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# CATALOG OF PRISTINE NON-MARE MATERIALS
## PART 2. ANORTHOSITES
## REVISED

GRAHAM RYDER AND MARC NORMAN
(NORTHROP SERVICES, INC.)

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Note: This is a reprinted version of the original edition, with the correction of the errors of commission and omission which have been brought to our attention. There has been no attempt to update the contents of this catalog.

# INTRODUCTION

This volume is Part 2 of a catalog of known pristine non-mare (highlands) materials and is devoted to anorthosites. As such it includes information on pristine samples which contain more than about 90 volume % plagioclase or more than about 32 weight % $Al_2O_3$, depending on what information is available. Part 1 deals with pristine non-anorthosite samples. The purpose is to encourage investigation of these samples by providing descriptive and processing information about them.

By pristine we mean lunar materials which were created by igneous events within the Moon and subsequently have retained their bulk chemistry without contamination by other lunar or non-lunar materials, and in general this is the same definition used by Warren and Wasson (1977, 1978). A pristine sample may have a plutonic, extrusive, metamorphic or brecciated texture; it is the chemistry and not necessarily the texture which is pristine. Pristine does not necessarily mean primitive or primordial. Pristine samples described in this volume include large whole-rocks, clasts in breccias, and rake and fines samples.

In establishing whether or not a sample is pristine we have relied heavily, but not exclusively, on the siderophile data of the Anders group at Chicago (e.g., Hertogen et al., 1977) and the Wasson group at Los Angeles (e.g., Warren and Wasson 1977, 1978). There is no clear-cut break in the distribution of abundances of siderophiles between pristine and non-pristine samples and the choice of a cut-off abundance level is partly subjective. In general this cut-off is $\sim 3 \times 10^{-4}$x chondrites (e.g., Warren and Wasson 1978) but is tempered by other considerations. In some cases siderophile data is not available and we have relied on petrographic/chemical criteria as outlined by Irving (1975) and Warren and Wasson (1977). As noted above, the purpose of this volume is to encourage investigation of this fundamentally significant group of samples, which contains critical information on the nature, origin, and evolution of the lunar crust. We have attempted to cover all non-mare samples known or strongly believed to be pristine, other than a few small fragments which were discovered only in thin sections. Undoubtedly a case can be made for the pristinity of some samples not included in these volumes, but we believe the present evidence is not strong enough to justify their inclusion. For each sample we give:

(i) Evidence for its pristinity, using criteria referred to above.

(ii) A description including tables and figures of what is known about the pristine sample. To accomplish this for pristine clasts it has been necessary to make extensive use of the processing data packs and other information kept at the Lunar Curatorial Facility to establish what allocations of the clast were made. This is important because frequently an investigator has received and studied a pristine sample but has no way of knowing with the information supplied to him/her that it was found by another investigator to be pristine.

For most clast samples, and for several whole-rocks we also give:

(iii) A table and selected photographs showing the splits and/or a "mug-shot" of the original pristine sample. (For most whole-rock pristine samples we have omitted this table as superfluous, but we have included the table if it is fairly short -- a subjective choice. We have also omitted the table in most cases where the sample consists only of white anorthosite and black glassy rind material. The table provides locations, masses and brief descriptions of the splits which contain the pristine material. For samples in RSPL the state of degradation is also contained in the description, except for potted butts, which have been through normal thin-sectioning procedures and contaminants. Parentheses around daughter number splits indicate that the daughter is not direct but a daughter of the split number preceding the parentheses. The word chip does not necessarily mean that split was chipped or pried off, merely that it is a single small piece.

This compendium is meant to enable an investigator to judge for him/herself that, or if, a sample satisfies his/her own criteria for pristinity, whether what is already known about a sample makes it interesting to him/her, whether there are data gaps the investigator would like to fill, and whether (and which) samples suitable for the study are available.

The information contained in the descriptions and the split tables is as correct as possible at the time of writing. If this volume fulfills its function, then more allocations will be made, and more information will be forthcoming. Therefore this volume has a planned obsolescence.

Abbreviations and/or possibly unfamiliar terms used in this volume include the following:

| | |
|---|---|
| BSV | Brooks Storage Vault - Comparatively inaccessible samples, San Antonio, Tx. |
| B01 | Building 1, JSC - Interim storage vault, samples accessible with difficulty |
| B16 | Building 16, JSC " |
| B45 | Building 45, JSC " |
| SSPL | Sample Storage and Processing Laboratory, Lunar Curatorial Facility, JSC |
| RSPL | Returned Sample Processing Laboratory, Lunar Curatorial Facility, JSC |

SCC Sample Control Center, Lunar Curatorial Facility, JSC
TSL Thin Section Laboratory, Lunar Curatorial Facility, JSC
TS Thin section
PM Probe mount
P.I. Principal Investigator
Ent. subd. Entirely subdivided
Generic listing: A computer listing compiled at the Lunar Curatorial Facility providing splits, masses, precise locations and brief physical descriptions of lunar samples.

In anticipation of a revised edition or a supplement, we solicit communications regarding errors of omission and comission, unpublished data, processing information, and suggestions for improvement. Input from investigators could greatly improve the volume.

ACKNOWLEDGEMENTS

Larry Nyquist provided us with unpublished data on 67035.

Jean Leecraft and Sue Goudie typed the manuscript, and Sherry Feicht did all the necessary drafting on figures and photographs.

Roy Brown oriented us on the microprobe fast enough for us to obtain some preliminary data included in this volume and Chuck Meyer provided helpful advice and suggestions.

TABLE OF CONTENTS AND AVAILABLE MASSES



*Not including material with P.I. which may not have been consumed and could be transferred (see specific tables), but including clean returned material in RSPL.

# 15295 Anorthosite Clast ~0.25 gm

Evidence for pristinity: Warren and Wasson (1978) analyzed fragments and found them to have low incompatible and meteoritic siderophile abundances.

Description: Sample 15295 was described in the Apollo 15 Lunar Sample Information Catalog as containing about 5% chalk white plagioclase clasts. This clast was sampled to represent them. The only published data is that of Warren and Wasson (1978) reproduced here as Table 1. This sample is extremely anorthositic with FeO > MgO and REE abundances similar to other anorthosites. Mineral compositions are $An_{95-96}$ and $Wo_{42}En_{41}$ (Warren and Wasson, 1978).

Table 1

| | | | |
|---|---|---|---|
| $SiO_2$ | 43.9 | Zn | 25.2 |
| $Al_2O_3$ | 35.5 | Ga | 3.97 |
| $Cr_2O_3$ | 0.003 | Ge ppb | 8.2 |
| FeO | 0.23 | Cd | 11 |
| MgO | 0.18 | In | < 0.6 |
| CaO | 19.5 | | |
| $Na_2O$ | 0.40 | La | 0.19 |
| | | Sm | 0.049 |
| Sc | 0.38 | Eu | 0.78 |
| Mn | 38 | | |
| Co | 1.4 | Ir ppb | 0.021 |
| Ni | <15 | Au ppb | 0.041 |

Oxides in wt. %, others in ppm except as indicated
From Warren and Wasson (1978)

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,5 | ,0 | SSPL | 3.150 | Mainly matrix. ,22 ,24 ,25 (,28) |
| ,22 | ,5 | Wasson | 0.140 | White chips |
| ,24 | ,5 | Wasson | 0.050 | PM. Thick, half matrix |
| ,25 | ,5 | RSPL | 0.190 | Potted butt, mainly matrix. ,28 |
| ,28 | ,25 | Wasson | 0.010 | PM, mainly matrix. |

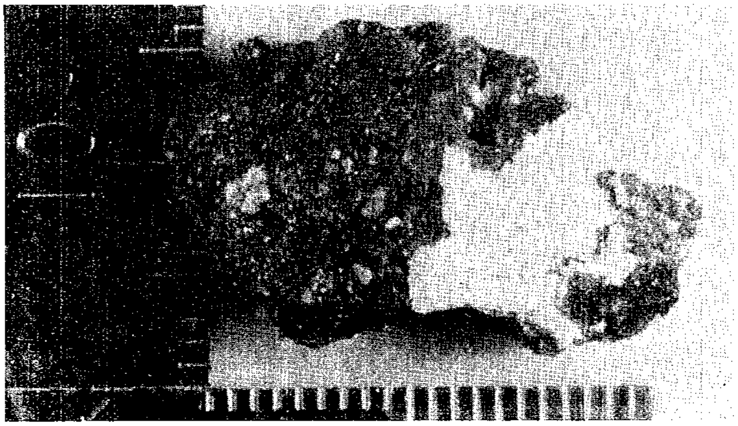


Figure 1. ,5, pre-split
Scale in millimeters.

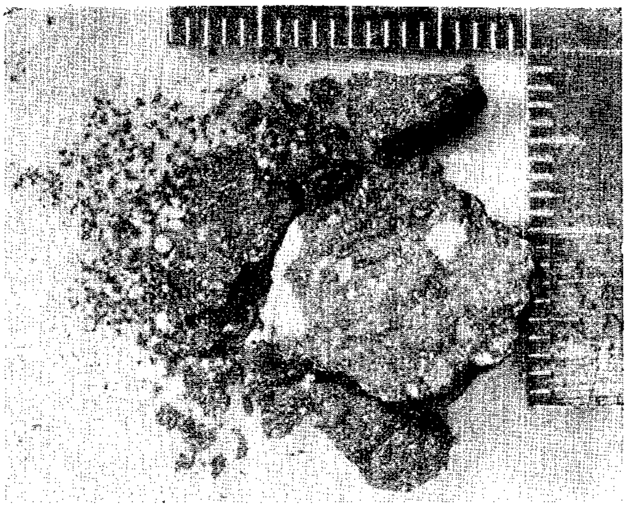


Figure 2. ,5, current sample
Scale in millimeters.

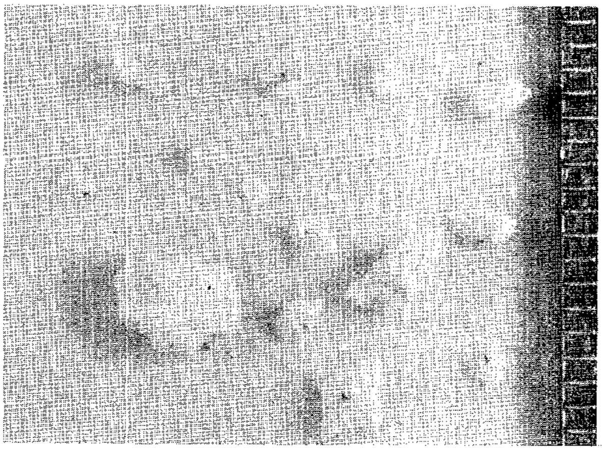


Figure 3. Chips sent to Wasson (,22) Scale in millimeters.

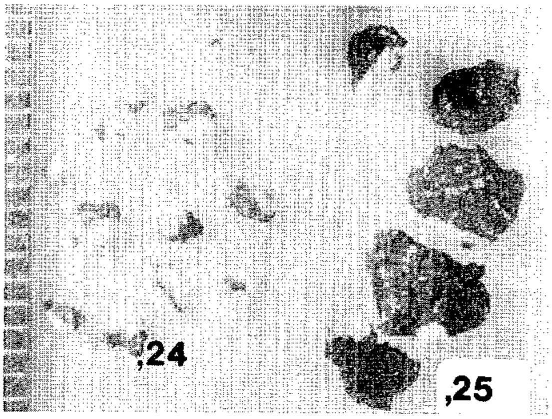



Figure 4. Chips for PM(,24) and potted butt(,25). Scale in millimeters.

## 15362 Cataclastic px-bearing anorthosite 4.2 gm

Evidence for pristinity: A split analyzed by Murali *et al.* (1977) had 10 ppm Ni (Table 1), within the range of pristine anorthosite values. Incompatible element levels are also very low (Laul *et al.*, 1972, Laul and Schmitt, 1973, Murali *et al.*, 1977).

Description: 15362 is a rake sample from Spur Crater. A petrographic description and microprobe analyses are given in Dowty *et al.* (1972, 1973) and Hlava *et al.* (1973). The anorthosite has a variable texture ranging from polygonal and irregular plagioclases to cataclastic (Figure 1), with some opaque veins probably due to shock. The modal plagioclase content is 97-98 volume %. Mineral compositions are given in Figure 2. Augite dominates over hypersthene, and ilmenite, chromite, and troilite are present in trace amounts. Olivine is absent. Structural data for pyroxene and plagioclase are also given in Dowty *et al.* (1972).

Bulk chemical analyses made by Dowty *et al.* (1972) (defocussed beam), Laul *et al.* (1972), Laul and Schmitt (1973) and Murali *et al.* (1977) are reproduced in Table 1 and Figure 3. The REE contents are typically anorthositic (Figure 3).

A $^{40}Ar/^{39}Ar$ analysis by Alexander and Kahl (1974) failed to define a good plateau (Figure 4). The authors state that the simplest explanation

Figure 1. Photomicrograph (crossed polarizers) of of 15362,6. Width of view ~2 mm.

of the release pattern is that material older than 4.1 b.y. was extensively but not completely outgassed around 3.92 b.y. This interpretation is not unique, and they suggest 3.98±0.06 b.y. as a minimum age of crystallization. Alexander and Kahl (1974) also calculate an exposure age of 428±43 m.y. for 15362.

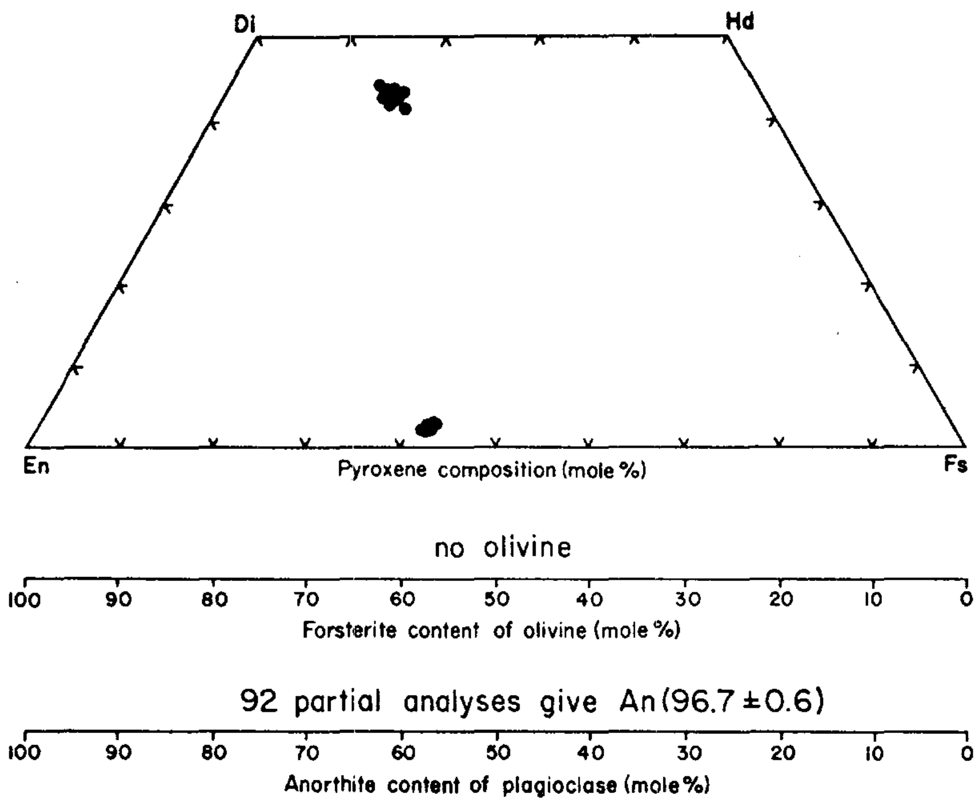


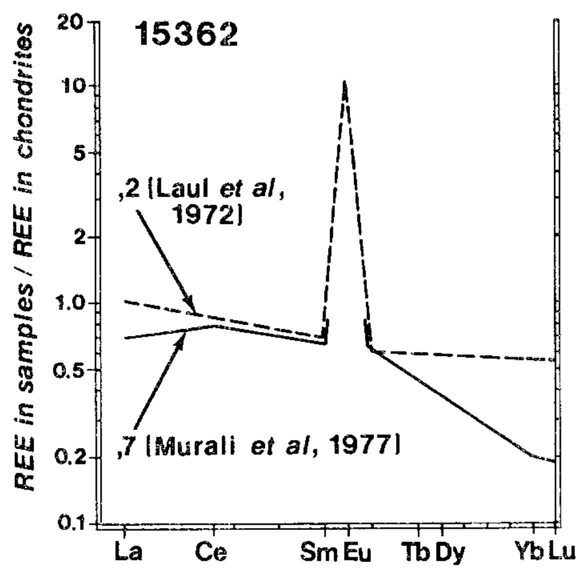

Figure 2. Compositions of minerals in 15362. From Dowty *et al.* (1972)

<u>Table 1</u>

| | 1) ,6 TS | 2) ,2 56 mg | 3) ,7 90 mg |
|---|---|---|---|
| $SiO_2$ | 44.0 | | |
| $TiO_2$ | 0.03 | 0.17,0.2 | |
| $Al_2O_3$ | 35.1 | 35.4 | 32.3 |
| $Cr_2O_3$ | 0.01 | 0.012 | 0.004 |
| FeO | 0.29 | 0.57 | 0.23 |
| MnO | 0.01 | 0.014,0.011 | 0.005 |
| MgO | 0.31 | | 0.3 |
| CaO | 19.8 | 18.4 | 17.0 |
| $Na_2O$ | 0.35 | 0.347 | 0.39 |
| $K_2O$ | 0.04 | <0.02 | 0.011 |
| $P_2O_5$ | 0.06 | | |
| Sc | | 1.6 | 0.7 |
| V | | 28, <28 | |
| Co | | 1.4 | 0.31 |
| Zr | | <70 | |
| Hf | | 0.1 | 0.5 |
| Ni | | | 10 |

| | 2) | 3) |
|---|---|---|
| La | 0.33 | 0.23 |
| Ce | | 0.72 |
| Sm | 0.12 | 0.12 |
| Eu | 0.79,0.80 | 0.80 |
| Tb | <0.04 | |
| Dy | 0.20 | |
| Yb | 0.25,<0.17 | 0.04 |
| Lu | 0.03,0.027 | 0.006 |

Oxides in wt. %, all others in ppm.
Col. 1 from Dowty *et al.* (1972, 1973), Hlava *et al.* (1973). Defocussed beam analysis, normalized to 100%.
Col. 2 from Laul *et al.* (1972), Laul and Schmitt (1973).
Col. 3 from Murali *et al.* (1977).




<u>Figure 3.</u> Rare earth abundances for 15362.

Figure 4. K/Ca and apparent age data from 15362,3. From Alexander and Kahl (1974).

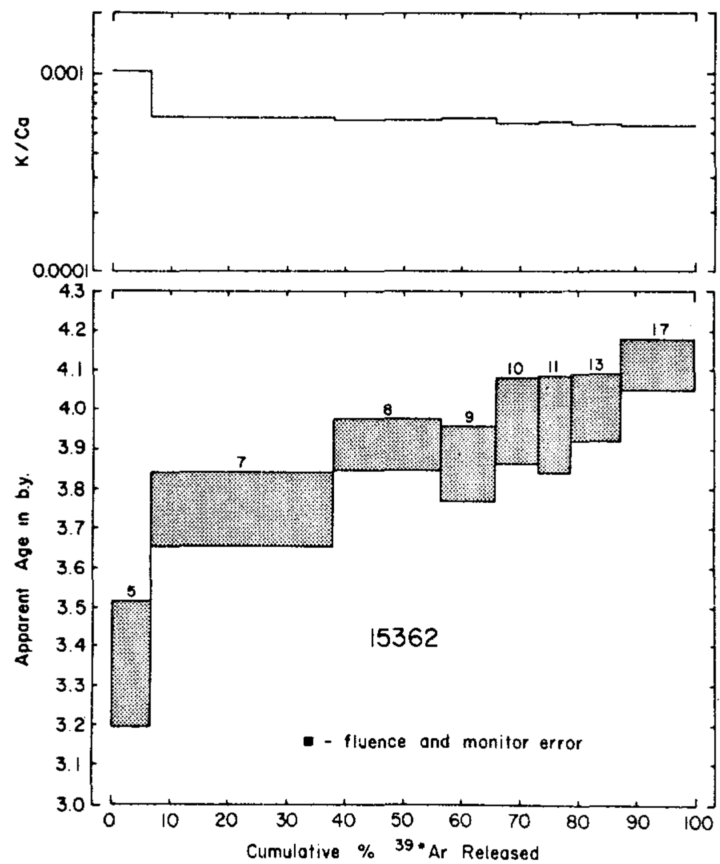


Table 2

| Split | Parent | Location | Mass | Description and daughters |
|---|---|---|---|---|
| ,0 | ,0 | SSPL | 2.950 | |
| ,1 | ,0 | Keil | 0.610 | Chip. ,6 ,11 |
| ,2 | ,0 | RSPL | 0.050 | Returned by Schmitt. Air, irradiated (neutron activation). |
| ,3 | ,0 | Reynolds | 0.300 | Chip |
| ,4 | ,0 | Price | 0.100 | Chip |
| ,5 | ,0 | Attrition | 0.040 | |
| ,6 | ,1 | Meyer | 0.010 | PM |
| ,7 | ,0 | RSPL | 0.088 | Returned by Schmitt. Air, irradiated (neutron activation). ,9 |
| ,8 | ,0 | Attrition | 0.030 | |
| ,9 | ,7 | Consumed, Schmitt | 0.012 | |
| ,11 | ,1 | Smith | 0.010 | TS |

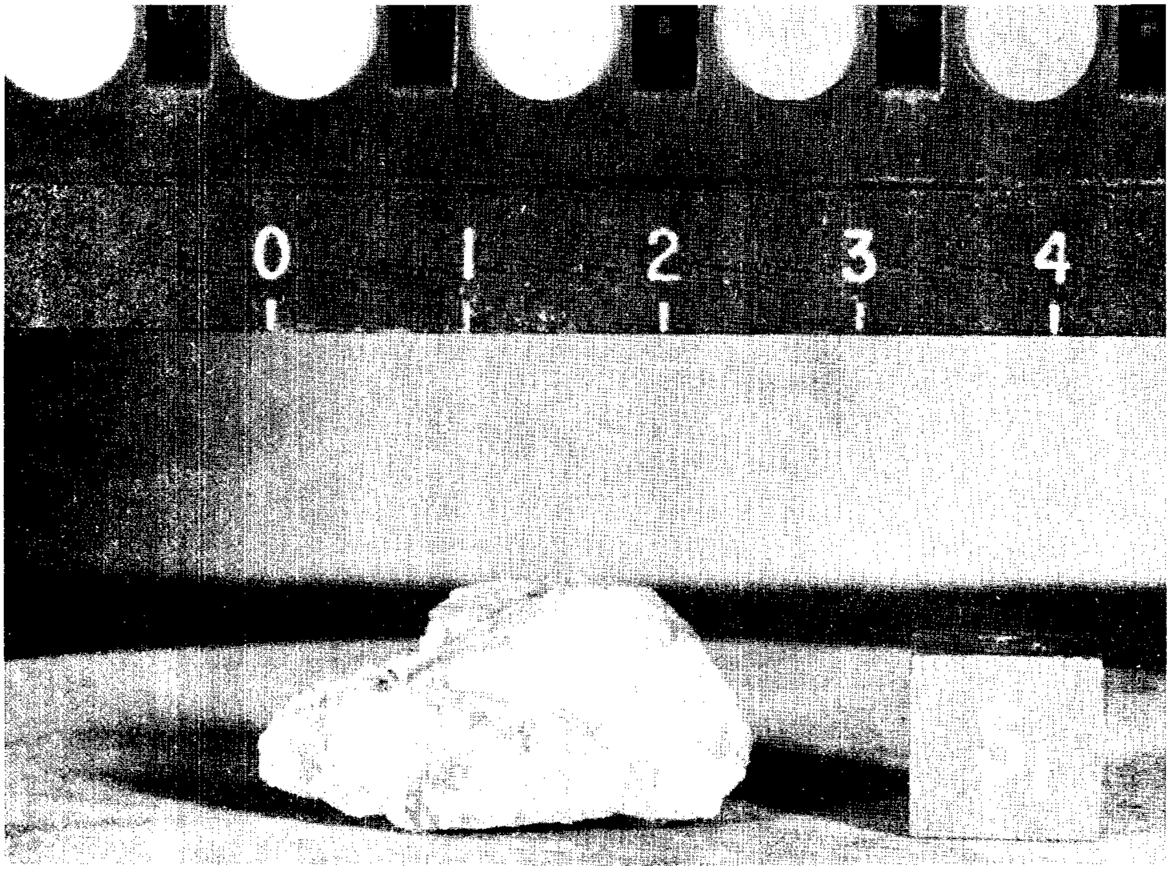



Figure 5. Original sample 15362. Scale is centimeters. (NASA S-71-49629)

## 15415 px-bearing recrystallized anorthosite 269.4 gm

Evidence for pristinity: A split analyzed by Ganapathy et al. (1973) was meteorite-free although both they and Wänke et al. (1975) found anomalously high gold. Metal is not of meteoritic origin (Hewins and Goldstein, 1975).

