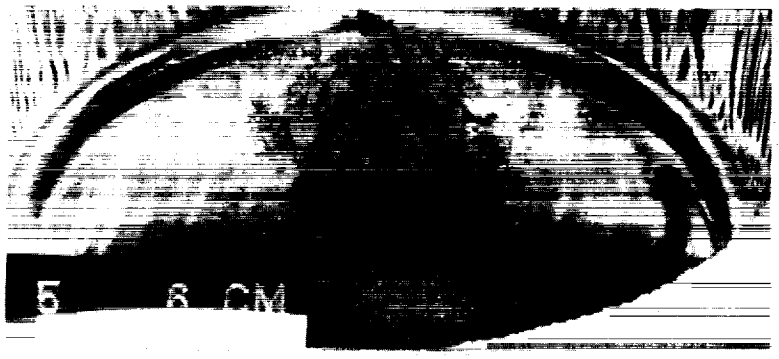


Fig. 1 15234,0
S-72-15957

15234,1 Agglutinates 5 particles 0.85g

15234,1 are friable breccias welded together by dark brownish-gray to yellowish-brown glass. The glass also occurs as coatings, which cover 25-50% of the particle surface areas. The coatings are generally thin, smooth, and vitreous, and have vesicles. Powell classified the breccias as the same type as 15244,5 (Fig. 2). None have been allocated.

Fig. 2 15234,1 S-72-16198

15234,2 Regolith breccia/crystalline non-mare(?) 2 particles 0.106g (0.16g)

Powell described two particles as non-mare crystalline rocks. However, one of them was split (Fig. 3), and a thin section of it is a regolith breccia. Powell described the two particles as similar to those in 15434,5 which is a collection of varied non-mare crystalline rocks.

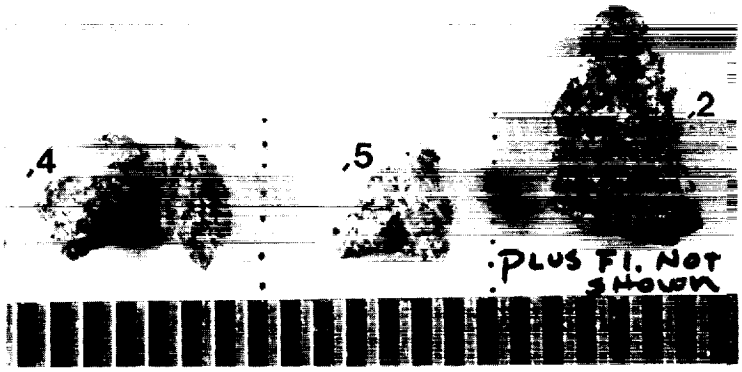


Fig. 3 Splitting of ,2 into two particles (,2 and ,4)

15234,2	Crystalline non-mare rock(?)	1 particle	0.106g

This particle has not been further described or allocated.

15234,4	Regolith breccia	1 particle	(~0.05g)

The particle is a regolith breccia, but it is much tougher than most. Thin section 15234,4,6 (Fig. 4) shows a breccia with a fragmental matrix and glass, particularly yellow glass, in the clast population. The groundmass also includes some brown glass. Several mineral and lithic fragments appear to be derived from KREEP basalts. Part (,4) was allocated for chemical analysis but none has been reported.

Fig. 4 Photomicrograph of 15234,4,6. Plane light, field of view ~ 1 mm wide.

15244 Station 6 32.6g

Groups	Individual particles	Subsamples	Thin sections/ Probe mounts
,0 (3.33g)			
,1 (7.21g)			
,2 (8.05g)			
,3 (0.99g)			
,4 (0.38g)			
,5 (7.76g)			
,6 (3.03g)			

15244,0 Fines and undescribed particles 3.33g

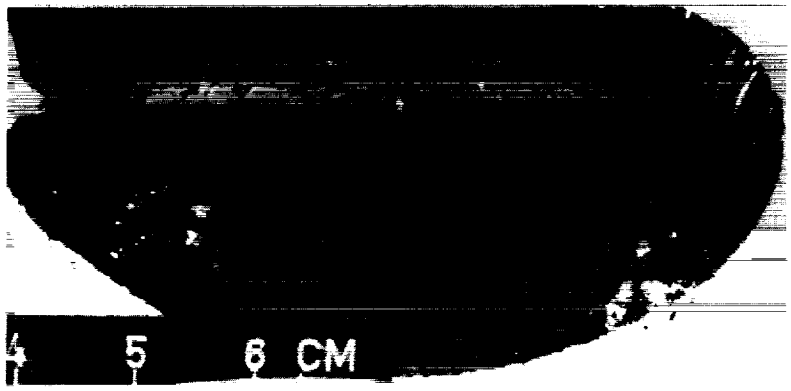


Fig. 1 15244,0
S-72-15971

15244,1 Regolith breccias with white lithic fragments 47 particles 7.21g

Powell described these particles as friable, subrounded to rounded, medium gray microbreccias (Fig 2.). They have very fine-grained matrices of undetermined character. Mineral and glass fragments range in size up to about 1 mm, but most are smaller. Rock clasts identifiable under a binocular microscope constitute 10 to 30% of the fragments. The distinguishing feature of this group is the presence of 5 to 10% angular light gray to white lithic fragments in the size range 0.5 to 2 mm. The particles have never been allocated.

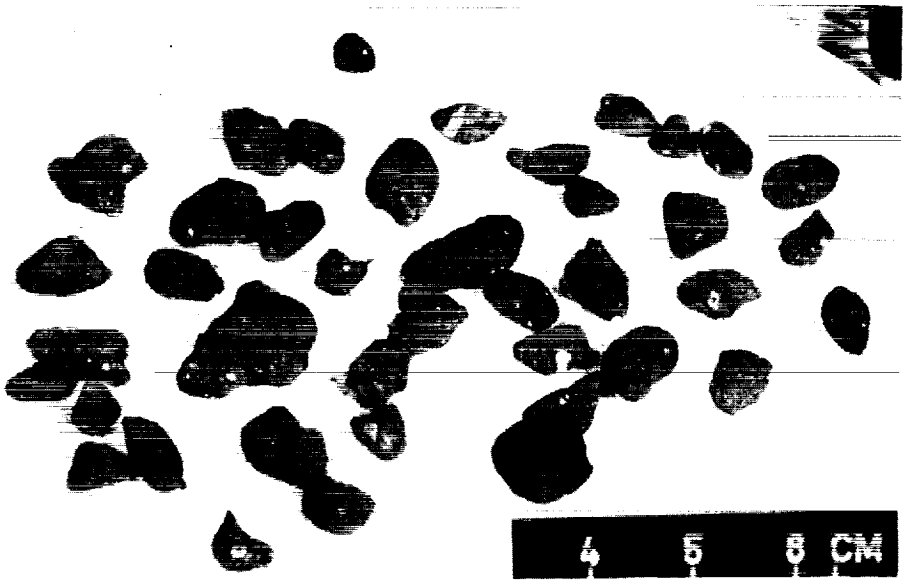


Fig. 2 15244,1
S-72-15127

15244,2	Regolith breccias	59 particles	8.05g

Powell described these particles as friable, subrounded to rounded, medium gray microbreccias (Fig. 3). They are essentially identical with 15244,1 with the exception of the lack of the white clasts in 15244,2. The distinction is gradational and arbitrary. The particles have never been allocated.

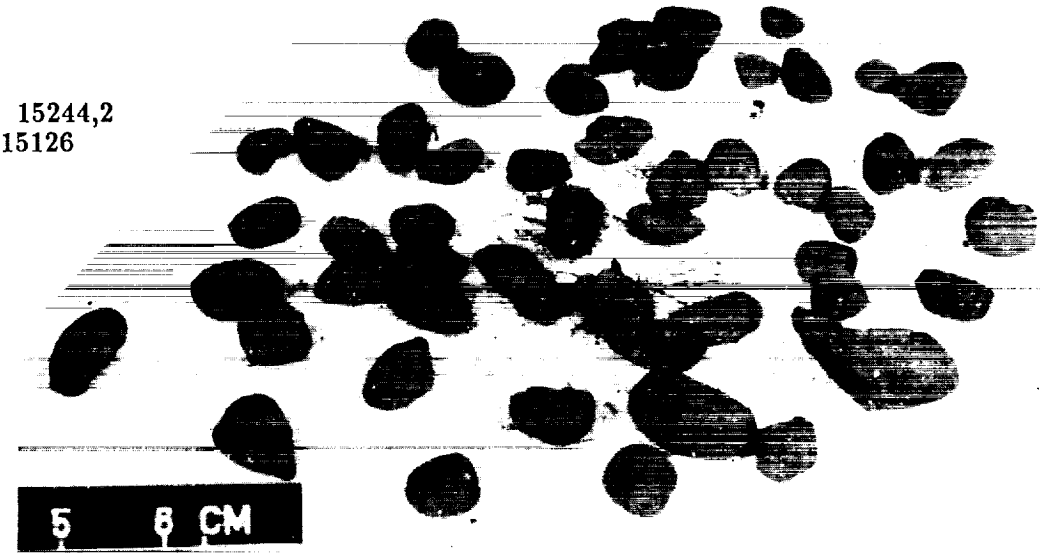


Fig. 3 15244,2
S-72-15126

15244,3	Regolith breccias with green glass	6 particles	0.99g

Powell described these particles as friable, subrounded to rounded, medium gray microbreccias. They are distinguished from 15244,1 and 15244,2 by the presence of green glass fragments and spheres, with at least one visible in each particle. The glass is probably less than 2% of each particle. The glasses range from 0.25 to 1 mm. The particles have never been allocated.

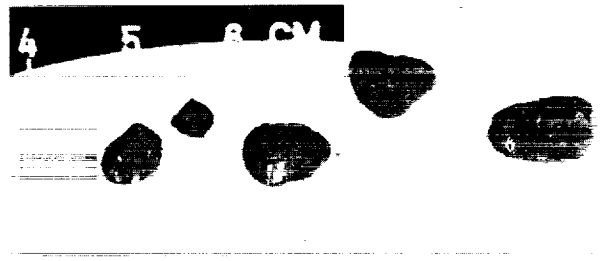
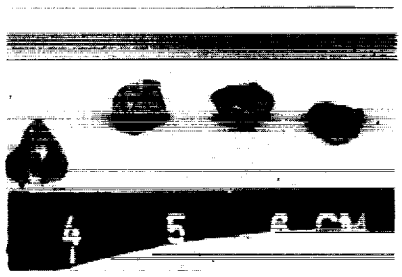


Fig. 4 15244,3
S-72-15125

15244,4	Crystalline? breccias	5 particles	0.38g

Powell described these particles as coherent to tough microbreccias that may be recrystallized. They may include impact melt breccias. They are subangular to subrounded and medium gray (Fig. 5). The fine-grained matrix contains clasts of light gray to white lithic and mineral fragments (feldspathic) and mafic mineral fragments (yellow-brown pyroxene or olivine or both). Two of the particles include a red mineral. The dominant feldspathic clasts compose 5 to 25% of each particle. The particles have never been allocated.

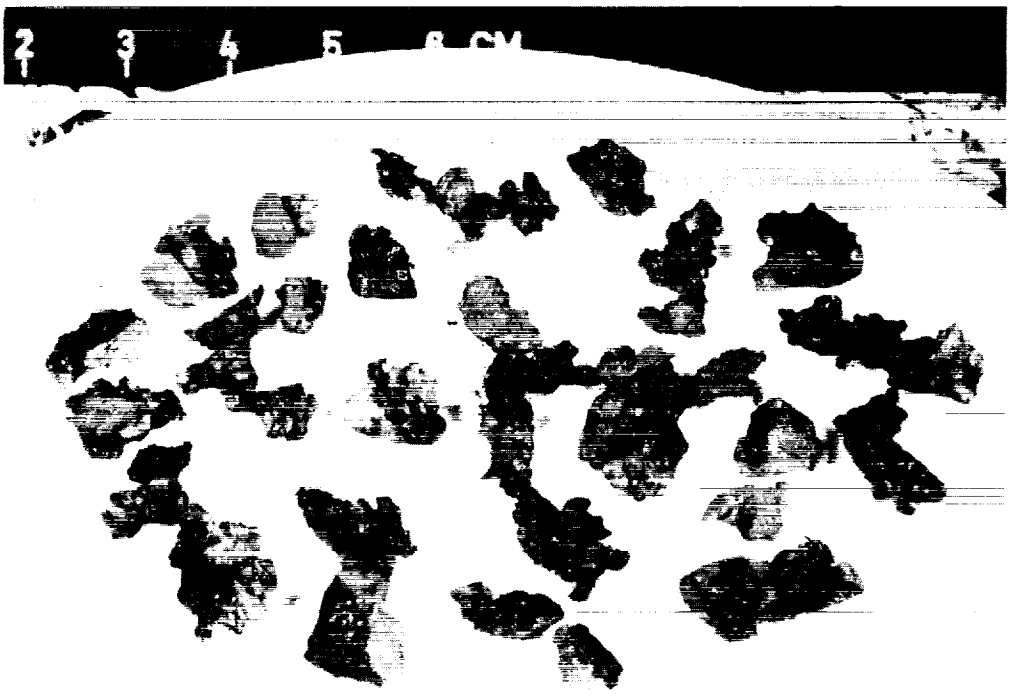
Fig. 5. 15244,4
S-72-15124



15244,5	Agglutinate/regolith breccia	44 particles	7.76g

Powell described these particles as varied from friable breccias to tough glassy particles (Fig. 6). They are irregularly shaped and each consists of both breccia and glass. The breccias are medium gray and the glass is dark brownish gray to yellowish brown. The glass is vesicular and occurs as coatings and bonds together regolith breccia pieces. The glasses are thin and coat 25 to 50% of the surfaces. The breccias are similar to 15244,1 and 15244,2. They have never been allocated.

Fig. 6 15244,5
S-72-15123



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15244,6	Glass-coated regolith breccias	18 particles	3.03g

Powell described these particles as friable, subrounded microbreccias with glass coatings (Fig. 7). The breccias are medium gray and similar to those in 15244,1 and 15244,2. The glasses are dark brownish-gray to yellowish brown and cover 10 to 50% of the surfaces. The coatings are thin with abundant circular "windows". Typically the glass coats one or two sides.

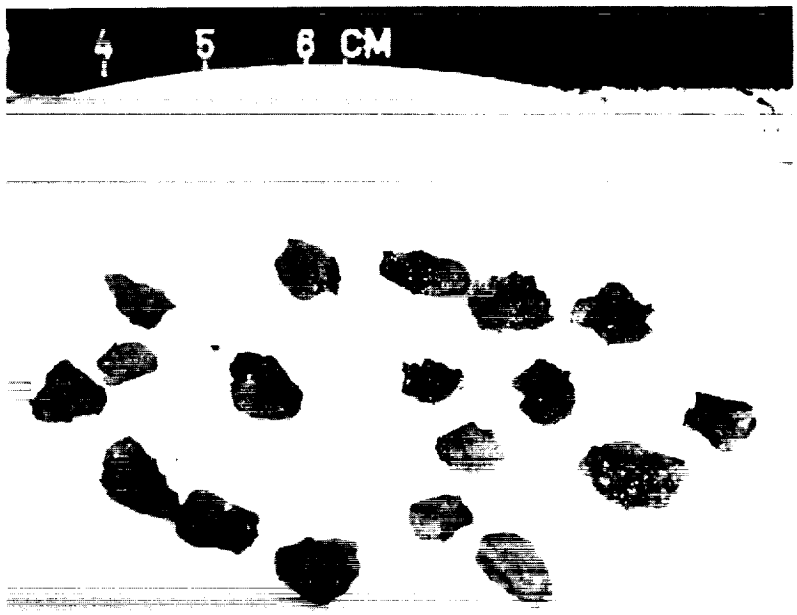


Fig. 7 15244,6
S-72-15122

15254 Station 6 1.2g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (0.67g)			
,1 (0.53g)			

15254,0 Fines and undescribed fragments 0.67g

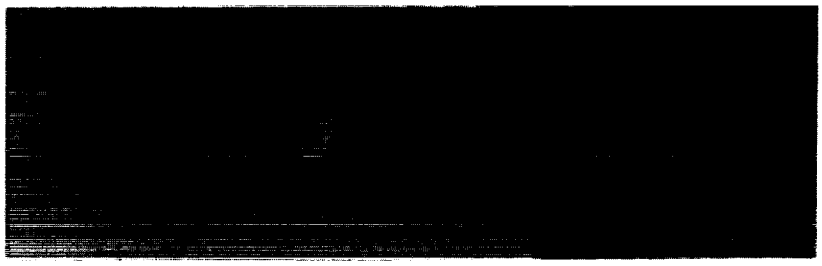
15254,0 consists of degraded fines and several small particles (Fig. 1). Most appear to be regolith breccias, some glass coated; one fragment may be crystalline.

Fig. 1 15254,0
S-72-15961

15254,1 Regolith breccia and crystalline(?) 4 particles 0.53g

Three of these particles are regolith breccias that are gray and rounded to subrounded (Fig. 2). The fourth particle is unusually conically shaped. According to Powell its convex base is greenish-white and appears to be a fine-grained mixture of white plagioclase and a pale apple-green phase (glass?). The whole particle may consist of this material covered in a thin dark soil veneer, or the pale-colored part may be a clast in a regolith breccia. These particles have not been allocated.

Fig. 2 15254,1
S-72-15961



15264 Station 6 4.5g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (2.08g)			
,1 (0.87g)			
,2 (0.46g)			
,3 (0.32g)			
,4 (0.093g)	,4 (0.093g)	,16 (ES, Powell)	,30 (15999,97)
		,31 (CONS, Powell)	
		,17 (0.03g, Ryder)	
		,21 (0.02g, Turner)	
		,33 (0.071g, Ryder)	
,5 (0.12g)	,5 (0.12g)	,18 (0.125g, RSV)	,19
		,20 (0.018g, RSV)	
		,29 (CONS, Mason)	
		,23 (0.02g)	
		,32 (0.031g, Laul)	

15264,0 Fines and clods 2.08g

15264,0 consists of fines and a few small friable clods of regolith material (Fig. 1).

Fig. 1 15264,0
S-72-16187

15264,1 Regolith breccias 7 particles 0.87g

Powell described the particles as friable, subrounded to rounded, and medium gray microbreccias (Fig.2), identical with 15244,2. Although Powell states that there are 8 particles, only 7 appear in the photograph.

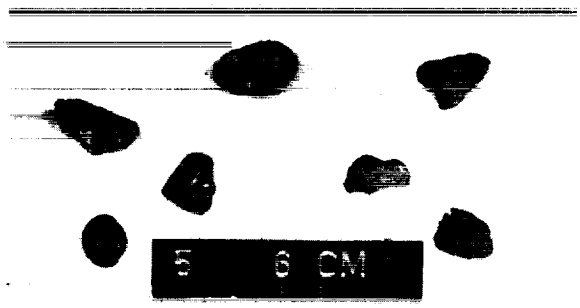
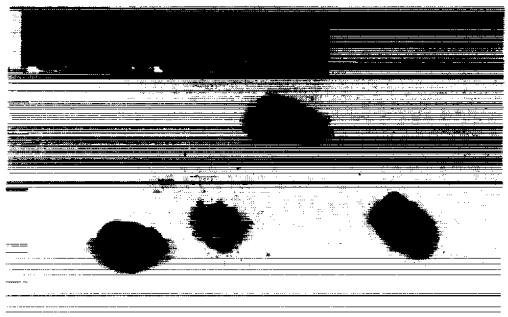


Fig. 2 15264,1
S-72-15168

15264,2	Glass-coated regolith breccias	4 particles	0.46g

Powell described 15264,2 as subrounded, friable, medium gray microbreccias with partial glass coatings. The breccia part is very finely granular (Fig. 3) and the glass, mainly hidden in the photograph, is smooth and vitreous. The particles are essentially identical to 15244,6.

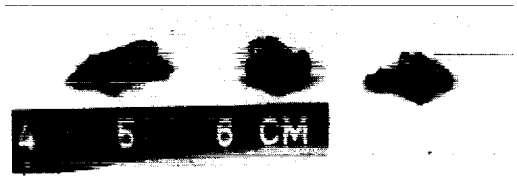
Fig. 3 15264,2
S-72-15167



15264,3	Agglutinates	3 particles	0.32g

Powell described the particles as consisting of friable breccias with tough glasses; they are irregularly shaped. The medium to dark gray breccias are very finely granular and the glasses, which are smooth and vitreous, bond to the breccias (Fig. 4). The particles are virtually identical with 15244,5.

Fig. 4 15264,3
S-72-15186



15264,4	KREEP basalt	1 particle	0.093g (0.28g)

15264,4	KREEP basalt	1 particle	0.093g (0.28g)

15264,4 is a tough, subangular, light grayish-brown fragment (Fig. 5) that is a volcanic KREEP basalt. Powell mistakenly identified it as an olivine basalt containing ~15% olivine, but the greenish-yellow phase is actually low-calcium pyroxene. Powell et al. (1973) identified the thin section as a KREEP basalt but provided no other information.

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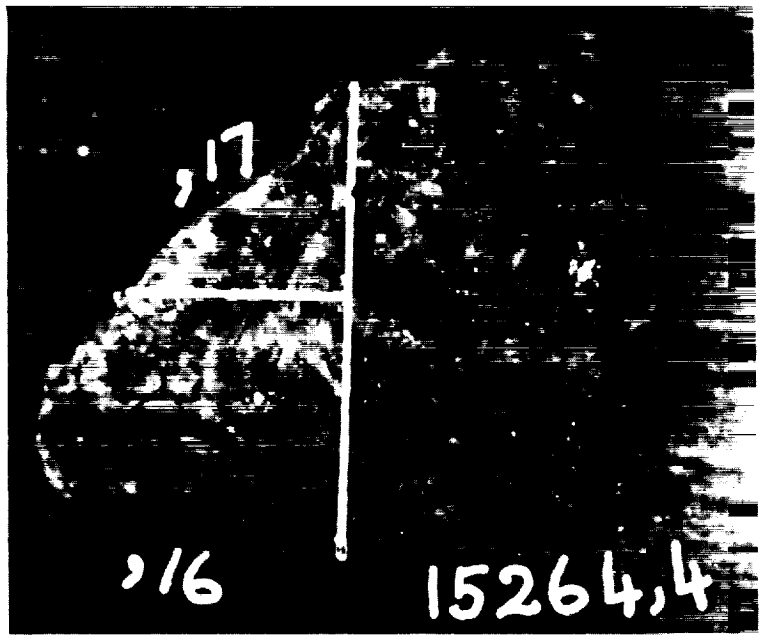


Fig. 5 Initial splitting of 15264,4. Fragment is about 7 mm in long dimension.

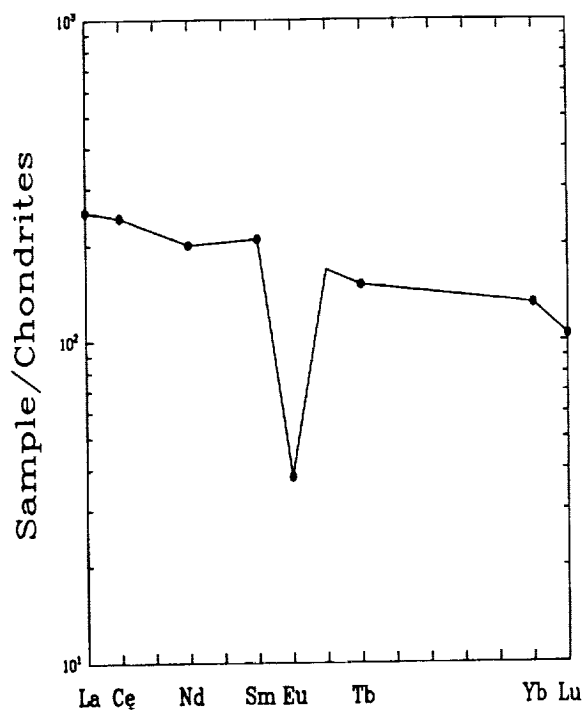
Fig. 6. Photomicrograph of 15264,4,30, compounded in 15999,97. Plane light, field of view about 2 mm wide.

15264,4,30 is among the coarser grained of the Apollo 15 KREEP basalts, containing plagioclase needles as long as 1 mm and pyroxenes almost as long (Fig. 6). About 30% of the basalt is an opaque, glassy to cryptocrystalline mesostasis. Cristobalite is well developed, and in the mesostasis there are prominent long (0.5 mm) ilmenite needles. Microprobe data (Ryder, unpublished) show that the pyroxenes and plagioclases have typical KREEP basalt trends. The pyroxene cores are orthopyroxenes (max. En~79) that are fairly homogeneous, and abruptly grade to pigeonites and more Ca-Fe-rich pyroxene compositions. Most of the plagioclases have compositions between An_{87} and An_{81}. A chemical analysis using neutron activation and microprobe fused bead methods (Ryder, unpublished) is shown in Table 1. The rare earths are plotted as Fig. 7. These data show that the sample, despite being coarser than most other KREEP basalts, is more evolved than most in Mg/Fe and in incompatible element abundances, consistent with the orthopyroxene core compositions which are more Fe-rich than in most samples. There is no evidence of meteoritic contamination (low Ni, Co, Au).

Table 1. Ryder (unpublished)
Microprobe fused bead (FB), INAA
15264,4,17+33 (~80 mg homogenized)

	FB	INAA (56 mg)
wt %		
SiO_2	52.3	
TiO_2	2.3	
Al_2O_3	15.4	
Cr_2O_3	0.28	0.27
FeO	10.7	10.4
MnO	0.16	
MgO	7.9	
CaO	9.8	
Na_2O	0.90	0.86
K_2O	0.76	0.67
P_2O_5	0.53	
Sum	101.0	
ppm		
Sc		22.4
Co		17.6
Ni		29 (+/-13)
Hf		32.6
Rb		22.9
Cs		0.93
Sr		86 (+/-17)
Ba		840
La		83.6
Ce		214
Nd		120 (+/-6)
Sm		37.7
Eu		2.62
Tb		7.1
Yb		26.1
Lu		3.6
Zr		1114 (+/-120)
Ta		3.6
U		4.3 (+/-0.16)
Th		14.8
ppb		
Au		<0.04

Fig. 7 Chondrite-normalized plot of rare earths in 15264,4,17+33 (Ryder, unpublished).



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15264,5	Noritic anorthosite	1 particle	0.12g (0.33g)

15264,5	Noritic anorthosite	1 particle	0.12g (0.33g)

Powell described 15264,5 as a recrystallized troctolitic microbreccia, although admitting the identification to be uncertain. The sample is a brecciated or cataclastic noritic anorthosite. Powell described the particle as tough, subangular, and greenish white. Dark glass coats one surface (Fig. 8). Macroscopically there appeared to be 40 to 45% of a pale green mineral, but the thin section (,5,19) contains much less mafic material than that. The fragment was originally split (or fell apart) into two pieces, one of which became ,18 and its daughters. The other piece remained as ,5 and produced ,32 (Fig. 9).

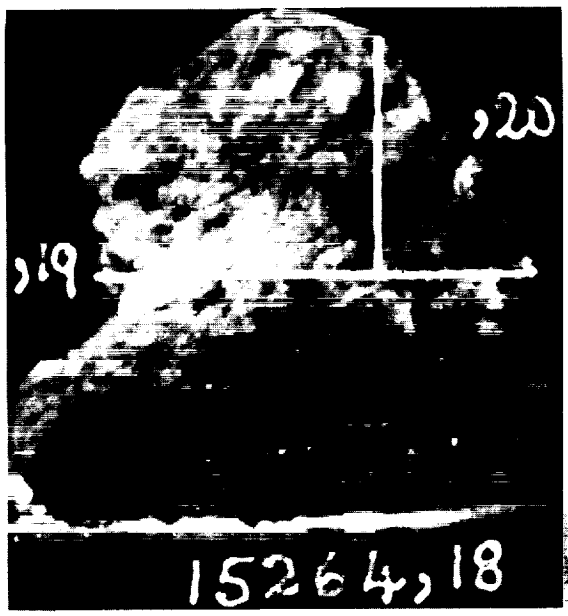
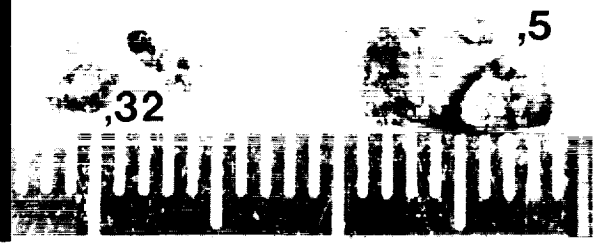


Fig. 8 15264,18 and its initial daughters. Particle is about 5 mm across.

Fig. 9 Part of 15264,5 and its daughter ,32. Scale is in mm.



Thin section 15264,5,19 is a noritic anorthosite with a brecciated or cataclastic texture (Fig. 10), consisting of plagioclase, orthopyroxene, minor interstitial silica and sulfide, and other trace phases. Mason (1972) described it as containing more than 90% plagioclase, and Simon et al. found it to contain 85.4% plagioclase. The largest plagioclase relics are about 0.5 mm across. Modal and microprobe data are given in Table 2.

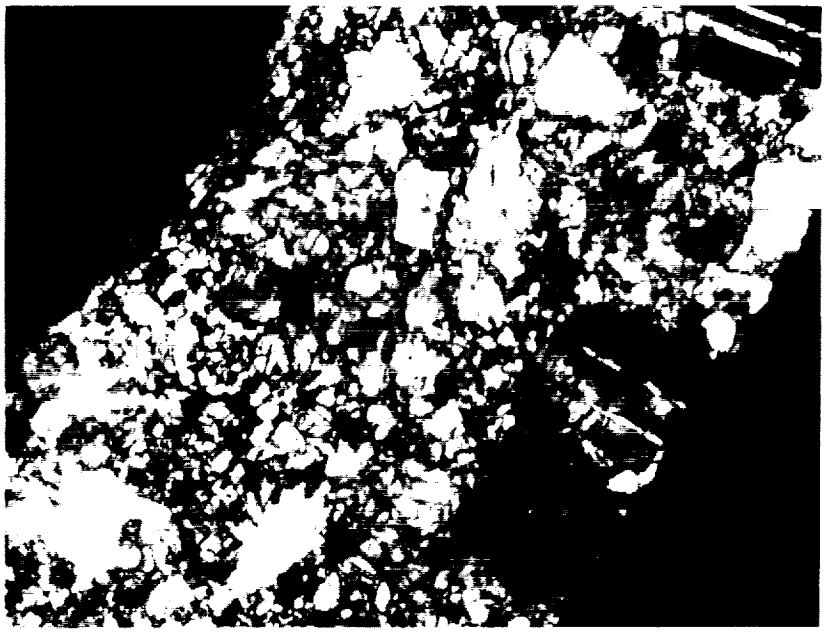
Table 2 Petrographic features of 15264,5,19

Mineral	Mode (1)	Mode (2)	Composition (1)	Composition (2)
Plag	>90%	85.4%	An_{99-90}	An_{96-90}
Opx	a little	13.9%	Ave. $En_{72}Wo_3$	~$En_{72-77}Wo_{3-5}$
Ilm	-	tr		
Sulf	-	0.1		
Fe	tr	-		
Chr	tr	-		
Other		0.6		

Refs:
(1) Mason 1972
(2) Simon et al. 1987

Simon et al. (1987) tabulated a pyroxene analysis and two plagioclase analyses. They group 15264,5 with Mg-suite rocks rather than ferroan anorthosites on the basis of the plagioclase and pyroxene compositions (plotted as An_{94}, Mg'_{78}). However, the more calcic plagioclases and the more Fe-rich pyroxenes create a field which overlaps with the more magnesian members of the ferroan anorthosites, and the placing of this sample into any category is arbitrary. No bulk chemical analysis was made.

Fig. 10 Photomicrograph of 15264,5,19. Crossed polarized light; field of view is about 2 mm wide.



15274 Station 6 4.4g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (2.26g)			
,1 (1.27g)			
,2 (0.22g)	,11 (0.128g, RSV)	,18 (CONS, Mason)	,12
		,13 (0.022g, RSV)	
	,2 (0.22g)	,14 (0.02g, Geiss)	
		,20 (0.024g)	
,3 (0.089g)	,3 (0.089g)	,21 (0.081g, Ryder)	
,4 (0.084g)	,4 (0.084g)	,22 (0.23g, RSV)	,23 (Ryder)
		,24 (0.053g, Ryder)	

15274,0 Fines and undescribed particles 2.26g

15274,0 contains fines and a large number of undescribed particles (Fig. 1). At least some of them have glass coats or intrusions, and some appear to be regolith breccias.

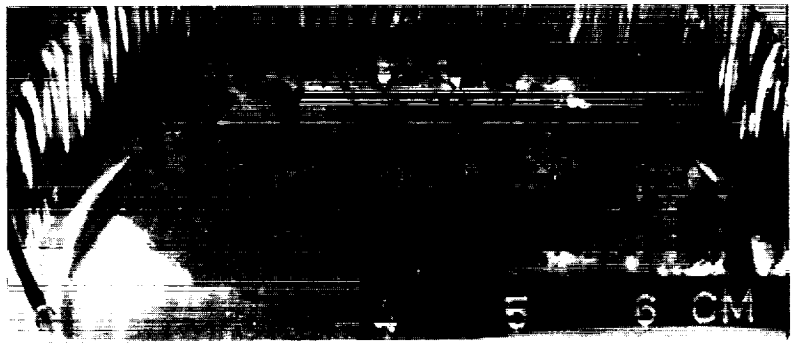


Fig. 1 15274,0
S-72-15962

15274,1 Regolith breccia/agglutinates 5 particles 1.27g

The 5 particles consists mainly of regolith breccia, and each has some glass either coating or intruding (Fig. 1). The particles are similar to those in 15244,5 and ,6. They have never been allocated.

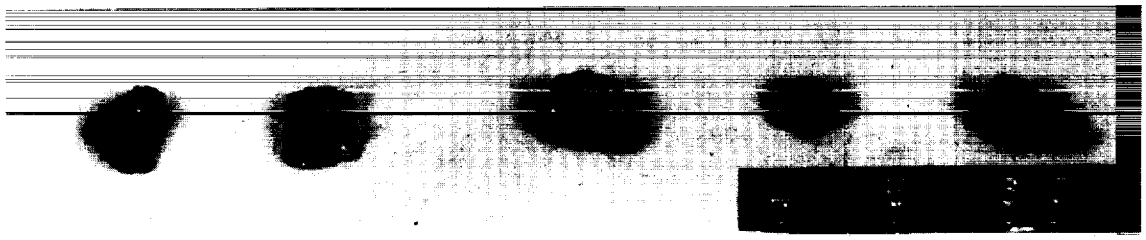


Fig. 2 15274,1 S-72-16194

15274,2 Non-mare impact melt(?) rocks 2 particles 0.22g (0.46g)

Powell described these two particles (Fig. 2) as crystalline, but the one from which a thin section was made is a glassy impact melt. The 2 particles are similar to some of those in 15434,5.

Fig. 3 15274,2
S-72-16155

15274,2 Non-mare crystalline rock(?) 1 particle 0.22g (0.26g)

15274,2 is a tough angular fragment (Fig. 4). Although small chips were allocated, no data have been published. No thin section was made.

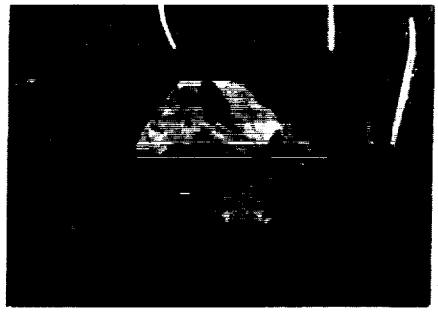


Fig. 4 15274,2
S-72-33624.
Particle is nearly
a centimeter long.

15274,11 Glassy impact melt 1 particle 0.128g (0.185g)

The fragment was subdivided. Mason (1972) described thin section ,11,12 as a breccia that consists of pale brown glass (~80%), which encloses angular fragments of plagioclase (An_{83-99}). The section is shown in Fig. 5. The plagioclases are less than 300 microns across. Other materials include lithic clasts of feldspathic basalt, and minute amounts of opaque material (Fe-metal in micron-sized particles). An analysis of the glass by microprobe given in Table 1 is similar to that of rock 15418.

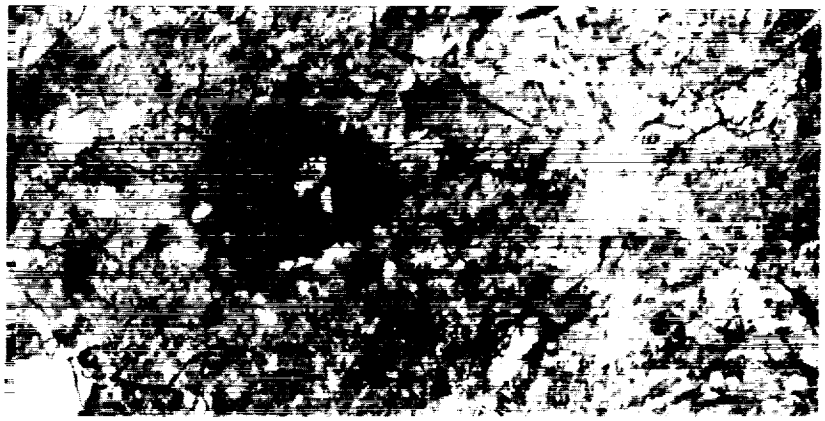


Fig. 5 Photomicrograph of 15274,11,12. Plane light, field of view about 2 mm wide.

Table 1 Microprobe analysis of glass in 15274,11,12 (Mason, 1972)

wt%	Ave.	Range
SiO_2	46.7	(44.9-48.8)
TiO_2	0.23	(0.11-0.38)
Al_2O_3	27.4	(25.3-31.4)
FeO	3.9	(1.0-7.3)
MnO	0.06	(0.02-0.10)
MgO	3.9	(0.6-7.0)
CaO	16.9	(15.5-19.0)
Na_2O	0.41	(0.36-0.46)
K_2O	0.05	(0.01-0.08)

15274,3	Picritic mare basalt	1 particle	0.089g (0.17g)

15274,3	Picritic mare basalt	1 particle	0.089g (0.17g)

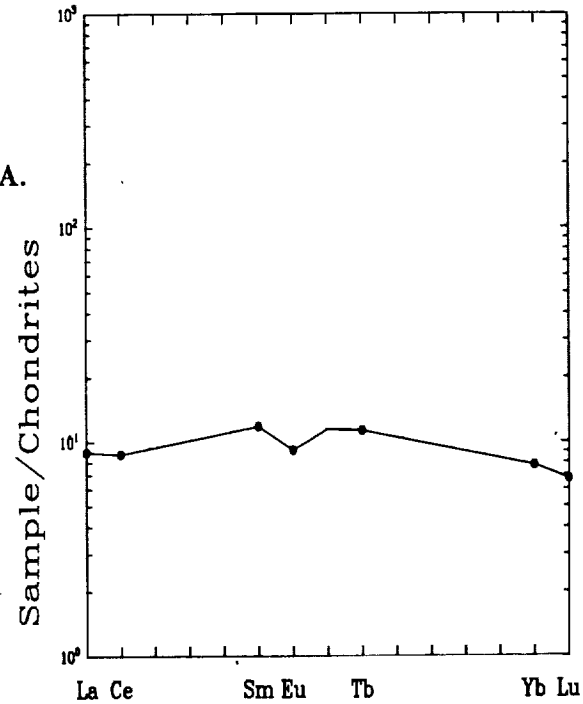
Powell described the particle (Fig. 6) as an olivine basalt, with a mean grain size of 0.5 mm and about 20% olivine. No thin section has been made, but a split was made for chemical analysis (Table 2, Fig. 7). The composition is similar to that of the coarse picritic (probably olivine cumulate) rocklets 15385 and 15387, i.e. more magnesian than the typical olivine-normative mare basalts, and with lower incompatible element abundances.

Fig. 6 15274,3
S-72-16215

Table 2. Ryder and Steele (1987). Microprobe fused bead (FB) and INAA. 15274,3,21 (81 mg)

wt%	FB	INAA
SiO_2	46.9	
TiO_2	1.39	
Al_2O_3	7.3	
FeO	21.1	21.3
MnO	0.32	
MgO	15.0	
CaO	6.7	
Na_2O	0:22	0.20
P_2O_5	0.09	

Fig. 7 Chondrite-normalized plot of rare-earths in 15274,3,21. Data of Ryder and Steele (1987).



ppm	
Sc	27.5
Cr	5280
Co	66.3
Hf	1.69
Th	0.42
La	2.95
Ce	7.7
Sm	2.14
Eu	0.63
Tb	0.53
Yb	1.55
Lu	0.228

15274,4 Vitrophyric ultramafic impact melt 1 particle 0.084g (0.17g)

15274,4 Vitrophyric ultramafic impact melt 1 particle 0.084g (0.17g)

Powell described 15274,4 as a tough, angular, dark gray, fine-grained basalt (Fig. 8). The thin section ,4,23 is a fine-grained impact melt containing about 50% skeletal zoned olivines in a glassy groundmass (Fig. 9). Some Fe-metal globules and one large olivine clast are present. Microprobe data (Ryder, unpublished) show that the skeletal olivines zone from cores of Fo_{82} to rims as Fe-rich as Fo_{62}; the olivine clast is Fo_{59}. The glass is an evolved mare glass with about 19% FeO and less than 3% MgO. A bulk chemical analysis by INAA and microprobe fused bead is given as Table 3 and shows that the fragment has a composition similar to the picritic basalts 15385 and 15387, and to the fragment 15274,3 (above). It would appear to have formed by impact into a source consisting of such rocks. It has obvious meteoritic contamination in its high Ni and Co.

Fig. 8 15274,4
S-72-16213

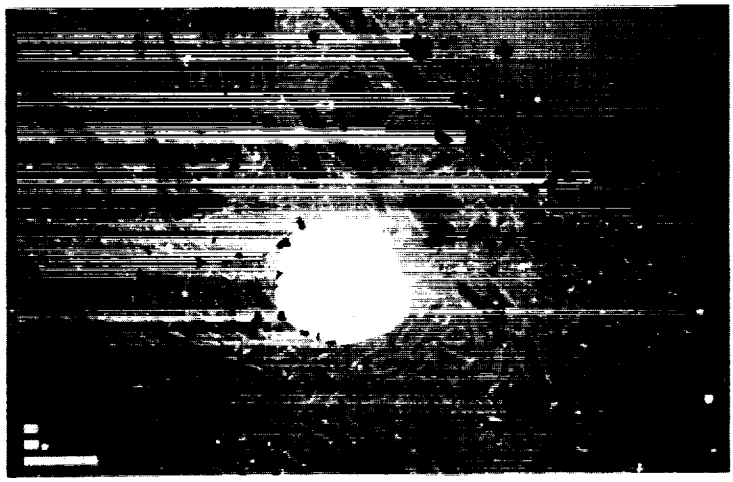
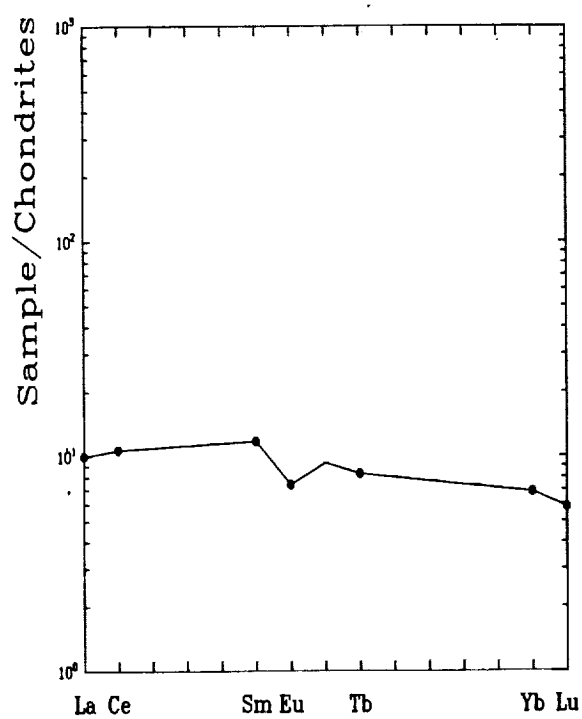


Fig. 9 15274,4,23. Microprobe backscattered image showing skeletal olivines, metal globule, and large olivine clast. Scale bar is 100 microns.

Table 3. Ryder (unpublished) INAA and microprobe fused bead (FB) 15274,4,24 (53 mg)

	FB	INAA
wt%		
SiO_2	43.1	
TiO_2	1.32	
Al_2O_3	5.3	
Cr_2O_3	1.4	0.97
FeO	22.5	24.4
MnO	0.28	
MgO	19.6	
CaO	5.25	
Na_2O	-	0.237
K_2O	0.02	
P_2O_5	0.01	
Sum	98.8	
ppm		
Sc		26.0
Co		145.5
Ni		1694.0
Hf		1.47
Zr		72.0 (+/-40)
Cs		0.36
Ba		33.0 (+/-10)
Th		0.30
Ta		0.165
La		3.30
Ce		9.4
Sm		2.13
Eu		0.510
Tb		0.39
Yb		1.37
Lu		0.198

Fig. 10 Chondrite-normalized plot of rare-earths in 15274,4,24. Data of Ryder (unpublished).



15284 Station 6 38.2g

Group	Individual particles	Subsamples	Thin sections/ Probe mounts
,0 (0.85g)			
,1 (13.39g)			
,2 (1.73g)			
,3 (21.59g)			
,4 (0.52g)	,4 (0.52g)		

15284,0 Fines and small fragments 0.85g

15284,0 consists of fines and a number of small fragments that have not been described (Fig. 1). Several appear to be regolith breccias.

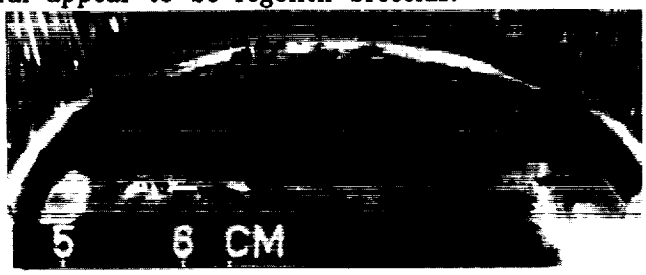
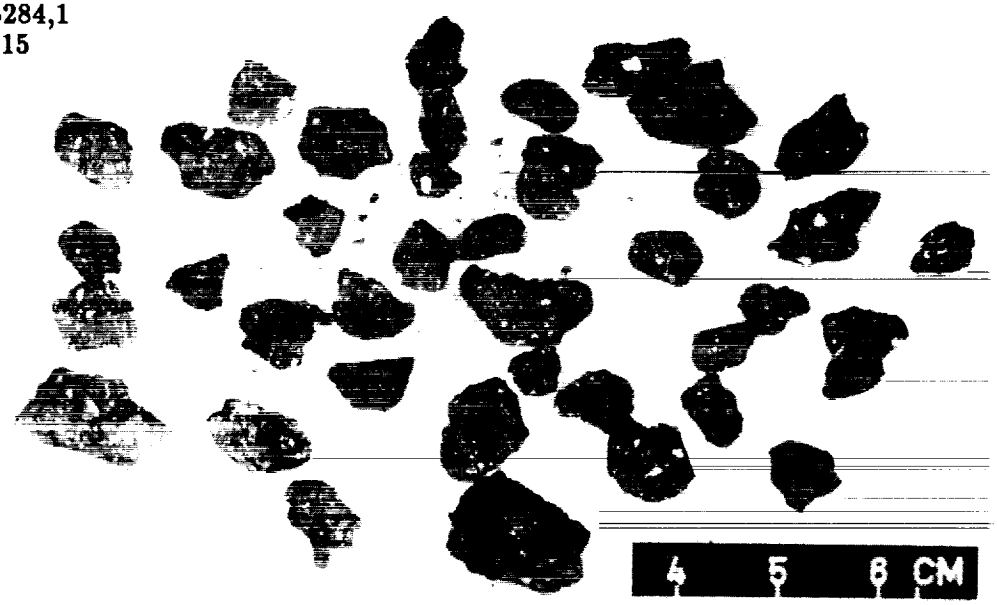


Fig. 1 15284,0
S-72-15977

15284,1 Glassy(?) regolith breccias 40 particles 13.39g

Powell described the fragments as very coherent microbreccias consisting of angular to rounded lithic and mineral clasts in a dark gray crystalline matrix (Fig. 2). From their appearance, including the angular shapes of the clasts, it is more likely that the matrix is glassy than recrystallized. The fragments are angular to subangular, and the abundant clasts (15 to 40% visible) have varied characters; most clasts are plagioclases. Powell also recognized feldspathic lithic clasts, pale basalt clasts, and other microbreccia clasts, as well as single phase clasts such as a red mineral (perhaps actually glass?).

Fig. 2 15284,1
S-72-15115



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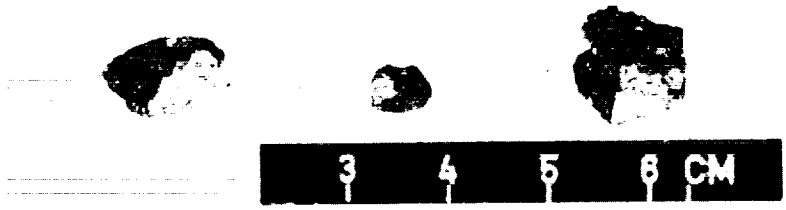
15284,2 Regolith breccias with basalt clasts 3 particles 1.73g

Powell described the three particles as microbreccias similar to 15284,1 except that they contain larger basalt clasts, 2 to 6 mm across (Fig. 3). The clasts are subophitic and pale-colored, with about 50% plagioclase; they are probably KREEP basalts.

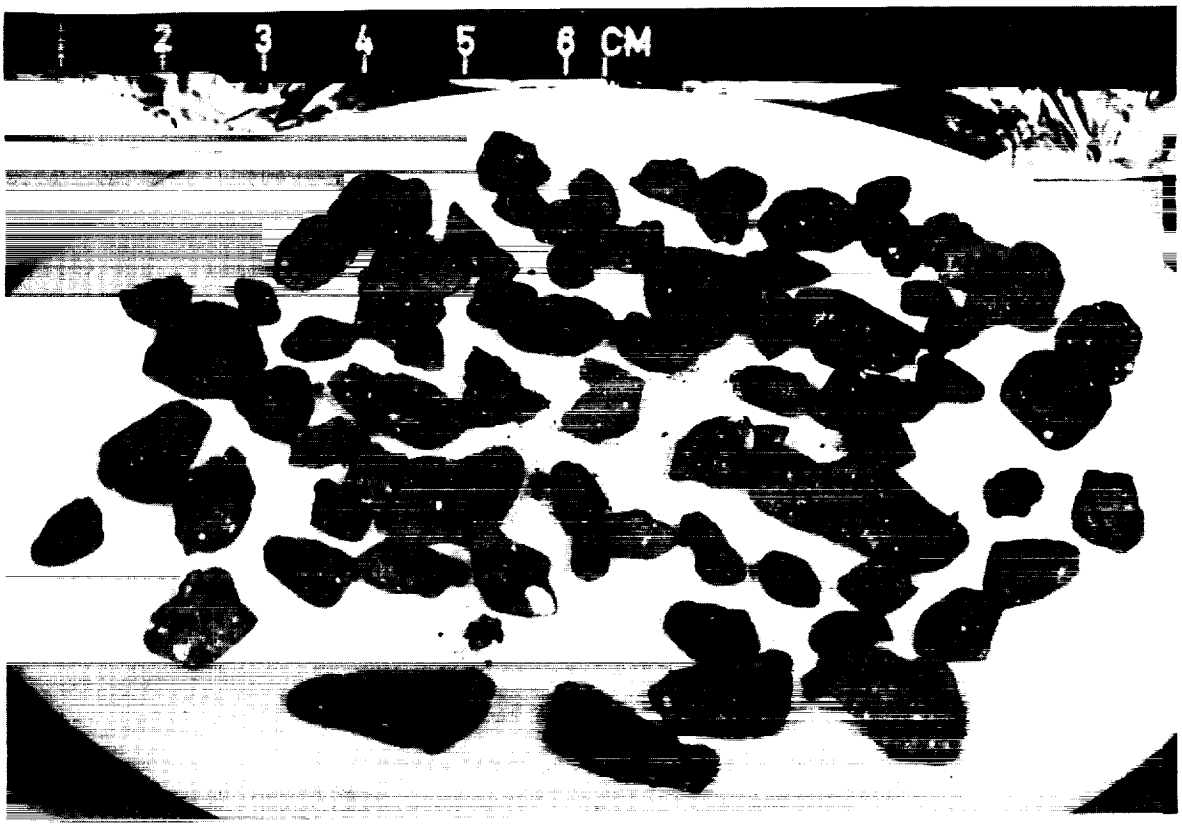
Fig. 3 15284,2
S-72-15114



15284,3 Regolith breccias 78 particles 21.59g

Powell described the particles as medium gray microbreccias (Fig. 4); they contrast with 15284,1 and ,2 in being more friable. They are subrounded to rounded and contain angular to rounded lithic and mineral fragments, and angular and spherical glasses. Apart from their friability they are similar to 15284,1. A few have thin splash glass coatings.

Fig. 4 15284,3 S-72-15113

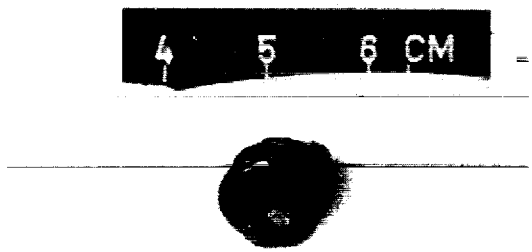


15284,4	Regolith breccia with green clast	1 particle	0.52g

15284,4	Regolith breccia with green clast	1 particle	0.52g

Powell described 15284,4 as being identical with 15284,3 particles, except that it contains a 5 mm lithic clast that is dominantly either olivine or green glass (Fig. 5). The color is pistacchio green and the clasts resembles some terrestrial dunites. Possibly the clast is a clod of volcanic green glass.

Fig. 5 15284,4
S-72-15112



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15294 Station 6 10.2g

Groups	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (0.77g)			
,1 (8.02g)			
,2 (0.95g)			
,3 (0.38g)			
,4 (0.07g)	,4 (0.07g)		
,5 (0.08g, Wasserburg)	,5 (0.08g, Wasserburg)		
,6 (0.073g, RSV)	,6 (0.073g, RSV)	,16 (0.05g, Wasserburg)	
		,18 (0.032g, Laul)	
		,19 (0.015g, RSV)	,20

15294,0 Undescribed particles (regolith breccias?) 2 particles 0.77g

15294,0 consists of two irregular particles and some fines (Fig. 1). The particles probably consist of regolith breccia and the larger one at least appears to have some glass.

Fig. 1 15294,0
S-72-15973

15294,1 Glassy(?) regolith breccias 24 particles 8.02g

Powell described these particles (Fig. 2) as recrystallized(?) microbreccias, identical with 15284,1. As such they are probably glassy matrix coherent regolith breccias. About half of them have thin splash coatings of dark grayish brown to yellowish brown vesicular glass on one or more faces.

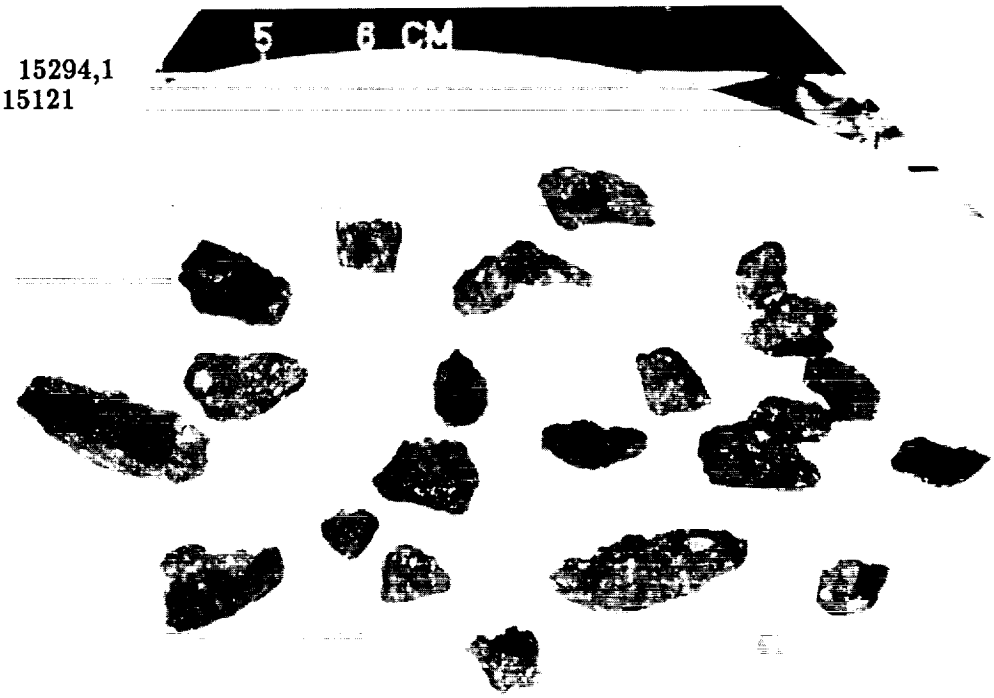
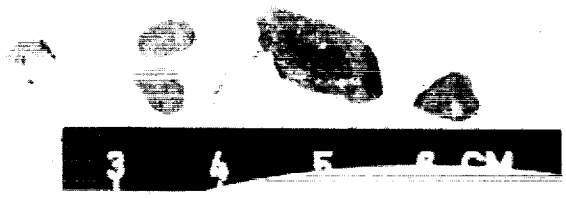


Fig. 2 15294,1
S-72-15121

15294,2	Regolith breccias	5 particles	0.95g

Powell described these particles as friable microbreccias identical with 15244,2. They are rounded to subrounded regolith breccias mainly lacking glass (Fig. 3).

Fig. 3 15294,2
S-72-15120



15294,3	Agglutinates	2 particles	0.38g

Powell described these particles as identical with 15244,5. They are regolith breccias with glass intruding and coating them (Fig. 4).

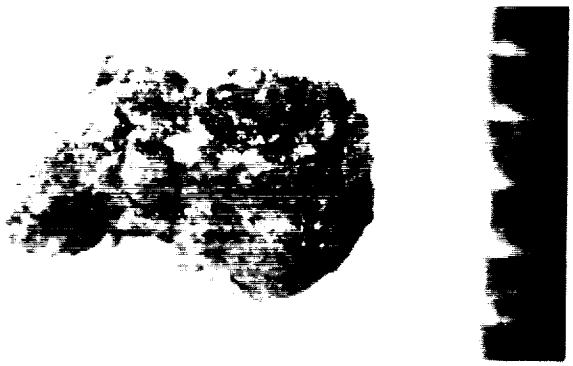
Fig. 4 15294,3
S-72-15119

15294,4	KREEP basalt(?)	1 particle	0.07g

15294,4	KREEP basalt(?)	1 particle	0.07g

Powell described 15294,4 as a tough basalt that is speckled light brown and angular (Fig. 5). It contains no vugs or vesicles, and is holocrystalline but fine-grained (0.25 mm average grain size). The texture appears to be subophitic to intergranular. The plagioclase abundance appears to be about 60%, and pyroxene 40%. It is most likely to be a volcanic KREEP basalt.

Fig. 5 15294,4
Scale is in mm.



15294,5	Olivine(?) basalt	1 particle	0.085g

15294,5	Olivine(?) basalt	1 particle	0.085g

Powell described the particle as a pale tan tough basalt that is fine-grained (mean grain size about 0.25 mm). He suggested a mode of 35% plagioclase, 40% pyroxene, and 20% of a pale yellow mineral (olivine?), commenting on the high olivine abundance. However, the identification is uncertain, and the fragment could be of a mare basalt, a KREEP basalt, or even an impact melt. It is subangular (Fig. 6) and has a penetrative fracture filled by a vein of dark cinnamon brown material, probably glass. The entire fragment was allocated as a single piece, but no data has been reported.

Fig. 6 15294,5
S-72-33627

15294,6	Impact melt	1 particle	0.073g (0.16g)

15294,6	Impact melt	1 particle	0.073g (0.16g)

Powell described the fragment as a tough recrystallized norite microbreccia, a term commonly used in early Apollo days for fragments now recognized as impact melts. The thin section 15294,6,20 shows that the sample is a poikilitic impact melt. Macroscopically the sample is subrounded, and light tannish-gray, with some vugs (Fig. 7) . It is fine-grained with an apparent xenomorphic-granular seriate texture.

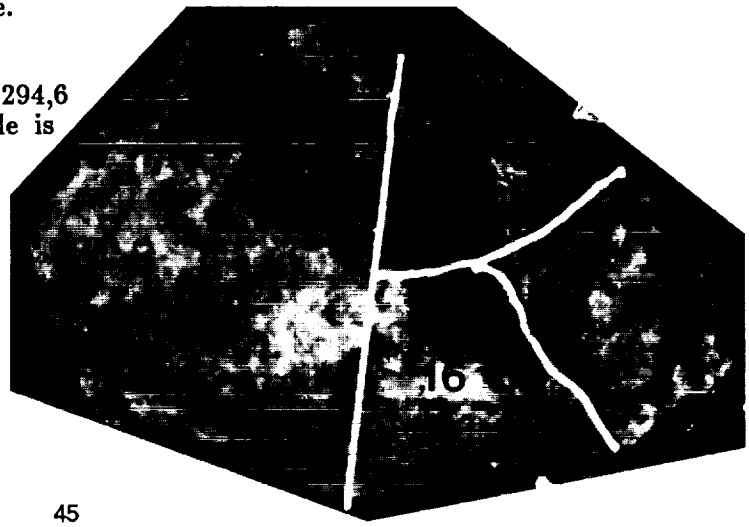


Fig. 7 Splitting of 15294,6
S-72-33617. Particle is
about 8 mm long.