Description: Petrographic analyses of the "Genesis" rock anorthosite reveal a rock that is >95% plagioclase (up to 3 cm) with accessory augite and hypersthene, ilmenite, silica, and perhaps olivine and phosphate (James, 1972, Stewart et al., 1972, Wilshire et al., 1972, Hargraves and Hollister, 1972, Steele and Smith, 1971, LSPET, 1972a). Plagioclase ($An_{97}$) is subhedral and has been extensively recrystallized and granulated (Figure 1) suggesting a complex metamorphic history. Augite ($Wo_{46}En_{39}$) and hypersthene ($Wo_3En_{58}$) (Figure 2) exist interstitially to plagioclase, as poikilitically enclosed grains, along healed fractures, and in exsolution relationship. Rare pigeonite is also present. Discrete pyroxene grains are commonly <0.1 mm (James, 1972, Stewart et al., 1972, Wilshire et al., 1972, Hargraves and Hollister, 1972, Steele and Smith, 1971, LSPET, 1972a).

Whole rock chemical data from several sources is given in Table 1 and Figure 3. REE concentrations are very low with a pronounced positive Eu anomaly. Rb-Sr data by Nyquist et al. (1973) is in agreement with the values in Table 1. Nyquist et al. (1973) also provide whole-rock Rb and Sr isotopic ratios. Nyquist (1977) calculates values for the $^{87}Sr/^{86}Sr$ ratio at 4.6 b.y.

Ar-Ar ages tend to cluster around 4.0 b.y. (Husain et al., 1972, Turner, 1972, Stettler et al., 1973). This is in good agreement with the U-Pb age of 3.8-4.1 b.y. (Tatsumoto et al., 1972, Tera et al., 1972).

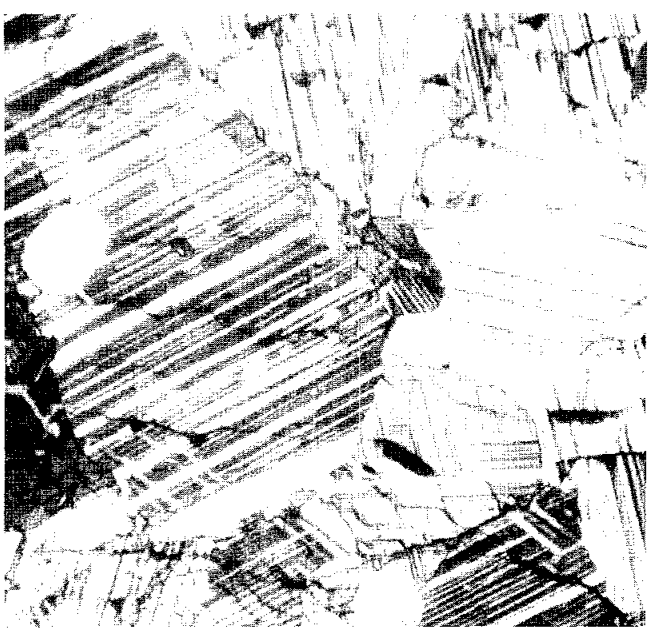


Figure 1. Photomicrograph (crossed polarizers) of 15415,29. Width of view ~2 mm.

<u>Other references</u>

Smith and Steele (1974) Pyroxene chemistry
Meyer *et al.* (1974) Limited chemical data by ion microprobe
Yokoyama *et al.* (1974) Exposure ages from $^{22}Na$ and $^{26}Al$
Clayton and Mayeda (1975) Oxygen isotopes
Niebuhs *et al.* (1973) Study of $Fe^{3+}$ using electron spin resonance
Mizutani and Newbigging (1973) Elastic wave velocities
Reed and Jovanovic (1972) Trace elements
Des Marais *et al.* (1974) Solar wind H and C
Lally *et al.* (1972) Electron petrography
Moore *et al.* (1973) Carbon

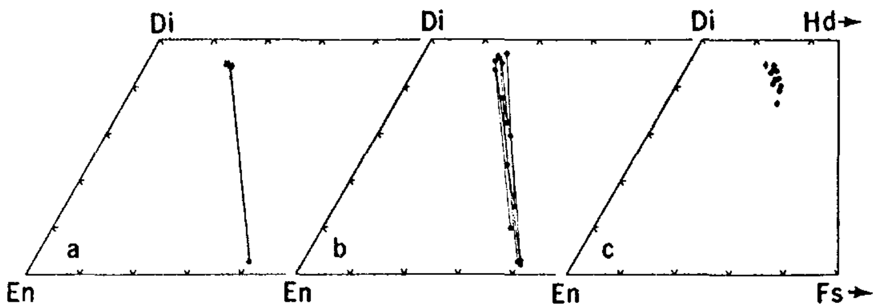



Figure 2. Compositions of pyroxenes in 15415,15. From James(1972).

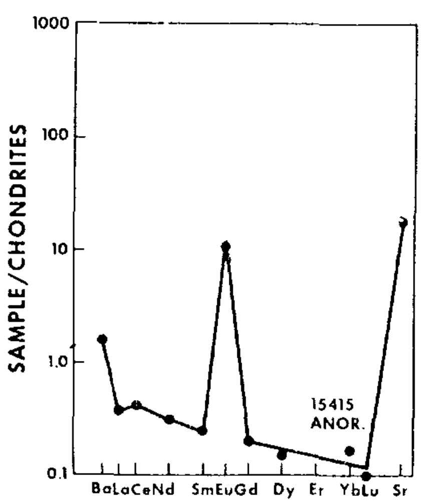



Figure 3. Incompatible element data for 15415. From Hubbard *et al.* (1971)

## Table 1

| | 1) | 2) | 3) | 4) | 5) | 6) | 7) |
|---|---|---|---|---|---|---|---|
| | ,123 portion of ,8 280 mg | portion of ,12 ?mg | portion of ,125 from ,11 | | portion of ,41 ?mg | portion of ,40 240mg | ,116 portion of ,12 91mg |
| | | | 53mg | 91mg | | | |
| $SiO_2$ | 44.08 | 44.94 | | | | | |
| $TiO_2$ | 0.02 | 0.02 | | 0.016 | | | |
| $Al_2O_3$ | 35.49 | 35.72 | | | | | |
| FeO | 0.23 | 0.21 | | | | | |
| MnO | 0.00 | 0.01 | | | | | |
| MgO | 0.09 | 0.53 | | 0.16 | | | |
| CaO | 19.68 | 20.58 | | | | | |
| $Na_2O$ | 0.34 | 0.38 | | 0.38 | | | |
| $K_2O$ | <0.01 | 0.02 | | | | | |
| $P_2O_5$ | 0.01 | | | | | | |
| La | | 0.21 | 0.12 | 0.118 | | | |
| Ce | | | 0.32 | 0.35 | | | |
| Nd | | | 0.20 | 0.175 | | | |
| Sm | | 0.062 | 0.049 | 0.046 | | | |
| Eu | | 0.82 | 0.807 | 0.806 | | | |
| Gd | | | 0.06 | 0.050 | | | |
| Dy | | 0.054 | 0.06 | 0.044 | | | |
| Yb | | 0.035 | 0.05 | 0.035 | | | |
| Lu | | 0.004 | 0.003 | 0.003 | | | |
| K | 120 | 138 | 127 | 120 | 151 | | |
| U ppb | 2.4 | 1.5 | | 0.98 | 1.5 | 2.4 | |
| Th ppb | 7 | | | 2.7 | 3.5 | 5.1 | |
| Pb | | | | | 0.25 | 0.23 | |
| Rb | | | 0.17 | 0.361 | 0.217 | | 0.11 |
| Sr | 184 | 173 | 178 | 148 | 173.3 | | |
| Co | | 0.26 | | | | | |
| Ni | | 3 | | | | | |
| Zn | | 31.8 | | | | | 0.26 |
| Au ppb | | 0.77 | | | | | 0.117 |
| Ir ppb | | | | | | | <0.010 |
| Re ppb | | | | | | | 0.00084 |

Oxides in wt. %, all others in ppm except as noted.
Col. 1 from LSPET (1972a)
Col. 2 from Wänke *et al.* (1975)
Col. 3 from Hubbard *et al.* (1971), Laul *et al.* (1972) and Wiesmann and Hubbard (1975)
Col. 4 from Wiesmann and Hubbard (1975)
Col. 5 from Tatsumoto *et al.* (1972) (average of presented data)
Col. 6 from Tera *et al.* (1972) (average of presented data)
Col. 7 from Ganapathy *et al.* (1973)

## 15465 Anorthosite clast ∿ 0.250 gm?

Evidence for pristinity: Warren and Wasson (1978) analyzed a small split and found it to be very low in meteoritic siderophiles and incompatibles (Table 1).

Description: The clast was described in the Apollo 15 Lunar Sample Information Catalog as coarse grained with euhedral white, gray feldspar laths with one or two opaque specks. The only two thin sections cut from ,1 (originally numbered 15469 and which contains the clast) do not contain recognizable anorthosite (Warren and Wasson, 1978, and our own observations).

Warren and Wasson (1978) made a bulk analysis reproduced here in Table 1, but note that their small sample mass caused much reduced precision. Clearly the clast is an anorthosite with FeO > MgO.

Table 1

| | Portion of ,56 26.5 mg | | |
|---|---|---|---|
| $SiO_2$ | 44.3 | Zn | 0.98 |
| $TiO_2$ | 0.267 | Ga | 4.05 |
| $Al_2O_3$ | 34.0 | Ge ppb | 53 |
| FeO | 1.55 | Cd | 3.8 |
| MgO | 0.83 | In | 0.34 |
| CaO | 19.3 | | |
| $Na_2O$ | 0.34 | La | 0.61 |
| $K_2O$ | 0.022 | Sm | 0.26 |
| | | Eu | 0.8 |
| Sc | 1.9 | | |
| Mn | 110 | Ir ppb | 0.090 |
| Co | 7.5 | Au ppb | 0.056 |
| Ni | <4 | | |

Oxides in wt. %, all others in ppm except as indicated.
From Warren and Wasson (1978).

Table 2

| Split | Parent | Location | Mass | Description |
|---|---|---|---|---|
| ,0 | | SSPL | 275.400 | Mainly glass and other fragments, trace of anorthosite |
| ,23 | ,1 | RSPL | 1.469 | Potted butt, mainly glass. |
| ,56 | ,0 | Wasson | 0.200 | Includes glass. |

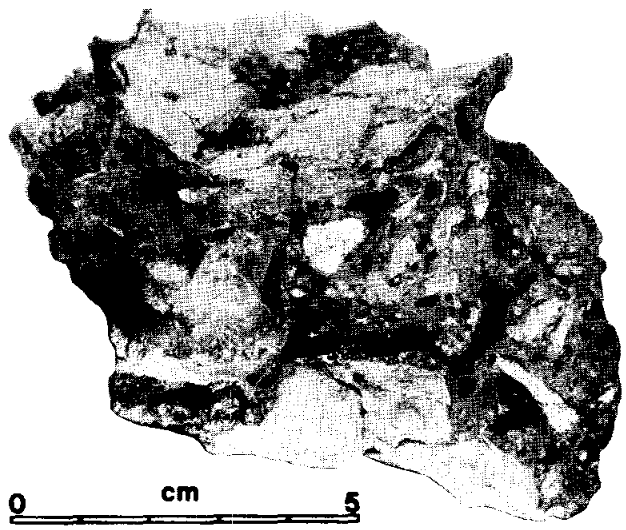



Figure 1. 15465,0, prior to chipping ,56.
The anorthosite is the white clast in the center.

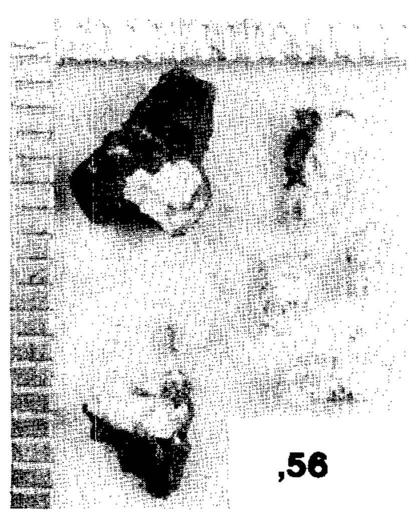



Figure 2. Split ,56, sent to Wasson.

## 60015 Cataclastic px-bearing anorthosite 5574 gm

Evidence for pristinity: Although no siderophile data are available, several lines of evidence point to a pristine chemistry. Rare earth concentrations (Laul and Schmitt, 1973, Taylor *et al.*, 1973) and the initial $^{87}Sr/^{86}Sr$ (Nyquist *et al.*, 1975, Nunes *et al.*, 1974) are very low. In addition, the relict grain size is coarse (Apollo 16 Lunar Sample Information Catalog).

Description: Macroscopically 60015 is a coherent, glass coated, coarsely crystalline anorthosite. Thin sections show a cataclastic texture with strained anhedral plagioclase sitting in a granulated matrix (Figure 1). Petrographic descriptions are given by Sclar *et al.* (1973), Sclar and Bauer (1974), Dixon and Papike (1975), Juan *et al.* (1974). Plagioclase ($An_{90-98}$) makes up ∿ 98% of the rock with fine-grained pyroxene accounting for the remainder. Olivine is absent. Compositions of pyroxenes are given in Figure 2. Orthopyroxene and augite tend to be concentrated in the matrix with rare ilmenite, spinel, and troilite. Occasional grains of orthopyroxene contain exsolution lamellae of augite (Dixon and Papike, 1975, Sclar *et al.*, 1973, Sclar and Bauer, 1974, Juan *et al.*, 1974).

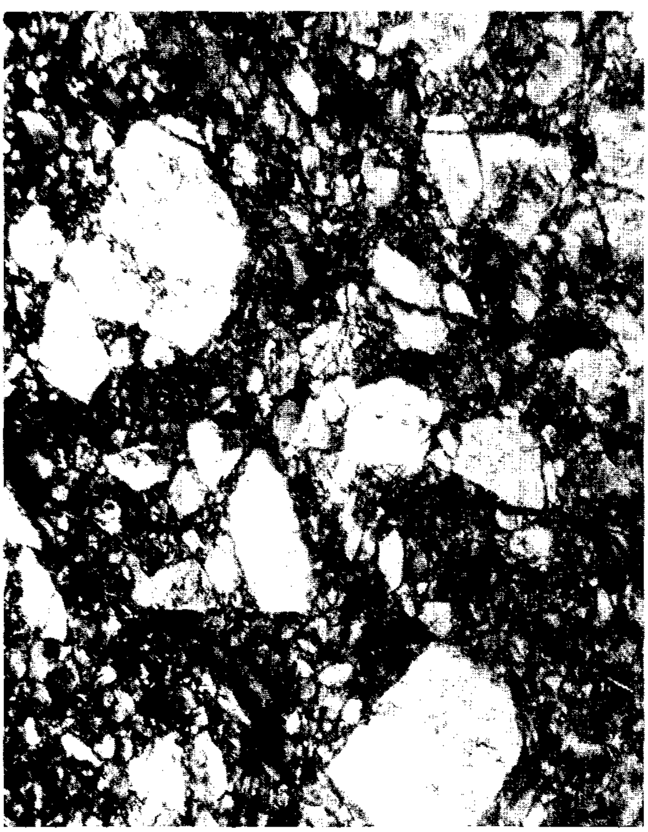


Figure 1. Photomicrograph (crossed polarizers) of 60015, 129. Width of view ∿2 mm.

Bulk chemical analyses are presented in Table 1 and Figure 3. Rare earth concentrations are very low and identical to 15415 (Laul and Schmitt, 1973, Taylor et al., 1973). Initial $^{87}Sr/^{86}Sr$ of 0.69902 (Nyquist et al., 1975) and 0.69892 (Nunes et al., 1974) are among the lowest of any lunar samples. Nickel is slightly high for a typical anorthosite (Table 1).

K-Ar and U-Th-Pb systematics appear to have been disturbed. Ar-Ar gives a well defined plateau at 3.5 b.y. (Figures 4a, 4b) and K-Ar yields an age of 3.37 b.y. (Schaeffer and Husain, 1974, Phinney et al., 1975). Nunes et al. (1973) calculate a Pb-Pb age of 3.80 b.y. using a three stage model or 3.57 b.y. using a two stage model. Rb-Sr model ages of 3.5 b.y. and 4.5 b.y. can be calculated by assuming different initial $^{87}Sr/^{86}Sr$ (Nyquist et al., 1975).

Other references

- Miller et al. (1974) Limited chemical data
- Hörz et al. (1975) Exposure ages
- Bhandari et al. (1973) Exposure ages
- Mao and Bell (1976) Metal compositions
- Hewins and Goldstein (1975) Metal compositions
- Leich and Niemeyer (1975) Noble gases
- Niemeyer and Leich (1976) Noble gases
- Cisowski et al. (1976) Magnetic effects of shock
- Collinson et al. (1973) Magnetic properties
- Stephenson et al. (1974) Magnetic properties
- Stephenson et al. (1975) Magnetic properties
- Herminghaus and Berckhimer (1974) Elastic wave properties
- Chung (1973) Elastic wave properties
- Chung and Westphal (1973) Electrical properties
- Moore et al. (1973) Carbon
- Ehmann and Chyi (1974) Zr-Hf data
- Jovanovic and Reed (1973) Trace elements

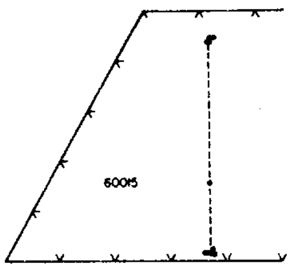



Figure 2. Compositions of pyroxenes in 60015. From Dixon and Papike (1975).

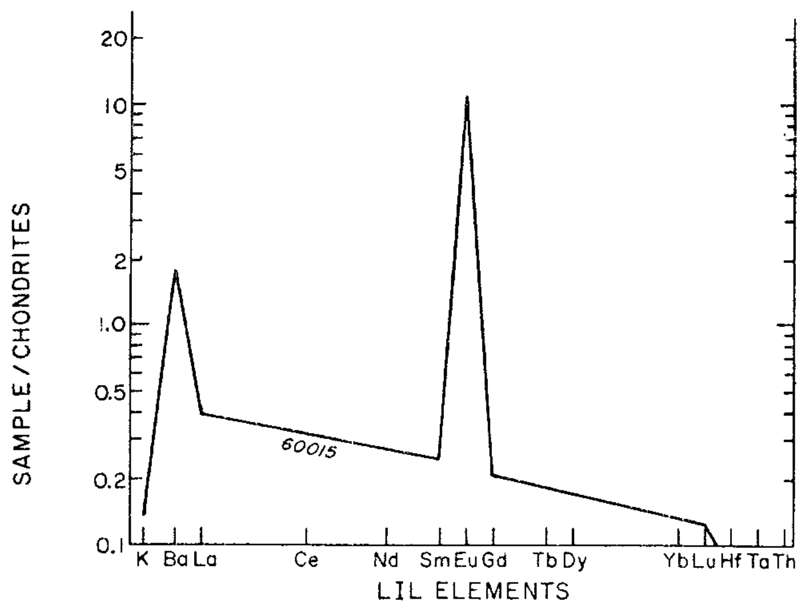



Figure 3. Incompatible element abundances in 60015. From Warner et al. (1976).

Table 1

| | 1) | 2) | 3) | 4) | 4) | 5) | 6) | 7) | 7) |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 44.2 | 43.97 | | 43.87 | 43.66 | | | | |
| $TiO_2$ | | 0.02 | <0.06 | | | | | | |
| $Al_2O_3$ | 35.7 | 35.83 | 35.5 | 34.40 | 33.45 | | | | |
| $Cr_2O_3$ | 0.006 | | 0.007 | | | | | | |
| FeO | 0.26 | 0.36 | 0.35 | | | | | | |
| MnO | | | 0.009 | 0.10 | | | | | |
| MgO | 0.35 | 0.25 | | 1.00 | | | | | |
| CaO | 19.3 | 18.95 | 20.0 | 17.36 | 19.18 | | | | |
| $Na_2O$ | 0.36 | 0.34 | 0.41 | 0.43 | 0.42 | | | | |
| $K_2O$ | 0.13 | 0.01 | <0.01 | | | | | | |
| La | | | 0.13 | | | | | | |
| Ce | 0.63 | | | | | | | | |
| Nd | 0.35 | | | | | | | | |
| Sm | 0.08 | | 0.051 | | | | | | |
| Eu | 0.81 | | 0.81 | | | | | | |
| Gd | 0.06 | | | | | | | | |
| Dy | | | <0.06 | | | | | | |
| Yb | | | 0.02 | | | | | | |
| Lu | | | 0.003 | | | | | | |
| K | | | | | | 54 | | | |
| Rb | 0.10 | <2 | | | | 0.1221 | | | |
| Sr | | 156 | | | | 166.2 | | | |
| Ba | 10 | | 8 | | | | | | |
| Zr | 1.1 | | | | | | | 0.135 | 0.086 |
| Hf ppb | | | 130 | | | | | 85 | 105 |
| Co | | 44 | 0.70 | | | | | | |
| Ni | | 30 | | | | | | | |
| Pb | 0.22 | | | | | 0.171 | .187 | | |
| U ppb | | | | | | 23 | 10 | | |
| Th ppb | | | | | | 60 | 32 | | |

Col. 1 from Taylor *et al.* (1973)
Col. 2 from Juan *et al.* (1974)
Col. 3 from Laul and Schmitt (1973)
Col. 4 from Janghorbani *et al.* (1973)
Col. 5 from Nunes *et al.* (1974)
Col. 6 from Nunes *et al.* (1973) - average of 4 analyses
Col. 7 from Garg and Ehmann (1976)

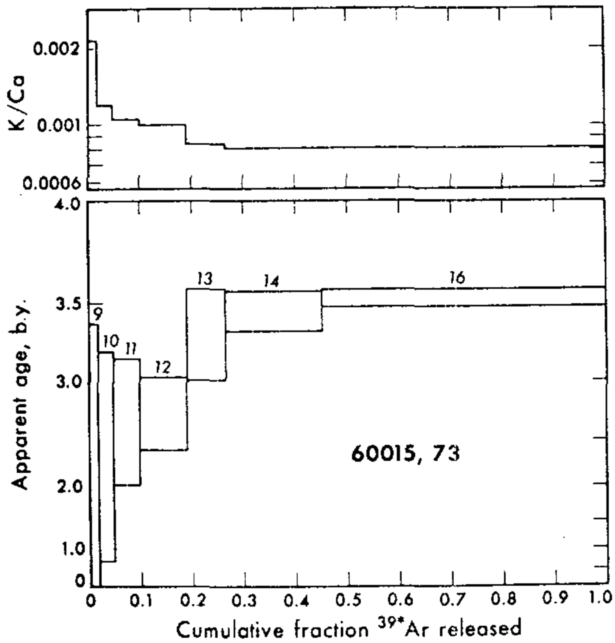



Figure 4a. K/Ca and apparent age data from 60015. From Phinney et al. (1975).