15294,6 was described and analyzed by Laul et al. (1987), who presented petrographic, microprobe, and chemical data from INAA. The melt is poikilitic with prominent clasts (Fig. 8). Laul et al. (1987) gave a mode of 10.8% pyroxene, 43.1% olivine, 45.1% plagioclase, 0.9% ilmenite, 0.1% spinel, and traces of sulfide and metal. Plagioclase ranges from An_{99-84} with most being An_{98-93}. The pyroxene is Mg-rich low Ca ($\sim En_{80}Wo_{6}$) with little variation; the olivine is Fo_{90-80}. These compositions are unusually calcic and magnesian for impact melts. The ilmenite is also magnesian. The spinel is a pleonaste, not a chromite. Laul et al. (1987) tabulated representative plagioclase, pyroxene, olivine, and spinel compositions. The chemical analysis is listed in Table 1 and the rare earths plotted in Fig. 9. Consistent with the mineralogy, the sample is extremely magnesian. By difference, the SiO_2 abundance is unusually low. The sample is contaminated with meteoritic siderophiles.

Fig. 8 Photomicrograph of 15294,6,20. Crossed polarized light; width of view about 2 mm.

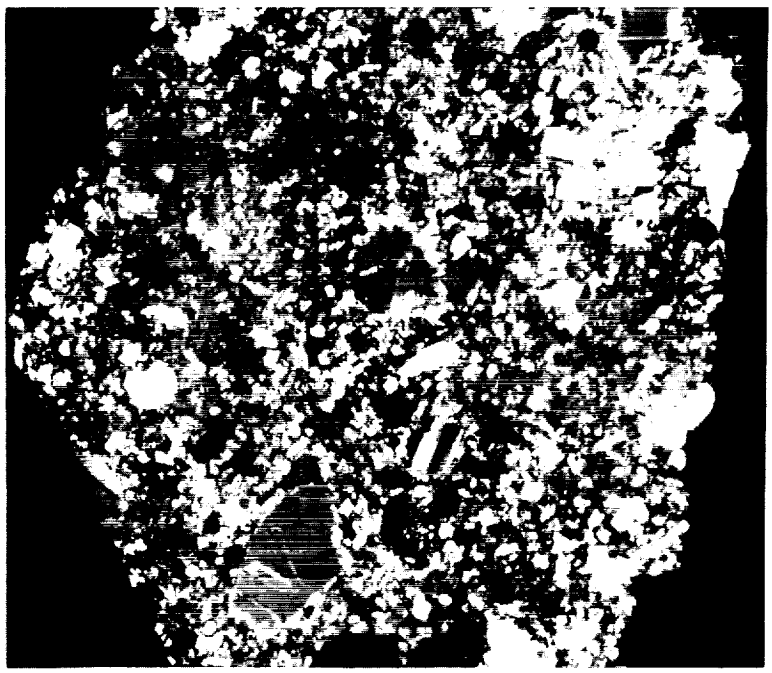


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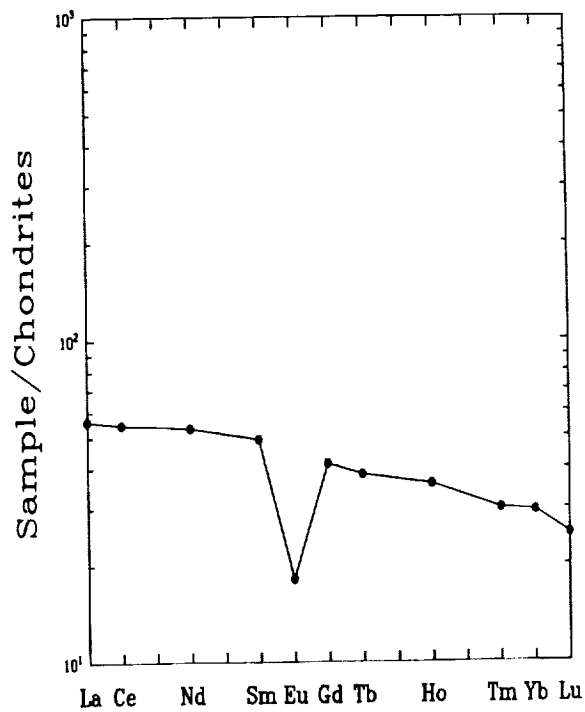
Table 1. Laul et al. (1987)
INAA 15294,6,18 (30 mg)

wt%	
SiO_2	(40.1) by diff.
TiO_2	1.0
Al_2O_3	19.3
Cr_2O_3	0.25
FeO	7.8
MnO	0.10
MgO	21.5
CaO	9.4
Na_2O	0.36
K_2O	0.14
ppm	
Sc	13.0
V	50
Ni	240
Co	32.4
Ba	210
Sr	120
Hf	6.0
Zr	230
Ta	0.8
Th	3.0
U	0.73
La	18.5
Ce	48
Nd	32
Sm	8.9
Eu	1.25
Gd	10.3
Tb	1.8
Dy	11
Ho	2.5
Tm	0.90
Yb	5.9
Lu	0.85
ppb	
Ir	3.2
Au	1.8

Fig. 9 Chondrite-normalized plot of rare-earths in 15294,6,18. Data of Laul et al. (1987)



15304 Station 7 7.3g

Groups	Individual particles	Subsamples	Thin Sections/ Probe mounts
,0 (0.457g, RSV)			
,1 (1.09g, RSV)	,12 (0.55g)	,21 (CONS, Phinney)	,58, ,59, ,60, ,61
		,37 (CONS, Gast)	
	,13 (0.09g, RSV)		
	,14 (0.437g)	,22 (0.06g, PB)	,62, ,63
		,41 (0.123g, Nyquist)	
,2 (0.31g, RSV)	,9 (0.11g, RSV)	,18 (0.03g, PB)	,51, ,52
	,10 (0.14g, RSV)	,19 (CONS, Phinney)	,53, ,54
,3 (0.87g, RSV)	,11 (0.23g, RSV)	,20 (ES, Phinney)	,55, ,56, ,57
		(,64 CONS, Phinney)	
,4 (0.34g, RSV)			
,5 (ES)	,6 (0.153g)	,15 (0.07g, PB)	,45 (James), ,46
		,25 (CONS, Gast)	
		,67 (0.029g, Laul)	
	,7 (0.155g)	,16 (0.04g, PB)	,47, ,48
		,29 (0.04g, Nyquist)	
		,66 (0.045g, Ryder)	
	,8 (0.681g)	,17 (0.05g, PB)	,49, ,50
		,24 (0.247g, Wasserburg)	
		,33 (0.325g, Nyquist)	
		,68 (0.029g)	

15304,0 Fines and undescribed fragments 0.437g

15304,0 consists of fines and several small fragments that appear to be mainly vesicular glasses or glassy regolith breccias (Fig. 1).

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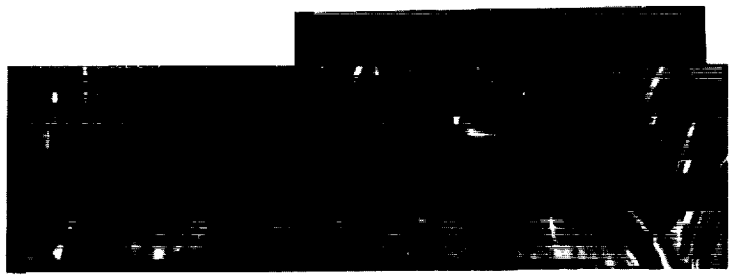
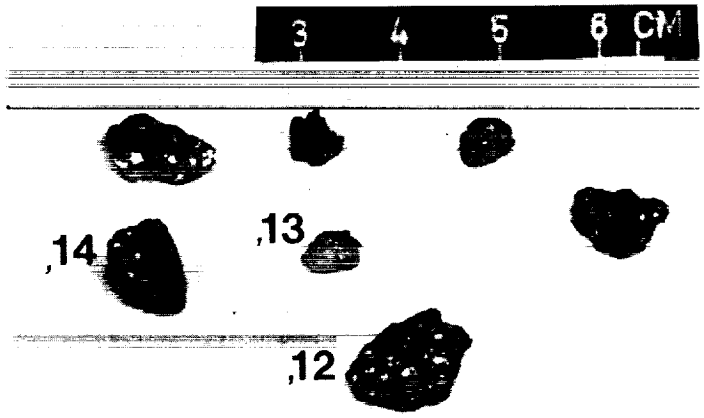
Fig. 1 15304,0
S-72-16217



15304,1 Coherent regolith breccias 7 particles 1.09g (2.51g)

Powell described the particles as microbreccias (recrystallized) that are angular to subangular, and dark gray speckled with white (Fig. 2). They contain 2 to 5 % green glass as angular fragments and spherules, and a red mineral; otherwise they are similar to 15284,1. Three have been individually numbered and two of these have been sectioned; they are regolith breccias.

Fig. 2 Original 7 particles of 15304,1. Identifications tentative. S-72-15173



15304,12 Coherent regolith breccia 1 particle 0.55g (0.68g)

15304,12 is a glassy regolith breccia with prominent white clasts (Fig. 3). 4 thin sections were made from three chips that constituted ,21. These have clasts of plagioclase-rich lithologies including anorthositic ones, and glass spherules (Fig. 4). Glass shards and spheres include both green and yellow varieties. A partial chemical analysis of a bulk sample chipped from the remaining ,12 particle (Table 1) shows that the regolith breccia has slightly lower incompatible elements than the host soil by about 15% (Fig. 5), probably because of excess green glass or anorthositic particles. Wiesmann and Hubbard (1975) also reported an $^{87}Sr/^{86}Sr$ ratio of 0.70477 +/- 7.

Fig. 3 Initial splitting of 15304,12 Particle is about 1 cm long. S-72-31259

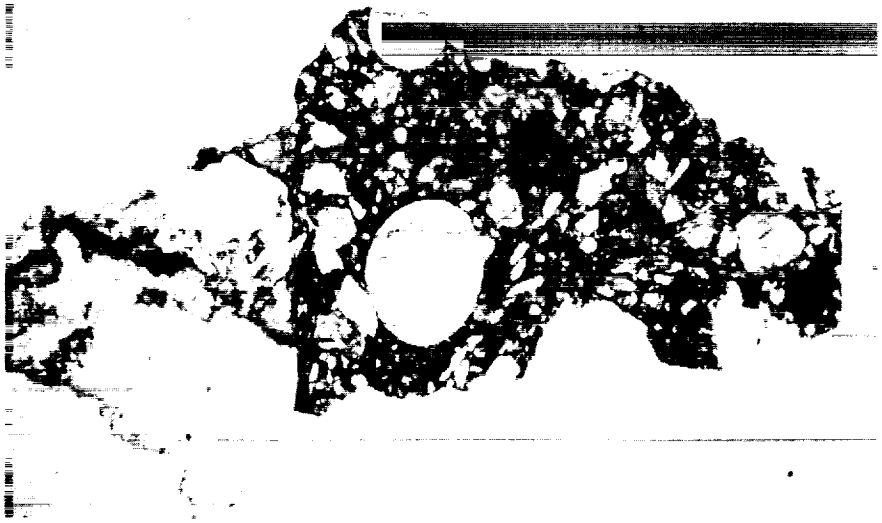


Fig. 4 Photomicrograph of 15304,12,59. Plane light; field of view about 2 mm wide.

Table 1. Wiesmann and Hubbard (1975).
Isotope dilution/mass spectrometry.
15304,12,37 (39 mg)

wt%	
TiO_2	0.92
Cr_2O_3	0.3000
Na_2O	0.38
K_2O	0.152
ppm	
Li	9.8
Rb	3.8
Sr	121
Ba	151
Th	2.59
Zr	199
Hf	5.3
La	14.7
Ce	37.2
Nd	23.4
Sm	6.80
Eu	1.07
Gd	8.25
Dy	9.80
Er	5.69
Yb	5.39

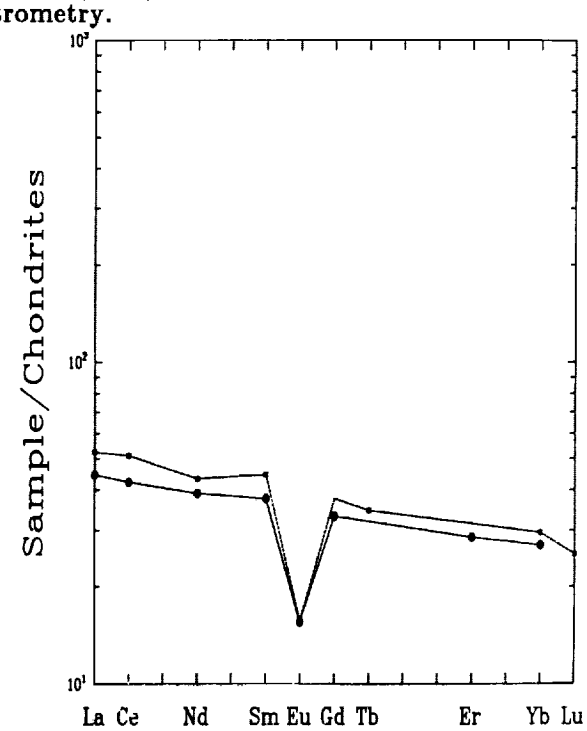


Fig. 5 Chondrite-normalized plot of rare earths in 15304,12,37 (large symbols) and host soil 15301 (small symbols). Data from Wiesmann and Hubbard (1975) for 15304 and Korotev (1987) for 15301.

15304,13	Regolith breccia	1 particle	0.09g

15304,13 has never been subdivided although it was given an individual number (see Fig. 2). It is clearly a regolith breccia.

15304,14	Regolith breccia	1 particle	0.437g (0.63g)

15304,14 is a regolith breccia (Figs. 2, 6). Two thin sections (one of which, ,63, is thin and badly plucked) show it to consist of a glassy matrix with a clast population that is dominated by feldspathic materials but includes yellow, orange, and green glasses (Fig. 7). A second small chip was removed after ,22 and allocated but no data for it have been published.

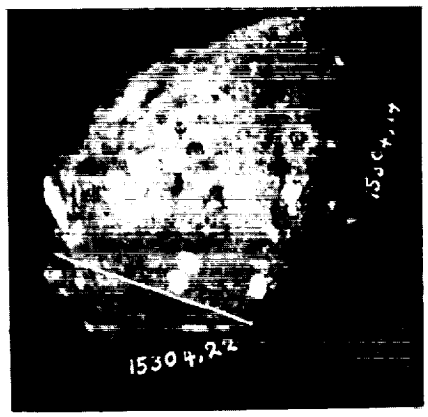


Fig. 6 Initial splitting of 15304,14. Particle is about 1 cm long. S-72-31260.

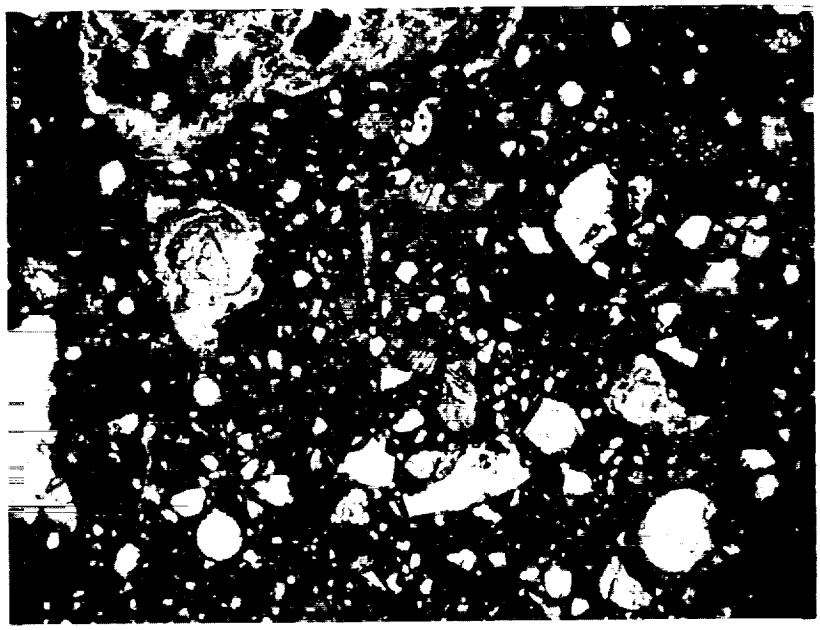


Fig. 7 Photomicrograph of 15304,12,62. Plane light, field of view about 2 mm wide.

15304,2 Glass-coated regolith breccias 4 particles 0.31g (0.66g)

Powell described these particles as glass coated recrystallized microbreccias, identical with 15304,1 except for the thin partial coatings of splashed dark brownish-gray vesicular glass (Fig. 8). Two were sectioned and are regolith breccias.

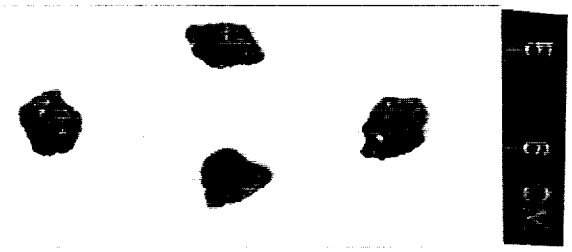


Fig. 8 Original 4 particles of 15304,2. S-72-15172

15304,9 Glass-coated regolith breccia 1 particle 0.11g (0.16g)

15304,9 was chipped (Fig. 9) and two thin sections made. These show the sample to be a coherent regolith breccia with abundant clasts, some of which are large (Fig. 10). Clasts include feldspathic lithic and mineral fragments, as well as spheres and shards of glass, including yellow, orange, and green varieties. Much of the plagioclase fragmental material shows shock deformation.

Fig. 9 Splitting of 15304,9 Fragment is about 7 mm long. S-72-31255

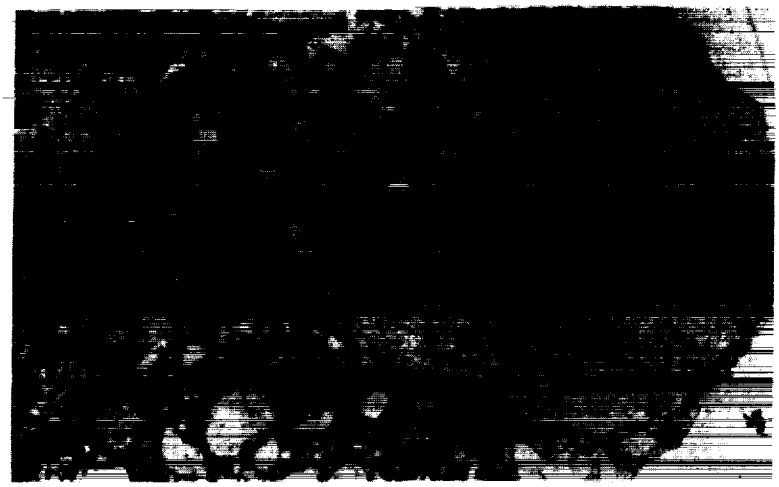


Fig. 10 Photomicrograph of 15304,9,51. Plane light; field of view about 2 mm wide.

15304,10 Glass-coated regolith breccia 1 particle 0.14g (0.19g)

15304,10 is very similar to 15304,9, and also contains abundant glass. It was chipped (Fig. 11) and two thin sections made from it show it to be a coherent regolith breccia (Fig. 12).

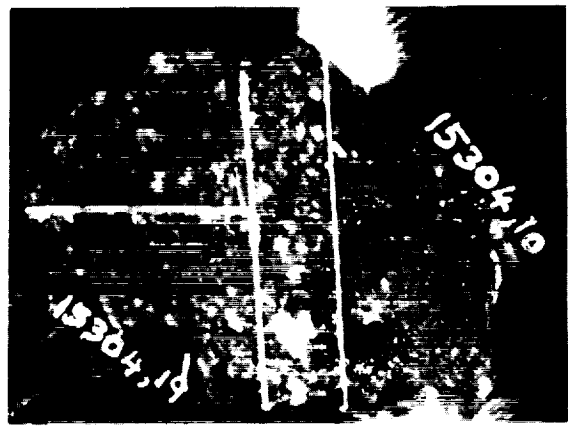


Fig. 11 Chipping of 15304,10. Lines are schematic. Only one chip, ,19, was numbered. Particle is about 7 mm long. S-72-31257

Fig. 12 Photomicrograph of 15304,10,53. Plane light; field of view about 2 mm wide.

15304,3 Friable to coherent regolith breccias 6 particles 0.87g (1.12g)

Powell described these particles as friable to coherent, subangular to subrounded, medium gray, and very finely granular microbreccias (Fig. 13). They contain notable abundances of green glass spherules and fragments (2 to 5 %).

Fig. 13 5 particles of 15304,3 following removal of particle 15304,11. S-72-32956. No scale available.

15304,11	Regolith breccia	1 particle	0.23g (0.25g)

15304,11 was separated and a chip (,20) removed for thin sections (Fig. 14). The sections show a regolith breccia with varied feldspathic lithic clasts and glass shards and spheres (Fig. 15).

Fig. 14 15304,11 prior to chipping. No scale available. S-72-31258

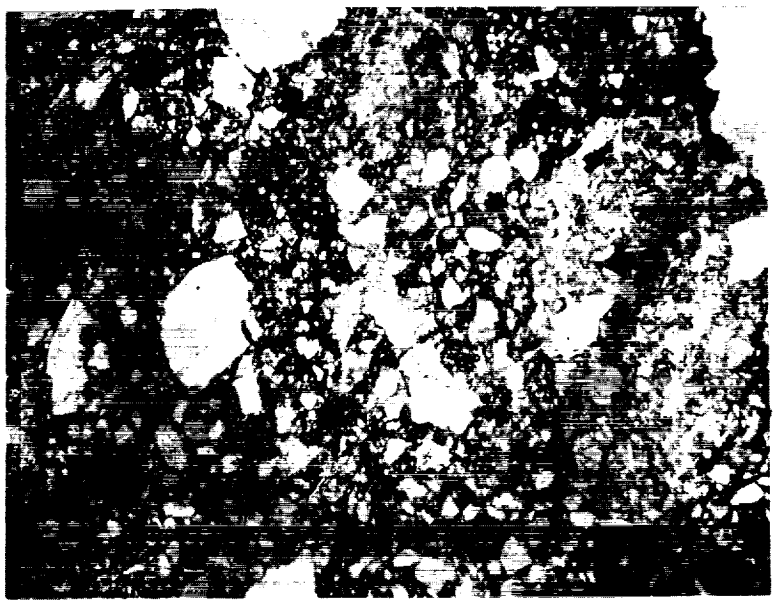


Fig. 15 Photomicrograph of 15304,11,57. Plane light; field of view about 2 mm.

15304,4 Agglutinates 3 particles 0.34g

15304,4 was described by Powell as friable agglutinates with irregular shapes (Fig. 16), consisting of friable microbreccias (i.e regolith breccias) welded by vesicular glass. The glass is dark brownish-gray to yellowish-brown. Powell listed 4 particles but all photographs show only 3. They have never been sectioned or allocated.

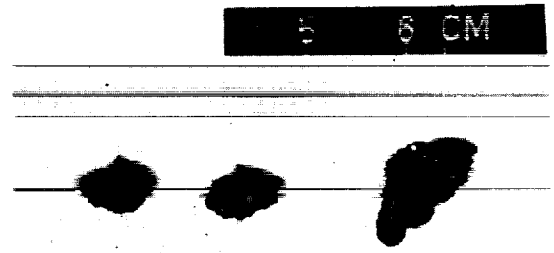


Fig. 16 15304,4
S-72-15171

15304,5 Crystalline non-mare rocks 3 particles 0.0g (1.98g)

Powell described 15304,5 as tough subrounded light tannish-gray non-mare crystalline rocks (Fig. 17). They consist of one KREEP basalt, one fine-grained impact melt, and one feldspathic granulite.

Fig. 17 15304,5 Numbering of ,6 and ,7 tentative.
S-72-15169

15304,6 KREEP basalt 1 particle 0.153g (0.31g)

The particle is a fine-grained KREEP basalt with crystals visible macroscopically (Fig. 18). Two thin sections were produced (Fig. 19). Simonds et al. (1975) described the basalt as an intersertal sample with a grain-size for plagioclase of 100 to 300 microns. They gave a mode of 51% plagioclase, 36% pyroxene, 7% ilmenite, 2% cristobalite, and 9% mesostasis. They noted the lack of olivine. Simon et al. (1987) gave a mode of 46.1% plagioclase, 39.8% pyroxene, 2.1% ilmenite, 3.0% cristobalite, 8.6% mesostasis, 0.3% phosphate, 0.1% metal, and traces of sulfide. They made analyses of 25 plagioclases, whose compositions are in the range for other KREEP basalts.

Fig. 18 Initial splitting of 15304,6. S-72-31253

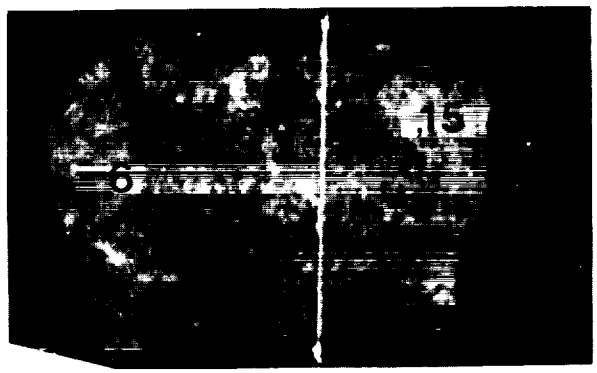


Fig. 19 Photomicrograph of 15304,6,46. Plane light; field of view about 2 mm wide.

Chemical analyses were produced by Hubbard et al. (1973) and by Simon et al. (1987). These are reproduced in Table 2 and the rare earths are plotted in Fig. 20. The two analyses are fairly consistent with each other and show an average Apollo 15 KREEP basalt. Nyquist et al. (1973) reported a bulk $^{87}Sr/^{86}Sr$ of 0.71283 +/- 12.

Table 2. Col. A: Hubbard et al. (1973) and Wiesmann and Hubbard (1975). Isotope dilution/mass spectrometry. 15304,6,25 (43.5 mg). Col. B: Simon et al. (1987). INAA. 15304,6,67 (listed in their table as ,46) (28.4 mg).

wt%	A	B
SiO_2	-	-
TiO_2	1.85	1.7
Al_2O_3	15.6	15.1
Cr_2O_3	0.3028	0.3402
FeO	10.3	10.0
MnO	-	0.136
MgO	8.49	9.2
CaO	9.94	9.3
Na_2O	0.71	0.74
K_2O	0.548	0.53
P_2O_5	-	-
ppm		
Sc	-	20.2
V	-	63
Co	-	20.0
Ni	-	<20
Rb	14.0	-
Sr	183.0	210
Zr	976	800
Hf	22.9	22.4
Ba	-	710
Th	10.9	12.2
U	3.14	3.3
Ta	-	2.8
Li	26.3	-
La	65.8	71.0
Ce	166	180
Nd	103	105
Sm	29.1	29.5
Eu	2.53	2.75
Gd	34.3	39
Tb	-	6.27
Dy	37.4	37
Ho	-	8.5
Er	21.9	-
Tm	-	3.1
Yb	20.2	20.5
Lu	-	3.0

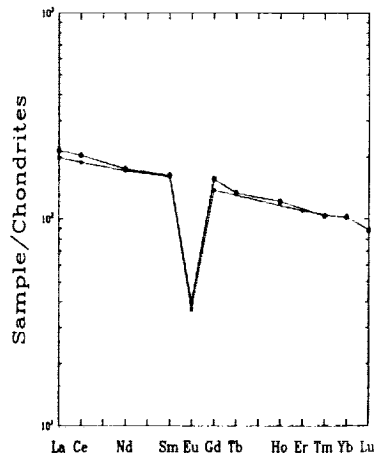


Fig. 20 Chondrite-normalized plot of rare earths in 15304,6. Data from Hubbard et al. (1973) (small symbols) and Simon et al. (1987) (large symbols).

15304,7 Fine-grained impact melt 1 particle 0.155g (0.30g)

15304,7 is a fine-grained crystalline particle (Fig. 21). Thin sections show that it is a fine-grained impact melt (Fig. 22). Simonds et al. (1975) described it as a clast-rich ophitic melt rather like 72315, with groundmass plagioclases 20 to 60 microns long. They stated that it had about 50% plagioclase (clasts + crystallized from melt). Ryder and Spudis (1987) found that the pyroxenes that enclosed the melt plagioclases were generally less than 100 microns across. Round vesicles are present but not common; clasts, mainly plagioclases, compose about 10% of the sample.

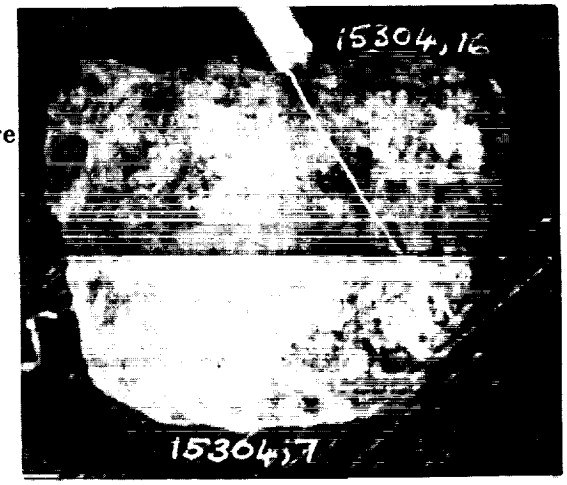


Fig. 21 Initial splitting of 15304,7. Subsequent chips were taken for chemical studies. S-72-31256

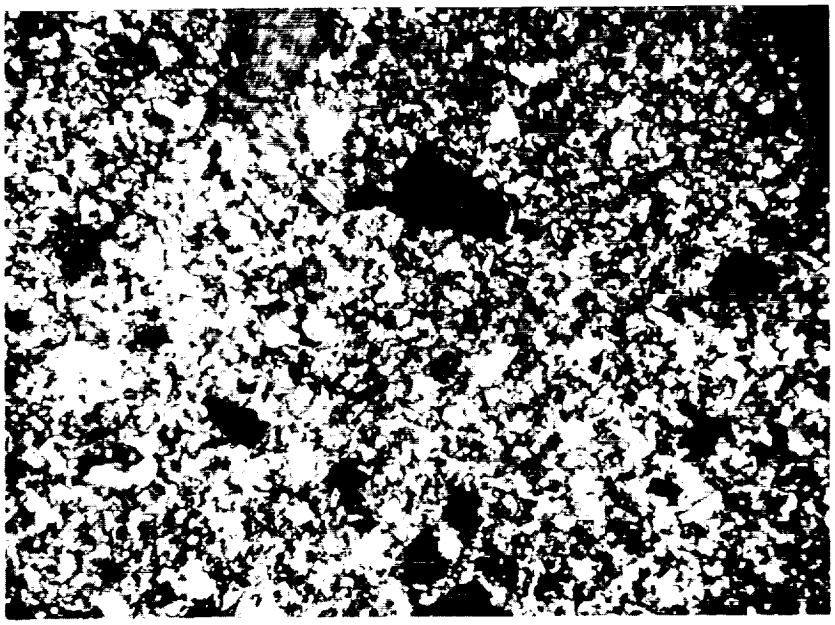


Fig. 22 Photomicrograph of 15304,7,47. Crossed polarized light; field of view about 2 mm wide.

A partial chemical analysis of a bulk sample (Table 3, Fig. 23) shows that the sample is a little more enriched in rare-earths than most impact melts, with light rare earths about 150 x chondrites. The Ni and Co abundances suggest meteoritic contamination.

Table 3. Ryder and Spudis (1987); INAA. 15304,7,66 (35 mg).

wt%	
FeO	11.5
ppm	
Sc	22.2
Cr	1833
Co	37.4
Ni	291
Ba	450
Rb	17
Cs	0.33
Zr	415
Hf	17.0
Th	7.5
U	2.4
Ta	2.0
La	52.6
Ce	143
Nd	90
Sm	25.5
Eu	2.00
Tb	4.9
Yb	16.4
Lu	2.42

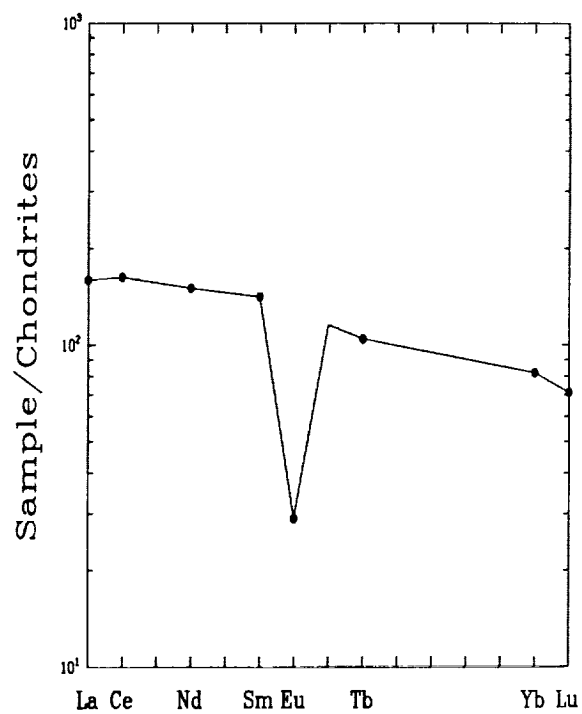


Fig. 23 Chondrite-normalized plot of rare-earths in 15304,7,66. Data of Ryder and Spudis (1987)

15304,8 Feldspathic granulite 1 particle 0.681g (1.37g)

The particle is a fine-grained crystalline rock sample (Fig. 24). In thin section it is granulitic, but it is fairly heterogenous compared with most, including large visible clasts (Fig. 25). Phinney et al. (1972) noted its higher state of recrystallization than most Apollo 15 particles, and provided some microprobe data (Fig. 26), distinguishing clasts and matrix. The sample appears not to be completely equilibrated. Simonds et al. (1975) described its texture as granulitic, with 78% plagioclase, 11% pyroxene, 11% olivine, and no mesostasis. The matrix plagioclase is 15 to 30 microns long.

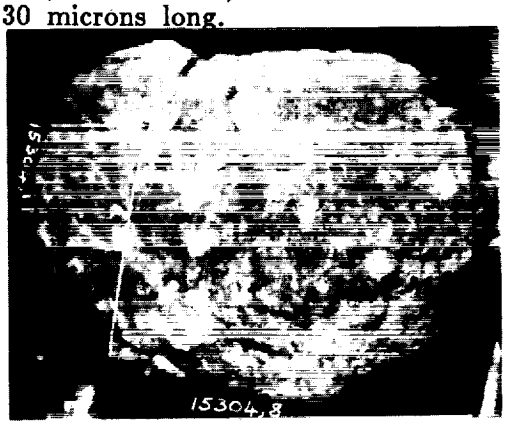


Fig. 24 Initial splitting of 15304,8. Subsequently more splits of the parent were made. S-72-31254.

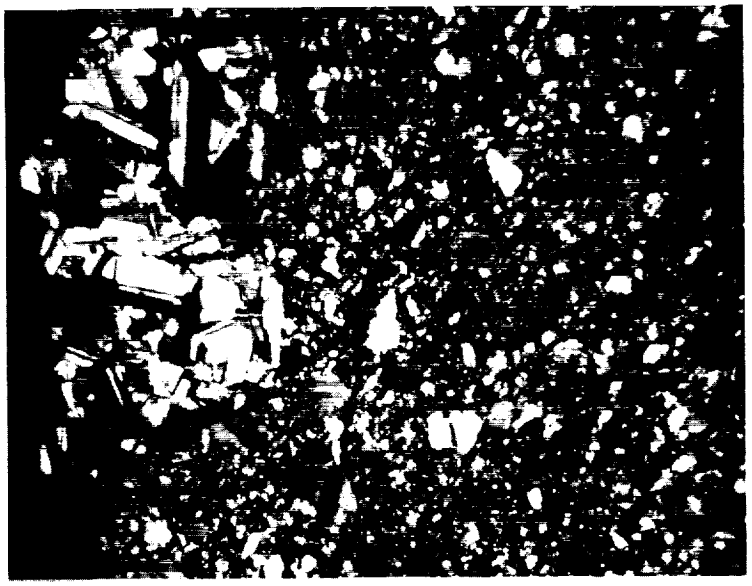
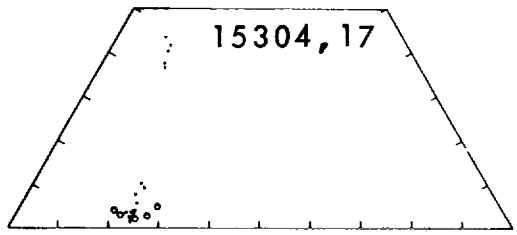


Fig. 25 Photomicrograph of 15304,8,50. Crossed polarized light; field of view about 2 mm wide.

Fig. 26. Mineral data for 15304,8 from Phinney et al. (1972).



	Matrix	Clasts
An	88-97	86-97
Fo	71-72	71-72

A partial chemical analysis of a bulk fragment was reported by Wiesmann and Hubbard (1975) (Table 4, Fig. 27). It is clearly higher in rare-earths than most feldspathic granulite samples, and has a distinct negative Eu anomaly. Nyquist et al. (1973) determined an $^{87}Sr/^{86}Sr$ ratio of 0.70328 +/- 6.

Table 4. Wiesmann and Hubbard (1975) Isotope dilution/mass spectrometry. 15304,8,33 (53 mg).

wt%	
Na_2O	0.65
TiO_2	0.57
K_2O	0.164
ppm	
Cr	800
Rb	4.065
Sr	177
Ba	218
U	1.17
Zr	266
Hf	6.6
Li	7.3
La	18.3
Ce	46.4
Nd	27.8
Sm	7.91
Eu	1.33
Gd	9.75
Dy	11.0
Er	6.85
Yb	6.71
Lu	0.988

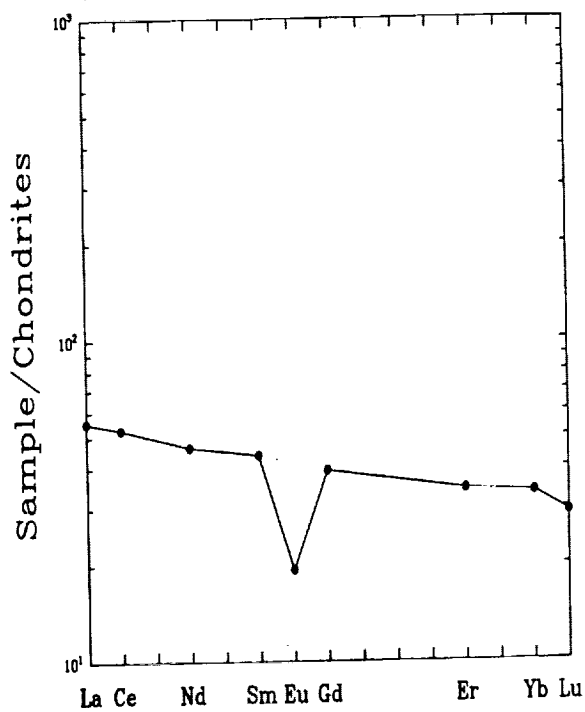
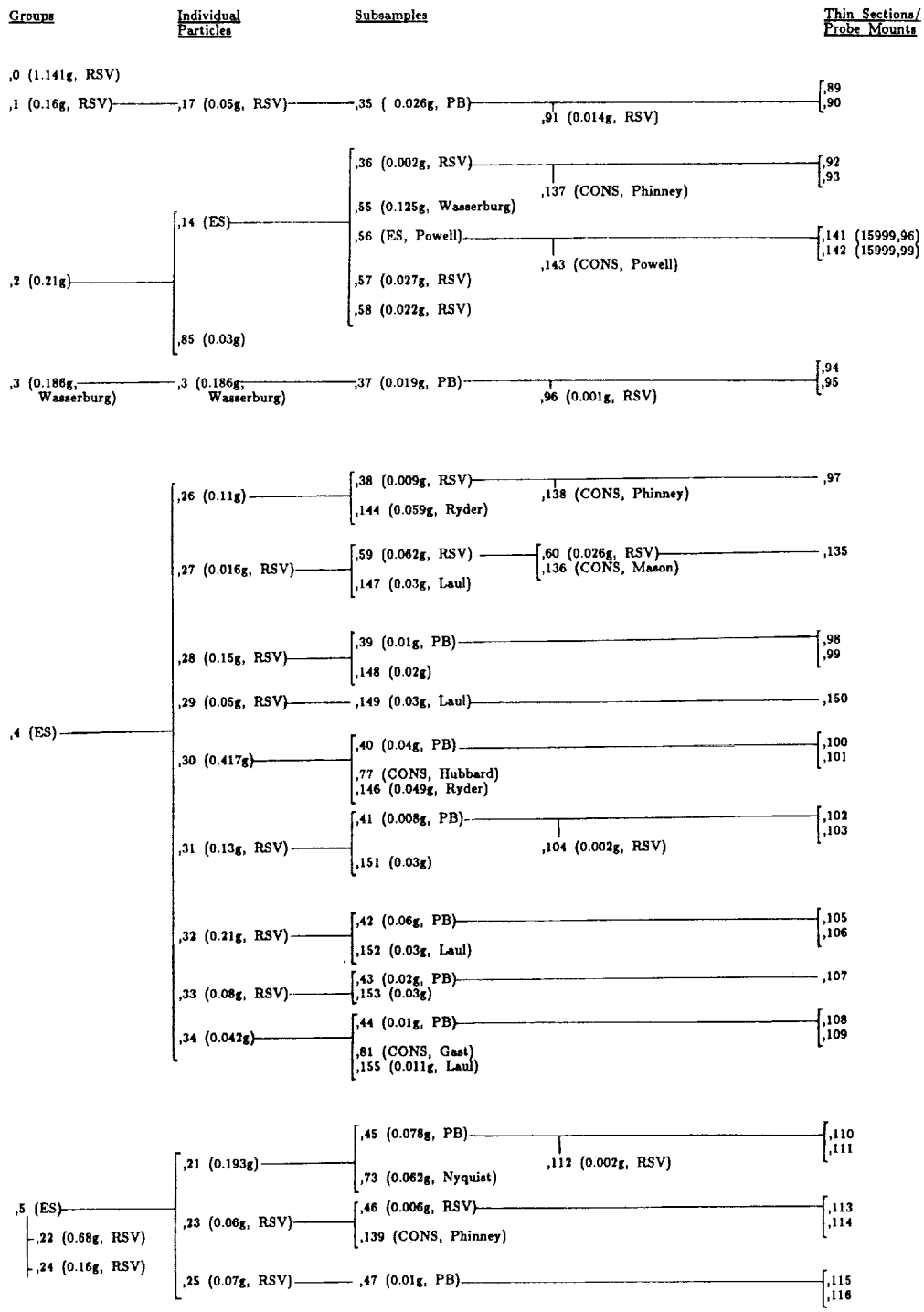
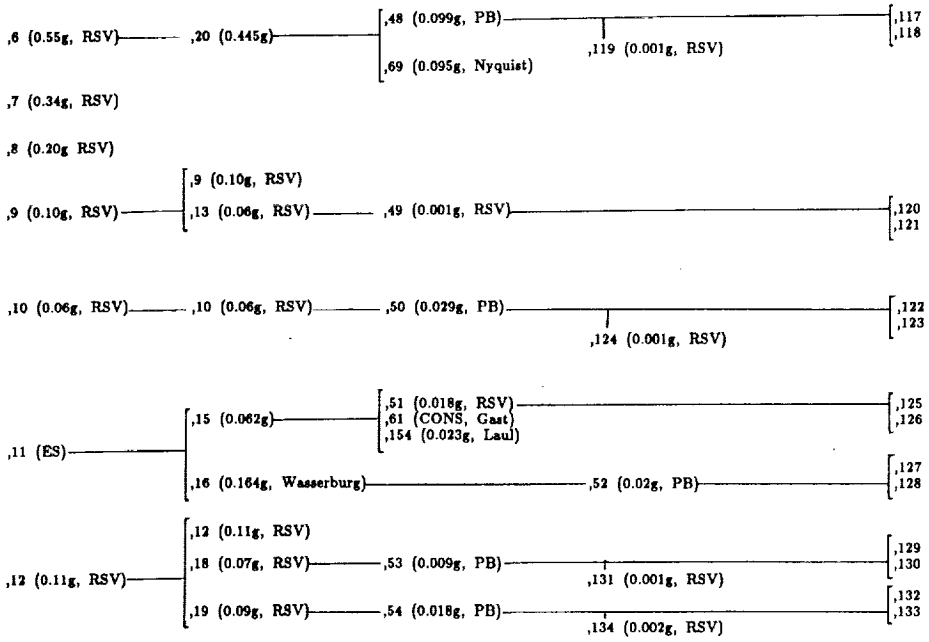


Fig. 27 Chondrite-normalized plot of 15304,8,33. Data of Wiesmann and Hubbard (1975).

15314 Station 7 8.4g





15314,0 Fines and small friable particles 1.14g

15314,0 consists almost entirely of fines (Fig. 1).

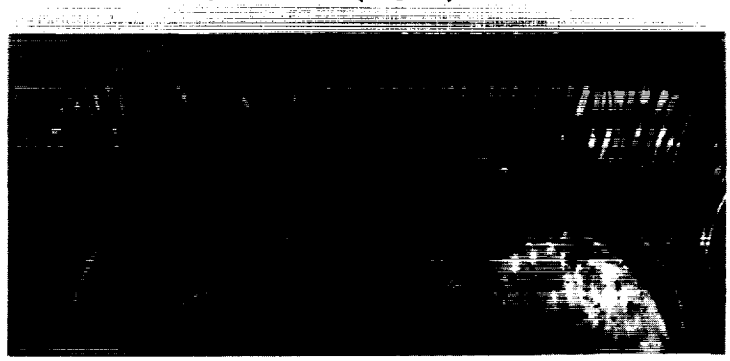


Fig. 1 15314,0
S-72-16185

15314,1 Friable green glass clods 3 particles 0.16g (0.24g)

The three particles are friable agglomerates of green glass (Fig. 2). They are well-rounded, finely granular, and apple green. Powell estimated that they consist of 90 to 100% green glass. The matrix is paler-colored than the spherules, which are mainly 0.1 to 0.5 mm in diameter. The spherules compose about 20% of the volume. Nothing other than green glass was recognized macroscopically.

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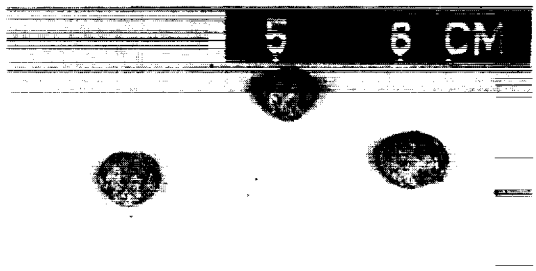

Fig. 2 Original 15314,1. One of the particles was given an individual number. S-72-15975

15314,17 Friable green glass clod 1 particle 0.05g (0.08g)

One fragment was removed from ,1 and a piece taken for thin sections. The sections consist almost entirely of green glass spherules and shards (Fig. 3). Minor amounts of pyroxene and plagioclase, and rare brown/yellow glass, are also present.

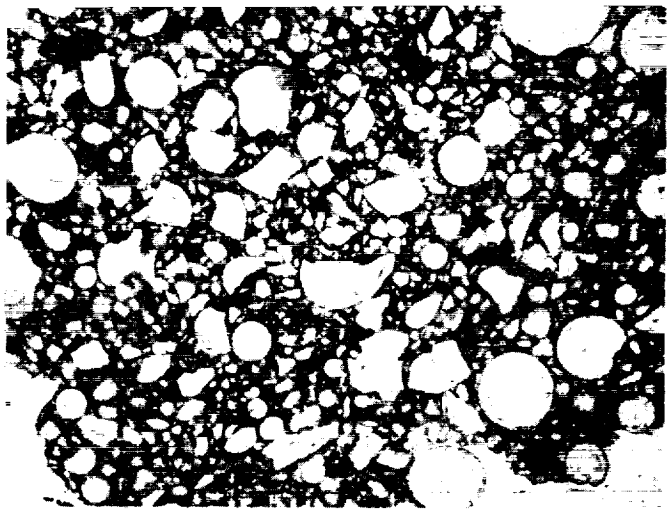

Fig. 3 Photomicrograph of 15314,17,90. Plane light, field of view about 2 mm wide.

15314,2 Mare basalts 5 particles 0.21g (0.57g)

Powell described these five fragments (Fig. 4) as diabases that were tough, subangular, and tan (mottled). They appeared to be coarse (0.5 to 1.0 mm) with a subophitic texture, containing 40% tabular to lath-shaped plagioclase, 45% anhedral tan to reddish-brown pyroxene, 5% yellow anhedral olivine, and 2-5% ilmenite. They lack vugs. The largest particle, from which a thin section was made, is an olivine-bearing mare basalt.

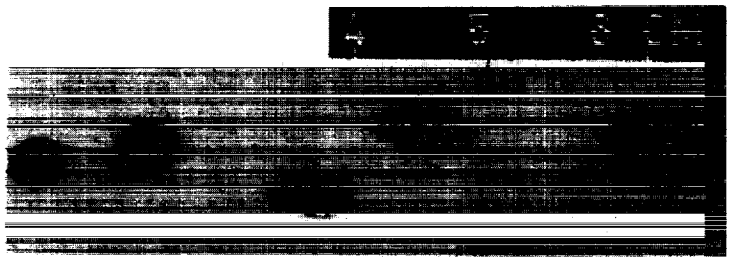

Fig. 4 Original particles of 15314,2. The largest particle was removed as ,14. One of the others (unidentified) became ,85. S-72-15974

15314,14 Olivine-normative mare basalt 1 particle 0.0g (0.310g)

15314,14 (Fig. 4) is an olivine-bearing mare basalt with plagioclases and pyroxenes up to 1 mm long (Fig. 5). It is mildly shock-cataclasized. According to Powell et al. (1973) it is an olivine-free and silica-free variety, distinct from any other mare basalt, that they termed Type IV. However, Ryder (in press) found early olivine, and cristobalite, in thin sections; both are suggestive of a relationship with the main olivine-normative basalts at the site. The chemical analysis made by Powell et al. (1973) (Table 1) is probably unrepresentative and pyroxene-rich, lacking olivine in the norm.

Table 1. Chemical analysis of 15314,14 made by microprobe analysis of fused bead of powdered sample.

SiO_2	49.46
TiO_2	2.43
Al_2O_3	10.09
Cr_2O_3	0.66
FeO	17.71
MnO	0.25
MgO	9.48
CaO	10.70
Na_2O	0.04
K_2O	0.05
P_2O_5	0.08
NiO	0.04
Sum	100.99

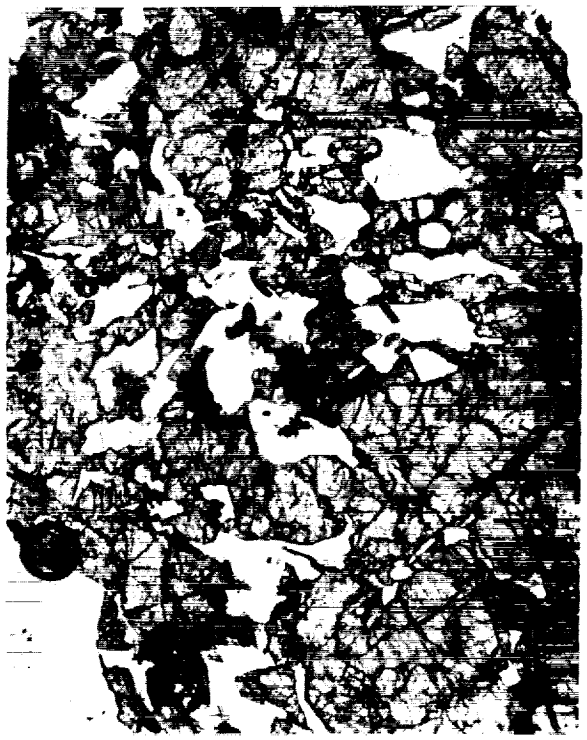

Fig. 5 Photomicrograph of 15434,14,92. Plane light, field of view about 2 mm wide.

15314,85 Mare basalt 1 particle 0.03g

Nothing is known about this particle, which was allocated but then returned unopened. It is probably the smallest of the particles shown in Fig. 4.

15314,3 Olivine-normative mare basalt 1 particle 0.186g (0.23g)

15314,3 Olivine-normative mare basalt 1 particle 0.186g (0.23g)

Powell described the particle as a tough basalt that is subrounded and dark brownish gray (Fig. 6). It is finer-grained than those in 15314,2 and appeared to lack (or have only accessory) olivine. Powell suggested 60% cinnamon brown pyroxene and 40% plagioclase. Ryder (in press) reported that the basalt consists of olivine phenocrysts set in a generally intrafasciculate-spherulitic groundmass of plagioclase, pyroxene, and anhedral olivines (Fig. 7). Interstitial areas contain cristobalite and fayalite.

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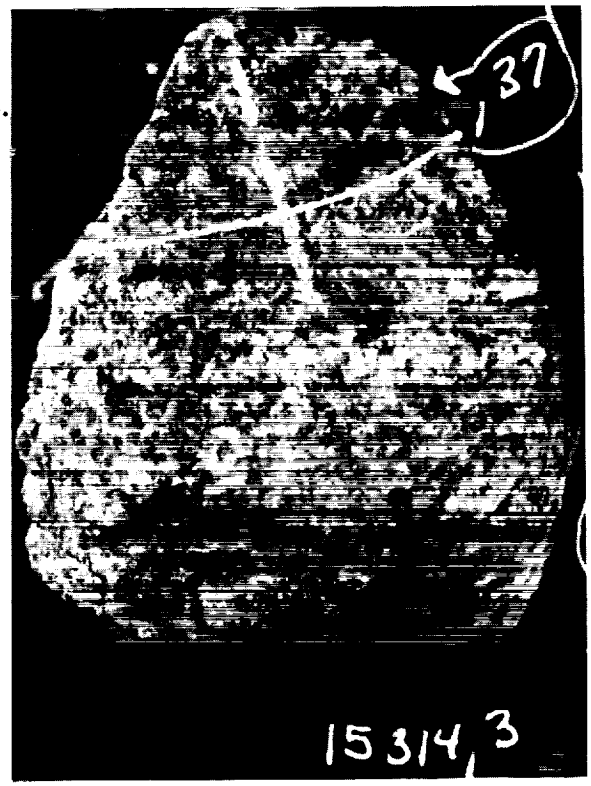


Fig. 6 Splitting plan for 15314,3. Particle is about 7 mm long. S-72-31452

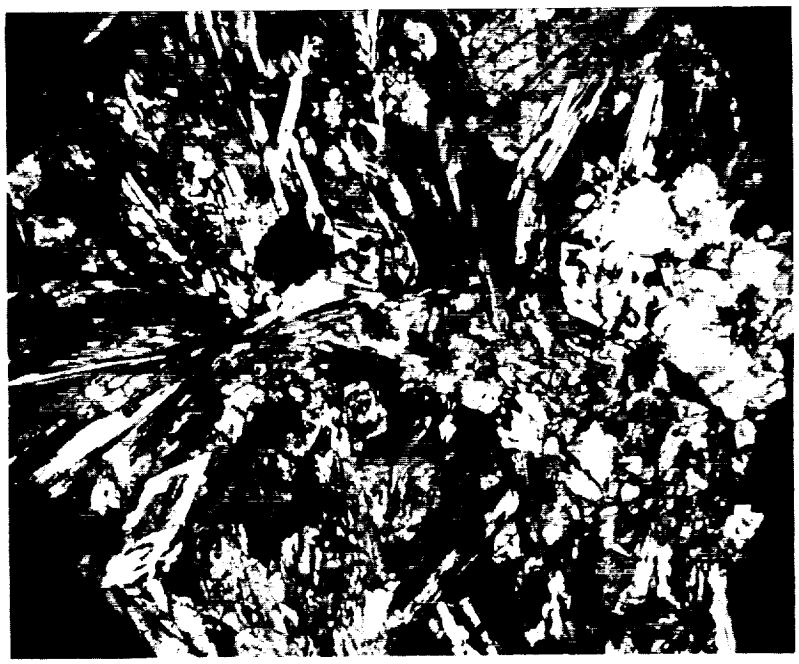


Fig. 7 Photomicrograph of 15314,3,94. Crossed polarized light; width of view about 2 mm.

15314,4 Crystalline rocks (non-mare and mare) 9 particles 0.0g (2.01g)

Powell described the 9 particles (Fig. 8) as non-mare crystalline rocks, all of which were tough, subangular, and medium to light tannish gray. All have individual designations and have been at least thin-sectioned. All but one are indeed non-mare rocks: five are impact melts, one is glass, one is a feldspathic granulite, one is a KREEP basalt, and one is a mare basalt.

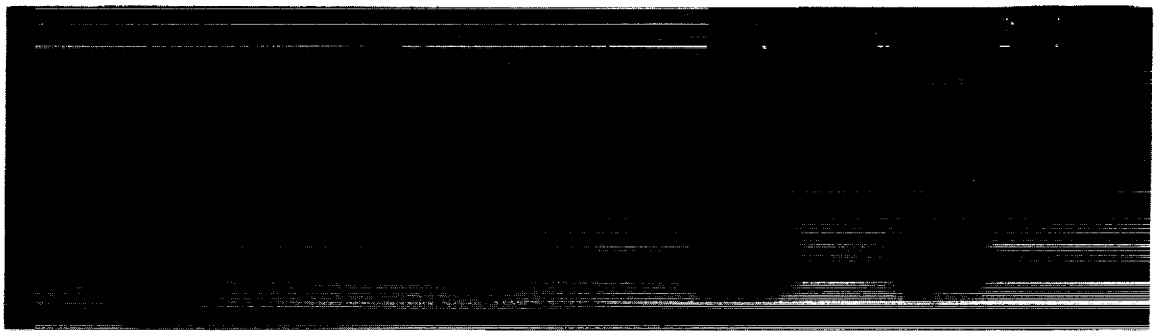
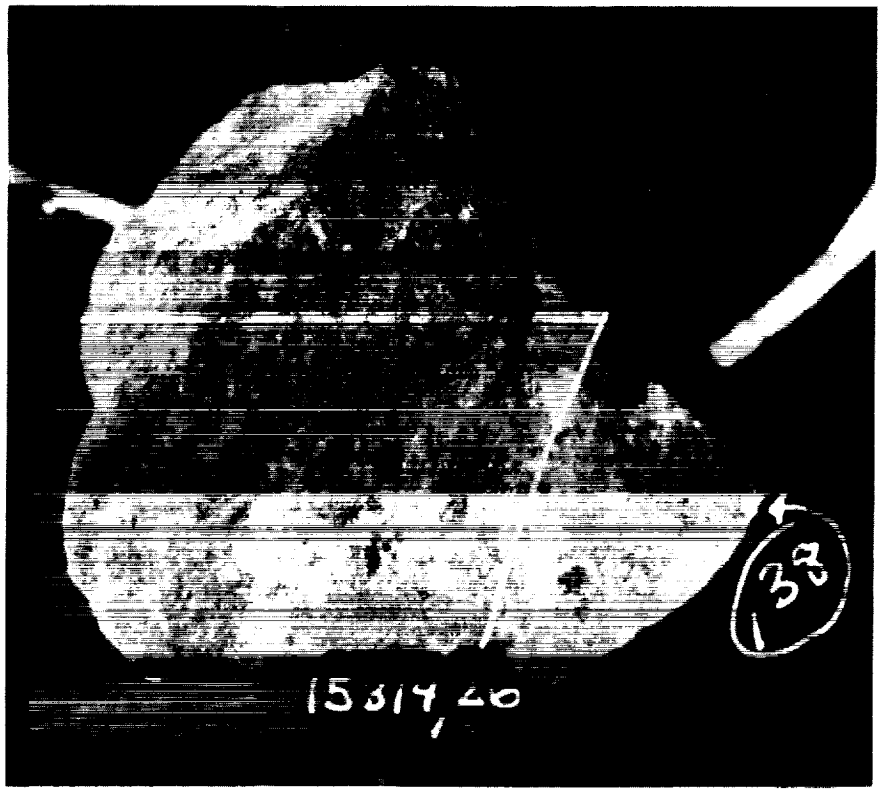


Fig. 8 15314,4 particles prior to any processing. S-72-15991

15314,26 Micropoikilitic impact melt 1 particle 0.11g (0.20g)

Fig. 9 Initial splitting plan for 15314,26. S-72-31453



The initial splitting of 15314,26 for a thin section is shown in Fig. 9. Simonds et al. (1975) described 15314,26 (,97) (Fig. 10) as an impact melt with a clast-rich ophitic texture similar to rock 72315. They gave a mode of 44% plagioclase, 38% pyroxene, 18% olivine, and less than 1% mesostasis; they estimated the matrix plagioclases as 20-50 microns long. Ryder and Spudis (1987) gave a more detailed description, stating that small clasts are not obvious. The pyroxene oikocrysts are less than 150 microns across and contain small (20 micron) plagioclases. Other plagioclases are blocky and up to 100 microns. Most clasts are plagioclase but a few (up to 500 microns) are mafic grains. A chemical analysis is given in Table 2, and shows the essential low-medium-K Fra Mauro composition (Group B of Ryder and Spudis, 1987). The high Ni and Co suggest meteoritic contamination. The rare earths are shown as Fig. 11.