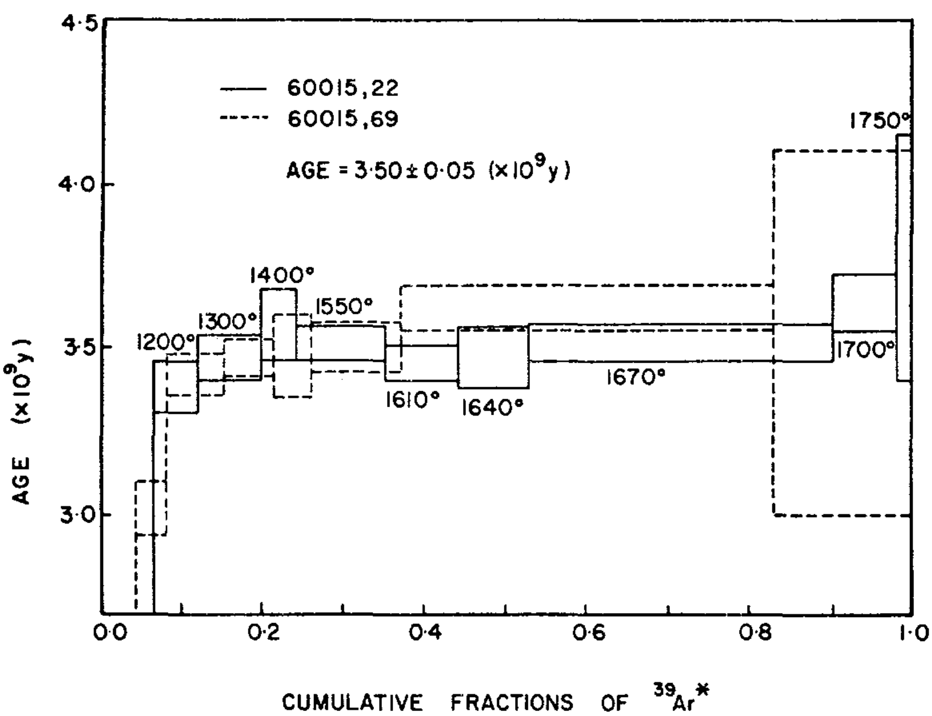



Figure 4b. Age data for 60015. From Schaeffer and Husain (1974).

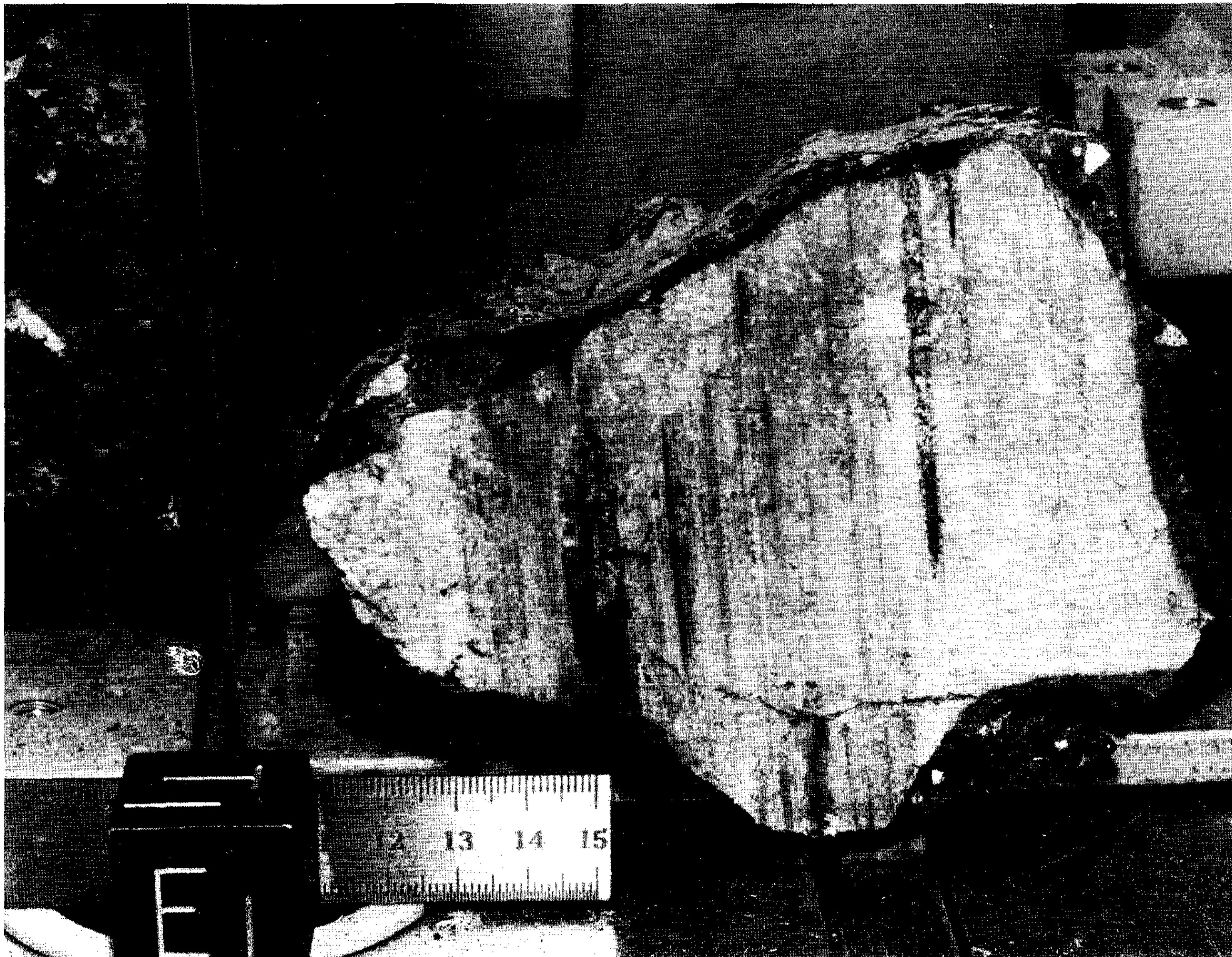



Figure 5. Sawn surface of 60015,2 showing glassy rind. (NASA S-76-21694)

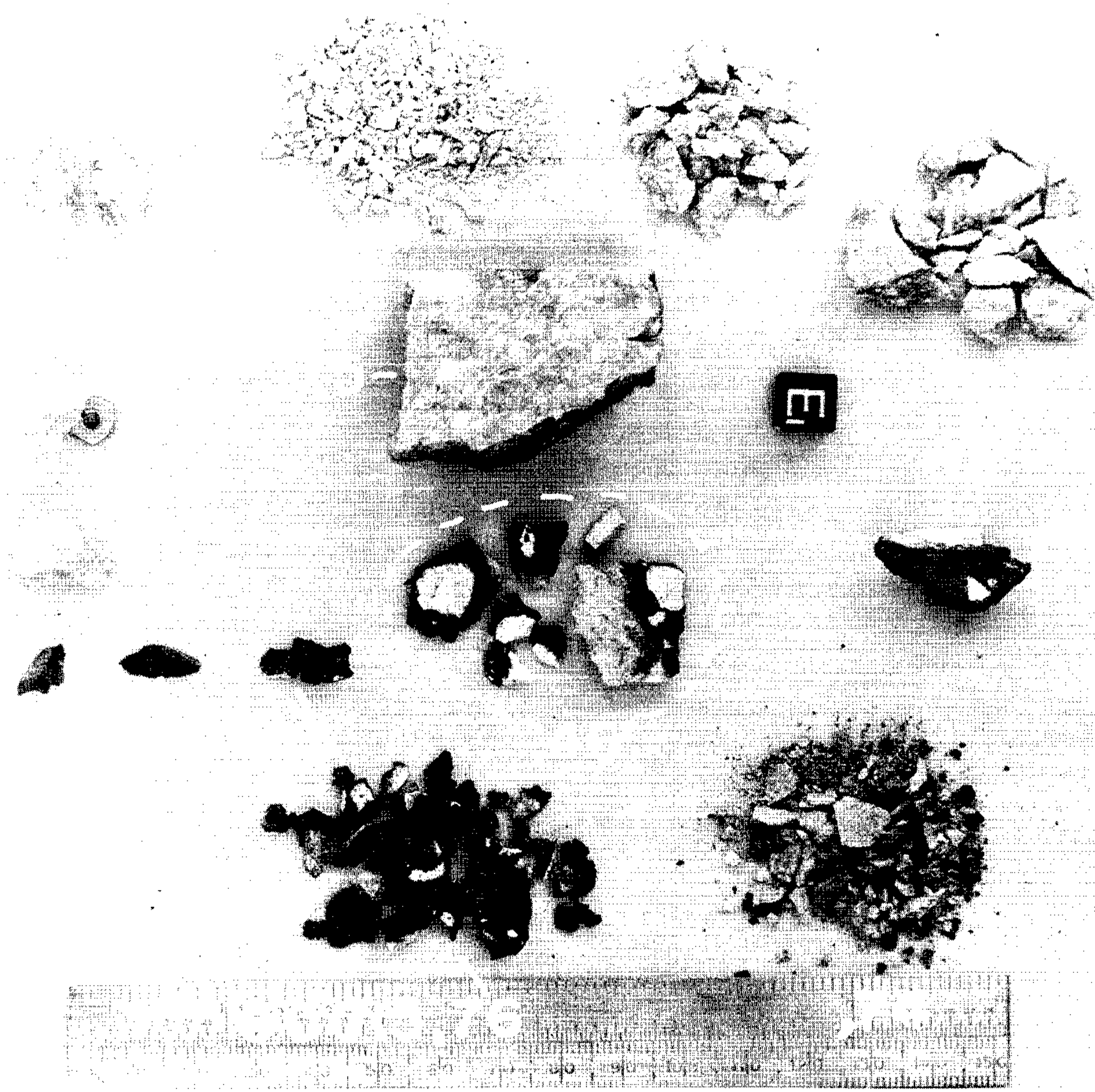


Figure 6. Examples of splits of 60015. (NASA S-72-55505)

## 60025 Cataclastic px-bearing anorthosite 1836 gm

Evidence for pristinity: Low concentrations of siderophiles indicate this rock is pristine (Krähenbühl *et al.*, 1973, Ganapathy *et al.*, 1974).

Description: 60025 is a coarse grained (up to 10 mm) moderately shocked anorthosite (Dixon and Papike, 1975, Hodges and Kushiro, 1973, Walker *et al.*, 1973). Anhedral plagioclase exhibits a variety of shock features and often sits in a matrix of granulated feldspar. Plagioclase makes up >95% of this rock and ranges in composition from $An_{94}$ to $An_{98}$ although no systematic zoning is present (Dixon and Papike, 1975, Hodges and Kushiro, 1973, Walker *et al.*, 1973). Anhedral pyroxenes (<0.5 mm) are concentrated in the matrix but also occur along twin lamellae, near grain boundaries, and as inclusions in undisturbed crystals. Orthopyroxene is the dominant mafic mineral although augite is also present (Figure 1). Exsolution of augite from opx. is rare. Trace amounts of ilmenite, Cr-spinel, silica, and glassy inclusions in plagioclase have also been reported. No olivine was found (Dixon and Papike, 1975, Hodges and Kushiro, 1973, Walker *et al.*, 1973).

Whole rock chemistry is presented in Table 1 and Figure 2. REE concentrations are low but nearly twice as high as in 15415. Pb values reported by Nunes *et al.* (1974) are high due to terrestrial contamination.

An Ar-Ar age of 4.19 b.y. (Schaeffer and Husain, 1974) is one of the oldest ages obtained by this method on a lunar rock.

Other references

- Longhi *et al.* (1976) Fe and Mg in plagioclase
- Nyquist *et al.* (1975) Rb-Sr data
- Takeda *et al.* (1976) Pyroxene studies
- Miller *et al.* (1974) Limited chemical data by INAA
- Ehmann and Chyi (1974) Limited Zr, Hf, Ti data
- Drozd *et al.* (1977) Exposure ages by Kr isotopes
- Fruchter *et al.* (1977) Exposure ages by $^{22}Na$, $^{26}Al$, and $^{53}Mn$
- Moore *et al.* (1973) Carbon content
- Lightner and Marti (1974b) Trapped Ar, Xe, Kr
- Taylor and Epstein (1973) O and Si isotopes
- Simmons *et al.* (1975) Microcracks
- Katsube and Collett (1973) Electrical characteristics
- Tera and Wasserburg (1972) U-Th-Pb systematics
- Papanastassiou and Wasserburg (1972) Rb-Sr systematics

## Table 1

| | 1) | 2) | 3) | 3) | 4) | 5) | 6) |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 45.3 | | 44.74 | | 43.93 | 42.8 | 44.4 |
| $TiO_2$ | <0.02 | <0.06 | 0.2 | | 0.02 | | 0.1 |
| $Al_2O_3$ | 34.2 | 35.5 | 35.28 | | 35.21 | 36.86 | 35 |
| $Cr_2O_3$ | 0.004 | 0.0022 | 0.03 | | | | 0.05 |
| FeO | 0.495 | 0.35 | 0.31 | | 0.67 | 1.29 | 0.66 |
| MnO | 0.008 | 0.0064 | 0.013 | | 0.03 | 0.01 | |
| MgO | 0.206 | | 0.17 | | 0.27 | 0.17 | 0.3 |
| CaO | 19.8 | 18.2 | 19.38 | | 18.92 | 17.22 | 19.5 |
| $Na_2O$ | 0.45 | 0.414 | 0.44 | | 0.49 | 0.45 | 0.43 |
| $K_2O$ | 0.113 | <0.01 | 0.028 | | 0.03 | | 0.02 |
| La | 0.28 | 0.30 | 0.301 | | | | |
| Ce | 0.65 | 0.8 | 0.645 | 0.641 | | | |
| Nd | 0.42 | 0.5 | 0.361 | | | | |
| Sm | 0.092 | 0.12 | 0.0881 | 0.0918 | | | |
| Eu | 1.04 | 1.04 | 1.044 | 1.030 | | | |
| Tb | 0.20 | <0.02 | | | | | |
| Gd | | | 0.0895 | 0.0921 | | | |
| Dy | 0.19 | 0.11 | 0.0783 | 0.0834 | | | |
| Er | 0.05 | | 0.0420 | 0.0409 | | | |
| Yb | 0.048 | 0.051 | 0.0429 | 0.0412 | | | |
| Lu | 0.0056 | 0.005 | 0.00465 | 0.00386 | | | |

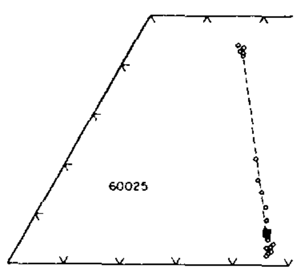
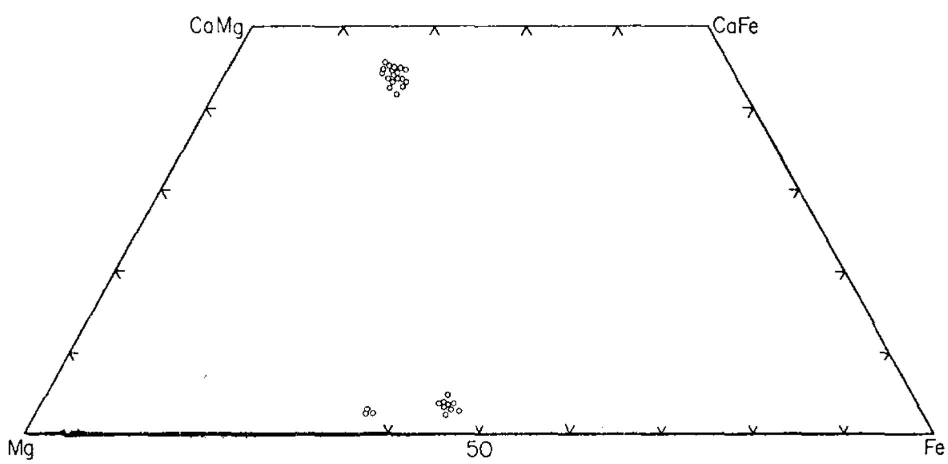



Figure 1. Compositions of pyroxenes in 60025. Top from Dixon and Papike (1975), bottom from Hodges and Kushiro (1973).



## Table 1 cont'd

| | 1) | 2) | 4) | 7) | 8) | 9) | 10) |
|---|---|---|---|---|---|---|---|
| K | | | | | 60 | 50.5 | |
| Rb | <0.1 | | 0.08 | 0.017 | 0.02017 | | |
| Sr | | | 205 | | 213.6 | | |
| U ppb | | | | 0.92 | 0.594, 0.502 | 0.79 | |
| Th ppb | | | | | 1.52, 1.08 | 3.8 | |
| Co | 0.73 | 0.70 | 3.6 | | | | 0.7 |
| Ni | 1.1 | | 30 | ≤3 | | | |
| Zn | <2.0 | | 15 | 0.17 | | | |
| Zr | | | <10 | | | | 0.48, 0.54 |
| Hf | 0.02 | 0.014 | | | | | 0.015, 0.018 |
| Ir ppb | | | | 0.0057 | | | |
| Re ppb | | | | 0.0016 | | | |
| Au ppb | | | | 0.0074 | | | |

Oxides in wt. %, others in ppm except as noted.
Col. 1 from Haskin et al. (1973)
Col. 2 from Laul and Schmitt (1973)
Col. 3 from Nakamura et al. (1973)
Col. 4 from Rose et al. (1973)
Col. 5 from Janghorbani et al. (1973)
Col. 6 from Walker et al. (1973)
Col. 7 from Krähenbühl et al. (1973)
Col. 8 from Nunes et al. (1974)
Col. 9 from Tera et al. (1973)
Col. 10 from Ehmann et al. (1975)

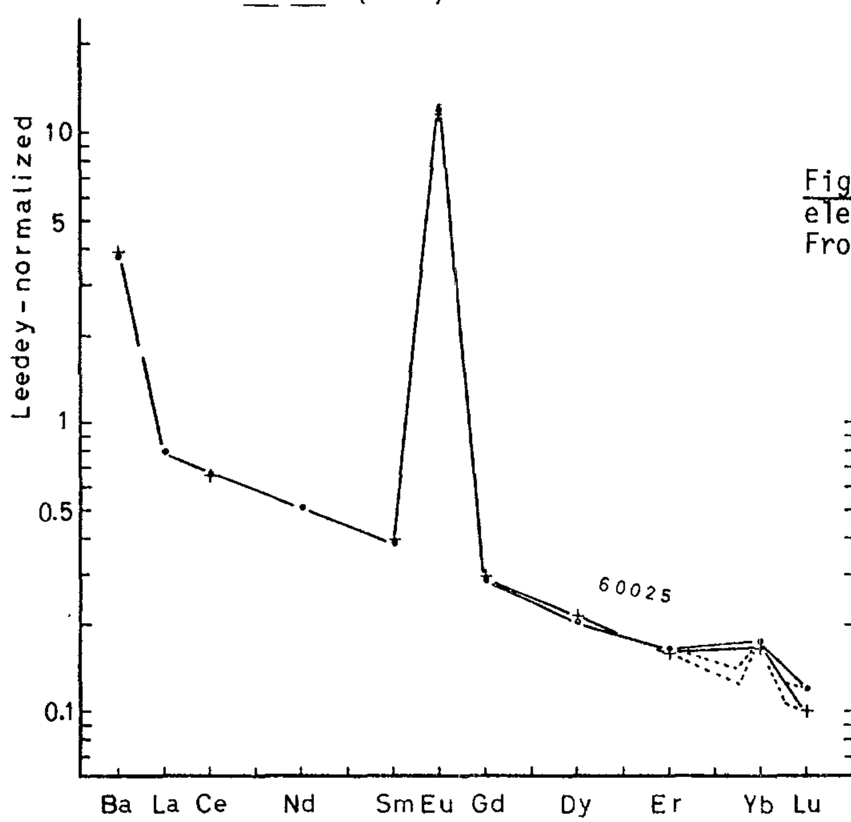



Figure 2. Incompatible element data for 60025. From Nakamura et al. (1973)

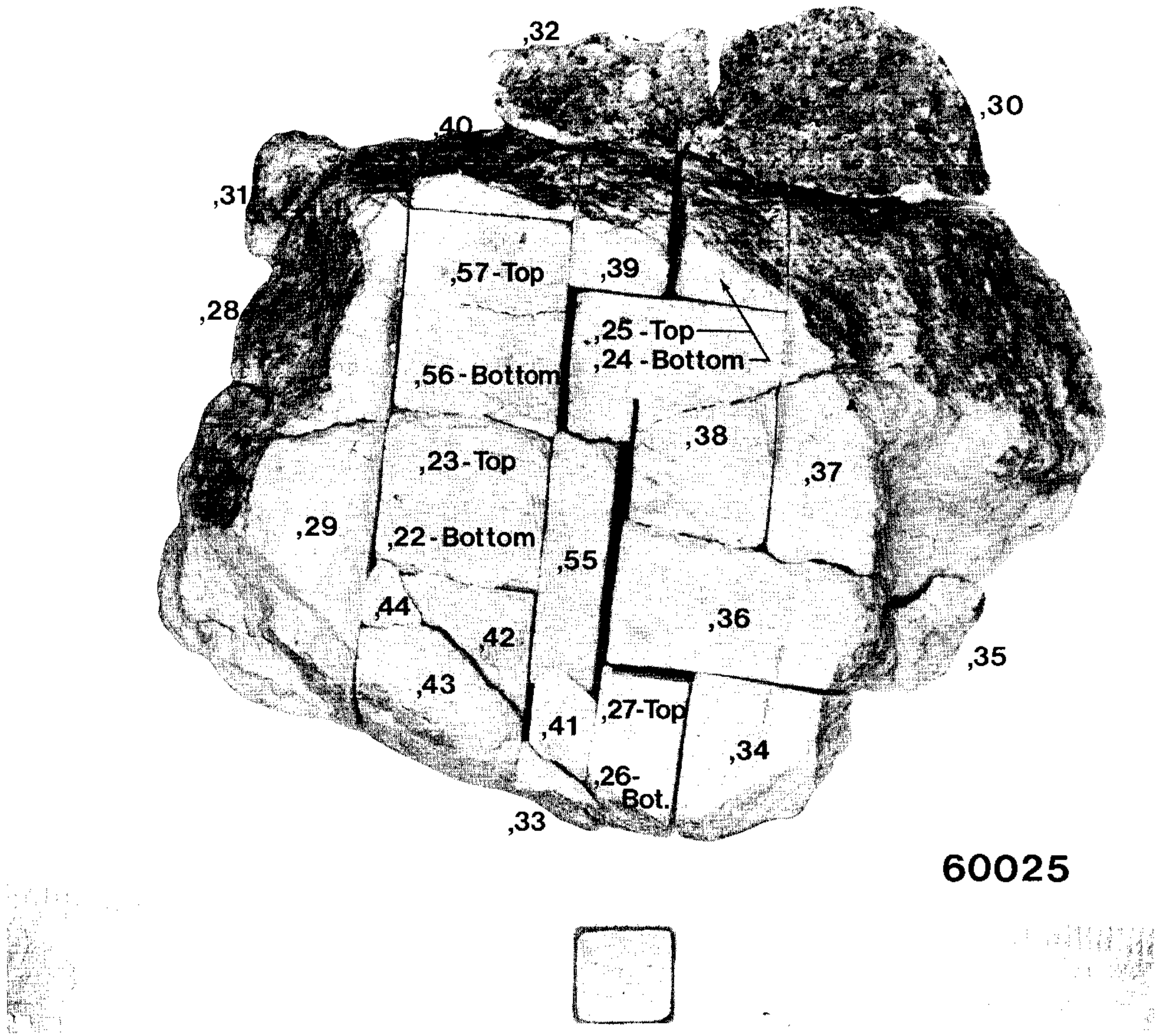



Figure 3. Example of splits of 60025: dissection of a slab. (NASA S-72-49095)

## 60055 Cataclastic px-bearing anorthosite 35.5 gm

Evidence for pristinity: Warren and Wasson (1978) analyzed a fragment and found it to be free of meteorite contamination and to have low incompatible element abundances (Table 1).

Description: 60055 is a homogeneous granular rock composed of ∿99% plagioclase. Warren and Wasson (1978) report 98% plagioclase and 2% pyroxenes in thin section ,5 with an original grain size >2 mm. Plagioclases are $An_{95.4-96.4}$ and pyroxenes are mainly high-Ca ($En_{42}$ $Wo_{42-44}$) but one analysis was a low-Ca exsolved pyroxene ($En_{61}$ $Wo_2$) (Warren and Wasson 1978). Our own observations of thin section ,4 and ,7 confirm that the clast is a porous, cataclastic anorthosite (Figure 1) with traces of a silica mineral and rare grains of ilmenite (with exsolved rutile lamellae) with at least one other, more-poorly-reflecting opaque phase. Rare relict grain boundaries between mafics and plagioclase are present.

An analysis made by Warren and Wasson (1978) is reproduced here in Table 1, and confirms the anorthositic nature of the clast.

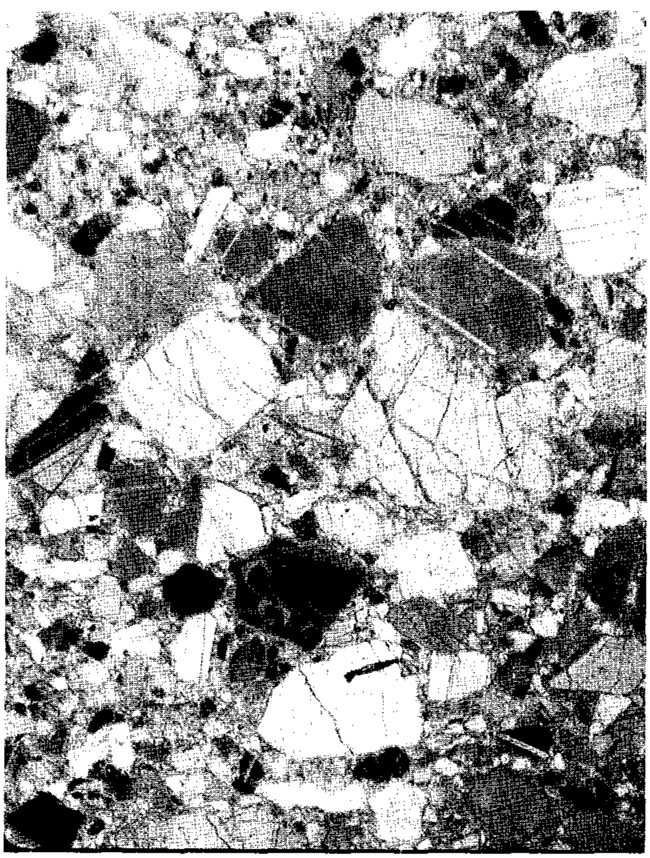


Figure 1. Photomicrograph (partially crossed polarizers) of 60055,4. Width of view ∿2 mm.

Table 1

| | ,1 290 mg | | |
|---|---|---|---|
| $SiO_2$ | 44.3 | Ge ppb | 16.6 |
| $Al_2O_3$ | 34.0 | Cd | 0.57 |
| $Cr_2O_3$ | 0.005 | In | 3.6 |
| FeO | 0.34 | | |
| MgO | 0.33 | Ba | 11 |
| CaO | 19.04 | La | 0.13 |
| $Na_2O$ | 0.335 | Ce | 0.27 |
| $K_2O$ | 0.010 | Sm | 0.040 |
| | | Eu | 0.76 |
| Sc | 0.55 | Yb | 0.035 |
| Mn | 74.6 | Lu | 0.0038 |
| Co | 0.84 | | |
| Ni | 1.9 | Re ppb | <0.0007 |
| Zn | 0.60 | Au ppb | 0.014 |
| Ga | 3.8 | | |

Oxides in wt. %, others in ppm except as noted.

From Warren and Wasson (1978)

Table 2

| Split | Parent | Location | Mass | Description |
|---|---|---|---|---|
| ,0 | | B01 | 16.710 | |
| ,1 | ,0 | Wasson | 0.290 | Chips |
| ,2 | ,0 | Ent. Subd. | 0.000 | Was chip. |
| ,3 | ,0 | SSPL | 4.610 | Chips |
| ,4 | ,2 | SCC | 0.010 | TS |
| ,5 | ,2 | Wasson | 0.010 | PM |
| ,6 | ,2 | Phinney | 0.010 | TS |
| ,7 | ,2 | SCC | 0.010 | TS |
| ,8 | ,2 | Attrition | 0.210 | -- |
| ,9 | ,0 | Reserve TSL | 0.000 | -- |
| ,10 | ,0 | SSPL | 13.250 | Small chips and fines. |
| ,11 | ,0 | Attrition | 0.370 | -- |

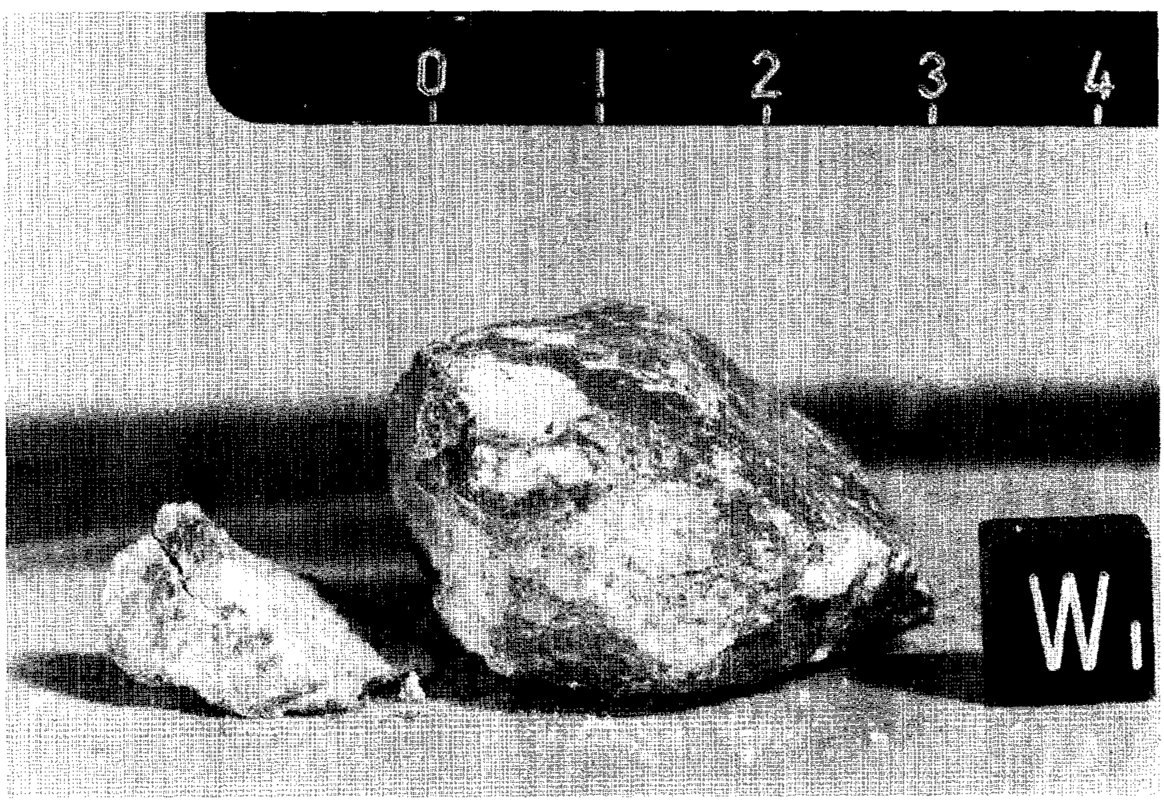



Figure 2. Original sample 60055. Gray is dust cover. Scale is centimeters (NASA S-72-41416).

## 60215 Cataclastic anorthosite 386 gm

Evidence for pristinity: A split analyzed by Rose et al. (1975) has very low contents of Co and Ni indicating no meteoritic contamination.

Description: 60215 is a coherent, cataclastic anorthosite with very low porosity (Figure 1). Its original coarse grain size is preserved as mineral and lithic clasts up to 4 mm long (Meyer and McCallister, 1973, Apollo 16 Lunar Sample Information Catalog). Although extensively crushed and disaggregated, this rock shows very little extremely fine grained matrix.

Plagioclase ($An_{96}$) makes up 97% of this rock. Small amounts of maskelynite are present and fibrous and microgranular recrystallization has occurred. Other homogeneous clasts appear unaffected by shock (Meyer and McCallister, 1973, Apollo 16 Lunar Sample Information Catalog).

Accessory minerals include orthopyroxene of composition $Wo_{1-2}$ $En_{62-68}$ (Figure 2), rare ilmenite, troilite, and metal (Meyer and McCallister, 1973, Dixon and Papike, 1975, Apollo 16 Lunar Sample Information Catalog). One grain of olivine was observed (Apollo 16 Lunar Sample Information Catalog). One large anorthosite clast contained a nest of disaggregated pyroxene of composition $Wo_5$ $En_{63}$ and a single grain of Cr-spinel (Meyer and McCallister, 1973). No exsolution of the pyroxenes was observed (Dixon and Papike, 1975).

Troctolitic rock fragments (Meyer and McCallister, 1973) account for up to 3% of one thin section (,13). These clasts are angular, generally <0.8 mm, and possess a subophitic texture (Figure 3). Plagioclase in these fragments is $An_{94}$ and olivine is $Fo_{80-90}$. Minor phases include intersertal glass and sulfides (Meyer and McCallister, 1973).

Major element chemistry (Table 1) indicates a nearly pure anorthositic composition.

Figure 1. Photomicrograph (crossed polarizers) of 60215,14. Width of view ~2 mm.

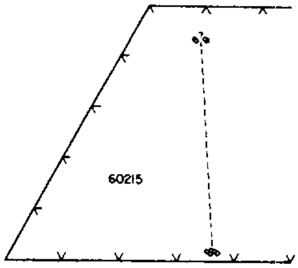



Figure 2. Compositions of pyroxenes in 60215. From Dixon and Papike (1975).

Table 1

| | | | | | |
|---|---|---|---|---|---|
| $SiO_2$ | 44.50 | Ba | <10 | Co | <2 |
| $Al_2O_3$ | 35.53 | Rb | <1 | Ni | 1.8 |
| $Cr_2O_3$ | 0.05 | Sr | 121 | Pb | <1 |
| FeO | 0.15 | La | <10 | Zn | <4 |
| MnO | 0.01 | Y | <0.5 | Cu | 1.0 |
| MgO | 0.14 | Yb | <0.5 | Ga | 2.2 |
| CaO | 19.34 | Zr | <10 | Li | 2.0 |
| $Na_2O$ | 0.40 | | | | |
| $K_2O$ | 0.02 | | | | |

Oxides in wt. %, all others in ppm.
Table 1 from Rose et al. (1975)

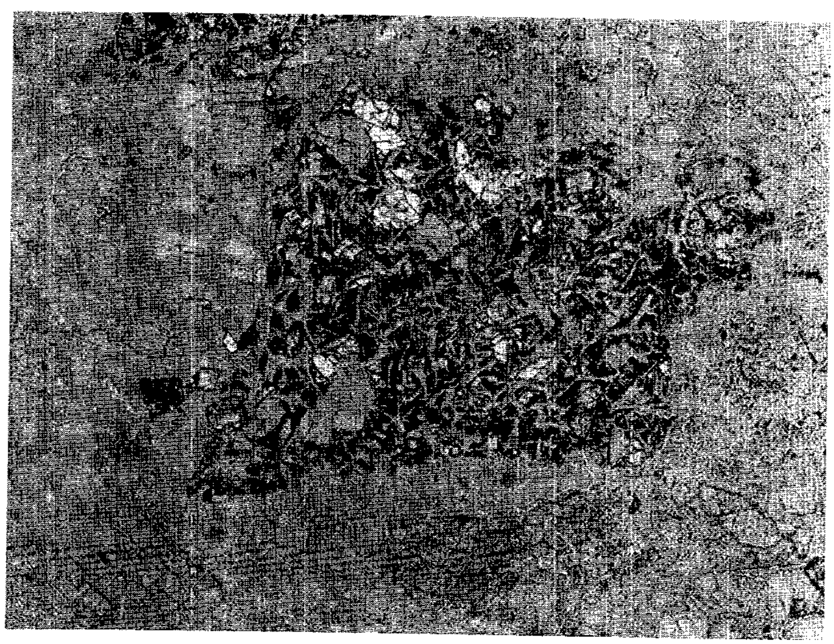


Figure 3. Troctolitic basaltic fragment in 60215,14. Width of view ~3 mm.

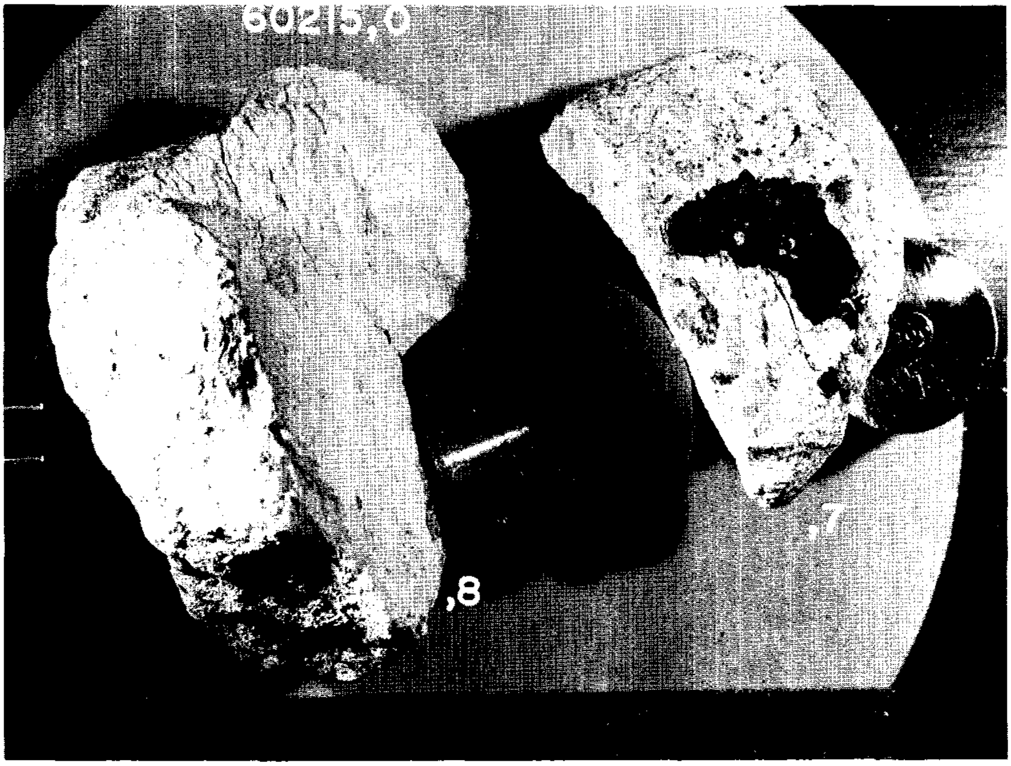



Figure 4. Main splits of 60215, showing patch of black glass on ,7. (NASA S-74-32059)

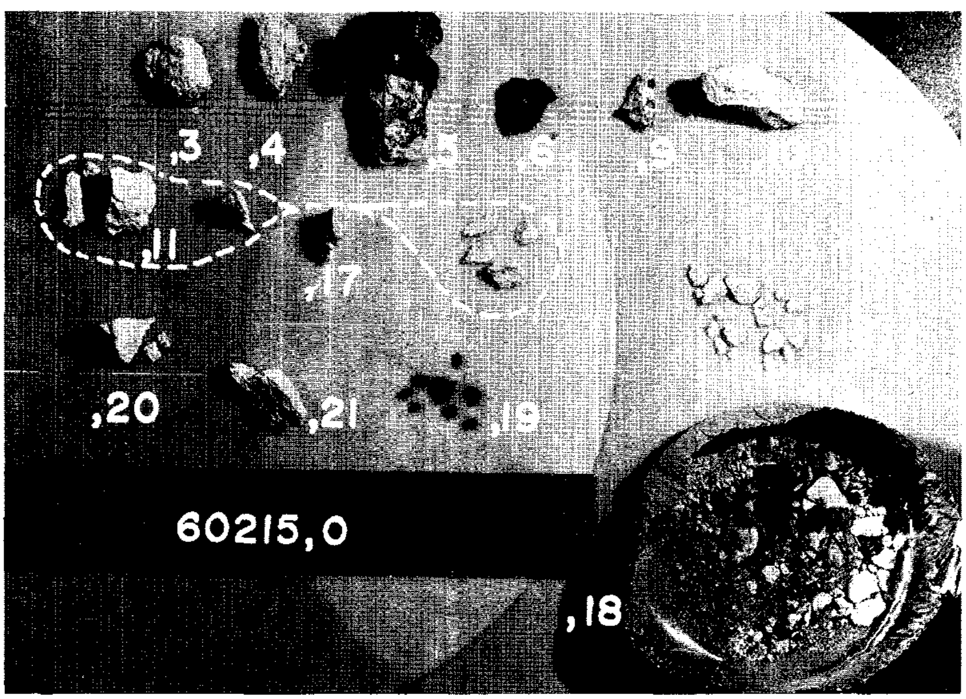



Figure 5. Smaller splits of 60215. (NASA S-74-32055)

Table 2

| Split | Parent | Location | Mass | Description and daughters |
|---|---|---|---|---|
| ,0 | ,0 | Ent. Sub. | | |
| ,1 | ,0 | | 3.726 | Potted butt ,2 ,13 ,14 ,16 |
| ,2 | ,1 | SCC | 0.010 | TS |
| ,3 | ,0 | SSPL | 1.060 | Exterior chip, some glass |
| ,4 | ,0 | SSPL | 0.920 | Exterior chip, some glass |
| ,5 | ,0 | SSPL | 5.700 | Chip, ∿ 50% glass |
| ,6 | ,0 | SSPL | 0.490 | Chip, mostly glass |
| ,7 | ,0 | BSV | 110.720 | End piece, ∿ 10% glass |
| ,8 | ,0 | B01 | 248.060 | End piece |
| ,9 | ,0 | SSPL | 0.260 | Exterior chip |
| ,10 | ,0 | SSPL | 2.650 | Exterior chip, some glass |
| ,11 | ,0 | RSPL | 1.153 | Interior fines, < 80μm Returned by Rose, crushed, air. ,30 |
| ,12 | ,0 | SSPL | 0.330 | Interior chip |
| ,13 | ,1 | Smith | 0.010 | TS |
| ,14 | ,1 | SCC | 0.010 | PM |
| ,15 | ,0 | RSPL | 0.054 | Chips. Returned by LRL Gas Analysis Lab, physically separated, sieved, air. |
| ,16 | ,1 | SCC | 0.010 | TS |
| ,17 | ,0 | Turner | 0.410 | Interior chip |
| ,18 | ,0 | SSPL | 5.540 | Chips and fines, some glass |
| ,19 | ,0 | Turner | 0.120 | Glass chips |
| ,20 | ,0 | SSPL | 0.590 | Interior chips |
| ,21 | ,0 | Ent. Sub. | | ,26 - ,29 |
| ,22 | ,0 | Attrition | 2.880 | |
| ,26 | ,21 | Destroyed,JSC | 0.179 | |
| ,27 | ,21 | Destroyed,JSC | 0.290 | |
| ,28 | ,21 | Consumed,Moore | 0.008 | |
| ,29 | ,21 | Destroyed,JSC | 0.293 | |
| ,30 | ,11 | Consumed,Rose | 0.327 | |

60639 Cataclastic px-bearing anorthosite clast, >10 gm.

Evidence for pristinity: Warren and Wasson (1978) analyzed fragments and found them to have low siderophile and incompatible element abundances (Table 1) showing them to be free of meteoritic contamination.

Description: Thin sections ,22 (Warren and Wasson 1978) and ,23 show that the anorthosite is cataclasized with few grains larger than 500 microns (Figure 1) but is of low porosity. The clast is almost monomineralic ($An_{96.0-96.8}$) with only rare pyroxenes ($En_{64-66}Wo_{1-2}$, $En_{43}Wo_{43}$, and some pigeonite) (Warren and Wasson 1978). Rare ilmenite is also present.

A bulk analysis made by Warren and Wasson (1978) is reproduced here as Table 1.

Figure 1. Photomicrograph (crossed polarizers) of 60639,23. Width of view ~2 mm.

Table 1

| | ,19 570 mg | | | | |
|---|---|---|---|---|---|
| $SiO_2$ | 44.3 | 44.7 | Zn | 2.7 | 1.1 |
| $Al_2O_3$ | 35.4 | 34.8 | Ga | 4.08 | 3.3 |
| $Cr_2O_3$ | 0.006 | 0.006 | Ge ppb | 13.3 | 14.1 |
| FeO | 0.36 | 0.32 | Cd | 76 | 65 |
| MgO | 0.38 | 0.32 | In | 159 | 176 |
| CaO | 19.3 | 19.6 | | | |
| $Na_2O$ | 0.38 | 0.38 | La | 0.14 | 0.08 |
| | | | Ce | 0.55 | 0.25 |
| Sc | 0.61 | 0.57 | Sm | 0.049 | 0.044 |
| Mn | 69.8 | 69.6 | Eu | 0.75 | 0.79 |
| Co | 1.08 | 0.93 | | | |
| Ni | <9.5 | 0.72 | Re ppb | | 0.013 |
| | | | Ir ppb | 0.042 | |
| | | | Au ppb | 0.020 | 0.017 |

Oxides in wt. %, all others in ppm except as indicated
From Warren and Wasson (1978)

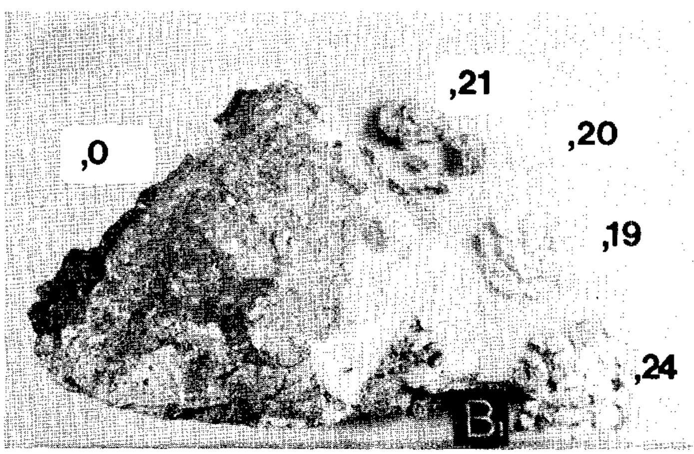



Figure 2. Sample 60639 showing splits of anorthosite clast (white mass in ,0). Cube has 1 cm dimensions.

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,0 | | SSPL | 163.050 | Main mass, mainly matrix and glass |
| ,1 | ,0 | Keil | 0.290 | 3 chips, one is clast |
| ,9 | ,0 | SSPL | 0.650 | Chip, contains basalt piece |
| ,10 | ,0 | SSPL | 0.340 | Chip |
| ,12 | ,0 | Schmitt | 0.060 | Chips |
| ,19 | ,0 | Wasson | 0.570 | Chips |
| ,20 | ,0 | RSPL | 0.120 | Potted butt. ,22 ,23 |
| ,21 | ,0 | SSPL | 0.990 | Chips |
| ,22 | ,20 | Wasson | 0.010 | PM |
| ,23 | ,20 | SCC | 0.010 | PM |
| ,24 | ,0 | SSPL | 2.450 | Chips and fines, probably include matrix. |

61016 Lithologies

61016 was an 11,745 g rock collected from the rim of Plum Crater, Station 1. This complex rock exhibits a wide range of shock-induced features. Despite this, portions have remained chemically pristine. Three main lithologies are present: 1) Light gray to white coarse grained anorthosite, 2) Medium-dark gray aphanitic to glassy troctolitic matrix material, and 3) A glassy melt crust of anorthositic-norite composition (Stöffler et al., 1975, Apollo 16 Lunar Sample Information Catalog).