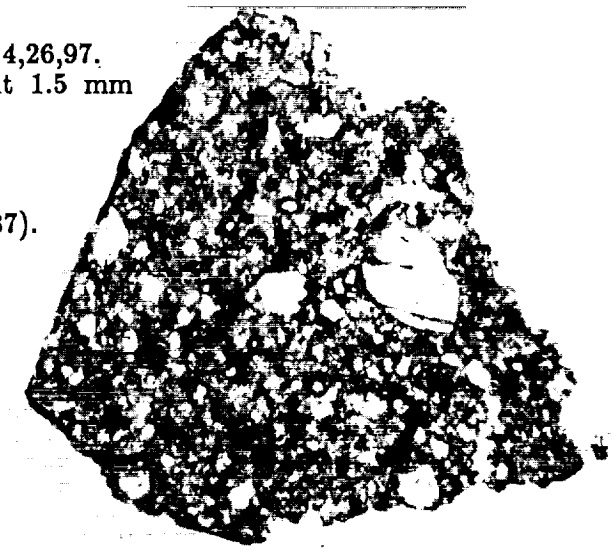


Fig. 10 Photomicrograph of 15314,26,97. Plane light, field of view about 1.5 mm wide.

Table 2. Ryder and Spudis (1987). 15314,26,144. Microprobe fused bead (FB) and neutron activation analysis (INAA). (45.6 mg)

wt% FB except as noted	
SiO_2	48.0
TiO_2	1.37
Al_2O_3	17.3
Cr_2O_3	0.18
FeO	8.6
FeO INAA	11.0
MnO	0.143
MgO	12.8
CaO	10.5
Na_2O	0.521
Na_2O INAA	0.557
K_2O	0.353
P_2O_5	0.367
Sum FB	100.13
ppm INAA	
Sc	21.1
Cr	1770
Co	50.6
Ni	305
Ba	450
Zr	390
Hf	15.6
Rb	15
Th	7.3
U	2.3
Cs	0.37
Ta	1.9
La	45.3
Ce	124
Nd	74
Sm	22.1
Eu	2.01
Tb	4.3
Yb	14.9
Lu	2.14

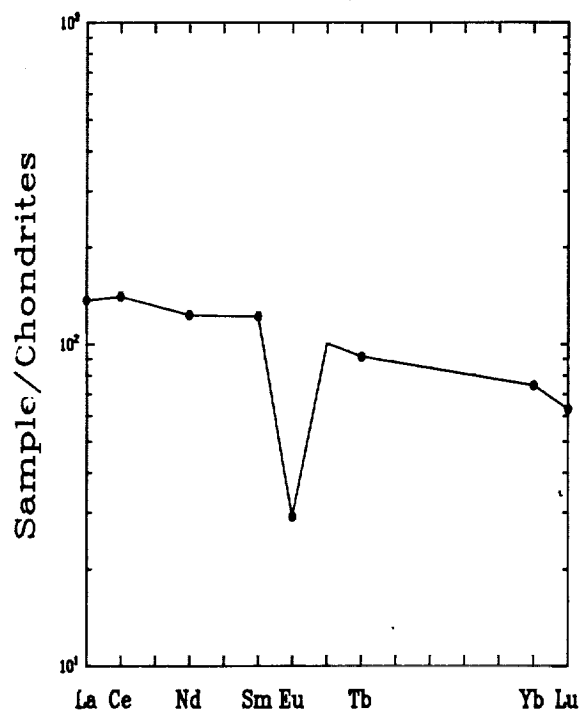


Fig. 11 Chondrite-normalized plot of rare-earth elements in 15314,26,144. Data of Ryder and Spudis (1987).

15314,27 Poikilitic impact melt 1 particle 0.016g (0.200g)

15314,27 (Fig. 12) is a poikilitic impact melt (Fig. 13). Two reported modes are shown in Table 3.

Fig. 12 Particle 15314,27 prior to processing. S-72-32944

Fig. 13 Photomicrograph of 15314,27,135. Crossed polarized light. Field of view about 2 mm wide.

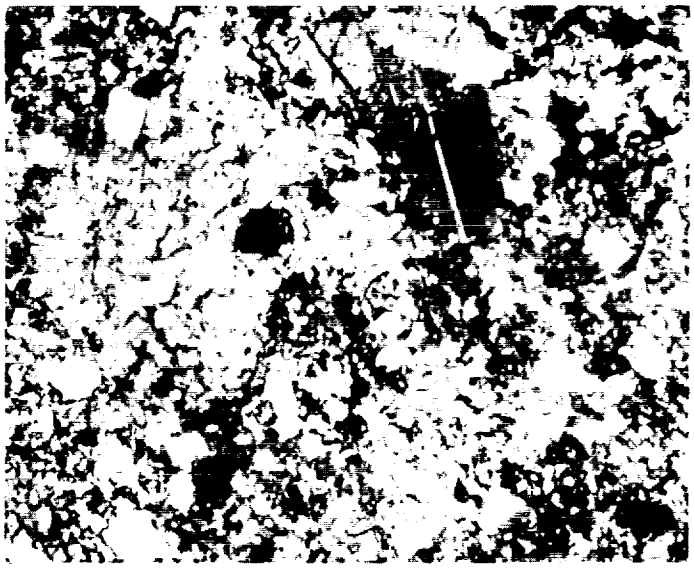


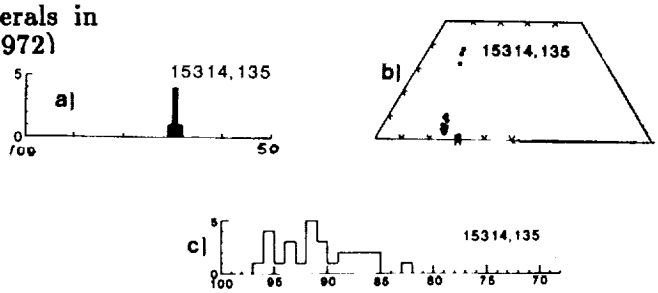
Table 3. Modes of 15314,27,59,135. A = Mason(1972) B = Laul et al. (1987).

	Plag	Olivine	Pyroxene	Ilmenite	Others
A	60%	10%	25%	5%	-
B	61.6%	9.7%	24.9%	3.2%	0.6%*

*= 0.1% sulfide, 0.4% mesostasis, 0.1% undefined.

Mason (1972) reported that plagioclase grains were An_{82-95} (mean An_{90}), with some grains weakly zoned. Most pyroxenes had pigeonite cores ($En_{69}Wo_7$) rimmed by subcalcic augites. Olivine grains are uniformly about Fo_{68}. Mason (1972) also described the texture as cataclastic and recrystallized, but the thin section is consistent with an impact melt rather than a recrystallized fragment. Laul et al. (1987) also reported mineral compositions (Fig. 14) that agree with those reported by Mason (1972), and tabulated analyses of 2 plagioclases; they did not provide any specific description of the sample but included it with their impact melt samples.

Fig. 14 Analyses of minerals in 15314,27,135 (Mason, 1972) a=olivine b= pyroxene c=plagioclase



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15314,28 Fine-grained ol-norm mare basalt 1 particle 0.15g (0.20g)

15314,28 is a fine-grained, slightly vesicular basalt. It is fine-grained with olivine phenocrysts. The processing plan for the thin section chip is shown as Fig. 15.

Fig. 15 Initial processing plan for 15314,28. S-72-31454

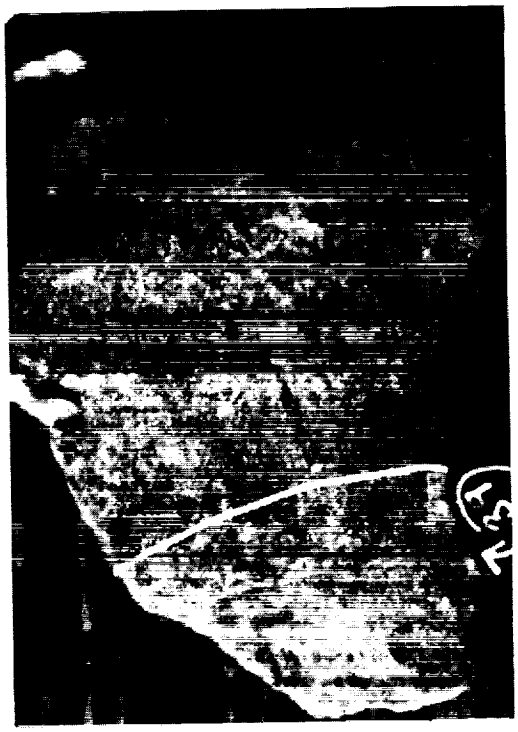
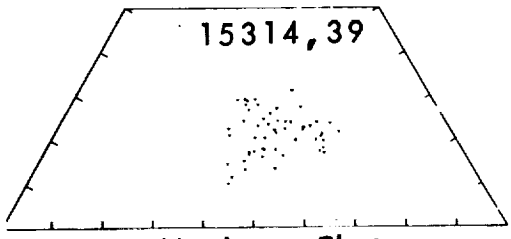


Fig. 16. Photomicrograph of 15314,28,98. Crossed polarized light; field of view about 2 mm wide. Large grains are olivines.

Phinney et al. (1972) and Simonds et al. (1975) interpreted 15314,28 as an impact melt (Simonds et al. misnumbered the subsample as 15314,48 instead of ,98). Phinney et al. (1972) reported mineral analyses (Fig. 17) that are similar to olivine-normative mare basalts. Simonds et al. (1975) reported a mode of 29% plagioclase, 47% pyroxene, 20 % olivine, and 1 % mesostasis. These authors interpreted the olivines as clasts, and the fine-grained groundmass as as impact melt. Ryder (in press) describes the sample as a fine-grained olivine-porphyritic mare basalt, pointing out that in an impact melt the clast population is usually more diverse and includes lithic fragments rather than displaying a single mineral type. The olivines appear to be partially resorbed phenocrysts, and the groundmass a rapidly-crystallized melt.

Fig. 17 Composition of minerals 15314,28,39 (TS ,98 or ,99). Phinney et al. (1972)

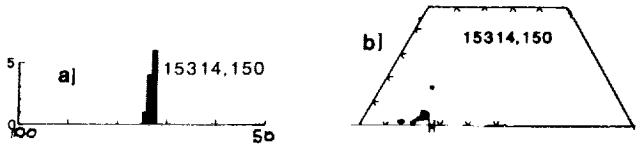


	Matrix	Clasts
An	90–93	none
Fo	none	39–69 (zoned)

15314,29 Impact melt 1 particle 0.05g (0.09g)

15314,29 was a tiny fine-grained tough particle (Fig. 18). Laul et al. (1987) include it in their study of impact melts. Although they provided no specific petrographic description they provided microprobe analyses of minerals (Fig. 19), including tabulating analyses of 2 plagioclases. The minerals appear to be fairly typical for Apollo 15 impact melts. Laul et al. (1987) gave a mode of 46.5% plagioclase, 35.8% pyroxene, 15.3% olivine, 1.7% ilmenite, 0.1% metal, 0.1% sulfide, and 0.5% unspecified.

Fig. 18 Particle 15314,29 prior to any processing. S-72-32946



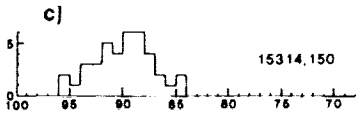


Fig. 19 Compositions of minerals in 15314,29,150 (Laul et al., 1987). a= olivine b= pyroxenes c= plagioclase

Laul et al. (1987) made a bulk rock chemical analysis using neutron activation techniques (Table 4). The rare earth elements are shown in Fig. 20. The sample is a fairly magnesian low-K Fra Mauro composition with obvious meteoritic contamination.

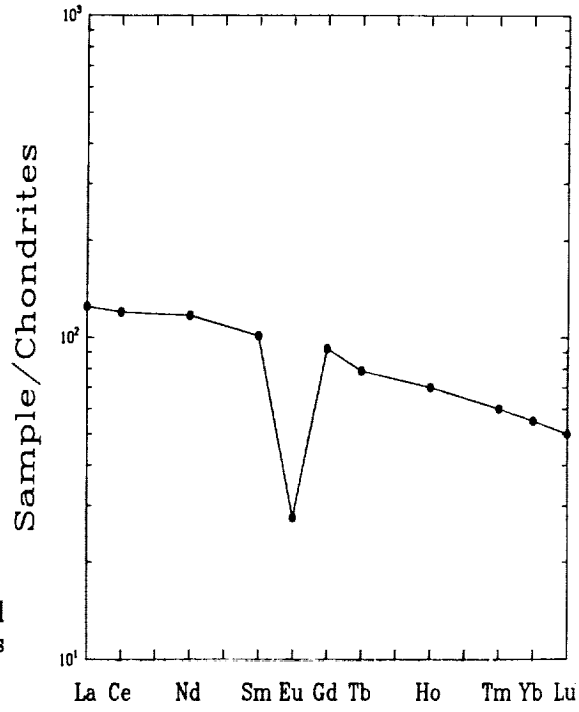


Fig. 20. Chondrite-normalized plot of rare earth elements in 15314,29,149. Data of Laul et al. (1987).

Table 4. Laul et al. (1987); INAA. 15314,29,149 (27.6 mg)

wt%					
SiO_2	--				
TiO_2	1.2				
Al_2O_3	15.2				
Cr_2O_3	0.44				
FeO	10.2				
MnO	0.125				
MgO	16.8				
CaO	9.4				
Na_2O	0.40				
K_2O	0.18				
ppm				**ppb**	
Sc	16.0	La	41.0	Ir	15
V	60.0	Ce	105	Au	12.7
Co	61.0	Nd	70		
Ni	620	Sm	18.3		
Ba	350	Eu	1.90		
Sr	150	Gd	23		
Zr	400	Tb	3.70		
Hf	11.0	Dy	22		
Th	6.0	Ho	4.9		
U	1.5	Tm	1.8		
Ta	1.5	Yb	11.0		
		Lu	1.70		

15314,30 Fine-grained impact melt 1 particle 0.417g (0.59g)

15314,30 is a fine-grained particle (Fig. 21). It is a fine-grained impact melt with obvious but not abundant clasts (Fig. 22). Simonds et al. (1975) described it as a mesostasis-rich basalt with mineral clasts, and gave a mode with 40% plagioclase (matrix grains 20 to 80 microns long), 1% pyroxene, 5% olivine, and 55% mesostasis. Laul et al. (1987) gave a mode of 44.8% plagioclase, 22.3% pyroxene, 32.3% olivine, 0.2% ilmenite, and 0.4% metal. The mesostasis was described by Ryder and Spudis (1987) to be about 30 to 40%, and to consist of a fine-grained mass of pyroxenes, metal, and oxide phases. The clasts are moderately angular and are mainly plagioclases less than 500 microns long. Laul et al. (1987) reported microprobe analyses of olivines and plagioclases in 1314,30,100 (Fig. 23), including tabulating a pyroxene analysis. They noted the sodic nature of the plagioclases.

Fig. 21 Pre-processing plan for cutting 15314,30. S-72-31455.

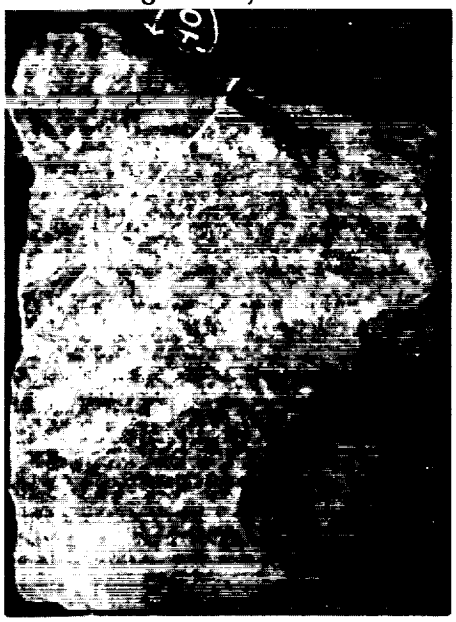
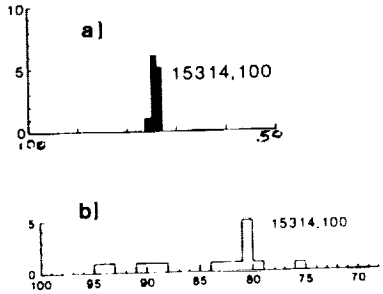


Fig. 22 Photomicrograph of 15314,30,100. Plane light, field of view about 2 mm wide.

Fig. 23. Microprobe analyses of olivines (a) and plagioclases (b) in 15314,30,100 (Laul et al., (1987).



Bulk chemical analyses are listed in Table 5, and the rare earths are plotted in Fig. 24. The analyes differ in rare earth element abundances by about 15%, which is surprising in view of the fine grain size used. The Ni and Co abundances suggest meteoritic contamination. Wiesmann and Hubbard (1975) also reported a bulk rock $^{87}Sr/^{86}Sr$ of 0.71024 +/- 9.

Table 5. Wiesmann and Hubbard (1975) Col. A (mainly isotope dilution) and Ryder and Spudis (1975) Col. B (microprobe fused bead FB and neutron activation INAA) A=15314,30,77, 54mg. B=15314,30,146, 49mg (34 mg for INAA)

wt%	A	B (FB except as noted)
SiO_2		48.5
TiO_2	1.09	1.31
Al_2O_3		16.1
Cr_2O_3	0.20	0.29
Cr_2O_3		0.32 (INAA)
FeO		8.6
FeO		11.3 (INAA)
MnO		0.153
MgO		13.8
CaO		10.2
Na_2O		0.583
Na_2O		0.609 (INAA)
K_2O	0.30	0.346
P_2O_5		0.340
Sum FB		99.9
ppm		(INAA)
Sc		20.2
Co		54.4
Ni		192
Ba	379	413
Sr	132	
Zr	492	485
Hf	12.5	13.1
Rb	8.11	13
Cs		0.34
Th	5.89	7.0
U	1.84	2.5
Ta		1.8
Li	22.1	
La	38.6	42.2
Ce	97.3	118
Nd	61.3	74
Sm	17.4	20.3
Eu	1.7	1.85
Gd	21.0	
Dy	22.5	
Tb		4.6
Er	13.2	
Yb	13.5	12.2
Lu	1.80	2.03

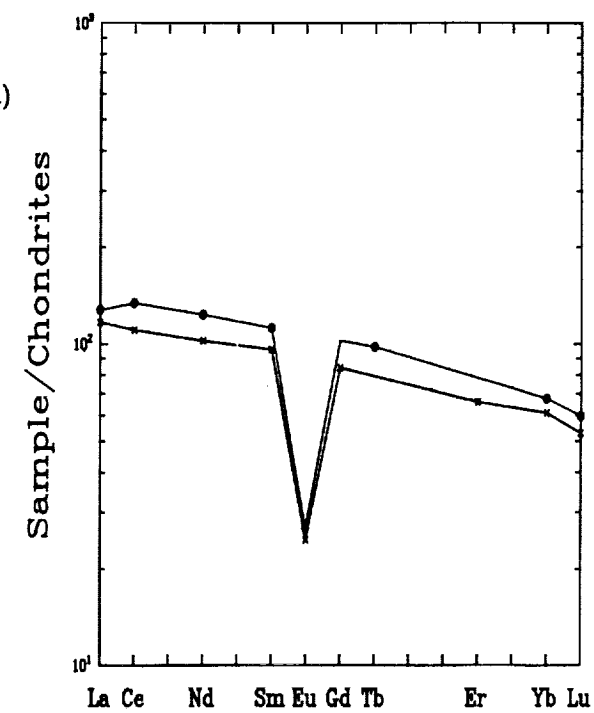


Fig. 24 Chondrite-normalized plot of rare earth elements in 15314,30. Heavy line and symbols = Ryder and Spudis (1987). Lighter line and symbols = Wiesmann and Hubbard (1975).

15314,31 Impact glass 1 particle 0.13g (0.19g)

The angular particle (Fig. 25) is an impact glass that is partly devitrified. It also contains fragments that are mainly plagioclases (Fig. 26). Phinney et al. (1972) made analyses of the glass using the microprobe. Their published average is given as Table 6; it is similar to low-K Fra Mauro compositions.

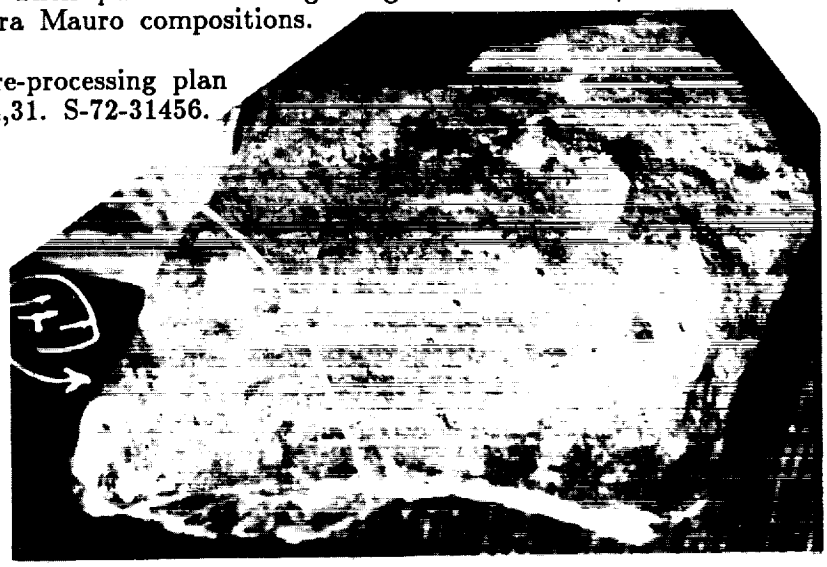


Fig. 25 Pre-processing plan for 15314,31. S-72-31456.

Fig. 26 Photomicrograph of 15314,31,103. Plane light; field is about 2 mm wide.

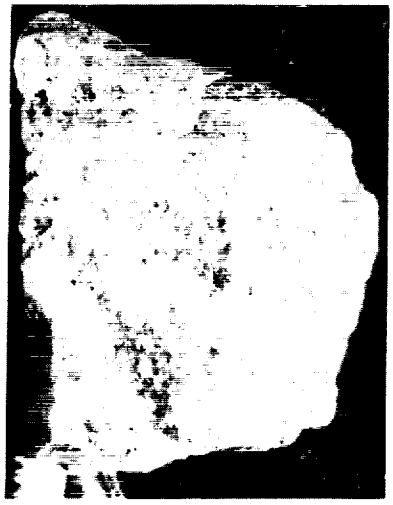
Table 6 Microprobe analysis of glass in 15314,31 (Phinney et al., 1972).

wt%	
SiO_2	48.41
TiO_2	1.04
Al_2O_3	18.04
FeO	9.71
MgO	8.33
CaO	11.86
Na_2O	0.68
K_2O	0.42
P_2O_5	0.18
Sum	98.7

15314,32 Clast-rich impact melt (?) 1 particle 0.21g (0.32g)

The angular, aphanitic particle (Fig. 27) is probably an impact melt, although it is possibly a feldspathic granulite. It is extremely clast-rich (Fig. 28), and most of the clasts are plagioclases.

Fig. 27. Pre-processing plans for 15314,32. S-72-31457.



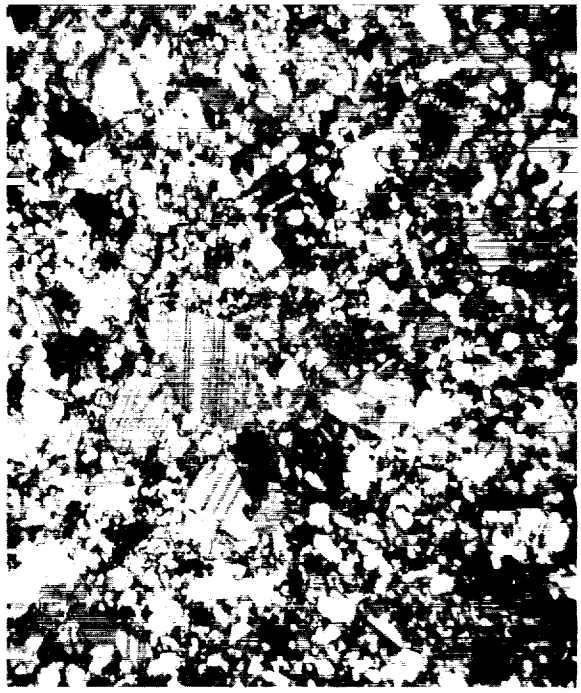
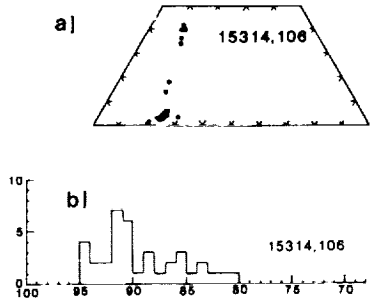


Fig. 28 Photomicrograph of 15314,32,105. Crossed polarized light; field of view about 2 mm wide.

Laul et al. (1987) reported a mode of 46.6% plagioclase, 51.9% pyroxene, no olivine, 1.0% ilmenite, 0.3% sulfide, and 0.2% metal. They made microprobe analyses of plagioclases and pyroxenes (Fig. 29), but gave no specific description; they included it as an impact melt. The range in Mg/Fe of the low-Ca pyroxenes and of the Ca/Na in the plagioclases (Fig. 29) suggest that the sample is not recrystallized but is an impact melt.

Fig. 29 Microprobe analyses of pyroxenes (a) and plagioclases (b) in 15314,29,106 (Laul et al., 1987).



Laul et al. (1987) reported a bulk chemical analysis for major and trace elements (Table 7). The rare earth elements are plotted in Fig. 30. The data show a fairly magnesian low-K Fra Mauro composition, obviously contaminated with meteoritic Ni, Ir, and Au.

Table 7. Laul et al. (1987). INAA
15314,32,152 (30.7 mg)

wt%	
SiO_2	--
TiO_2	0.97
Al_2O_3	16.2
Cr_2O_3	0.250
FeO	8.7
MnO	0.122
MgO	13.2
CaO	9.7
Na_2O	0.55
K_2O	0.44
ppm	
Sc	18.0
V	60
Co	30.5
Ni	210
Ba	450
Sr	180
Zr	420
Hf	12.1
Th	6.70
U	1.6
Ta	1.5
La	40.5
Ce	100
Nd	64
Sm	17.2
Eu	1.95
Gd	22
Tb	3.50
Dy	23
Ho	5.0
Tm	2.0
Yb	13.0
Lu	1.90
ppb	
Ir	2.9
Au	4.0

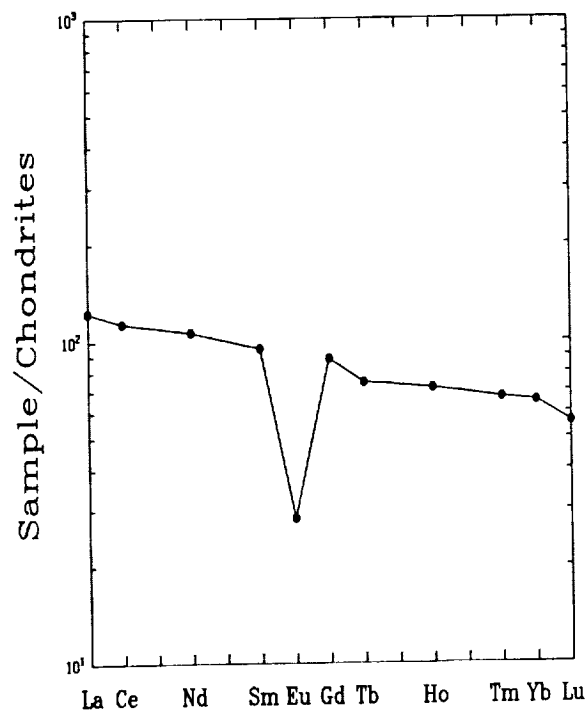


Fig. 30 Chondrite-normalized plot of rare earth elements in 15314,32,152 (Data of Laul et al. (1987).

15314,33 Feldspathic granulite 1 particle 0.08g (0.14g)

15314,33 (Fig. 31) is a tough irregular particle; it is a crystalline breccia similar to feldspathic granulites. Simonds et al. (1975) referred to it as a metabreccia consisting of clasts of feldspar in a matrix that is about 40% feldspar and 60% mafic minerals. Overall there is about 70% feldspar; the clasts are prominent in the thin section (Fig. 32). Simonds et al. (1975) noted that the matrix feldspars were only about 7 microns long on average. It is possible that the matrix was once a fine-grained melt. No mineral analyses have been reported. The thin section shows a prominent darker vein.

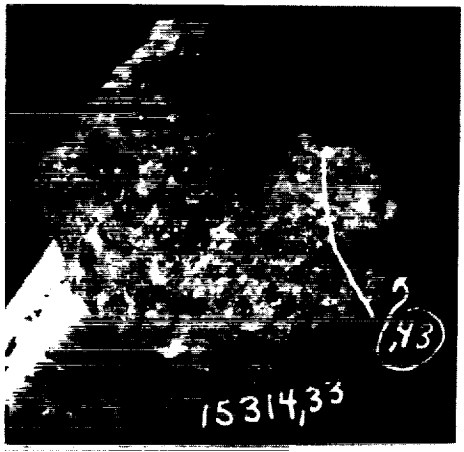


Fig. 31 Original splitting plan for 15314,33. Subsequently another chip was removed. S-72-31459

Fig. 32 Photomicrograph of 15314,33,107. Plane light. Width of field is about 2 mm. The white fragments are plagioclase clasts.

15314,34	KREEP basalt	1 particle	0.042g (0.11g)

15314,34 (Fig. 33) is a fine-grained crystalline fragment that is an Apollo 15 volcanic KREEP basalt. The texture is intersertal (Fig. 34). Two published modes are given in Table 8.

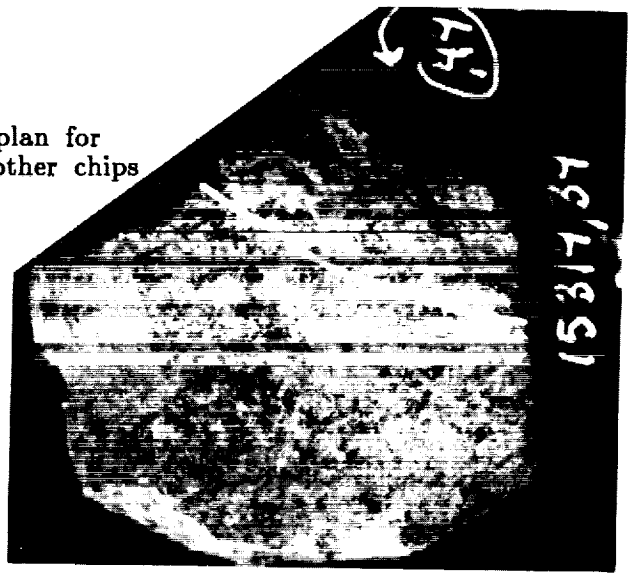


Fig. 33 Original splitting plan for 15314,34. Subsequently other chips were taken. S-72- 31458

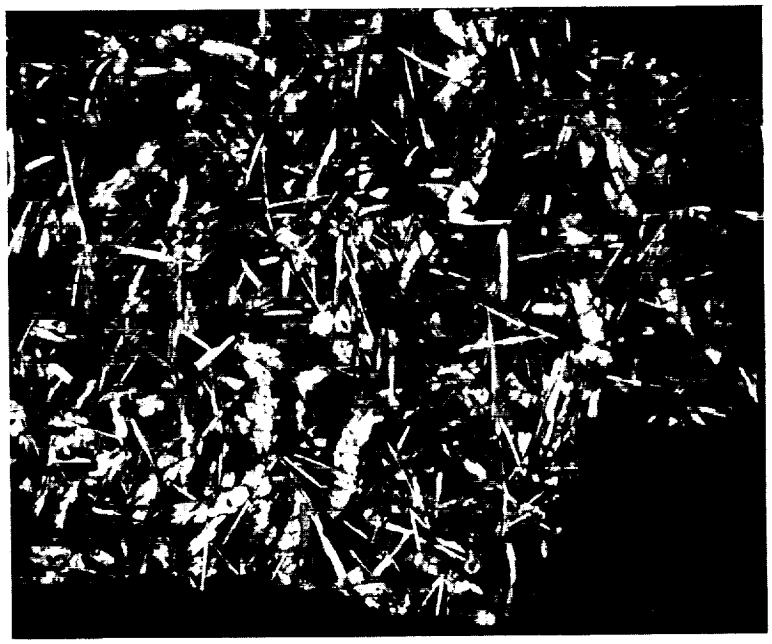


Fig. 34 Photomicrograph of 15314,34,108. Crossed polarized light; field of view about 2 mm wide.

Table 8. Modes of 15314,34. A = Simonds et al. (1975). B = Simon et al. (1987).

	Plag	Pyrox	Olivine	Meso	Other
A	51%	38%	0%	8%	-
B	43.3%	42.0%	0%	11.3%	3.3%*

* = 3.3% ilmenite, traces of sulfide and metal.

Simonds et al. (1975) reported that matrix plagioclases were mainly 300 to 500 microns long. Simonds et al. (1987) published a photomicrograph and reported 25 plagioclase analyses on a ternary diagram; the range is from An_{88} to An_{79} (Fig. 35), typical of Apollo 15 KREEP basalts.

Fig. 35 Compositions of plagioclases in 15314,34,109. (Simon et al., 1987).

Chemical analyses are listed in Table 9. The rare earth elements are plotted in Fig. 36. The analysis of Simon et al. (1987) is different from both that of Apollo 15 KREEP basalts in general and that of the same particle by Hubbard et al. (1973), in particular in having low incompatible element abundances. The Simon et al. (1987) sample was small and the analysis is likely to be unrepresentative. Neither of the analyses show signs of meteoritic contamination. Wiesmann and Hubbard (1975) also reported a bulk particle $^{87}Sr/^{86}Sr$ ratio of 0.71206 +/- 8.

Table 9. A = Hubbard et al. (1973, Wiesmann and Hubbard (1975), mainly isotope dilution. 15314,34,81 (24mg)
B = Simon et al. (1987). INAA (11 mg)

	A	B
wt%		
SiO_2	-	-
TiO_2	2.02	1.3
Al_2O_3	16.7	15.0
Cr_2O_3	0.31	0.33
FeO	10.4	12.1
MnO	-	0.15
MgO	8.55	9.9
CaO	7.67	10.2
Na_2O	0.68	0.49
K_2O	0.529	0.25
ppm		
Sc		24.0
V		70
Co		35.5
Ni		120
Rb	13.58	
Sr	185	130
Zr	1009	400
Hf	25.7	10.3
Ba	676	370
Th	10.8	6.0
U	3.1	1.6
Li	26.5	
Ta		1.4
La	67.9	33.0
Ce	174	85
Nd	108	61
Sm	30.2	15.4
Eu	2.58	1.65
Gd	35.9	18
Tb		3.2
Dy	39.2	20
Ho		4.4
Er	22.9	
Tm		1.7
Yb	20.5	11.0
Lu		1.55

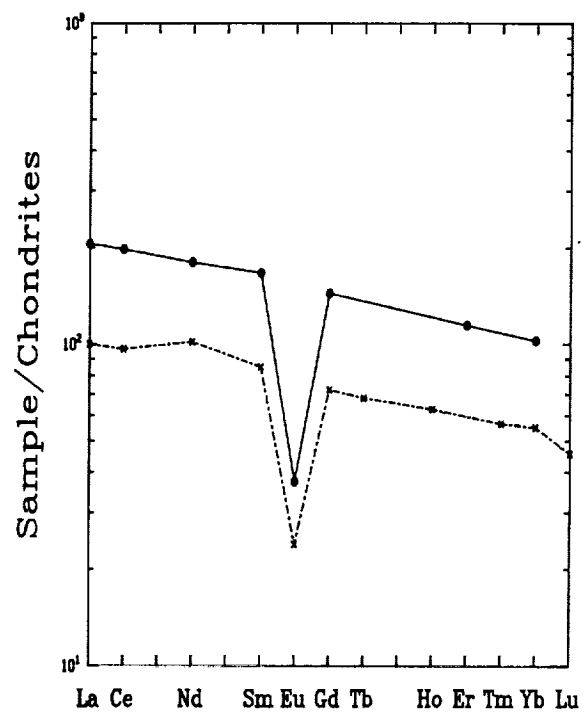


Fig. 36 Chondrite-normalized plot of rare earth elements in 15314,34. Heavy line and symbols, Hubbard et al. (1973). Lighter line and symbols, Simon et al. (1987)

15314,5 Coherent regolith breccias 8 particles 0.0g (1.49g)

Powell described these particles (Fig. 37) as recrystallized microbreccias that were tough, subangular, and dark gray speckled with white. They are similar to other coherent regolith breccias except that they contain a higher abundance of green glass fragments and spherules (which is why they were grouped). Three of the particles have been sectioned and show that the group consists of regolith breccias. The other five particles have been separated into ,22 (3 particles; Fig. 38) and ,24 (2 particles; Fig. 39); the basis for the separation was not recorded.

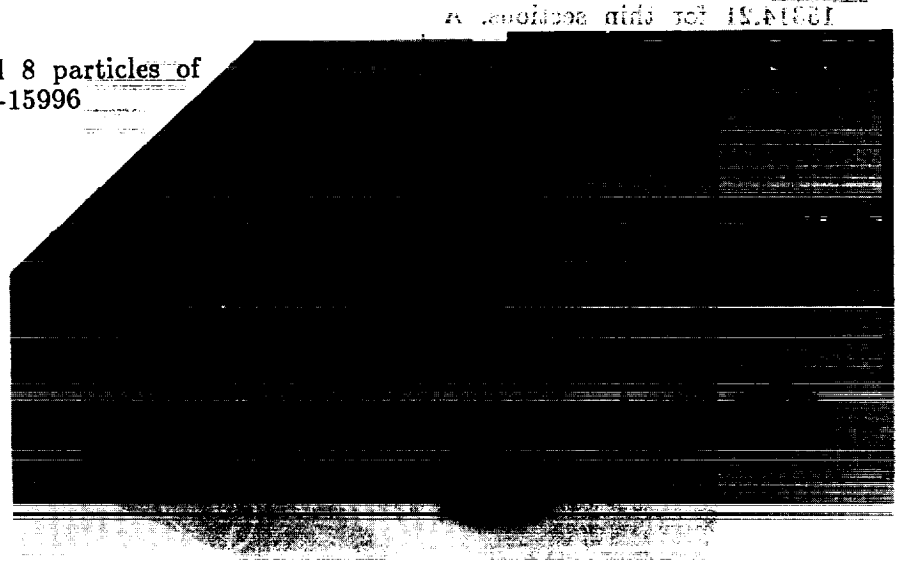


Fig. 37 Original 8 particles of 15314,5. S-72-15996

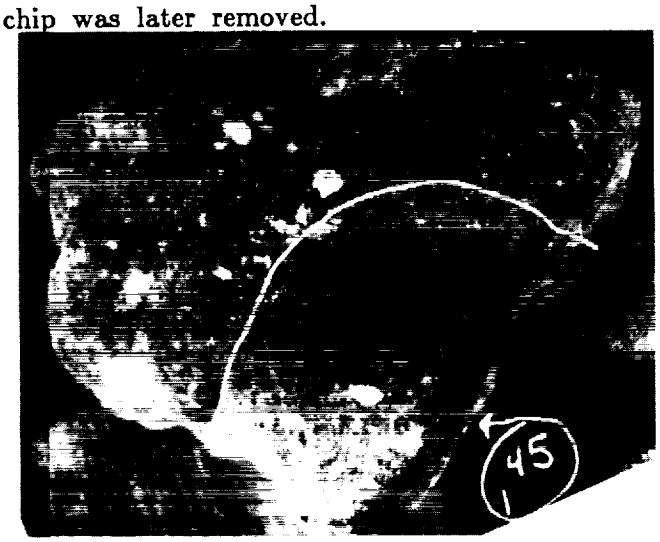
Fig. 38 15314,22. Three particles. S-72-32947

Fig. 39 15314,24. Two particles. S-72-32949

15314,21 Coherent regolith breccia 1 particle 0.193g (0.43g)

15314,21 was subdivided (Fig. 40); no data have been reported. The thin sections are of a regolith breccia containing green glass fragments and spherules, as well as the more prominent feldspathic debris and some yellow glass (Fig. 41). There is brown glass in the matrix.

Fig. 40 Initial subdivision of 15314,21 for thin sections. A second chip was later removed.



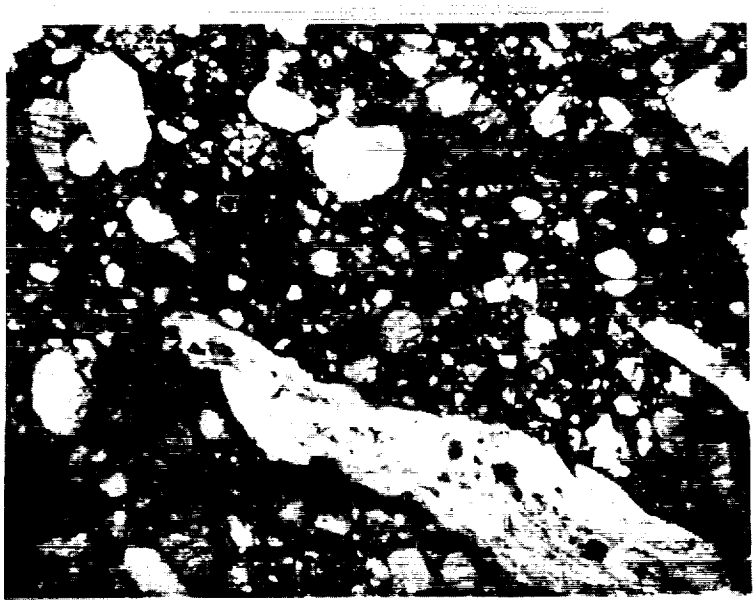


Fig. 41 Photomicrograph of 15314,21,110. Plane light; field of view about 2 mm wide.

15314,23 Coherent regolith breccia 1 particle 0.06g (0.11g)

15314,23 was subdivided (Fig. 42) for a chip for thin sections specifically to include a white clast. The sample is a regolith breccia (Fig. 43) containing green glass spherules and fragments, abundant feldspathic materials, and other glasses. The large white clast appears to be a feldspathic granulite. No data have been reported.

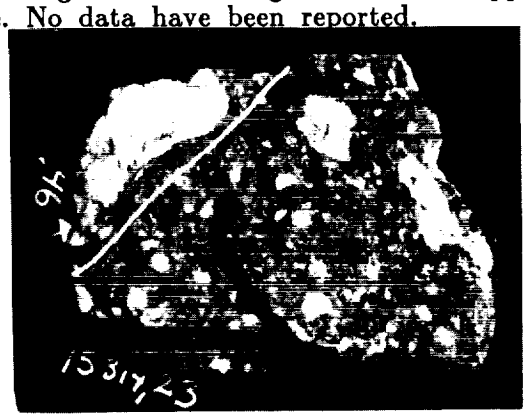


Fig. 42 Cutting plan for 15314,23 S-72-31461

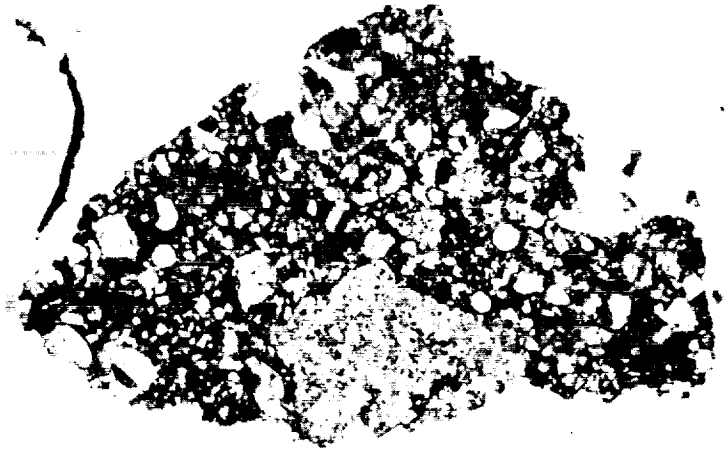


Fig. 43 Photomicrograph of 15314,23,114. Plane light; field of view about 2 mm wide. Larger white clast is a feldspathic granulite.

15314,25 Coherent regolith breccia 1 particle 0.07g (0.10g)

15314,25 was chipped for a thin section (Fig. 44). The sample is a fine-grained regolith breccia with a brown glassy matrix (Fig. 45). It contains a typical assemblage of clasts (mainly feldspathic fragments and glasses). No data have been reported.

Fig. 44 Plan for cutting 15314,25 for a thin section. S-72-31462

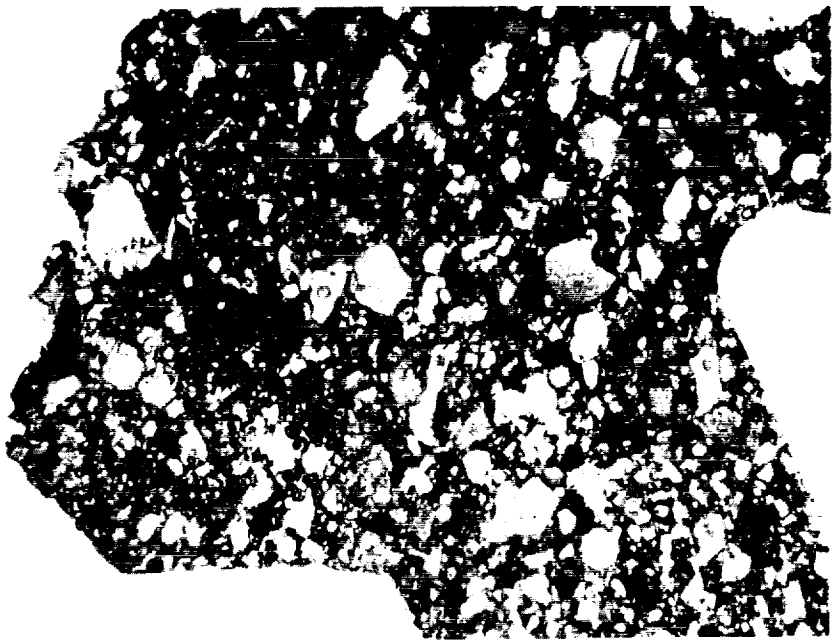


Fig. 45 Photomicrograph of 15314,25,116. Plane light; field of view is about 2 mm across.

15314,6 Glass-coated coherent regolith breccias 4 particles 0.55g (1.21g)

Powell described the four particles of 15314,6 (Fig. 46) as recrystallized microbreccias that were glass-coated, the latter being their distinctive group feature. The glass is thin, splashed on, dark brownish-gray, and vesicular. One particle was numbered and subdivided so that ,6 is now 3 particles (Fig 47).

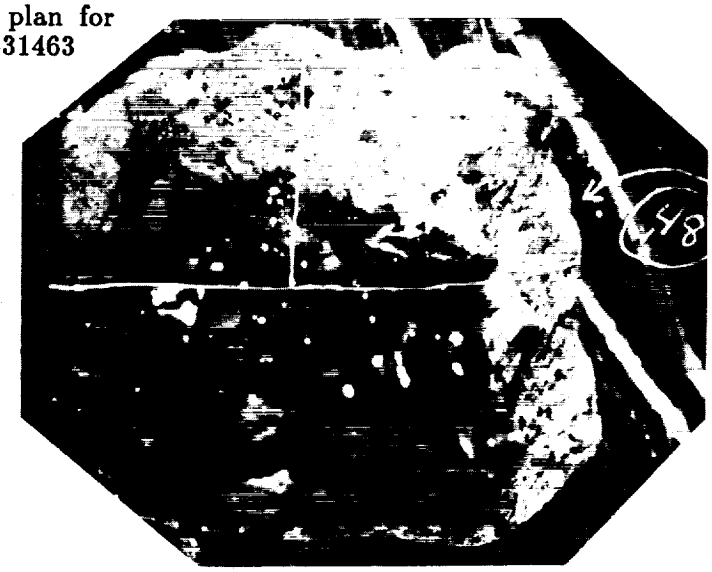
Fig. 46 Original four particles of 15314,6. The largest was removed, numbered ,20, and subdivided. S-72-15989

Fig. 47 Present three particles of 15314,6 S-72-32948

15314,20 Glass-coated regolith breccia 1 particle 0.445g (0.55g)

15314,20 (Fig. 48) was subdivided. The thin sections show it to be a typical regolith breccia with a fragment population of feldspathic materials and glass in a glassy matrix (Fig. 49). No data have been reported.

Fig. 48 Splitting plan for 15314,20. S-72-31463



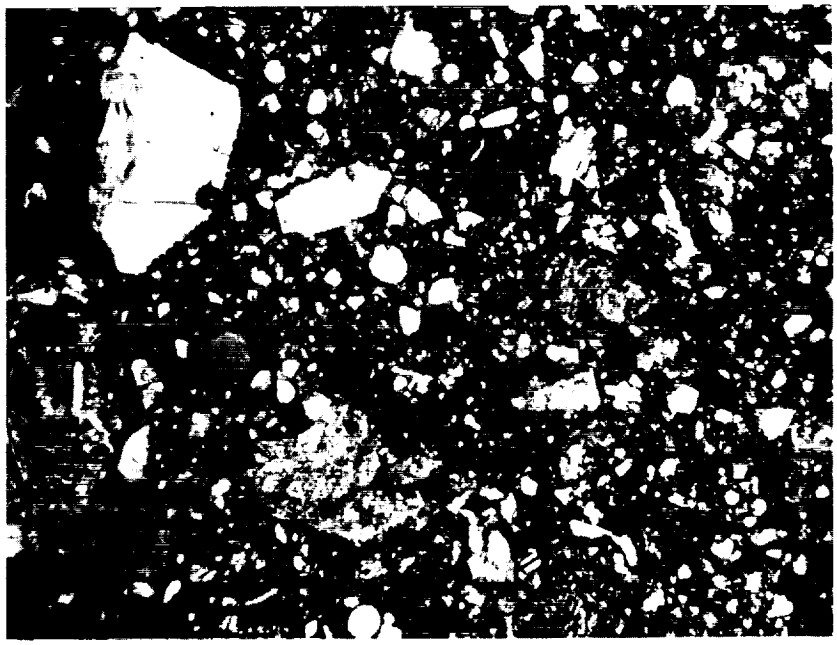


Fig. 49 Photomicrograph of 15314,20,117. Plane light; field of view about 2 mm wide.

15314,7	Friable regolith breccias	4 particles	0.34g

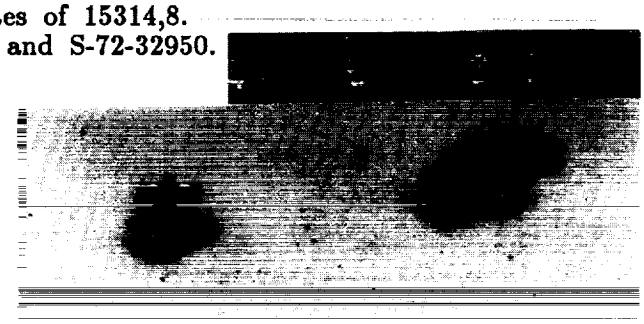
Powell described the four particles as friable, subrounded to rounded microbreccias (Fig. 50), similar to those of 15434,2. They are very finely granular and medium gray. Two contain visible glass spheres or fragments or both. They have never been allocated.

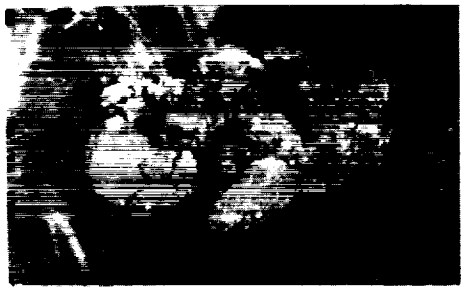
Fig. 50 15314,7 Each particle is about 5 mm across. S-72-32952

15314,8	Agglutinates	2 particles	0.20g

Powell described the particles as irregular, friable agglutinates, consisting of glass and microbreccia (Fig. 51). The microbreccia is friable regolith breccia and loose regolith that is very finely granular and medium to dark gray. It is welded with the smooth vesicular glass that is dark brownish-gray. They have never been allocated.

Fig. 51 The two agglutinates of 15314,8. Combination of S-72-15992 and S-72-32950.





15314,9 Friable regolith breccias 2 particles 0.10g (0.19g)

Powell described the fragments as friable microbreccias (Fig. 52) that were similar to 15314,7 except for the presence of clasts (clods) of green glass microbreccia. The one that was sectioned (,13) shows the green glass spherules. By numbering one of the particles (,13), the remaining particle ,9 became a single though unstudied particle

Fig. 52 Original two particles 15314,9. S-72-16193

15314,9 Friable regolith breccia 1 particle 0.10g

The particle remaining after removal of ,13 became a single particle (Fig. 53), but was never allocated for study.

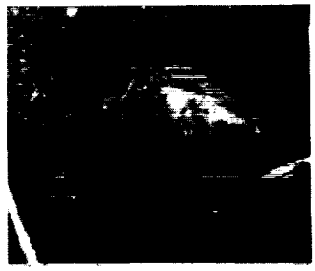


Fig. 53 Particle ,9 after removal of ,13. S-72-32953

15314,13 Friable regolith breccia 1 particle 0.06g (~0.10g)

The particle 15314,13 was chipped for thin sections (Fig. 54). The thin sections show a regolith breccia that has clods of material rich in green glass, as spherules and as fragments (Fig. 55). The regolith breccia is typical, with a glassy matrix, glass fragments (including green and yellow), and feldspathic debris.

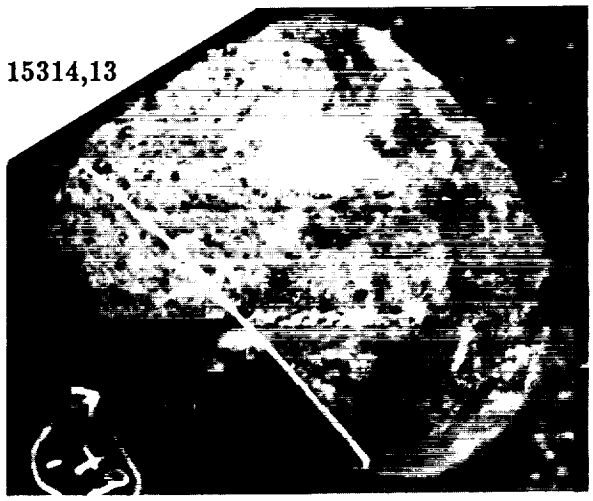


Fig. 54 Chipping plan for 15314,13 S-72-31464

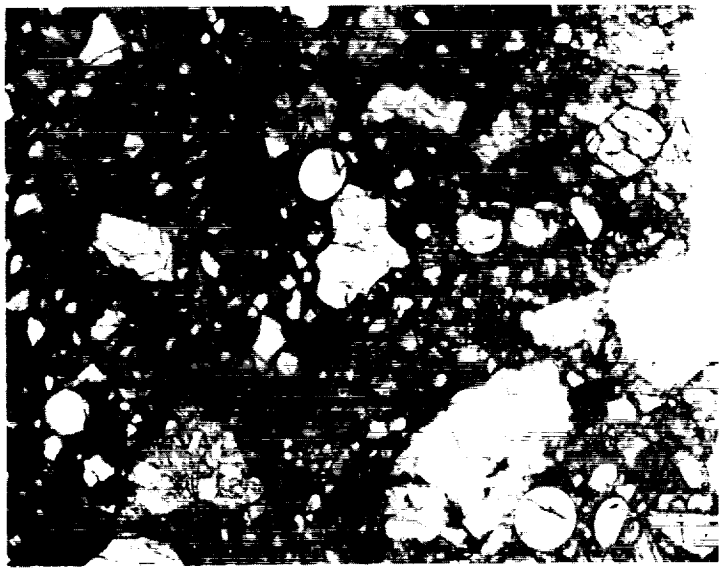
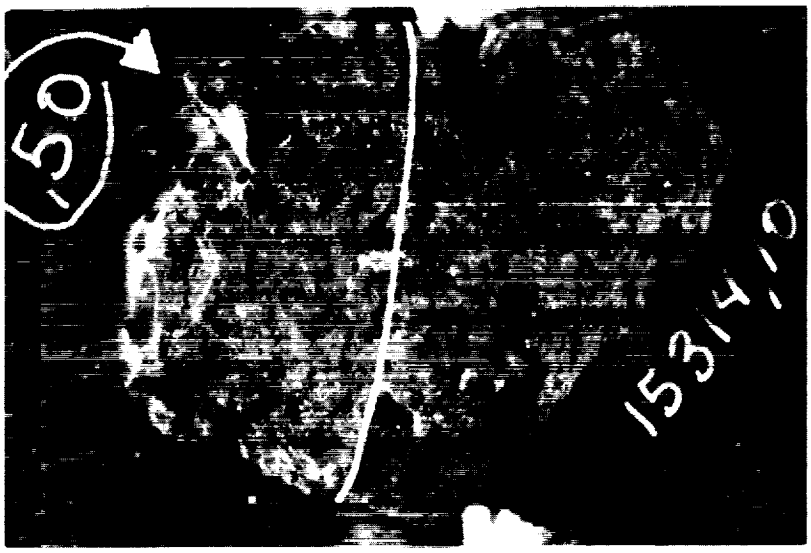


Fig. 55 Photomicrograph of 15314,13,120. Plane light; width of field is about 2 mm. Paler zone is rich in green glass.

15314,10	Vesicular glassy impact melt	1 particle	0.06g	(0.10g)

This group of a single particle was described by Powell as a tough vesicular basalt that was angular and dark gray (Fig. 56). A thin section shows that it is a glassy melt with numerous tiny fragments. Powell remarked that is was too fine-grained for identification of the minerals; the vesicles are 0.2 to 1.0 mm across and about 10 to 15% of the particle.

Fig. 56 Chipping plan for 15314,10.
S-72-31465



15314,10 Vesicular glassy impact melt 1 particle 0.06g (0.10g)

The vesicular glass contains abundant minute inclusions; the vesicles are flattened and give the impression of a mild foliation (Fig. 57) although the macroscopic view does not indicate foliation. The glass is brownish. One larger fragment in thin section ,122 is a pyroxene. No data have been reported.

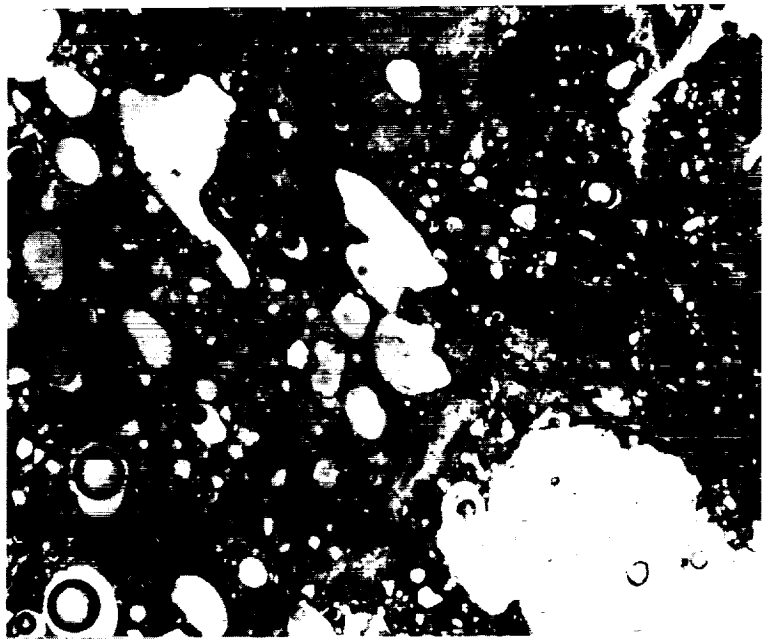


Fig. 57. Photomicrograph of 15314,10,122. Plane light; field of view is about 2 mm. The large pale clast is a plagioclase.

15314,11 Cataclastic anorthosites 2 particles 0.0g (0.37g)

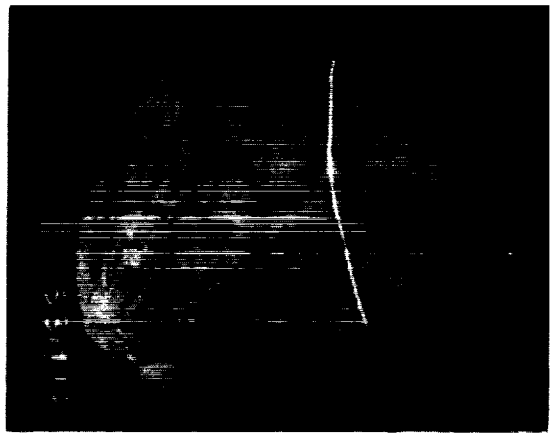
Powell identified the two particles as plagioclase-rich (more than 90% plagioclase) lithic types with non-igneous textures. In fact, both are cataclastic anorthositic lithologies as shown by thin sections. Powell described the particles as white, tough, and subangular, with inequigranular seriate textures suggestive of recrystallization. One appeared to be all plagioclase, the other to have about 10% of a pale yellowish-tan pyroxene(?) and less than 1% opaques. Each particle was individually numbered.

15314,15 Troctolitic anorthosite 1 particle 0.062g (0.17g)

The particle was chipped to produce thin sections and for chemical analyses (Fig. 58). The thin section shows a very plagioclase-rich cataclastic lithology (Fig. 59). Two published modes are given in Table 10. Simon et al. (1987) on the basis of their mode referred to the sample as a troctolitic anorthosite; Simonds et al. (1975) referred to it as a shocked, annealed, feldspathic norite, although their mode too contains olivine. Our inspection of the thin sections indicates that the sample is more appropriately referred to as a troctolitic anorthosite. The pyroxene is poikilitic.

C-2

Fig. 58 Chipping plan for 15314,15
S-72-31466



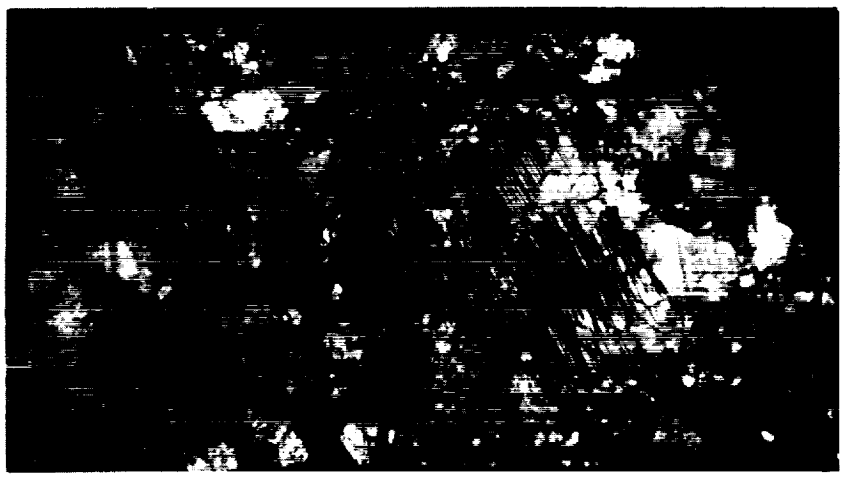


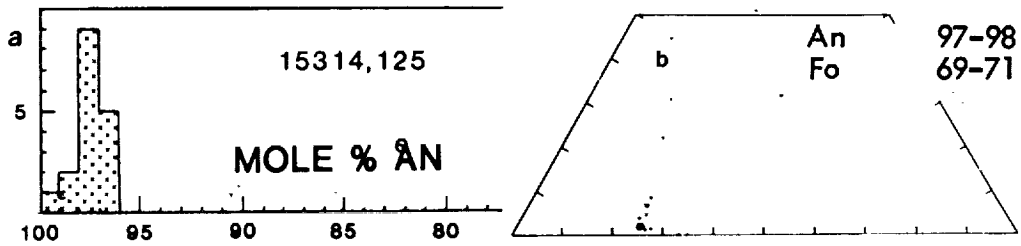
Fig. 59 Photomicrograph of 15314,15,125. Crossed polarized light; field of view about 2 mm across.

Table 10. Modes of 15314,15 A = Simon et al. (1987). B = Simonds et al. (1975).

	Plag	Pyrox	Olivine	Ilmenite	Other
A	81.9%	5.5%	12.4%	0.2%	-
B	70%	15%	15%	-	-

Simon et al. (1987) showed a photomicrograph and made microprobe analyses of mineral phases. They gave a histogram of plagioclase compositions (Fig. 60a), tabulated two olivine analyses ($Fo_{69.8}$, $Fo_{69.0}$), and showed pyroxene analyses on a quadrilateral diagram. Phinney et al. (1972) reported mineral analyses similar to those of Simon et al. (1987) (Fig. 60b); on their figure they misnumbered the sample as 15314,55 (the chip was ,51).

Fig. 60 Analyses of minerals in 15314,15. a) plagioclase analyses of Simon et al. (1987). b) analyses of Phinney et al. (1972).



Chemical analyses were reported by Hubbard et al. (1973) and Wiesmann and Hubbard (1975), and by Simon et al. (1987). The analyses are given in Table 11; the rare earth elements are plotted in Fig. 61. The analyses are not substantially different, except that the unanalyzed element silica would be much higher in the Simon et al. (1987) analysis. The analyses show a very feldspathic rock with low incompatible element abundances and no evidence of meteoritic contamination. Simon et al. (1987) grouped the sample with ferroan anorthosites on the basis of the mineral analyses, noting that it was a little more mafic than most. Wiesmann and Hubbard (1975) reported a bulk rock $^{87}Sr/^{86}Sr$ of 0.69962 +/- 4.

Table 11. A = Hubbard et al. (1973), Wiesmann and Hubbard (1975). Colorimetry, atomic absorption, and isotope dilution/ mass spectrometry. 15314,15,61 (39.5 mg) B= Simon et al. (1987) INAA 15314,15,154 (22.4 mg)

wt%	A	B
SiO_2	-	-
TiO_2	0.028	<0.1
Al_2O_3	29.6	29.7
Cr_2O_3	0.36	0.025
FeO	5.1	2.50
MnO	-	0.032
MgO	5.88	3.3
CaO	16.7	16.3
Na_2O	0.18	0.25
K_2O	0.01	0.014
ppm		
Sc		2.8
V		<10
Co		5.8
Ni		<10
Ba	4.8	<20
Rb	0.456	
Sr	150	135
Zr	18	<10
Hf	0.4	0.082
Th	0.12	<0.05
U	0.023	<0.01
Ta		<0.05
Li	1.8	
La	0.15	0.21
Ce	0.38	<1
Nd	0.218	<1
Sm	0.06	0.10
Eu	0.604	0.73
Gd	-	<1
Tb		0.025
Dy	0.087	<0.3
Ho		<0.3
Er	0.060	
Tm		<0.1
Yb	0.067	0.11
Lu		0.017

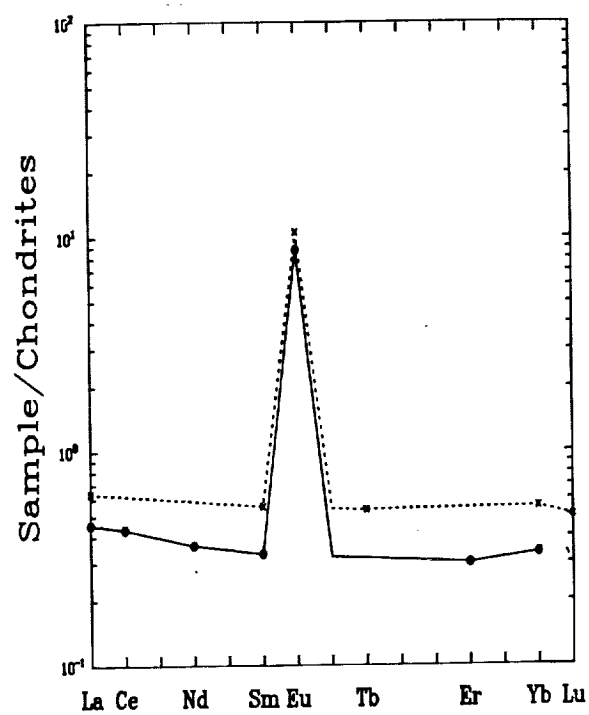


Fig. 61 Chondrite-normalized plot of rare earth elements in 15314,15. Data of Hubbard et al. (1973) and Wiesmann and Hubbard (1975) (heavy symbols and line); and Simon et al. (1987) (lighter symbols and line).

15314,16 Cataclastic noritic anorthosite 1 particle 0.164g (0.20g)

The particle was chipped for a thin section (Fig. 62). Simonds et al. (1975) reported a mode of 70 to 90% plagioclase and 10 to 30% pyroxene, with plagioclases about 1 mm across. They referred to the sample as a cataclastic feldspathic norite with poikilitic pyroxene. Our inspection of the thin sections (Fig. 63) shows that the sample is texturally and mineralogically similar to the anorthositic norite in 15455. The pyroxene is orthorhombic, and the fragment has been cataclasized into zones or stripes. Traces of opaque minerals (sulfide at least) are present, as well as a silica phase.

Fig. 62 Chipping plan for 15314,16.
S-72-31467

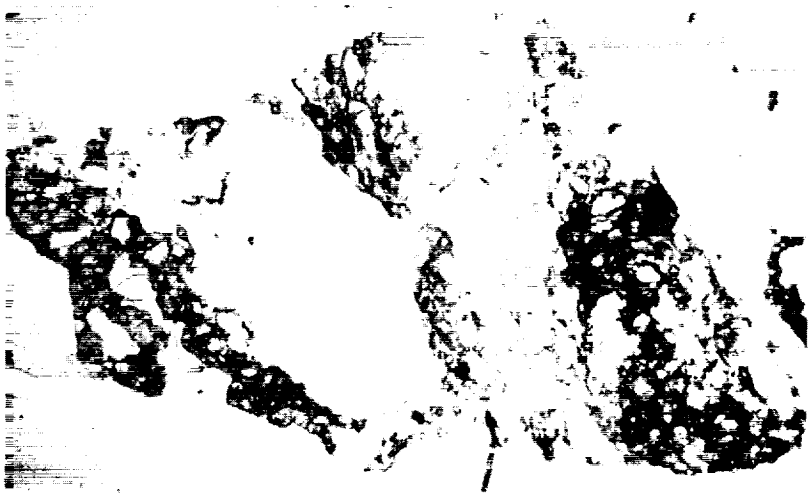


Fig. 63 Photomicrograph of 15314,16,127. Plane light; field of view about 2 mm across.

15314,12 Glass or glass-rich breccias 3 particles 0.11g (0.35g)

Powell described the three particles as tough, irregular and subangular, and medium to dark gray (Fig. 64), similar to those in 15434,1. Two were ropy in appearance, the third blocky. The thin sections made from two of themn confirm that the particles are glassy.

Fig. 64 Original three particles of 15314,12. S-72-16190.

15314,12	Glass?	1 particle	0.11g (0.11g)

On removal of the two ropy glasses, the remaining blocky glass made ,12 (Fig. 65) a single particle by default. However, it has never been allocated for study.

Fig. 65 The single remaining particle of 15314,12. S-72-32951

15314,18	Ropy glassy breccia	1 particle	0.07g (0.10g)

The particle was split (Fig. 66) for thin sections. The sections show a single generation of brown banded glass with numerous fragmental inclusions (Fig. 67), ranging from pale yellow glass to plagioclases and highlands impact melt breccias. Most of the inclusions are tiny. Vesicles are present and are slit-like.

Fig. 66 Splitting plan for 15314,18. S-72-31468

Fig. 67 Photomicrograph of 15314,18,130. Plane light; field of view is about 2 mm wide. A foliation marked by inclusions and vesicles is apparent.

15314.19 Glassy breccia 1 particle 0.09g (0.12g)

15314,19 was split for thin sections (Fig. 68). The sections show a single generation of brown glass, with some fragmental inclusions (Fig. 69). Unlike 15314,18 there is no apparent foliation. Clast-poor patches of clear glass have partly devitrified and crystallized into brown patches. Fragments are mainly feldspathic.

Fig. 68 Splitting plan for 15314,19. S-72-31469

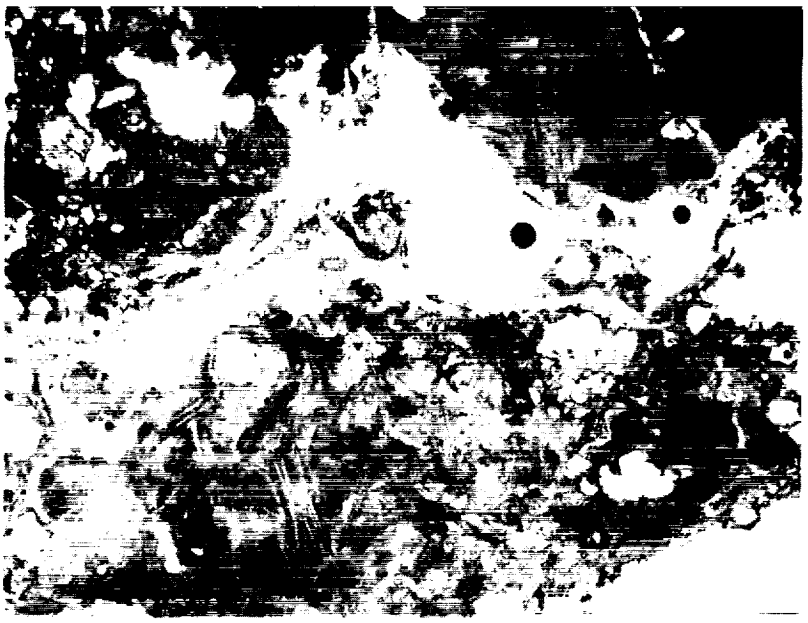


Fig. 69 Photomicrograph of 15314,19,132. Plane light; field of view is about 2 mm wide. Most of the visible area is partly devitrified and brown.

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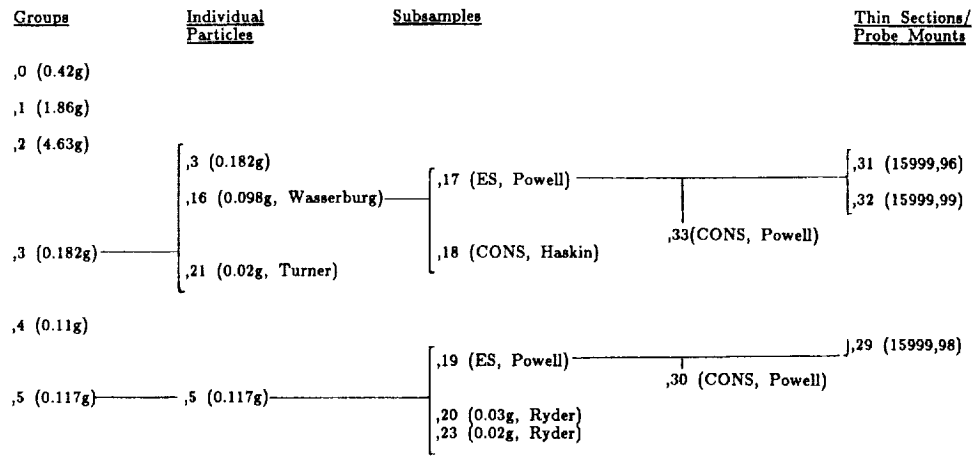
15404 Station 6a 7.9g



15404,0 Fines and undescribed particles 0.42g

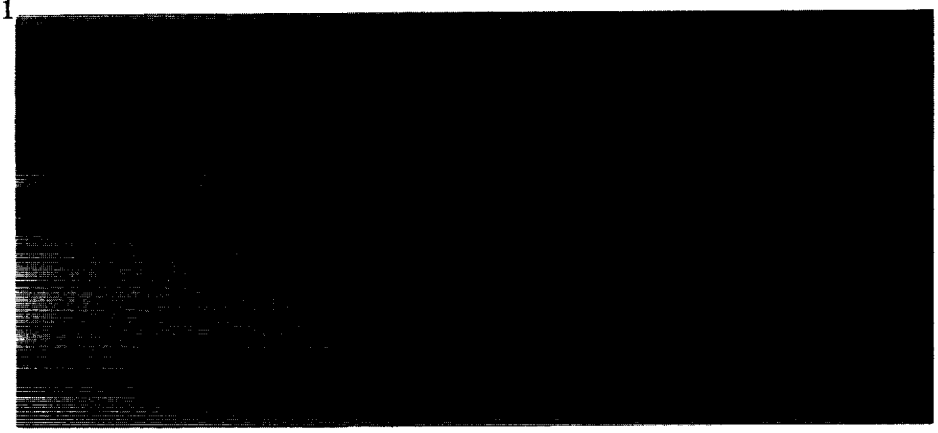
15404,0 is mainly fine material, with a few small particles (Fig. 1). It has never been allocated.

Fig. 1 15404,0
S-72-16184

15404,1 Regolith breccias 9 particles 1.86g

15404,1 are coherent, subrounded to rounded, medium gray regolith breccias (Fig. 2). Powell described the nine particles as very finely granular and essentially similar to 15284,3. They have never been subdivided or allocated.

Fig. 2 15404,1
S-72-16183



15404,2 Recrystallized(?) breccias 13 particles 4.63g

15404,2 are tough, angular to subangular, fine-grained dark gray breccias, and most have visible clasts (Fig. 3). The surfaces of the particles are hackly and most have small (~0.5 mm) vugs. The matrices resemble very fine-grained basalts. In general the clasts are angular but some are irregularly shaped; most are white and probably feldspathic. Powell suggested that they were recrystallized microbreccias, but they may be fine-grained KREEP impact melts derived from the adjacent boulder, from which 15405 was collected. 15404,2 has never been allocated.

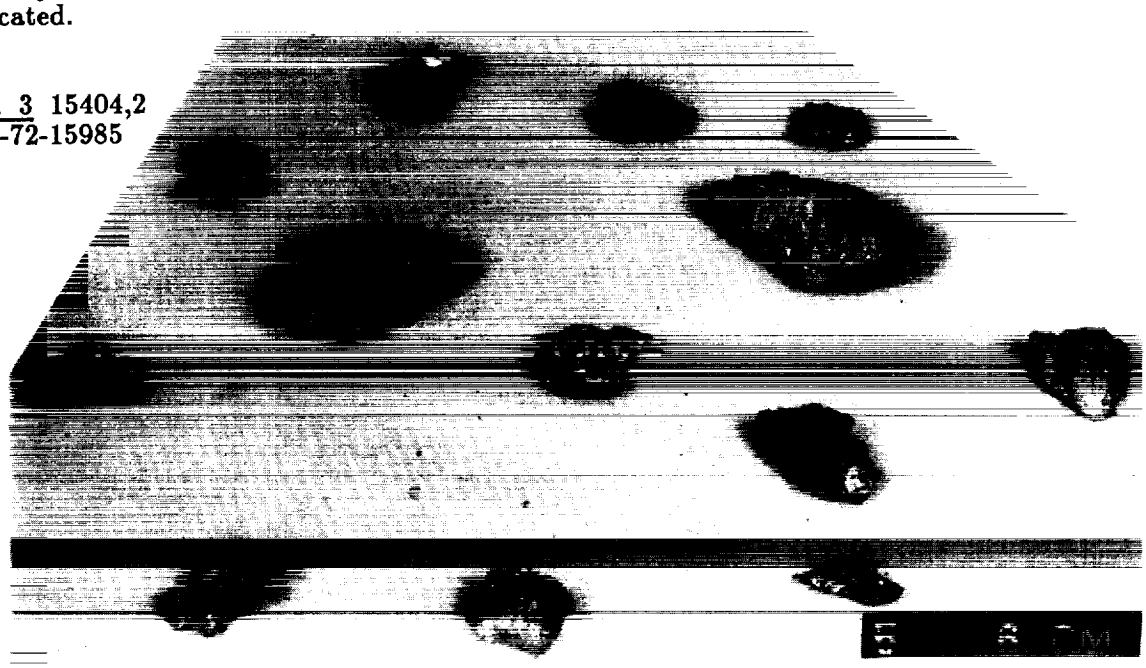


Fig. 3 15404,2 S-72-15985

15404,3 Fine-grained impact melts +? 3 particles 0.18g (1.04g)

Powell described 15404,3 as dark gray, tough, subangular, very fine-grained basalts. Small vugs are present but not abundant. Powell noted that the identification as basalt was uncertain. The one that has been thin sectioned is a glassy or fine-grained impact melt of KREEP basalt composition. The other particles have not been studied.

The data packs lead to some confusion about 15404,3. Although Powell describes the 3 particles as dark gray, one is clearly much paler than the others (Fig. 4). One dark particle was split to create ,16, 17, and ,18. A small chip ,21 was taken of the other dark particle, which is ,3. There is no further record of the third particle, the light one, and the masses indicate that the subdivisions of ,3 do not add up to the original mass. Possibly some renumbering went improperly recorded.

Fig. 4 Original 3 particles of 15404,3. S-72-15990

15404,3 Fine-grained impact melt? 1 particle 0.182g (0.202g)

15404,3 appears to be the right hand particle in Fig. 4. A small chip was taken from it (,21), but no section has ever been made and no data reported.

15404,16 Fine-grained impact melt 1 particle 0.098g (0.178g)

15404,16 appears to be the central particle in Fig. 4. It was subdivided for petrographic, chemical, and isotopic study (Fig. 5). It is a fine-grained to glassy impact melt (Fig. 6) of Apollo 15 KREEP basalt composition. Powell (quoted in Helmke et al., 1973) reported that it was mostly glass ".. with evidence of heterogeneity. It may be partially melted breccia. It is not certain that ..[these rocks]..were originally basalts..". Powell et al. (1973) described it as a highly degraded glass-rich material and not a primary igneous basalt; they mistakenly ascribed this description to 15024,13 in their text. The texture is actually microcrystalline, not unlike the groundmass of sample 15405 from the adjacent boulder. Clasts are obvious (Fig. 6).

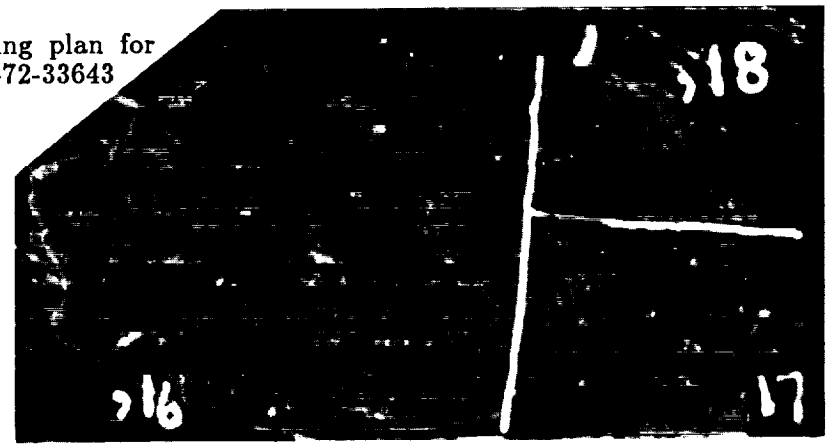


Fig. 4 Splitting plan for 15404,16. S-72-33643

Fig. 6 Photomicrograph of 15404,16,17 (on 15999,96). Plane light; width of field about 2 mm.

Trace element analyses were reported by Helme and Haskin (1972) and Helmke et al. (1973), and a major element analysis was made by Powell (unpublished) using microprobe fused bead techniques. (The Powell analysis was included in a KREEP average given by Powell et al., 1973). These are given in Tables 1 and 2; the rare earths are plotted in Fig. 7. These analyses show that the sample is similar to Apollo 15 KREEP basalts in chemistry, though a little higher in incompatible elements. It is similarly not unlike the groundmass of 15405.

Table 1. Helmke and Haskin (1972), Helmke et al. (1973). RNAA. 15404,16,18. (25 mg)

ppm	
Sc	32.2
Co	28.2
Hf	33
La	93
Ce	210
Nd	138
Sm	43.9
Eu	2.92
Gd	49
Tb	8.7
Dy	59.7
Ho	13
Er	32
Yb	30.4
Lu	4.51

Table 2. Powell (unpublished) Fused bead, microprobe. 15404,16,33

wt%	
SiO_2	51.22
TiO_2	1.81
Al_2O_3	16.92
Cr_2O_3	0.31
FeO	10.47
MnO	0.16
MgO	7.56
CaO	10.44
Na_2O	0.72
K_2O	0.62
P_2O_5	0.60
Ni	<0.02
Sum	100.4

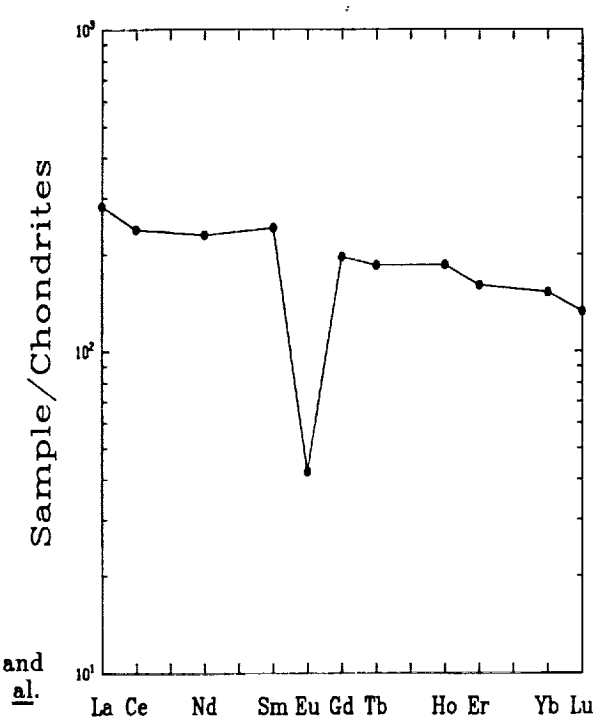


Fig. 7 Chondrite-normalized plot of rare earths in 15404,16,18. Data of Helmke and Haskin (1972) and Helmke et al. (1973).

15404,4 Vesicular Glass 1 particle 0.11g

Powell described 15404,4 as a tough, subangular, dark gray vesicular glass (Fig. 8). It has a few large vesicles (up to 1 mm). The glass may be devitrified. There is a 4 mm inclusion of granular olivine basalt (grain size ~0.5mm). The particle has never been allocated.

Fig. 8. 15404,4
S-72-15988

15404,5 KREEP Basalt 1 particle 0.117g (0.17g)

15404,5 KREEP basalt 1 particle 0.117g (0.17g)

Powell decribed the tough, subangular, light gray mottled fragment (Fig. 9) as an olivine diabase. In fact the 30% greenish-yellow phase that he identified as olivine is orthopyroxene, and the sample is an Apollo 15 KREEP basalt with an unusual glomeroporphyritic texture (Fig. 10).

Powell et al. (1973) briefly described the sample, with a photomicrograph, as porphyritic intergranular decussate, with large subhedral pyroxene with plagioclase laths intergrown with the pyroxene rim. Although Powell et al. (1973) said that this texture was characteristic of KREEP basalts, this texture is actually unique. Ryder (1987) described the particle, with photomicrographs, as glomeroporphyritic. It contains about 20% glomerocrysts of orthopyroxene and plagioclase up to 1.5mm long; the groundmass is much finer-grained (mainly less than 100 microns). Ryder (1987) interpreted the texture as produced by initial slow cooling and then rapid cooling of a cotectic melt. Microprobe data (Ryder, unpublished) show that the orthopyroxenes have aluminous cores that are among the most En-rich (En_{83}) of Apollo 15 KREEP basalts; they show only minor zoning.

Fig. 9 Original splitting plan for 15404,5. S-72-33636

Fig. 10 Photomicrograph of 15404,5,29 (on 15999,98). Plane light; field of view is about 3 mm wide.

A chemical analysis by Ryder (unpublished) is reproduced in Table 3. Although the coarse grain-size and the small sample size cause uncertainty in how representative the analysis is, the sample is clearly an Apollo 15 KREEP basalt that lacks meteoritic contamination. It has a typical KREEP rare-earth pattern (Fig. 11). In accordance with its texture (possibly partly cumulate) and the orthopyroxene compositions, the analysis is among the lowest in incompatible elements and is among the highest in Mg/Fe.

Table 3. Ryder (unpublished) 15404,5,20+,23. Microprobe fused bead (FB) and neutron activation (INAA). (50 mg)

wt%	FB, except as indicated	
SiO_2		52.2
TiO_2		1.78
Al_2O_3		15.5
Cr_2O_3		0.37
Cr_2O_3	INAA	0.37
FeO		9.7
FeO	INAA	9.2
MnO		0.14
MgO		10.95
CaO		9.27
CaO	INAA	9.6
Na_2O		0.66
Na_2O	INAA	0.70
K_2O		0.48
K_2O	INAA	0.43
P_2O_5		0.31
Sum		101.4

ppm (INAA)	
Sc	19.6
Co	25.6
Ni	68
Sr	178
Rb	15.2
Cs	0.52
Ba	590
Zr	711
Hf	20.7
Ta	2.21
U	2.33
Th	9.21
La	55.8
Ce	143
Nd	84
Sm	26.1
Eu	2.22
Tb	4.48
Yb	17.3
Lu	2.25

ppb (INAA)	
Au	<3

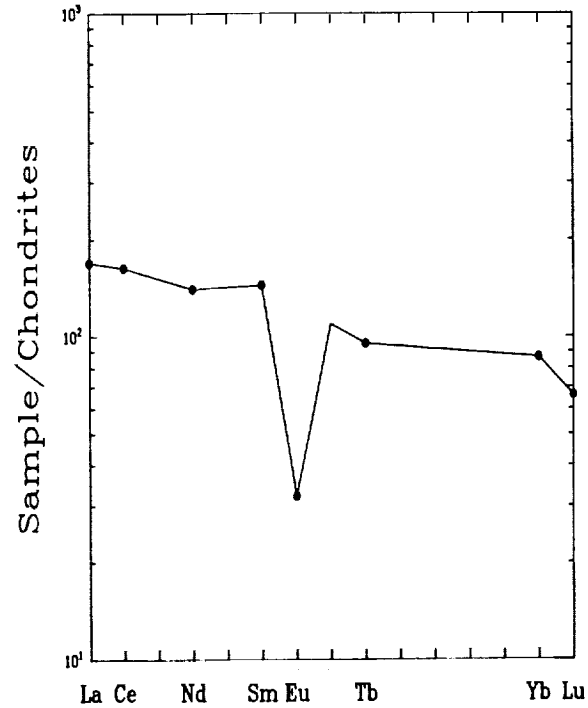
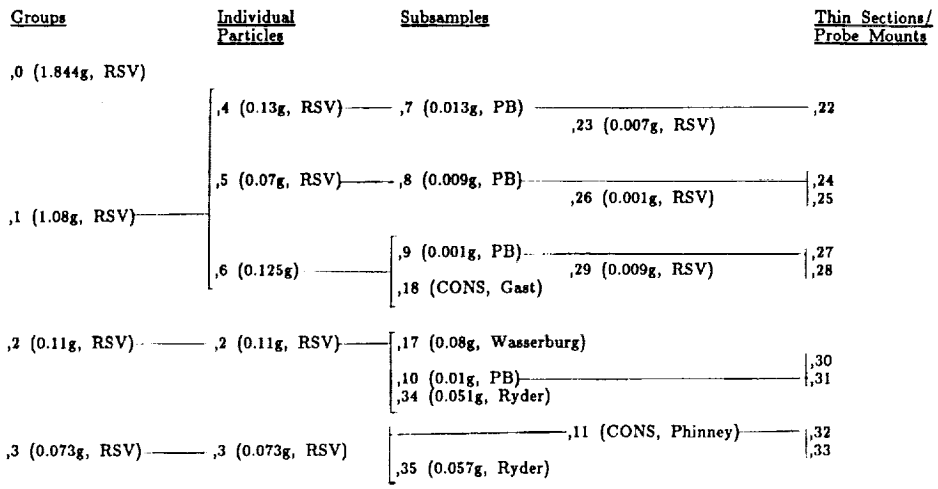


Fig. 11 Chondrite-normalized rare-earth element plot for 15404,5,20+,23. Data of Ryder (unpublished).

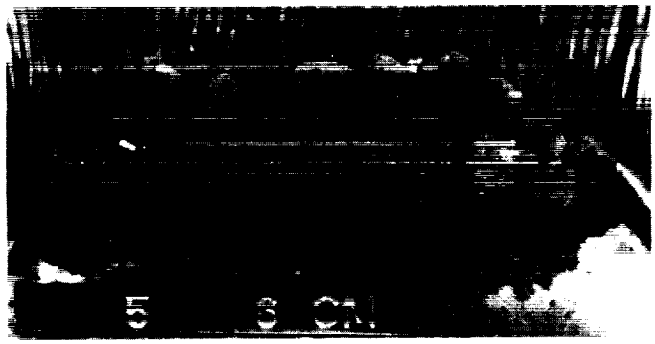
15414 Station 7 4.0g



15414,0 Fines and undescribed particles 1.84g

15414,0 includes degraded fines and several small particles (Fig. 1). The particles appear to be mainly regolith breccias, but one appears to be white and crystalline, and another to be glass or glass-coated.

Fig. 1 15414,0
S-72-15959



15414,1 Regolith breccias 7 particles 1.08g (1.58g)

Powell described these particles as microbreccias similar to those of 15434,2. They are regolith breccias with varied friability, some with typical splash glass coatings (Fig. 2). Three have been sectioned.

Fig. 2 Original 7 particles of 15414,1
S-72-16212

15414,4 Regolith breccia 1 particle 0.13g (0.16g)

15414,4 has a splash glass coat; a chip for a thin section avoided the glass (Fig. 3). The breccia has a brown glassy matrix, and the fragments include plagioclases, some mafic minerals, and glasses (Fig. 4). The latter include green and yellow fragments and spheres. There are no lithic fragments in the section. No data have been reported.

Fig. 3 Original chipping plan for 15414,4. S-72-31470.

Fig. 4 Photomicrograph of 15414,4,22. Plane light; field of view is about 2 mm across.

15414,5 Regolith breccia 1 particle 0.07g (0.11g)

15414,5 was chipped for thin sections (Fig. 5). It is a regolith breccia that is somewhat heterogeneous (Fig. 6). It has a dark matrix but includes areas or clasts of clear glass, and lithic fragments include crystalline feldspathic basalt (either volcanic or impact melt). Mineral fragments, particularly plagioclase, are abundant. No data have been reported.

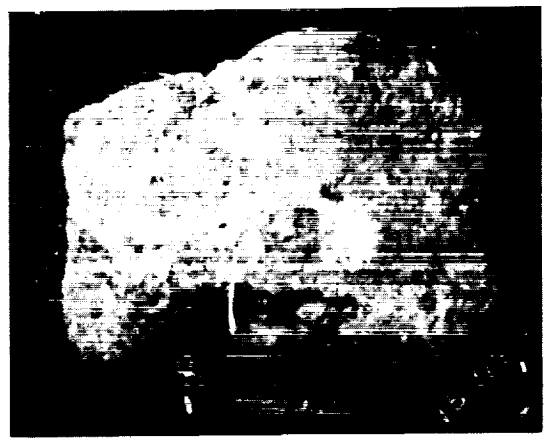


Fig. 5 Original chipping plan for 15414,5. S-72-31471

Fig. 6 Photomicrograph of 15414,5,24. Plane light; field of view is about 2 mm across.

15414,6	Regolith breccia	1 particle	0.125g (0.22g)

15414,6, which is glass coated, was chipped for a thin section (Fig. 7), and subsequently for chemistry. The particle is a regolith breccia with a brown glassy matrix (Fig. 8) and prominent green glass spheres. The fragment population includes silicate mineral fragments, small highlands lithic fragments, and glasses. Phinney et al. (1972) published an average of green glass compositions (from microprobe data), and an analyses of brown matrix glass, duplicated here as Table 1. Wiesmann and Hubbard (1975) made a trace element analysis of the bulk sample (Table 2, Fig. 9). These analyses show that the regolith breccia is not of typical Apennine Front composition but has higher incompatible element abundances. Wiesmann and Hubbard (1975) also reported a bulk rock $^{87}Sr/^{86}Sr$ of 0.70798 +/- 15.

Fig. 7. Original chipping plan for 15414,6. S-72-31472

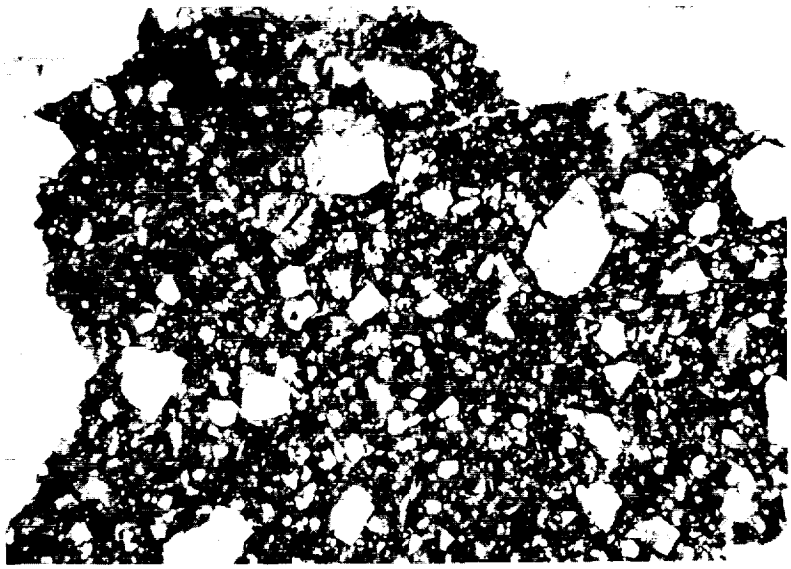


Fig. 8. Photomicrograph of 15414,6,28. Plane light; field of view is about 2 mm wide. The splash glass coat is barely visible at the top of the image.

Table 1. Microprobe analysis of brown matrix glass in 15414,5,27 (Phinney et al., 1972). The authors increased the analysis values by 10% to account for matrix porosity.

wt%	
SiO_2	46.99
TiO_2	1.18
Al_2O_3	17.42
FeO	11.0
MgO	8.95
CaO	11.66
Na_2O	0.57
K_2O	0.19
P_2O_5	0.40
Sum	98.36

Table 2. Wiesmann and Hubbard (1975). Atomic absorption, isotope dilution/mass spectrometry. 15414,6,18. (45 mg)

wt%	
Na_2O	0.42
TiO_2	1.42
K_2O	0.257
ppm	
Cr	2245
Li	15.0
Ba	320
Sr	141
Rb	6.962
Zr	453
Hf	11.2
Th	5.15
U	1.43
La	31.0
Ce	79.4
Nd	49.0
Sm	14.0
Eu	1.52
Dy	18.8
Er	11.3
Yb	10.0

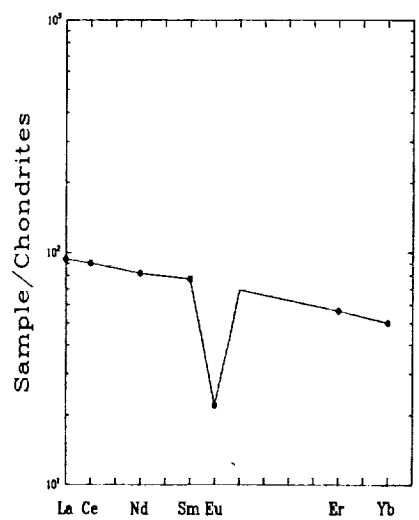


Fig. 9 Chondrite-normalized plot of rare earth elements in 15414,6,18. Data of Wiesmann and Hubbard (1975).

15414,2 Vesicular impact melt 1 particle 0.11g (0.27g)

Powell described 15414,2 as a tough vesicular basalt that was medium gray and angular (Fig. 10). Its grain size was too small for identification of phases. The vesicles are up to 1 mm diameter and compose 10 to 15% of the rock. The thin sections show that the particle is an impact melt; the chemsistry shows it to be KREEP-rich.

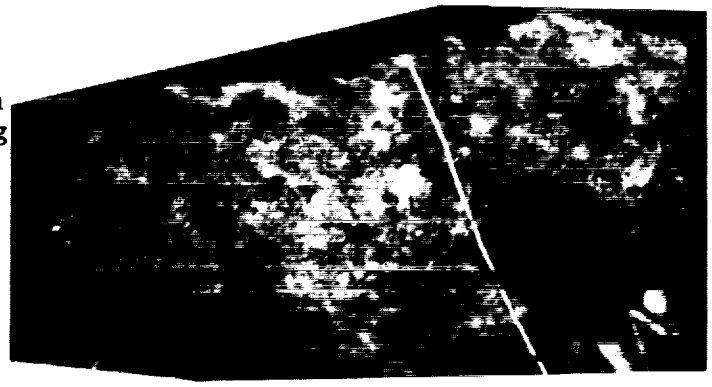


Fig. 10 Original chipping plan of 15414,2. Further chipping was done. S-72-31473.

15414,2 Vesicular impact melt 1 particle 0.11g (0.27g)

15414,2 is a very vesicular micropoikilitic impact melt (Fig. 11), with oikocrysts that vary in size from only a few tens of microns to perhaps 150 microns (Ryder and Spudis, 1987). Clasts are conspicuous (perhaps 40% of the total) and most are plagioclases; lithic clasts appear to be absent.

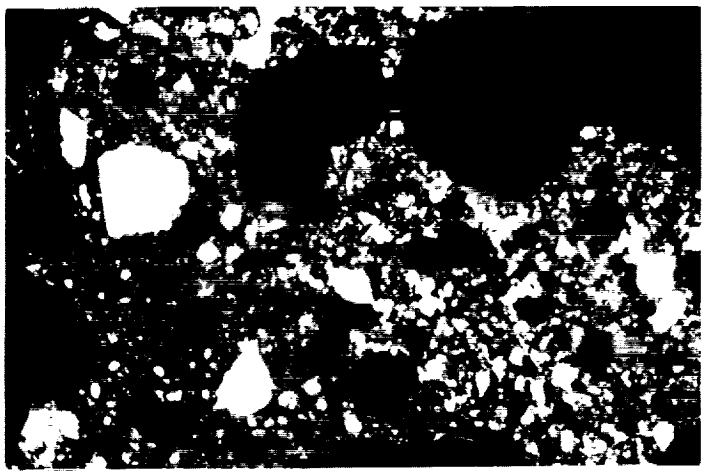


Fig. 11 Photomicrograph of 15414,2,31. Crossed polarized light; field of view is about 2 mm across.

Ryder and Spudis (1987) made a bulk rock analysis of the particle (Table 3, Fig. 12). It has a composition similar to Apollo 15 KREEP basalts; as it is clearly an impact melt it may be derived by impacting into a KREEP target. However, the analysis does not represent the composition of the melt itself unless the melt has a composition similar to an aggregate of the clasts, because the sample is so rich in clasts.

Table 3 Ryder and Spudis (1987) Microprobe fused bead (FB) and neutron activation (INAA). 15414,2,34. (35.6 mg)

wt%	FB except as noted.
SiO_2	49.6
TiO_2	1.47
Al_2O_3	18.3
Cr_2O_3	0.17
Cr_2O_3 INAA	0.17
FeO	8.9
FeO INAA	9.7
MnO	0.141
MgO	8.5
CaO	11.5
Na_2O	0.82
K_2O	0.529
P_2O_5	0.578
Sum FB	100.5

ppm	INAA
Sc	19.4
Co	19.1
Ba	780
Zr	1070
Hf	28.6
Ta	3.1
Th	13.4
U	3.8
Cs	0.51
Rb	13
La	81.5
Ce	229
Nd	139
Sm	39.1
Eu	2.83
Tb	8.7
Yb	23.3
Lu	3.35

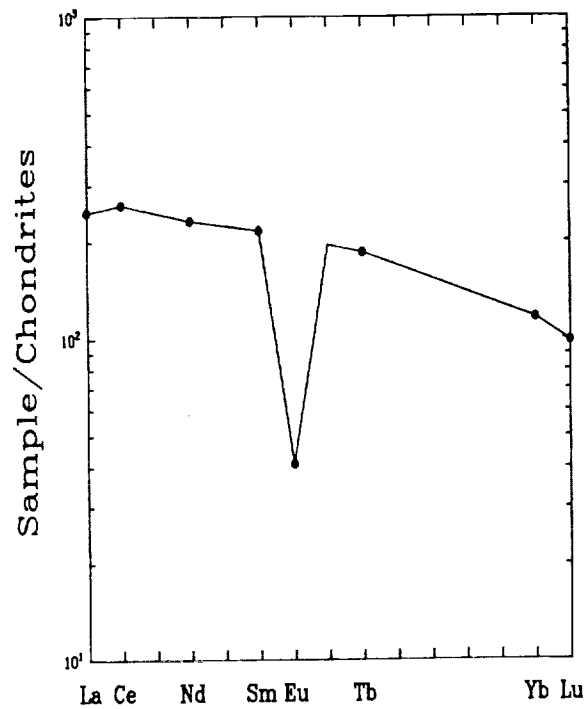


Fig. 12 Chondrite-normalized plot of rare earth elements in 15414,2,34. Data of Ryder and Spudis (1987).

15414,3 Micropoikilitic impact melt 1 particle 0.073g (0.17g)

Powell described the particle as a tough, angular, dark gray crystalline rock that was probably a basalt. The grain-size was too small for minerals to be identified. The particle was initially split as shown in Fig. 13, but was later further subdivided. Thin sections show that 15414,3 is a fine-grained impact melt; it has unusually low incompatible element abundances.

Fig. 13 Original cutting plan for particle 15414,3. S-72-31474

15414,3 Micropoikilitic impact melt 1 particle 0.073g (0.17g)

15414,3 has a micropoikilitic texture that Ryder and Spudis (1987) interpreted as of impact melt origin (Fig. 14). Phinney et al. (1972) referred to the particle as having a recrystallized texture, like the "15314,38 group" but lacking a gap in pyroxene compositions, containing no mafic clasts, and having Ca-rich plagioclases. (15314,38 is from particle 15314,26 and is, like most others in 15314,4, an impact melt). Mineral compositions from Phinney et al. (1972) are shown as Fig. 15. Simonds et al. (1975) called the particle a poikilitic rock with mineral clasts. They gave a mode of 72% plagioclase, ~15% pyroxene, ~12% olivine, and 2% mesostasis, with a plagioclase grain size of 15 to 25 microns. Ryder and Spudis (1987) described the particle, with a photomicrograph, as micropoikilitic with a mottled texture. The oikocrysts are 400 to 500 microns across, much larger than the plagioclases. The ilmenites are blades and form chains.

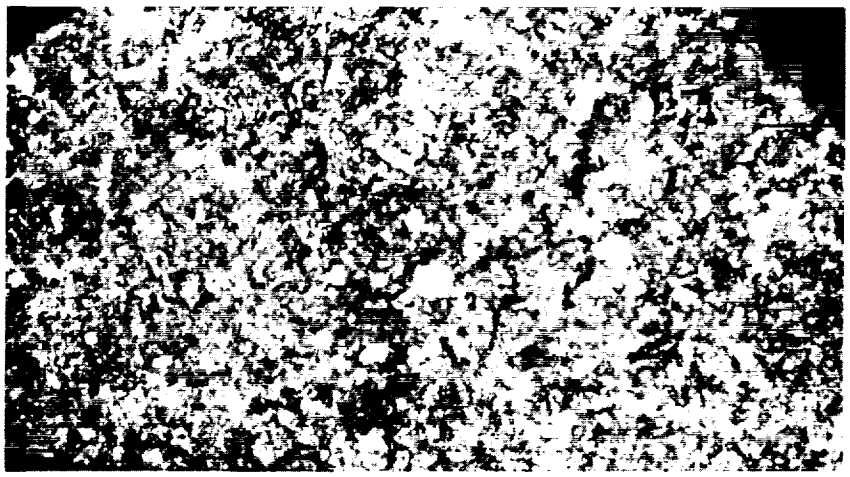
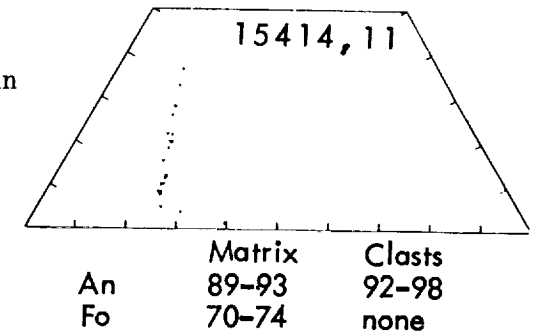


Fig. 14 Photomicrograph of 15414,3,33. Plane light; field of view is about 2 mm wide. Mineral clasts are small; lithic clasts are absent.

Fig. 15 Compositions of minerals in 15414,3,11,32. Phinney et al. (1972).



Ryder and Spudis (1987) made a major and trace element analysis of a bulk rock fragment (Table 4, Fig. 16). The composition is distinct from all other impact melts that they analyzed (sole member of their Group E), with more alumina (22%% Al_2O_3) and much lower incompatible elements (La < 10x chondrites) than other impact melts from the Apollo 15 site.

Table 4. Ryder and Spudis (1987) Microprobe fused bead (FB) and INAA 15414,3,35 (45 mg)

wt%	(FB except as noted)	
SiO_2		43.1
TiO_2		2.38
Al_2O_3		22.4
Cr_2O_3		0.90
Cr_2O_3	INAA	0.95
FeO		8.3
FeO	INAA	7.7
MnO		0.101
MgO		9.0
CaO		13.2
Na_2O		0.484
Na_2O	INAA	0.548
K_2O		0.046
P_2O_5		-
Sum (FB)		99.91
ppm	**(INAA)**	
Sc		14.8
Co		16.9
Ni		46
Rb		3
Cs		0.07
Ba		79
Zr		69
Hf		1.49
Ta		0.41
U		0.07
Th		0.32
La		2.91
Ce		6.3
Nd		5.4
Sm		1.84
Eu		1.23
Tb		0.58
Yb		1.88
Lu		0.278

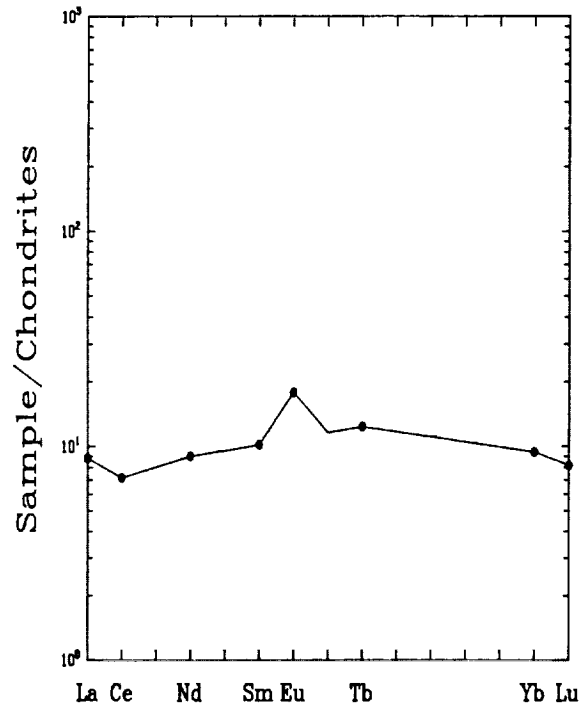


Fig. 16 Chondrite-normalized plot of rare earth elements in 15414,3,35. Data of Ryder and Spudis (1987)

15424 Station 7 19.5g

Group	Individual/ particles	Subsamples	Thin sections/ Probe mounts
,0 (19.5g)			

15424,0 Disaggregated clods 19.5g

15424,0 at first consisted of particles in the 4-10 mm size range (Fig. 1), but on handling they disaggregated into finer materials. They appear to have been friable clods consisting mainly of green glass. They have never been allocated for study.

Fig. 1 15424,0 prior to the disaggregation of the particles. S-71-52526

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15434 Station 7 51.6g

Group	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,0 (20.54g, RSV)		,60 (0.23g, RSV)	
		,68 (0.058g, RSV)	
,1 (2.09g, RSV)	,11 (0.09g, RSV)	,36 (CONS, Phinney)	,107
			,108
,30 (1.12g, RSV)	,28 (0.206g)	,37 (0.02g, PB)	,130
			,131
		,202 (0.144g, Ryder)	
	,29 (0.028g, RSV)	,38 (CONS, Phinney)	,111
			,112
		,204 (0.052g, Ryder)	
	,31 (0.045g, RSV)	,39 (CONS, Phinney)	,113
			,114
		,61 (0.09g, Wasserburg)	
		,62 (0.13g, RSV)	
,2 (2.06g, RSV)	,25 (0.157g)	,40 (CONS, Phinney)	,115
			,116
		,71 (CONS, Anders)	
		,200 (0.191g, Ryder)	
		,201 (0.242g)	
,24 (1.06g, RSV)	,26 (0.200g)	,41 (0.02g, PB)	,117
			,118
	,27 (0.25g, RSV)	,42 (CONS, Phinney)	,119
			,120
	,33 (0.174g)	,43 (CONS, Phinney)	,106
			,121
		,90 (0.058g, Nyquist)	
	,34 (0.23g, RSV)	,44 (CONS, Phinney)	,122
			,123
	,35 (0.529g)	,45 (CONS, Phinney)	,124
			,125
		,89 (0.061g, Nyquist)	
,3 (4.20g, RSV)	,32 (0.38g, RSV)	,46 (0.05g, PB)	,126
			,127

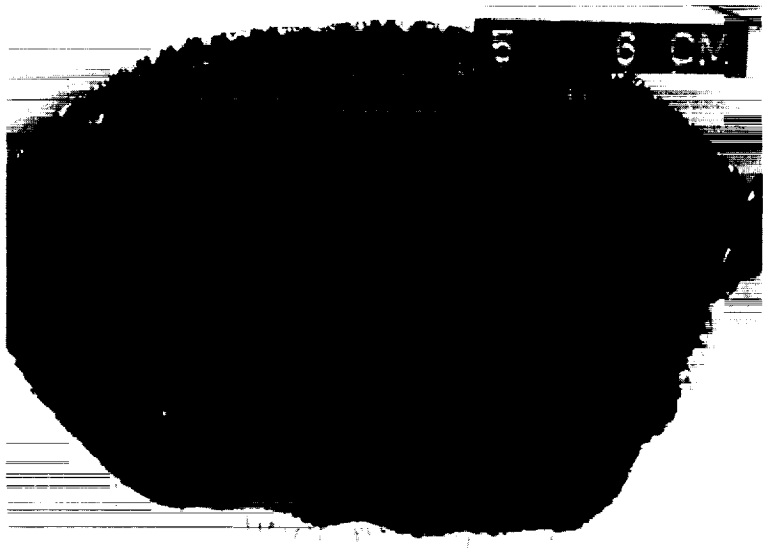
Group	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,4 (0.531g)	,16 (0.154g)	,47 (CONS, Phinney)	,128
			,129
		,73 (0.07g, Nyquist)	
		,152 (0.059g, Marti)	
		,198 (0.094g, Ryder)	
	,17 (ES)	,48 (0.03g, PB)	,109
			,110
		,63 (ES, Powell)	
		,76 (CONS, Powell)	,74 (15999,95)
			,75 (15999,99)
		,64 (0.035g, Ryder)	
	,18 (0.385g)	,49 (CONS, Phinney)	,132
			,133
		,77 (0.100g, Nyquist)	
		,153 (0.052g, Marti)	
		,199 (0.147g, Ryder)	
	,93 (0.020g, Turner)		
	,189 (0.282g)	,190 (0.028g, PB)	,205
		,191 (0.095g, Ryder)	
	,192 (0.069g, Ryder)	,193 (0.011g, PB)	,206
	,194 (0.028g, Ryder)	,195 (0.006g, PB)	,207
,5 (0.002g, RSV)	,9 (0.17g, RSV)	,50 (CONS, Phinney)	,134
			,135
	,10 (0.039g, RSV)	,51 (0.030g, RSV)	,136
		,178 (0.041g, Ryder)	
	,12 (0.023g, RSV)	,52 (CONS, Phinney)	,138
			,139
		,65 (0.238g, Wasserburg)	
		,179 (0.104g, Ryder)	
	,13 (0.051g, Ryder)	,53 (0.02g, PB)	,140
			,141
	,14 (0.04g, RSV)	,54 (CONS, Phinney)	,142
			,143
		,175 (0.018g, RSV)	
		,176 (0.022g, RSV)	
	,15 (0.517g)	,55 (CONS, Phinney)	,144
			,145
		,69 (0.060g, Nyquist)	
		,177 (0.022g, Laul)	
	,157 (0.101g, RSV)	,163 (0.026g, PB)	,182
		,164 (0.034g, Laul)	
	,158 (0.109g, RSV)	,165 (0.017g, PB)	,183
		,166 (0.020g, Laul)	
	,159 (0.027g, RSV)	,167 (0.011g, PB)	,184
		,168 (0.012g, Laul)	
	,160 (0.197g, RSV)	,169 (0.006g, PB)	,185
		,170 (0.108g, Laul)	
	,161 (0.076g, RSV)	,171 (0.024g, PB)	,186
		,172 (0.023g, RSV)	
	,162 (0.190g, RSV)	,173 (0.029g, PB)	,187
		,174 (0.018g, Laul)	

Group	Individual Particles	Subsamples	Thin Sections/ Probe Mounts
,6 (0.110g)	,6 (0.110g)		
,7 (1.52g)	,20 (0.07g, RSV)		
	,21 (ES)	,56 (CONS, Phinney)	,146 ,147
		,66 (ES, Powell)	
		,80 (CONS, Powell)	,78 (15999,96) ,79 (15999,99)
		,67 (CONS, Haskin)	
,19 (1.05g, RSV)	,22 (0.33g, RSV)	,57 (CONS, Phinney)	,148 ,149
	,23 (0.195g, RSV)	,58 (CONS, Phinney)	,150 ,151
		,180 (0.075g, Ryder)	
	,94 (0.02g)		
,8 (0.148g, RSV)	,8 (0.148g, RSV)	,59 (LOST, Phinney)	
		,155 (0.029g, PB)	,181 ,188
		,156 (0.033g, Laul)	

15434,0 Fines 20.54g

15434,0 is entirely very fine material that is the residue from processing of the coarser particles (Fig. 1). It has never been allocated. The tiny subsamples 15434,60 and ,68 also consist of processing fines and cabinet sweepings.

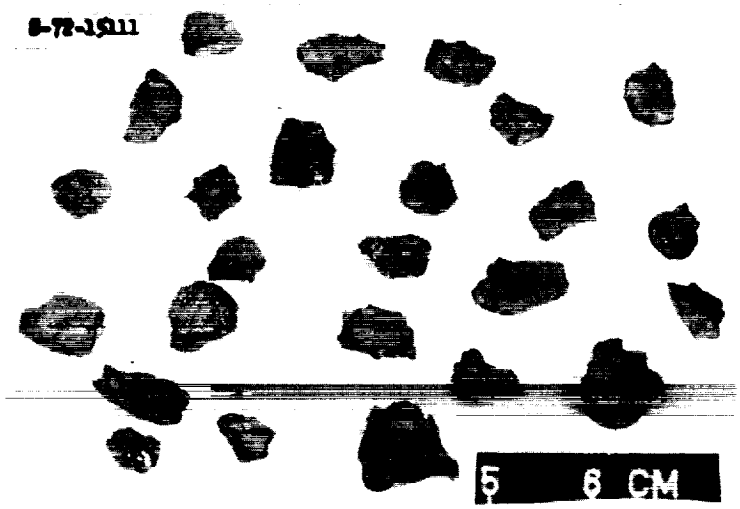
Fig. 1 15434,0
S-72-15976



15434,1 Glass and glass-rich breccias 26 particles 2.09g (4.09g)

Powell described these particles as nearly pure glass or mixed materials consisting of at least 75% glass, and this interpretation is generally borne out by the four particles from which thin sections were made. The particles are tough, subangular to ropey (one sphere), with smooth surfaces (Fig. 2). They are dark gray, brownish gray, or black, with a chonchoidal fracture and a vitreous lustre on broken surfaces. Most have soil adhering to some surfaces, making it difficult to elucidate the internal character. Four of the particles were separated for more detailed study. Another seven were made into a subgroup of particles (15434,30); the reason for creating such a subgroup was not recorded.

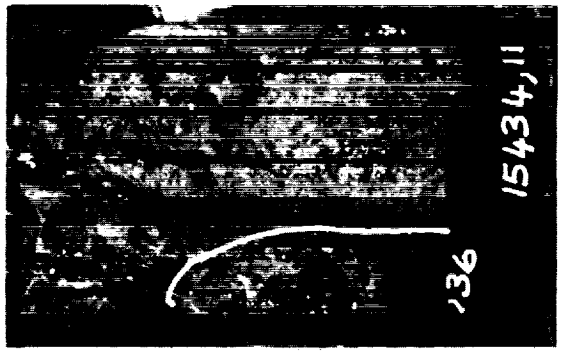
Fig. 2 15434,1. The image shows only 25 particles, and apparently was taken after the sphere (15434,28) was separated.



15434,11 Ropey glassy impact breccia 1 particle 0.09g (0.16g)

15434,11 is a layered or ropey glassy particle that is either mixed with or partly coated with fine regolith (Fig. 3). A chip for thin sections was taken from a glassy part. The particle consists of a clear, very pale yellow/green glass that is vesicular, flow banded, and contains fragments (Fig. 4); it might be termed an agglutinate. There appears to be only one generation of glass. One large fragment is a feldspathic basaltic breccia that contains interstitial glass.

Fig. 3 Original splitting plan for 15434,11. S-72-32971



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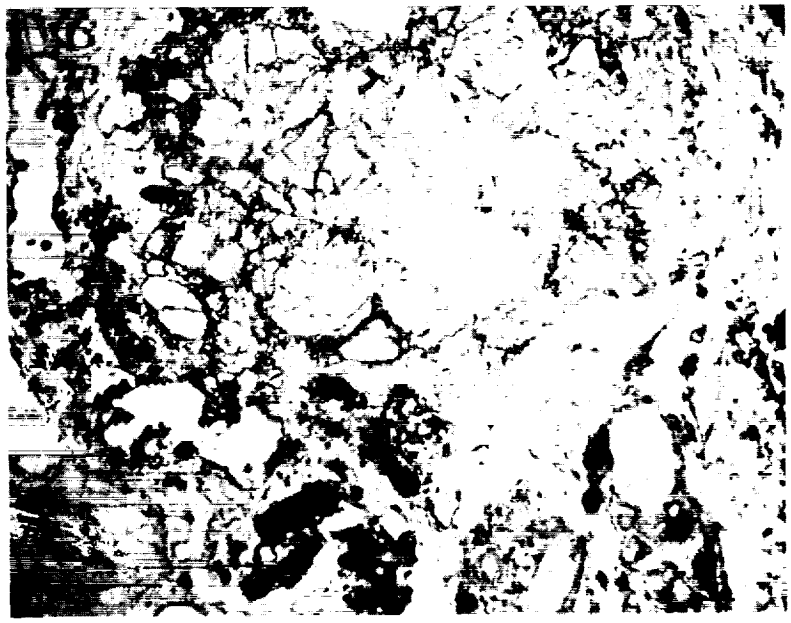

Fig. 4 Photomicrograph of 15434,11,108. Plane light; field of view is about 2 mm wide.