The anorthosite portion consists of one large clast accounting for ~25 volume % of the rock (Figure 1). Fine grained troctolitic matrix makes up most of the interior of the rock. It has a sub-ophitic, mesostasis-rich texture and contains numerous large xenocrysts and xenoliths of anorthositic material. The glassy crust forms a thin rind on the $B_1$ surface. A more complete discussion of all three lithologies can be found in Stöffler et al. (1975).

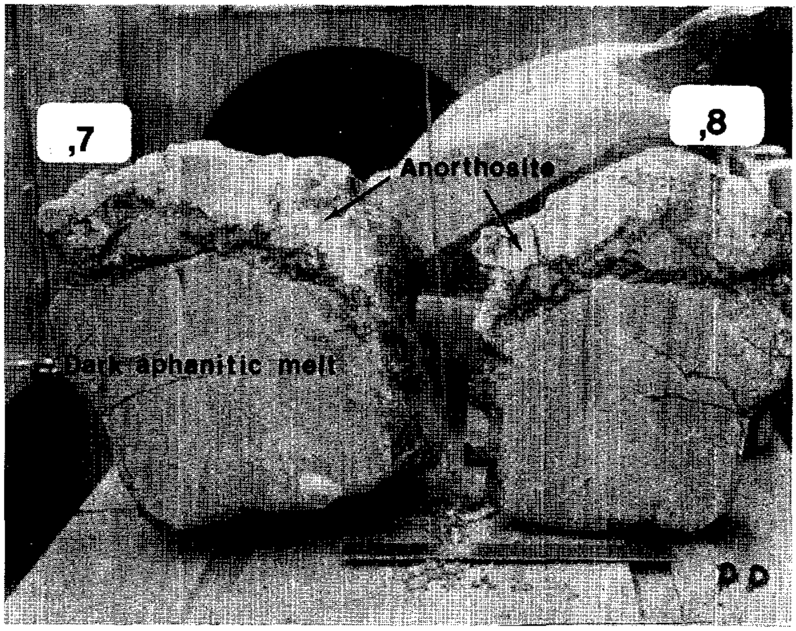



Figure 1. Sawn surfaces of 61016 showing anorthosite and aphanitic melt lithologies. Rule is 15 cms.

61016 Recrystallized anorthosite 11,745 gm

Evidence for pristinity: A split of the anorthosite analyzed by Krähenbühl et al. (1973) was free of meteoritic siderophiles.

Description: The anorthositic portion of this rock displays a complex recrystallized texture as shown in Figure 1. Plagioclase exists in several forms, including a radial to fibrous habit, microgranular ("cherty) grains, and as maskelynite (Stöffler et al., 1975, Apollo 16 Lunar Sample Information Catalog). None of the anorthositic thin sections currently in the SCC library show a brecciated character although "cataclastic" textures have been reported (Steele and Smith 1973). Cataclastic textures have also been found in the large xenocrysts contained in the troctolitic matrix (Dixon and Papike, 1975, Drake, 1974, Misra and Taylor, 1975).

Plagioclase is somewhat variable in composition ($An_{92-98}$) but is predominantly $\sim An_{96}$ (Stöffler et al., 1975, Steele and Smith, 1973, Dixon and Papike, 1975, Drake, 1974, Nava, 1974, Philpotts et al., 1973). A plot of FeO in plagioclase is shown as Figure 2. Pyroxenes in both the anorthosite (Steele and Smith, 1973) and in the xenocrysts (Dixon and Papike, 1975, Drake, 1974) have compositions near $Wo_2\ En_{58}$ and $Wo_{44}\ En_{41}$ (Figure 3). No exsolution was found. A single olivine of $Fo_{63}$ was reported by Drake (1974).

Bulk chemical analyses are presented in Table 1 and Figure 4. From Data Pack information it appears that the analysis of 61016,3 (Apollo 16 Preliminary Science Report) may have been contaminated by a small amount of dark matrix material resulting in higher ferromagnesian elements.

$^{87}Sr/^{86}Sr$ was determined to be 0.69903 by Nyquist et al. (1973).

Other references

Bhandari et al. (1975) Surface radioactivity
Bhandari et al. (1976) Exposure ages
Thorde and Rees (1976) Sulfur isotopes

Figure 1. Photomicrograph (crossed polarizers) of 61016,223. Width of view ~2 mm.

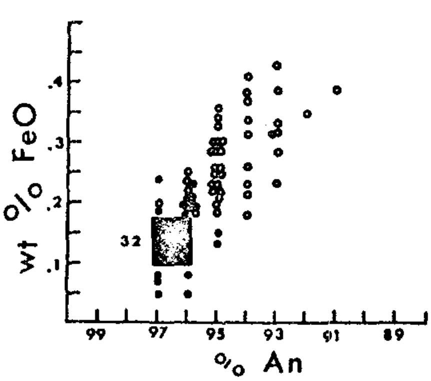



Figure 2. FeO in plagioclase in 61016. From Drake (1974).

Table 1

| | 1) ,184 | 2) ,3 | 3) ,79 | 4) ,79 | 5) ,84 | 6) ,180 | 7) ,184 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 45.0 | 44.15 | | | | -- | |
| $TiO_2$ | 0.02 | 0.20 | | | | -- | |
| $Al_2O_3$ | 34.85 | 33.19 | | | | 34.40 | |
| $Cr_2O_3$ | 0.002 | -- | | | | 0.003 | |
| FeO | <0.05 | 1.40 | | | | -- | |
| MnO | <0.005 | 0.02 | | | | -- | |
| MgO | <0.03 | 2.51 | | | | -- | |
| CaO | 19.58 | 18.30 | | | | -- | |
| $Na_2O$ | 0.41 | 0.34 | 0.43 | 0.32 | 0.32 | 0.42 | |
| $K_2O$ | 0.005 | 0.02 | | | | | |
| $P_2O_5$ | 0.047 | 0.05 | | | | | |
| K | | | 729 | 40 | 40 | | 44.8 |
| Rb | | | 0.038 | 0.017 | 0.040 | | 0.030 |
| Sr | | | 180.4 | 179.0 | 181.7 | | 149.0 |
| Ba | | | 6.97 | 7.05 | 7.11 | | 6.01 |
| La | | | <0.3 | 0.143 | -- | -- | -- |
| Ce | | | <0.7 | 0.37 | 0.44 | 0.3 | 0.253 |
| Nd | | | 0.20 | 0.205 | | -- | 0.145 |
| Sm | | | 0.045 | 0.058 | | 0.1 | 0.036 |
| Eu | | | 0.805 | 0.77 | | 0.9 | 0.671 |
| Gd | | | 0.045 | 0.054 | | | -- |
| Dy | | | 0.025 | 0.065 | | | 0.027 |
| Er | | | 0.067 | 0.040 | | | 0.014 |
| Yb | | | 0.020 | 0.045 | | | 0.017 |
| Lu | | | 0.005 | 0.025 | | | -- |

| | 2) | 3) | 4) | 5) | 6) | 8) ,156 |
|---|---|---|---|---|---|---|
| Co | -- | -- | -- | -- | 0.5 | -- |
| Ni | 39 | -- | -- | -- | -- | -- |
| Cr | 200 | <20 | 375 | <46 | 21 | -- |
| U ppb | -- | 2 | 1.5 | -- | | 0.88 |
| Th | 1.7 | -- | -- | -- | | -- |
| Zr | 48 | 3 | 2.4 | -- | | -- |
| Hf ppb | | | | 0.2 | | -- |
| Ir ppb | | | | | | 0.0099 |
| Re ppb | | | | | | 0.0022 |
| Au ppb | | | | | | 0.020 |

Index for Table 1

Oxides in wt. %, others in ppm except as noted.
Col. 1 from Nava (1974)
Col. 2 from Apollo 16 Preliminary Science Report (LSPET)
Col. 3, 4, 5 from Hubbard et al. (1974)
Col. 6 from Fruchter et al. (1974)
Col. 7 from Philpotts et al. (1973)
Col. 8 from Krähenbühl et al. (1973)

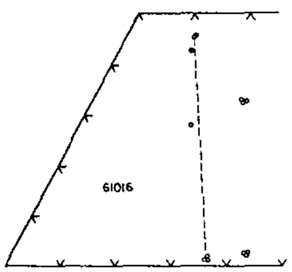



Figure 3. Compositions of pyroxenes in 61016 anorthosite. From Dixon and Papike (1975).

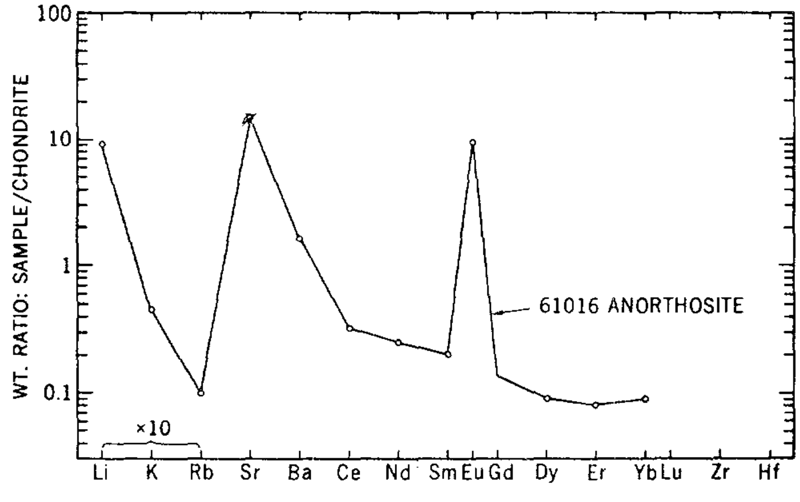



Figure 4. Incompatible element abundances in 61016 anorthosite. From Philpotts et al. (1973).

## 62255 Glass-coated cataclastic px-bearing anorthosite ~ 1,000 gm

Evidence for pristinity: Hertogen et al. (1977) analyzed a fragment and found it to be meteorite-free (Table 1).

Description: 62255 is an anorthosite with a partial coating and intrusions of black glassy material. Schaal et al. (1976) reported that the anorthosite consists almost entirely of plagioclase ($An_{92-96}$) with diameters up to ~ 6 mm, with hypersthene ($En_{50}$ $Wo_4$) less than 5%. Our own study shows plagioclase restricted to $An_{95-97}$ and two pyroxenes, $En_{45-50}$ $Wo_{4-8}$ and $En_{34-36}$ $Wo_{39-45}$. The high-calcium pyroxene occurs as rare small discrete grains with a higher birefringence than low-Ca pyroxene and as an exsolved phase. Low-Ca pyroxene occurs mainly as discrete grains rarely up to 2 mm in diameter, but some plagioclases contain numerous tiny pyroxenes. Sparse ilmenite and very rare troilite are present. Relict grain boundaries are visible in some places, showing a primary hypidiomorphic granular texture (Figure 1), but most areas observed in the thin sections are cataclastic.

A chemical analysis of the anorthosite by Taylor et al. (1974) is reproduced in Table 1 and Figure 2. Hertogen et al. (1977) report that the anorthosite is enriched in the volatiles Tl, Cd, Br.

Other references:
- Cripe and Moore (1974) Sulfur
- Moore and Lewis (1976) Nitrogen
- Lightner and Marti (1974a) Xenon, exposure age.
- Lightner and Marti (1974b) Xenon (Kr, Ar) isotopes, trapped xenon.
- Padawer et al. (1974) Surface H, C, Fl.
- Brownlee et al. (1975) Microcrater melts.
- Hörz et al. (1975) Exposure ages (quoted).

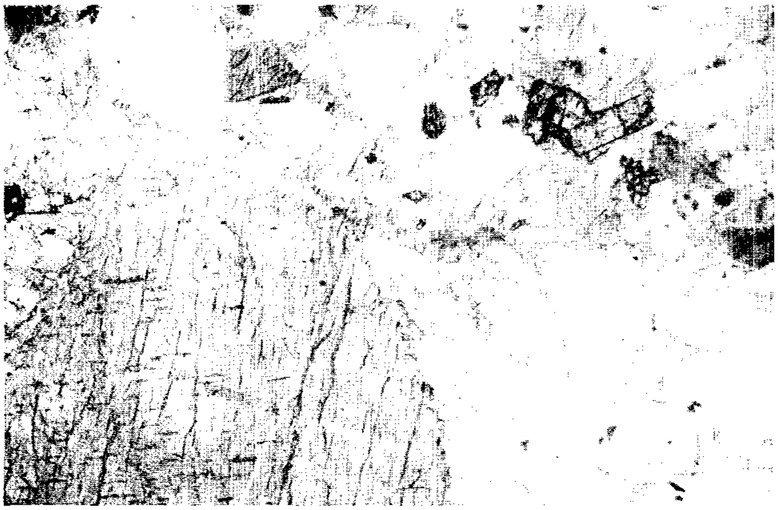


Figure 1. Photomicrograph (partially crossed polarizers) of 62255,35. Width of view ~2 mm.

## Table 1

| | 1) | | 1) | | 2) |
|---|---|---|---|---|---|
| ,47, portion of ,20 521 mg | | | | ,71, portion of ,17 193 mg | |
| $SiO_2$ | 44.1 | La | 0.46 | | |
| $Al_2O_3$ | 35.3 | Ce | 0.72 | Ir ppb | 0.016 |
| FeO | 0.20 | Pr | 0.07 | Os ppb | 0.018 |
| MgO | 0.37 | Nd | 0.32 | Re ppb | 0.0087 |
| CaO | 19.1 | Sm | 0.11 | Au ppb | 0.062 |
| $Na_2O$ | 0.49 | Eu | 0.80 | Ni | 1.6 |
| $K_2O$ | 0.09 | Gd | 0.10 | | |
| Ba | 14.6 | Ho | 0.02 | Rb | 0.025 |
| Pb | 0.6 | Er | 0.06 | Cs ppb | 0.52 |
| Zr | 0.45 | Yb | 0.06 | U ppb | 1.37 |
| Nb | 0.15 | | | | |
| Cr | 17 | | | | |
| V | 7 | | | | |
| Cu | <1 | | | | |

Oxides in wt. %, all others in ppm except as indicated.
Col. 1 from Taylor *et al*. (1974)
Col. 2 from Hertogen *et al*. (1977)

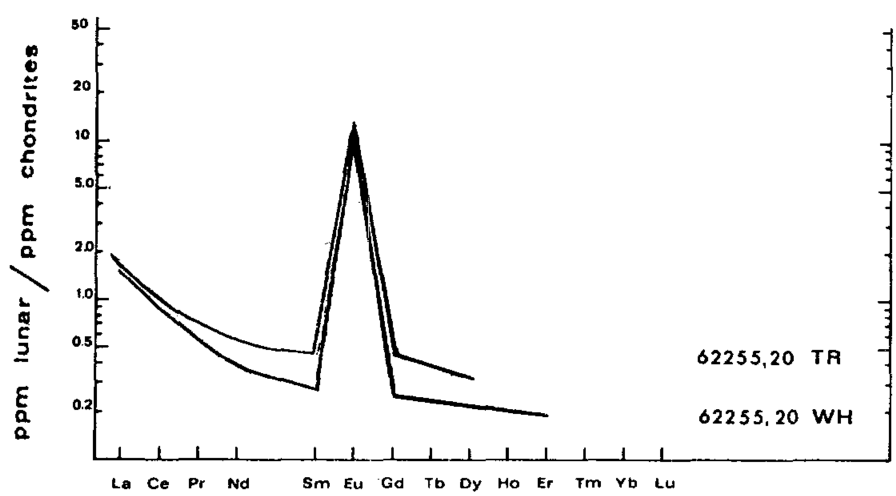



Figure 2. REE data for 62255. TR=Total rock, WH=White. From Taylor and Bence (1975).

<u>Figure 3.</u> Sawn surface of 62255, showing relation of anorthosite (white) to dark aphanitic material. (NASA S-75-33052)

## 64435 Cataclastic anorthosite clasts ~200 gm

Evidence for pristinity: One anorthosite clast had very low rare earth elements and low Co (Laul et al., 1974). Another clast has metal with Co too high to be of meteoritic origin (Hewins and Goldstein, 1975).

Description: Breccia 64435 consists of three main lithologies: anorthositic clasts, light gray matrix, and a dark glass coating. The anorthosite clasts range in size from several centimeters down to fractions of a millimeter (Mason, unpublished information from Data Packs).

Inspection of SCC thin sections show that the clasts have been brecciated and somewhat recrystallized (Figure 1). These clasts consist of up to 97% plagioclase ($An_{95-100}$) with minor amounts of olivine, orthopyroxene, and augite (Laul and Schmitt, 1974). One grain of augite had the composition $Wo_{44}En_{36}$ (Mason, unpublished).

Bulk chemistry is given in Table 1 and Figure 2. REE's are slightly higher than in 15415 and 60015 but show the depletion in heavy elements characteristic of pristine lunar anorthosites (Figure 2).

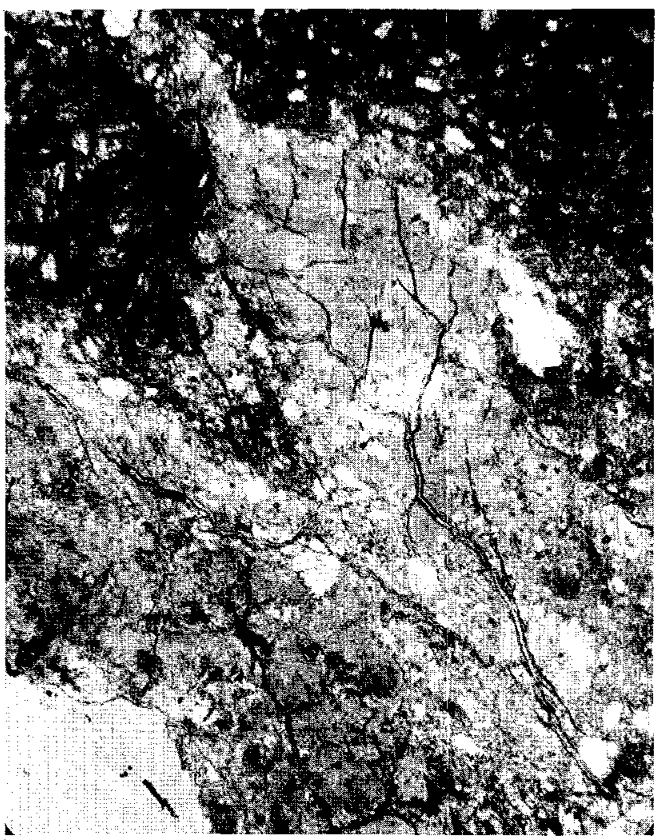


Figure 1. Photomicrograph (partially crossed polarizers) of 64435,73. Width of view ~2 mm.

Table 1

| | | | |
|---|---|---|---|
| $TiO_2$ | <0.1 | Ba | <9 |
| $Al_2O_3$ | 35.5 | La | 0.16 |
| $Cr_2O_3$ | 0.0083 | Nd | <0.4 |
| FeO | 0.61 | Sm | 0.086 |
| MnO | 0.011 | Eu | 0.69 |
| CaO | 19.0 | Tb | 0.03 |
| $Na_2O$ | 0.29 | Dy | 0.2 |
| $K_2O$ | 0.025 | Yb | 0.06 |
| | | Lu | 0.008 |
| | | Hf | 0.03 |
| | | U | <0.02 |
| | | Co | 1.30 |

Oxides in wt %, others in ppm.
Table 1 from Laul et al. (1974)

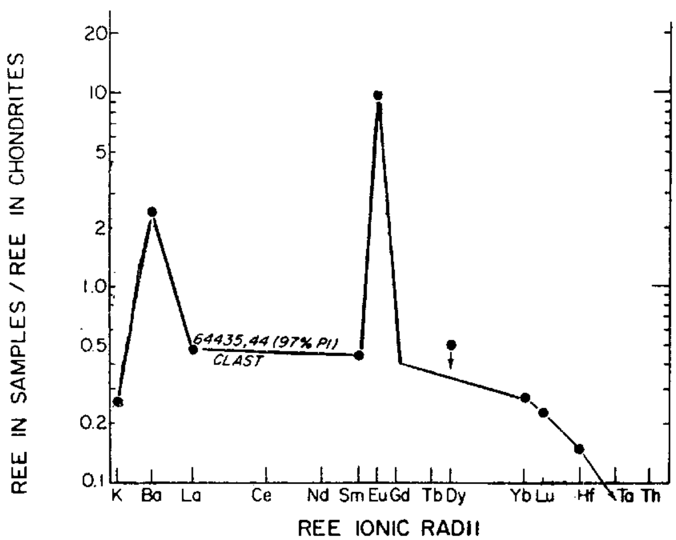



Figure 2. Incompatible element abundances in 64435. From Laul et al. (1974).

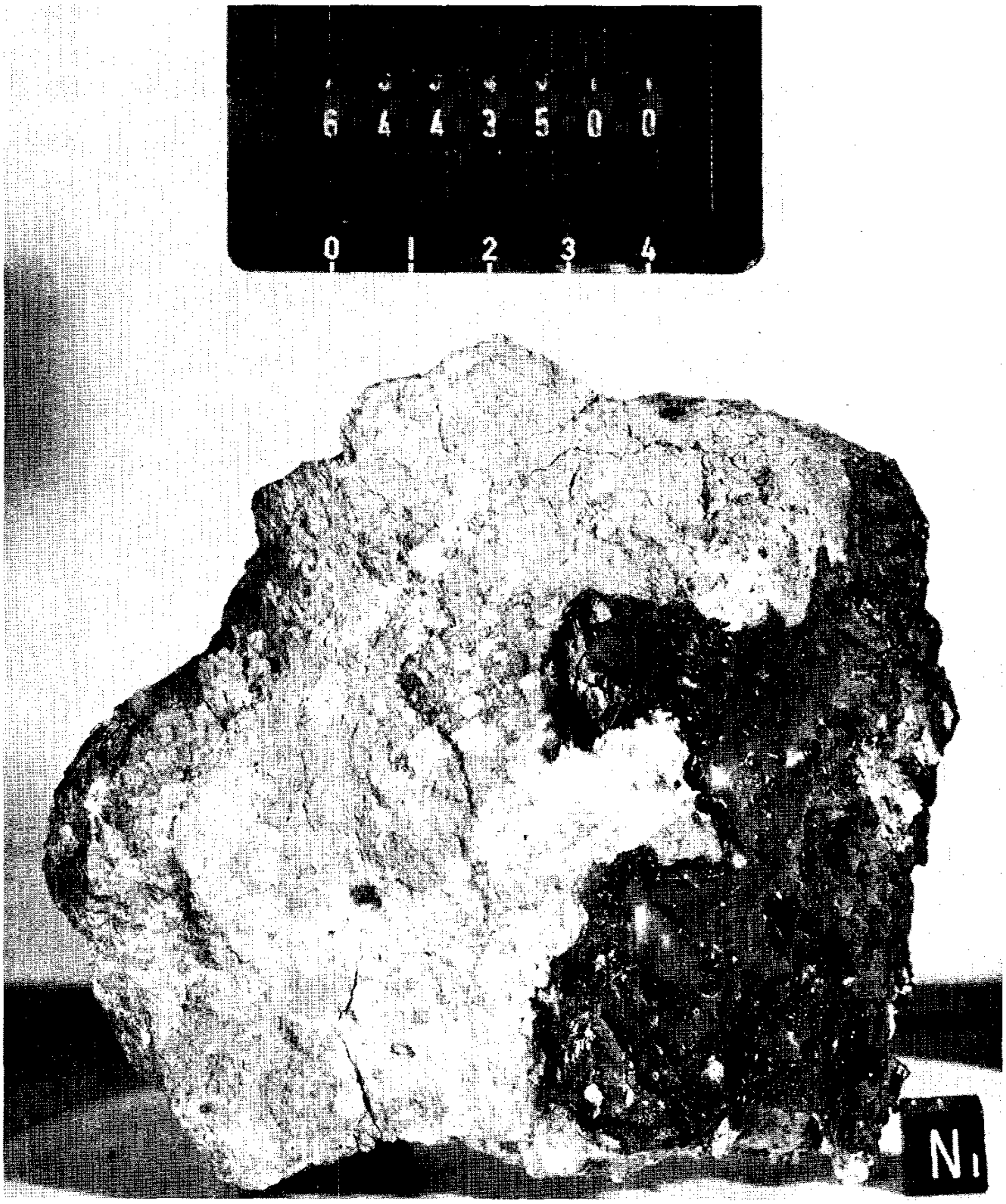



Figure 3. Original (pre-split) sample 64435 showing anorthosite material enclosed in aphanitic gray matrix, with splash glass to right. (NASA S-72-39674).