15434,28 Orange impact glass sphere 1 particle 0.206g (0.39g)

15434,28 is a bumpy sphere (Fig. 5) that consists mainly of a clear orange glass (pale yellow in thin section) of mare basalt composition. The glass contains a few fragments, adjacent to which it has partly devitrified (Fig. 6). A perlitic cracking exists in the glass. The few clasts are plagioclases and orthopyroxenes and may be from a single coarse norite source. The chip was from the outside edge of the particle, and interior chips appear to be clearer and not devitrified.

(A numbering mistake in processing caused some confusion in that thin sections made from 15434,28,37 were incorrectly attributed to 15434,17,48. Thin sections made from 15434,17,48 were incorrectly attributed to 15434,28,37).

Fig. 5 Original chipping plan for 15434,28. The sphere was later chipped more. S-72-32974

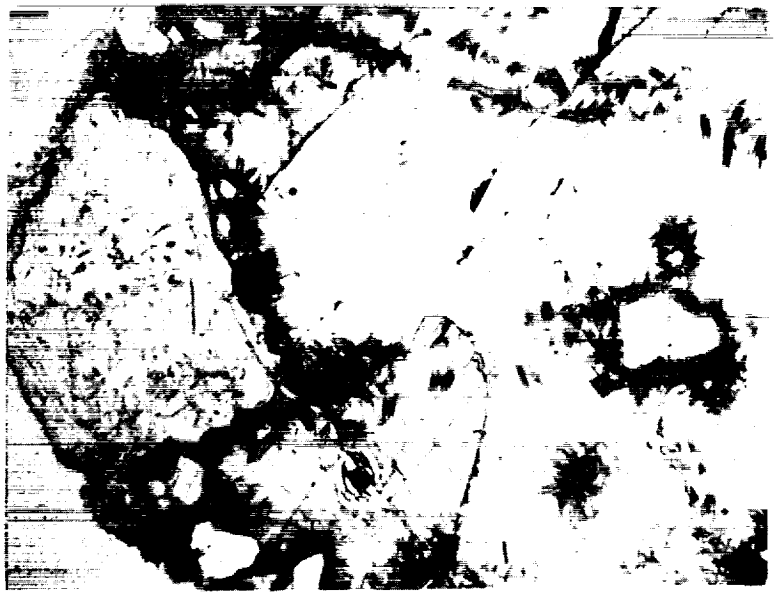

Fig. 6 Photomicrograph of 15434,28,131. Plane light; field of view is about 2 mm wide. Most of the section is pale yellow glass; the dark patches are devitrification.

Phinney et al. (1972) reported a microprobe analysis of the glass (mis-tabulated as ,48; see above), and a similar analysis was made by D. Vaniman and J. Papike (unpublished) (Table 1). A major and trace element analysis of a bulk fragment was made by Ryder (unpublished) (Table 2). The microprobe glass analyses and the bulk analysis agree well, indicating that the fragments are a minor part of the particle. The glass is an olivine-normative mare basalt higher in TiO_2 than the local basalts, and it has higher incompatible element abundances than such basalts. It does not have a KREEP signature (Fig. 7) or detected meteoritic contamination. The analysis probably closely resembles a mare basalt magma or an impacted mixture of mare basalts.

Table 1. Microprobe analyses of glass in 15434,28 thin sections. A, Phinney et al. (1972) B, Vaniman and Papike (unpublished) (average of 6 points)

	A	B
wt%		
SiO2	42.64	43.3
TiO_2	3.50	3.5
Al_2O_3	9.28	9.3
Cr_2O_3	-	0.48
FeO	21.03	20.9
MnO	-	0.29
MgO	10.26	10.5
CaO	9.24	8.7
Na_2O	0.74	0.66
K_2O	0.14	0.14
P_2O_5	0.43	-
Sum	97.25	97.8

Table 2. Ryder (unpublished)
15434,28,202 Microprobe fused bead (FB) and INAA. (INAA 25.3 mg)

wt% (FB except as noted)		
SiO_2		43.4
TiO_2		3.21
Al_2O_3		9.00
Cr_2O_3		0.45
Cr_2O_3	(INAA)	0.4332
FeO		21.28
FeO	(INAA)	21.65
MnO		0.28
MgO		10.82
CaO		9.0
Na_2O		0.58
Na_2O	(INAA)	0.597
K_2O		0.13
K_2O	(INAA)	0.11
P_2O_5		0.37
Sum FB		98.7
ppm (INAA)		
Sc		38.4
Co		56.7
Ni		77
Sr		174
Cs		0.3
Ba		165
Zr		265
Hf		8.1
Ta		0.88
U		0.27
Th		1.56
La		21.55
Ce		65.6
Nd		40
Sm		13.33
Eu		2.07
Tb		2.37
Yb		6.22
Lu		0.903
ppb (INAA)		
Au		<3

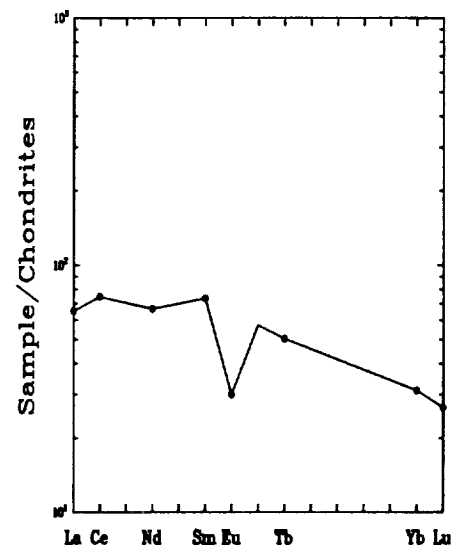

Fig. 7 Chondrite-normalized plot of rare earth elements in 15434,28,202. Data of Ryder (unpublished).

15434,29 KREEP basalt, impact splashed 1 particle 0.029g (0.14g)

15434,29 is a glassy-looking particle (Fig. 8) that consists of yellow glass and mineral fragments (Fig. 9). Phinney et al. (1972) made microprobe analyses of plagioclases, pyroxenes, and glass (Fig. 10; Table 3). They interpreted these KREEP basalts as a partial melting series, and this particle as near one of the extremes, with limited Fe enrichment in pyroxenes and limited Na enrichment in plagiolases. They noted that the glass fills fractures in the crystals, and resembles the matrix of a breccia. Simonds et al. (1975) referred to the particle

as a partially melted basaltic KREEP, possibly with ladder texture, and with only the plagioclase and pyroxene unfused.

Ryder (1988, and unpublished) also made microprobe analyses of silicates and glass, with results similar to Phinney et al. (1972); the mineral fragments are indeed restricted to the earlier products of crystallization of a KREEP basalt magma, and the yellow glass has a composition of the residue of crystallization from such phases (Table 3). The yellow glass is fairly homogeneous. However, Ryder interpreted the fragments texture to result from impact disruption and quenching of a crystallizing flow, not from partial melting of a once-solid basalt.

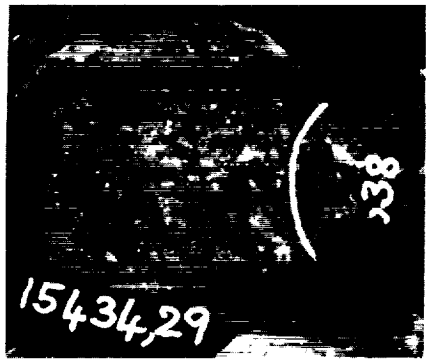

Fig. 8 Original splitting plan for 15434,29. S-72-32972

Fig. 9. Photomicrograph of 15434,29,111. Plane light; field of view is about 2 mm wide. The white fragments are plagioclases, orthopyroxenes, and pigeonites; the gray phase that occupies about 30 % of the sample is a yellow, Ti-rich glass.

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Fig. 10. Microprobe analyses of mineral phases in 15434,29,111 (Phinney et al. (1972) plotted on a pyroxene quadrilateral (top) and partial plagioclase ternary (bottom).

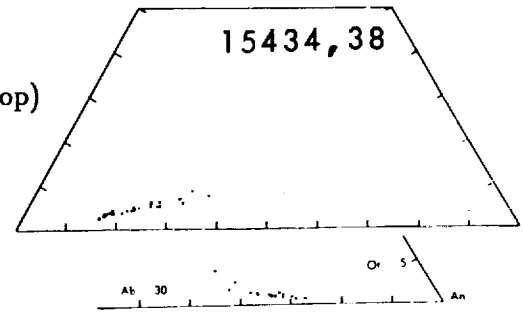


Table 3. Microprobe analyses of glass in 15434,29,111.
A, Phinney et al. (1972)
B, Ryder (unpublished) (average of 10 points).

	A	B
wt%		
SiO_2	47.69	47.3
TiO_2	5.27	5.0
Al_2O_3	9.84	9.0
Cr_2O_3	0.18	0.189
FeO	16.3	17.5
MnO	---	0.23
MgO	4.31	4.2
CaO	9.43	10.1
Na_2O	0.57	0.50
K_2O	1.25	1.2
P_2O_5	1.82	2.1
ZrO_2	0.45	---
Sum	96.7	97.3

Ryder (unpublished) made an analysis of a bulk sample for major and trace elements (Table 4; Fig. 11). The analyses show that the bulk composition is that of an average Apollo 15 KREEP basalt, with a typical abundances of incompatible elements. There is no evidence of any meteoritic contamination.

Table 4. Ryder (unpublished) 15434,29,204. Microprobe fused bead (FB) and INAA. (INAA 26 mg)

wt% (FB except as noted)		
SiO_2		51.3
TiO_2		1.96
Al_2O_3		15.5
Cr_2O_3		0.35
Cr_2O_3	(INAA)	0.33
FeO		9.7
FeO	(INAA)	9.6
MnO		0.16
MgO		8.8
CaO		9.6
Na_2O		0.75
Na_2O	(INAA)	0.79
K_2O		0.50
K_2O	(INAA)	0.48
P_2O_5		0.46
Sum FB		99.1

ppm (INAA)	
Sc	20.51
Co	20.74
Ni	34
Sr	202
Rb	12.8
Cs	0.55
Ba	649
Zr	749
Hf	23.9
Ta	2.67
U	2.96
Th	10.2
La	64.7
Ce	167
Nd	99
Sm	29.8
Eu	2.48
Tb	5.55
Yb	20.0
Lu	2.68

ppb (INAA)	
Au	<2

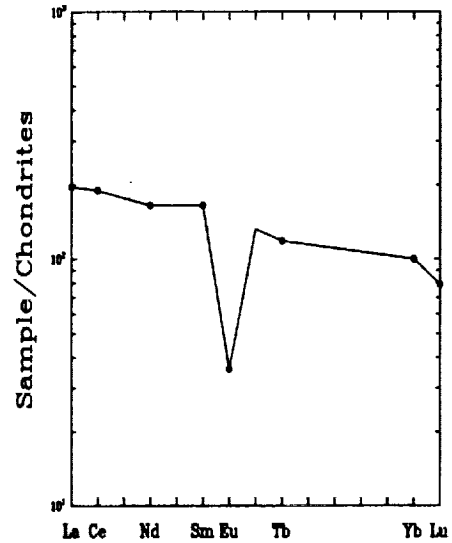


Fig. 11. Chondrite-normalized plot of rare earth elements in 15434,29,204. Data of Ryder (unpublished).

15434,31 KREEP Glass 1 particle 0.045g (0.33g)

15434,31 is an angular glass fragment with a coating of dust (Fig. 12). It was substantially subdivided and allocated but little data has been reported for it. The glass in thin section is pale green and it is devitrified at two ends, but is otherwise clear and clast-free (Fig. 13). It does contain small round vesicles. Microprobe analyses of the glass (Ryder, unpublished) (Table 5) show that it is homogeneous, and has a medium-K Fra Mauro basalt composition. It is different from Apollo 15 KREEP basalts in having lower SiO_2, TiO_2, and K_2O, and higher Al_2O_3, but it is more potassic than most low-K Fra Mauro impact melts.

Fig. 12 Original splitting plan for 15434,31. The particle was subsequently further divided.
S-72-32975

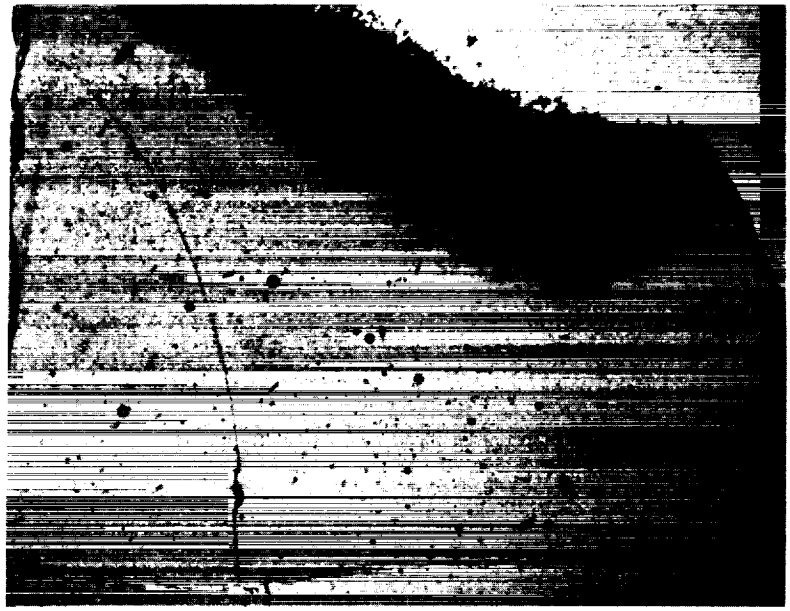


Fig. 13 Photomicrograph of 15434,31,113. Plane light; field of view is about 2 mm wide.

Table 5. Microprobe analyis of glass in 15434,31,113 (Ryder, unpublished) (average of 10 points).

wt%	
SiO_2	48.2
TiO_2	0.88
Al_2O_3	19.8
Cr_2O_3	0.23
FeO	9.11
MnO	0.12
MgO	7.8
CaO	12.1
Na_2O	0.59
K_2O	0.46
P_2O_5	0.18
Sum	99.6

Griscom and Marquardt (1972) made ferromagnetic resonance measurements on a chip of 15434,31 (,62), and described its surface. They infer that there are tiny iron grains in the chip, and that they are probably spheroidal. They also suggest that the metal contains 25 +/- 5 % nickel. They estimate a total of 0.4 wt% metallic iron in particle sizes ranging from 300 angstroms to 1 micron.

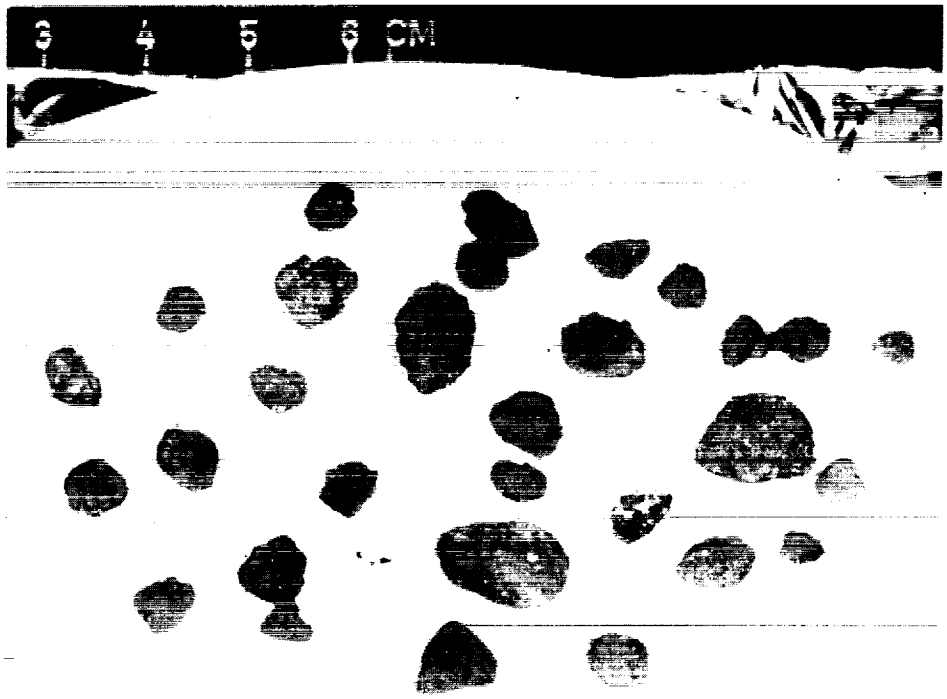
15434,2 Mare and KREEP basalts, impact melts, and breccias 30 particles
2.09g (5.99g)

Powell described these particles (Fig. 14) as friable to coherent microbreccias. Most Apollo 15 coarse fines particles so described turned out to be regolith breccias, but the six in 15434,2 studied in more detail include 2 mare basalts, 1 KREEP basalt, and 1 impact melt in addition to the 2 regolith-produced particles. Powell noted that most of the particles were covered in very fine adhering soil that made classification difficult.

Powell described the particles as subrounded to rounded, very finely granular, and medium gray. They are typically heterogeneous on a fine scale (< 1mm) and consist of glass, mineral, and lithic fragments of various sizes and shapes set in very fine-grained matrices. Mineral fragments recognized include pyroxene (brown to cinnamon), plagioclase (white), and olivine(?) (yellow to yellowish-green). Glass fragments range in color from black to brown to yellow to green (rare).

9 particles were made into a subgroup (15434,24) so that 15434,2 now consists of about 15 particles, and the other 6 have individual numbers.

Fig. 14 15434,2 prior to any subdivision. S-72-15110



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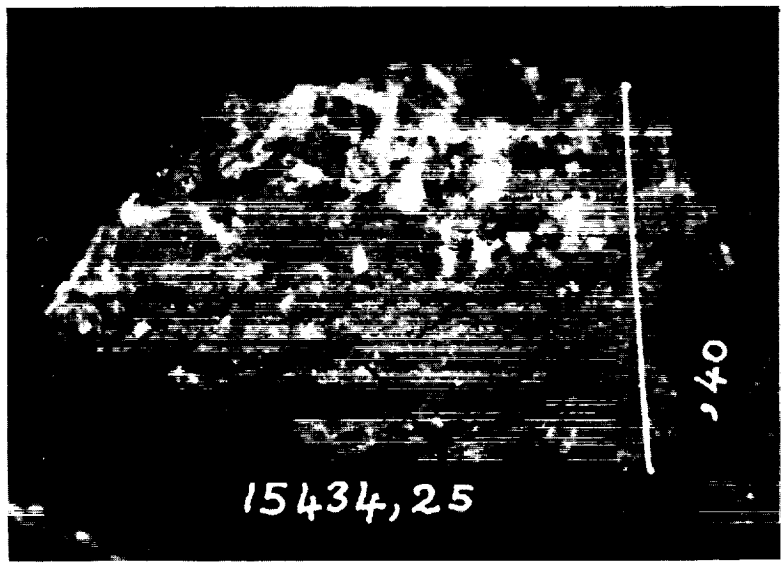
15434,25 Glass-coated KREEP basalt 1 particle 0.157g (0.67g)

15434,25, which must be one of the larger fragments in Fig. 14, is a coarse crystalline fragment that is partially coated with dark glass (Fig. 15). It is an Apollo 15 KREEP basalt that has been shocked; it is partly coated with a glass with a composition similar to Apollo 15 KREEP basalts (not local regolith). It has been extensively subdivided for study.

Fig. 15. Original cutting plan for 15434,25. It was later more extensively subdivided. S-72-32970



15434,25 is a coarse KREEP basalt, with well-developed orthopyroxene and plagioclase up to 2 mm long, but with an interstitial yellow glass; the silicates are fractured and the yellow glass intrudes the fractures (Fig. 16). The sample has been partially described by Phinney et al. (1972) and Simonds et al. (1975) (their ,40); Vaniman and Papike (1980) (their ,116, but they generally refer to it merely as 15434; however, their listed chemical analysis for 15434 is not for 15434,25); and Ryder (1988 and unpublished).

Phinney et al. (1972) recognized 15434,25 as an Apollo 15 KREEP basalt. They made microprobe analyses of pyroxenes and plagioclases (Fig. 17a), and glass (Table 6). Similar silicate data were published by Vaniman and Papike (1980) (Fig. 17b). Simonds et al. (1975) noted the grain size as much greater than 1 mm. Ryder (1988) also analyzed the yellow glass, noting that it had immiscibly separated a hi-Si/K glass (Table 6).

Fig. 16 Photomicrograph of 15434,25,115. Crossed polarized light; field of view about 2 mm across. Dark areas are mainly glassy or cryptocrystalline areas; silicates are plagioclases and orthopyroxene (some pigeonite).

Fig. 17 Microprobe analyses of silicates in 15434,25.
a) Phinney et al. (1972) Pyroxene quadrilateral (top) and partial plagioclase ternary (bottom).
b) Vaniman and Papike (1980) Pyroxene quadrilateral and minor elements (top) and partial plagioclase ternary (bottom).

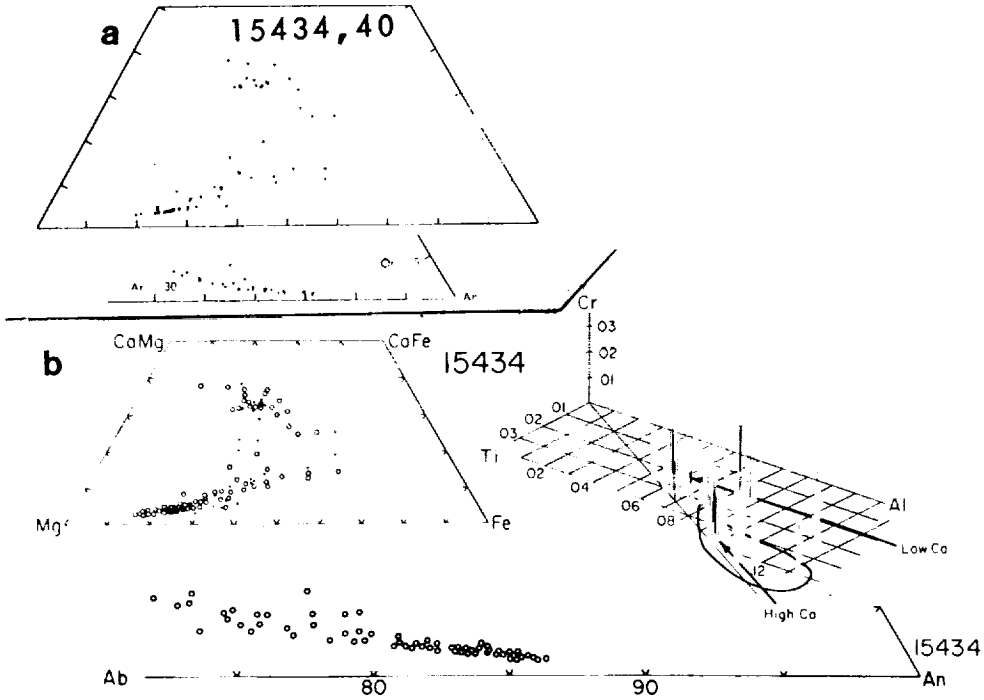


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Table 6. Analyses of yellow glass in 15434,25,115. A) Phinney et al. (1972). B) Ryder (1988).

wt%	A	B
SiO_2	41.52	45.2
TiO_2	7.12	4.7
Al_2O_3	7.49	7.9
Cr_2O_3	0.17	0.08
FeO	21.18	22.3
MnO	---	0.29
MgO	4.25	2.8
CaO	10.23	10.0
Na_2O	0.46	0.49
K_2O	0.83	1.4
P_2O_5	3.33	3.3
ZrO_2	0.63	---
Sum	97.2	98.5

Table 7. Microprobe analysis of glass coat on 15434,25,115. Ryder (unpublished) (average of 2 analyses).

wt%	
SiO_2	51.5
TiO_2	1.56
Al_2O_3	17.4
Cr_2O_3	0.23
FeO	9.7
MnO	0.13
MgO	8.3
CaO	10.5
Na_2O	0.67
K_2O	0.58
P_2O_5	0.48
Sum	101.0

The glass composition given by Phinney et al. (1972) differs considerably from that of Ryder (1988 and unpublished). Part of the difference represents a real heterogeneity of the glass, and part results from the immiscibility of the glass. The high Si/K glass contains 78 to 80% SiO_2 and 3 to 5% K_2O.

The impact-produced glass coat was analyzed by Ryder (unpublished) (Table 7). It is colorless in thin section and partly mingles with the yellow glass, suggesting both were liquid at the same time. The coating glass is unusual in that it is of Apollo 15 KREEP basalt composition, and not of local regolith composition, suggesting that it was not created recently.

Phinney et al. (1972) and Simonds et al. (1975) interpreted the Apollo 15 KREEP basalts as a partial melting sequence (the yellow glass being a partial melting product of a once-solid rock), with 15434,25 as one of the least melted particles. Neither they nor Vaniman and Papike (1980) made reference to the fracturing, the immiscibility, or the glass coating. Vaniman and Papike (1980) gave a general description for the Apollo 15 KREEP basalts based on 15386 and this particular sample 15434,25; they apparently assumed that 15434 was a single rock rather than a collection of coarse fines. They showed a photomicrograph of 15434,25,116.

Ryder (1988 and unpublished) interpreted the texture and chemistry (below) as resulting from impact into a nearly-crystallized basalt, with the residue quenching to a yellow glass. Such a model explains the fracturing, intrusion, and quenching of an otherwise coarse basalt that had crystallized into an immiscibility field. He found less than 10% yellow glass.

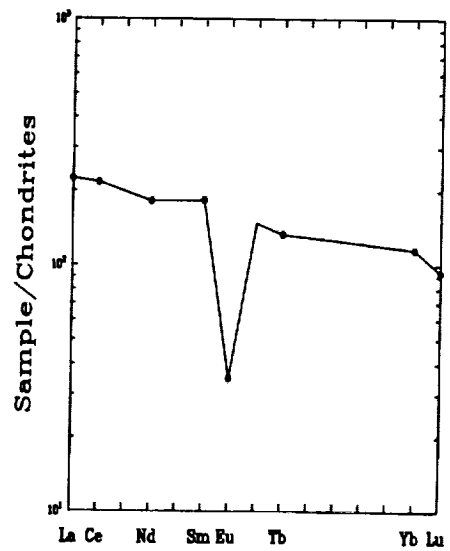
Bulk rock analyses for major and trace elements were produced by Ryder (unpublished) and Anders et al. (unpublished) (Table 8). The data show that the particle is a fairly typical Apollo 15 KREEP basalt in most major and trace elements; the data of Ryder (unpublished) for a sample lacking coating glass gives no indication of meteoritic contamination. The analysis of Anders et al. agrees well with that of Ryder for the few elements analyzed in both studies, except that the Anders et al. analysis shows higher Ni, hence meteoritic contamination, that is confirmed by the Au and Ir detected. Their sample appears to have included the glass coat.

Table 8 A) Ryder (unpublished) 15434,25,200. INAA (60mg)
B) Anders et al. (unpublished) 15434,25,71 RNAA (20mg)

wt% (FB except as noted)		A	B
SiO_2		51.5	
TiO_2		2.32	
Al_2O_3		14.7	
Cr_2O_3		0.300	
Cr_2O_3	(INAA)	0.300	
FeO		10.0	
FeO	(INAA)		9.5
MnO		0.14	
MgO		8.0	
CaO		9.6	
Na_2O		0.79	
Na_2O	(INAA)	0.81	
K_2O		0.72	
K_2O	(INAA)	0.78	
P_2O_5		0.58	
Sum FB		98.6	

ppm (A, INAA; B, RNAA)		
Sc	21.3	
Co	19.7	
Ni	16	43
Sr	183	
Rb	20.4	22.2
Cs	0.9	0.934
Zn		3.15
Ba	752	
Zr	905	
Hf	28.5	
Ta	3.15	
U	3.51	3.71
Th	12.9	
La	74.2	
Ce	191	187
Nd	109	116
Sm	33.2	
Eu	2.42	2.25
Tb	6.27	6.72
Yb	23.2	21.3
Lu	3.17	3.18

Fig. 18. Chondrite-normalized plot of rare earth elements in 15434,25,200. Data of Ryder (unpublished)



ppb (RNAA except as noted)	A	B
Au	<2 (INAA)	0.24
Ir		0.685
Os		0.768
Re		0.049
Pd		<2.3
Sb		0.45
Ge		74.2
Se		90.9
Te		4.0
Ag		1.67
In		4.14
Bi		8.6
Cd		32
Tl		5.43

15434,26 Olivine-normative mare basalt 1 particle 0.200g (0.25g)

15434,26 is a crystalline particle with a glass coat and adhering fine regolith material (Fig. 19). It was split for thin sections. The thin sections show that the basalt has the fine- to medium-grained intergranular, plagioclase-poikilitic texture common among the olivine-normative mare basalts (Fig. 20). It has granular groundmass olivine and late cristobalite and fayalite, and there is no doubt that it belongs to the typical local olivine-normative mare basalt group (Ryder, 1988b). The opaque phases include chromite and ilmenite, but most are ulvospinels. The glass coat is flow banded, contains some mare debris, and shows the adhering fine dust (Fig. 20).

Fig. 19. Original splitting plan for 15434,26. S-72-32973

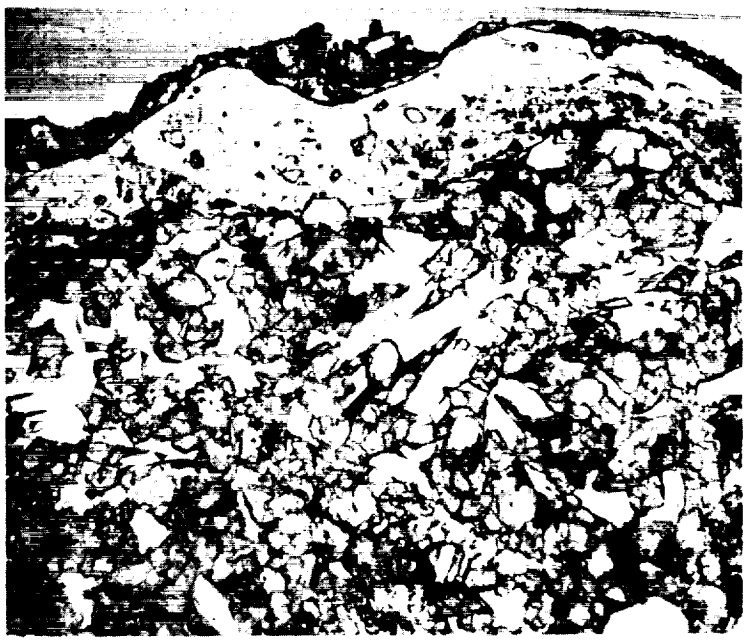


Fig. 20 Photomicrograph of 15434,26,117. Plane light; field of view about 2 mm wide. Glass coat with adhering dust is at the top.

15434,27 Olivine-normative mare basalt 1 particle 0.250g (0.32g)

15434,27 is a crystalline basalt without much adhering dust (Fig. 21). It was split for thin sections. Its texture is unusually variolitic or spherulitic (Fig. 22). It contains some early olivine and late

cristobalite and sulfide. The plagioclases include hollow varieties, and elongate opaque minerals (ulvospinel/ilmenite). It appears to be an olivine-normative basalt but it might be a variety distinct from most local basalts.

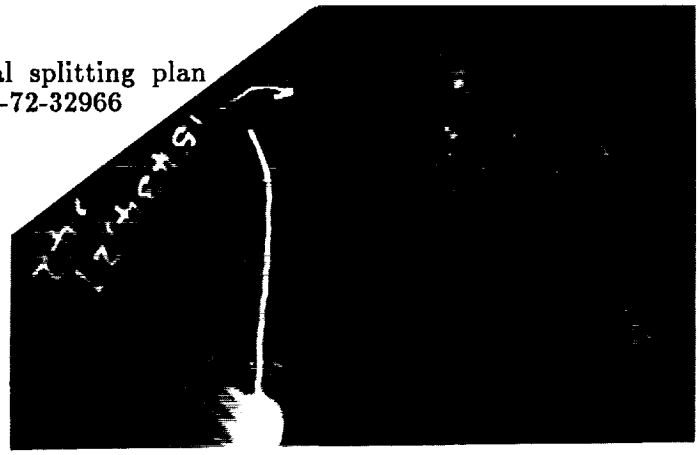


Fig. 21 Original splitting plan for 15434,27. S-72-32966

Fig. 22 Photomicrograph of 15434,27,119. Plane light; field of view is about 2 mm across.

15434,33 Fine-grained impact melt 1 particle 0.174g (0.32g)

15434,33 is a tough, dark, mottled-appearing particle (Fig. 23). It was chipped for thin sections. The sections show that the particle is a fine-grained, vesicular impact melt (Fig. 24). The groundmass is dense and dark; it contains tiny plagioclase laths. The melt is either devitrified glass or crystallized rapidly in the first place. The clasts are rounded and unshocked; none are glassy. Most clasts are single mineral fragments, but one lithic clast contains plagioclase and pink spinel. The mineral clasts also include rare pink spinels.

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Fig. 23 Original chipping plan for 15434,33. S-72-32979

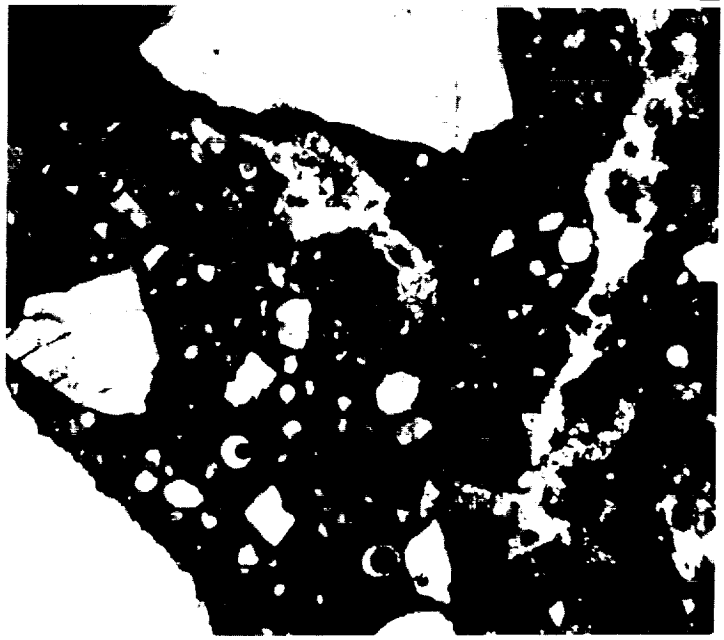
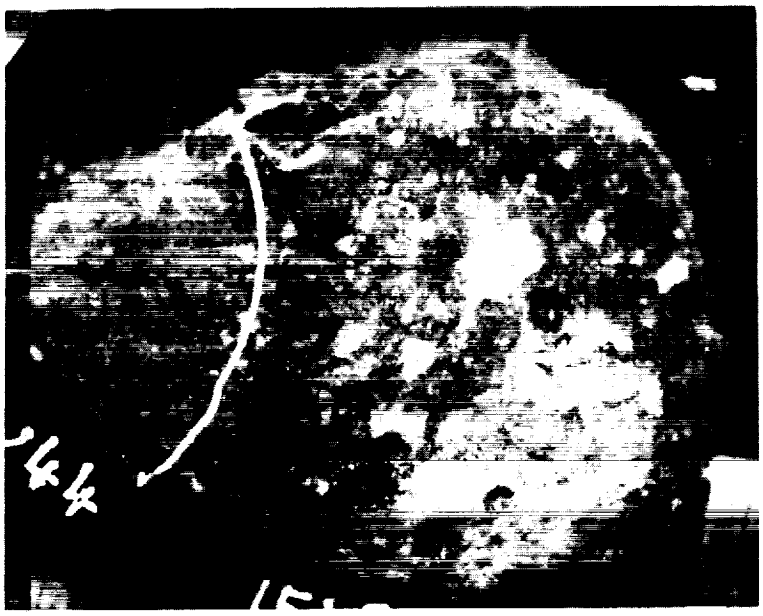


Fig. 24 Photomicrograph of 15434,33,121. Plane light; field of view about 2 mm across.

15434,34	Regolith breccia	1 particle	0.230g (0.27g)

15434,34 is regolith breccia with a dark, dense matrix and white clasts (Fig. 25). The matrix is dominantly glassy with fine clasts; one larger clast is a KREEP basalt (Fig. 26). Other clasts include glass, some of it yellow.

Fig. 25. Original splitting plan for 15434,34,122. S-72-32977



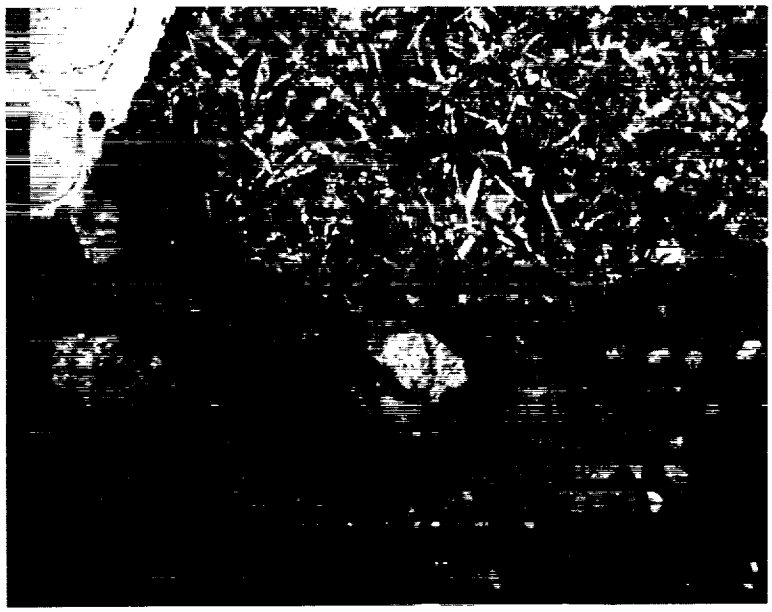


Fig. 26. Photomicrograph of 15434,34,122. Plane light; field of view about 2 mm across.

15434,35 Agglutinate/glassy breccia 1 particle 0.529g (0.680)

15434,35 is a tough, rough, dark fragment with small white clasts (Fig. 27). It was chipped for thin sections. The particle consists mainly of a clear to very pale yellow banded glass (Fig. 28) that contains small fragments. Phinney et al. (1972) gave a microprobe analysis of the glass (their 15434,45), which they described as flow-banded orange glass (Table 9). The composition is similar to that of Apollo 15 KREEP basalts, and Phinney et al. (1972) included it with

those samples. They stated that it contained 10 to 20% clasts of pyroxene and plagioclase.

Fig. 27. Original splitting plan for 15434,35. S-72-32982

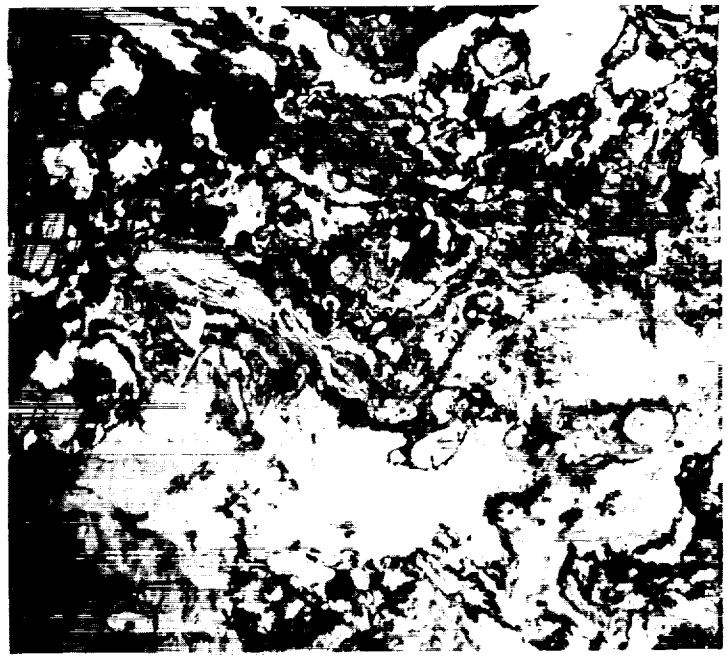


Fig. 28. Photomicrograph of 15434,35,124. Plane light; field of view is about 2 mm wide.

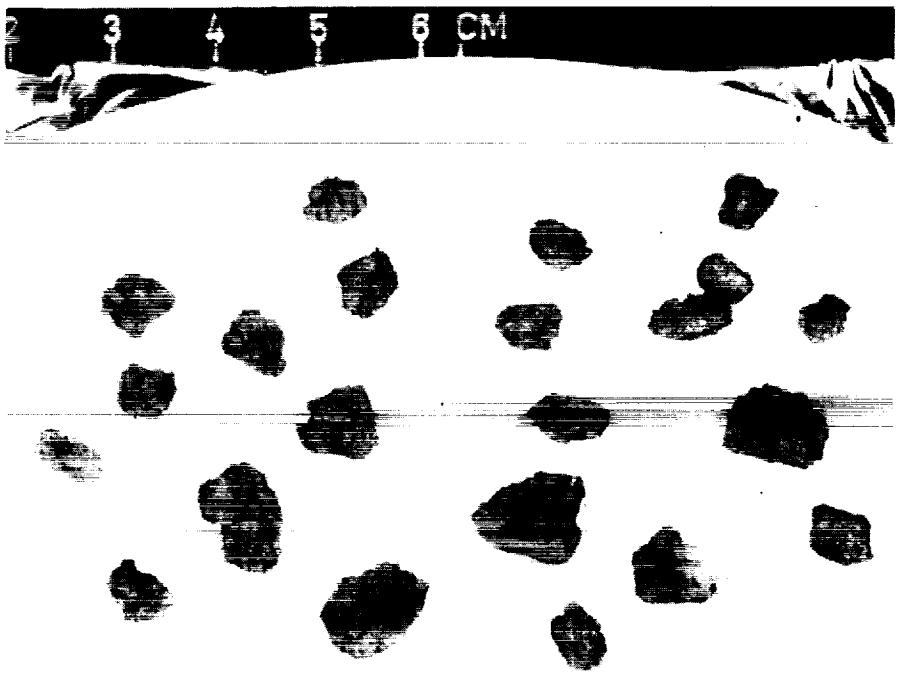
Table 9. Microprobe analysis of glass in 15434,35,124. (Phinney et al., 1972)

wt%	
SiO_2	49.81
TiO_2	1.36
Al_2O_3	16.81
FeO	9.32
MgO	8.63
CaO	10.67
Na_2O	0.75
K_2O	0.48
P_2O_5	0.39
Sum	98.2

15434,3 Agglutinates/Fine-grained melts 22 particles 4.20g (4.89g)

Powell described these particles as friable to coherent agglutinates, mixed particles consisting of several smaller particles loosely bonded (welded?) together by dark glass (Fig. 29). They are irregularly angular to subangular and medium-gray, with smooth to very finely granular surfaces. Most of the recognizable fragments are microbreccias (= regolith breccias) and dark glasses. Much fine soil adheres to the particles and is incorporated within them. The bonding glass is not abundant and is generally not vesicular. The one sample thin sectioned is mainly a vesicular, very fine-grained impact melt or agglutinate; it is not identifiable on Fig. 29 and does not look particularly like any of them, apparently lacking the regolith material.

Fig. 29. Original 22 particles of 15434,3. S-72-15109.



15434,32 Fine-grained impact melt 1 particle 0.38g (0.46g)

15434,32 is a dark, tough, dense particle without obvious clasts (Fig. 30). It has round vesicules and is homogeneous. If regolith breccia is attached to the particle, it must be on the side not visible in Fig. 30. The thin sections show that the particle is a fine-grained melt (Fig. 31) with a micropoikilitic or subophitic texture, and it appears to be feldspathic. The small scattered clasts are mainly unshocked plagioclases and olivines; some metal and other opaques (including ilmenite) and silica are present but rare.

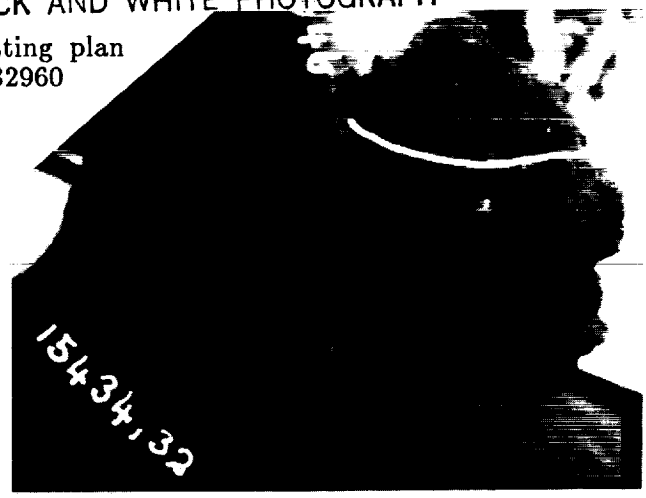


Fig. 30. Original splitting plan for 15434,32. S-72-32960

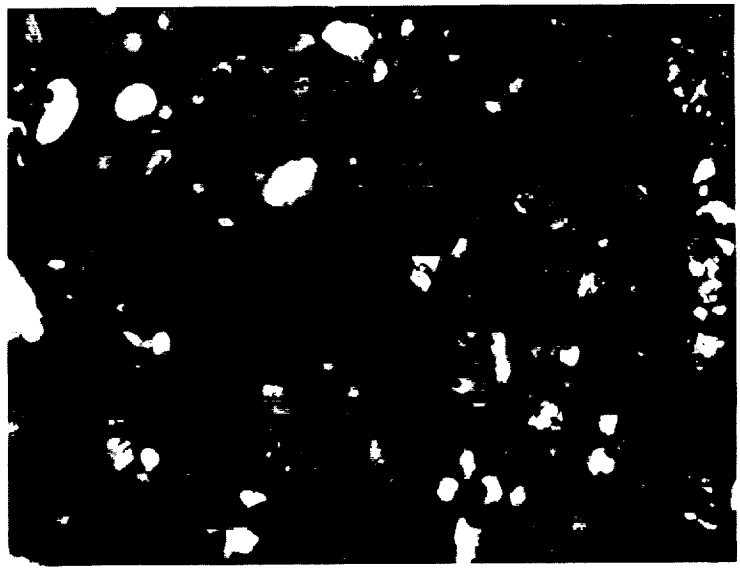
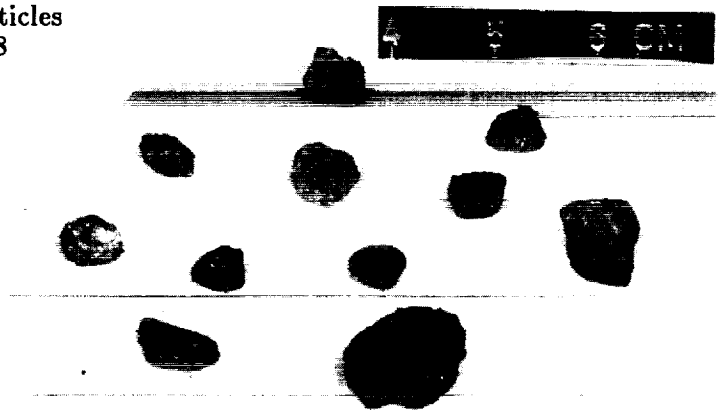


Fig. 31. Photomicrograph of 15434,32,127. Plane light; field of view about 2 mm across. White areas include both vesicles and mineral clasts.

15434,4	Mainly(?) KREEP basalts	11 particles	0.531g (2.52g)

Powell described these particles as tough basalts with a few vugs. They are dark gray, speckled, and subrounded (Fig. 32). They are holocrystalline with equigranular textures and a mean grain size of 0.25 mm. Six of the particles have been sectioned and are Apollo 15 KREEP basalts; it is likely that all of them are. Powell recognized 40% white lath-shaped plagioclase, 60% dark brownish-gray anhedral (clino)pyroxene, less than 1% of a greenish-yellow anhedral mineral (olivine?) and tiny amounts of an anhedral cinnamon-brown mineral and minute opaque minerals. Some of the dark material he identified as pyroxene is evidently dark mesostasis, and the greenish-yellow mineral is probably orthopyroxene.

Fig. 32 Original 11 particles of 15434,4. S-72-15178



15434,16 KREEP basalt 1 particle 0.15g (0.44g)

15434,16 is probably the second largest particle in Fig. 32, but no processing photograph is available. Its grain size is among the coarsest observed for this basalt type (Fig. 33). It has a subophitic-intersertal texture, with partly hollowed plagioclases up to 1.5 mm long, orthopyroxene cores to pigeonites, and a dark cryptocrystalline mesostasis with ilmenite needles. Simonds et al. (1975) gave a mode of 45% plagioclase, 43% pyroxene, and 10% mesostasis, with plagioclases up to 1.4 mm. Crawford and Hollister (1977) reported grain sizes of 1 to 3 mm wide and 10 mm long for this sample (15434,128), but that is an order of magnitude too great. Microprobe data by Ryder (unpublished) shows typical Apollo 15 KREEP basalt mineral compositions, with orthopyroxene cores of Mg' ~80. Simonds et al. (1975) included this basalt with their "partial melting" model for the origin of the textures of these KREEP basalts.

Fig. 33 Photomicrograph of 15434,16,129. Plane light; field of view about 2 mm wide. Coarse grain size and dark cryptocrystalline mesostasis with ilmenite needles are apparent.

A bulk particle analysis for major and trace elements was made by Ryder (unpublished) (Table 10, Fig. 34). Rb data by Nyquist et al. (1974) are consistent with this analysis; their Sr abundance is somewhat lower than most Apollo 15 KREEP basalts; however, they did not really attempt to obtain a whole rock point from their small split. The chemical data indicate a rather average composition for the KREEP basalt group, with no evidence for meteoritic contamination.

Table 10. A) Ryder (unpublished). 15434,16,198. Microprobe fused bead (FB) and INAA. (INAA 49 mg). B) Nyquist et al. (1974), isotope dilution, mass spectrometry; data may not well represent bulk rock.

	A	B
wt% (FB except as noted)		
SiO_2	51.4	
TiO_2	2.16	
Al_2O_3	15.7	
Cr_2O_3	0.31	
Cr_2O_3 (INAA)	0.303	
FeO	10.0	
FeO (INAA)	9.8	
MnO	0.155	
MgO	8.0	
CaO	9.8	
Na_2O	0.79	
Na_2O (INAA)	0.83	
K_2O	0.60	
K_2O (INAA)	0.56	
P_2O_5	0.56	
Sum FB	98.9	
ppm (INAA)		
Sc	21.3	
Co	19.2	
Ni	23	
Sr	190	140.7
Rb	16.0	15.77
Cs	0.76	
Ba	680	
Zr	794	
Hf	25.9	
Ta	2.9	
U	3.1	
Th	11.0	
La	69.0	
Ce	180	
Nd	101	
Sm	31.7	
Eu	2.54	
Tb	5.9	
Yb	21.2	
Lu	2.9	
ppb (INAA)		
Au	<4	

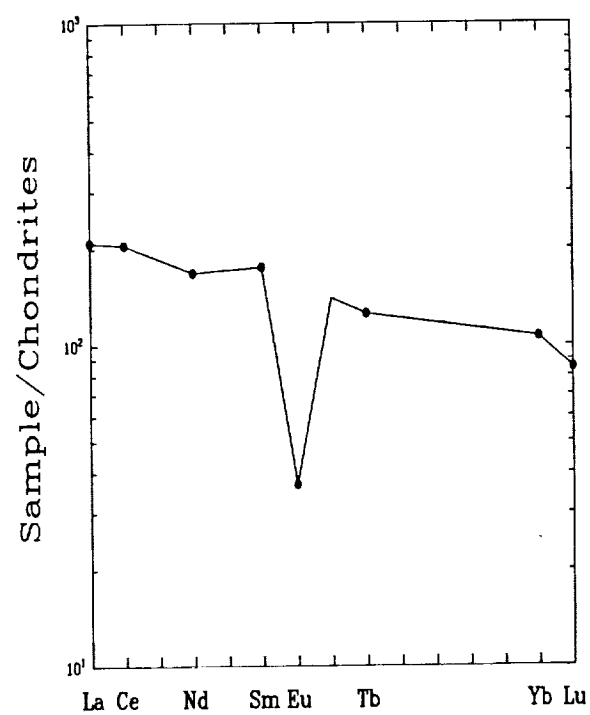


Fig. 34 Chondrite-normalized plot of rare earth elements in 15434,16,198. Data of Ryder (unpublished).

Nyquist et al. (1974) made mineral separates and isotopic analyses for Rb and Sr, producing a Rb-Sr isochron age of 3.91 +/- 0.04 Ga (λ= 1.39 x

$10^{-11}y^{-1}$) [3.83 Ga, $\lambda = 1.42 \times 10^{-11}y^{-1}$]. The initial $^{87}Sr/^{86}Sr$ was 0.70070 +/- 0.0001 (Fig. 35). This initial ratio is distinctly higher than that of the only two other Apollo 15 KREEP basalts analyzed (rake samples 15382 and 15386) although the ages are not distinct.

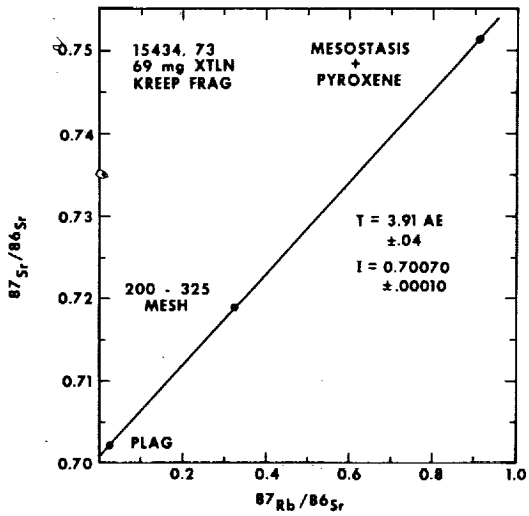


Fig. 35 Rb-Sr mineral isochron for 15434,16,73 (Nyquist et al., 1974).

15434,17 KREEP basalt 1 particle 0.0g (0.20g)

15434,17 is a crystalline particle that was subdivided for study (Figs. 36, 37). There was an error made in the thin section lab that caused confusion between subsamples 15434,28,37 and 15434,17,48; descriptions by Phinney et al. (1972) of 15434,48 apply to 15434,28 (see 15434,28 for an explanation). Their descriptions for 15434,37 apply to 15434,17. In fact, two separate chips of 15434,17 were made into thin sections (chips ,48 and ,63).

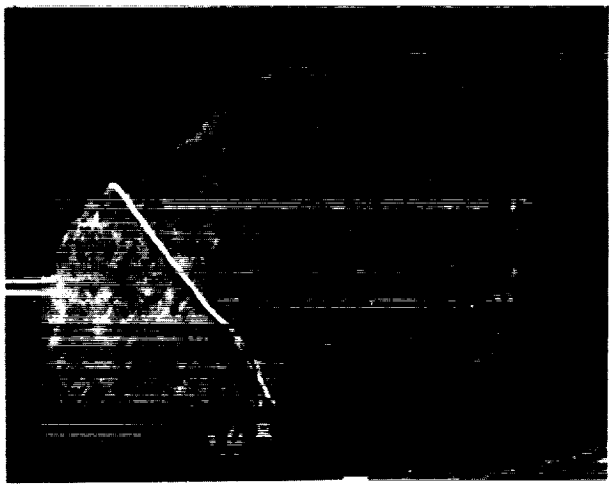


Fig. 36 Initial splitting plan for 15434,17. S-72-32980

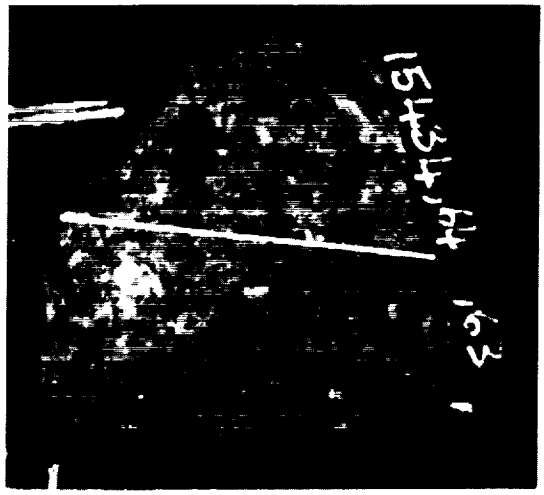


Fig. 37 Continued dissection plan for 15434,17, entirely subdivided to ,63 and ,64. S-72-33596

Phinney et al. (1972) and Powell et al. (1973) included the particle in their KREEP basalt groups. The sample has a subophitic to intersertal texture and is intermediate in grain-size among this basalt group. Scattered elongated pyroxene phenocrysts (up to 1.5 mm long) with orthopyroxene cores are intergrown with smaller laths of plagioclase, some of which are curved (Fig. 38). A dark cryptocrystalline mesostasis is present. Simonds et al. (1975) gave a mode of 48% plagioclase, 28% pyroxene, and 20% mesostasis, with plagioclase grain size listed as 100 to 200 microns (their data listed under ,37,109). Phinney et al. (1972) diagrammed microprobe analyses for plagioclases and pyroxenes (Fig. 39) that show a wide range of compositions typical of these basalts. They also gave an analysis of the mesostasis , showing its high Si and K composition (Table 11). Microprobe analyses of silicates by Ryder (unpublished) are consistent with those of Phinney et al. (1972). Both Phinney et al. (1972) and Simonds et al. (1975) interpret the sample as a partial melt product, the mesostasis glass being the partial melt. However, the textures are consistent with this sample, like most other Apollo 15 KREEP basalts, being a simply-crystallized lava.

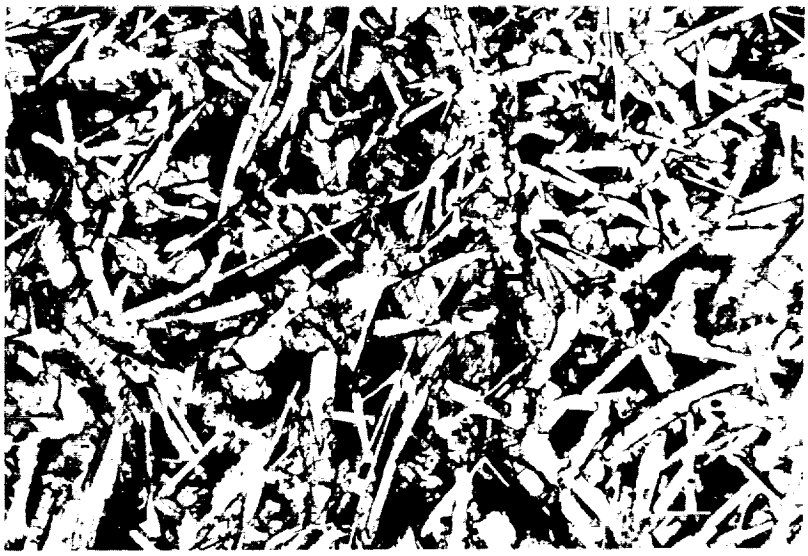


Fig. 38 Photomicrograph of 15434,17,63 (on 15999,95). Plane light; field of view is about 3 mm across.

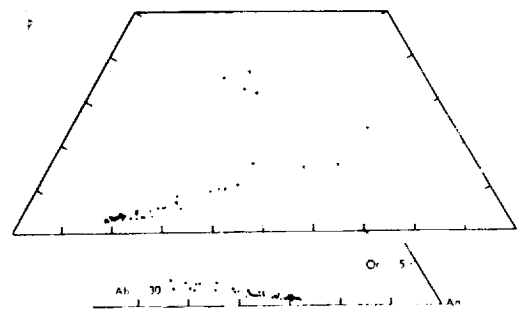


Fig. 39 Microprobe analyses of pyroxene (top) and plagioclases (bottom) in 15434,17,109. (Phinney et al., 1972).

Table 11. Microprobe analysis of mesostasis in 15434,17,109. (Phinney et al., 1972).

wt%	
SiO_2	68.84
TiO_2	0.97
Al_2O_3	11.34
FeO	6.15
MgO	0.13
CaO	2.45
Na_2O	0.90
K_2O	5.81
P_2O_5	0.81
ZrO_2	0.54
Sum	97.94

Major element analyses for the particle were made by Powell (unpublished, quoted in Irving, 1976)) and Ryder (unpublished), both using microprobe fused bead techniques (Table 12). (The Ryder bead gave very low Na, K, and P results, not listed, suggesting problems in the making of the fused bead; possibly Fe exchanged with the molybdenum strip). Trace elements were also analyzed by Ryder (unpublished) (Table 12). The analyses show that 15434,17 is an average to evolved sample of this basalt group, with typical incompatible element relative abundances (Fig. 40), and no evidence for meteoritic contamination.

Table 12. A) Ryder (unpublished) 15434,17,64. Microprobe fused bead (FB) and INAA. (INAA sample 22.5 mg) B) Powell (unpublished) 15434,17,63. Microprobe fused bead.

wt% (FB except as noted)		A	B
SiO_2		53.5	52.1
TiO_2		2.2	2.3
Al_2O_3		16.2	17.0
Cr_2O_3		0.27	0.30
Cr_2O_3	(INAA)	0.287	
FeO		9.5	11.1
FeO	(INAA)	10.0	
MnO		0.16	0.23
MgO		7.6	6.3
CaO		9.8	10.3
Na_2O		-	0.58
Na_2O	(INAA)	0.894	
K_2O		-	0.73
K_2O	(INAA)	0.83	
P_2O_5		-	0.60
Sum FB		99.2	101.5

ppm (INAA)	
Sc	22.6
Co	18.4
Ni	31
Sr	201
Rb	22.5
Cs	1.0
Ba	846
Zr	1038
Hf	31.6
Ta	3.5
U	4.3
Th	14.8
La	80.9
Ce	211
Nd	121
Sm	36.8
Eu	2.65
Tb	7.1
Yb	25.7
Lu	3.5

ppb (INAA)	
Au	<3
Ir	<6

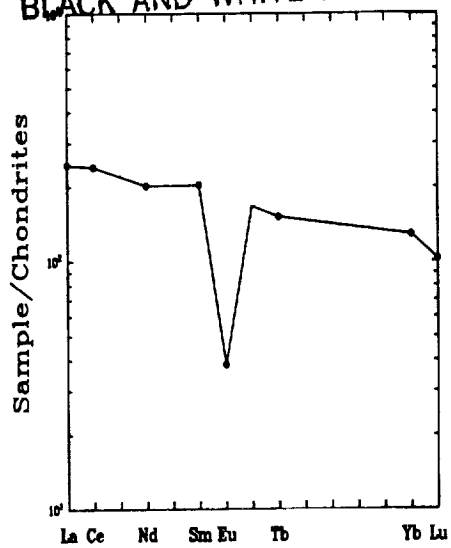


Fig. 40 Chondrite-normalized plot of rare earth elements in 15434,17,64. Data of Ryder (unpublished).

15434,18 KREEP basalt 1 particle 0.385g (0.74g)

15434,18 is the largest particle in Fig. 32. It is a tough crystalline particle that was partly dissected for study (Fig. 41). It is an Apollo 15 KREEP basalt with an intermediate grain size for that group.

Fig. 41 Original cutting plan for 15434,18. The sample was later further dissected. S-72-32981.

The thin sections show a mesostasis-rich basalt with plagioclase laths (some curved) intergrown with pigeonites (Fig. 42). A vew vesicles are present. Othopyroxene cores are present in the pigeonites. Simonds et al. (1975) gave a mode (,49,132, misnumbered as ,135) of 45% plagioclase, 34% pyroxene, and 15% mesostasis, with plagioclase 40 to 60 microns long; this stated grain size appears to be much too small, and the mesostasis appears to be about 25 or 30%, not 15% (see Fig. 42). Microprobe analyses by Ryder (unpublished) show typical silicate compositions for this basalt group, but the orthopyroxenes are not as magnesian as many others (Mg' only 78 or 79 rather than 82 or so).

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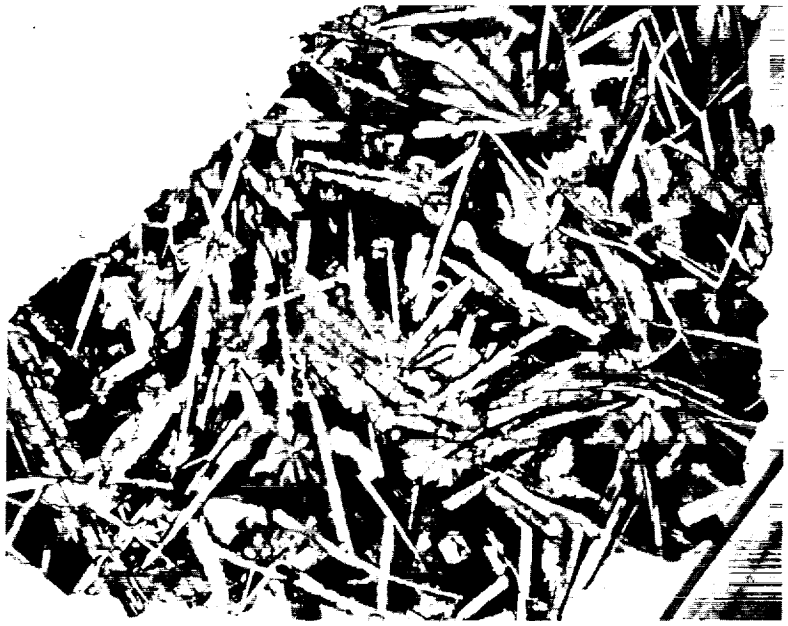

Fig. 42 Photomicrograph of 15434,18,132. Plane light; field of view is about 2 mm wide.

Ryder (unpublished) made analyses for major and trace elements in bulk rock samples (Table 13; Fig. 43). The analyses were made on two separate chips; one was 25 mg (A) and the other 121 mg (B). The analyses show that the sample is an Apollo 15 KREEP basalt with an average to evolved composition for the group, and no evidence for meteoritic contamination. The two chips are very similar in composition, with the rare earth abundances differing by a maximimum of 7%, showing the homogeneity of this particle at a very small scale.

Table 13 Ryder (unpublished)
A) 15434,18,199-A (INAA 15.4 mg)
B) 15434,18,199-B (INAA 47 mg)
Microprobe fused bead (FB) and INAA.

wt% (FB except as noted)		A	B
SiO_2		52.8	52.6
TiO_2		2.14	2.10
Al_2O_3		15.2	15.4
Cr_2O_3		0.29	0.28
Cr_2O_3	(INAA)	0.29	0.28
FeO		10.0	10.0
FeO	(INAA)	10.1	9.8
MnO		0.15	0.15
MgO		7.4	7.6
CaO		9.4	9.4
Na_2O		0.85	0.85
Na_2O	(INAA)	0.89	0.87
K_2O		0.77	0.76
K_2O	(INAA)	0.65	0.62
P_2O_5		0.62	0.62
Sum FB		99.6	99.8

ppm (INAA)		
Sc	23.2	22.1
Co	18.6	17.7
Ni	25	20
Sr	170	200
Rb	23.5	22.6
Cs	1.02	0.94
Ba	871	795
Zr	995	975
Hf	31.5	30.2
Ta	3.42	3.40
U	4.3	3.8
Th	14.9	14.0
La	83.5	78.3
Ce	216	202
Nd	125	114
Sm	38.2	35.5
Eu	2.63	2.55
Tb	7.1	6.7
Yb	25.1	24.5
Lu	3.60	3.36
ppb (INAA)		
Au	<2	<3

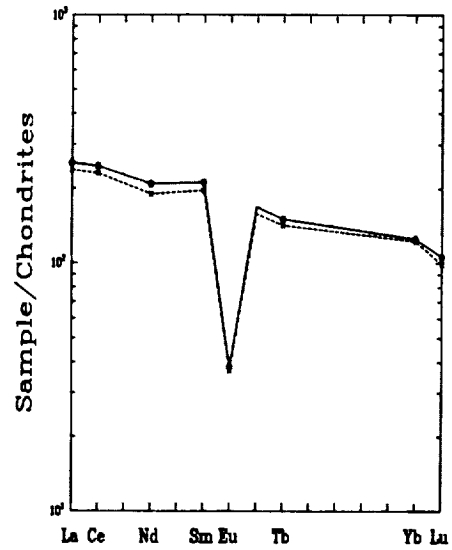

Fig. 43 Chondrite-normalized plot of rare earth elements in 15434,18,199A (solid line) and 199B (dotted line). Data of Ryder (unpublished).

15434,93 KREEP basalt ? 1 particle 0.020g

A small sample was taken from 15434,4 and allocated; there is no processing documentation. The sample appears to be too small to be an entire particle and it is probably a chip of one of them.

15434,189 KREEP basalt 1 particle 0.282g (0.41g)

Particle 15434,189 was an entire particle. It was subdivided for study. The sample is an Apollo 15 KREEP basalt with a spherulitic and vitric texture, with abundant cryptocrystalline and glassy mesostasis (Fig. 44). The plagioclase laths do not form an interconnecting network, and rarely reach 1 mm long. Both plagioclases and pyroxenes include hollow forms; sporadic orthopyroxenes are euhedral. Microprobe data for plagioclases and pyroxenes by Ryder (unpublished) show typical KREEP basalt phase compositions.

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Fig. 44 Photomicrograph of 15434,189,205. Plane light; field of view is about 2 mm across.

An analysis for major and trace elements by Ryder (unpublished) (Table 14) shows that the sample is a KREEP basalt, with typical absolute and relative abundances of incompatible elements (Fig. 45). There is no evidence for meteoritic contamination. The INAA data is for two aliquots of the same ground powder.

Table 14. Ryder (unpublished) 15434,189,191. Microprobe fused bead (FB) and INAA (two analyses of same homogenized powder. (Bulk powder = 95 mg, A = 46 mg, B = 17 mg)

wt% (FB except as noted)		A	B
SiO_2		51.6	
TiO_2		1.92	
Al_2O_3		16.4	
Cr_2O_3		0.32	
Cr_2O_3	(INAA)	0.32	0.33
FeO		10.0	
FeO	(INAA)	9.5	9.6
MnO		0.14	
MgO		9.2	
CaO		9.8	
Na_2O		0.80	
Na_2O	(INAA)	0.78	0.79
K_2O		0.55	
K_2O	(INAA)	0.53	0.49
P_2O_5		0.46	
Sum FB		100.7	

ppm (INAA)		
Sc	19.4	19.7
Co	19.7	20.2
Ni	<20	<30
Sr	187	203
Rb	14.7	15.4
Cs	0.62	0.63
Ba	664	670
Zr	729	764
Hf	23.6	23.1
Ta	2.63	2.57
U	2.9	2.9
Th	10.5	10.6
La	63.0	63.9
Ce	164	167
Nd	92	97
Sm	28.8	30.1
Eu	2.39	2.49
Tb	5.3	5.4
Yb	19.6	18.9
Lu	2.65	2.74
ppb (INAA)		
Au	<3	<4

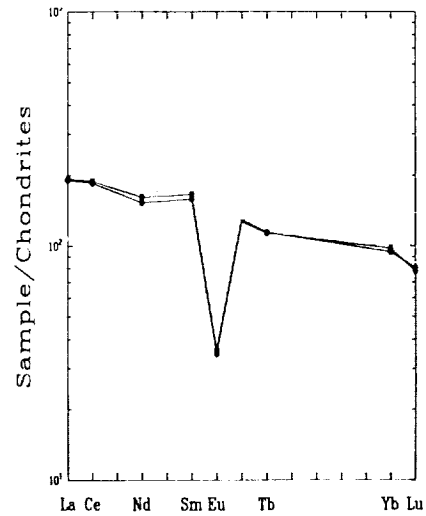


Fig. 45 Chondrite-normalized plot of rare earth elements in 15434,189,191. Data of Ryder (unpublished).

15434,192 KREEP basalt 1 particle 0.0 g (~0.10 g)

15434,192 was a small particle that was subdivided entirely for study. It is an Apollo 15 KREEP basalt with an unusual texture: porphyritic / glomeroporphyritic (Fig. 46). The sample contains large partly intergrown crystals of plagioclase and orthopyroxene / pigeonite, and a fine cryptocrystalline groundmass. The orthopyroxenes are abruptly overgrown with strongly-zoned pigeonite. Microprobe data for pyroxenes and plagioclases by Ryder (unpublished) show typical KREEP basalt phase compositions. A few plagioclases are swallow-tailed and there are patches of K-feldspar/silica intergrowths.

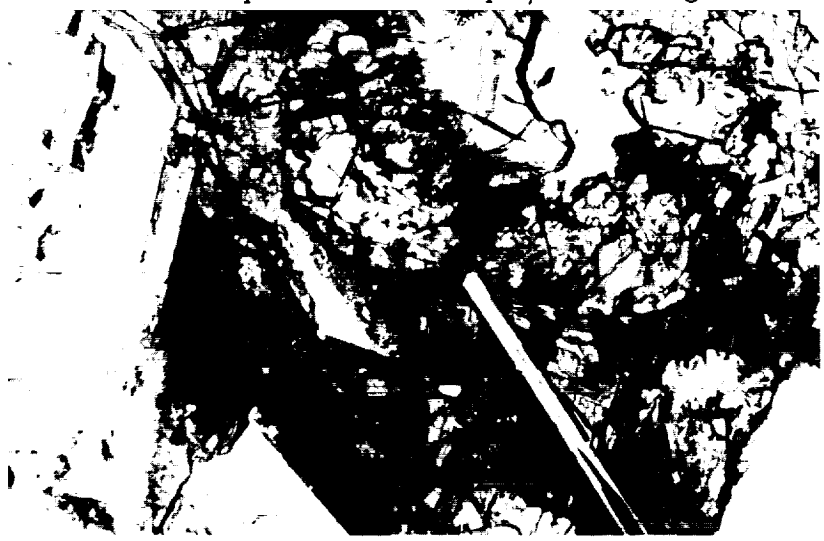


Fig. 46. Photomicrograph of 15434,192,206. Plane light; field of view is about 2 mm across.

An analysis for major and trace elements of a bulk sample by Ryder (unpublished) (Table 15) shows that the particle is an Apollo 15 KREEP basalt with typical relative and absolute abundances of the incompatible elements (Fig. 47). There is no evidence for meteoritic contamination.

Table 15. Ryder (unpublished) 15434,192. Microprobe fused bead (FB) and INAA. (INAA = 43 mg)

wt% (FB except as noted)		
SiO_2		51.9
TiO_2		2.09
Al_2O_3		15.14
Cr_2O_3		0.32
Cr_2O_3	(INAA)	0.30
FeO		10.5
FeO	(INAA)	10.0
MnO		0.17
MgO		8.6
CaO		9.5
Na_2O		0.84
Na_2O	(INAA)	0.83
K_2O		0.72
K_2O	(INAA)	0.72
P_2O_5		0.58
Sum FB		99.9

ppm (INAA)	
Sc	22.5
Co	18.8
Ni	25
Sr	173
Rb	20.9
Cs	0.94
Ba	816
Zr	963
Hf	30.2
Ta	3.4
U	3.8
Th	13.6
La	78.2
Ce	203
Nd	115
Sm	35.7
Eu	2.49
Tb	6.7
Yb	24.5
Lu	3.35

ppb (INAA)	
Au	<3
Ir	<5

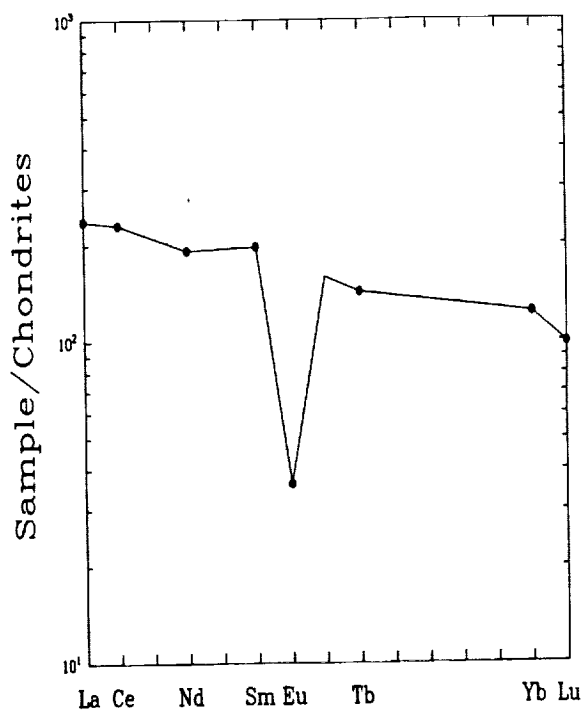


Fig. 47 Chondrite-normalized plot of rare earth elements in 15434,192. Data of Ryder (unpublished).

15434,194 KREEP basalt 1 particle 0.0g (~0.05g)

15434,194 was a small particle that was subdivided for study. It is an Apollo 15 KREEP basalt with an intersertal texture that is mesostasis-rich (about 40%?) (Fig. 48). A poorly-developed network of plagioclase is partly-intergrown with pyroxene. Most of the pyroxene is pigeonite, but some orthopyroxene cores are present. Microprobe data by Ryder (unpublished) show that these are less magnesian (Mg' about 78) than is the case for most of these Apollo 15 KREEP basalts; otherwise the phase compositions are typical for this group of basalts.

Fig. 48. Photomicrograph of 15434,194,207. Plane light; field of view is about 2 mm across.

An analysis for major and trace elements by Ryder (unpublished) (Table 16) shows that the sample is a somewhat evolved member of the Apollo 15 KREEP basalt series, consistent with the orthopyroxene compositions. The absolute and relative abundances of the incompatible elements (Fig. 49) are within the typical range. There is no evidence for meteoritic contamination.

Table 16. Ryder (unpublished)
15434,194 Microprobe fused bead (FB) and INAA. (INAA = 28 mg)

wt% (FB except as noted)

SiO_2		52.8
TiO_2		2.17
Al_2O_3		15.0
Cr_2O_3		0.28
Cr_2O_3	(INAA)	0.28
FeO		10.6
FeO	(INAA)	10.0
MnO		0.15
MgO		7.6
CaO		9.5
Na_2O		0.87
Na_2O	(INAA)	0.88
K_2O		0.76
K_2O	(INAA)	0.65
P_2O_5		0.63
Sum FB		100.0

ppm (INAA)

Sc	22.3
Co	18.0
Ni	<25
Sr	187
Rb	22.5
Cs	0.92
Ba	849
Zr	957
Hf	31.1
Ta	3.4
U	4.1
Th	14.9
La	81.4
Ce	215
Nd	125
Sm	37.8
Eu	2.59
Tb	7.0
Yb	24.8
Lu	3.54

ppb (INAA)

Au	<3

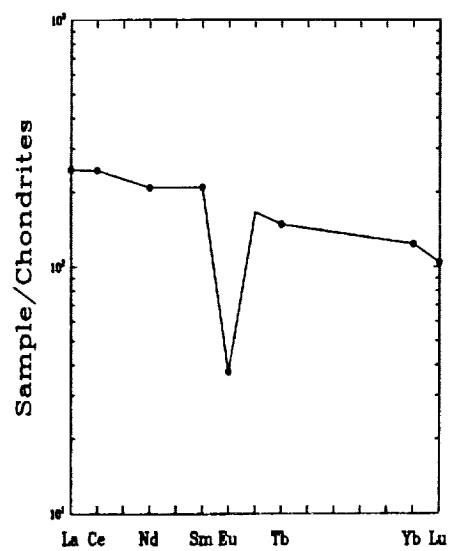


Fig. 49. Chondrite-normalized plot of rare earth elements in 15434,194. Data of Ryder (unpublished).

15434,5 Highlands igneous and impact breccias 12 particles 0.002g (2.92g)

Powell described these particles as tough crystalline rocks of non-mare character (Fig. 13). More than half of them are impact melt breccias, and the others include anorthosite and evolved plutonics. Powell described them as subangular to subrounded and medium- to light-gray or tan; they did not appear to be igneous so much as recrystallized cataclastic. The textures are equigranular to inequigranular seriate; all are xenomorphic-granular. In some particles angular mineral grains are visible, with plagioclase clearly dominant; accessory yellow-green is present. The opaque mineral content is low. Powell noted that these particles may include "recrystallized noritic microbreccias", an old term for rocks subsequently recognized as impact melts. The grain-size is characteristically small. All the particles have been subdivided and given individual numbers. It is not clear why the photograph shows 13 particles, unless one is broken.

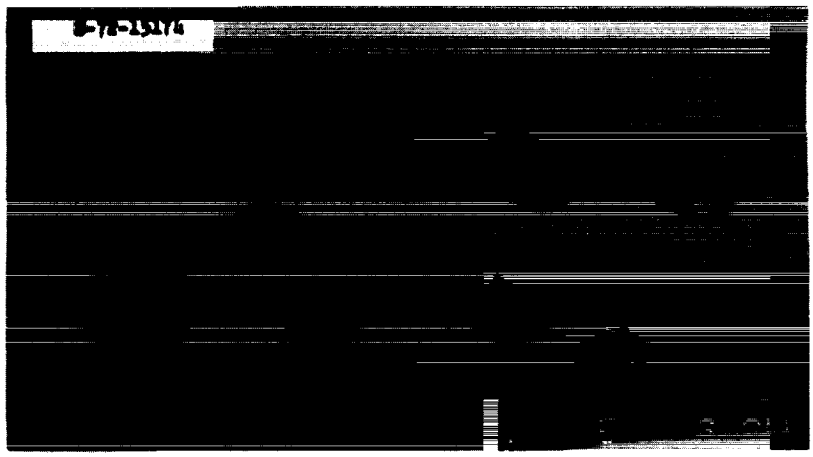


Fig. 50 Pre-splitting photograph of the particles in 15434,5.

15434,9 Ferroan anorthosite 1 particle 0.17g (0.22g)

Phinney et al. (1972) and Simonds et al. (1975) described the particle as a crushed or brecciated anorthosite (Fig. 51), with the thin sections consisting of little more than two large feldspar grains and some augite (Fig. 52). Phinney et al. (1972) provided microprobe data that show that the sample is similar to anorthosite 15415 (Fig. 53). Simonds et al. (1975) gave a mode of 99% feldspar and 1% pyroxene; there is no olivine; they gave a grain size for plagioclases of 2 mm.

Fig. 51 Splitting plan for 15434,9. S-72-32969

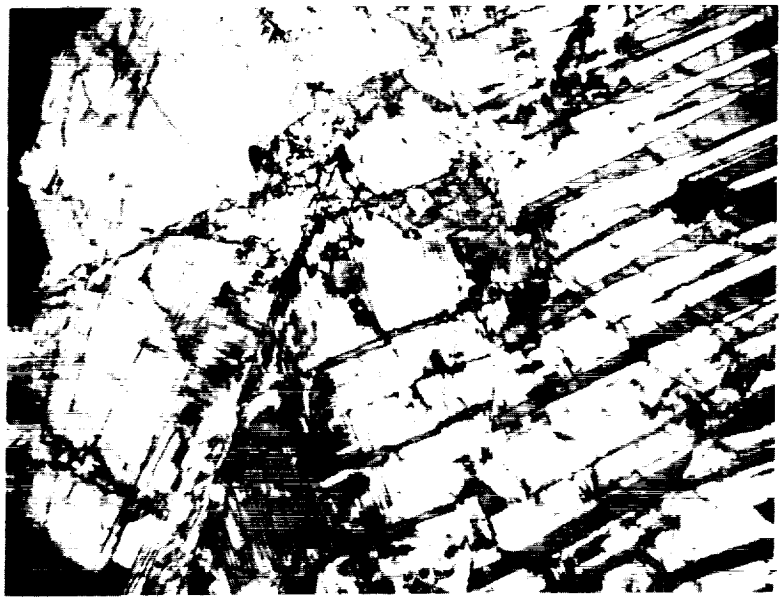
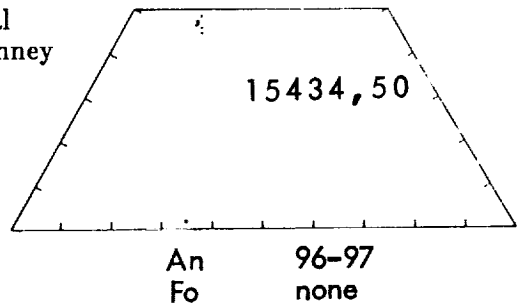


Fig. 52. Photomicrograph of 15434,9,134. Crossed polarized light; field of view is about 2 mm across. Little is visible other than mildly deformed large plagioclase grains.

Fig. 53. Microprobe mineral data for 15434,9,134 (Phinney et al., 1972).



15434,10 Cataclastic granite 1 particle 0.039g (0.12g)

The particle is a small piece of a cataclasized evolved plutonic rock, consisting largely of silica, potash feldspar, and exsolved pyroxene. It was subdivided for study (Fig. 54). It was briefly described by Martinez and Ryder (1989). The thin section, which is plucked, shows a lithology that was originally coarse-grained but was subsequently cataclasized (Fig. 55). It consists of a central zone of intergrown silica and potash feldspar, and adjacent zones are dominantly pyroxenes. One end of the section is a complex zone that contains troilite, ilmenite, phosphate, silica, and fayalitic olivine. Zircon appears to be absent. The compositions of the phases are similar to those in the quartz-monzodiorite fragments from 15405 (e.g. Fig. 56), except that the little plagioclase present is much more sodic than in the quartz-monzodiorite. The sample may be an unrepresentative fragment of a lithology closely related to the quartz-monzodiorite; modally it is an alkali granite.

Fig. 54. Original splitting plan for 15434,10. S-72-32961

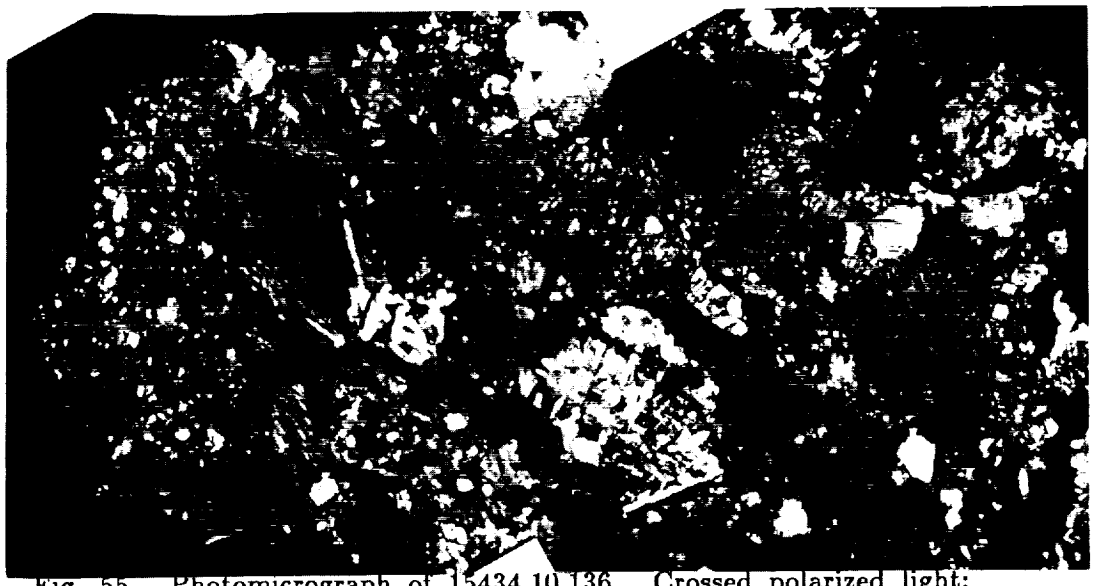
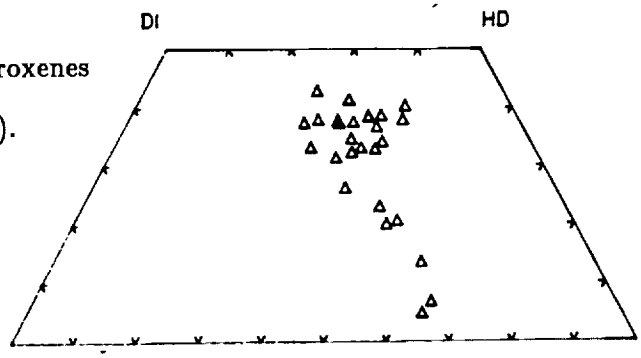


Fig. 55. Photomicrograph of 15434,10,136. Crossed polarized light; field of view is about 3 mm wide. Thin section is thin, so image is dark.

Fig. 56 Compositions of pyroxenes in 15434,10,136. Data of Martinez and Ryder (1989).



Chemical analyses for two splits of a single chip of 15434,10 were reported by Martinez and Ryder (1989) (Table 17, Fig. 57). Major element analyses were made for only one of the splits, except for FeO which differs between the two splits. The more complete analysis has the norm of a granite. The trace elements of the two splits are fairly similar, but the one higher in FeO is also higher in Sc and Co, indicating more pyroxene. The low alumina content indicates that the analysis is not that of a liquid, and both chips may be unrepresentative or the chip is a cumulate lacking plagioclase, or both. The rare earth abundances are much lower that those of the quartz-

monzodiorite. They are at about the level of Apollo 15 KREEP basalts, although the pattern is much flatter, consistent with a deficiency of plagioclase. The pattern is not bow-shaped like many lunar granites.

Table 17. Martinez and Ryder (1989). 15434,10,178 (two splits of a single chip). Microprobe fused bead (FB) and INAA. (INAA: A = 49 mg, B = 30 mg)

wt% (FB except as noted)		A	B
SiO_2		56.9	
TiO_2		1.13	
Al_2O_3		6.4	
Cr_2O_3		0.17	
Cr_2O_3	(INAA)	0.154	0.148
FeO		17.8	
FeO	(INAA)	18.3	26.2
MnO		0.28	
MgO		4.7	
CaO		8.3	
Na_2O		0.56	
Na_2O	(INAA)	0.547	0.464
K_2O		2.17	
K_2O	(INAA)	2.17	
P_2O_5		1.33	
Sum FB		99.7	
ppm (INAA)			
Sc		39.6	59.4
Co		23.2	81.4
Ni		<35	
Sr		111	
Rb		63	43
Cs		0.51	
Ba		2022	1560
Zr		848	727
Hf		30.8	25.3
Ta		3.9	4.9
U		8.3	4
Th		23.2	16.4
La		65.7	63.7
Ce		172	174
Nd		98	
Sm		31.5	34.5
Eu		1.55	1.34
Tb		6.5	8.2
Yb		29.0	36.1
Lu		4.3	5.6
ppb (INAA)			
Au		<2	

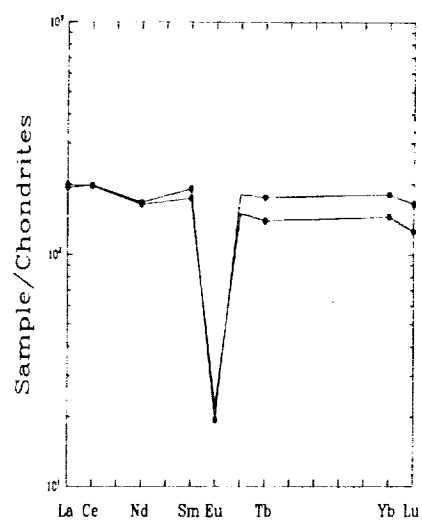


Fig. 57. Chondrite-normalized plot of rare earth elements in 15434,10,178. Data of Martinez and Ryder (1989).

15434,12 Cataclastic Fe-gabbro 1 particle 0.023g (0.62g)

The particle is the largest one in Fig. 50. It is rather mottled in appearance, and obviously not of pristine igneous texture (Fig. 58a). The two thin sections show light and dark bands, predominantly plagioclase and pyroxene respectively, forming a cataclastic gabbro (Fig. 58b). Silica is a minor phase, and silica/potash feldspar intergrowths are present but rare. Zircon(?), ilmenite, and fayalite are present. Rare original grain boundaries and coarse grains are preserved. The pyroxenes are brownish and exsolved; the exsolution was described by Ryder and Martinez (1989). The compositions of pyroxene are shown in Fig. 59; they are similar to those in 15434,10; 15434,14; and the quartzmonzodiorite in 15405. The plagioclases are mainly in the range An_{80-85}.

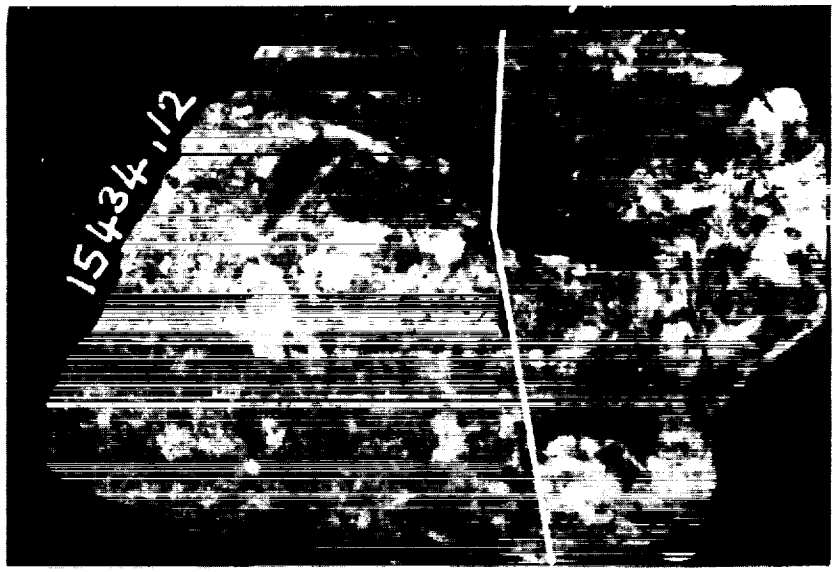


Fig. 58a. Original splitting plan for 15434,12. S-72-33595.

Fig. 58b. Photomicrograph of 15434,12,138. Plane light; field of view is about 2 mm across. The sample is very dense and possibly glassy; the thin section is plucked and poor.

Ryder (unpublished) made replicate analyses for major elements and a single analysis for trace elements of a chip of the particle (Table 18; Fig. 60). The analysis is silica- and iron-rich, indicating abundant pyroxene; the low alumina indicates that the sample does not represent a liquid. Ni (not detected) and Co (17.7 ppm) do not indicate meteoritic contamination, but the Au abundance of 21 ppm indicates substantial contamination, so the rock does not necessarily represent a pristine igneous lithology despite its unusual composition. The rare earth abundances have a pattern similar to that of the granitic fragment 15434,10, but the abundances are somewhat lower. The precursor(s) of this breccia are somewhat obscure without further work.

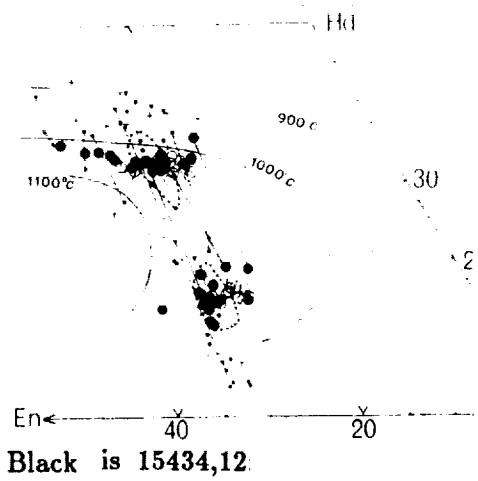
Table 18. Ryder (unpublished). Microprobe fused bead (FB) and INAA. 15434,10,179. (INAA on A = 19 mg from about 100 mg homogenized).

wt% (FB except as noted)		A	B
SiO_2		56.0	56.2
TiO_2		1.11	0.93
Al_2O_3		9.8	9.8
Cr_2O_3		0.27	
Cr_2O_3	(INAA)	0.258	
FeO		14.7	14.2
FeO	(INAA)	14.6	
MnO		0.27	0.27
MgO		5.5	5.0
CaO		10.5	10.1
Na_2O		0.66	0.71
Na_2O	(INAA)	0.67	
K_2O		0.72	0.53
K_2O	(INAA)	0.71	
P_2O_5		0.29	0.25
Sum FB		100.0	

ppm	(INAA)	
Sc		42.9
Co		17.7
Ni		
Sr		139
Rb		17.8
Cs		0.57
Ba		738
Zr		722
Hf		22.0
Ta		2.01
U		3.04
Th		10.6
La		46.3
Ce		121
Nd		72
Sm		23.5
Eu		1.71
Tb		5.0
Yb		21.6
Lu		3.06

ppb	(INAA)	
Au		21

Fig. 59. Compositions of pyroxenes in 15434,12 and other samples (Ryder and Martinez, 1989).



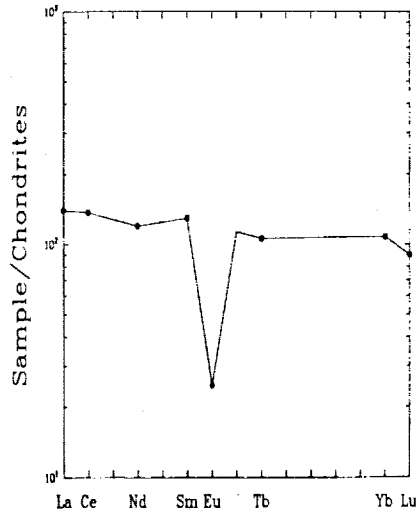


Fig. 60. Chondrite-normalized plot of rare earth elements in 15434,12,179. Data of Ryder (unpublished).

15434,13 Fine-grained impact melt 1 particle 0.0g (0.10g)

The tiny particle is a very fine-grained impact melt with a microophitic or micropoikilitic texture. It has been entirely split for allocations (Fig. 61). It was described by Ryder and Spudis (1987). It contains about 10 % obvious clastic material (Fig. 62), most of which are plagioclase crystals. The melt phase consists of tiny (50 microns?) pigeonite oikocrysts enclosing tiny (less than 20 microns) lathy to stubby plagioclases. Ilmenites are tiny and most are anhedral. Laul et al. (1987) included the sample in their study of impact melts, and gave a mode of 50.1% plagioclase, 47.3% pyroxene, 2.2% ilmenite, 0.2% metal, 0.1% sulfide, and 0.1% spinel. They also diagrammed microprobe analyses of plagioclases and pyroxenes (Fig. 63), and tabulated 3 pyroxene analyses.

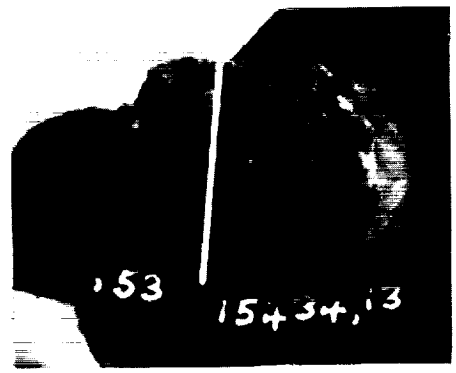


Fig. 61 Original splitting plan for 15434,13. Eventually the entire particle was allocated.

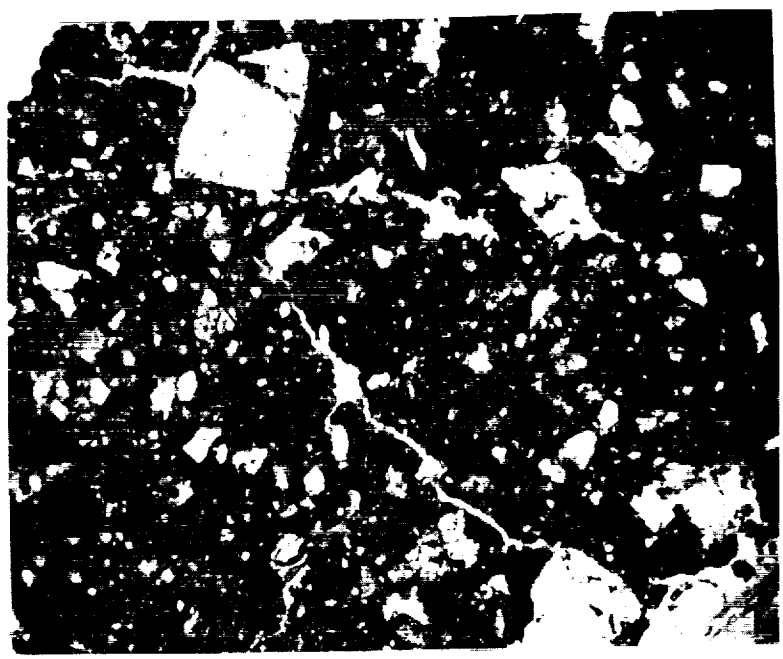


Fig. 62. Photomicrograph of 15434,13,140. Plane light; field of view is about 2 mm across. Most of the visible clasts are plagioclases.

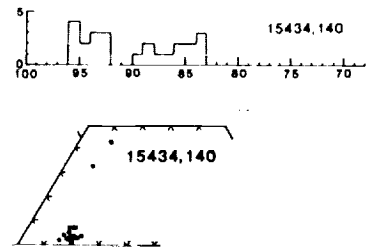
A bulk chemical analysis for major and trace elements was made by Ryder and Spudis (1987) (Table 19; Fig. 64). The analysis shows a low-K Fra Mauro composition with Co and Ni abundances indicative of meteoritic contamination. The rare earth elements have a KREEP pattern except for a slight flattening of the lightest ones (Fig. 64). Ryder and Spudis (1987) placed 15434,13 in their group B impact

melt compositions, but noted that it contains much lower K, Rb, and Cs than most group B samples, perhaps a result of volatile loss during impacting.

Table 19. Ryder and Spudis (1987) 15434,13. Microprobe fused bead (FB) and INAA. (INAA = 35 mg).

wt% (FB except as noted)		
SiO_2		48.5
TiO_2		1.24
Al_2O_3		15.7
Cr_2O_3		0.27
Cr_2O_3	(INAA)	0.322
FeO		7.6
FeO	(INAA)	8.3
MnO		0.129
MgO		15.2
CaO		10.1
Na_2O		0.421
K_2O		0.072
Sum FB		99.2
ppm (INAA)		
Sc		21.9
Co		42.5
Ni		503
Rb		<10
Cs		0.1
Zr		560
Hf		15.6
Ba		430
Ta		1.9
U		2.9
Th		7.4
La		45.0
Ce		125
Nd		81
Sm		21.7
Eu		1.88
Tb		4.8
Yb		14.5
Lu		2.15

Fig. 63. Microprobe analyses of plagioclases and pyroxenes in 15434,13,140. Laul et al. (1987).



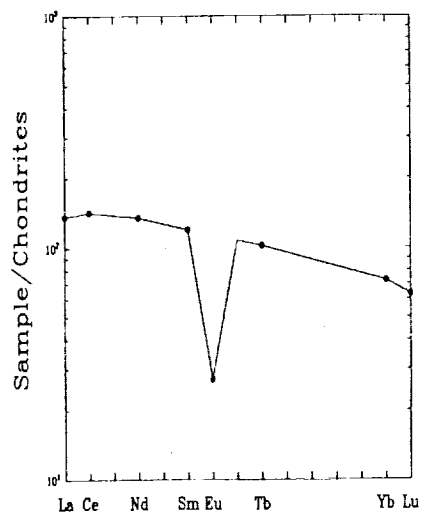


Fig. 64 Chondrite-normalized plot of rare earth elements in 15434,13. Data of Ryder and Spudis (1987).

15434,14 Cataclastic quartz-monzodiorite and polymict breccia
1 particle 0.04g (0.15g)

The particle was apparently a single breccia fragment, but no initial processing picture is available. The sample has been somewhat subdivided. The thin sections consist of a few small particles, and apparently the fragment fell apart under sectioning. The two thin sections contain 3 and 4 particles. Three are similar dense breccias that are brownish (Fig. 65); the fourth is an Apollo 15 KREEP basalt fragment. The breccias consist of a fine-grained host, a cataclasized silicic plutonic rock, and small areas of glassy breccia, in differing proportions. Presumably the KREEP basalt was a clast in the breccia.

The silicic plutonic is extremely cataclasized, and partly interfingered with the host breccia. Most grains are less than 40 microns across. Its mode is that of a quartz-monzodiorite or granite. Exsolved pyroxene is common; the compositions, shown in Fig. 59 (section on 15434,12) are similar to those in 15434,10 and 15434,12. Small amounts of fayalite, phosphate, troilite, and ilmenite are present, with trace amounts of zircon and ulvospinel.

The composition of the glassy breccia, determined by microprobe, is very similar to that of the 15405 quartz-monmzodiorite, except that it has only 1% K_2O (cf. 2% in 15405 clast). The composition of the glassy breccia may be the best estimate for the 15434,14 quartz-monzodiorite composition. The host breccia is quite different in composition, being a low-K Fra Mauro basalt composition.

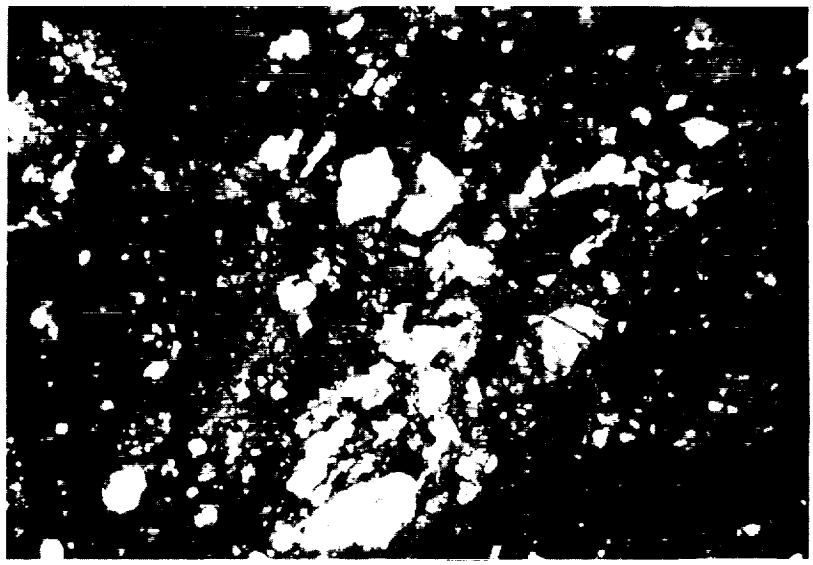
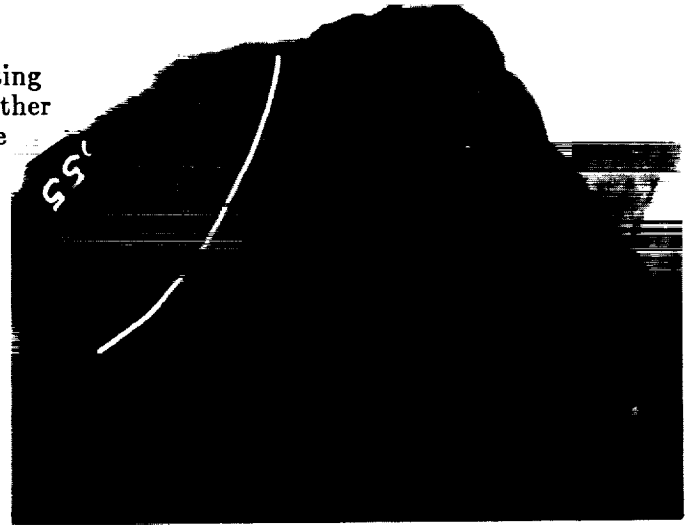


Fig. 65. Photomicrograph of 15434,14,142. Plane light; field of view is about 2 mm across.

15434,15 Fine-grained clast-rich impact melt 1 particle 0.517g (0.68g)

15434,15, the darker of the two largest particles in Fig. 50, has been partly subdivided (Fig. 66). It is an impact melt with a large proportion of clasts (Fig. 67); the groundmass is micro-ophitic with interstitial glass, small ilmenite blades, and some metal. The clasts include prominent plagioclase and olivine; one mafic grain exsolved rutile. Phinney et al. (1972) described the fragment as a recrystallized breccia, with a higher degree of recrystallization and slightly more magnesian pyroxenes than most. Microprobe analyses were provided by Phinney et al. (1972) and Laul et al. (1987), who classified the sample as an impact melt. The pyroxenes and plagioclases show a wide range of compositions; the olivines show a much narrower range (Fig. 68). Laul et al. (1987) gave a mode for 15434,15,145 of 40.7% plagioclase, 53.5% pyroxene, 3.8% olivine, 1.8% ilmenite, 0.2% spinel, and traces of sulfide and metal. They noted that the spinel encloses euhedral ilmenite.

Fig. 66. Original splitting plan for 15434,15. Further subdivisions were made later. S-72-32963



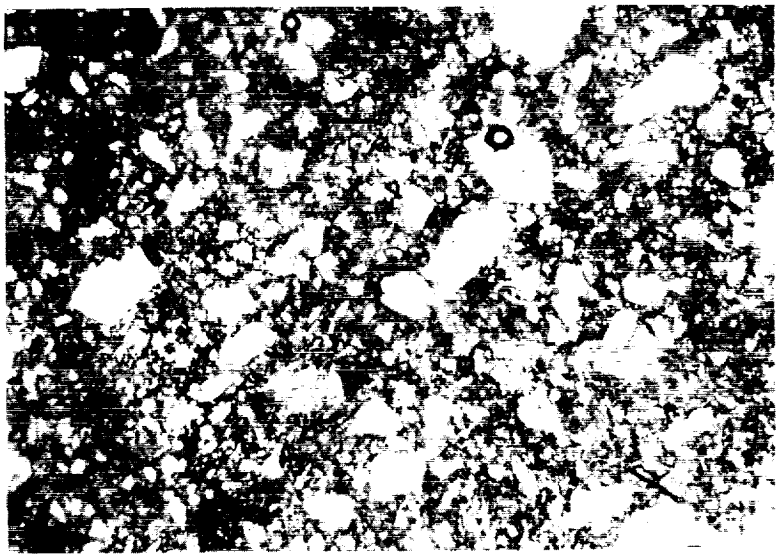


Fig. 67. Photomicrograph of 15434,15,144. Plane light; field of view is about 2 mm wide. High clast content is obvious.

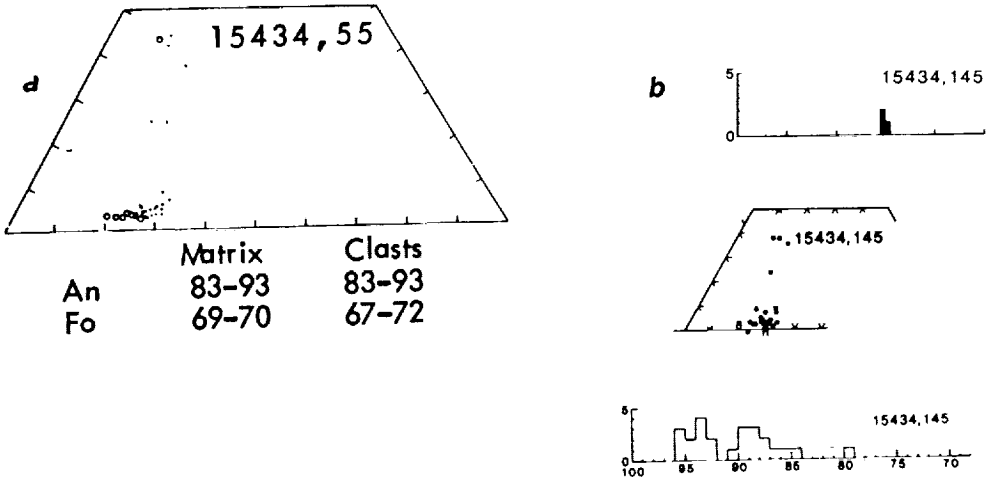


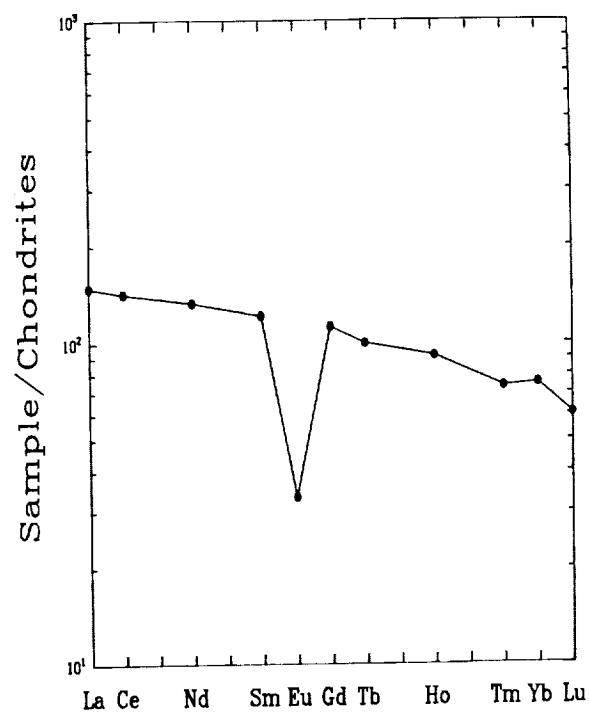
Fig. 68. Microprobe analyses of silicate minerals in 15434,15. a) Phinney et al. (1972) b) Laul et al. (1987); top is olivine; quadrilateral is pyroxene; bottom is plagioclase.

A bulk particle chemical analysis was made by Laul et al. (1987) (Table 20; Fig. 69). (Note a misprint in their Table 7: 15434,147 should read 15434,145, which is their designation for this particle. Their chemical split was 15434,177). The analysis shows a low-K Fra Mauro composition, rather like the Ryder and Spudis (1987) group B samples i.e. light rare earth elements at about 150 x chondrites. The analysis shows clear evidence for meteoritic contamination of the melt.

Table 20. Laul et al. (1987). 15434,15,177 (their designation is 15434,145). INAA. (21.3 mg)

	wt%
SiO_2	---
TiO_2	1.0
Al_2O_3	16.0
Cr_2O_3	0.271
FeO	9.6
MnO	0.127
MgO	11.8
CaO	10.4
Na_2O	0.57
K_2O	0.35
ppm	
Sc	20.0
V	50
Co	25.7
Ni	160
Sr	160
Ba	480
Zr	350
Hf	9.5
Ta	1.3
U	1.6
Th	6.05
La	49.0
Ce	125
Nd	80
Sm	22.0
Eu	2.3
Gd	28
Tb	4.7
Dy	30
Ho	6.4
Tm	2.2
Yb	15.0
Lu	2.05
ppb	
Au	2.0
Ir	5.0

Fig. 69. Chondrite-normalized plot of rare earth elements in 15434,15,177. Data of Laul et al. (1987) (their 15434,145).



15434,157 Fine-grained impact melt 1 particle ~0.17g (0.101g)

15434,157 is a fine-grained impact melt that has mainly plagioclase clasts. Laul et al. (1987) gave a mode of 52.3% plagioclase, 30.5% pyroxene, 12.6% olivine, 4.4% ilmenite, 0.2% sulfide, and traces of metal and spinel. They also provided microprobe analyses of silicates (Fig. 70), which show a wide range of plagioclase compositions but narrow ranges of olivine and pyroxene compositions. Laul et al. (1987) tabulated representative analyses of plagioclases, pyroxenes, and ilmenites. Laul et al. (1987) also made a bulk particle chemical analysis for major and trace elements (Table 21; Fig. 71); despite the rather ordinary mineralogy and major element analysis, the

incompatible trace elements are unusually low, displaying a negligible Eu anomaly. The sample has some meteoritic contamination.

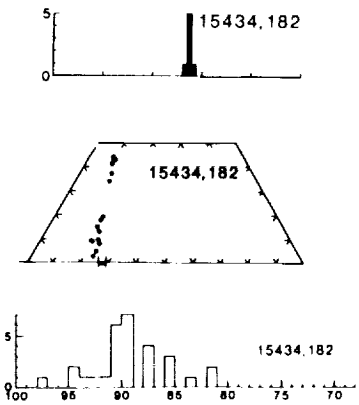


Fig. 70 Microprobe analyses of silicate minerals in 15434,157,182; olivine (top), pyroxene (quadrilateral), and plagioclase (bottom). Laul et al. (1987).

Table 21. Laul et al. (1987). 15434,157,164 (their ,182). INAA (33.3 mg)

wt%	
SiO_2	---
TiO_2	2.0
Al_2O_3	19.3
Cr_2O_3	0.141
FeO	7.90
MnO	0.104
MgO	11.1
CaO	11.6
Na_2O	0.64
K_2O	0.12
ppm	
Sc	18.0
V	30
Co	18.0
Ni	60
Sr	180
Ba	140
Zr	140
Hf	4.0
Ta	0.69
U	0.55
Th	2.20
La	11.0
Ce	27
Nd	18
Sm	5.10
Eu	1.70
Gd	6.8
Tb	1.20
Dy	7.6
Ho	1.9
Tm	0.73
Yb	4.7
Lu	0.71
ppb	
Au	<2
Ir	2.0

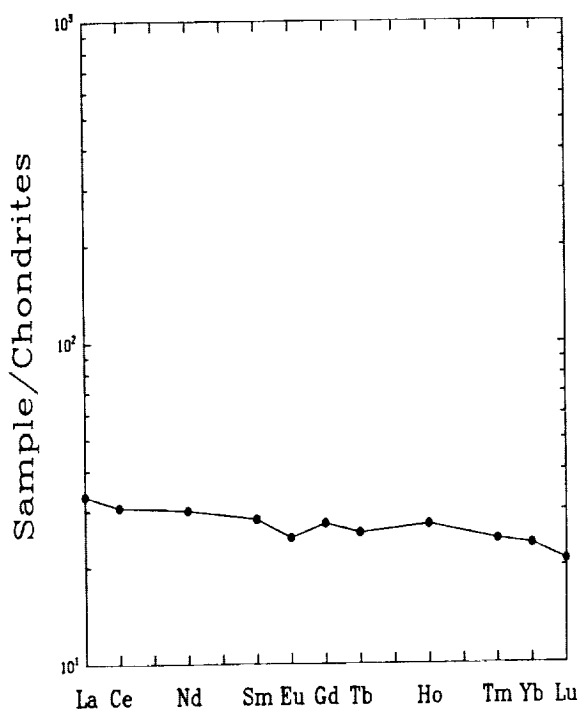


Fig. 71. Chondrite-normalized plot of rare earth elements in 15434,157,164 (their ,182). Data of Laul et al. (1987).

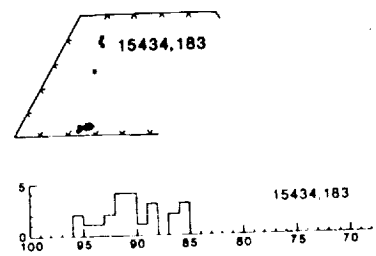
15434,158 Fine-grained impact melt 1 particle 0.109g (~0.16g)

15434,158 is a fine-grained impact melt that has mainly plagioclase clasts. Laul et al. (1987) gave a mode of 51.8% plagioclase, 46.8% pyroxene, 0.4% ilmenite, 0.1% sulfide, 0.4% metal, traces of spinel, and 0.5% of "other". There is apparently no olivine. They also provided microprobe analyses of silicates (Fig. 72) which show some range in plagioclases but little range in pyroxenes. They tabulated spinel and ilmenite analyses. Laul et al. (1987) also made a bulk particle chemical analysis for major and trace elements (Table 22; Fig. 73). The sample has a low-K Fra Mauro composition similar to group B of Ryder and Spudis (1987). The sample shows clear effects of meteoritic contamination.

Table 22. Laul et al. (1987). 15434,158,166 (their ,182). INAA (17.0 mg)

wt%	
SiO_2	---
TiO_2	0.91
Al_2O_3	16.8
Cr_2O_3	0.260
FeO	9.30
MnO	0.125
MgO	11.5
CaO	10.9
Na_2O	0.56
K_2O	0.35
ppm	
Sc	18.0
V	50
Co	47.0
Ni	420
Sr	160
Ba	460
Zr	410
Hf	11.0
Ta	1.4
U	1.6
Th	7.0
La	42.0
Ce	105
Nd	70
Sm	18.5
Eu	2.10
Gd	23
Tb	3.60
Dy	23
Ho	5.2
Tm	2.0
Yb	13.5
Lu	1.91
ppb	
Au	5.7
Ir	12

Fig. 72. Microprobe analyses of minerals in 15434,158,183; pyroxene (top) and plagioclase (bottom). Laul et al. (1987).



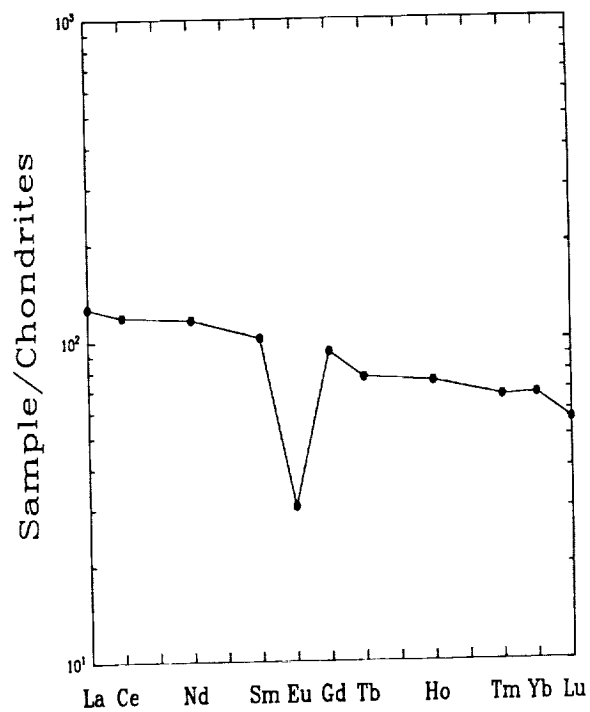


Fig. 73. Chondrite-normalized plot of rare earth elements in 15434,158,166 (their ,183). Data of Laul et al. (1987).

15434,159 Fine-grained impact melt 1 particle 0.027g (~0.06g)

15434,159 is a fine-grained impact melt that is rather clast-rich and has some adhering regolith breccia. Laul et al. (1987) gave a mode of 57.6% plagioclase, 36.3% pyroxene, 1.3% ilmenite, 0.3% sulfide, 0.3% spinel, 3.5% mesostasis, traces of Fe-metal, and 0.7% undefined "other". There is apparently no olivine. They also provided microprobe analyses of pyroxenes and plagioclases (Fig. 74), including listed representative analyses. These analyses show a wide range of plagioclase compositions but a narrow range of pyroxene compositions. Laul et al. (1987) noted that the plagioclase included more that is more sodic than An_{85} than most of the Apollo 15 impact melts that they analyzed. The pyroxene is also a much more Fe-pigeonite than common in the others.