## 65315 Cataclastic px-bearing anorthosite 300 gm

Evidence for pristinity: A split analyzed by Wänke et al. (1974) was free of meteoritic siderophiles and very low in incompatible elements.

Description: Macroscopically 65315 is a coherent, monomict anorthositic breccia with irregularly distributed surface glass (Apollo 16 Lunar Sample Information Catalog). Inspection of the SCC thin sections show a cataclastic anorthosite with <2% pyroxene and no olivine (Figure 1). No evidence of recrystallization or shock melting was found. Relict plagioclase grains up to 3 mm long are present.

Dixon and Papike (1975) found plagioclase to be $An_{97}$. Pyroxene chemistry is shown in Figure 2. Orthopyroxene is $Wo_2En_{66}$ and clinopyroxene is $Wo_{43}En_{41}$.

Bulk chemistry is given in Table 1. Rare earths are very low, comparable to 15415 and 60015.

Other references

Nagel et al. (1976) Microcraters

Filleux et al. (1977) Surface carbon

Figure 1. Transmitted light photomicrograph of 65315,94. Width of view ∿2 mm.

Table 1

| | | | |
|---|---|---|---|
| $SiO_2$ | 44.30 | Rb | 0.17 |
| $TiO_2$ | 0.01 | Sr | 167 |
| $Al_2O_3$ | 34.87 | Ba | 4.8 |
| FeO | 0.31 | La | 0.12 |
| MgO | 0.25 | Sm | 0.04 |
| CaO | 19.07 | Eu | 0.74 |
| | | Dy | 0.056 |
| | | Yb | 0.026 |
| Na | 2250 | Lu | 0.004 |
| P | 40 | | |
| K | 58 | | |
| Cr | 20 | | |
| Mn | 59 | | |
| Co | 0.58 | | |
| Ni | 1.4 | | |
| Cu | 2.1 | | |
| Zn | 93 | | |
| Ga | 3.25 | | |
| Zr | 15 | | |
| Hf | 7.25 | | |
| Au ppb | 1.0 | | |
| U ppb | <0.6 | | |

Oxides in wt %, others in ppm except as noted.
From Wänke *et al*. (1974)

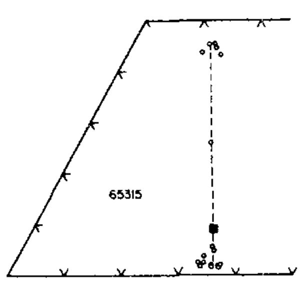



Figure 2. Compositions of pyroxenes in 65315. From Dixon and Papike (1975).

## 65325 Cataclastic px-bearing anorthosite 67.84 gm

Evidence for pristinity: Warren and Wasson (1978) analyzed fragments and found them to be free of meteoritic contamination (Table 1).

Description: 65325 was described as a white friable sample with 99% plagioclase and traces of dark mafic silicates and opaques (Keil *et al.*, 1972). A partial crust of glass occurs on one surface. Thin sections ,5 (Warren and Wasson 1978) and ,6 show that the sample is a cataclastic anorthosite (Figure 1) with some porosity. Few grains are more than 1 mm long with most less than 500 microns. Rare mafics and traces of ilmenite are present. Plagioclases are $An_{96-97}$ and pyroxenes are $En_{63}Wo_2$ (Warren and Wasson 1978).

Warren and Wasson (1978) made a bulk analysis, reproduced here as Table 1. The only other allocation, to Kirsten, was to study microcraters rather than the anorthosite *per se*.

Figure 1. Photomicrograph (crossed polarizers) of 65325,6. Width of view ~2 mm.

## Table 1

| | ,1 300 mg | | | | |
|---|---|---|---|---|---|
| $SiO_2$ | | 44.1 | Ga | 4.49 | 4.0 |
| $Al_2O_3$ | | 35.2 | Ge ppb | 16.1 | 39 |
| $Cr_2O_3$ | 0.004 | 0.005 | Cd | 39 | 32 |
| FeO | 0.30 | 0.27 | In | <70 | 72 |
| MgO | | 0.23 | | | |
| CaO | 19.6 | 19.7 | La | 0.11 | 0.13 |
| $Na_2O$ | 0.390 | 0.375 | Ce | | 0.32 |
| | | | Sm | 0.040 | 0.044 |
| Sc | 0.44 | 0.41 | Eu | 0.78 | 0.83 |
| Mn | 63.8 | 64.2 | Yb | | 0.04 |
| Co | 1.08 | 0.93 | | | |
| Ni | <23 | 0.68 | Re ppb | | 0.015 |
| Zn | 0.24 | | Ir ppb | 0.12 | |
| | | | Au ppb | 0.052 | 0.021 |

Oxides in wt. %, all others in ppm except as indicated.
From Warren and Wasson (1978)

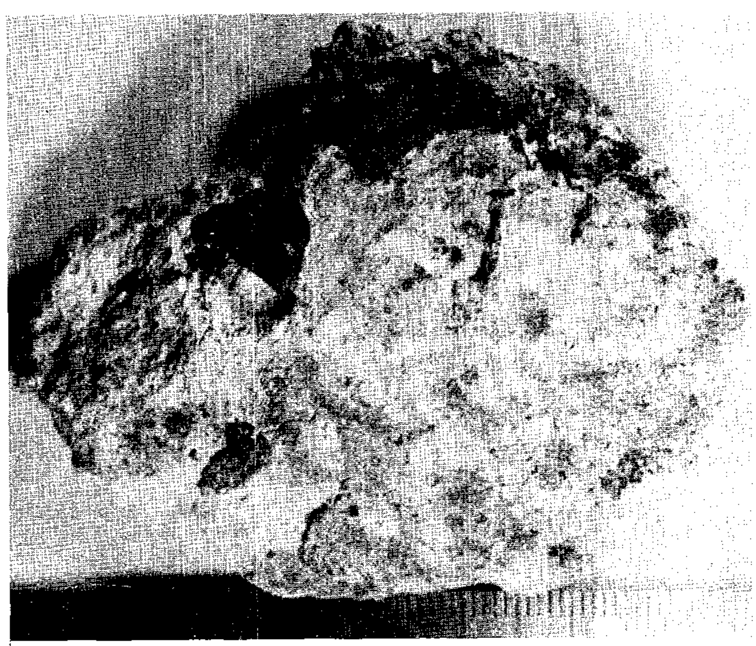


Figure 2. Original sample 65325. Smallest scale division is millimeters.

Table 2

| Split | Parent | Location | Mass. | Description and daughters containing clast |
|---|---|---|---|---|
| ,0 | | SSPL | 66.920 | |
| ,1 | ,0 | Wasson | 0.390 | Interior chips |
| ,2 | ,0 | Kirsten | 0.200 | Zap pit chips |
| ,3 | ,0 | RSPL | 0.060 | Potted butt. ,5 ,6 |
| ,4 | ,0 | SSPL | 0.280 | Fines |
| ,5 | ,3 | Wasson | 0.010 | PM |
| ,6 | ,3 | SCC | 0.010 | TS |

## 65327 Cataclastic px-bearing anorthosite 6.97 gm

Evidence of pristinity: Warren and Wasson (1978) analyzed fragments and found them to be free of meteoritic contamination (Table 1).

Description: 65327 was described as a white friable sample with more than 99% plagioclase and traces of honey-yellow mafics and opaques (Keil et al., 1972). Small patches of glassy crust are present. Thin sections ,4 (Warren and Wasson 1978) and ,5 show that the sample is a cataclastic anorthosite (Figure 1) with some porosity. Most areas of ,5 are severely granulated with grains <100 microns. Rare mafics and opaques occur. Plagioclases are $An_{96.6-97.2}$ and pyroxenes are $En_{62-67}Wo_2$ (Warren and Wasson 1978).

Warren and Wasson (1978) made a bulk analysis, reproduced here as Table 1.

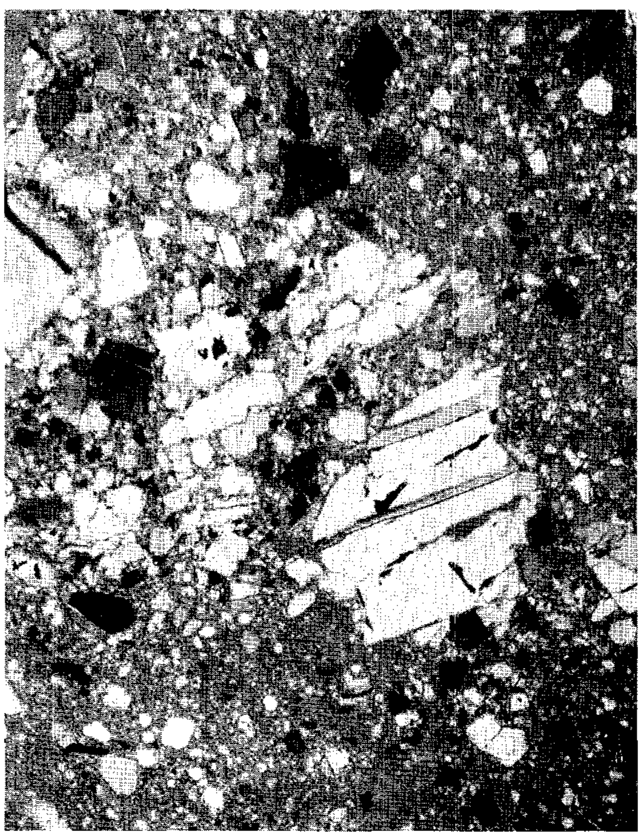


Figure 1. Photomicrograph (partially crossed polarizers) of 65327,5. Width of view ~2 mm.

Table 1

| ,1 150 mg | | | |
|---|---|---|---|
| $SiO_2$ | 44.5 | Ga | 3.8 |
| $Al_2O_3$ | 34.4 | Ge ppb | 48.0 |
| $Cr_2O_3$ | 0.003 | Cd | 950 |
| FeO | 0.34 | In | 470 |
| MgO | 0.33 | | |
| CaO | 19.74 | La | 0.08 |
| $Na_2O$ | 0.297 | Sm | 0.035 |
| | | Eu | 0.70 |
| Sc | 0.40 | | |
| Mn | 67.7 | Re ppb | <0.0022 |
| Co | 0.96 | Au ppb | 0.012 |
| Ni | <0.9 | | |
| Zn | 22.0 | | |

Oxides in wt. %, others in ppm except as indicated.

From Warren and Wasson (1978)

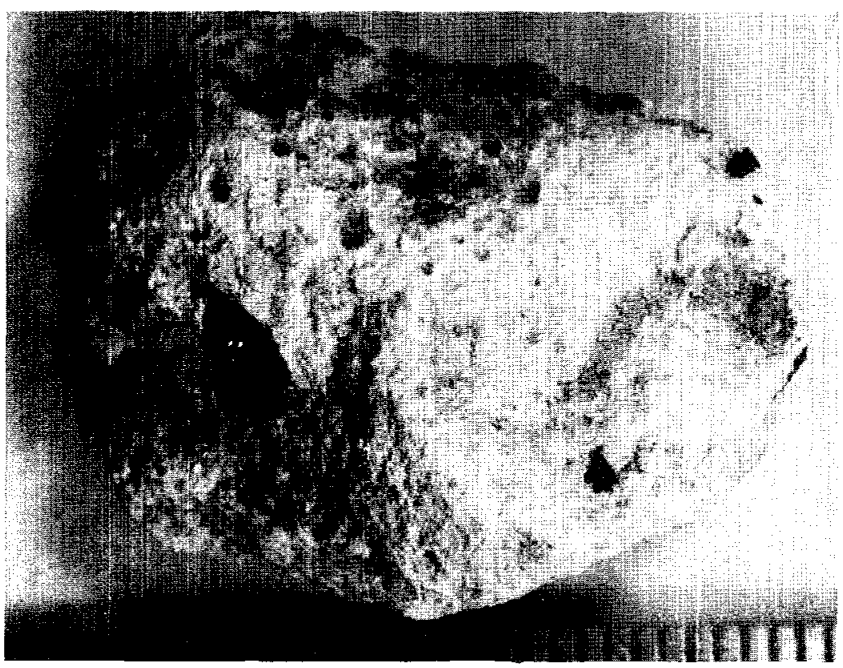


Figure 2. Original sample 65327,0. Scale units are millimeters.

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,0 | | B45 | 4.940 | |
| ,1 | ,0 | Wasson | 0.150 | Interior chips |
| ,2 | ,0 | RSPL | 0.140 | Potted butt. ,4 ,5 |
| ,3 | ,0 | SSPL | 0.750 | Exterior chip |
| ,4 | ,2 | Wasson | 0.010 | PM |
| ,5 | ,2 | SCC | 0.010 | PM |
| ,6 | ,0 | SSPL | 0.810 | Chips and fines |

67035 px-bearing anorthosite clast 0.18 gm

Evidence for pristinity: Hertogen et al. (1977) analyzed a fragment and found it to be free of meteoritic contamination (Table 1).

Description: The anorthosite clast was a single loose fragment picked out of the many small pieces of light matrix breccia 67035. As seen in thin section ,10, the clast was originally coarse-grained (at least 2 mm) but is now cataclasized along grain boundaries (Figure 1). The original texture was cumulate with interstitial pyroxene. Our own preliminary mineral analyses show that the mafic phase is a low-Ca pyroxene averaging $\sim En_{60}$ (Figure 2), not unusual for an anorthosite.

The data of Hertogen et al. (1977) shows rather higher Rb and U contents for an anorthosite (Table 1). This is confirmed in the unpublished data of Nyquist (Table 1) which also shows higher MgO than is typical of anorthosite, as well as a high $^{87}Sr/^{86}Sr$. The REE abundances are typically anorthositic.

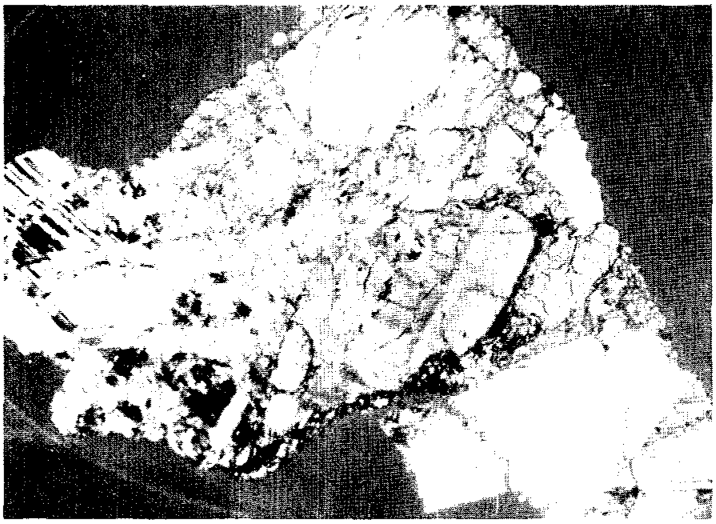


Figure 1. Photomicrograph (partially crossed polarizers) of 67035,10. Width of view ~2 mm.

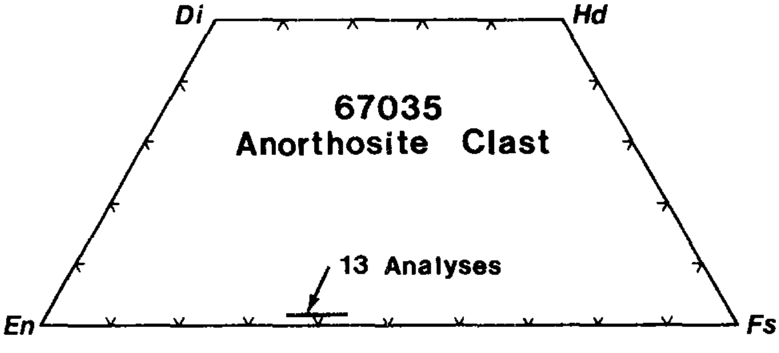



Figure 2. Compositions of pyroxenes in 67035. From our own unpublished data.

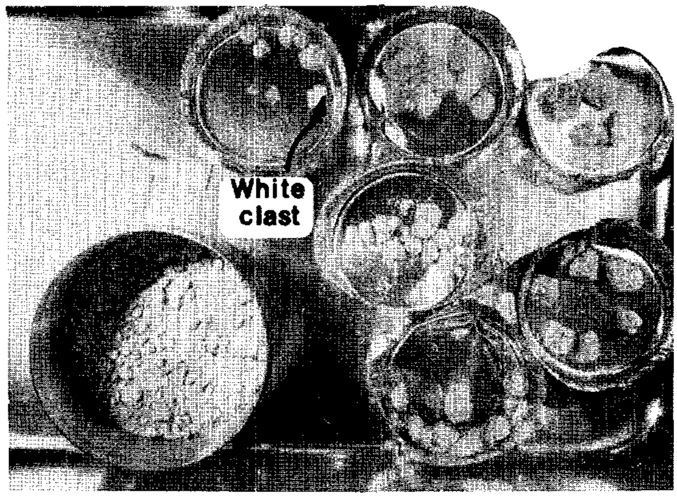



Figure 3. The anorthosite clast in the fragments of the friable breccia 67035,18.

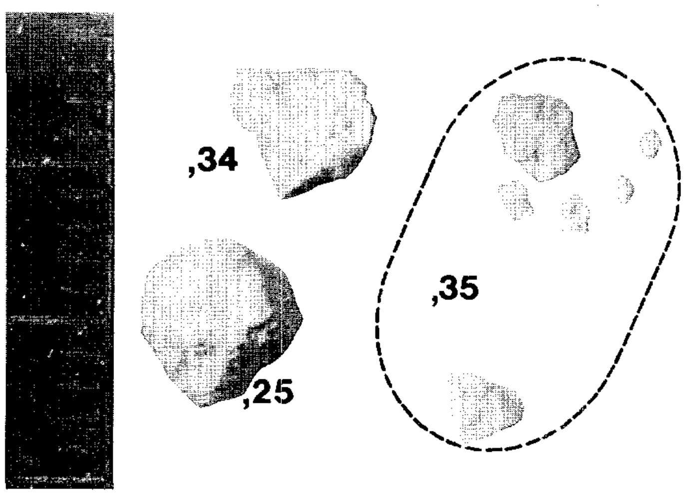



Figure 4. Splits of the 67035 anorthosite clast.

Table 1

| | 1) ,34 40 mg | | 1) | | 2) ,63, portion of ,25, 71 mg |
|---|---|---|---|---|---|
| $TiO_2$ | 0.032 | La | 0.22 | Rb | 0.84 |
| MgO | 1.0524 | Ce | 0.60 | Cs | 40.8 |
| $Cr_2O_3$ | 0.017 | Nd | 0.35 | U | 6.2 |
| $K_2O$ | 0.023 | Sm | 0.072 | Ir ppb | 0.045 |
| | | Eu | 0.746 | Os ppb | 0.052 |
| Li | 2.2 | Dy | 0.11 | Re ppb | 0.0097 |
| Rb | 0.709 | Yb | 0.056 | Au ppb | 0.031 |
| Sr | 164 | | | Ni | 3.4 |
| Ba | 19.9 | $^{87}Sr/^{86}Sr$ | 0.69976±8 | | |

Oxides in wt. %, all other data ppm except as indicated.

Col. 1 from Nyquist (unpublished)
Col. 2 from Hertogen *et al*. (1977)

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,10 | ,35 | SCC | 0.010 | TS |
| ,25 | ,18 | RSPL | 0.039 | Fines, returned by Anders. Air, crushed (in agate). ,34 ,35 (,10) ,63 |
| ,34 | ,25 | Consumed, Nyquist | 0.040 | Chip |
| ,35 | ,25 | RSPL | 0.020 | Potted butt. ,10 |
| ,63 | ,25 | Consumed, Anders | 0.071 | Chip |

## 67075 Cataclastic/polygonal px-bearing anorthosite 219 gm

Evidence for pristinity: The Ni content of splits analyzed by Haskin *et al.* (1973) and Hertogen *et al.* (1977) is very low (Table 1), indicating pristinity. The rock is probably not entirely pristine because the split analyzed by Hertogen *et al.* (1977) and a split analyzed by Wänke *et al.* (1975) showed Re, Au, and Ir contents above the levels normally chosen as indicative of meteoritic contamination (Table 1).

Description: 67075 is a very friable white anorthosite. Petrographic descriptions and mineral analyses have been given by Brown *et al.* (1973), Peckett and Brown (1973), Steele and Smith (1973), McCallum *et al.* (1975), and Dixon and Papike (1975). The anorthosite is variable in texture and largely consists of large mineral grains and lithic clasts set in a finer-grained porous matrix (Figure 1). The range in mafic mineral compositions has led to the suggestion that the rock is polymict but that the intermixed rocks were genetically related in a plutonic layered complex (Brown *et al.*, 1973, Peckett and Brown, 1973, McCallum *et al.*, 1975).

The rock consists mainly of plagioclase, with pyroxene, minor olivine, ilmenite and silica (up to 100μm) and traces of troilite, Ti-chromite, and Fe-Ni metal. The lithic fragments have a microgranoblastic texture with plagioclases up to ∿500μm and contain about 95% plagioclase. Plagioclases in lithic fragments and the matrix are mainly $An_{96-98}$. Some large pyroxenes in the matrix are coarsely exsolved (Peckett and Brown 1973, Brown *et al.* 1973, McCallum *et al.* 1975) but those in lithic fragments are never exsolved (McCallum *et al.* 1975). Examples of pyroxene compositions are given in Figures 2a and 2b. The general pyroxene compositional ranges are $En_{65-40}Wo_{2-5}$ and $En_{42-30}Wo_{42-47}$, but the distribution is not uniform; two maxima were noted by McCallum *et al.* (1975). X-ray precession data for the pyroxenes was given by McCallum *et al.* (1975) who also reported exsolved Cr-spinel in the pyroxenes. Olivine is sparse in the matrix; reported compositions range from $\sim Fo_{60}$ to $\sim Fo_{40}$. Steele and Smith (1975) reported minor element abundances for olivine ($Fo_{60}$).

El Goresy *et al.* (1973), in a study of the opaque phases, reported that there were two occurrences of Ti-chromite: one primary, the other (associated with sulfide and exclusively exsolved from pyroxene) they interpret as reduced from Cr-Al-ulvöspinel. This interpretation was criticized by McCallum *et al.* (1975). Analyses of the spinels (∿3-8% $TiO_2$) are given in El Goresy *et al.* (1973).

Bulk chemical analyses from several sources are given in Table 1, with an example of REE abundances given in Figure 3. The data indicates that at the scale of sampling 67075 is variable but is clearly a ferroan anorthosite. Silver (1973) noted that the Th/U ratio is very low, an observation substantiated by the data of Hubbard *et al.* (1974). The lead concentration of 320 ppb and $^{238}U/^{204}Pb$ of 16.4 is similar to anorthosites 15415 and 60025 (Silver 1973).

Turner et al. (1973) inferred a $^{40}Ar-^{39}Ar$ plateau age of 4.04±0.05 b.y. (Figure 4) for 67075, after making a correction for a calculated value of trapped $^{40}Ar$. The nature of the release indicates that the sample is chemically homogeneous. An exposure age of 46 m.y. was also derived by Turner et al. (1973).

Nyquist et al. (1974, 1975, 1976) provide Rb-Sr isotope data, and calculate a mineral isochron age of 3.66±0.63 b.y. with an initial $^{87}Sr/^{86}Sr$ of 0.69911±9 (Figure 5). This age is in agreement with the more precise $^{40}Ar-^{39}Ar$ age of Turner et al. (1973). Much of the scatter in the data is attributed to incomplete homogenization during recrystallization; the anorthosite is believed to be older. Model ages of 3.66±0.31 b.y. and 4.38±0.52 b.y. ($T_{BABI}$) and 4.18±0.31 and 4.78±0.52 b.y. ($T_{LUNI}$) are calculated.

Other references:

Okamura et al. (1976) Cr-spinel exsolution
Smith and Steele (1974) Inclusions in plagioclase
Meyer et al. (1974) Ion probe, trace elements in plagioclase
LSPET (1972b) Photomicrograph
Nord et al. (1975) Electron petrography
Moore et al. (1973) Carbon
Lightner and Marti (1974b) Xenon isotopes, trapped xenon
Drozd et al. (1977) Xenon isotopes
Jovanovic and Reed (1976) Ru and Os

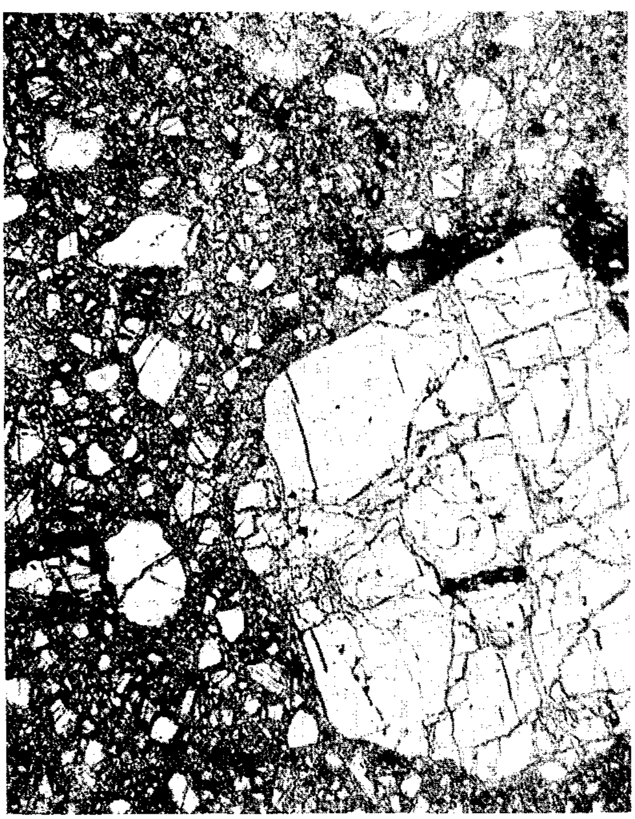


Figure 1. Photomicrograph (reflected light) of of 67075,48. Width of view ~2 mm.

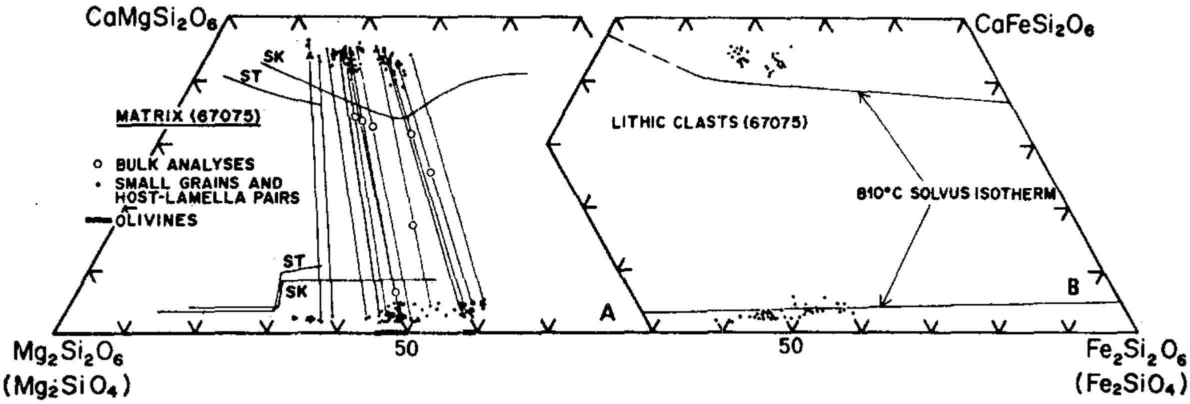



Figure 2a. Compositions of pyroxenes and olivines in 67075. From McCallum et al. (1975). (ST=Stillwater trend, SK=Skaergaard trend.)

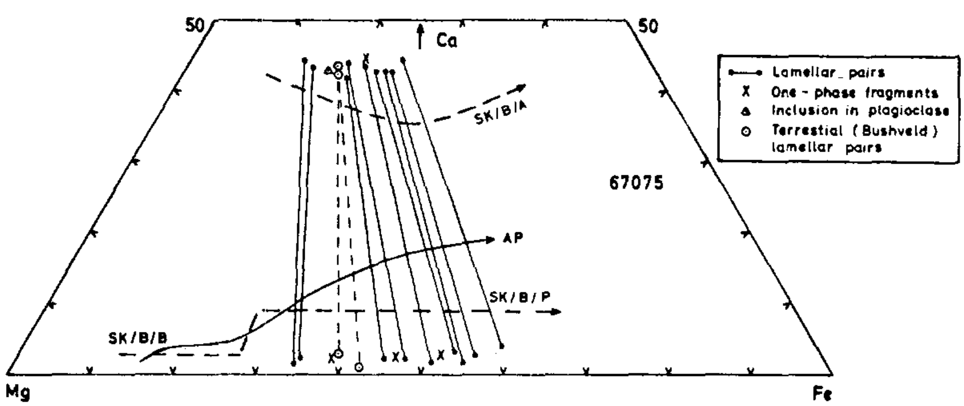



Figure 2b. Compositions of pyroxenes in 67075. From Brown et al. (1973). (SK=Skaergaard trend, B=Bushvelt trend, A=augite, P=pigeonite, AP=trend for lunar pigeonites.)

## Table 1

| | 1) portion of ,17 500mg | 2) ,55,portion of ,4 30mg | 3) ,53 64mg | 4) ,58,portion of ,22 2.128gm | 5) portion(?) of ,11 ?mg | 6) portion of ,17 56mg | 7) ,59 portion of ,9 51mg | 8) portion of ,5 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 45.5 | 44.8 | | 44.42 | 45.4 | | | |
| $TiO_2$ | 0.05 | 0.09 | | 0.11 | 0.10 | | | |
| $Al_2O_3$ | 34.2 | 31.54 | | 31.73 | 31.2 | | | |
| FeO | 1.07 | 3.41 | | 3.00 | 3.96 | | | |
| MnO | 0.017 | 0.06 | | 0.04 | 0.06 | | | |
| MgO | 0.47 | 2.42 | | 2.35 | 3.14 | | | |
| CaO | 19.9 | 18.09 | | 18.12 | 17.12 | | | |
| $Na_2O$ | 0.34 | 0.26 | | 0.27 | 0.26 | | | |
| $K_2O$ | 0.0233 | 0.01 | 0.015 | 0.03 | 0.013 | | | |
| $P_2O_5$ | | 0.00 | | 0.04 | 0.016 | | | |
| S | | 0.01 | | 0.01 | <10 | | | |
| Rb | 0.63 | 0.8 | 0.593 | | 0.67 | 0.499 | 0.40 | |
| Cs | 0.037 | | | | 0.030 | | 0.031 | |
| U | | | 0.013 | | 0.0052 | | 0.021 | 0.0355 |
| Th | | | 0.023 | | | | | 0.0460 |
| Pb | | | | | | | | 0.320 |
| Ba | | | 8.85 | | 13 | | | |
| Sr | | 144 | 145.0 | | 127 | 158 | | |
| La | 0.33 | | 0.393 | | 0.32 | | | |
| Ce | 0.75 | | 0.891 | | 0.80 | | | |
| Pr | | | | | 0.12 | | | |
| Nd | 0.50 | | 0.664 | | | | | |
| Sm | 0.134 | | 0.209 | | 0.16 | | | |
| Eu | 0.73 | | 0.650 | | 0.63 | | | |
| Gd | | | 0.301 | | 0.30 | | | |
| Tb | 0.033 | | | | 0.047 | | | |
| Dy | 0.226 | | 0.343 | | 0.33 | | | |
| Er | | | 0.255 | | 0.24 | | | |
| Yb | 0.117 | | 0.251 | | 0.25 | | | |
| Lu | 0.0154 | | 0.038 | | 0.04 | | | |
| Y | | 2.5 | | | | | | |
| Co | 1.63 | | | | 7.34 | | | |
| Cr | 119.0 | 420 | 372 | | 560 | | | |
| Ga | 3.14 | | | | 2.33 | | | |
| Hf | 0.055 | | 0.12 | | 0.12 | | | |

Table 1 cont'd

| | 1) | 2) | 3) | 4) | 5) | 6) | 7) | 8) |
|---|---|---|---|---|---|---|---|---|
| Zr | | 2.7 | 7.6 | | | | | |
| Zn | ≤1.0 | | | | 15.1 | | 4.26 | |
| Sc | 1.89 | | | | 7.68 | | | |
| Ni | 1.0 | | | | | | ≤4 | |
| Cu | | | | | 13.2 | | | |
| As | | | | | 2.0 | | | |
| Ta | | | | | 0.011 | | | |
| W | | | | | 0.015 | | | |
| Re ppb | | | | | ~0.2 | | 0.020 | |
| Au ppb | | | | | 0.66 | | 0.048 | |
| Ir ppb | | | | | | | 0.319 | |

Oxides in wt. %, others in ppm except as indicated.

Col. 1 from Haskin et al. (1973)
Col. 2 from LSPET (1972b)
Col. 3 from Hubbard et al. (1974)
Col. 4 from Scoon (1974)
Col. 5 from Wänke et al. (1975)
Col. 6 from Nyquist et al. (1976)
Col. 7 from Hertogen et al. (1977)
Col. 8 from Silver (1973).

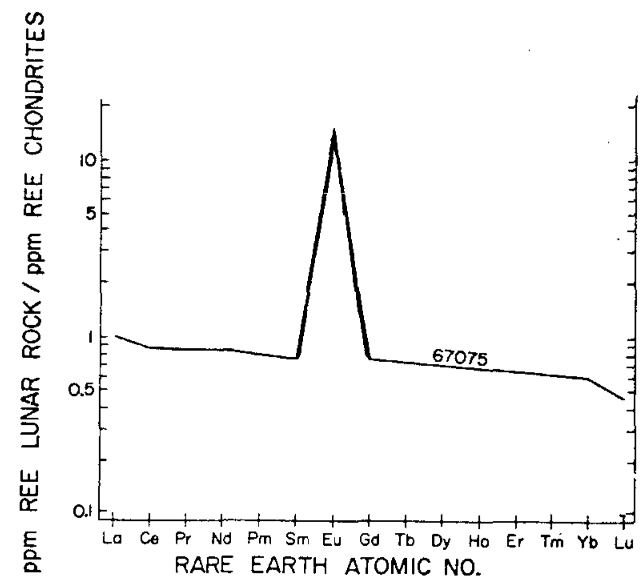



Figure 3. REE data for 67075. From Haskin et al. (1973).

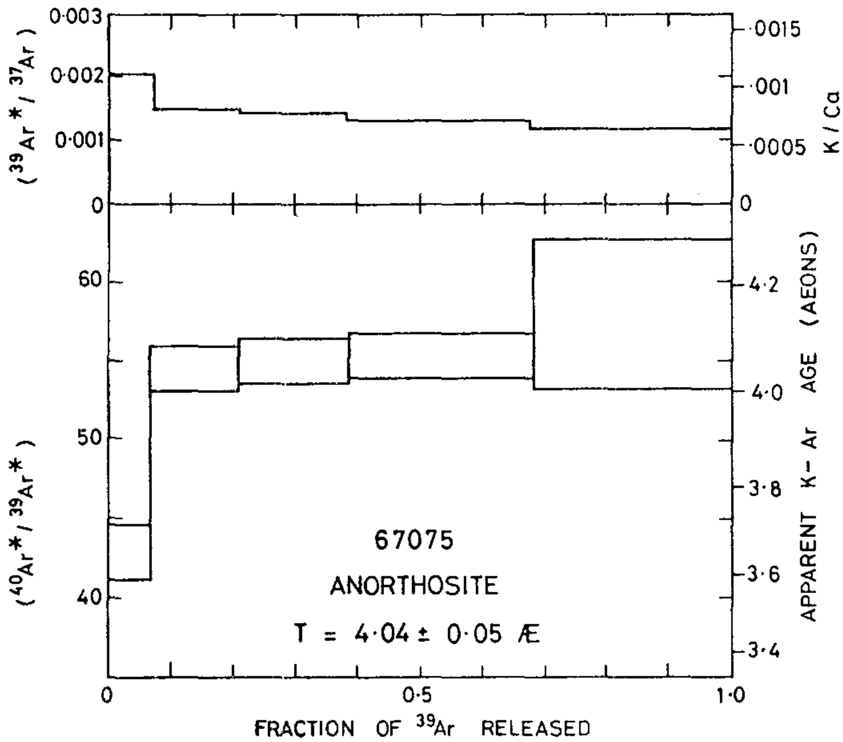



Figure 4. K/Ca and apparent age for 67075. From Turner et al. (1973).

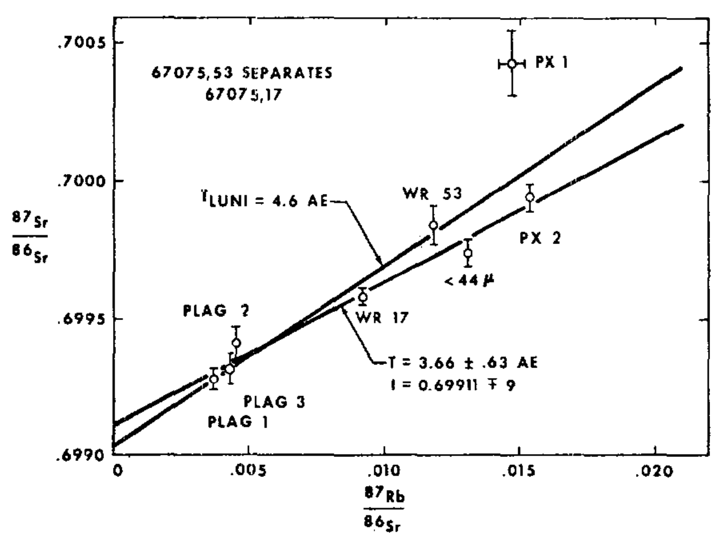



Figure 5. Mineral separate and whole rock Rb-Sr isotopic data for 67075. From Nyquist et al. (1976).

67455,30 Cataclastic ol-bearing anorthosite clast 1.74 gm

Evidence for pristinity: Hertogen et al. (1977) analyzed a fragment and found it to be free of meteoritic contamination (Table 1).

Description: The clast was a loose fragment from the sieved residues of the extremely friable rock 67455. Chao (unpublished data pack information) described the ~ 1 cm clast as a milky white shocked, compact anorthosite with granular yellow streaks of crushed olivine and brown specks which were probably pyroxene. Minkin et al. (1977) discuss cataclastic anorthosites in 67455 in general and comment on the iron-rich olivines but do not discuss this clast specifically. However they do report two mineral analyses from the clast in thin section ,106: $An_{96.8}$ and $Fo_{49.9}$.

Lindstrom et al. (1977) made an analysis of the clast (,127) which is reproduced here in Table 1 and Figures 1 and 2. The analysis confirms that the clast is an anorthosite, with FeO>MgO.

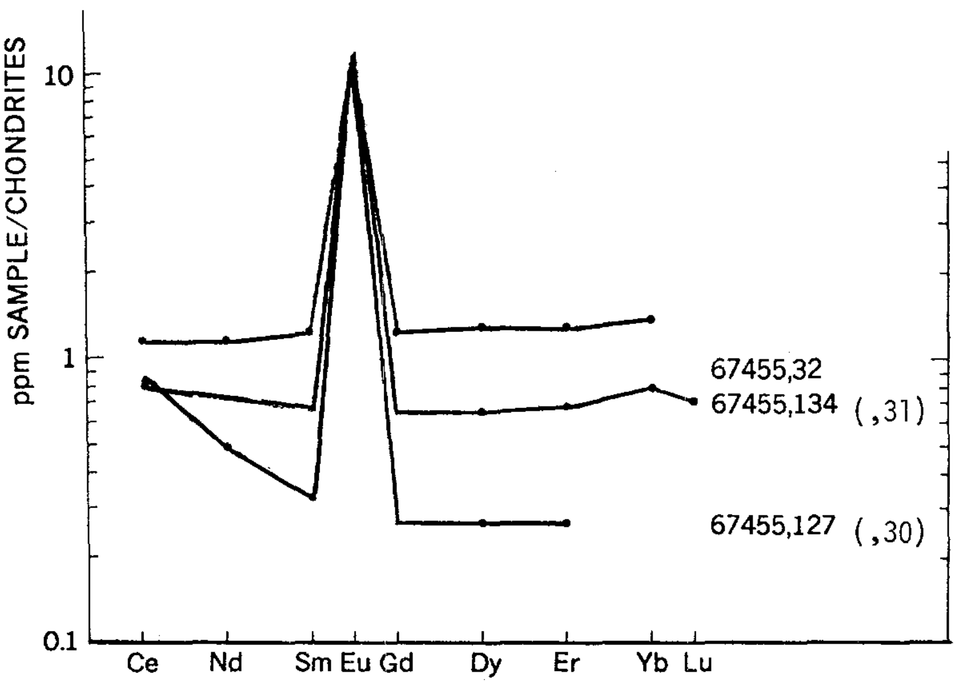



Figure 1. REE data for 67455,30 (split ,127) anorthosite and two other meteorite-free clasts from 67455. From Lindstrom et al. (1977).

## Table 1

| 1) | | 1) | | 2) | |
|---|---|---|---|---|---|
| ,244, portion of ,127 234 mg | | | | ,126 60 mg | |
| $SiO_2$ | 44.0 | Li | 2.57 | Ir ppb | 0.0028 |
| $TiO_2$ | <0.05 | K | 144 | Os ppb | ≤0.004 |
| $Al_2O_3$ | 34.21 | Rb | 0.492 | Re ppb | ≤0.0004 |
| FeO | 1.46 | Sr | 155 | Au ppb | 0.0073 |
| MnO | 0.02 | Ba | 9.97 | Ni | ≤7 |
| MgO | 0.94 | | | Rb | 0.49 |
| CaO | 18.73 | Ce | 0.660 | Cs ppb | 35.2 |
| $Na_2O$ | 0.32 | Nd | 0.283 | U ppb | 16 |
| $K_2O$ | 0.02 | Sm | 0.0601 | | |
| $P_2O_5$ | 0.04 | Eu | 0.687 | | |
| $Cr_2O_3$ | <0.005 | Dy | 0.080 | | |
| | | Er | 0.050 | | |

Oxides in wt. %, all others in ppm except as indicated.

Col. 1 from Lindstrom *et al.* (1977)
Col. 2 from Hertogen *et al.* (1977)

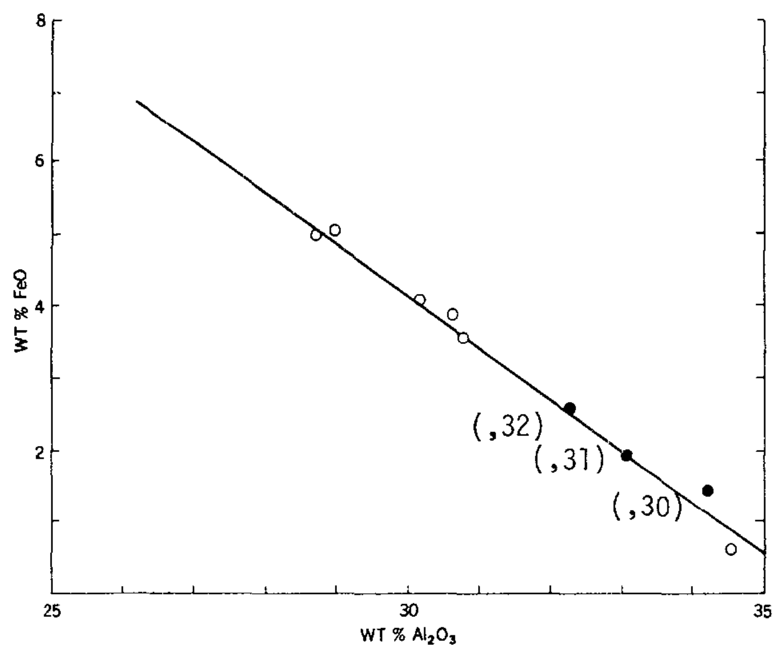



Figure 2. FeO v. $Al_2O_3$ for samples from 67455. Labelled samples are meteorite-free. Other samples are contaminated or have not been analyzed for siderophiles. From Lindstrom *et al.* (1977).

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,30 | ,0 | SSPL | 0.900 | Fragment. ,71 (,105,106) ,126 ,127 (,244) ,128 ,129 ,130. |
| ,71 | ,30 | RSPL | 0.080 | Potted butt. ,105 ,106. |
| ,105 | ,71 | Chao | 0.010 | TS |
| ,106 | ,71 | Chao | 0.010 | TS |
| ,126 | ,30 | Consumed, Anders | 0.060 | Chip |
| ,127 | ,30 | RSPL | 0.036 | Powder, returned by Nava. Air, crushed. ,244 |
| ,128 | ,30 | Tatsumoto | 0.240 | Chip |
| ,129 | ,30 | Geiss | 0.230 | 5 small chips |
| ,130 | ,30 | SSPL | 0.030 | Small chips and fines |
| ,244 | ,127 | Consumed, Nava | 0.234 | Chip |

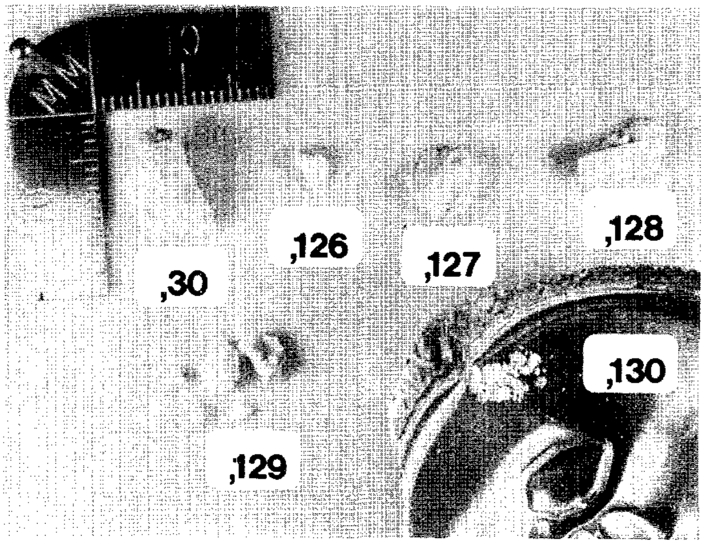



Figure 3. Splits of the 67455,30 anorthosite clast.

67455,31 Cataclastic px-bearing anorthosite clast 0.897 gm

Evidence for pristinity: Hertogen et al. (1977) analyzed a fragment and found it to be meteorite-free (Table 1).

Description: The clast was a loose fragment from the sieved residues of the extremely friable rock 67455. Chao (unpublished data pack information) described the clast as a streaky milky white cataclastic pyroxene-bearing anorthosite, typical of a major component of 67455. The clast was not included in the general petrographic description of 67455 by Minkin et al. (1977). Lindstrom et al. (1977) describe it as containing interstitial pigeonite. Thin sections ,108 and ,156 show a cataclasized rock with very little pore-space. The mafic phase is a pyroxene showing exsolution lamellae; our own preliminary analyses show composition $En_{43-45}Wo_{4-9}$ and $En_{34-36}Wo_{41-44}$. Plagioclase is $An_{96}$. The pyroxene contains blebs of ilmenite. Troilite also occurs, normally spatially associated with pyroxene. ,156 is less brecciated than ,108 and displays a relict cumulate texture (Figure 1). The modes are very different, ,156 containing about 25% pyroxene but ,108 (which has a much greater area) less than 5% pyroxene.