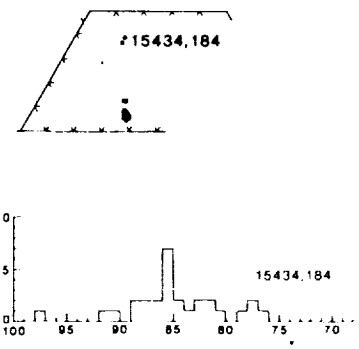


Fig. 74. Microprobe analyses of pyroxenes (top) and plagioclases (bottom) in 15434,159,184; Laul et al. (1987).

15434,160 Fine-grained impact melt 1 particle 0.197g (~0.32g)

15434,160 is a fine-grained impact melt that has a micropoikilitic texture and many plagioclase clasts, many of which reach several hundred microns across. Laul et al. (1987) gave a mode of 58.5% plagioclase, 28.2% pyroxene, 10.9% olivine, 2.4% ilmenite, and traces of sulfide. They also provided microprobe data for the silicates (Fig. 75), all of which show some range in compositions and not an equilibrium assemblage. Laul et al. (1987) tabulated representative compositions of olivines and ilmenite.

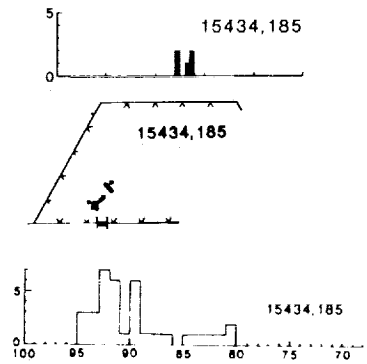


Fig. 75. Microprobe analyses of silicates in 15434,160,185; olivine (top), pyroxene (quadrilateral), and plagioclase (bottom). Laul et al. (1987).

Laul et al. (1987) also made a bulk particle analysis for major and trace elements (Table 23; Fig. 76). The analysis is the most feldspathic of those they analyzed, has very low rare-earth element abundances, and contains no recognizable meteoritic contamination despite its obvious impact origin. Laul et al. (1987) claim a small positive Eu anomaly.

Table 23. Laul et al. (1987).
15434,160,170 (their ,185).
INAA (16.9 mg)

wt%	
SiO_2	--
TiO_2	1.4
Al_2O_3	20.8
Cr_2O_3	0.152
FeO	7.10
MnO	0.09
MgO	10.0
CaO	12.4
Na_2O	0.69
K_2O	0.14

ppm	
Sc	15.0
V	30
Co	18.0
Ni	70
Sr	210
Ba	160
Zr	150
Hf	3.5
Ta	0.63
U	0.45
Th	1.90
La	10.0
Ce	25
Nd	17
Sm	4.70
Eu	1.90
Gd	6.4
Tb	1.00
Dy	6.8
Ho	1.5
Tm	0.64
Yb	4.00
Lu	0.60

ppb	
Au	<2
Ir	<2

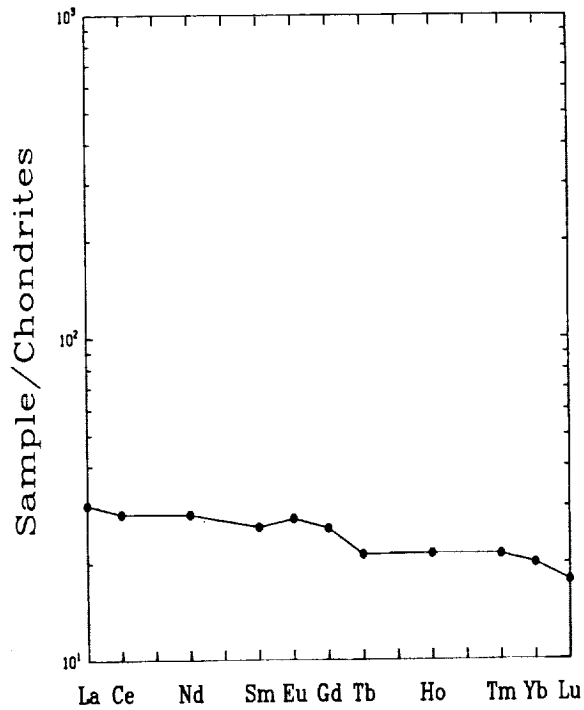
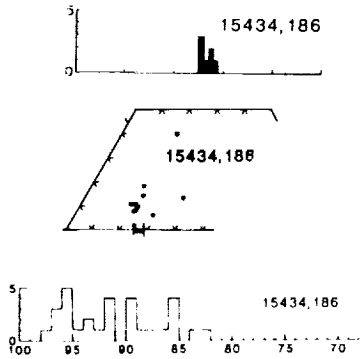


Fig. 76. Chondrite-normalized plot of rare earth elements in 15434,160,170 (their ,185). Data of Laul et al. (1987).

15434,161 Fine-grained impact melt 1 particle 0.076g (~0.13g)

15434,161 is a very fine-grained impact melt. The thin section shows one zone of much more feldspathic material, hence it is not homogeneous. Most of the clasts are small plagioclases (less than 100 microns). Laul et al. (1987) gave a mode of 49.7% plagioclase, 26.3% pyroxene, 21.6% olivine, 2.2% ilmenite, and 0.2% lithic clasts. They also provided microprobe analyses of the silicate minerals (Fig. 77); they show a wide range of calcic plagioclases and some pyroxenes substantially more Fe-rich than most of the others. The olivine has a more restricted range.

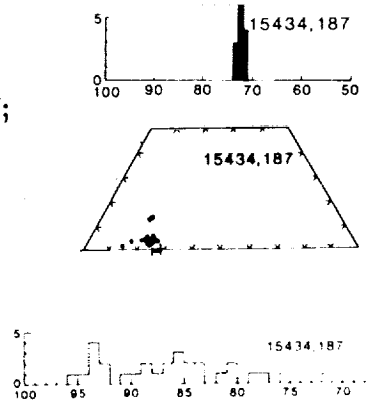
Fig. 77 Microprobe analyses of silicate minerals in 15434,161,186; olivine (top), pyroxene (quadrilateral), and plagioclase (bottom). Laul et al. (1987).



15434,162 Fine-grained impact melt 1 particle 0.190g (~0.25g)

15434,162 is a very fine-grained impact melt that appears homogeneous; it contains only small clasts (less than 100 microns). Most of the clasts are plagioclases. Laul et al. (1987) gave a mode of 42.3% plagioclase, 35.1% pyroxene, 21.0% olivine, 1.3% ilmenite, 0.3% metal, and a trace of spinel. They provided microprobe analyses of the silicate minerals (Fig. 78), including two tabulated representative olivine analyses. The plagioclases and pyroxenes show a wide range, the olivines a rather restricted range. They also tabulated two spinel analyses.

Fig. 78. Microprobe analyses of silicate minerals in 15434,162,187; olivine (top), pyroxene (quadrilateral) and plagioclases (bottom). Laul et al. (1987).



Laul et al. (1987) reported an analysis for major and trace elements for a bulk particle sample (Table 24; Fig. 79). The analysis is low in alumina and high in magnesia, consistent with its olivine-rich mode, and with rare earth element abundances similar to those of the low-K Fra Mauro group B of Ryder and Spudis (1987) (Fig. 79). The sample has a definite meteoritic component.

Table 24. Laul et al. (1987)
15434,162,174 (their ,187).
INAA (16.8 mg)

wt%	
SiO_2	--
TiO_2	1.1
Al_2O_3	12.9
Cr_2O_3	0.275
FeO	11.2
MnO	0.15
MgO	15.7
CaO	8.2
Na_2O	0.58
K_2O	0.094

ppm	
Sc	19.0
V	50
Co	35.0
Ni	360
Sr	120
Ba	400
Zr	420
Hf	12.5
Ta	1.7
U	1.8
Th	7.20
La	43.0
Ce	110
Nd	70
Sm	19.5
Eu	1.75
Gd	24
Tb	3.90
Dy	25
Ho	5.9
Tm	2.0
Yb	13.1
Lu	1.95

ppb	
Au	6.9
Ir	4.7

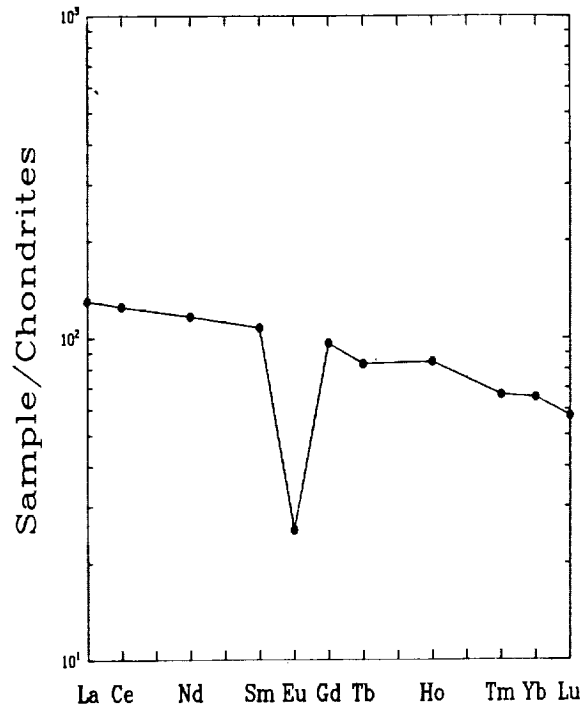


Fig. 79. Chondrite-normalized plot of rare earth elements in 15434, 162,174 (their ,187). Laul et al. (1987).

15434,6	Gabbro (mare affinity) ?	1 particle	0.11g

15434,6	Gabbro (mare affinity) ?	1 particle	0.11g

Powell described this particle as a tough subangular gabbro (Fig. 80). It is brown speckled, holocrystalline, and equigranular, with a mean grain size of about 1 mm. Powell recognized tabular subhedral white plagioclases and cinnamon brown clinopyroxene as major phases. A yellow-brown mineral that Powell identified as probably another clinopyroxene is also present, and possiblly yellow olivine (less than 5%). The opaque mineral content is low, and the plagioclase: pyroxene ratio is about 1:2. Although Powell suggested this was a mare rock, it is possible that this small particle is a KREEP basalt. It has never been allocated, but has partly disintegrated.

Fig. 80. Macroscopic view of 15434,6 before it partly disintegrated during processing. Scale is in millimeters. S-72-59932.

15434,7 Fine-grained impact and volcanic melts 17 particles 1.52g (3.63g)

Powell described these particles as crystalline rocks (fine-grained basalt?) whose identity was not completely certain. The grain-sizes approach the limits of resolution of the binocular microscope, and in some a granularity is visible. Of the three which have been studied, one is a KREEP basalt, one is a brown devitrified glass, and one is an unusual mafic impact melt.

Powell noted that many of the particles possessed a small number of vesicles. The luster on fresh broken surfaces is dull, not vitreous, suggesting fine-grained basalts. The fragments are tough, angular to subangular, and dark to medium gray (Fig. 81). Four of the particles were separated as 15434,19 but the reason for this distinction was not recorded. Four other fragments were given individual numbers. Another particle was used to produce 15434,94, but the parent particle apparently remains one of those in 15434,7 and there is no processing documentation.

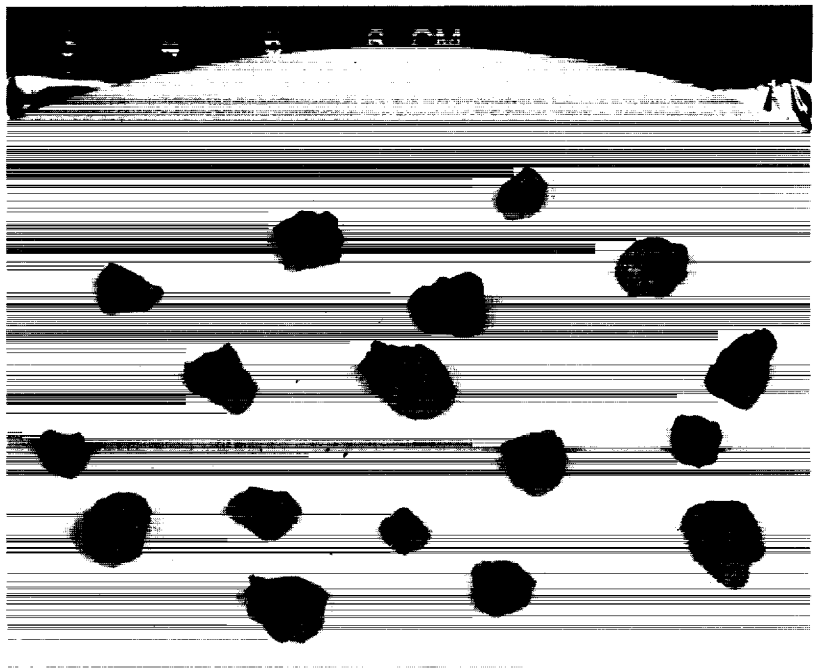


Fig. 81. 15434,7 prior to any subdivisions being made. S-72-15176

15434,20 Fine-grained crystalline rock 1 particle 0.07g

15434,20 was a small particle that was never allocated, hence little is known about it. It appears to be vesicular or otherwise pitted (Fig. 82).

Fig. 82. 15434,20
S-72-33630

15434,21 is a fine-grained volcanic Apollo 15 KREEP basalt with residual quenched yellow glass. The particle was extensively subdivided for study (Fig. 83), despite its small size, and no pristine material now remains. Unusually, two of the chips were consumed for thin sections.

Fig. 83. Initial subdivision of 15434,21. S-72-33638

The thin sections show a fine-grained basalt with skeletal plagioclase laths, hollow pyroxenes, residual yellow glass, and some opaque material (Fig. 84). In detail, the yellow glass can be seen to have intruded and cut silicates prior to quenching (Ryder, 1988). The particle is almost entirely surrounded by adhering regolith breccia.

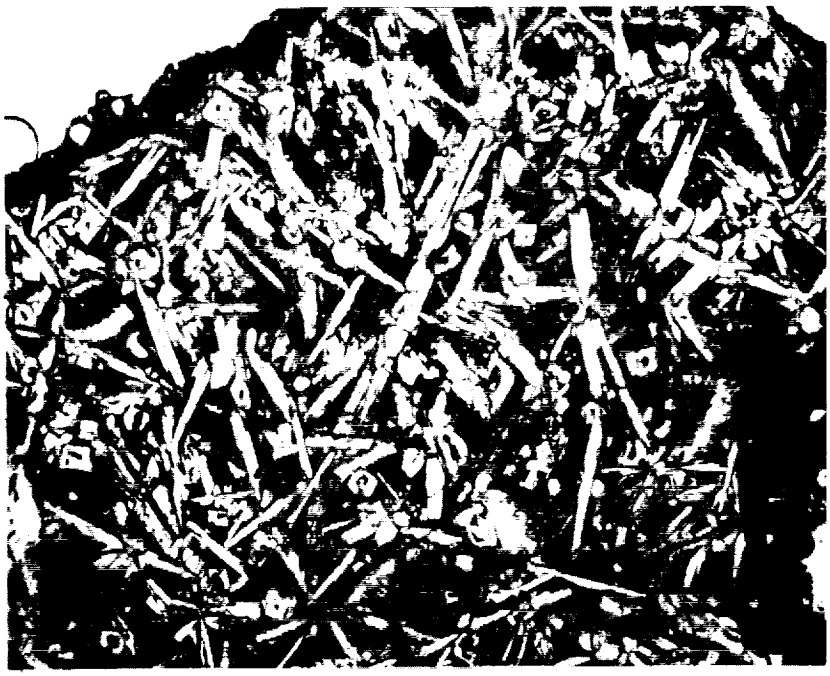


Fig. 84. Photomicrograph of 15434,21,78 (compounded on 15999,96). Plane light; field of view about 2 mm across.

Phinney et al. (1972) and Simonds et al. (1975) included the particle in their Apollo 15 KREEP basalts. Phinney et al. (1972) included it in their partial melting model for these basalts with this particular particle not much melted: "...show further decrease in the extent of the Fe and Na enrichment trends of pyroxene and plagioclase respectively....". They gave an analysis of the yellow glass, similar to that of Ryder (1988) (Table 25). Some of the Fe-rich glass analyzed by Hollister and Crawford (1977) is similar to these analyses, but not all. Simonds et al. (1987) referred to the basalt as intersertal, with 14% mesostasis glass, 41% plagioclase, and 38% pyroxene. They

gave a grain size for plagioclases of 100 to 300 microns. The mode of Simonds et al. (1975) differs substantially from that of Crawford and Hollister (1977) and Hollister and Crawford (1977) who gave 22.0% plagioclase, 35.4% pyroxene, 7.2% opaque material, 3.5% matrix minerals, and 31.8% glass.

Table 25. Microprobe analyses of residual yellow glass in 15434,21. A = Phinney et al. (1972); B = Ryder (1988)

	A	B
wt%		
SiO_2	47.82	46.4
TiO_2	4.60	5.3
Al_2O_3	9.66	9.2
Cr_2O_3	0.09	0.11
FeO	18.59	18.1
MnO	--	0.25
MgO	4.18	3.7
CaO	10.27	10.9
Na_2O	0.44	0.43
K_2O	1.20	1.2
P_2O_5	2.68	2.7
ZrO_2	0.42	--
Sum	100.0	98.3

Crawford and Hollister (1977) described the crystallization history and depicted the hollow pyroxenes, the skeletal plagioclases, and the glassy groundmass, all suggestive of very rapid crystallization (quenching). They noted that the matrix contains crystallites of plagioclase, ilmenite, crystalline SiO_2, FeS, zircon, and whitlockite. They interpreted features of the glass as immiscible. These were described in more detail by Hollister and Crawford (1977), with microprobe analyses of glasses. Crawford and Hollister (1977) diagrammed compositions of plagioclases. They stated that 15434,66 lacks orthopyroxene, but this is incorrect; the pyroxene cores do include orthopyroxenes. Hollister and Crawford (1977) described the chemistry and occurrence of features they interpreted as immiscible liquids in 15434,66; however, it is not at all clear that the residual liquid went immiscible in this sample (Ryder, unpublished data). Hollister and Crawford (1977) claim that immiscibility took place after no more than 58% crystallization of the sample.

Ryder (unpublished) made microprobe analyses of pyroxenes, plagioclases, and glasses in the sample. The data show typical Apollo 15 KREEP basalt mineral compositions, with orthopyroxene cores showing a maximum Mg/(Mg+Fe) of 0.81, with more than 3% Al_2O_3 in the cores. However, the most sodic plagioclases and iron-rich pyroxenes present in other samples are not present, because of the late quenching.

Ryder (1988) described the sample as mildly disrupted by impact during crystallization. The impact forced the residual yellow glass to move over distances of millimeters, intrude impact-induced fractures in the silicates, and then quench.

An analysis for major elements for a bulk particle sample was made by Powell (unpublished) (Table 26), and a trace element analysis was made by Helmke et al. (1973) (Table 26, Fig. 85). The analyses are consistent with the sample being an Apollo 15 volcanic KREEP basalt. The rare earth element abundances among the highest for this basalt type. The meteoritic elements were not analyzed, with the exception of Co which is higher than most Apollo 15 KREEP basalts. So is the Sc, and it appears that the sample analyzed was probably contaminated with regolith, which is visible surrounding the particle in the thin section.

Table 26. A = Powell (unpublished) microprobe fused bead. B = Helmke et al. (1973). RNAA (33 mg)

wt%	A	B
SiO_2	52.14	
TiO_2	2.23	
Al_2O_3	16.16	
Cr_2O_3	0.36	
FeO	10.82	
MnO	0.17	
MgO	7.84	
CaO	9.67	
Na_2O	0.64	
K_2O	0.61	
P_2O_5	0.71	
Ni	<0.04	
Sum	101.4	
ppm		
Sc		38.7
Co		36
Hf		40
La		90
Ce		228
Nd		150
Sm		40.4
Eu		3.00
Gd		48
Tb		7.9
Dy		51.7
Ho		11
Er		27
Yb		27.2
Lu		4.12

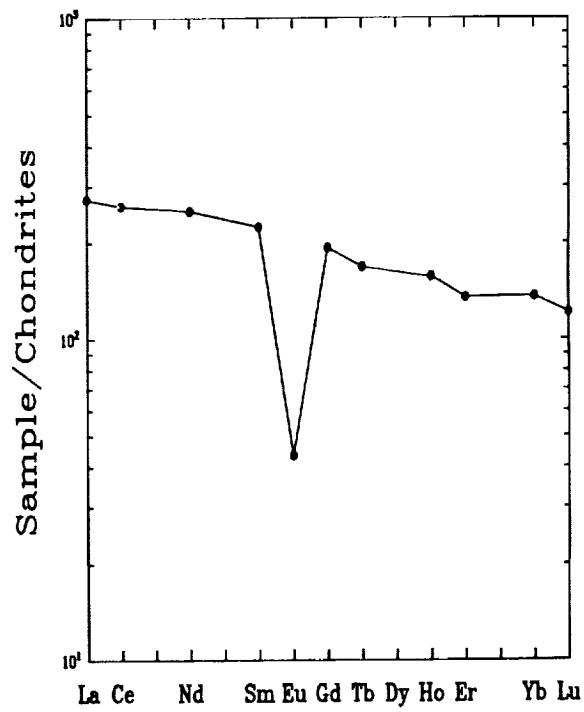


Fig. 85. Chondrite-normalized plot of rare earth elements in 15434,21,67. Data of Helmke et al. (1973).

15434,22 Impact glass with inclusions 1 particle 0.33g (0.38g)

15434,22 is a tough dense particle that was partly subdivided for study (Fig. 86), although no data has been published. It is a brown vesicular glass that contains inclusions, and it is partly devitrified (Fig. 87). It is evidently of impact origin.

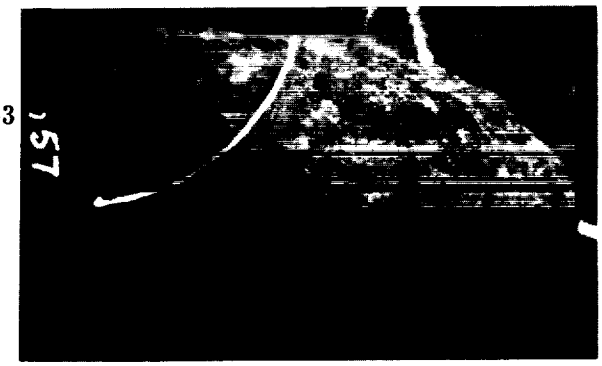


Fig. 86. Original splitting plan for 15434,22. Only a chip for thin sections was produced. S-72-32963

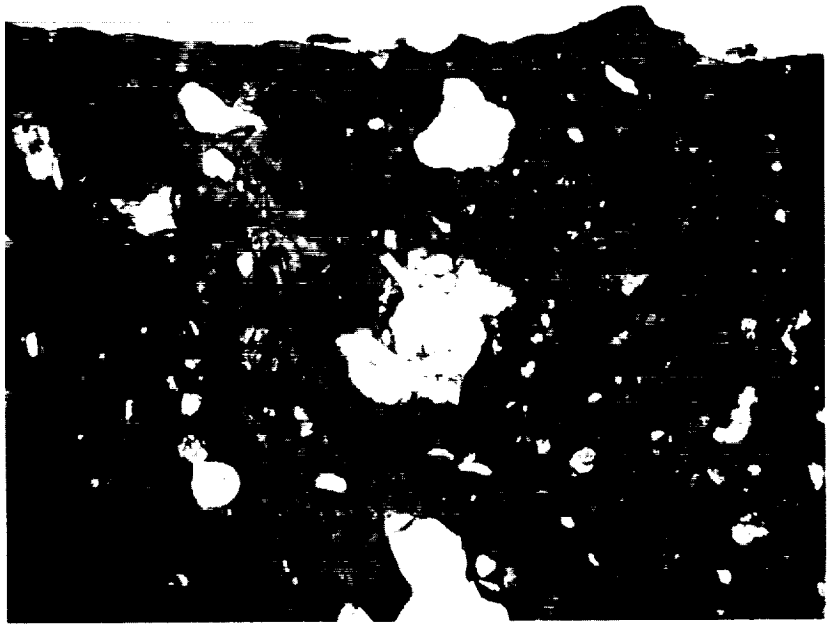
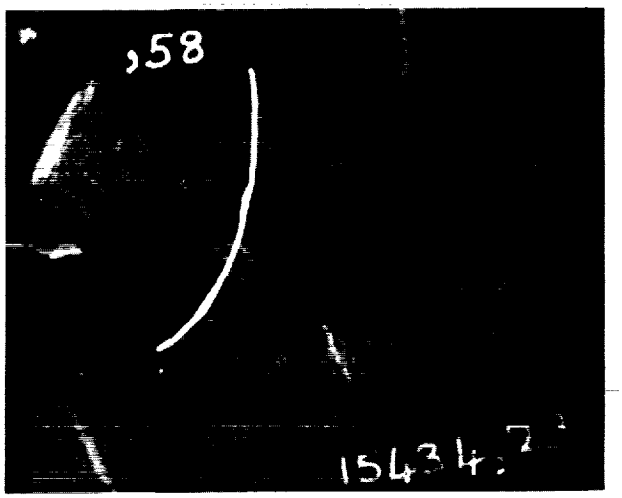


Fig. 87. Photomicrograph of 15434,22,148. Plane light; field of view is about 2 mm across.

15434,23	Clast-free impact melt	1 particle	0.195g	(0.33g)

15434,23 is a clast-free impact melt with an unusual quench texture and a magnesian low-K Fra Mauro composition. Laths and some vugs or vesicles are visible macrosopically (Fig. 88). The thin sections show a crystallized melt that is fairly mafic, with elongated crystals (Fig. 89) and interstitial glass or cryptocrystalline material. The cores of the laths are olivines that are up to at least 4 mm long (the size of the sections). Some of the laths occur in parallel groups (as in barred chondrules); others radiate from a common point. They are overgrown with pyroxenes and hollow plagioclase laths. The opaque interstitial material consists of pyroxenes and glass with saw-tooth-like ilmenite needles. Neither of the two thin sections contains any inclusions, and the interpretation of the sample as an impact melt rather than a volcanic one depends on its chemistry, particularly the meteoritic siderophiles abundances (below).

Fig. 88 Original splitting plan for 15434,23. Another chip was later removed. S-72-32978



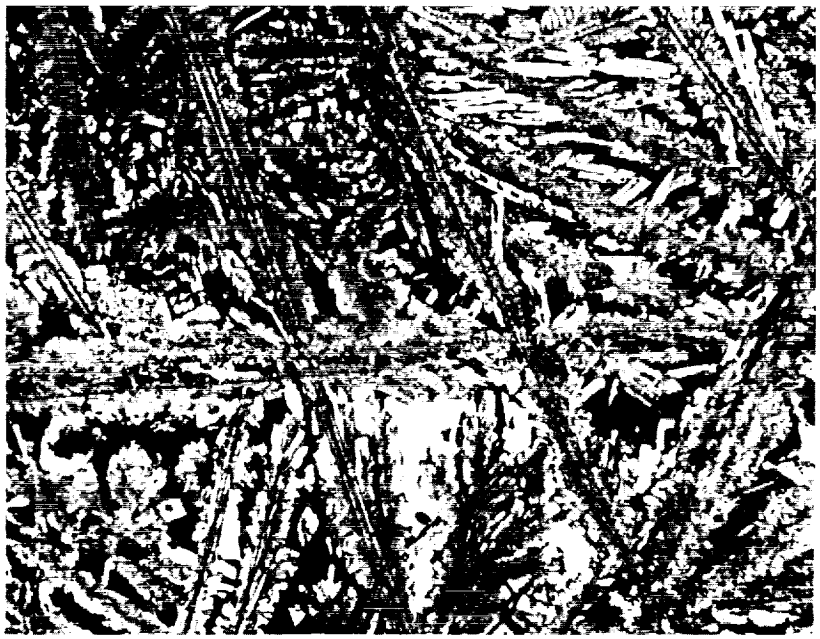


Fig. 89. Photomicrograph of 15434,23,150. Plane light; field of view is about 2 mm across. Narrow cores of laths are olivines.

Two analyses of a single powder for major and trace elements were made for a bulk particle split by Ryder (unpublished) (Table 27, Fig. 90). The analyses show that the sample has a magnesian low-K Fra Mauro composition, with light rare earths about 75 x chondrites. This composition is almost identical with the compositions of the melt phase of the large rocks 15445 and 15455. The sample is clearly contaminated with meteoritic material.

Table 27 Ryder (unpublished) 15434,23,180. Microprobe fused bead (FB) and INAA. (75 mg homogenized. INAA, A= ~30 mg, B = 3.8 mg)

		A	B
wt% (FB except as noted)			
SiO_2		45.7	46.1
TiO_2		1.21	1.32
Al_2O_3		17.7	18.0
Cr_2O_3		--	0.20
Cr_2O_3	(INAA)	0.17	0.20
FeO		8.3	8.1
FeO	(INAA)	9.0	8.8
MnO		0.06	0.11
MgO		15.8	16.5
CaO		10.3	10.5
CaO	(INAA)	--	10.7
Na_2O		0.32	0.34
Na_2O	(INAA)	0.372	0.360
K_2O		--	0.13
K_2O	(INAA)	--	0.10
P_2O_5		0.17	0.10
Sum FB		99.6	101.4
ppm (INAA)			
Sc		14.1	15.0
Co		46.6	52.9
Ni		440	470
Sr		110	148
Rb		--	7
Cs		0.24	0.23
Ba		273	287
Zr		301	346
Hf		8.3	10.0
Ta		1.1	1.1
U		1.35	0.84
Th		3.6	4.3
La		25.9	28.0
Ce		67	72
Nd		40	42
Sm		12.4	13.2
Eu		1.71	1.76
Tb		2.5	2.3
Yb		7.9	8.7
Lu		1.17	1.12
ppb (INAA)			
Au		--	7
Ir		--	9

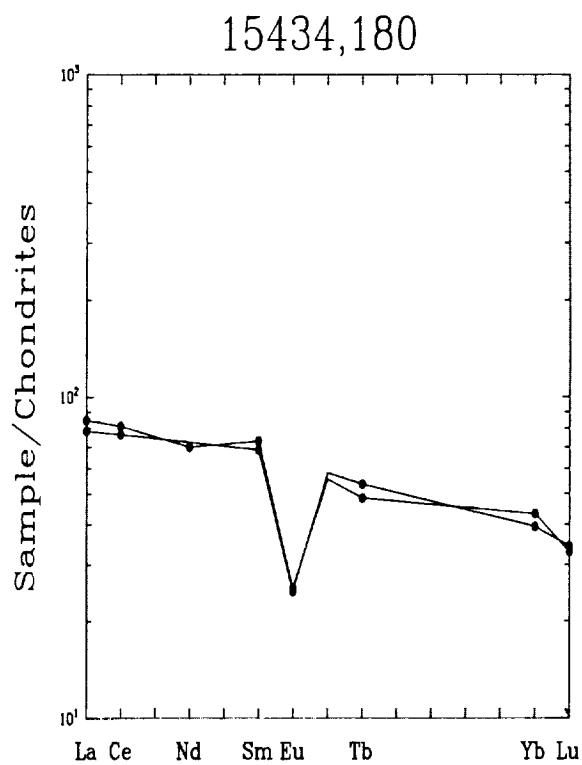


Fig. 90. Chondrite-normalized plot of rare earth elements in 15434,23,180. Data of Ryder (unpublished).

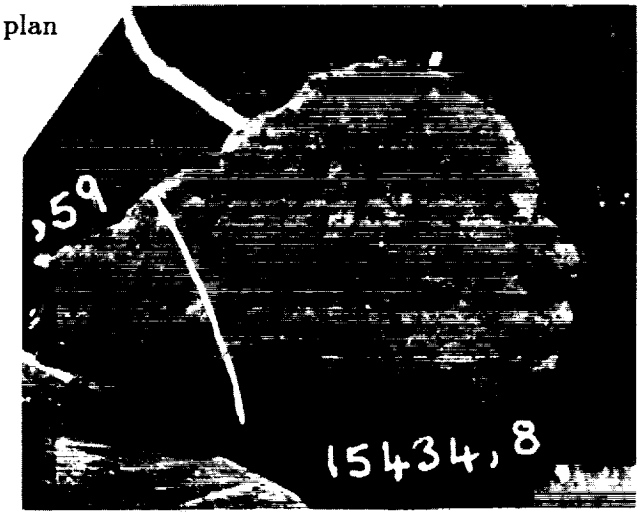
15434,94 Crystalline rock 1 particle 0.02g

A small chip was taken from 15434,7 and allocated; there is no processing documentation. It might be an entire small particle or a chip of a larger one that remains in 15434,7.

15434,8 Orthopyroxene-porphyritic KREEP basalt 1 particle 0.148g (0.32g)

15434,8 is a group of only one particle. Powell described the particle as a tough non-mare crystalline rock that had a high olivine content; in fact the "olivine" is orthopyroxene that forms phenocrysts in an Apollo 15 KREEP basalt. The particle is macroscopically similar to those in 15434,5 except for the greenish-yellow mineral that constitutes 20 to 30% of the mode. The particle is light yellowish gray and subrounded (Fig. 91).

Fig. 91. Original cutting plan for 15434,8. S-72-32938



15434,8 Orthopyroxene-porphyritic KREEP basalt 1 particle 0.148g (0.32g)

15434,8 was described and depicted by Ryder (1987) and Simon et al. (1987). It is unique in containing orthopyroxene phenocrysts set in a fine-grained intersertal groundmass (Fig. 92; also see Ryder, 1987, Fig. 2a,b). The orthopyroxene phenocrysts are up to 2 mm long and subhedral, and lack significant optical zoning. The thin section contains about 30% phenocrysts. The intersertal groundmass has acicular plagioclases (less than 200 microns long) with pigeonite, and some augite, cristobalite, and abundant interstitial glass. The latter contains examples of silicate liquid immiscibility. Ryder (1987) interpreted the textures as resulting from two-stage cooling of a cotectic melt, with some orthopyroxene accumulation.

Table 28. Simon et al. (1987). 15434,8,156 (their ,181). INAA (30.9 mg)

wt%	
SiO_2	--
TiO_2	1.9
Al_2O_3	14.6
Cr_2O_3	0.350
FeO	10.4
MnO	0.150
MgO	8.8
CaO	9.0
Na_2O	0.81
K_2O	0.56

ppm	
Sc	21.2
V	60
Co	19.0
Ni	<20
Sr	180
Ba	780
Zr	980
Hf	23.9
Ta	2.9
U	3.5
Th	12.8
La	74.0
Ce	190
Nd	110
Sm	33.0
Eu	2.70
Gd	40
Tb	6.50
Dy	42
Ho	9.1
Tm	3.4
Yb	21.8
Lu	3.20

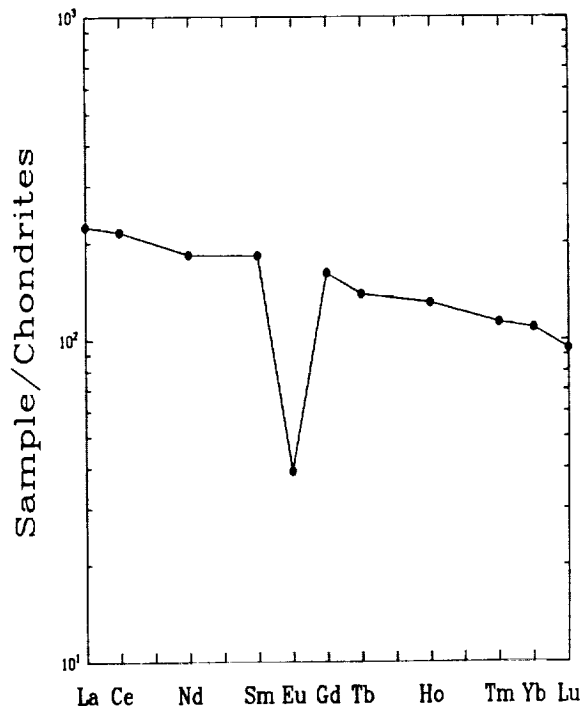


Fig. 94. Chondrite-normalized plot of rare earth elements in 15434,8,156 (their ,181). Data of Laul et al. (1987).

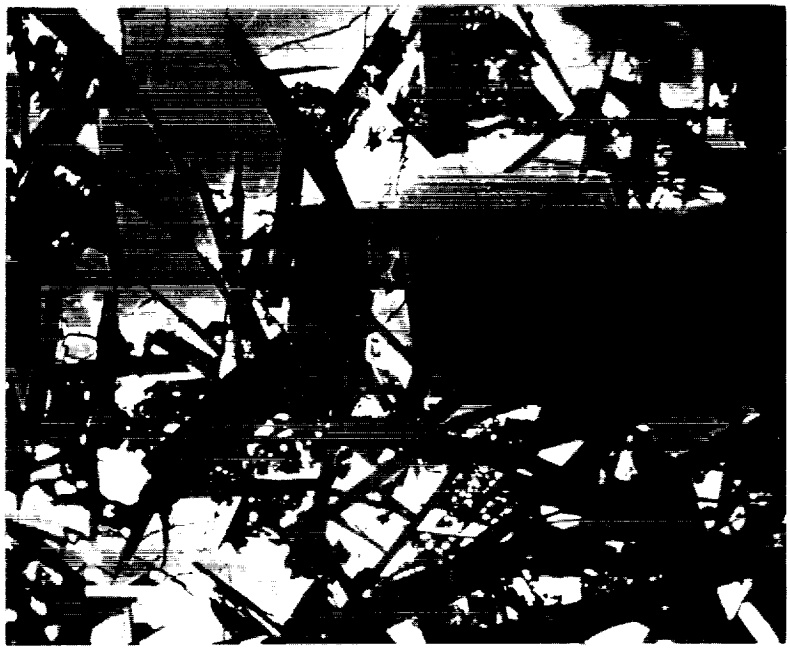


Fig. 92. Backscattered electron microprobe image of a small part of 15434,8,188. Scale bar is 100 microns. Dark gray laths are plagioclases, medium gray areas are ends of orthopyroxene phenocrysts, pale gray and white areas are evolved pyroxenes, and white/black speckled areas are mesostasis patches.

Simon et al. (1987) gave a mode of 41.7% plagioclase, 41.1% pyroxene, 13.7% mesostasis, 1.8% cristobalite, 1.5% ilmenite, 0.2% sulfide, and traces of metal. They also made microprobe analyses, diagramming those for plagioclase (Fig. 93) and tabulating 3 pyroxene, two plagioclase, and two whitlockite analyses. Their data and that of Ryder (unpublished) show the identity with other Apollo 15 KREEP basalt fragments. The orthopyroxene cores are among the most magnesian for this group of basalts [max Mg/(Mg+Fe) = 0.84].

Fig. 93. Microprobe analyses of plagioclases in 15434,8,181. Simon et al. (1987).

An analysis for major and trace elements was made by Simon et al. (1987) (Table 28, Fig. 94). The analysis shows an average to primitive member of the Apollo 15 KREEP basalt series, lacking meteoritic siderophiles. The analysis does not suggest any great accumulation of orthopyroxene.

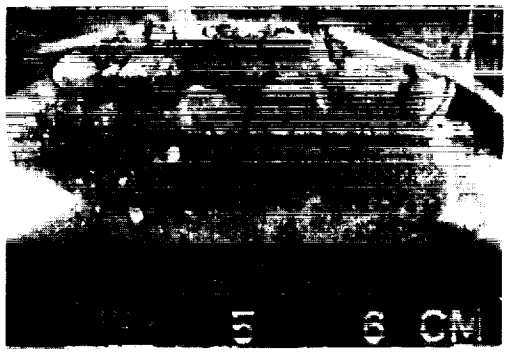
15474 Station 4 4.7g

Group	Individual particles	Subsamples	Thin Sections/ Probe mounts
,0 (1.26g)			
,1 (2.635g)	,11 (ES, Powell)	,21 (CONS, Powell)	,19 (15999,95) ,20 (15999,99)
	,12 (0.033g, RSV)		
	,16 (0.03g)		
,2 (0.13g, RSV)	,2 (0.13g, RSV)		
	,13 (0.104g Wasserburg)		
,3 (0.14g)	,3 (0.14g)		
,4 (0.089g)	,4 (0.089g)	,14 (ES, Powell)	,22 (15999,96) ,23 (15999,99)
		,24 (CONS, Powell)	
		,15 (0.03g, RSV)	
		,18 (0.02g, Turner)	

15474,0 Fines and undescribed particles 1.26g

15474,0 consists of degraded fines with some small particles (Fig. 1) of uncertain affinity. Some appear to be glassy or glass-coated; others may be crystalline.

Fig. 1 15474,0
S-72-15967



15474,1 Olivine-normative mare basalts+ 7 particles 2.635g (2.91g)

Powell described these seven particles as olivine diabases (Figs. 2,3) that were essentially similar to those of 15074,1 (of which the only one studied appears to be a quartz-normative basalt). One of the particles in 15474,1 is 2.5 cm long. The only particle in 15474,1 that has been studied is an olivine-normative mare basalt.

Fig. 2 Original seven particles of 15474,1. S-72-15489

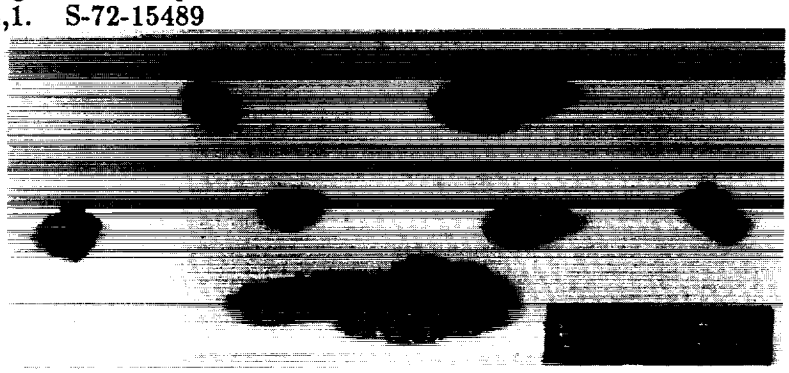
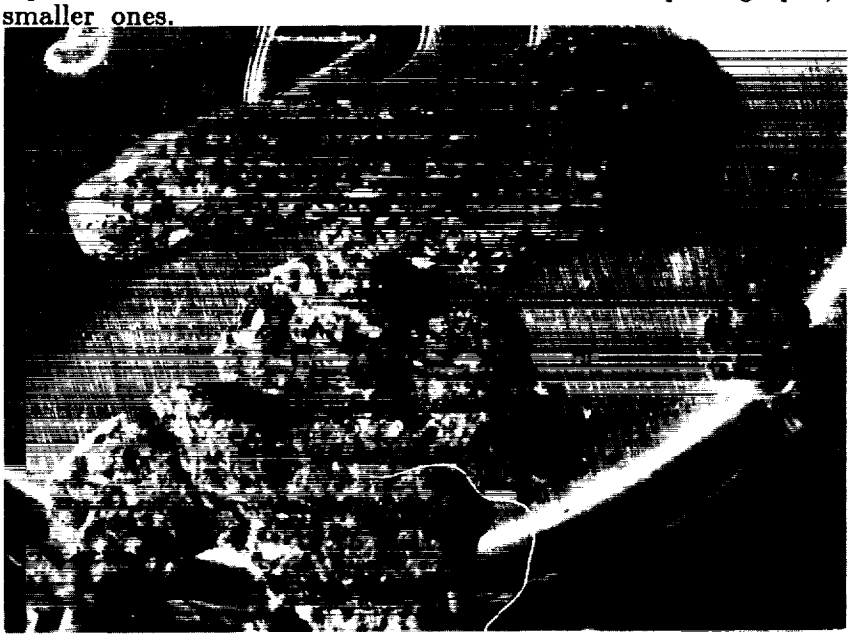


Fig. 3 15474,1 after removal of particle 15474,11. Later, one other small particle was removed (,12) and another partly removed (,16). None of these processed particles were identified in the documentation photographs, but they are the smaller ones.



15474,11 Olivine-normative mare basalt 1 particle 0.0g (0.195g)

15474,11 (Fig. 4) is an olivine-normative mare basalt. It was included by Powell et al. (1973) in their group III (olivine-cristobalite) mare basalts. They showed a photomicrograph, but gave no other specific description. They included a major element chemical analysis of the particle (microprobe fused bead) in an average for group III (the average is unusually silica rich for this group and is quartz-normative). The sample is medium- to coarse-grained (Fig. 5) and has large pyroxenes; olivine is not well-developed. The cristobalite forms conspicuous interstitial grains. The residue also contains fayalite and high-Si/high K glass.

Fig. 4 15474,11 prior to chipping. S-72-33625.

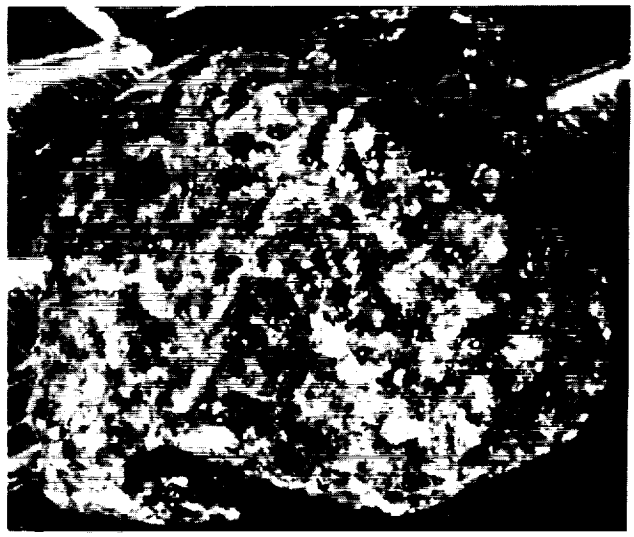
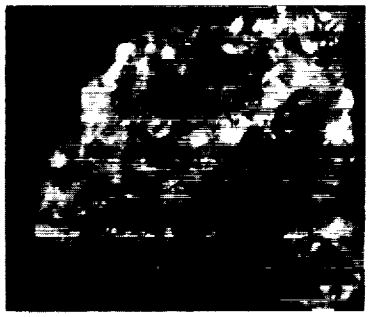


Fig. 5 Photomicrograph of 15474,11,19 (15999,95). Plane light; field of view is about 2 mm wide. Larger grains to right are pyroxenes; cristobalite is conspicuous.

15474,12	Mare basalt	1 particle	0.033g

One small particle was removed from 15474,1 (Fig. 6) and allocated; it was returned unstudied. It appears to be a mare basalt.

Fig. 6 15474,12 S-72-33602



15474,16	Mare basalt(?)	1 particle	0.03g

An unidentified particle from 15474,1 was either chipped or removed to produce 15474,16. There is no documentation of this processing. The chip was allocated but returned unstudied.

15474,2	Anorthosites(?) or feldspathic breccias	2 particles	0.13g (0.24g)

Powell described these two particles (Fig. 7) as "anorthosite", macroscopically similar to those in 15314,11 (which were anorthositic lithologies). One of them is essentially 100% anorthosite; the other has about 5% light gray pyroxene plus opaques.

Fig. 7 15474,2 prior to separation of one of the particles as ,13. S-72-15490

15474,2	Anorthosite(?)	1 particle	0.13g

With the removal of 15474,13, the remainder of 15474,2 became a single particle by default. It appears to be the less pure of the two particles (Fig. 8). It has never been allocated.

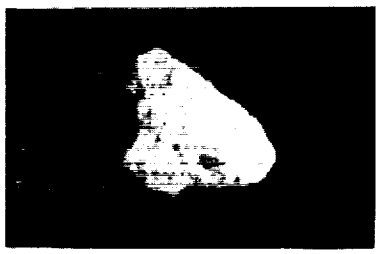


Fig. 8 15474,2 S-72-33631

15474,13	Anorthosite(?)	1 particle	0.104g

15474,13, (Fig. 9), apparently the purer feldspathic of the two particles of 15474,2, was allocated, but no data have been reported for it.

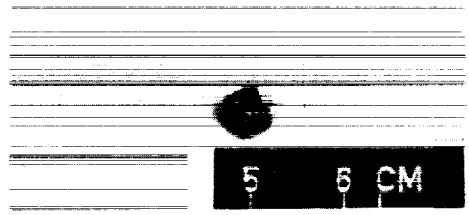
Fig. 9 15474,13 S-72-15491

15474,3	Recrystallized regolith breccia(?)	1 particle	0.14g

15474,3	Recrystallized regolith breccia(?)	1 particle	0.14g

Powell described 15474,3 as a recrystallized microbreccia (Fig. 10) that is essentially similar to those of 15244,4 (which were never allocated). It is probably a coherent regolith breccia or some other type of crystalline breccia such as an impact melt.

Fig. 10 15474,3
S-72-15491



15474,4	Olivine-augite vitrophyre mare basalt	1 particle	0.089g (0.18g)

Powell described this single particle as a tough, porphyritic olivine basalt (?) that was subangular and dark gray (Fig. 11). It has orange-yellow phenocrysts that he suggested were olivines, and a dark matrix that was too fine-grained for identification of phases. The sample is a vitrophyric basalt with olivine and augite phenocrysts. It was subdivided (Fig. 12)

Fig. 11 15474,4 prior to processing. S-72-15492

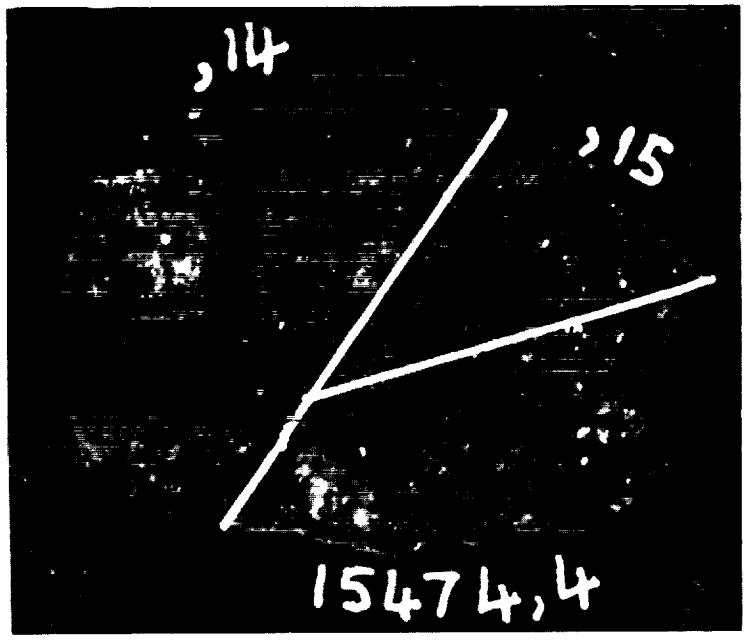


Fig. 12 Original splitting plan for 15474,4. S-72-33642

15474,4 Olivine-augite vitrophyre mare basalt 1 particle 0.089g (0.18g)

Powell et al. (1973) described the particle (stated in their text as 15484,14 instead of 15474,14) as an olivine-pyroxene vitrophyre that was the only particle in their mare basalt V group; they also showed a photmicrograph. The particle appears to be unique among Apollo 15 coarse fines and rocks. It was distinguished by the abundance of olivine phenocrysts (Fig. 13), which are up to 1 mm, euhedral to subhedral, partly resorbed, and zoned (Fo_{55-38}). The sample also contains skeletal pleochroic pink "totem pole" augite phenocrysts. The groundmass is dark and glassy, and partly devitrified. Accessory oxides include chromite (in the olivine), and ulvospinel microphenocrysts. Powell et al. (1973) gave a modal analysis of 21.5% olivine, 31% pyroxene, 0.5% oxides, and 47% glass (= glass+ultrafine crystalline material). Fe metal and troilite are each less than 1%. Powell et al. (1973) reported that the pyroxenes are unusually rich in calcium ($Wo_{46}En_{25}$), titanium (TiO_2 3.1%) and alumina (Al_2O_3 6.8%).

Fig. 13 Photomicrograph of 15474,4,23 (15999,99). Plane light; field of view is about 2 mm wide. Larger crystals are olivines; elongated "totem poles" are augites.

Powell et al. (1973) gave a bulk analysis for the major elements made from microprobe fused bead technique (Table 1). The analysis confirms that the sample is a mare basalt, but is quartz-normative (there is perhaps some systematic error in the Powell et al. (1973) analyses, because the average for particles independently identified as olivine-normative basalts is also quartz-normative).

Table 1. Powell et al. (1973) 15474,4,14 Microprobe fused bead.

wt%	
SiO_2	46.42
TiO_2	2.12
Al_2O_3	8.47
Cr_2O_3	0.59
FeO	22.06
MnO	0.31
MgO	9.52
CaO	9.55
Na_2O	0.01
K_2O	0.04
P_2O_5	0.17
NiO	0.00
Sum	99.6

15504 Station 9 4.1g

Groups	Individual Particles	Subsamples	Thin sections/ Probe mounts
,0 (0.53g)			
,2 (3.6g)			

15504,0 Fines and undescribed particles 0.53g

15504,0 consists of degraded fines and some dust-covered undescribed particles of unknown affinity (Fig. 1).

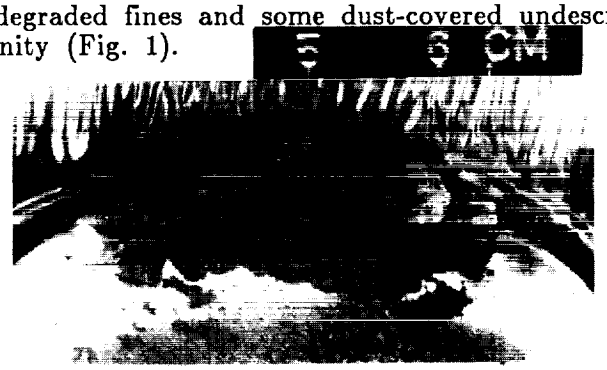


Fig. 1 15504,0
S-72-15964

15504,1 Regolith breccias 11 particles 3.60g

Powell described these particles (Fig. 2) as microbreccias similar to those in 15244,2 and 15244,6. They appear to be a varied mixture of friable to coherent regolith breccias, some of which have glass in or on them.

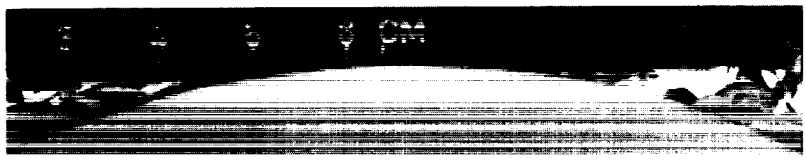
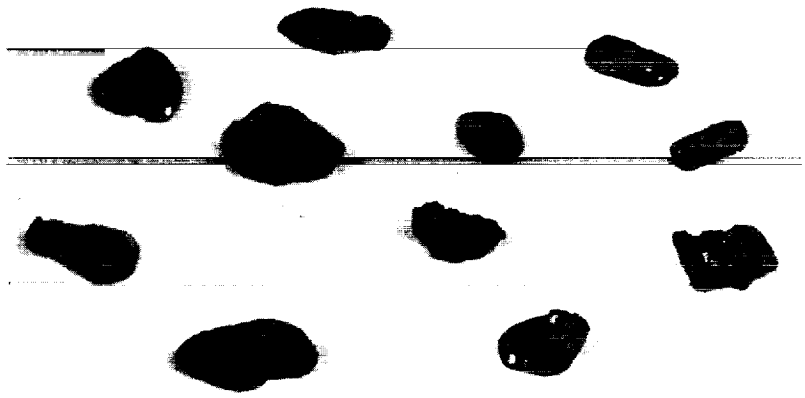


Fig. 2 15504,1
S-72-15493



15514 Station 9 1.1g

Group	Individual particles	Subsamples	Thin sections/ Probe mounts
,0 (0.22g)			
,1 (0.13g)	,1 (0.13g)		
,2 (0.33g)	,2 (0.33g)		
,3 (0.019g)	,3 (0.019g)	,11 (ES, Powell)	,14 (15999,96)
		,16 (CONS, Powell)	
		,15 (CONS, 15999,99)	
		,12 (0.029g, RSV)	
		,13 (0.02g, Turner)	
,4 (0.16g)	,4 (0.16g)		

15514,0 Undescribed fines 0.22g

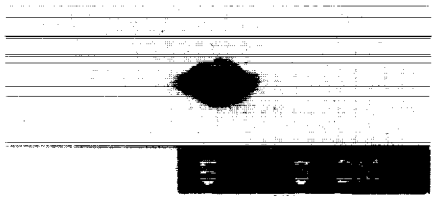
15514,0 consists of a small amount of degraded fines and regolith. It has never been allocated.

15514,1 Glass-coated regolith breccia 1 particle 0.13g

15514,1 Glass-coated regolith breccia 1 particle 0.13g

Powell described the particle as a glass-coated microbreccia (Fig. 1), essentially similar to those of 15244,4. The glass coat is thin, dark, and vesicular, and is on only a part of the surface. The mass listed in Powell of 0.07g was apparently discrepant, the particle being about twice that mass.

Fig. 1 15514,1
S-72-15487



15514,2 Mare basalt 1 particle 0.33g

15514,2 Mare basalt 1 particle 0.33g

Powell described the particle (Fig. 2) as a tough diabase that was subangular and brown. He recognized subhedral white plagioclase laths and anhedral equidimensional dark brown to orange-brown pyroxene. The grain-size was 0.5 to 1.0 mm (granular diabase or coarse basalt).

Fig. 2 15514,2
S-72-15494

15514,3	Olivine-normative mare basalt	1 particle	0.019g (0.22g)

15514,3	Olivine-normative mare basalt	1 particle	0.010g (0.22g)

Powell described the particle as a tough, angular, and vesicular basalt (Fig. 3). It is light brown and very fine-grained, with small anhedral phenocrysts (0.5 mm) of honey yellow olivine(?). The groundmass consists of white to gray plagioclase laths and anhedral brownish-gray pyroxene. The sample was subdivided (Fig. 3). The thin sections show that the sample is a fine-grained olivine-normative mare basalt with small olivine phenocrysts (Fig. 4). Powell et al. (1973) included the sample in their olivine-cristobalite basalts (their group III) but did not give a specific description of this particle. They made a microprobe fused bead analysis of the bulk particle that they included in an average for group III.

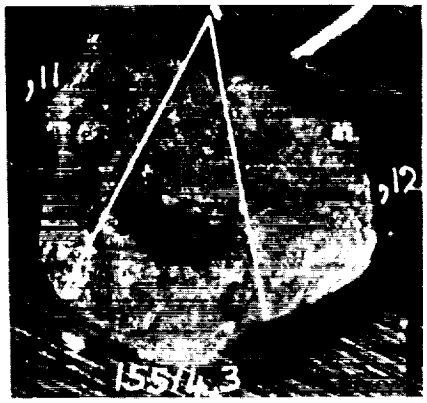


Fig. 3 Original splitting plan for 15514,3. S-72-33600.

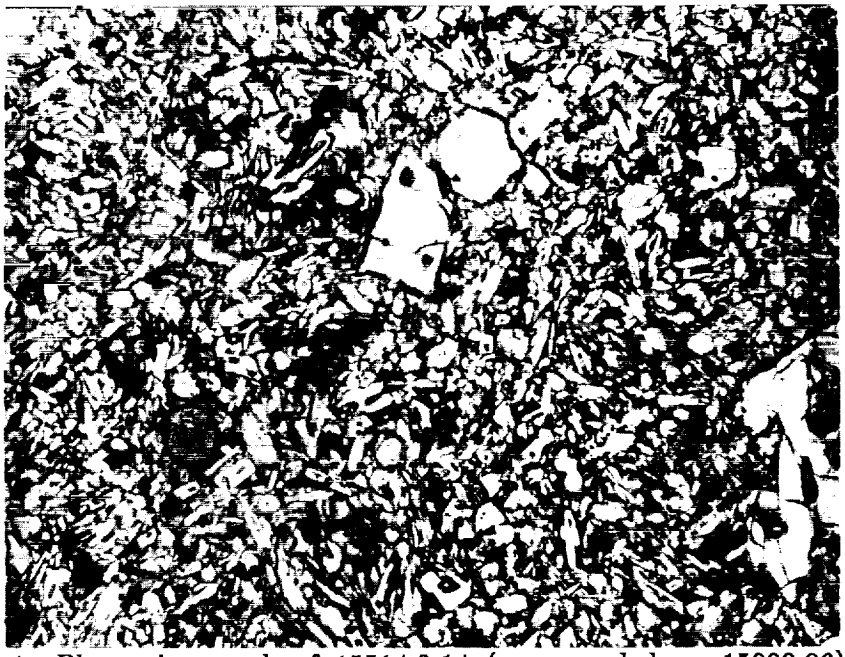


Fig. 4 Photomicrograph of 15514,3,14 (compounded on 15999,96). Plane light; field of view is about 2 mm wide. In centre are small, subhedral olivine phenocrysts; to right is a larger, hollowed and resorbed-looking olivine phenocryst.

15514,4	Glassy basalt(?)	1 particle	0.16g

15514,4	Glassy basalt(?)	1 particle	0.16g

Powell described the particle as a hyalocrystalline basalt that was tough and angular (Fig. 5). It is dark gray with an apparently glassy matrix with a few vugs and vesicles. It has a yellow-green olivine(?) grains.