Lindstrom et al. (1977) made an analysis of the clast (,134) which is reproduced here in Table 1 and in Figures 1 and 2 of the section on the 67455,30 clast. The analysis confirms that the clast is an anorthosite, with FeO>MgO.

Figure 1. Photomicrograph (crossed polarizers) of 67455,156. Width of view ~2 mm.

Table 1

| | 1) | | 1) | | 2) |
|---|---|---|---|---|---|
| | ,244, portion of ,134 211 mg | | | | ,133 40 mg |
| $SiO_2$ | 45.3 | Li | 3.29 | Ir ppb | 0.0040 |
| $TiO_2$ | 0.05 | K | 195 | Os ppb | <0.003 |
| $Al_2O_3$ | 33.03 | Rb | 0.751 | Re ppb | 0.0003 |
| FeO | 1.94 | Sr | 163 | Au ppb | 0.015 |
| MnO | 0.03 | Ba | 11.3 | Ni | <5 |
| MgO | 1.12 | | | | |
| CaO | 18.45 | Ce | 0.676 | Rb | 0.74 |
| $Na_2O$ | 0.42 | Sm | 0.122 | Cs ppb | 51.7 |
| $K_2O$ | 0.02 | Eu | 0.799 | U ppb | 11.3 |
| $P_2O_5$ | 0.04 | Dy | 0.199 | | |
| $Cr_2O_3$ | 0.01 | Er | 0.124 | | |
| | | Yb | 0.150 | | |
| | | Lu | 0.0215 | | |

Oxides in wt. %, all others in ppm except as indicated

Col. 1 from Lindstrom *et al.* (1977)
Col. 2 from Hertogen *et al.* (1977)

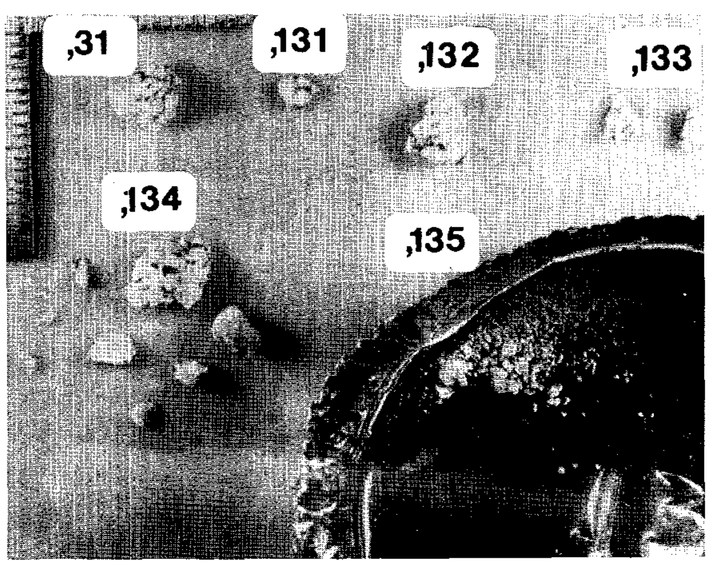



Figure 2. Splits of the 67455,31 anorthosite clast

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,31 | ,0 | Tatsumoto | 0.160 | Fragment. ,72 (,107,108) ,131 (,135,136,156,157) ,132 ,133 ,134 (,245) ,135 |
| ,72 | ,31 | Ent. Subdivided | 0.000 | Was potted butt. ,107 ,108 |
| ,107 | ,72 | Chao | 0.010 | TS |
| ,108 | ,72 | SCC | 0.010 | TS |
| ,131 | ,31 | Ent. Subdivided | 0.000 | Was potted butt. ,135 ,136 ,156 ,157 |
| ,132 | ,31 | Geiss | 0.140 | Chip |
| ,133 | ,31 | Consumed, Anders | 0.040 | Chip |
| ,134 | ,31 | RSPL | 0.159 | Powder, returned by Nava. Air, crushed. ,245 |
| ,135 | ,31 | SSPL | 0.070 | Small chips and fines |
| ,156 | ,131 | SCC | 0.010 | TS |
| ,157 | ,131 | Ramdohr | 0.010 | TS |
| ,245 | ,134 | Consumed, Nava | 0.211 | Chip |

## 67455,32 px-bearing anorthosite clast 0.32 gm

Evidence for pristinity: Hertogen et al. (1977) analyzed a fragment and found it to be free of meteoritic contamination (Table 1).

Description: The clast was a loose fragment from the sieved residues of the extremely friable rock 67455. Chao (unpublished data pack information) described the clast as a milky white anorthosite, similar to ,31 but with blebs of troilite and dark streaks. One thin section (,160) was included in the study of 67455 by Minkin et al. (1977) but they do not report specific data for the clast. Presumably the pyroxene is iron-rich since Minkin et al. (1977) do not indicate any exceptions to their general conclusion that the anorthosites in 67455 have iron-rich pyroxenes (e.g. $En_{40-43}Wo_{5-7}$). The thin sections show a lightly to moderately cataclasized anorthosite (Figure 1) with low porosity. The plagioclase grains were originally at least 3 mm,with the pyroxenes, which contain exsolution lamellae, interstitial to them. Original grain boundaries and triple junctions are preserved. Ilmenite is the main opaque, and occurs both as oriented rods in some of the pyroxenes, and as blebby grains. Troilite and other unidentified opaques (chromite, armalcolite?) are also present.

Lindstrom et al. (1977) made an analysis of the clast (,32) which is reproduced here in Table 1, and in Figures 1 and 2 of the section on the 67455,30 anorthosite clast. The analysis confirms that the clast is an anorthosite, with FeO>MgO.

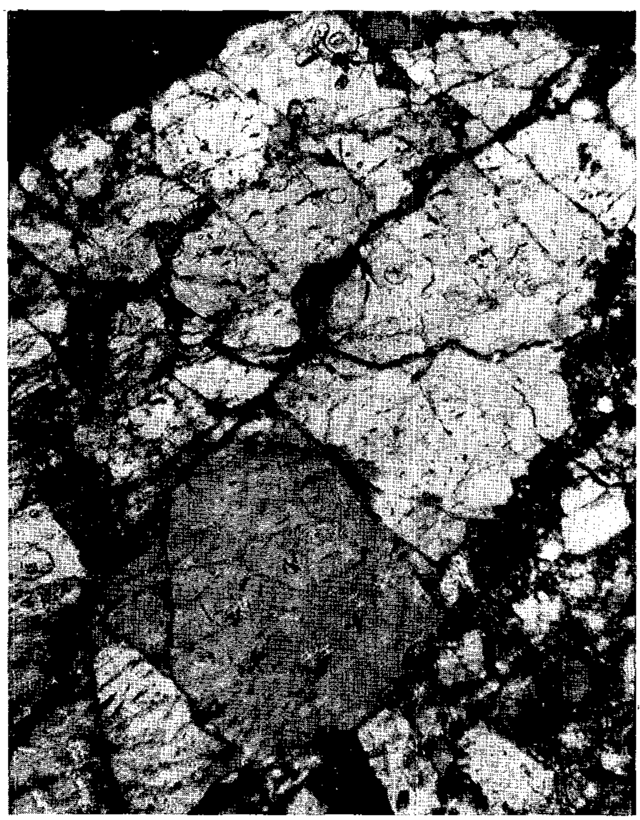


Figure 1. Photomicrograph (crossed polarizers) of 67455,10. Width of view ~2 mm.

Table 1

| | 1) | | 1) | | 2) |
|---|---|---|---|---|---|
| ,92, portion of ,32 | | 155 mg | | ,74 | 70 mg |
| $SiO_2$ | 44.9 | Li | 3.47 | Ir ppb | 0.001 |
| $TiO_2$ | 0.13 | K | 235 | Os ppb | <0.012 |
| $Al_2O_3$ | 32.28 | Rb | 0.870 | Re ppb | ≤0.0003 |
| FeO | 2.62 | Sr | 116 | Au ppb | 0.0025 |
| MnO | 0.04 | Ba | 13.6 | Ni | 2.5 |
| MgO | 1.31 | | | | |
| CaO | 18.10 | Ce | 0.924 | Rb | 0.90 |
| $Na_2O$ | 0.42 | Nd | 0.673 | Cs ppb | 56.0 |
| $K_2O$ | 0.03 | Sm | 0.228 | U ppb | 5.7 |
| $P_2O_5$ | <0.02 | Eu | 0.802 | | |
| $Cr_2O_3$ | 0.02 | Gd | 0.324 | | |
| | | Dy | 0.394 | | |
| | | Er | 0.235 | | |
| | | Yb | 0.260 | | |
| | | Lu | 0.030 | | |

Oxides in wt. %, all others in ppm except as indicated

Col. 1 from Lindstrom *et al.* (1977)
Col. 2 from Hertogen *et al.* (1977)

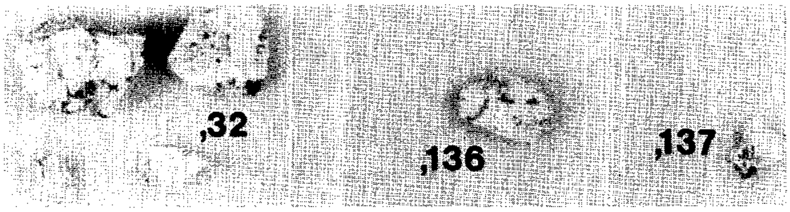



Figure 2. Initial splits of the 67455,32 clast. Largest chip is about 5 mm.

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,32 | ,0 | RSPL | 0.115 | Powder, returned by Nava. Air, crushed. ,73 (,109,110) ,92 ,136 (,158,159) ,137 (,160,215). |
| ,73 | ,32 | Entirely Sub. | 0.000 | Was potted butt. ,109 ,110. |
| ,74 | ,32 | Consumed, Anders | 0.070 | Chip |
| ,92 | ,32 | Consumed, Nava | 0.155 | Chip |
| ,109 | ,73 | SCC | 0.005 | TS |
| ,110 | ,73 | SCC | 0.005 | TS |
| ,136 | ,32 | RSPL | 0.010 | Potted butt ,158 ,159 |
| ,137 | ,32 | Entirely Sub. | 0.000 | Potted butt ,160 ,215 |
| ,158 | ,136 | SCC | 0.010 | TS |
| ,159 | ,136 | Ramdohr | 0.010 | TS |
| ,160 | ,137 | SCC | 0.005 | TS |
| ,215 | ,137 | SCC | 0.005 | TS |

## 67975 Cataclastic anorthosite clast ~0.1 gm

Evidence for pristinity: Hertogen et al. (1977) analyzed a fragment and found it to be free of meteoritic contamination (Table 1).

Description: The clast was sampled to represent white, crystalline to granular, very chalky clasts in 67975, which is a glass-coated light matrix breccia. Photographs of the thin sections indicate that the clast is a cataclastic anorthosite with few mafics. The only published data is that of Hertogen et al. (1977) reproduced in part in Table 1. This data is inconclusive as to the character of the clast, the Rb content being compatible with anorthosite or troctolite, but lower than most lunar norites.

Table 1

| | | | |
|---|---|---|---|
| Ir | 0.091 | Rb ppm | 0.58 |
| Os | 0.069 | Cs | 55.8 |
| Re | 0.0084 | U | 26.7 |
| Au | 0.0084 | | |
| Ni ppm | ≤11 | | |

Elements in ppb except as indicated

From Hertogen et al. (1977)

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,15 | ,0 | SSPL | 3.640 | Matrix chips, possibly include clast. ,26 (,76) ,27 (,57 ,58) |
| ,26 | ,15 | RSPL | 0.001 | Fines, returned by Anders. ,76 |
| ,27 | ,15 | RSPL | 0.050 | Potted butt. |
| ,57 | ,27 | Bell | 0.010 | TS |
| ,58 | ,27 | Smith | 0.010 | TS |
| ,76 | ,26 | Consumed, Anders | .009 | |

Probably 2 or 3 more thin sections could be made from ,27.

## 69955 Glass-veined cataclastic anorthosite 75.9 gm

Evidence for pristinity: That some portions of 69955 are meteorite-free is indicated by an analysis by Laul and Schmitt (1973) which has very low Co contents, and low incompatibles (Table 1). However, the entire anorthosite is not pristine, as other data from Laul and Schmitt (1973), Rose et al. (1973), and Krähenbühl et al. (1973), reproduced in Table 1, shows higher levels of incompatibles and meteoritic siderophiles.

Description: The anorthosite is a light gray tough rock in which some plagioclase has been converted to glass. One dark glass vein cuts the sample. The texture is cataclastic (Figure 1) in the thin sections, which were all from the same chip near the glass vein. This texture may not be representative of the entire anorthosite. No mineral analyses have been published.

Bulk chemical analyses (Table 1 and Figure 2) demonstrate that the rock is a ferroan anorthosite with generally low levels of incompatibles but rather heterogeneous, probably due to shock.

Other references

Pepin et al. (1974) Exposure ages
Yokoyama et al. (1974) $^{22}Na$-$^{26}Al$
Misra and Taylor (1975) Metal in glass vein

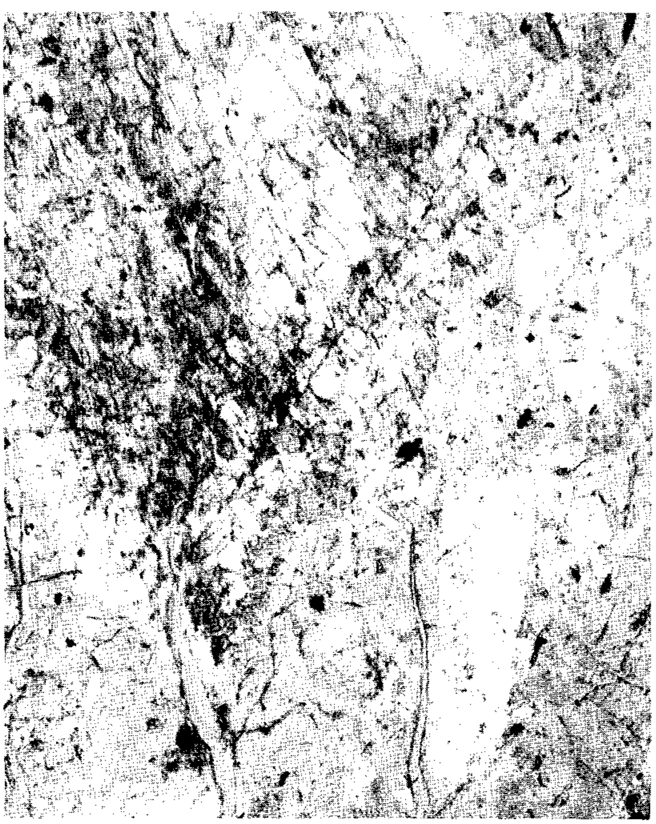


Figure 1. Photomicrograph (partially crossed polarizers) of 69955,27. Width of view ∿2 mm.

Table 1

| | 1) ,20 portion of ,14 13 mg | 2) ,22 portion of ,12 250 mg | 3) ,21 portion of ,11 117 mg |
|---|---|---|---|
| $SiO_2$ | | 44.10 | |
| $TiO_2$ | <0.04 | 0.01 | |
| $Al_2O_3$ | 35.5 | 35.15 | |
| $Cr_2O_3$ | 0.0053 | 0.04 | |
| FeO | 0.49 | 0.36 | |
| MnO | 0.011 | 0.01 | |
| MgO | | 0.23 | |
| CaO | 18.9 | 19.30 | |
| $Na_2O$ | 0.400 | 0.42 | |
| $K_2O$ | <0.01 | 0.02 | |
| $P_2O_5$ | | 0.01 | |
| Sc | 0.84 | <1.0 | |
| V | <7 | <10 | |
| Co | 0.80 | | |
| Ni | | 43 | 9.8 |
| Pb | | 11 | |
| Cu | | 1.1 | |
| Ga | | 1.2 | |
| Hf | 0.024 | | |
| U | 0.03(0.50) | | 0.0259 |
| Li | | 1.6 | |
| Rb | | 0.7 | 0.15 |
| Sr | | 135 | |
| Cs ppb | | | 11 |
| Ir ppb | | | 0.289 |
| Re ppb | | | 0.0278 |
| Au ppb | | | 0.307 |

| | 1) | 1) | 2) |
|---|---|---|---|
| Ba | 10 | 50 | 11 |
| La | 0.27 | 2.2 | |
| Ce | | 4.1 | |
| Nd | 0.6 | 2 | |
| Sm | 0.13 | 0.49 | |
| Eu | 0.87 | 1.20 | |
| Tb | <0.02 | | |
| Dy | 0.12 | 0.24 | |
| Yb | 0.068 | 0.081 | |
| Lu | 0.002 | 0.013 | |
| Ta | <0.01 | <0.02 | |

Oxides in wt. %, all others in ppm except as indicated.

Col. 1 from Laul and Schmitt (1973)
Col. 2 from Rose *et al.* (1973)
Col. 3 from Krähenbühl *et al.* (1973)

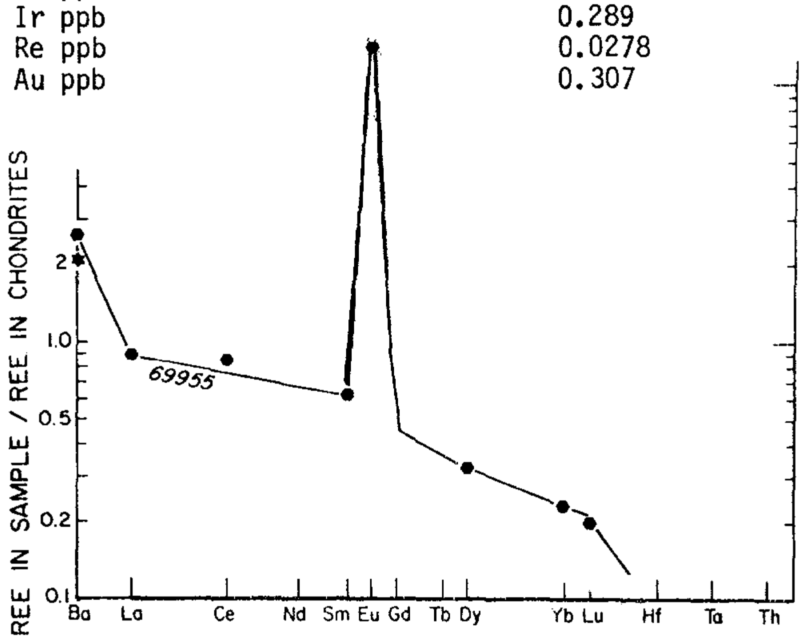



Figure 2. Incompatible element abundances in 69955. From Laul and Schmitt (1973).

Table 2

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,0 | | Ent. Subdivided | 0.000 | |
| ,1 | ,0 | SSPL | 0.120 | Residues |
| ,2 | ,0 | Attrition | 0.050 | |
| ,3 | ,0 | RSPL | 0.005 | (Glass grains, returned by Hörz/ PET.) ,31 |
| ,4 | ,0 | Bhandari | 3.440 | End pieces |
| ,5 | ,0 | Wasserburg | 4.510 | Interior chip |
| ,6 | ,0 | SSPL | 1.650 | (Glass veins) |
| ,7 | ,0 | SSPL | 5.100 | Interior chip ,33 ,34 |
| ,8 | ,0 | SSPL | 3.780 | (Glass) |
| ,9 | ,0 | RSPL | 1.480 | Potted butt. Includes glass. ,27-,30 |
| ,10 | ,0 | SSPL | 1.220 | Interior chip |
| ,11 | ,0 | RSPL | 0.393 | Chips and fines, returned by Anders. Air.,21 |
| ,12 | ,0 | Ent. Subdivided | 0.000 | ,22 ,32 |
| ,13 | ,0 | RSPL | 0.990 | Chip, returned by Davis/PET. Unopened. |
| ,14 | ,0 | RSPL | 0.001 | Fines, returned by Schmitt. Air. ,19 ,20 |
| ,15 | ,0 | SSPL | 2.060 | Chips and fines |
| ,16 | ,0 | Walker, R.M. | 2.220 | Surface, includes glass. |
| ,17 | ,0 | B01 | 46.4 | Main piece |
| ,18 | ,0 | Attrition | 0.769 | |
| ,19 | ,14 | RSPL | 0.516 | Fines, returned by Schmitt. Air, irradiated with thermal neutrons. |
| ,20 | ,14 | Consumed, Schmitt | 0.013 | Chips |
| ,21 | ,11 | Consumed, Anders | 0.117 | Chips |
| ,22 | ,12 | Consumed, Rose | 0.250 | Chips |
| ,27 | ,9 | SCC | 0.010 | TS |
| ,28 | ,9 | SCC | 0.010 | TS |
| ,29 | ,9 | Meyer | 0.010 | PM |

(Table 2 cont'd)

| Split | Parent | Location | Mass | Description and daughters containing clast |
|---|---|---|---|---|
| ,30 | ,9 | SCC | 0.010 | PM |
| ,31 | ,3 | Consumed, Hörz | 0.006 | |
| ,32 | ,12 | RSPL | 0.240 | Powder, returned by Rose. Air, crushed. |
| ,33 | ,7 | Perkins | 0.460 | Small chips |
| ,34 | ,7 | Attrition | 0.110 | |

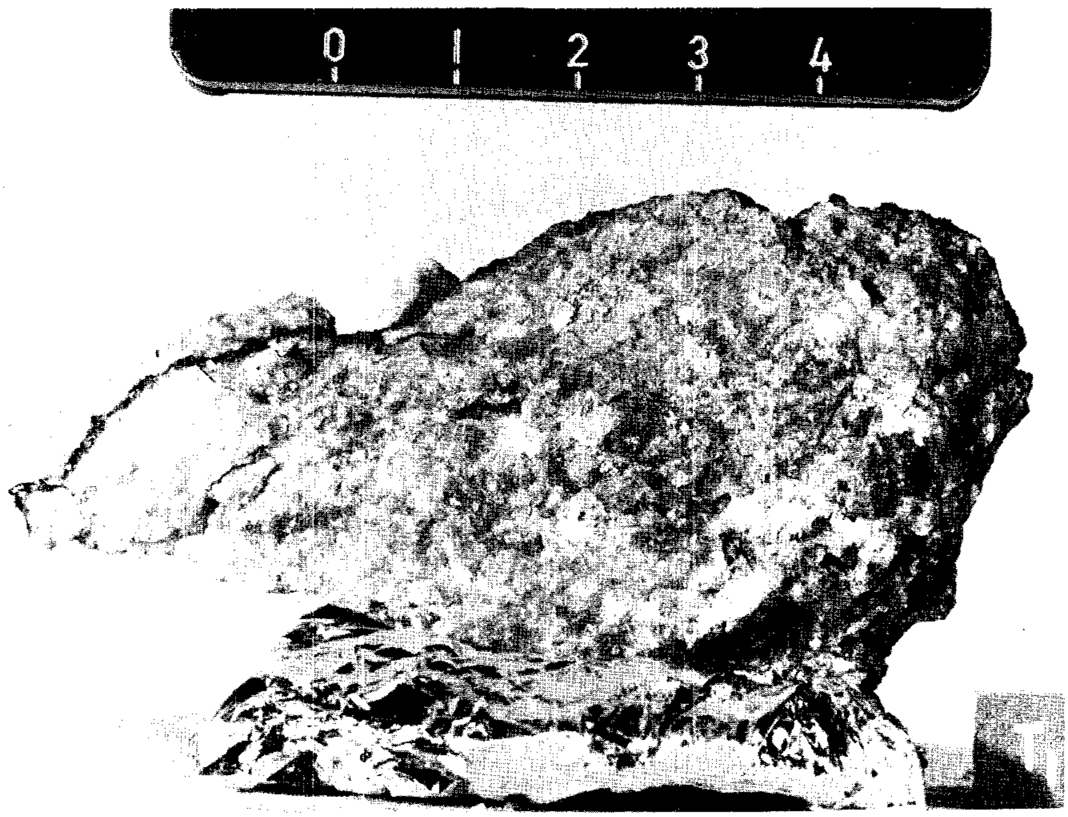



Figure 3. Pre-split photo of sample 69955. Scale in centimeters. (NASA S-72-43825)

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