Fig. 5 15514,4
S-72-15483

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

15534 Station 9a 6.0g

Group	Individual particles	Subsamples	Thin sections/ Probe mounts
,0 (0.76g)			
,1 (1.872g)	,16 (0.163g, RSV)	,17 (CONS, Haskin)	
		,18 (ES, Powell)	,26 (15999,97)
		,27 (CONS, Powell)	
	,21 (0.03g, Geiss)		
,2 (2.461g)	,19 (ES, Powell)		,24 (15999,98)
		,25 (CONS, Powell)	
		,20 (CONS, Haskin)	
	,23 (0.03g)		
,3 (0.32g)			

15534,0 Fines and undescribed particles 0.76g

15534,0 consists of a small number of particles and some fines. The particles have not been described, but some appear to be glassy and others appear to be crystalline (Fig. 1).

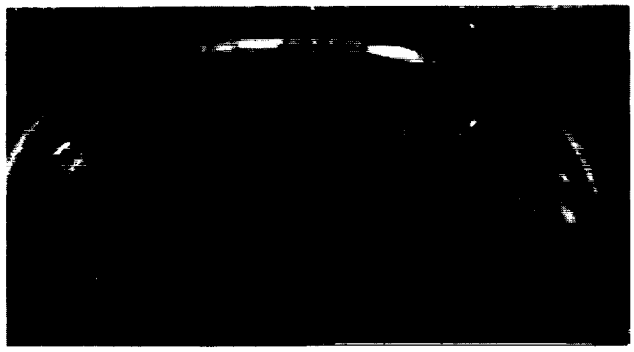
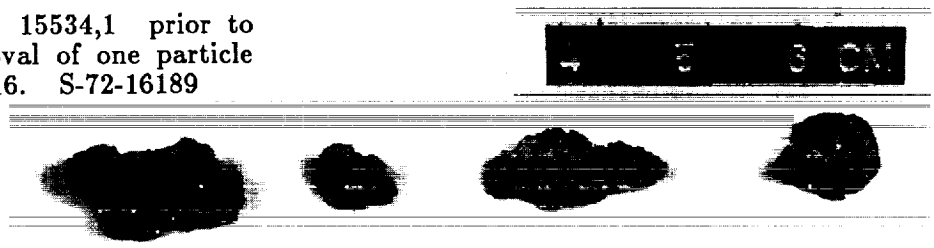


Fig. 1 15534,0
S-72-16186

15534,1 Vesicular mare basalts 4 particles 1.87g (2.15g)

Powell described these particles as tough vesicular basalts that are angular, with large spherical vesicles (Fig. 2). They are light brown, and essentially identical with the particles in 15564,7. The one studied in 15534,1 and the one studied in 15564,7 are olivine-normative mare basalts.

Fig. 2 15534,1 prior to removal of one particle as ,16. S-72-16189



15534,16 Olivine-normative mare basalt 1 particle 0.163g (0.236g)

15534,16, which appears to be the right hand particle in Fig. 2, was subdivided for analysis (Fig. 3). The sample is a coarse- to medium-grained olivine-normative mare basalt (Fig. 4) containing large zoned pyroxenes as well as olivines. Powell et al. (1973) included the particle with their mare basalt III group of olivine-cristobalite basalts.

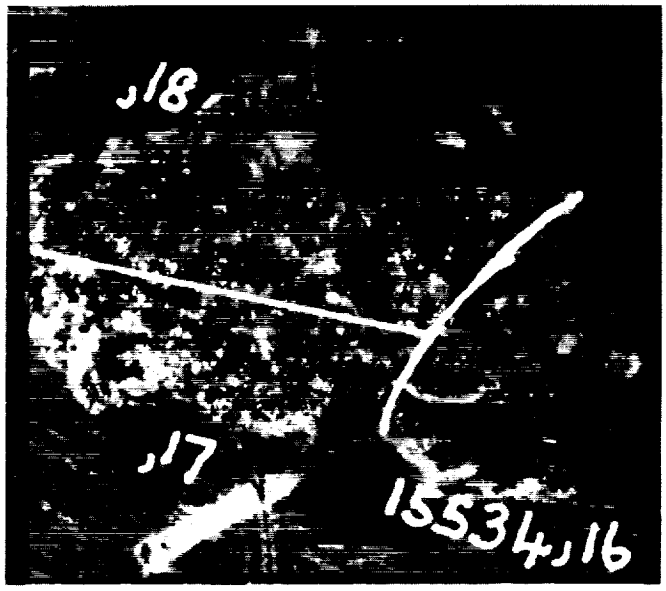


Fig. 3 Original splitting plan for 15534,16. S-72-33590.

Fig. 4 Photomicrograph of 15534,16,26 (on 15999,97). Plane light; field of view about 2 mm wide.

C-3

Helmke et al. (1973) published a trace element analysis for a bulk particle sample (Table 1, Fig. 5). The sample appears to be similar to the local mare basalts, but the data are inadequate by themselves to specify the variety. The rare earth element pattern is slightly flatter in the light rare earths than other local basalts, but the small sample size and the coarse grain size suggest that the sample may not be representative.

Table 1. Helmke et al. (1973)
15534,16,17. RNAA (26 mg)

ppm	
Sc	40.9
Co	54
Hf	3.4
La	7.5
Ce	22.0
Nd	16
Sm	4.93
Eu	1.20
Gd	7.3
Tb	1.14
Dy	7.3
Ho	1.3
Er	3.4
Yb	3.1
Lu	0.45

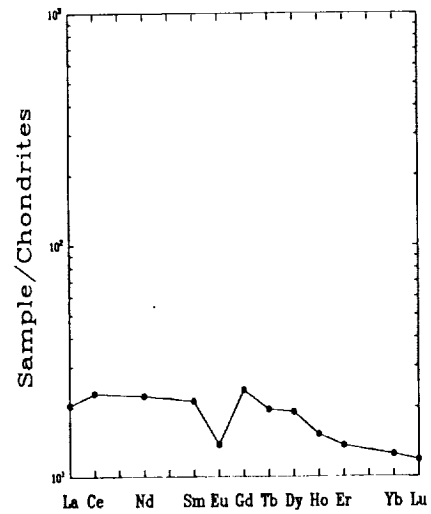


Fig. 5 Chondrite-normalized plot of rare earth elements in 15534,16,17. Data of Helme et al. (1973).

15534,21 Mare basalt(?) 1 particle 0.03g

A chip was removed from 15534,1 and allocated. There was no photographic documentation of this processing, and it is not clear if this was an entire or partial particle. No data have been reported.

15534,2 Mare basalts (+ KREEP basalts?) 10 particles 2.461g (2.65g)

Powell described these particles as tough, subangular to subrounded basalts (Fig. 6). They are medium to light gray, and they have vugs. Powell described them as essentially similar to 15564,5, of which the only one sectioned was a KREEP basalt; the only one of 15534,2 sectioned is an olivine-normative mare basalt.

Fig. 6 15534,2 prior to separation of ,19. S-72-16188

15534,19 Olivine-normative mare basalt 1 particle 0.0g (0.149g)

One particle (not identified from Fig. 6, but clearly one of the smaller ones) was subdivided (Fig. 7). The particle is a medium-grained olivine-normative mare basalt (Fig. 8) with a granular texture and ophitic plagioclases. Powell et al. (1973) included the particle with their mare basalt III group of olivine-cristobalite basalts, but gave no specific description.

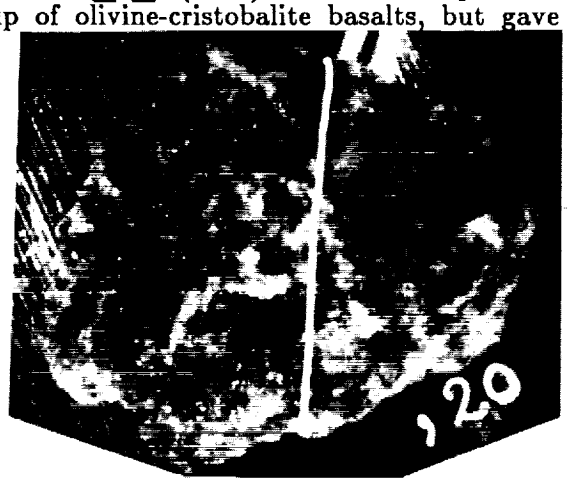


Fig. 7 Original splitting plan for 15534,19. S-72-33629 (on the original, the sample is incorrectly labelled as ,9).

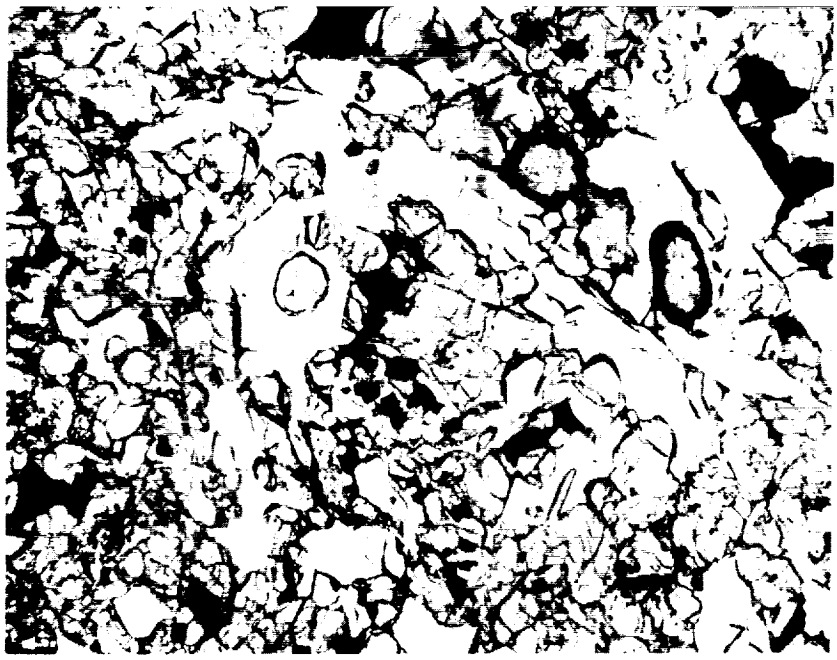


Fig. 8 Photomicrograph of 15534,19,24 (on 15999,98). Plane light; field of view is about 2 mm wide.

Helmke et al. (1973) reported a trace element analysis for a bulk particle sample (Table 2; Fig. 9). The data show that the particle is a local mare basalts, but by themselves are inadequate to distinguish the variety.

Table 2 Helmke et al. (1973)
15534,19,20. RNAA (40 mg)

ppm	
Sc	43.3
Co	47
Hf	2.2
La	4.8
Ce	13.8
Nd	11
Sm	3.41
Eu	0.95
Gd	5.0
Tb	0.79
Dy	5.4
Ho	0.97
Er	3
Yb	2.3
Lu	0.31

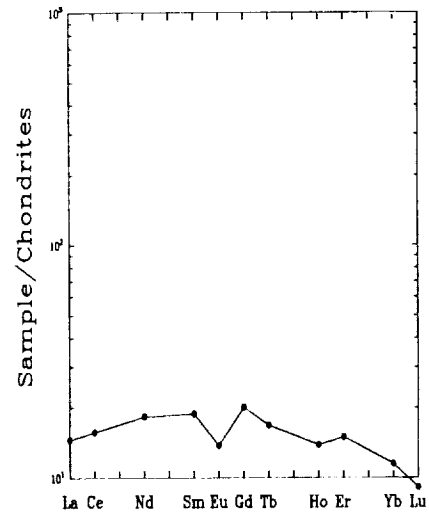


Fig. 9 Chondrite-normalized plot of rare earth elements in 15534,19,20. Data of Helmke et al. (1973).

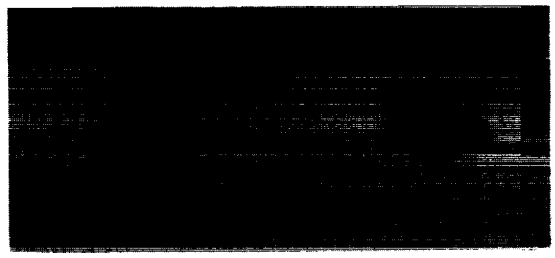
15534,23 Mare basalt(?) 1 particle 0.03g

A chip was separated from 15534,2 and allocated. The chip was not documented, and it is not clear whether this was an entire or a partial particle. No data have been reported.

15534,3 Glass-coated regolith(?) breccias 2 particles 0.32g

Powell described these particles as recrystallized microbreccias that had thin coatings of dark gray vesicular glass on one or more surfaces (Fig. 10). They are tough and subangular; they may be coherent regolith breccias. They are similar to the particles in 15244,4 (which were never allocated).

Fig. 10 15534,3
S-72-16216.



15564 Station 9a 50.0g

Group	Individual particles	Subsamples	Thin sections/ Probe mounts
,0 (10.36g)			
,1 (32.65g)			
,2 (ES)			
,10 (3.43g)			
,11 (5.13g)			
,3 (0.50g)			
,4 (0.28g)			
,5 (0.906g)	,16 (ES, Powell)	,24 (CONS, Powell)	,22 (15999,95)
		,17 (CONS, Haskin)	,23 (15999,99)
	,21 (0.03g, Turner)		
,6 (0.94g)			
,7 (0.663g, RSV)	,18 (0.076g)	,19 (ES, Powell)	,25 (15999,96)
		,27 (CONS, Powell)	,26 (15999,99)
		,20 (CONS, Haskin)	
,8 (0.29g)			

15564,0 Fines and undescribed particles 10.36g

15564,0 consists of a large number of small particles and degraded fines or regolith (Fig. 1). The particles appear to include crystalline fragments (presumably mainly mare basalts) and regolith breccias. None of these have been allocated.

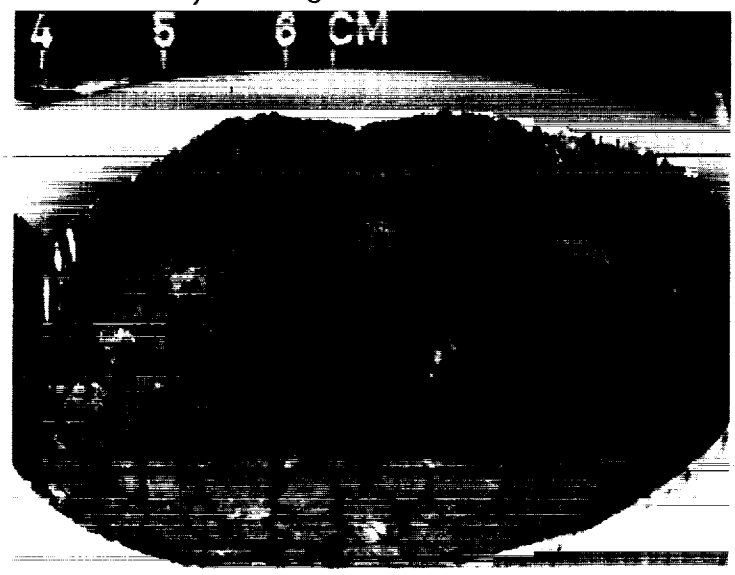
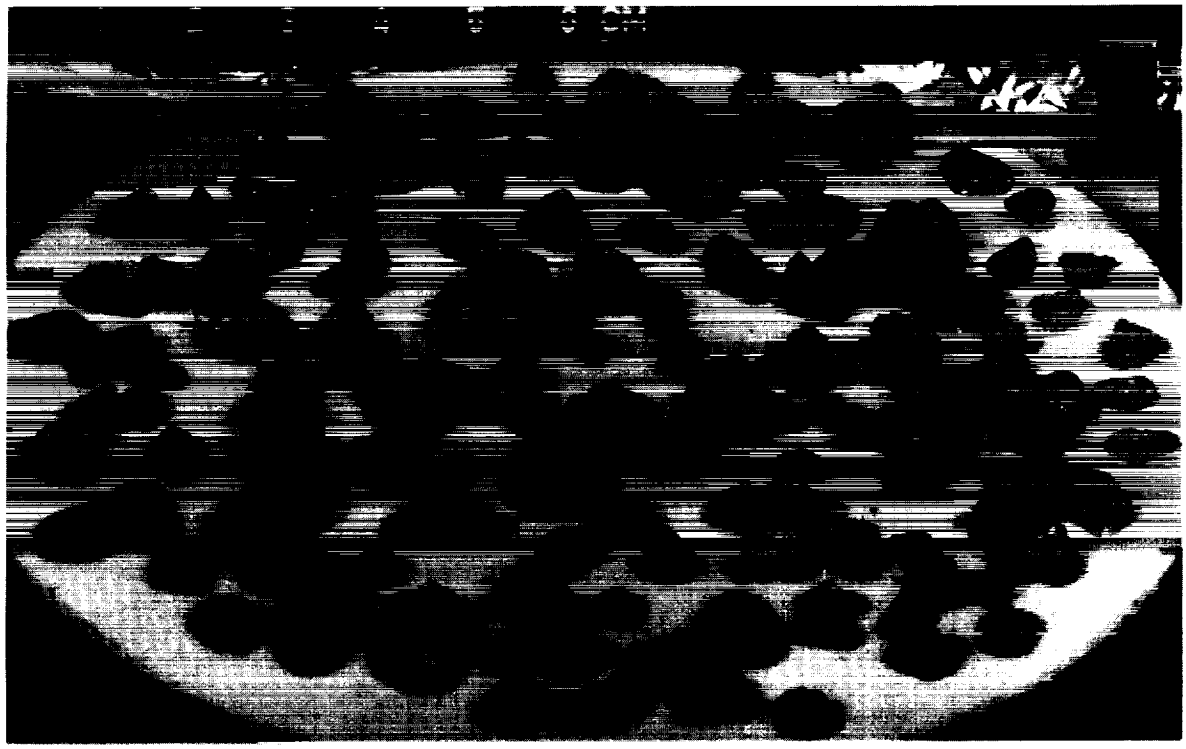


Fig. 1 15564,0
S-72-15969

15564,1 Regolith breccias 132 particles 32.65g

Powell described these particles as friable to coherent microbreccias. They are medium gray and range from subrounded to rounded (Fig. 2). A variety of visible clasts composes 10 to 30% of each particle, and include glass, mineral, and lithic fragments. Most clasts are basalts, with textures ranging from granular to ophitic; highlands rock types are scarce. Mineral clasts include white plagioclase; yellow, orange, brown, and cinnamon pyroxene, and yellow-green olivine. Glasses are dark brown, orange, and green (rare), and occur as angular fragments and as spherules. Most clasts are less than 1 mm. None of these particles has been allocated.

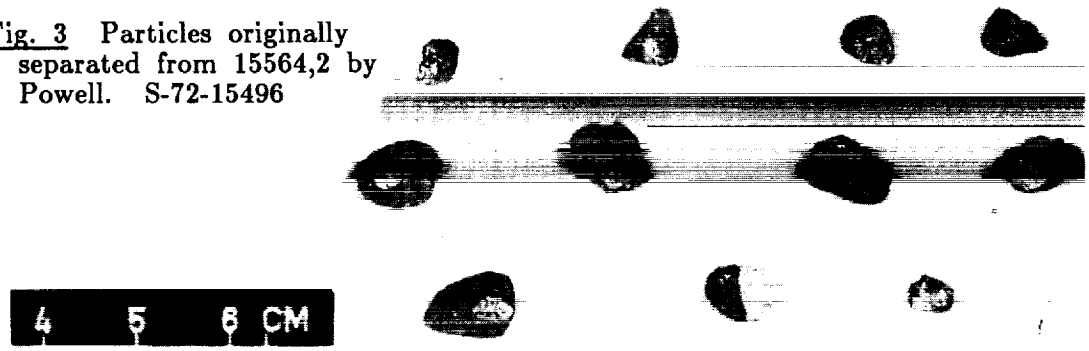
Fig. 2 15564,1
S-72-15499



15564,2 Regolith breccias and fines 11 particles+ 0.0g (8.56g)

Powell described 15564,2 as friable to coherent microbreccias that were medium gray, and subrounded to rounded (Fig. 3). They are similar to 15564,1 except that they contain larger (2 to 5 mm) separable basalt clasts, similar to the basalts in 15564,5-,7. A check on mass uncertainty (1981) showed that Powells listed mass of 2.73 g was incorrect, and ,2 consisted of fines as well as the particles, totalling more than 8 g. 15564,2 was divided into separate splits of 15564,10 (3.43 g), which was the coarser particles; and 15564,11 (5.13 g), which was the finer material, mainly regolith.

Fig. 3 Particles originally separated from 15564,2 by Powell. S-72-15496



15564,3	Glass-coated regolith breccias	2 particles	0.50g

Powell described the two particles of 15564,3 as friable to coherent microbreccias that were medium gray, subrounded, and having vesicular glass on one face (Fig. 4). The glass coat is the only feature that distinguishes these two particles from those in 15564,1.

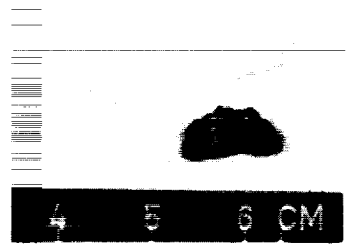
Fig. 4 15564,3
S-72-15485

15564,4	Agglutinate	1 particle	0.28g

15564,4	Agglutinate	1 particle	0.28g

Powell described this fragment as a coherent, irregular and subangular agglutinate, consisting of several small particles of microbreccia (= regolith breccia) welded together by dark, grayish-brown vesicular glass (Fig. 5). The breccias are medium gray; the overall appearance is mottled.

Fig. 5 15564,4
S-72-15497



15564,5	KREEP basalts	9 particles	0.906g (1.11g)

Powell described these fragments as basalts (diabase) that were tough, subangular to rounded, and medium to light gray (Figs. 6,7). The one that was studied is a volcanic Apollo 15 KREEP basalt, and the characters of the others as described by Powell suggests that most, if not all, of them are similar basalts, not mare basalts.

Fig. 6 15564,5 prior to separation of the front center particle (,16)

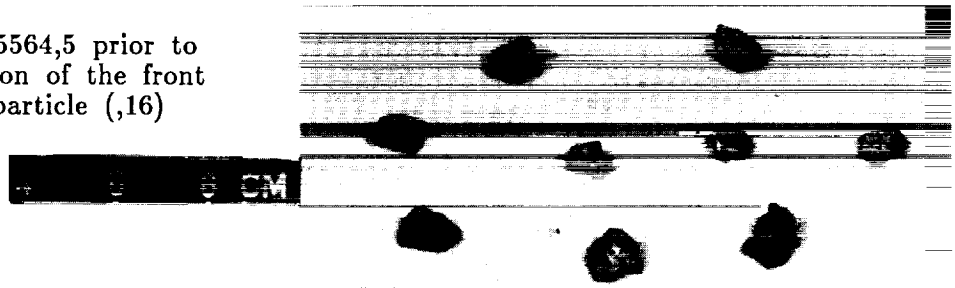


Fig. 7 Remaining 15564,5 after removal of ,16 S-72-33633

Powell described the basalts as holocrystalline, coarse-grained, and subophitic (basalt or diabase). He recognized about 45% white, lath-shaped plagioclases 0.5 to 1 mm long; 45-50% grayish-brown to yellowish-brown, anhedral pyroxene; 5% greenish-yellow, anhedral to subhedral grains that he identified as olivine; and less than 2% minute black opaque grains. The plagioclase and pyroxenes are 0.5 to 1.0 mm long. There are a few small vugs, 0.2 to 0.5 mm across. It is likely that the greenish-yellow grains are orthopyroxenes, not olivines.

15564,16	KREEP basalt	1 particle	0.0g	(0.16g)

The particle was subdivided (Fig. 8) and eventually entirely used up. It is a KREEP basalt with an intersertal-subophitic texture (Fig. 9). Powell et al. (1973) published a photomicrogaph and described the particle as consisting mainly of orthopyroxene and abundant lath-shaped plagioclase. Interstitial material includes Ca-poor pyroxene, ilmenite, cristobalite, and brownish glass.

Fig. 8 Initial splitting plan for 15564,16. S-72-33592

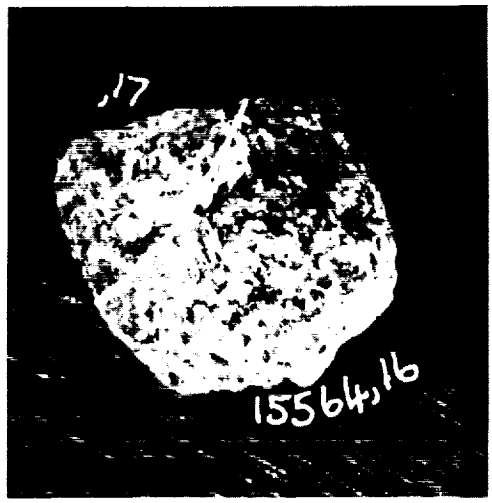


Fig. 9 Photomicrograph of 15564,16,22 (15999,96). Plane light; field of view about 2 mm wide.

Powell (unpublished) made a bulk analysis of the major elements using microprobe fused bead techniques (Table 1). This analysis confirms that the sample is a KREEP basalt, and was used in an average for KREEP basalts by Powell et al. (1973). Helmke et al. (1973) made a bulk particle trace element analysis using neutron activation techniques. The absolute and relative abundances of the incompatible elements are similar to those of other Apollo 15 KREEP basalts.

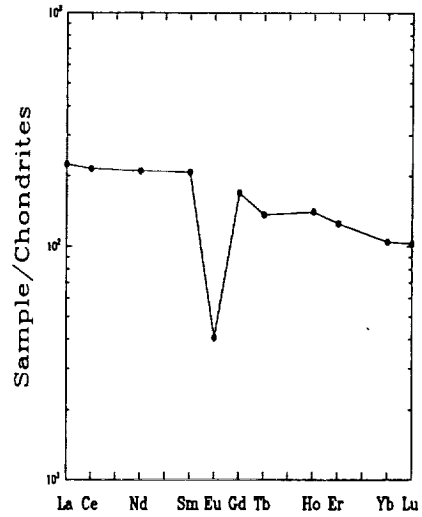
Table 1. Powell (unpublished). Microprobe fused bead. 15564,16,27

wt%	
SiO_2	52.0
TiO_2	2.1
Al_2O_3	15.62
Cr_2O_3	0.42
FeO	10.07
MnO	0.17
MgO	8.40
CaO	10.25
Na_2O	0.70
K_2O	0.50
P_2O_5	0.49
Sum	100.7

Table 2. Helmke et al. (1973) 15564,16,17 RNAA. (33 mg)

ppm	
Sc	23.1
Co	22.9
Hf	24.0
La	74
Ce	189
Nd	126
Sm	37.5
Eu	2.8
Gd	42
Tb	6.4
Dy	45.5
Ho	9.8
Er	25
Yb	20.9
Lu	3.5

Fig. 10 Chondrite normalized plot of rare earth elements in 15564,16,17. Data of Helme et al. (1973)



15564,21 KREEP basalt(?) 1 particle 0.03g

A small fragment chipped from the particles in ,5 was allocated. The documentation does not reveal which particle was chipped, and most of the parent particle for ,21 presumable remains in ,5. No data have been reported for it.

15564,6 KREEP(?) or mare(?) basalts 4 particles 0.94g

Powell described the particles as olivine basalts (microgabbro) that were tough, subangular, and mottled tan (Fig. 11). However, except for their tanner color, their description is almost identical with that for 15564,5, which include (and may all be) KREEP basalts. Two of the particles are finer-grained (0.2 to 0.5 mm) than those in 15564,5. These particles are probably KREEP basalts in which the greenish-yellow mineral composing 5 to 20% of the sample is orthopyroxene, not olivine. It is certainly not impossible that they are, or include, mare basalts. They have never been subdivided or allocated.

Fig. 11 15564,6
S-72-15484

15564,7 Vesicular mare basalts 4 particles 0.663g (0.83g)

Powell described these particles as tough, vesicular, light brown basalts. The particles are angular, and the vesicles are large and prominent (Fig. 12). The one that has been studied (,18, second from left in Fig. 12) is an olivine-normative mare basalt.

Fig. 12 Original four particles of 15564,6. S-72-15970

Powell described the particles as fine-grained (0.1 to 0.2 mm grain-size), equigranular subophitic to granular basalts. He found 45% plagioclase (white, subhedral, laths); 45% pyroxene (yellow-brown to tan, euhedral), 5% olivine (greenish-yellow), and opaques. (The modal opaques are listed as 25%, but that must be a typographical error). The vesicles are remarkably spherical and occupy 20 to 30% of the volume; some are lined with a higher concentration of dark minerals (most opaues, some pyroxene) than the rest of the rock. Minerals are tangential to the vesicle wall, and do not protrude into the cavities.

15564,18 Olivine-normative mare basalt 1 particle 0.076g (0.156g)

The particle was subdivided and allocated (Fig. 13). It is a vesicular olivine-normative mare basalt (Fig. 14), with small olivine phenocrysts and ragged plagioclase laths. Powell et al. (1973) showed a photomicrograph showing the large vesicles. They described the olivines (Fo_{65-60}) as partly resorbed, and included the particle in their group III of olivine-cristobalite mare basalts.

Fig. 13 Original splitting plan for 15564,18 S-72-33594

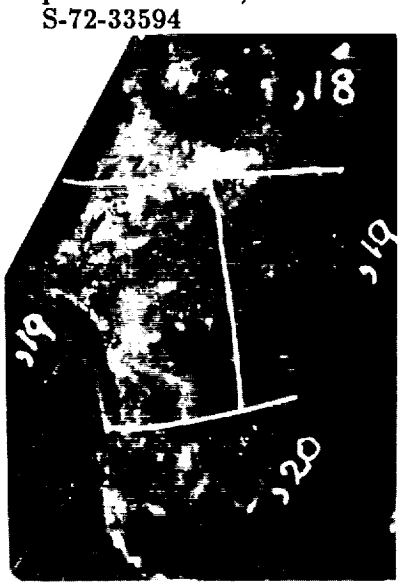


Fig. 14 Photomicrograph of 15564,18,25 (15999,96). Plane light; field of view about 2 mm wide. Prominent vesicle at right; olivine phenocryst in center.

Powell et al. (1973) used a microprobe fused bead analysis of a bulk sample of 15564,18,19 in their average of type III basalts (this average has unusually high SiO2 and normative quartz for such basalts.). They did not publish the specific analysis. Helmke et al. (1973) made a trace element analysis of a bulk sample (Table 3; Fig. 15). The analysis shows that the particle is a local mare basalt, but is inadequate by itself to specify to which group it belongs.

Table 3 Helmke et al. (1973)
15564,18,20. RNAA (27 mg)

Sc	48.8
Co	50
Hf	2.6
La	5.3
Ce	15.7
Nd	11
Sm	4.01
Eu	1.03
Gd	5.5
Tb	0.84
Dy	5.9
Ho	1.1
Er	2.3
Yb	2.5
Lu	0.36

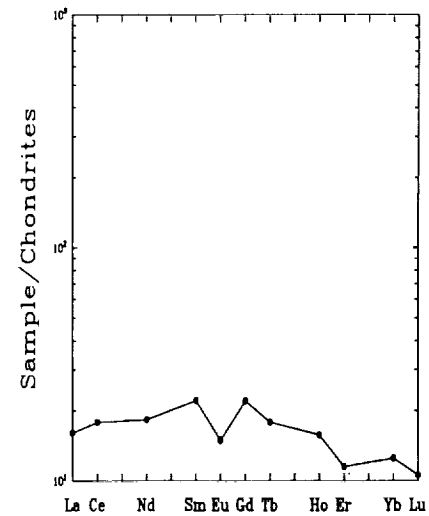
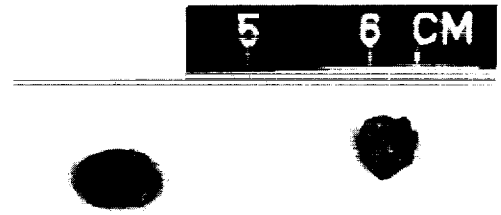


Fig. 15 Chondrite-normalized plot of rare earth elements in 15564,18,20. Data of Helmke et al. (1973).

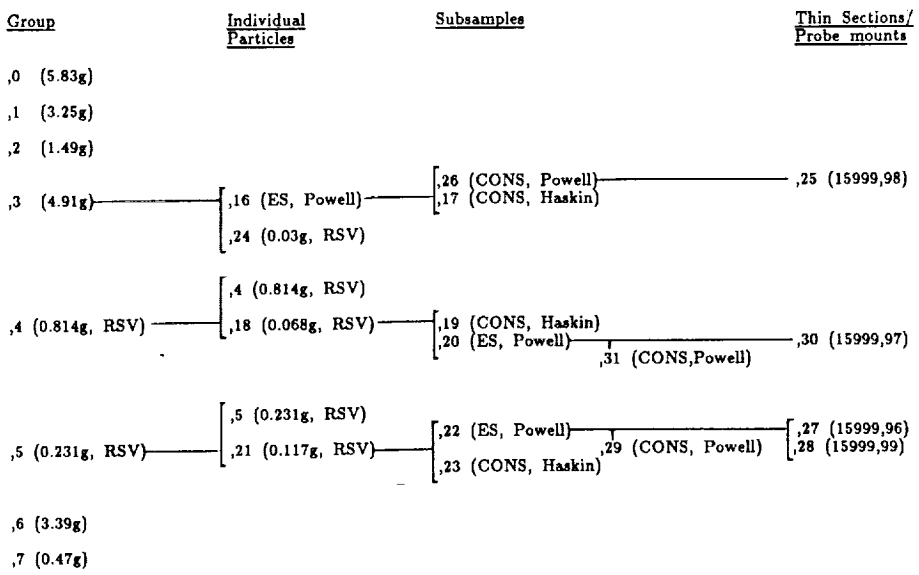
15564,8 Coherent regolith breccias or impact melts 2 particles 0.29g

Powell described these two particles as tough, rounded, dark gray mottled, crystalline microbreccias (Fig. 16). He described them as fine-grained inequigranular seriate crystalline rocks with non-igneous texture; they appear to be well crystallized. They are distinct in texture and modal mineralogy (roughly equal parts anhedral white plagioclase and unidentified dark gray mineral) from the basalts from this location. They may well be impact melts of uncertain affinity, or they may be coherent regolith breccias. They have never been subdivided or allocated.

Fig. 16 15564,8
S-72-15978



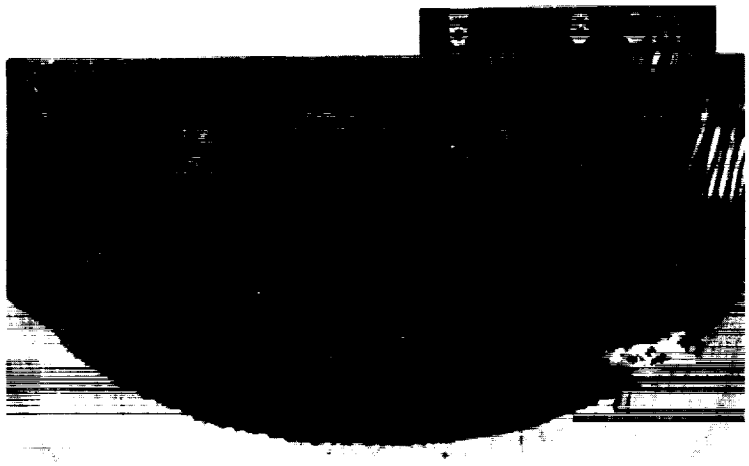
15604 Station 9a 21.5g



15604,0 Fines and undescribed small particles 5.83g

15604,0 consists of many small particles and degraded fines. The particles clearly include vesicular mare basalts, friable regolith breccias, and glass (Fig. 1).

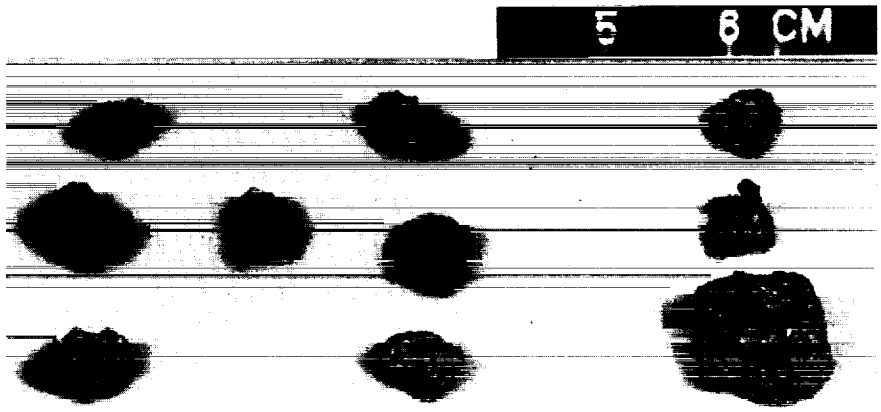
Fig. 1 15604,0
S-72-15986



15604,1 Vesicular mare basalts 10 particles 3.25g

Powell described these particles as tough vesicular basalts (Fig. 2). They are angular, light brown, and fine- to medium-grained (0.2 to 0.5 mm grains). Some of the vesicles are up to 5 mm across. They have never been allocated or subdivided.

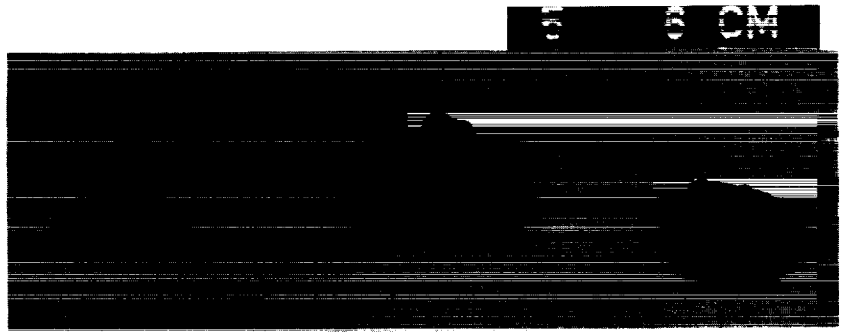
Fig. 2 15604,1
S-72-15972



15604,2 Vesicular porphyritic mare basalts 3 particles 1.49g

Powell described these particles as tough vesicular basalts that have vesicles and olivine phenocrysts (Fig. 3). They are finer-grained than the 15604,1 particles (less than 0.1 mm grains), and anhedral equidimensional greenish-yellow olivine phenocrysts (up to 1 mm) compose 5 to 10% of the particles. The vesicles are spherical, mainly about 1 mm across, and occupy 5 to 10% of the volume. The groundmass contains white plagioclase, grayish-brown pyroxene(?), and black ilmenite(?). The particles have never been subdivided or allocated.

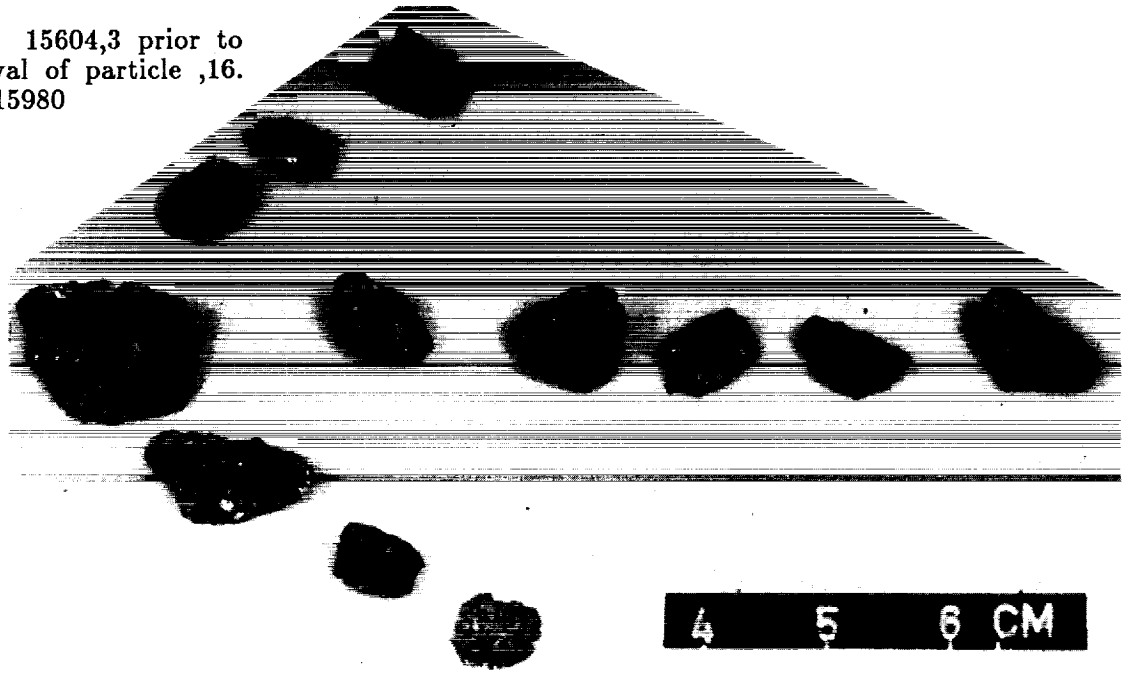
Fig. 3 15604,2
S-72-15979



15604,3 Olivine-normative mare basalts 12 particles 4.91g (5.12g)

Powell described the particles as tough, subangular to subrounded olivine basalts (Fig. 4). The one that has been studied (,16) is an olivine-normative mare basalt. The particles are grayish tan, and have vugs up to 1mm; vugs are not abundant. The basalts are medium- to coarse-grained (mean grain-size 0.5 to 1.0 mm) with granular to subophitic textures. Plagioclase is white, subhedral tabular to anhedral (40 to 45%); pyroxene is grayish-brown to yellowish brown and anhderal (45 to 50%); olivine is greenish-yellow and anhedral (5 to 15%). Minute anhedral opaques compose 1 to 2%.

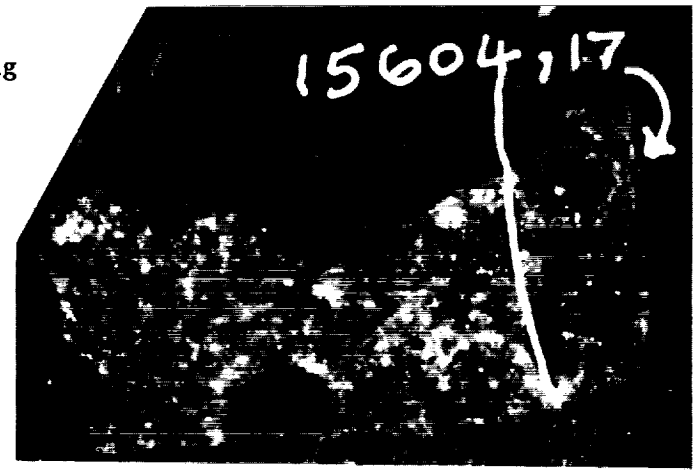
Fig. 4 15604,3 prior to removal of particle ,16. S-72-15980



15604,16 Olivine-normative mare basalt 1 particle 0.0g (0.163g)

15604,16 (not identified on Fig. 4) was entirely subdivided for thin sections following removal of a chip for a chemical analysis (Fig. 5).

Fig. 5 Original splitting plan for 15604,16. S-72-33615



Powell et al. (1973) described the particle as an olivine-cristobalite basalt (their group III) but did not give a specific description. The sample is an olivine-normative mare basalt with small olivine phenocrysts (Fig. 6). The texture is somewhat granular.

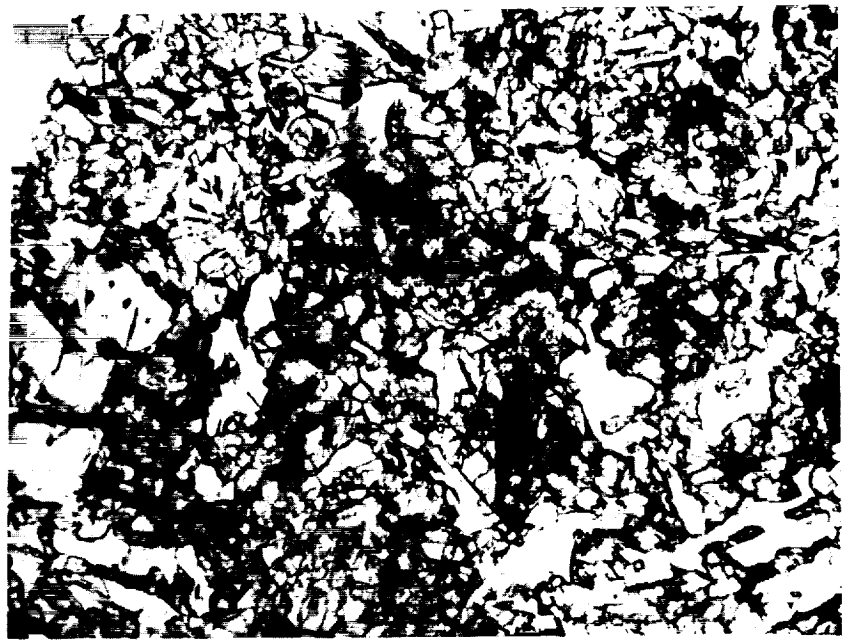


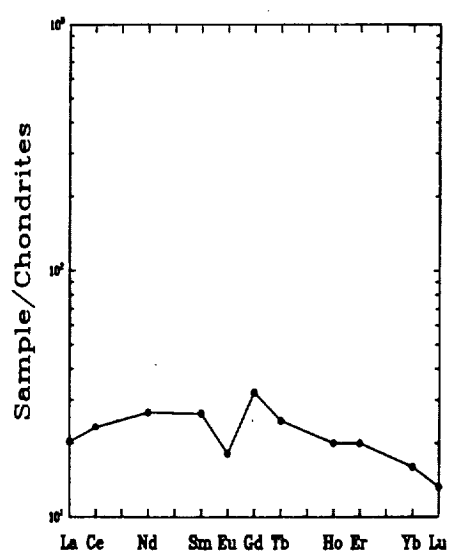
Fig. 6 Photomicrograph of 15604,16,25. Plane light; field of view about 2 mm across. Olivines are visible on the left of the image.

An analysis for trace elements by Helmke et al. (1973) (Table 1; Fig. 7) shows that the sample is a mare basalt, with a typical Apollo 15 rare earth element pattern. The data by themselves are inadequate to distinguish which type of local mare basalt the fragment is.

Table 1 Helmke et al. (1973)
RNAA. 15604,16,17 (35 mg)

Sc	43.9
Co	42
Hf	2.8
La	6.7
Ce	20.4
Nd	16
Sm	4.78
Eu	1.25
Gd	8
Tb	1.16
Dy	7.2
Ho	1.4
Er	4
Yb	3.2
Lu	0.45

Fig. 7 Chondrite-normalized plot of rare earth element abundances in 15604,16,17. Data of Helmke et al. (1973).



15604,24 Olivine-normative mare basalt(?) 1 particle 0.03g

A small fragment from ,3 was allocated, but returned. This fragment was not from particle ,16, but it is not known from which fragment it was taken; most of the parent presumably remains in ,3.

15604,4 Quartz-normative mare basalts 2 particles 0.814g (0.95g)

Powell described these particles (Fig. 8) as tough olivine basalts (diabases). However, the one investigated is a quartz-normative basalt, lacking olivine. Powell described the basalts as subangular, dark gray, and having vugs with euhedral brown pyroxene crystals, a feature more characteristic of the quartz-normative basalts. The anhedral phenocrysts, 0.5 to 1 mm, are greenish-yellow and were (mis)identified by Powell as olivines. The groundmass is much finer (0.1 to 0.4 mmm grains).

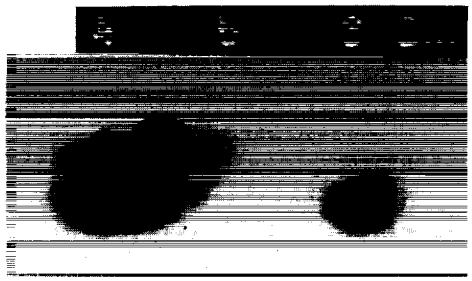


Fig. 8 15604,4. The smaller particle was processed as ,18. S-72-15982

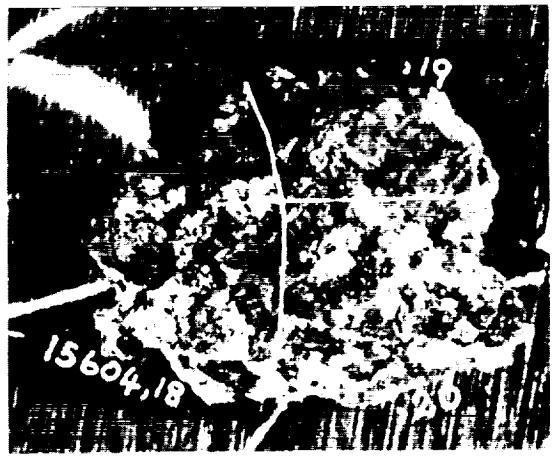
15604,4 Porphyritic quartz-normative mare basalt(?) 1 particle 0.814g

The largest particle of ,4 became, by default, a singly numbered particle withthe removal of ,18. However, this large particle has never been subdivided or allocated.

15604,18 Porphyritic quartz-normative mare basalt 1 particle 0.068g (0.128g)

Powell et al. (1973) described the particle (Figs. 9, 10) as a variolitic pyroxene basalt (their group II), with euhedral skeletal pyroxenes in a groundmass of clinopyroxene, plagioclase, ulvospinel, and ilmenite. The pyroxene is zoned. They gave a mode for the group apparently based on this sample: 73% pyroxene, 24% plagioclase, 3% oxides, and less than 1% each of metal and troilite. Olivine is absent. The sample is clearly a fairly typical member of the Apollo 15 quartz-normative basalt group.

Fig. 9 Original splitting plan for 15604,18.



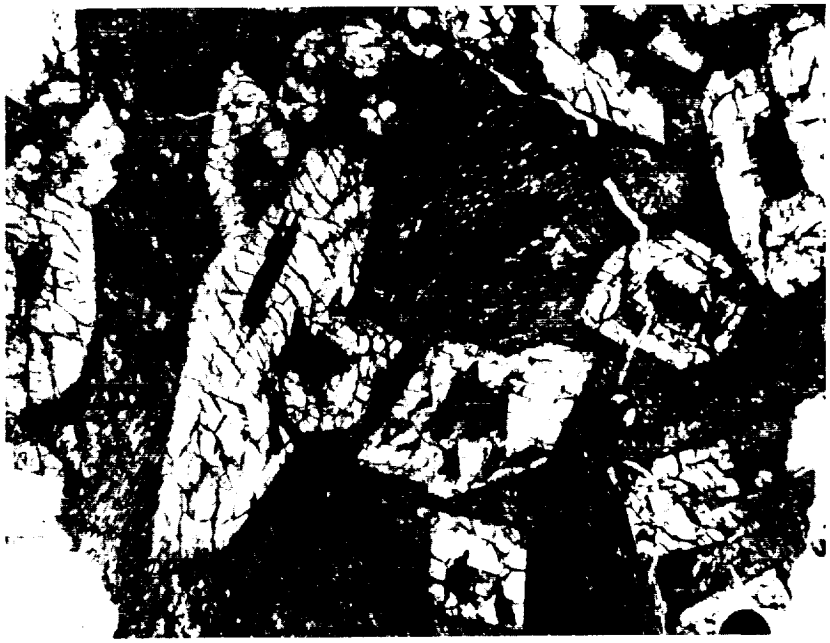


Fig. 10 Photomicrograph of 15604,18,30. Plane light; field of view about 2 mm wide.

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A trace element analysis was reported by Helmke et al. (1973) (Table 2, Fig. 11). The data show that the sample is a local mare basalt, but are inadequate to distinguish it as a quartz-normative basalt.

Table 2. Helmke et al. (1973) RNAA. 15604,18,19 (20 mg)

Sc	41.8
Co	44
Hf	3.1
La	6.9
Ce	21.3
Nd	15.5
Sm	4.44
Eu	1.19
Gd	5.9
Tb	0.98
Dy	6.8
Ho	1.3
Er	4.3
Yb	3.2
Lu	0.44

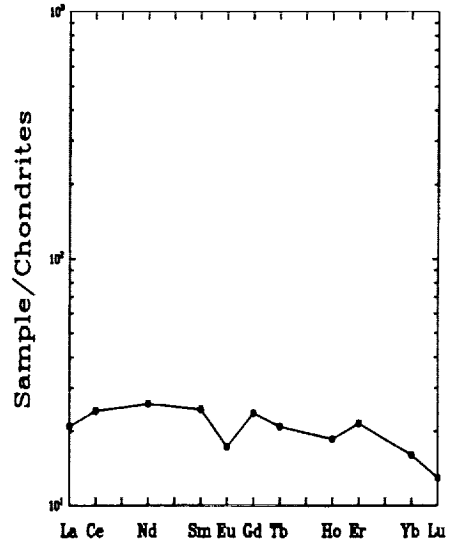
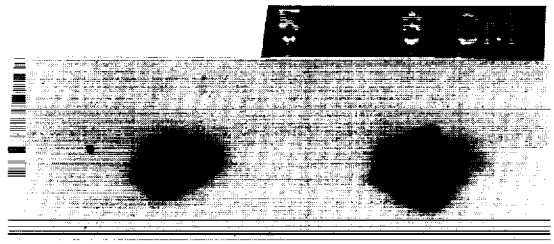


Fig. 11 Chondrite-nomalized plot of rare-earth elements in 15604,18,19. Data of Helmke et al. (1973)

15604,5 Vitrophyric quartz-normative basalts 2 particles 0.231g (0.41g)

Powell described the two particles as tough, subangular, dark gray basalts (Fig. 12) that were fine-grained (grain-size less than 0.3 mm). He identified 30% lath-shaped white plagioclase, 65% dark gray pyroxene, 3% yellow-green olivine, and 2% opaques. However, the one thin sectioned consists of pyroxene and glass.

Fig. 12 15604,5 prior to subdivision of ,21.



15604,5 Vitrophyric quartz-normative basalt(?) 1 particle 0.231g

15604,5 is the larger of the two particles in Fig. 12. It became, by default, a single particle after the removal of ,21. However, ,5 has never been subdivided or allocated.

15604,21 Vitrophyric quartz-normative mare basalt 1 particle 0.117g (0.175g)

15604,21, the smaller of the two particles in Fig. 12, was subdivided (Fig. 13). Powell et al. (1973) placed it in their group II of pyroxene vitrophyres, and gave a photomicrograph but no other specific description. The sample consists essentially of euhedral skeletal

laths of pigeonite in a glassy groundmass (Fig. 14). There is about 50% pyroxene; the laths are about 1 mm long.

Fig. 13 Original splitting plan for 15604,21. S-72-33599

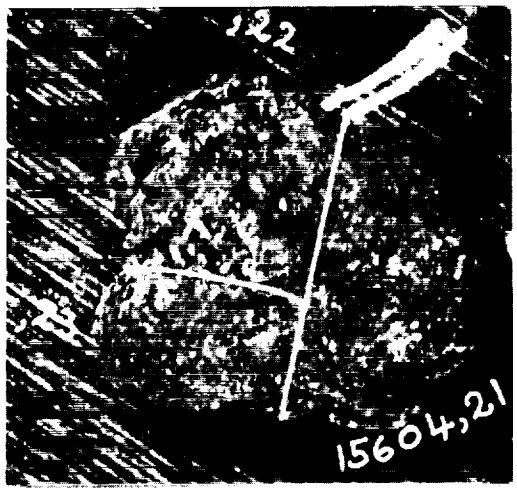


Fig. 14 Photomicrograph of 15604,21,27. Plane light; field of view about 2 mm across.

Powell et al. (1973) reported a major element bulk analysis (microprobe fused bead technique) (Table 3). The analysis shows that the sample is a fairly typical Apollo 15 quartz-normative mare basalt. A trace element analysis was reported by Helmke et al. (1973) (Table 4, Fig. 15). The analysis shows that the sample is a local mare basalt but is inadequate to distinguish the particular variety.

Table 3. Powell et al. (1973) Microprobe fused bead. 15604,21,29.

SiO_2	48.64
TiO_2	1.90
Al_2O_3	10.13
Cr_2O_3	0.62
FeO	19.42
MnO	0.21
MgO	8.31
CaO	11.33
Na_2O	0.23
K_2O	0.05
P_2O_5	0.09
NiO	0.03
Sum	100.96

Table 4. Helmke et al. (1973) RNAA 15604,21,23 (25 mg)

Sc	45.6
Co	44
Hf	3.0
La	6.7
Ce	18.6
Nd	14.2
Sm	4.25
Eu	1.05
Gd	5.3
Tb	0.88
Dy	6.14
Ho	1.2
Er	3.3
Yb	2.8
Lu	0.41

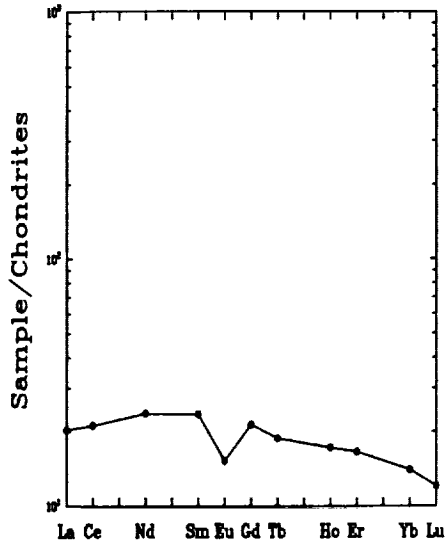
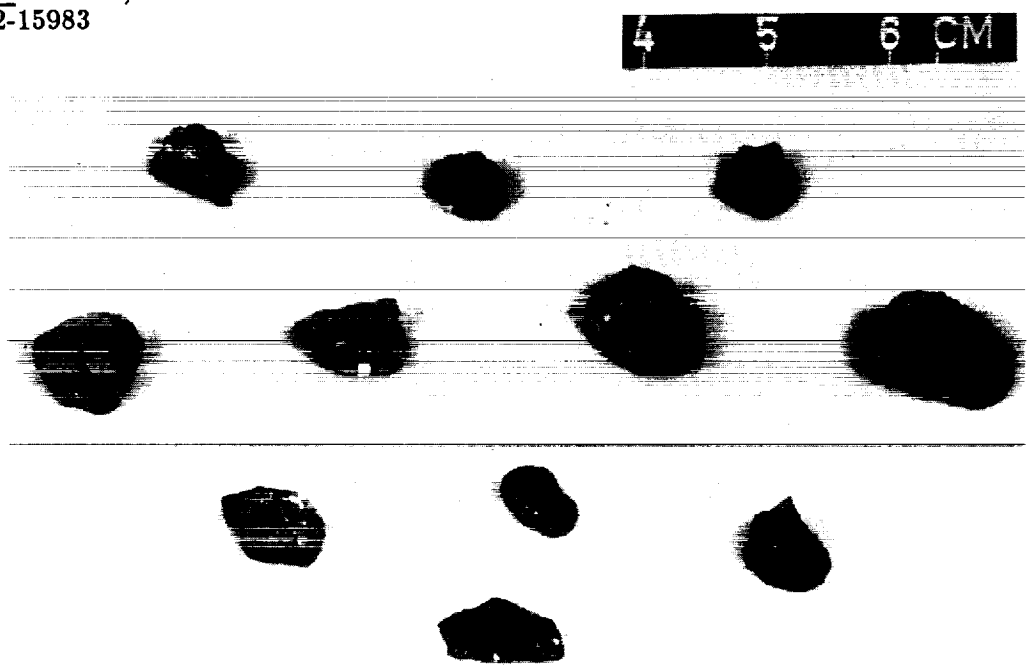


Fig. 15 Chondrite-normalized plot of rare earth elements in 15604,21,23. Data of Helmke et al. (1973).

15604,6 Regolith breccias 12 particles 3.39g

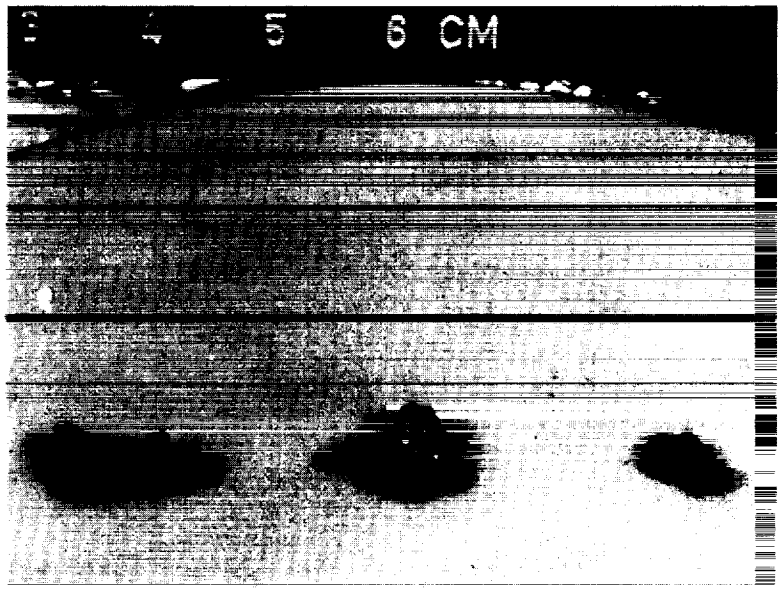
Powell described these particles as friable to coherent microbreccias (Fig. 16). They are variably subrounded to round, with smooth to very finely granular surfaces, and a few have splash glass coatings.

Fig. 16 15604,6
S-72-15983



Powell described thes particles as coherent to friable agglutinates (Fig. 17). They are medium to dark gray, irregular in shape, and are essentially glass-bonded regolith breccias.

Fig. 17 15604,7
S-72-15984



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